MINERAL AND WATER RESOURCES OF OREGON

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MINERAL AND WATER RESOURCES OF OREGON

By

A. E. Weissenborn, Editor
U. S. Geological Survey

1969

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90th Congress
2d Session } COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF OREGON

REPORT

PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

AND

UNITED STATES BUREAU OF RECLAMATION

AND

BONNEVILLE POWER ADMINISTRATION

AND

UNITED STATES BUREAU OF MINES

AT THE REQUEST OF

SENATOR MARK O. HATFIELD
OF OREGON

OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
UNITED STATES SENATE

Printed for the use of the Committee on Interior and Insular Affairs

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MEMORANDUM FROM THE CHAIRMAN

To Members of the Senate Committee on Interior and Insular Affairs:

I am transmitting for your information a report entitled "Mineral and Water Resources of Oregon," prepared by the U.S. Geological Survey, the Bureau of Reclamation, the Bonneville Power Administration, and the Bureau of Mines, with the cooperation of appropriate State agencies, at the request of our colleague, Senator Mark O. Hatfield.

This detailed survey will be particularly helpful to government and business leaders in Oregon. It will also be valuable to the Congress and members of this committee as we consider legislation regarding mineral and water development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

This report was prepared at my request by the U.S. Geological Survey in cooperation with the State of Oregon Department of Geology and Mineral Industries.

Significant and factual information concerning the mineral and water resources of Oregon is important to many individuals and groups. I am pleased to note the result which has been achieved. It will be a valuable source of information.

My great appreciation is extended to all of those involved in the preparation of this report.

MARK O. HATFIELD.

MINERAL AND WATER RESOURCES OF OREGON

SECTION 1

GEOLOGY AND MINERAL RESOURCES

PREPARED BY

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

STATE OF OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

AND

UNITED STATES BUREAU OF MINES

LETTER OF TRANSMITTAL

U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., November 13, 1968.

Hon. MARK O. HATFIELD,
U.S. Senate,
Washington, D.C.

DEAR SENATOR HATFIELD: We are pleased to transmit herewith a summary report on the mineral and water resources of Oregon, which has been prepared in response to your request of January 17, 1967. The report has been prepared by the U.S. Geological Survey, the Oregon Department of Geology and Mineral Industries, the U.S. Bureau of Reclamation, the Bonneville Power Administration, and the U.S. Bureau of Mines.

The first section of the report describes the geology of the State and presents information on the known and potential mineral resources. All mineral commodities known to exist in potentially significant amounts are discussed.

The second section deals with the water resources of the State. The quantity, quality, and distribution of both surface and ground water are summarized. Water resource development, including hydroelectric power, potential water power, irrigation, navigation, flood control, and recreation also is discussed.

The report has been prepared as a technical presentation of factual or descriptive information. It does not purport to express any viewpoint on matters of resource management policy and has not been reviewed for unintended implications in that direction.

It is hoped the report will supply the needed information in a form that meets with your approval.

Sincerely yours,

STEWART L. UDALL,
Secretary of the Interior.

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PREFACE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Oregon's rich mineral and water resources have provided much of the raw materials and energy sources for the development and growth of its present vigorous economy. The potential resources that can be a basis for further growth are described in this report. A brief description of the geology of Oregon provides summary knowledge about the distribution of different resources. Each of the mineral resources is described as to occurrence, production, uses, economic significance, and future outlook. Past and present mineral production of Oregon has come from 13 metallic and at least 12 nonmetallic commodities. The present report describes and evaluates each, whether current use is made of them or not. Surface and ground-water resources are described, and current and potential utilization are discussed in terms of availability, distribution, and use for irrigation, power generation, industrial and domestic uses, and recreation. A comprehensive list of references is provided for those who may wish more detailed information on particular subjects. It is hoped that the report will provide a thorough, up-to-date, comprehensive survey for the general reader and will serve as a useful starting point for a more detailed study.

Although Oregon has a population of less than 2 million, its record of mineral production and water resource development reflects a highly progressive and rapidly expanding economy. Total mineral production is valued at $1.3 billion; production in 1966 is valued at $107.8 million. The remarkable growth of Oregon mineral production within the last decade is an especially strong indication of things to come. Water resources are also extensively used. Power generating plants now in use or under construction will provide 4,310 megawatts of power. Existing irrigation facilities provide water to more than 2,650 square miles of cropland. Despite the already extensive use of Oregon's natural resources, a growing population and a vigorous economy will unquestionably lead to increasing demands and expanded use in the years to come.

This report is the joint effort of the U.S. Geological Survey, the State of Oregon Department of Geology and Mineral Industries, the U.S. Bureau of Mines, Bonneville Power Administration, and Bureau of Reclamation. Organization, assembly, and editing was done by A. E. Weissenborn, assisted by P. L. Weis. Individual authors are cited at appropriate places in the text. Hollis M. Dole, Director of the State of Oregon Department of Geology and Mineral Industries, was particularly helpful in coordinating the work of his staff and providing extensive information from departmental files. Stanley F. Kapustka, U.S. Geological Survey, and Gilbert V. Shirk, U.S. Bureau of Reclamation, coordinated the preparation of the sections on water resources and water resources development.

SECTION I

GEOLOGY AND MINERAL RESOURCES

INTRODUCTION

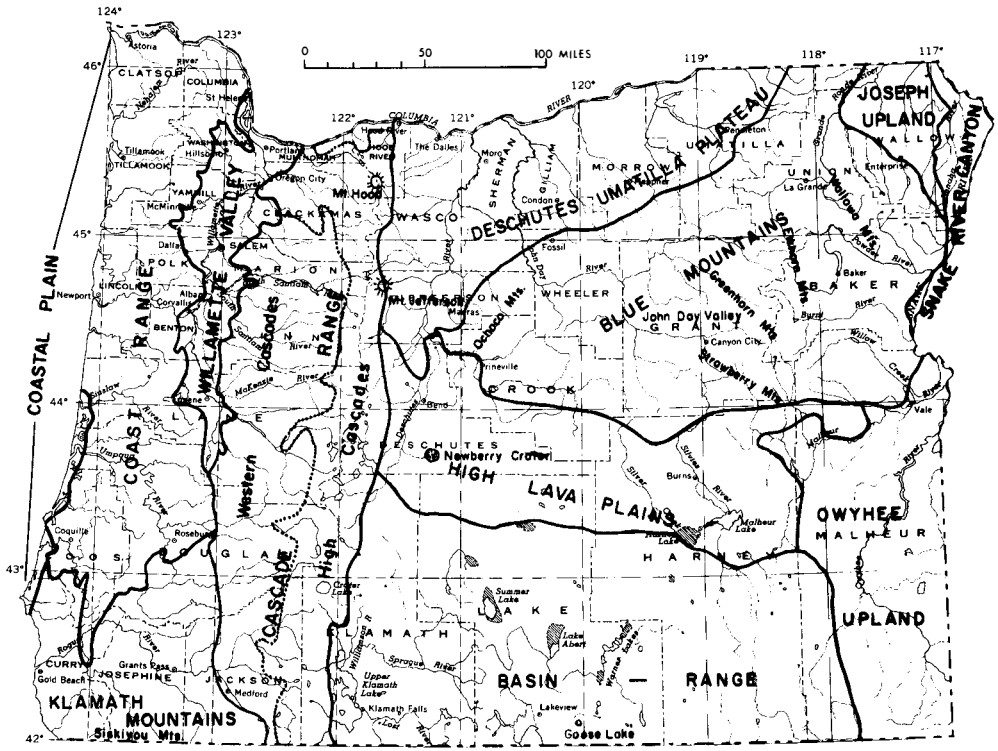
(By Hollis M. Dole, State of Oregon Department of Geology and Mineral Industries, Portland, Oreg., and A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Oregon, the Beaver State, ranks 10th in area among the States and its population of nearly 2 million is 32d in the Nation. Its area of 96,981 square miles contains some of the most varied and spectacular scenery of any of the Western States. The State can be divided in 12 geomorphic units, each differing markedly in climate, topography, geology, and natural resources. These differences are the results of geologic processes that over countless millenia have operated to shape the landscape as we see it now.

GEOMORPHOLOGY

The twelve geomorphic units or provinces into which Oregon can be divided are shown on figure 1. The most conspicuous of the geomorphic provinces is the volcano-crowned Cascade Range whose towering snow-capped peaks separate Oregon into a well-watered tree-covered western part and an arid or semiarid eastern part. Mount Hood, which at 12,235 feet is the highest point in Oregon stands at its northern border overlooking the scenic gorge of the Columbia River. The fertile Willamette Valley, the magnet which in the middle 1800's drew thousands of settlers to the Oregon Country, and still the agricultural and industrial heart of the State, nestles between the Cascades and the less lofty Coast Range that extends nearly the whole length of Oregon from the Klamath Mountains to Astoria. Fringing the Coast Range is the narrow Coastal Plain whose magnificent beaches stretch for miles between rocky sea-carved headlands. South of the Coast Range lie the Klamath Mountains, a region of many valleys, numerous rivers, and sharp mountainous ridges.

East of the Cascades the complicated series of ranges and intervening valleys that make up the Blue Mountains is perhaps the most conspicuous feature. Its higher mountains reach elevations of 10,000 feet and it is an area of spectacular and diverse scenery. Bordering the Blue Mountains on the north is the Deschutes-Umatilla Plateau, whose loess-covered basalt surface slopes from an altitude of 3,000 feet on the south where it meets the Blue Mountains to 600 feet at the Columbia River on the north. It is a region of broad gently rolling interstream uplands deeply dissected by youthful streams. This nearly treeless area is the heart of Oregon's wheatland. Between the Blue Mountains and the Snake River Canyon lies the Joseph Upland,


0 50 100 MILES
COASTAL PLAIN
COAST RANGE
WILLAMETTE VALLEY
Western Cascades
High Cascades
CASCADE RANGE
HIGH LAVA PLAINS
BLUE MOUNTAINS
JOSEPH UPLAND
UMATILLA PLATEAU
SNAKE RIVER CANYON
OWYHEE UPLAND
BASIN — RANGE
KLAMATH MOUNTAINS
Siskiyou Mts.
Newberry Crater
Mt. Hood
Mt. Jefferson
Crater Lake
Summer Lake
Lake Abert
Malheur Lake
Upper Klamath Lake
Klamath Falls
Lakeview
Goose Lake
Grants Pass
Medford
Coquille
Gold Beach
Astoria
Tillamook
Newport
Albany
Corvallis
Salem
Dallas
McMinnville
Oregon City
Portland
Hillsboro
The Dalles
Hood River
Condon
Fossil
Prineville
Redmond
Madras
Bend
Sisters
Burns
Canyon City
La Grande
Enterprise
Baker
Vale
Ontario
Pendleton
Roseburg
Reedsport
Coos Bay
Columbia River
Willamette River
Deschutes River
John Day River
Snake River
Owyhee River
Malheur River
Sprague River
Williamson River
Wallowa Mts.
Strawberry Mts.
Greenhorn Mts.
Ochoco Mts.
Aldrich Mts.
Blue Mts.
Cascade Mts.
Coast Range
Calapooia Mts.
Umpqua River
Rogue River
Applegate River
Illinois River
Chetco River
Klamath River
Lost River
Pit River
Silvies River
Owyhee Reservoir
Malheur Lake
Harney Lake
Abert Lake
Summer Lake
Upper Klamath Lake
Crater Lake
Newberry Crater
Mt. Bachelor
Mt. Hood
Mt. Jefferson
Mt. Washington
Three Sisters
Mt. McLoughlin
Mt. Thielsen
Mt. Scott
Mt. Shasta
Mt. Adams
Mt. Rainier
Mt. St. Helens
Mt. Adams
Mt. Rainier
Mt. St. Helens
Mt. Adams
Mt. Rainier
Mt. St. Helens

a semiarid plateau lying at altitudes of 3,000 to 5,000 feet through which the streams flowing from the Blue Mountains have cut deep canyons.

Bordering the Blue Mountains on the south are the High Lava Plains, an elevated region of young lava flows 3,500 to 6,000 feet above sea level whose nearly uneroded surface carry few established streams. The region is quite arid. East of these High Lava Plains is the Owyhee Upland, a moderately dissected upland surface 2,000 to 6,000 feet above sea level with few permanent streams. South of the High Lava Plains and west of the Owyhee Upland is the Basin and Range province, an arid region characterized by fault block mountains, broad graben valleys, interior drainage and shallow alkaline lakes and playas. Elevations range from 4,000 feet above sea level to 9,000 feet in the higher mountains.

For more than 60 miles along the northeastern boundary of the State the Snake River has cut a canyon 4,000 to 6,000 feet deep, the deepest canyon in the United States. The river channel is generally narrow and in many places is deeply entrenched between sheer rock walls. The canyon is characterized by nearly vertical cliffs, narrow benches, talus slopes, and countless sharply incised side canyons.

This, then, is Oregon, a region of very great contrasts in its climate, its topography, its geology, and its resources. Because natural resources are so intimately related to the geology of the areas in which they occur, they cannot be adequately understood without an understanding of the geology. This account of the mineral and water resources of Oregon will begin, therefore, with a summary of the geology of the State. The geology of each of the geomorphic provinces will be described by geologists who have spent many years working in the area they discuss. For convenience the Willamette Valley, Coast Range, and Coastal Plain will be described together.

Geologic Mapping in Oregon

Our present day knowledge of the geology of Oregon is built on a sound foundation laid down by the many geologists who over a period of years have labored to piece together the story that is written in Oregon's rocks. Numerous individuals and organizations have contributed; the U.S. Geological Survey, the State of Oregon Department of Geology and Mineral Industries and its predecessor the Oregon Bureau of Mines and Geology, the various universities, as well as oil and mining company geologists. The lengthy bibliography at the end of the first section of this report gives an indication of the great number of geologists who have contributed to our understanding of the geology of the State.

Figure 2 shows published geologic maps in Oregon. The symbols distinguish mapping on scales smaller than 1:63,360 from mapping on larger scales. Geologic mapping on scales smaller than 1:250,000 is considered as reconnaissance and is not shown. Neither is mapping shown that has been done for college and university theses and has not been published elsewhere because this mapping is often not readily available to the general public.

Study of figure 2 shows that except for some large areas in eastern Oregon the geologic map coverage is fairly good. However, only a very

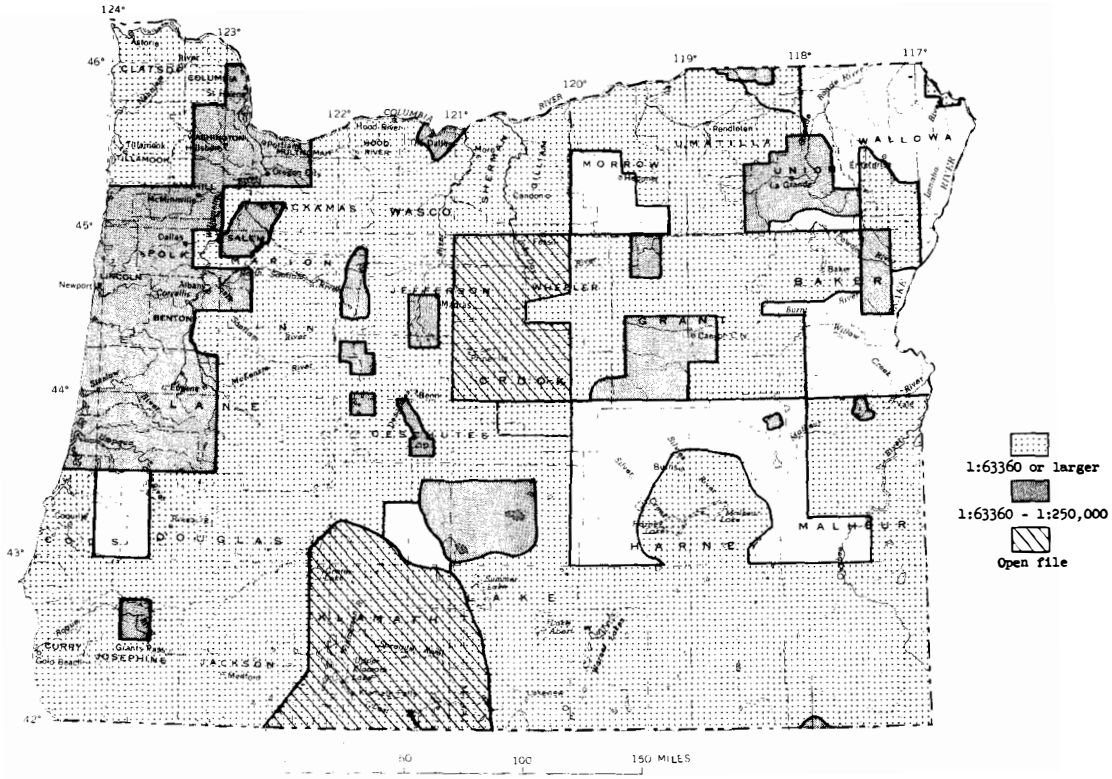


FIGURE 2.—Published geologic maps in Oregon.

small portion of the State has been mapped at detailed scales (1:63,360 or larger) and much remains to be done before we can consider that the geology of the State has been adequately mapped. The geology of the western part of the State is better known than that of the eastern part and a geologic map of the State west of the 121st meridian has been published by the U.S. Geological Survey in cooperation with the State of Oregon Department of Geology and Mineral Industries (Wells and Peck, 1961. No comparable map of the eastern part of the State has yet been published. Indeed, figure 3, which was prepared especially for this report, is the first geologic map of the entire State that has ever been published, except for the highly generalized map that forms part of the geologic map of the United States published by the U.S. Geological Survey. Plans are in progress to complete and publish a larger scale, more detailed map of Oregon within the next few years.

Topographic Mapping

Topographic maps are essential for many purposes but are especially necessary as bases on which to compile geology. It is impossible to make a satisfactory geologic map without an accurate topographic base. Published topographic map coverage in Oregon is shown in figure 4.

West of Longitude 122°W coverage by 7½ minute or 15 minute quadrangle mapping is complete. East of Longitude 122°W there are large gaps in the topographic map coverage particularly in southeastern Oregon. Mapping of a substantial area in northeastern Oregon which shows blank on figure 4 is in progress.

Geophysical and Geochemical Studies

GEOPHYSICS

Except through the examination of mine workings and study of cores or cuttings from deep drill holes a geologist's observation must of necessity be limited to what he can see on the surface. He may obtain some knowledge of what changes take place at depth through his interpretation of the geologic structure, but frequently it becomes desirable to learn more about the third dimension than can be gained through the surface observation alone. Modern geophysics provide a tool by which considerably more may be learned of the underlying rocks and their structures. Geophysics involves the execution and interpretation of certain physical measurements in order to detect variation in subsurface geological conditions.[1] Its purpose is to obtain information about rocks that cannot be viewed directly. Geophysical surveys have been used in Oregon both in attempting to find mineral deposits and in doing basic research on the structure of the earth. Types of geophysical specialization that have been utilized in Oregon and for which published reports or maps are available are magnetic, gravity, and seismic surveying.

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[1] This part of this chapter was prepared by R. G. Bowen, Oregon Department of Geology and Mineral Industries, Portland, Oreg.

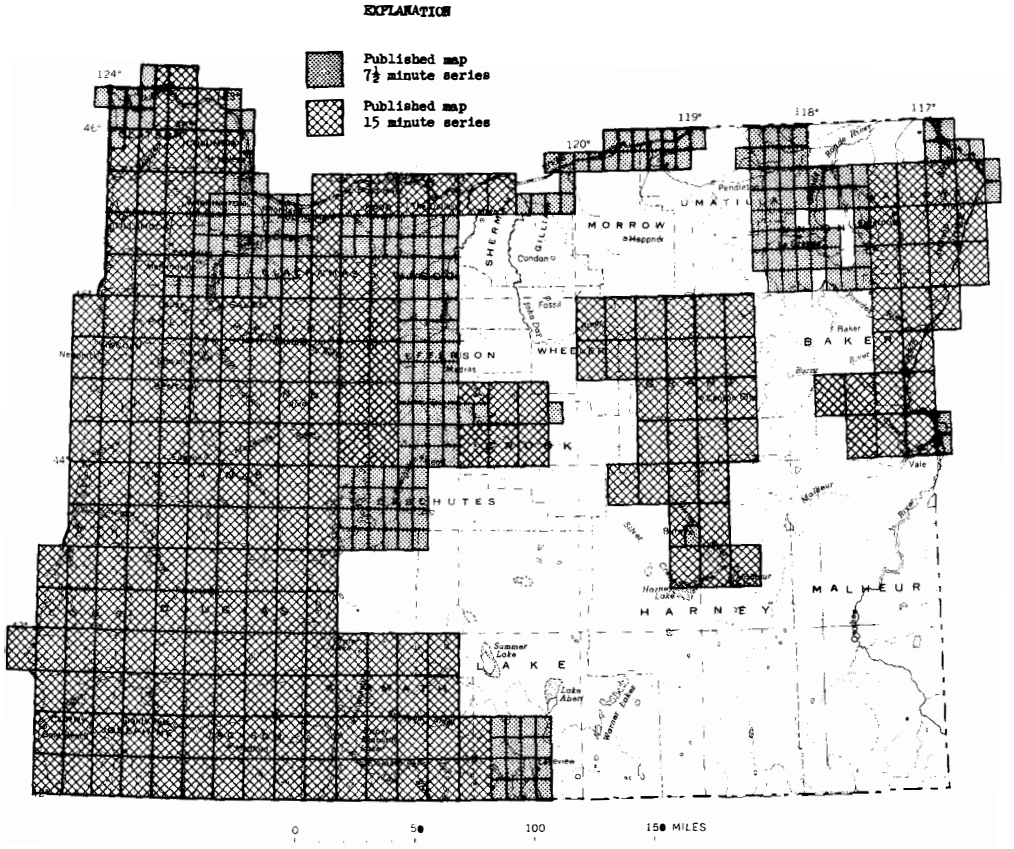

FIGURE 4.—Topographic mapping in Oregon.

Magnetic methods

Variations in the earth's magnetic field produced by different rock masses below the surface may be measured by a simple dip needle or by the more precise magnetometer. The magnetic susceptibility of different types of rocks varies widely and provides a good indication of structure, rock type, and, under some conditions, degree of alteration. Aeromagnetic surveys of selected parts of the State have been made in connection with geologic studies; the published ones are:

1. Aeromagnetic map of the Kerby and part of the Grants Pass quadrangles, Josephine and Curry Counties, Oregon, by J. R. Balsey, R. W. Bromery, E. W. Remington, and others (U.S. Geol. Survey Map GP–197).
2. Geologic interpretation of the aeromagnetic map of the Lebanon quadrangle, Linn and Marion Counties, Oregon, by R. W. Bromery (U.S. Geol. Survey Map GP–212).
3. Aeromagnetic map of the Albany-Newport area, Oregon and its geologic interpretation, by R. W. Bromery (U.S. Geol. Survey Map GP–481).
4. Geologic interpretation of the reconnaissance gravity and aeromagnetic surveys in northwestern Oregon, by R. W. Bromery and P. D. Snavely, Jr. (U.S. Geol. Survey Bull. 1181–M, N).

The areas covered by these studies are shown in figure 5.

Gravity methods

Gravity studies measure variations of the relative densities of rock lying below the surface. Knowing the density variations, interpretations can be made regarding probable rock types beneath the surface. From 1962 to 1966, a program to establish gravity base station control and compile data for more than 8,000 gravity measurements made in Oregon was conducted by Oregon State University.

Woollard and Rose (1963) established 10 base stations in Oregon as part of the international gravity network, and published the first gravity map of Oregon. Berg and Thiruvathukal (1965) refined the values of gravity for the 10 base stations and established 22 additional bases, and Bromery and Snavely (1964) published a simple Bouguer gravity anomaly map of northwestern Oregon. H. R. Blank, Jr. (1965) published a Bouguer gravity anomaly map of southwestern Oregon; also, he discussed the general features of the Bouguer gravity field in southwestern Oregon (Blank, 1966).

Two state-wide and one offshore gravity maps, using a 10-milligal contour interval, have recently (1967) been compiled by the Geophysical Research Group, Department of Oceanography, Oregon State University, under the direction of J. W. Berg, Jr., and J. V. Thiruvathukal. These maps were published by the Oregon Department of Geology and Mineral Industries, as GMS 4–a, *Free-air gravity anomaly map of Oregon;* GMS 4–b, *Complete Bouguer gravity anomaly map of Oregon;* and GMS 4–c, *Free-air gravity anomaly map west of Oregon.* The areas covered are shown in figure 5.

Seismic methods

Variations in the elastic properties of rocks affect the speed of transmission of seismic waves, so measurements of travel time can

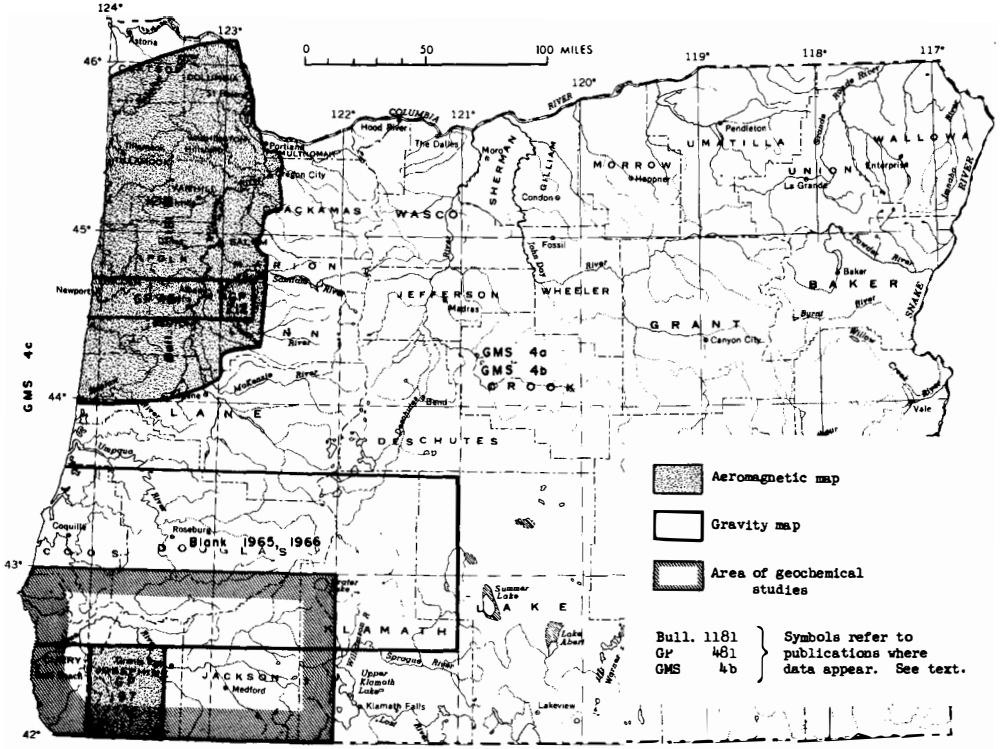

FIGURE 5.—Geophysical and geochemical studies in Oregon.

reveal much about the nature of concealed rock masses. Study of natural seismic waves generated by earthquakes provides information regarding the gross structure of the crust of the earth. Seismic surveys have been performed in several parts of the State by private interests as part of the search for oil, but they are generally not available for public inspection. Detailed studies (Chiburis, 1965; Dehlinger and French, 1965) of the deep crustal features of Oregon and the Pacific Northwest have been made in connection with world wide seismic studies and the establishment of a seismic station in Corvallis, Oregon, as part of the world-wide Standard Seismograph Network.

GEOCHEMISTRY

Geochemical prospecting for minerals includes any method of mineral exploration based on systematic measurement of the content—generally in trace amounts—of some metallic element or group of elements in such naturally occurring materials as soil, vegetation, stream sediment, and water. The purpose of the measurements is the discovery of abnormal chemical patterns (geochemical anomalies) related to mineralization.

Geochemical studies have been carried out by mining companies in Oregon, but as this information is proprietary it is not publicly available. Since 1963 the Oregon Department of Geology and Mineral Industries has had a geochemical sampling program. Over three thousand stream sediment samples have been analyzed for copper, zinc, molybdenum, and mercury. The results of these analyses are available for inspection at the Portland office and will be available in published form in late 1968 or 1969. The area covered is indicated on figure 5.

GEOLOGY

General Geologic History of Oregon

(By R. E. Corcoran, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Oregon's location on the western edge of the North American continent places it in a zone where the earth's crust has undergone severe deformation over long periods of geologic time. The mobility in this region is reflected by the intensely folded and metamorphosed older strata and the nearly continuous record of volcanism in its geologic history, extending from the oldest rocks (more than 400 million years) in the Klamath Mountains to the very young lavas (less than 2,000 years old) in the High Cascades. In this area many of the early geologic events are missing. The older strata are either hidden beneath a cover of younger rocks, or their story has been largely obliterated by metamorphism or by erosion. For this reason we can only make generalized interpretations of the Paleozoic and Mesozoic geologic Eras in the State. From the beginning of the Cenozoic, about 60 million years ago, the picture becomes clearer and we are able to interpret it with more certainty.

The pre-Cenozoic rocks can be observed through two rather large "windows," where younger strata have either been uplifted and strip-

ped off by erosion or never existed. These are: the Klamath Mountains of southwest Oregon and a sprawling, mountainous region in central and northeast Oregon generally referred to as the Blue Mountains.[2] A third, much smaller window is in the Pueblo Mountains on the Oregon-Nevada border, where metamorphosed sedimentary and volcanic rocks of probably Permian or Triassic age, together with some intrusive rocks, form the core of the mountains. A small area of granodiorite in the western Trout Creek Mountains represents the extreme northern extension of a large Mesozoic intrusive that lies south of the State line. The remainder of the State, and by far its greater area, is blanketed by diverse volcanic rocks or by marine and continental sediments of the Cenozoic Era.

PALEOZOIC ERA

No rocks of Precambrian age (oldest in geologic time) are known, and outcrops of Paleozoic age are very restricted. Consequently, attempting to unravel the early geologic history of Oregon is much like assembling a jigsaw puzzle with most of the pieces missing. Highly metamorphosed schists, probably derived from ancient sediments and volcanics, crop out along the Oregon-California border in southern Jackson County (Wells and others, 1940; Wells, 1956). According to Baldwin (1964b), there is no direct geologic evidence in Oregon which could be used to date these schists, but about 20 miles southeast of the State line in California, sedimentary rocks containing Silurian fossils (early Paleozoic) overlie similar schists and in places grade downward into it.

Oregon's geologic past can, however, be dated with certainty back more than 400 million years. In Crook County in central Oregon, and in the eastern part of the Blue Mountains, fossil remains date the formations from Devonian (middle Paleozoic) to Permian (late Paleozoic) (Merrian and Berthiaume, 1943; Kleweno and Jeffords, 1961; Bostwick and Koch, 1962). The marine beds mark several repeated invasions of warm shallow seas throughout most of the State during this long span of time. Lime, mud, sand, and volcanic flows and breccias deposited in these seas were subsequently uplifted, folded, and faulted several times by mountain-building processes. For example, sedimentary rocks of Pennsylvanian age (late Paleozoic), which crop out near Suplee in southeastern Crook County, contain layers of leaf-bearing course-grained sandstone, and are therefore of nonmarine origin. These continental beds are in contrast to the Paleozoic marine limestones and mudstones which make up the bulk of the Paleozoic sedimentary section in this region.

MESOZOIC ERA

Near the end of the Paleozoic Era and continuing into the early part of the Mesozoic, much of western United States was above the sea and was undergoing complex diastrophism, intrusion, and volcanism.

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[2] This geographic unit actually consists of several distinct Mountain groups or ranges in which the Paleozoic and Mesozoic rocks crop out in a discontinuous belt from the vicinity of Prineville on the west to the Snake River on the east. Among the best known are: the Wallowa Mountains in the northeast corner of the State, Elkhorn Ridge west of Baker, the Greenhorn Mountains north of Prairie City, and the Strawberry and Aldrich Mountains, southeast and southwest of John Day.

In Oregon, which is within this mobile belt, the uplift and folding were accompanied by emplacement of ultramafic rocks (largely peridotite), serpentinite, gabbro, diorite, and granite (Thayer and Brown, 1964).

During the remainder of the Mesozoic (Late Triassic, Jurassic, and Cretaceous Periods), a huge, rapidly sinking, complex marine trough, or eugeosyncline, developed across Oregon. Its formation was intermittent, but in a general way it extended from the Klamath Mountains to the Wallowas. Rocks now exposed at the surface indicate that many thousands of feet of sediments were laid down in the seas that occupied this trough. Dickinson and Vigrass (1965) report that in the Suplee-Izee area of east-central Oregon the rocks show almost continuous volcanism from Late Triassic through Late Jurassic time. Tremendous volumes of volcanic ejecta (pyroclastics) as well as lava flows and breccias were erupted on the land and poured out onto the sea floor. These materials provided the source of most of the marine sediments. Northeast of this region, in what is now the southern Wallowa Mountains and Snake River gorge, volcanism was equally as great, although there were periods of relative quiescence that allowed limestone reefs to build in the more shallow parts of the sea (Gilluly, 1937; Vallier, 1967, The geology of part of the Snake River Canyon and adjacent areas in northeastern Oregon and western Idaho: Oregon State Univ. doctoral thesis). In southwest Oregon, exposures in the Rogue River Canyon show a typical eugeosynclinal section of graywackes and volcanic sediments, with interbedded lava flows and pyroclastics of various types.

Within the broad trough smaller marine basins were formed, each basin being one of a related sequence developed by more or less contemporaneous crustal movement (Brown and Thayer, 1966 a, b, c). Volcanoes erupted within or near the main depositional troughs and formed archipelagoes and individual islands much like those that lie off the east coast of Asia today. Erosion of these islands formed the source of the sediments to fill the basins again. Basin development, uplift, and erosion, although continuous over a long period of time, are spasmodic when viewed over the space of a few million years.

In southwest Oregon the Triassic-Jurassic rocks appear to have passed through a depositional-tectonic history very much like that of the central and northeastern part of the State, but the deformation that took place near the end of the Jurassic obliterated much of the evidence (Wells, Hotz, and Cater, 1949).

Beginning in the Late Jurassic and continuing into Early Cretaceous time, another major mountain-forming interval occurred which was characterized by strong folding and faulting and regional metamorphism. In southwest Oregon, thick sheets of peridotite were emplaced, accompanied by smaller bodies of amphibole gabbro, quartz diorite, and dacite porphyry (Diller, 1914; Ramp, 1961). In northeastern Oregon, gabbro, norite, quartz diorite, granodiorite, and quartz monzonite were intruded at about the same time as satellite outliers of the Idaho batholith (Taubeneck, 1957; Taubeneck and Poldervaart, 1960). These intrusives are of particular importance to the State because many of the principal metalliferous deposits appear to be related to them (Lindgren, 1901).

Near the close of the Mesozoic, much of the State was covered by warm, shallow, tropical seas, as indicated by fossil evidence of Late Cretaceous age in the Medford and Mitchell areas and along the southwest Oregon coast (Condon, 1902). Buddenhagen (1967, p. 135) notes that in the Suplee-Izee area ". . . the marine Upper Cretaceous sediments: (1) appear to rest unconformably on Triassic beds in this area, thus overlapping the entire Jurassic and probably much of the Triassic section, and (2) similar marine Upper Cretaceous deposits occur in north-central and northwestern Washington and in southwestern Oregon. The implication is that much of the *terra incognita* below the Tertiary lavas westerly from this area is underlain by unmetamorphosed Cretaceous, and probably also Jurassic and Triassic, marine beds." In discussing the regional geologic history of the pre-Tertiary of southwest Oregon, Howard and Dott (1961, p. 79) state, "Scattered Late Cretaceous deposits of the whole Klamath-Siskiyou province represent eroded remnants of a once far more extensive overlapping sequence which apparently blanketed much of the region after the last strong mid-Cretaceous orogenic pulse. The writers envision a rise in relative sea level in the Cape Sebastian area in Late Cretaceous (Campanian?) time resulting in a series of embayments into which rivers debouched sands and mud that accumulated on deltas and shallow shelves. . . . Because the topography was moderately irregular, and because marine transgression spanned practically all of Late Cretaceous time, the exact age of the basal 'postorogenic' deposits varies considerably from place to place."

Cenozoic Era

The Cenozoic Era is the most widely represented geologic age division in Oregon and is therefore of special interest. It is characterized by marine sedimentary and volcanic rocks in the western part of the State and continental sedimentary rocks and associated volcanic eruptives in the eastern part. Crustal deformation took place throughout the whole of this interval and has continued, to a moderate degree at least, up to the present time.

PALEOCENE AND EOCENE EPOCHS

Western Oregon

During the Paleocene and Eocene Epochs, 63 to 36 million years ago, western Oregon was covered by a shallow sea where thousands of feet of sediments and volcanic rocks accumulated. At that time the Coast Range and much of the Willamette Valley were occupied by a large, partially enclosed, geosynclinal basin which probably extended from the Klamath Mountains northward about 400 miles through western Washington (Snavely and Wagner, 1963). The eastern margin of the sea probably was somewhere beneath the present Cascade Range. In all probability, a chain of volcanic peaks much like the modern Aleutian Islands existed west of the shoreline, and from them came vast quantities of lava, breccia, and pyroclastics which were deposited on the sea floor. These materials interfingered with coarse-grained sedi-

ments eroded from the Klamath Mountains to the south and volcanic detritus from the east.

Volcanism was particularly active during early Eocene time, when more than 10,000 feet of basalt flows and breccias gradually built up above the level of the sea. Erosion in the present Coast Range has exposed these thick piles of lava in the upper reaches of the Siletz River west of Dallas and farther north in the Tillamook highlands. Snavely and Wagner (1963, p. 4) state that, "Although the volcanic rocks thin toward the margins of the geosyncline, there is probably no place in the Coast Ranges where Mesozoic strata can be reached by a drill without penetrating a thick section of lower Eocene flows or breccia. These basaltic lavas are estimated to have the largest volume of any volcanic unit in the Pacific Northwest, at least 60,000 cubic miles." In 1955, Sinclair Oil & Gas Co. put down an exploratory test in the Coast Range approximately 15 miles east of Florence. The drill entered lower Eocene volcanic rocks at a depth of 6,660 feet, and the company abandoned the hole, still in volcanics, at a depth of 12,880 feet.

During middle Eocene time, uplift of the Klamath Mountains and vigorous erosion caused tremendous quantities of sands and silts to be deposited in the geosyncline (Diller, 1902). The sediments accumulated temporarily on deltas and large submarine fans at the mouths of the major streams or rivers. Periodic slumping of the unconsolidated material resulted in turbidity currents that moved the sands and silts into the deeper parts of the trough. The currents produced graded beds in which the coarser material settled first, with the finer sediments on top. Many of the pre-existing volcanic mounds or islands were buried beneath these deposits as the geosyncline continued to subside, and about 10,000 feet of rhythmic-bedded strata accumulated along the axis of the trough (Snavely and Wagner, 1963).

By late Eocene time local uplift and active volcanism had separated the geosyncline into several smaller basins so that areas of marine deposition were considerably reduced. Fossil pollen and spores found in Eocene sedimentary rocks indicate that in the Coos Bay area the climate was temperate to subtropical. The coastal region was low and swampy and was covered with lush and dense flora. To the east, upland areas supported a warm, temperate vegetation probably much like the hardwood forests in the eastern United States today. The higher portions of the mountains to the south and east and probably much of the interior region supported a more temperate flora (Hopkins, 1967). Coal swamps developed in the Coos Bay area, and intermittent downwarping produced interfingering marine and nonmarine sediments. In the northern part of the geosyncline lower and middle Eocene rocks in the highlands were eroded and contributed about 5,000 feet of basaltic and arkosic sands.

Baldwin (1964b, p. 1) states:

> As one visualizes the basin in which the western Oregon marine formations were deposited, he should see a basin with shifting shorelines, widening as the basin sank and narrowing as deltas pushed out into shallowing waters. Coarser sands along the delta fronts would interfinger with silty beds farther from shore. During times of slight uplift some of the earlier sedimentary beds would be removed and coarser beds containing pebbles of older formations would likely rest upon the truncated surface.

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Central and eastern Oregon

The general uplift of the land toward the end of the Cretaceous Period caused the seas to retreat westward. Beginning in the early Tertiary, accumulated materials from numerous volcanic eruptions along the present axis of the Cascade Range acted as a barrier to further marine transgression. Sporadic eruptions produced thick accumulations of mudflow breccia, stream drainages became dammed, and ashy sediments filled ponded basins. Hornblende andesite, basalt, and rhyolite flows, mostly from central vents, covered wide areas. Fossil plants found in great variety in the Clarno Formation of central Oregon indicate a temperate to subtropical climate in this part of the State (Hergert, 1961).

OLIGOCENE EPOCH

Western Oregon

During the Oligocene, 36 to 25 million years ago, the sedimentary basin of western Oregon continued to shrink and the present Coast Range began to form (fig. 1). An arm of the early Oligocene sea extended southward as a shallow marine embayment into what is now the Willamette Valley (Lowry, 1947). By the end of this epoch most of western Oregon was above sea level. In the period of uplift along the present site of the Coast Range there was widespread emplacement of gabbroic sills, some of which are as much as 1,000 feet thick.

The Cascade Range was probably only a low ridge of volcanic hills at this time, and the predecessors of the John Day, Crooked, and Deschutes Rivers flowed westward across the State directly into the Willamette trough. These rivers carried large quantities of ash erupted from volcanoes on the shore into the marine basins to form thick layers of tuffaceous sediments. The rapid deposition of sediments buried the upper Eocene coastal plains, and coal swamps existed in only a few places. Several thin beds of subbituminous coal crop out in the Oligocene section in the northern Coast Range near Vernonia and in the foothills of the Western Cascades near Wilhoit.

Central and eastern Oregon

Lava flows and pyroclastics continued to erupt in the Cascade Mountains and farther east in central Oregon. Ash, carried many miles by wind and rivers, was deposited as the John Day Formation partly in fresh-water lakes, preserving a large number of plant and animal remains. Of special interest are the formations in the John Day River valley, where down-cutting by the river has exposed high, jagged cliffs of green, red, and buff volcanic tuffs. The exceptionally fine vertebrate fossils found in these beds may be seen in museums throughout America and Europe.

In the area between Willowdale and Ashwood in Jefferson County, a number of pyroclastic eruptions poured out onto the land surface and inundated a large part of central Oregon. Strongly to weakly welded rhyolitic ash flows interbedded with air-fall tuffs built up more than 4,000 feet of volcanic rocks in a relatively short period of time (Peck, 1964). The ash flows make distinctive stratigraphic marker horizons, and some of these have been traced for distances of more than 50 miles.

MIOCENE EPOCH

During the Miocene Epoch, from 25 to 13 million years ago, general uplift of most of western Oregon continued, particularly in the present Coast Range, which resulted in an almost complete withdrawal of the sea. There were still a few minor embayments along the coast and at the mouth of the Columbia River where fossiliferous marine muds and sands were deposited. This deposition is further described by Snavely and Wagner (1963, p. 20–21) :

> Contemporaneously with middle Miocene deposition, basalt flows and breccias were extruded onto the sea floor from a north-trending group of vents and fissures located near the strand line. Thick accumulations of these volcanics formed small islands, and the subaerial flows on these islands can be traced into pillow lavas that are interbedded with marine strata. Many of the headlands along the northern part of the Oregon coast, such as Yaquina Head, were local centers of middle Miocene volcanism.

During this epoch, volcanism continued to pile up lavas, tuffs, and other volcanic rocks in the Cascade region. Pyroclastic eruptions showered central Oregon with ash that aided in preservation of still more fossil plants and animals, making the John Day country one of the most important areas in the world for collecting vertebrate fossils. The varicolored tuffs along U.S. Highway 26 between Picture Gorge and John Day and along Succor Creek near the Idaho border are examples of Miocene sedimentation in central and eastern Oregon.

The outstanding event in Miocene time occurred during the middle of the epoch, when basaltic lavas poured out flow upon flow over extensive areas, particularly in northern Oregon and southeastern Washington, to form the famous Columbia River basalt plateau. In all, more than 35,000 cubic miles of lava erupted to cover 100,000 square miles in Oregon, Washington, and Idaho (Waters, 1955). The source vents for these flows are difficult to find because of the thick lava capping, but they appear to have originated from groups of dikes, a few of which have been uncovered by post-Miocene erosion. The Grande Ronde and Cornucopia dike swarms are exposed in, and north and south of the Wallowa Mountains and extend northward across the Snake River into the headwaters of the Walla Walla River in Washington. The Monument dike swarm in western Grant County extends from the North Fork of the John Day River to the western end of the Aldrich Mountains (Brown and Thayer, 1966a). The lavas were extremely fluid at the time they were erupted, as shown by single flows or flow units which have been traced for distances of as much as 100 miles.

While the basalts of the Columbia River Group were pouring out, basaltic to rhyolitic volcanoes were active in the southern Blue Mountain region and in the southeastern part of the State. The Blue Mountain region was buried under the basalt, and products from other volcanoes formed a widespread blanket of ash and ignimbrite.

In northwestern Oregon, swamps or small lakes formed on the uneven lava topography. Iron oxide, derived through chemical decomposition of the basalts, was precipitated in the swampy areas under the influence of organic, chemical, or mechanical agents and accumulated to form beds of limonitic ore. Deep, chemical weathering of the top flows of this basalt, which probably was most intensive during late Miocene-early Pliocene time, resulted in the formation of large

deposits of lateritic bauxite, a potential ore of aluminum. These laterites are found in Columbia, Washington, Multnomah, and Marion Counties, Oregon, and extend into Cowlitz County, Washington.

PLIOCENE EPOCH

During the Pliocene Epoch, 12 to 1 million years ago, almost all of the present land within the State rose above the sea level. There were a few small bays or estuaries along what is now the coastal fringe, principally in the vicinity of Coos Bay and a few miles farther south at Cape Blanco. In these basins more than 3,000 feet of shallow-water marine strata rest unconformably upon older Tertiary rocks. Pliocene strata consist mainly of debris eroded from older Tertiary formations that bordered the basin.

The main Cascade Range developed along a great north and south line of crustal weakness probably during late Tertiary time. However, the majestic volcanic cones forming the present High Cascades evolved later from eruptions in Pliocene-Pleistocene time. While the High Cascade volcanoes were growing, thick piedmont deposits were being laid down, chiefly by rivers but also in lakes to the east and west. These sediments, for the most part, consist of cross-bedded, fluviatile silts, sands, and gravels composed of andesitic and basaltic debris.

One of the most interesting events that took place in the Bend area during Pliocene time was the eruption of a welded dacite tuff. According to Williams (1957) :

> This was laid down by glowing avalanches discharged from a parasitic vent high on the northeast flank of the Broken Top volcano, about a mile and a half west of Three Creek Lake. Some avalanches sweept eastward from this source to pour down the canyon of Tumalo Creek and then overflow its banks to empty into the valley of the Deschutes River about a mile and a half south of Bend. But most of the avalanches raced northeastward to inundate almost the whole of the Bend quadrangle west of the Deschutes River, and their deposits also underlie much of the flat country around the Sisters, on the adjacent Three Sisters quadrangle.

Williams indicates that the ash flow covers more than 200 square miles, ranging in thickness between 20 and 50 feet.

Extensive deposits of rhyolitic ash flows are fairly common in the eastern part of the State, particularly in the broad upland region from John Day southward as far as the Harney Basin (Lund, 1966; Walker and Repenning, 1965).

Building of the Cascades caused a great climatic revolution. The mountain range became an obstacle to the moisture-laden winds from the coast, resulting in a large decrease in rainfall in the interior of the State. Thus the rise of the Cascades separated the State into two characteristically different climatic provinces. Western Oregon has a humid climate, thick vegetation, and several large rivers; eastern Oregon has a range from semiarid to arid climate, sparse vegetation, and only a few perennial streams and rivers.

Great fault blocks began forming in south-central and southeastern Oregon, leaving such mammoth escarpments as Abert Rim and Steens Mountain, together with many lesser ones. Intermontane lakes that formed in basins between these fault block mountains fluctuated greatly in size depending on seasonal variation in rainfall, but over

a period of time they accumulated thick beds of volcanic sediments as well as distinctive white deposits of diatomite. The Blue Mountains, as we see them now, were blocked out by folding and faulting in early middle Pliocene time. Some faulting has continued up to the present, as at Hot Lake and along the west side of the Grande Ronde Valley. Near the end of the Pliocene Epoch, several olivine basalt flows, which were extremely fluid at the time of their eruption, covered wide areas of central and eastern Oregon.

PLEISTOCENE EPOCH

By the beginning of the Pleistocene, only about 1 million years ago, the ocean had receded and left notable terraces containing black sand along the southern Oregon coast. The black sand is a concentration of heavy minerals (magnetite, chromite, zircon, garnet, gold, and platinum) formed by the concentrating action of waves along a beach. The over-all landscape at that time was probably much like it is today, although the climate was cooler and wetter, with the lakes in central Oregon occupying a larger portion of the State (Allison, 1966).

One of the outstanding events of the Pleistocene Epoch was the building of a row of large composite volcanic cones, extending from Mount Baker in Washington to Mount Lassen in California. Volcanoes such as Mount Hood, Mount Jefferson, and Mount Mazama (Crater Lake) were superimposed on the older rocks of the Cascade Range.

The Pleistocene was also the time of the great Ice Age, and although continental ice sheets did not extend as far south as Oregon, alpine glaciers covered many of the peaks in the Cascade Range as well as the higher parts of the Blue and Klamath Mountains. Glacier-scoured, U-shaped valleys on the slopes of Steens Mountain show that ice once covered the crest of that upraised fault block in what is now one of the more arid areas of southeastern Oregon.

Williams (1957) states that in the High Cascades:

> Glacial erosion has modified the shapes of all these volcanoes; indeed, most of them have been reduced to radiating ridges separated by glacial cirques. The parasitic cones on their flanks have been all but demolished. The fragmental cones on their summits have been denuded until the more resistant fillings of their central pipes have been left standing as gigantic monoliths, like miniature Matterhorns. Especially vivid examples of such deeply dissected volcanoes include Three Fingered Jack, Mount Washington, North Sister, Husband, Mount Yoran, Lakeview, Cowhorn, Sawtooth and Howlock Mountains, Mount Thielsen, and Union Peak.

Meltwaters from these glaciers carried much coarse debris from the mountain sides, filling many of the lower stream canyons and valleys.

HOLOCENE EPOCH

During the last 10,000 years, representing the Holocene Epoch, there have been a number of significant geologic events in Oregon. Mount Mazama erupted about 7,000 years ago with such rapid removal of magma that the summit collapsed to form Crater Lake caldera. At about the same time, another caldera formed on top of Newberry Volcano south of Bend, but on a slightly smaller scale. Several cubic miles of airborne ash from both the Mazama and Newberry eruptions spread over a vast area of central Oregon, and some of this material carried by winds has been identified from as far away as Banff,

Alberta, Canada, and Montana (Fryxell, 1965). Since that time, flows of basalt have poured out on the surface at McKenzie Pass, Santiam Pass, and Lava Butte near Bend; Diamond Craters south of Burns; Jordan Craters near Jordan Valley. Trees that were covered by these flows and preserved from decay have recently been dated by carbon-14 and show that some of the lavas are less than 1,500 years old. Other flows on which no absolute age dates are yet available appear to be less than 1,000 years old.

The streams and rivers emptying into the ocean have carried tremendous quantities of sediment from the land surface since the beginning of the Pleistocene and deposited it on the Continental Shelf (Byrne, 1963). One of the significant features at the base of the Continental Slope off the northern Oregon coast is the Astoria Fan, a depositional apron consisting of sediment discharged from the mouth of the Columbia River into Astoria Canyon. The fan is about 50 miles wide at its widest point and more than 75 miles long. Astoria Canyon heads in about 60 fathoms of water approximately 10 miles west of the mouth of the Columbia River. The upper or shallow portion of the canyon probably developed during the Pleistocene by subaerial erosion when sea level was several hundred feet lower than at present. Movement of material down the canyon in response to gravity has served to erode the canyon into deeper water and to keep it essentially clear of great quantities of sedimentary debris.

Over the past few thousand years normal geologic processes have modified Oregon's landscape. Existing glaciers have shrunk to small remnants; streams have eroded canyons in mountainous regions and have filled valleys and basins with sediment; landslides have carried large masses of material to lower elevations; the ocean has worn away many points of land, leaving isolated off-shore rocks or sea stacks; the wind has built sand dunes along the coast. Man has also done his bit to alter the landscape, sometimes inadvertently, sometimes in order to suit the needs or desires of an ever increasing population. A casual glance at his surroundings will convince him of the changes that he has wrought.

GEOLOGY OF WESTERN OREGON NORTH OF THE KLAMATH MOUNTAINS

(By P. D. Snavely, Jr., H. C. Wagner, and N. S. MacLeod, U.S. Geological Survey, Menlo Park, Calif.)

Western Oregon, as discussed in this section, includes the Coast Range and the Willamette Valley as far east as the foothills of the Cascade Range. The Coast Range is a mountainous belt extending from the Klamath Mountains northward beyond the Columbia River into Washington. The Willamette Valley, a nearly flat alluvial plain and low hills, is part of the nearly continuous line of troughs extending from Pudget Sound to the Klamath Mountains.

In the past 60 million years the Coast Range area was first the site of the deepest part of a basin of marine deposition and later was an area of uplift that restricted the Pacific Ocean to its present position rather than permitting it to lap against the foothills of the Cascade

Range. This history is complicated by changes in the environments of deposition during accumulation of many thousands of feet of marine sediments, by great outpourings of volcanic material on the sea floor, by emplacement of extensive sheets of gabbro and other igneous rocks, and by several major periods of uplift, folding, and erosion.

The origin of the deep north-trending trough in which about 50,000 feet of Tertiary sedimentary and volcanic rocks have accumulated within this time span of 60 million years is open to speculation because much of the data needed for an interpretation of its origin are not available. Its eastern margin is buried beneath the lava flows of the Cascade Range, its western margin is covered by the Pacific Ocean, and the basement rocks underlying the center of the trough are as yet unknown as they neither crop out, nor have they been reached by exploratory drilling. Only in the Klamath Mountains to the south can older rocks be seen, and these older rocks probably do not underlie most of the Oregon Coast Range. Nevertheless data obtained from investigations on the areal distribution, environments of deposition, ages, and compositions of the sedimentary and volcanic rocks, as well as the location and ages of folds, faults, and unconformities, makes possible a preliminary reconstruction of the evolution of the trough.

The area in which this Tertiary trough occurred lies within the circum-Pacific orogenic belt astride the mobile boundary between the continent and the deep ocean. Elsewhere in this circum-Pacific belt, major earth forces have deformed the surface and formed deep trenches or troughs marginal to the continents. Some of these troughs have been filled with thick accumulations of volcanic and sedimentary rocks. The possible origins of troughs similar to the one that occupied western Oregon and Washington in early Tertiary time have been explained by a variety of hypotheses such as (1) tensional rifting (tearing apart) resulting in lateral separation of crustal material, (2) crustal downbuckling as a result of a spreading sea floor thrusting itself beneath the continental crustal block, and (3) downwarping of the crust as the continents are thrust seaward over the oceanic floor.

Although the origin of the trough that existed in Oregon during the early Tertiary is unclear, its shape at various times in the past can be reconstructed from the distribution of the marine rocks deposited in it. Recent summaries of the distribution of rocks in western Oregon have been published by Baldwin (1959, 1964), Wells and Peck (1961), and Snavely and Wagner (1963, 1964).

The lower Tertiary trough extended northward from the Klamath Mountains about 400 miles to southern Vancouver Island, and westward from the Cascade Range to near the present edge of the continental margin (fig. 6), (Snavely and Wagner, 1963). The north-trending axis of the trough was located between the present coastline and the crest of the Oregon and Washington Coast Ranges. Subsequent changes in the inferred shape of the basin of deposition and in the nature of sediments and volcanic rocks deposited in different places within the basin at successive epochs in Tertiary time are shown in a sequence of paleogeologic maps (figs. 8–13) and the major stratigraphic units are given in figure 7.

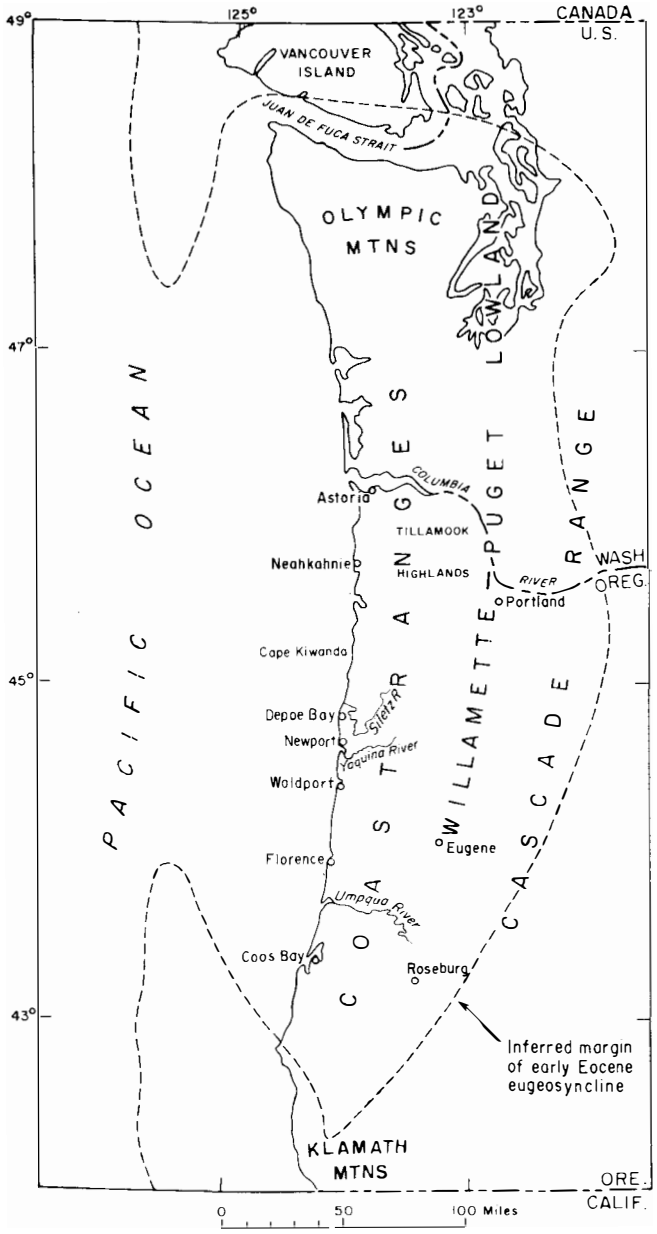

FIGURE 6.—Probable extent of the lower Eocene eugeosyncline in western Oregon and Washington.

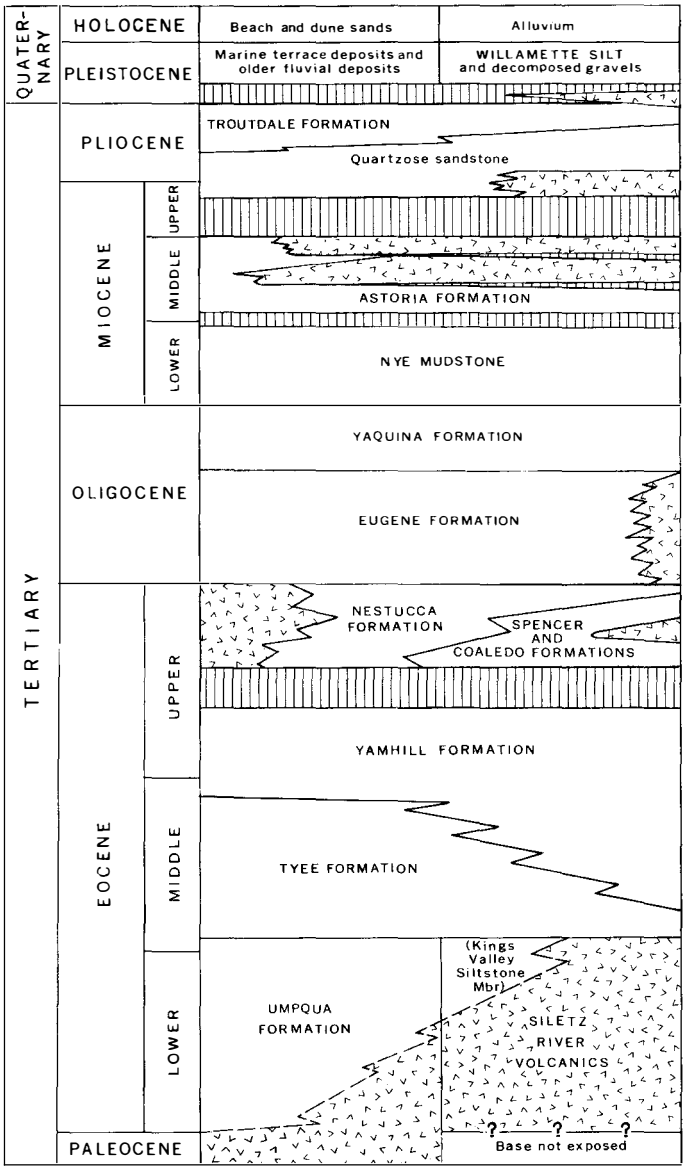

FIGURE 7.—Generalized stratigraphic column showing positions of major units in western Oregon.

GEOLOGIC HISTORY

The first event recorded in the depositional history of this trough was the submarine outpouring of vast quantities of basaltic lava (fig. 8). Upon extrusion into cool sea water the hot lava was rapidly quenched and producing fragmental debris composed of angular basaltic glass; where less drastically quenched, thick accumulations of pillow basalt were formed. The volcanic rocks intertongue complexly with marine tuffaceous siltstone and basaltic sandstone that contain fossils indicative of Paleocene, early Eocene and early middle Eocene age. As the trough subsided, submarine basalts continued to be erupted, and near centers of volcanism they attained a thickness in excess of 15,000 feet. The base of the volcanic sequence is not exposed in the central and northern parts of the trough nor has it been penetrated by drill holes as deep as 12,880 feet.

Most of the rugged upland areas in the Oregon Coast Range are formed on volcanic rocks of this lower to middle Eocene sequence which is designated the Tillamook Volcanic Series in the northern part of the range (Warren and others, 1945), the Siletz River Volcanics in the central part (Snavely and Baldwin, 1948; Snavely and others, 1968) and in the southern part form the volcanic rocks of the

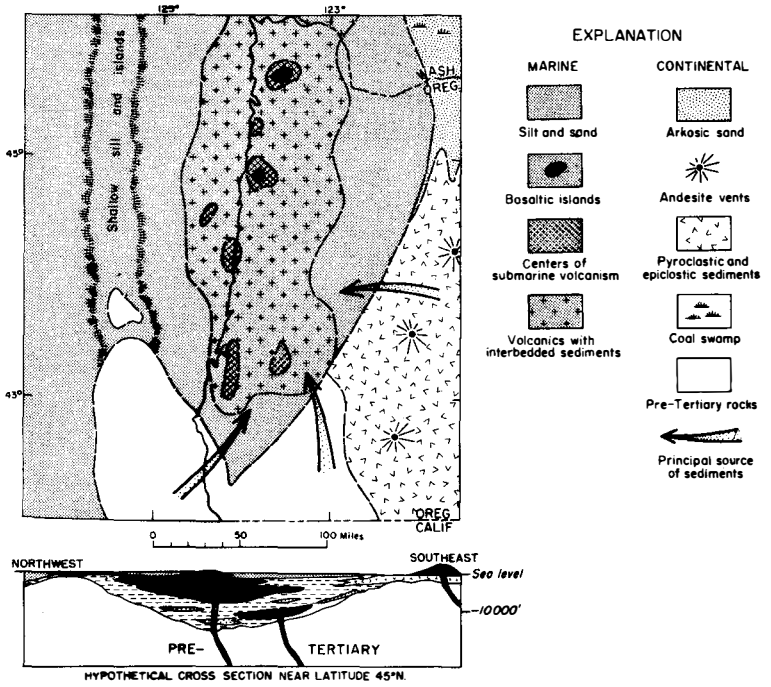

FIGURE 8.—Paleogeologic map of western Oregon during early Eocene time.

Umpqua Formation (Diller, 1898; Wells and Waters, 1935; Hoover, 1963; Baldwin, 1965). The Siletz River Volcanics can be divided on the basis of age and petrochemistry into a lower tholeiitic basalt unit and an overlying alkalic basalt unit (Snavely and others, 1965; Snavely and others, 1968). The lower unit consists of two types of tholeiitic basalt, the older of which contains less TiO_2 and more MgO and has more primitive chemical characteristics. The compositions of these two parts of the lower unit are given in table 1. These tholeiitic basalts have strong affinities to oceanic tholeiitic basalts as represented by samples reported upon by Engel and others (1965) and Muir and Tilley (1966) from the Pacific and Atlantic Oceans as shown in columns 3 and 4, table 1. Late in this volcanic epoch extrusion of lava in places exceeded the rate of downwarping sufficiently to form volcanic islands. Beneath such islands, as in the central part of the Oregon Coast Range near latitude 45° (fig. 8), the basaltic magma was ponded in shallow magma chambers where it was differentiated and later erupted as alkalic basalt, ankaramite, picrite basalt and feldspar-phyric basalt which form the upper alkalic unit. The volcanic history represented in the lower to lower middle Eocene basaltic rocks of the Oregon Coast Range is considered to have closely paralleled that of the Hawaiian Islands insofar as the eruptive cycle and composition of the rocks (col. 5, table 1) are concerned (Snavely and others, 1968).

TABLE 1.—AVERAGE COMPOSITION OF THOLEIITIC BASALT FROM THE LOWER UNIT, SILETZ RIVER VOLCANICS, COMPARED WITH THOLEIITIC BASALT FROM OCEANIC AREAS (AVERAGES RECALCULATED WATER-FREE)

	(1)	(2)	(3)	(4)	(5)
SiO_2	49.0	48.3	50.2	50.0	49.9
Al_2O_3	14.5	14.6	15.3	15.3	14.1
Fe_2O_3	3.9	5.3	2.1	2.2	3.1
FeO	7.7	8.5	8.0	8.5	8.6
MgO	8.3	5.8	7.4	7.9	8.5
CaO	12.2	11.5	11.9	11.2	10.4
Na_2O	2.3	2.6	2.7	2.8	2.0
K_2O	0.17	0.14	0.19	0.17	0.38
TiO_2	1.6	2.7	1.7	1.6	2.5
P_2O_5	0.15	0.31	0.18	0.13	0.26
MnO	0.19	0.25	0.19	0.18	0.16

(1) Older part of lower unit, Siletz River Volcanics (average of 3 samples).
(2) Younger part of lower unit, Siletz River Volcanics (average of 5 samples).
(3) Pacific Ocean (average of 4 analyses from Engel and others, 1965, p. 720, table 1; includes samples PVD–3, PVD–4c, PV17, and EM, but does not include PVD–1 which is probably a feldspar-phyric basalt).
(4) Atlantic Ocean, Atlantis and Chain suites (average of 9 analyses from Muir and Tilley, 1966, p. 197, table 3, col. 2).
(5) Hawaiian Islands (average of 181 analyses from Macdonald and Katsura, 1964, p. 124, table 9, col. 8).

Near the close of this early volcanism dark gray massive to thin-bedded tuffaceous siltstone and interbedded volcanic, feldspathic and argillaceous sandstone were deposited. In places these strata are interbedded with the submarine volcanics, particularly in the southern part of the Coast Range. These sediments, which are referred to the Umpqua Formation (Diller, 1898; Baldwin, 1965), are of early to middle Eocene age and represent reworked volcanic debris within the basin as well as continental detritus carried in by turbidity currents from land areas south and east of the basin (fig. 8). Unconformities within the Umpqua Formation attest to spasmodic tectonic events in the southern part of the basin (Baldwin, 1965). The upper part of the Umpqua Formation is predominantly siltstone and is equivalent to a similar sequence of rocks in the Corvallis area, the Kings Valley

Siltstone Member of the Siletz River Volcanics (Vokes and others, 1954). These lower middle Eocene sedimentary rocks are equivalent in age to the eruptions of differentiated basaltic rocks which formed islands in the central part of the Oregon Coast Range near latitude 45° N. Volcanic islands probably also existed in the Tillamook Highlands in the northern part of the Coast Range where a similar basaltic sequence, containing both submarine and subaerial flows, crops out. Lenses of impure bioclastic limestone occur at the top of the Eocene basalts in the Dallas area (Baldwin, 1964b) and have been quarried for agricultural lime and for the production of Portland cement.

At the close of this volcanic epoch in middle Eocene time crustal forces, perhaps related to those that originally formed the trough, resulted in a major downwarp of the basin and a concomitant uplift of the Klamath Mountains area. In the southern part of the trough this deformation and associated erosion is shown where the Tyee Formation (middle Eocene) was deposited unconformably on strata as old as the lower part of the Umpqua Formation. Material was rapidly eroded from the Klamath highland area and large deltas and submarine fans formed along the southern margin of the trough. Periodic slumping of large masses of unconsolidated material at steep delta fronts, perhaps triggered by earthquake shocks, moved large masses of water-saturated sediments basinward. These mass movements are believed to have been transformed into turbidity currents that transported the debris northward along the axis of the trough for a distance of more than 150 miles (Snavely, Wagner, and MacLeod, 1964). Pre-existing volcanic highs were buried and as much as 10,000 feet of rhythmic-bedded strata accumulated (fig. 9). This predominantly unfossiliferous sandstone unit, the Tyee Formation (Diller, 1898), consists of graded units 2 to 10 feet thick that are composed of medium-grained feldspathic and argillaceous sandstone in the lower part and carbonaceous siltstone in the upper part. The bottoms of graded units are sharply defined and commonly contain sedimentary structures, such as groove casts and flute casts, whose orientation permits one to determine the direction of sediment transport. An analysis of more than 500 of these sole markings (Snavely and others, 1964b) indicates that the detrital material that comprises the Tyee Formation was transported northward in the trough, flowed around obstructions such as volcanic highs, and eventually blanketed the entire southern end of the basin (fig. 9). Pelagic clays at the top of some of the graded units contain foraminiferal faunas which indicate deposition in water depths in excess of 5,000 feet. In the southern end of the basin, nearer to the source area, conglomerate lenses form thick units in this sequence and represent less readily transported material which was deposited in part from streams near the southern margin of the basin. Contemporaneous deposition north of latitude 45° N consisted of marine pelagic siltstone and lesser amounts of basaltic and arkosic sandstone.

Near the close of middle Eocene time the Klamath Mountain area had apparently been eroded to a region of moderate relief and furnished only minor debris to the basin. By that time the basin was essentially filled with turbidity current deposits, and coal-bearing continental beds and nearshore sands were laid down along the south-

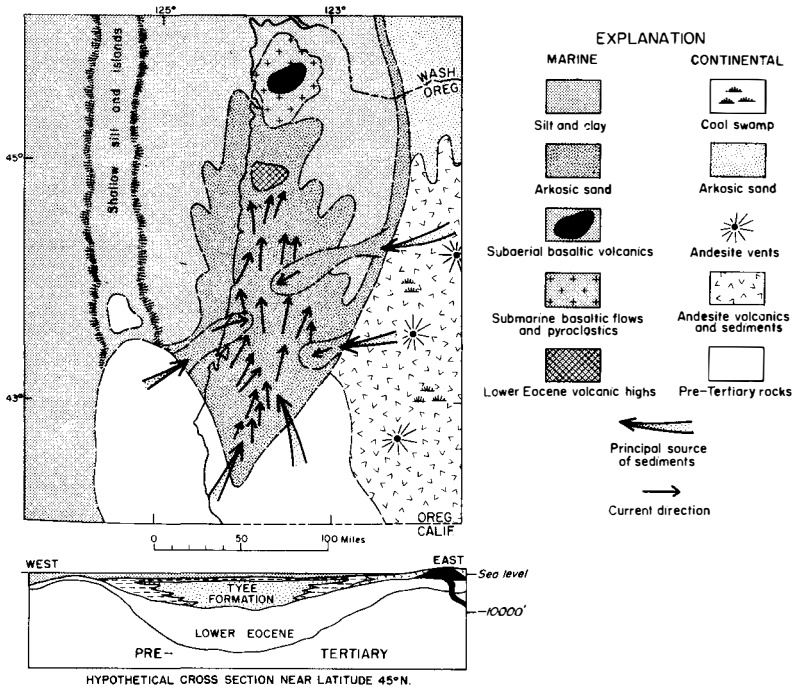

FIGURE 9.—Paleogeologic map of western Oregon during middle Eocene time.

ern fringe of the basin whereas silt and clay were the dominant sediments deposit d in its deeper parts. In the central part of the Oregon Coast Range the siltstone units thus formed comprise the Yamhill Formation (Baldwin and others, 1955); in the northern part fine-grained marine deposits of this age represent pelagic deposition that continued uninterrupted from middle to late Eocene time. Interbedded in the pelagic siltstones north of latitude 45° are thick units of basaltic sandstone which were derived from volcanic highs.

In middle late Eocene time the eugeosynclinal trough was subjected to renewed deformation which produced broad uplifts of the older sedimentary and volcanic rocks and formed several islands and depressions in a generally shallow marine basin. Erosion of these island areas contributed coarse clastic detritus to the marine environment and produced deposits that are thickest marginal to the structural highs. This middle late Eocene uplift and erosion is recorded in a major unconformity that can be recognized around structural highs in much of western Oregon and Washington. However, toward the open sea, in the area of the present continental shelf, sedimentation probably continued essentially uninterrupted.

In late Eocene time a broad belt of nearshore marine sandstone was laid down along the eastern and southern margins of the basin (fig. 10). These massive to thin-bedded, micaceous arkosic sandstones along

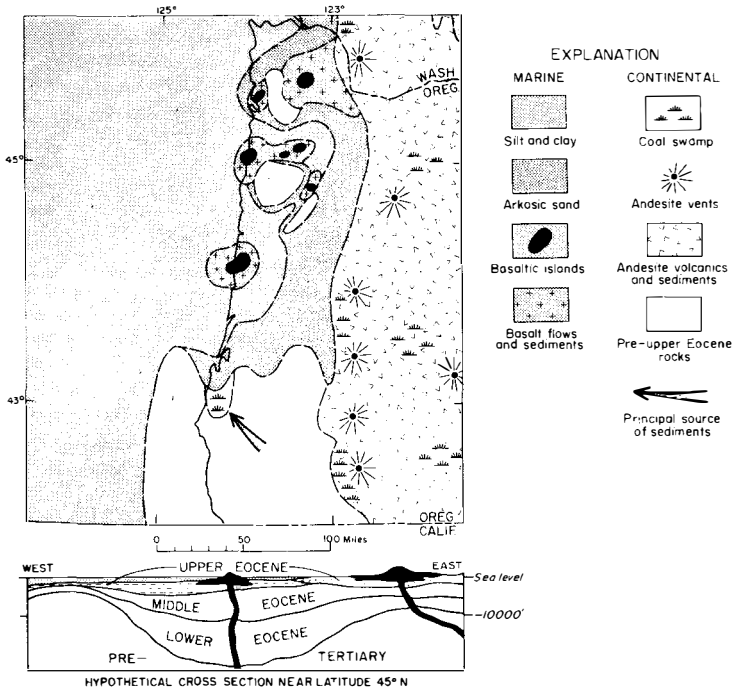

FIGURE 10.—Paleogeologic map of western Oregon during late Eocene time.

the eastern margin are assigned to the Spencer Formation (Turner, 1938) and contain interbedded basaltic sandstone, carbonaceous siltstone, and tuff beds, and interfinger basinward with marine tuffaceous siltstone. Arkosic sandstone in this unit locally has high porosity and could serve as reservoir rocks for petroleum accumulation. Fringing this marine environment was a broad coastal plain where sedimentation and intermittent downwarping resulted in interfingering marine and brackish water sandstones and siltstones as well as non-marine mudflow deposits, tuffaceous rocks, volcanic breccias, and lava flows of andesitic composition (Peck and others, 1964). Coal-forming plant debris accumulated locally in this coastal-plain environment, but not in sufficient thickne to be of economic value due to constant dilution by volcanic detritus. However, farther removed from the andesitic volcanic fields of the ancestral Cascade Range, near Coos Bay, plant debris accumulated to form the coal beds (Allen and Baldwin, 1944) that are found interbedded with sandstone and siltstone of the Coaledo Formation (Diller, 1899). These coal beds have been mined since the 19th century and have yielded several million tons of coal. Estimated reserves exceed 65 million tons which comprise the major portion of coal reserves in Oregon. The sedimentary rocks of the Coaledo Formation have been interpreted as representing deposition in a deltaic environment (Dott, 1966). Toward the open sea, tuffaceous silt and clay

were deposited in deeper water. These organic-rich argillaceous rocks, as described in the Nestucca Formation (Snavely and Vokes, 1949), are commonly thin bedded and contain thin ash beds. Intercalated with these finer clastics are basaltic and arkosic sandstones derived from islands of lower and middle Eocene volcanic and sedimentary rocks.

In late Eocene time basalt was erupted from vents onto the floor of the shallow marine basin in several areas, and produced breccia and less common pillow basalts which interfinger with marine siltstone. Islands formed where volcanic accumulations were thickest, and the flows that erupted on these islands can be traced laterally into submarine breccias and pillow lavas. Pyroclastic material was ejected from vents near the shores of islands. and accumulated as water-laid tuff lenses that intertongued with marine strata. Beds of basaltic sandstone and cobble and boulder conglomerate of earliest Oligocene age were derived from these subaerial volcanics and formed fringing deposits around these islands throughout much of the basin.

In early Oligocene time orogenic activity along the southern margin of the basin resulted in regional uplift and a general northward shift of the shoreline which further restricted the basin of marine deposition (fig. 11). Vigorous pyroclastic volcanism in the ancestral Cascade Range along the eastern margin of the geosyncline brought about a

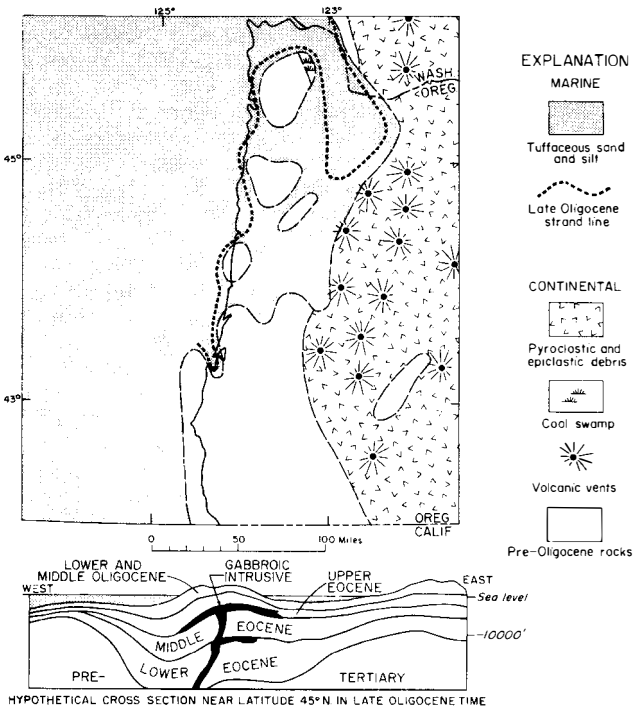

FIGURE 11.—Paleogeologic map of western Oregon during Oligocene time.

marked change in the type of sediments deposited in the basin during Oligocene time. Volcanic ash falls and stream-transported ash and pumice accumulated in large quantities in the basin, and the ash was locally mixed with argillaceous material eroded from islands and from land areas marginal to the basin. The marine rocks thus produced consist mainly of massive to thick-bedded tuffaceous siltstone and sandstone with intercalated ash beds; pumice lapilli tuff and glauconitic sandstone are common, and limy concretions occur locally. The Eugene Formation (Smith, 1924; Schenck, 1927) is typical of marine units deposited in early and middle Oligocene time in western Oregon.

In late Oligocene time broad uplift in the Coast Range area was accompanied by widespread emplacement of gabbroic sills as much as 1,000 feet thick that now cap many of the higher peaks in the central part of the Oregon Coast Range. During cooling, the magma that formed these sills differentiated to produce rocks of gabbroic to granitic composition (Snavely and Wagner, 1961). These gabbroic sills are now a major source of jetty rock. The late Oligocene uplift essentially restricted marine deposition to the western flank of the uplift except for a restricted embayment that extended eastward along the Columbia River downward into the northern part of the Willamette trough (fig. 11). Several westward flowing streams breached the ancestral Coast Range and carried sands and gravels into the marine environment to form thick deltaic deposits of cross-bedded pumiceous, carbonaceous sandstone and pebble congomerate. Typical of these deposits is the Yaquina Formation (Harrison and Eaton, 1920; Vokes and others, 1949) exposed in the vicinity of Newport. This formation is composed predominantly of sandstone which locally has high porosity and would serve as a potential reservoir rock for petroleum accumulation. Sandstone units of this formation intertongue laterally with tuffaceous siltstone and glauconitic sandstone. Much of the material that composes these sands is detritus that was eroded from local highlands in which the Tyee Formation was exposed.

Marine deposition in structural basins along the western flank of the Coast Range uplift continued essentially uninterrupted from late Oligocene to early Miocene time. The waning of vigorous pyroclastic volcanism in the Cascade Range in early Miocene time was reflected in a diminished supply of ash to the marine environment and organic-rich siltstone and mudstone was deposited in the deeper parts of open margin basins (fig. 12). These rocks have a petroliferous odor when freshly broken and represent potential source beds for petroleum. Typical of these deposits is the Nye Mudstone (Schenck, 1927; Snavely, Rau, and Wagner, 1964) in the Newport embayment. Similar rocks were probably deposited in north-trending basins which exist on the present continental shelf.

The record of upper Oligocene to lower Miocene sedimentation in the Willamette downwarp is poorly known as much of this area is masked by Quaternary deposits. Marine strata that were deposited in the northern part of the Willamette downwarp consist of volcanic and arkosic sandstone, shallow water deposits of water-laid tuff, and less abundant siltstone and pebble conglomerate. In the central and southern parts of the Willamette downwarp brackish water and lacustrine plant-bearing tuff and tuffaceous siltstone and volcanic sandstone

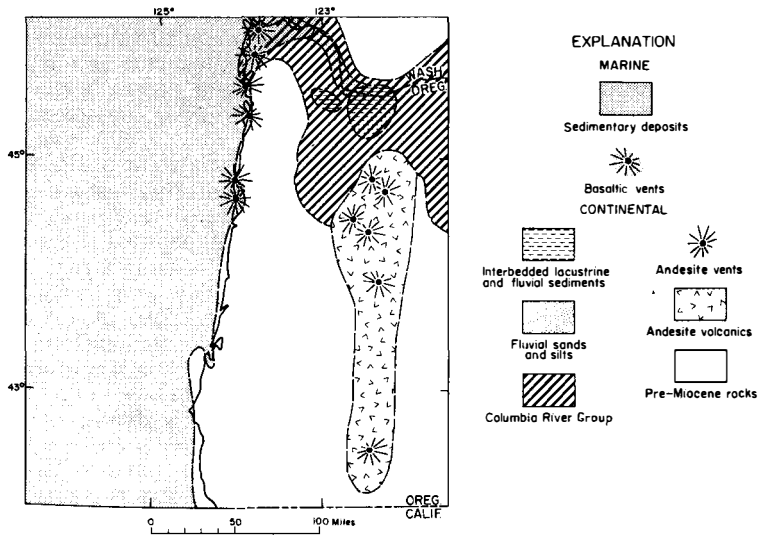

FIGURE 12.—Paleogeologic map of western Oregon during Miocene time.

were laid down. Near the coastal plain, plant material accumulated locally to form beds of lignitic coal. Eastward, both the marine and non-marine sedimentary deposits interfinger with andesitic and dacitic tuffs as well as with andesite and olivine basalt flows and breccia (Peck and others, 1964). The olivine basalt flows extended westward from the Cascade Range into parts of the Willamette downwarp.

The crustal unrest that characterizes the late Tertiary history of the continental border of Oregon is recorded in several major and minor unconformities within sequences of Miocene age and in the eruption of lava from small volcanoes near the present coast. Large quantities of sand and silt were furnished to the marine environment in middle Miocene time, and the resulting thick deposits of near-shore sandstone and siltstone are refered to the Astoria Formation (Weaver, 1937; Warren and others, 1945; Snavely, Rau, and Wagner, 1964). Strata of this formation are found in structural embayments extending from the Coos Bay embayment on the south to the Astoria embayment on the north. In places, such as north of Newport, the Astoria Formation overlaps the Nye Formation (lower Miocene) and rests on the Yaquina Formation (Oligocene). Although these fossiliferous sedimentary rocks near the present coastline attain a thickness of only 1,000 feet, a much thicker and finer-grained facies exists in the basins on the continental shelf. Interbedded sandstone in this offshore facies may serve as reservoir rocks for petroleum accumulation. The arkosic sandstone of the Astoria Formation contains a heavy mineral suite that suggests that much of the coarser detritus was transported from igneous and metamorphic terranes in north-central Washington and southern British Columbia by an ancestral Columbia River. Several ash beds present in the sequence, particularly in the Newport

embayment, are dacitic in composition and probably had their source from volcanoes in the Cascade Range. In response to tectonic events the strandline fluctuated across a belt several miles wide as indicated by the intertonguing of nearshore sandstone and deeper water siltstone. Beds of basaltic sandstone derived from older basalts are not uncommon in the sequence.

In middle Miocene to early Pliocene time intermittent uplift in the Coast Range again shifted the strandline generally westward and basalt was erupted from several volcanoes near the present coast. Three eruptive events, separated by unconformities, are recorded in the middle Miocene to lower Pliocene(?) rocks along coastal Oregon and southwestern Washington. The oldest of the basaltic units is the most widespread and voluminous. Eruptive centers marked by extensive dike swarms and irregular shallow intrusions are located at Tillamook Head, Cape Falcon, Cape Meares, Cape Lookout, Cape Kiwanda and Depoe Bay. In places magma did not reach the surface and was intruded into the upper Tertiary sequence at shallow depths to form thick (500–1000 feet) sill-like bodies of gabbroic rock such as are now found at Mount Hebo and Neahkahnie Mountain. Some of the volcanoes erupted beneath the sea and as a result of rapid cooling the molten lava was intensely fragmented and produced thick aprons of basaltic breccia adjacent to these volcanic centers. In a few places pillow basalts were formed by submarine extrusion of lava or where thick subaerial flows entered the sea. Islands formed where accumulations of shallow water submarine basalts built up above sea level, and part of the basalt was extruded on land.

The middle volcanic unit is found along the coast between Depoe Bay and Cape Foulweather, at Yaquina Head and Seal Rock, and in the vicinity of the Columbia River. These volcanic rocks form one of the major sources of road rock in western Oregon. The lower and middle units are typically separated by nearshore massive sandstone and less commonly by brackish water arkosic sandstone and siltstone (Snavely and Vokes, 1949). The middle unit consists predominantly of basalt breccia and waterlaid fragmental debris with lesser amounts of massive flows and pillow lavas. Feeder dikes to this basalt sequence are abundant and sills, such as at Seal Rock, locally intrude upper Tertiary rocks.

The upper volcanic unit may be as young as early Pliocene and occurs as flows, dikes and sills in western Washington on the north side of the Columbia River. Flows of this upper basalt unit probably extend south of the Columbia River into Oregon some 20 miles east of Astoria.

The petrochemistry of the three flow sequences that erupted from volcanoes along coastal Oregon is essentially identical to that of flow sequences within the Columbia River Basalt (as used by Waters, 1961; Snavely and others, 1965) that were erupted from large fissures east of the Cascade Range in the Columbia River Plateau. These flood basalts flowed westward down the Columbia River downwarp (which existed along the same general area that is now occupied by the Columbia River but several miles to the south) and extended westward

to the sea and also southward into the northern part of the Willamette Valley (fig. 12). About 15 miles east of Astoria, near Big Creek, breccias derived from volcanoes along the coast appear to intertongue with breccias and pillow lavas that formed where westward-flowing lava of the Columbia River Group poured into the sea. Deposits of low-grade ferruginous bauxite, formed by the weathering of Miocene basalt, occur west of Portland and near Salem (Libbey and others, 1945).

A major period of uplift and erosion occurred near the close of Miocene time or early in Pliocene time. Except in the Coos Bay basin this orogenic event shifted the strandline west of the present Oregon coastline (fig. 13). In the Coos Bay basin nearshore sandstone and siltstone of Pliocene age grade rapidly northwestward into a predominantly siltstone sequence on the continental shelf. In other nearby areas upper Miocene(?) or Pliocene strata lapped onto folded and faulted older strata (Baldwin, 1966; Dott, 1966). The thickest marine deposits of Pliocene age now exist in north-trending linear basins on the continental shelf.

In a broad structural downwarp along the Columbia River massive crossbedded quartzose sands and silts of late(?) Miocene and Pliocene age were laid down on flows of the Columbia River Group. These sands and silts are more than 500 feet thick and contain much partially carbonized wood and finely-comminuted carbonaceous debris. The rocks are in part equivalent in age to the fluviatile and lacustrine sediments that fill the structural basins underlying the Tualatin Valley and the downwarp east of the Portland Hills. These poorly consolidated sediments, which are referred in part to the Troutdale

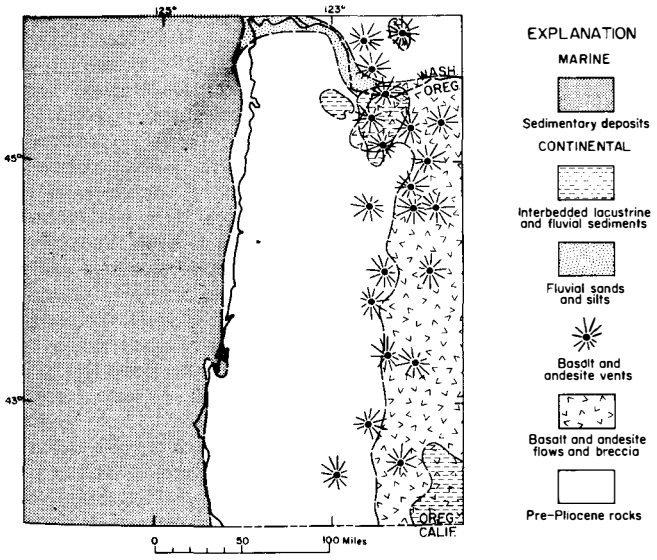

FIGURE 13.—Paleogeologic map of western Oregon during Pliocene time.

Formation (Hodge, 1933; Treasher, 1942; and Trimble, 1963), are more than 1,000 feet thick in the Tualatin Valley and consist predominantly of carbonaceous claystone, siltstone, and fine-grained sandstone. Coarse sand and gravel which occur as lenses in the Troutdale Formation are utilized as a source of aggregate. Locally along the western flank of the Portland Hills anticline, gray porous olivine basalt was erupted from a number of vents. These lavas are the Boring Lava of Treasher (1942) and are assigned a late Pliocene to late(?) Pleistocene age by Trimble (1963).

Maximum uplift of the Oregon Coast Range probably took place in late Pliocene and Pleistocene time. This vertical uplift was accompanied by movement along north and northwest-trending faults and by broad warping in response to compressional forces. Marginal to this region of general uplift, elongate basins were downwarped in the area of the present Willamette Valley and on the continental shelf. The rapid erosion that accompanied the uplift shed much clastic debris into the Williamette Valley and into the linear, north-trending offshore basins. In the eastern part of the Willamette Valley, reddish-brown decomposed gravels and interbedded sand and silt underlie widespread deposits of light-brown silt of late Pleistocene age, the Willamette Silt (Allison, 1953).

As sea level in late Pleistocene time was some 400 feet lower than at present, the great quantities of sand that were eroded from the Coast Range were deposited as broad coalescing alluvial fans that extended west of the present coastline and into the marine environment. Abundant fragments of wood and plants as well as heavy minerals derived from erosion of igneous rocks in the Klamath Mountains were deposited in these sheets of marine sand that prograde westward onto the continental shelf. Great quantities of sand and lesser amounts of gravel were discharged by the Columbia River at the time when its mouth was some miles west of the present coastline. This sediment was transported down the Astoria Submarine Canyon by turbidity currents to the deep sea floor where it formed a large submarine fan. Longshore currents carried large quantities of sand south of the Columbia River to form an extensive area of beach ridges.

Near the close of Pleistocene time much of the part of the Coast Range that was underlain by sedimentary rocks was reduced to an area of low relief, and large rivers like the Yaquina meandered across the landscape. Successive uplifts in late Pleistocene to Holocene time are recorded by marine terraces found at several elevations up to at least 500 feet along the west side of the Coast Range and by the incisement of large rivers. The Coast Range probably attained its maximum elevation in latest Pleistocene time. In Holocene time the general rise in sea level has exceeded uplift and the mouths of coastal streams have been drowned to form the many bays that indent the present coastline, and large spits and bars have been constructed across the mouths of most of the bays. Sand derived chiefly from erosion of the terrace deposits as sea level rose formed broad beaches and onshore winds have transported the sand inland to form large dunes, such as those near Florence (Cooper, 1958).

GEOLOGY OF THE KLAMATH MOUNTAINS PROVINCE

(By Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg.)

The Klamath Mountains province (fig. 1, geomorphic divisions of Oregon) is a region of generally rugged topography, with oversteepened slopes, narrow ridges, and deep canyons. Elevations are from sea level to 7,500 feet; relief is commonly from 2,000 to 5,000 feet. The ridge tops in a large part of the area are of fairly uniform elevation, about 4,000 feet, and are believed to represent an old erosion surface (Diller, 1902). A few isolated remnant patches of Tertiary gravel rest on this old erosion surface. Uplift of the area probably began in late Tertiary time and continued into the Quaternary, possibly into the Holocene.

The province by definition contains only pre-Tertiary sedimentary, igneous, and metamorphic rocks, and its boundaries are drawn where the Tertiary rocks overlie the pre-Tertiary. On the eastern margin the pre-Tertiary rocks are overlain by Tertiary continental sedimentary rocks, which grade upward into volcanic rocks of the Western Cascades. To the north and west the overlying Tertiary rocks are marine sediments of the southern Coast Range. The southern boundary lies in California. The geology of the area has been compiled by Wells and Peck (1961).

Paleozoic Schist

The oldest rocks exposed in the Klamath Mountains province of Oregon, and possibly the oldest in the State, are highly metamorphosed scists of probable Paleozoic age (fig. 4), which crop out in a small area along the California border about 20 miles south of Medford (fig. 3). Baldwin (1964b) suggests that these schists may be correlated with the Salmon Hornblende and Abrams Mica Schists (Carboniferous) of northern California. The schists are of three types somewhat gradational into each other. Wells (1940) described the most abundant variety as a medium to dark green plagioclase hornblende schist with variable amounts of epidote and another common variety as a dark gray graphitic schist. There are a few masses of silvery white quartz sericite schist with pyrite cubes.

Triassic Rock

Unconformably overlying the Paleozoic schist is a great apparent thickness of altered volcanic and sedimentary rocks belonging to the Applegate Group (Triassic). These tightly folded rocks are exposed over a large area of the Klamath Mountains province. They extend from the Ashland batholith, 10 miles southeast of Medford, about 35 miles westward to the egg-shaped diorite body surrounding Grants Pass (fig. 3), and from as far north as the Tiller area on the South Umpqua River (43° latitude) southward into northern California.

These rocks have been subjected to regional tectonic metamorphism as well as contact alteration around the margins of numerous granitoid intrusives where schists and gneisses are developed. Altered sedimentary rocks in the group include argillite, quartzite, marble, chert,

GENERALIZED STRATIGRAPHIC CHART FOR THE KLAMATH MTS.

ERA	SYSTEM	FORMATION AND DESCRIPTION
CENOZOIC	Quaternary	Beach sands and marine terraces along coast Bench gravels and alluvium along streams and glacial moraine and till Auriferous gravels (in former stream channels) (order not indicative of relative age)
	Tertiary	Old gravels - on Klamath peneplain Small intrusions of dacite porphyry and nepheline syenite Tyee Formation, Umpqua Formation } Extend into Klamath Mountains from southern Coast Range; also in Medford-Ashland area.
MESOZOIC	Upper Cretaceous	Marine beds in Gold Beach area Hornbrook Formation - Marine beds in Medford-Ashland area & upper Grave Creek
	Lower Cretaceous and Upper Jurassic(?)	Myrtle Group (coast area): Rocky Point Formation, Humbug Mountain Conglomerate, Otter Point Formation of Koch, 1966 Myrtle Group (inland area): Days Creek Formation, Riddle Formation
	Upper Jurassic	Nevadan Orogeny - Intrusive rocks: peridotite, serpentinite, gabbro, diorite, granite, pegmatite. Galice Formation, Rogue Formation, Dothan Formation } Succession uncertain
	Triassic	Applegate Group - Metasediments, metavolcanics and intrusives. Age of the lower part uncertain
PALEOZOIC		Pre-Triassic schist - age uncertain

FIGURE 14.—Generalized stratigraphic chart of the Klamath Mountains.

and some highly indurated conglomerate with stretched pebbles. The volcanic phase which makes up possibly two-thirds of the section includes altered lavas (basalt, andesite, and some rhyolite) and altered tuff and tuffaceous sediments.

JURASSIC FORMATIONS

The Galice, Rogue, and Dothan Formations, taken as a group, are somewhat similar in lithology and origin to the Applegate Group but are, in most places, less metamorphosed. These formations are older than the Upper Jurassic intrusive rocks in the area. They are dated as late Jurassic in age, but the stratigraphic relation of the Galice and Dothan Formations is still under investigation. The formations crop out in the area west of Grants Pass for a distance of about 30 miles measured across the strike to a point near Marial on the lower Rogue River. The Galice and Dothan Formations extend northward from northern California to a point east of Roseburg, where they are overlain by volcanic rocks of the Western Cascades. This represents a strike distance of nearly 100 miles from the California line. The

Rogue Formation, sandwiched between the Galice and Dothan Formations in the Galice area (Wells and Walker, 1953), covers a smaller area, and its aerial extent outside the Galice quadrangle has not been determined.

The Galice Formation lies on the east and is in thrust-fault contact with the Applegate Group. It is composed mainly of slaty siltstone, sandstone with occasional conglomerate lenses, and thick interbeds of lavas, tuffs, and tuffaceous sediments. All these rocks have been subjected to low-grade regional metamorphism, and the volcanics are generally altered to hard, in part siliceous, and chloritic greenstones. The Galice Formation is dated as early Late Jurassic (Oxfordian-Kimmeridgian) on the basis of fossils collected from 18 localities (Imlay, 1961).

The Rogue Formation lies west of the Galice Formation and is best exposed along the Rogue River from the Almeda mine north of Galice about 7 miles to a point below the Benton mine. It is composed of fine- to coarse-grained tuff, in part tuffaceous sediments, agglomerate, flow breccia, and andesitic lavas. These volcanic rocks are tightly folded and metamorphosed in varying degree from siliceous greenstone in the northern part of the area to amphibole gneiss south of Galice. The Rogue Formation appears to be the most favored for mineral deposits of the three Jurassic formations. Scattered mineralization in the form of gold-bearing fissure veins and related sulfides are found in the formation from the Canyonville area south to the Illinois River area.

The Dothan Formation is the most extensive of the three Upper Jurassic formations. It is a thick series of massive graywacke sandstone with some shale, conglomerate, chert, and pillow basalt. Type locality of the Dothan Formation is along Cow Creek near West Fork station, formerly Dothan Post Office (Diller and Kay, 1924). It forms a broad north- to northeast-trending band of the sedimentary rock that extends through the province from northern California to a point 10 miles east of Roseburg with only one break in continuity, in the Canyonville and Riddle area, where it is interrupted by a downfaulted segment of Cretaceous sediments. Like the Galice Formation, the Dothan Formation has sustained considerable deformation and is overturned in places.

Isoclinal folding and longitudinal faulting of the entire Dothan-Rogue-Galice group has resulted in confusion as to which of the formations is the youngest. Diller (1914), who first studied these rocks in detail, believed the Dothan Formation youngest. Taliaferro (1942) examined the section critically and concluded that the Dothan Formation belonged at the bottom of the series, as did Wells and Walker (1953). Dott (1965) also presents evidence that the Dothan Formation is the oldest of the series. Irwin (1964), on the other hand, working in the Klamath Mountains of northern California, believes the Galice and Rogue Formations are older than the Dothan, and that the Dothan Formation is post-Nevadan orogeny and has been moved into its present position by thrust faulting. Field investigations of this problem are continuing, but as yet no diagnostic fossils have been found in the Dothan Formation, and no conclusive evidence of the age relationships has been obtained.

Upper Jurassic-Lower Cretaceous Formations

MYRTLE GROUP

The Myrtle Formation, originally described by Diller (1898) and assigned to the Cretaceous, was later raised to group status (Imlay and others, 1959) to include several post-Nevadan Upper Jurassic-Lower Cretaceous units (fig. 14). The Myrtle Group is exposed along the western fringe and in various down-faulted blocks within the Klamath Mountains province. It consists chiefly of siltstone, sandstone, and conglomerate. Units within the group are similar lithologically, and differentiation is based largely on evolution of a mussel-like clam *Buchia*. Subdivisions of the Myrtle Group along the coast from oldest to youngest include the Otter Point Formation, Humbug Mountain Conglomerate, and Rocky Point Formation of Koch (1966). Similar rocks exposed inland consist of the Riddle and Days Creek Formations (Imlay and others, 1959).

The Otter Point Formation, which is exposed in the Gold Beach-Port Orford area, consists of about 10,000 feet of mudstone, sandstone, bedded chert, tuff, and pillow lava. (Gold Beach is at the mouth of Rogue River, and Port Orford is about 25 miles north.) Rocks of the Otter Point Formation are steeply folded, but much less altered than the underlying pre-Nevadan Jurassic formations. Where exposed in the Port Orford area, the Humbug Mountain Conglomerate and the overlying Rocky Point Formation (dominantly mudstone and sandstone) have a combined thickness of about 9,000 feet.

The Riddle Formation unconformably overlies pre-Nevadan Jurrassic rocks along the South Umpqua River near the town of Days Creek and along Cow Creek near Riddle. (The Riddle-Days Creek area is about 43° latitude and 50 miles from the coast.) The formation consists of dark gray siltstone with limestone lenses, chert-pebble conglomerate, and sandstone; at the type locality near Days Creek, where it is overturned, it measures about 1,088 feet thick.

The Days Creek Formation overlies the Riddle Formation concordantly at the type section along the South Umpqua River near Days Creek. The formation is composed of alternating dark gray sandstone and siltstone and is about 800 feet thick in this area. It occurs in all areas where the Riddle Formation is found as well as in the Takilma-Waldo area east of O'Brien (about 4 miles north of the California line and 30 miles from the coast), where it unconformably overlies the Galice Formation.

UPPER CRETACEOUS UNITS

Near-shore marine deposits of sandstone, siltstone, and conglomerate with fairly abundant marine fossils of Late Cretaceous age are found as scattered remnants in the Jacksonville-Medford-Ashland area and as a down-faulted block on upper Grave Creek about 30 miles northwest of Medford. These rocks belong to the Hornbrook Formation (Peck, Imlay, and Popenoe, 1956). The rocks are gently folded, but dip as much as 40° where the formation laps on the east flanks of the uplifted Ashland batholith.

Cretaceous rocks younger than the Hornbrook Formation are mapped and described by Howard and Dott (1961) along the coastal

area of Cape Sebastian and Pistol River, about 8 miles south of Gold Beach. A lower section of massive sandstone with minor conglomerate at the base is about 800 feet thick. The upper section of alternating shale and sandstone with a few distinctive fossils is about 600 feet thick.

Tertiary Formations

Tertiary rocks, not a part of the Klamath Mountains province, are mentioned here only because they extend southward into the area as a large synclinal trough in the Eden Ridge-Agness area and lap on the east edge of the province in the Medford area, where they are in turn overlain by western Cascades volcanic rocks.

In the Eden Ridge-Agness area of southern Coos and northern Curry Counties, these rocks are Eocene marine sediments of the Umpqua and Tyee Formations. The underlying Umpqua Formation extends as far south as a point on the Illinois River near the mouth of Silver Creek where it lies unconformably on the Dothan Formation and gabbroic rocks. The Umpqua Formation in this area is chiefly a well-bedded sandstone and siltstone and some massive conglomerate. The overlying Tyee Formation. which extends as far south as Bald Knob on the north side of the Rogue River, consists of coal-bearing shales, sandstone, and conglomerate.

Tertiary sediments in the Medford area are mapped as Umpqua Formation (Wells, 1956). The formation is predominantly a medium-grained, buff-colored sandstone with some conglomerate and shale and a few lenses of coal. It grades from near-shore marine sediments at the base, unconformably overlying the Hornbrook Formation, upward through continental deposits to volcanic sediments and tuffs near the top.

Tertiary and Quaternary Alluvial Deposits

Remnant stream deposits occurring at various elevations, and marine terraces along the coast, give evidence of stillstand periods during uplift of the Klamath Mountains. Many of these deposits have been worked for placer gold. The stream deposits have been divided into five categories (Wells and others, 1949). Four of these are listed:

1. "Old gravels" of Miocene or Pliocene age. These deposits lie on erosion surfaces at about 4,000 feet elevation. The poorly sorted cobbles and pebbles are partially decomposed and firmly cemented in a sandy matrix.
2. "Auriferous gravels of the second cycle of erosion" of Late Pliocene or Pleistocene age. These are poorly sorted, partly cemented gravels that occur as detached remnants of former stream channels on divides of the present drainage system.
3. Llano de Oro Formation or high bench gravels of Pleistocene age. These include terrace deposits lying as much as 400 feet above the channels of the present-day streams that deposited them. Lower, younger bench gravels occur in some areas as mapped near Galice by Wells and Walker (1953) and are evidence of continuing recent uplift of the province.
4. Holocene alluvium deposits are in part fluvioglacial in origin. The deposits consist of stratified gravel, sand, and silt on lower flood terraces, banks, and bars of the streams.

MARINE DEPOSITS

Baldwin (1964, p. 34) and Griggs (1945) describe six major terraces ranging from sea level to as high as 1,600 feet, that were cut during sea-level changes from Late Pliocene through Pleistocene time. The lower, more extensive terraces contain black sand deposits that have been mined in the past for chromite, gold, and platinum.

INTRUSIVE ROCKS

Igneous rocks ranging from ultramafic to granitic and a few related pegmatites were emplaced mainly during the Nevadan orogeny of Late Jurassic time. Koch (1966) specifies an intra-Late Jurassic age for the Pearse Peak Diorite of Kaiser (*in* Koch and others, 1961) near Port Orford by both stratigraphic and radiometric (K–Ar) methods (141±7 m.y. and 146±4 m.y.). It is generally accepted that the more mafic intrusives, peridotite, and gabbros were intruded earlier and the diorites and granites followed.

Not all the intrusive rocks in the area are related to the Nevadan orogeny. Some of the ultramafic rocks are believed to be significantly older. A few altered hypabyssal intrusive rocks are reported in the Applegate Group as well as in the Galice-Rogue-Dothan group.

Tertiary intrusives are also found within the Klamath Mountains province. They consist of a few dacite porphyry dikes and the nepheline syenite of Mount Emily about 8 miles north of the extreme southwest corner of the State. Some mineralization is related to these Tertiary intrusives, but most of the mineralization is tied to igneous activity of the Nevadan orogeny.

MINERAL RESOURCES

The complex geology of the Klamath Mountains province is a favorable environment for mineral deposits. The principal metallic ores have been those of gold, nickel, and chromium, with smaller amounts of antimony, copper, iron, mercury, platinum, silver, tungsten, and zinc. Metallic minerals known to occur in the area, but with limited or uncertain potential, include manganese and molybdenite. Metallic ores having some potential for significant increased or renewed production include gold, copper, nickel, and iron. Potential metallic mineral products of coastal beach sands include chromite, ilmenite, magnetite, gold, platinum, and zircon.

The area has produced significant amounts of crushed rock, sand and gravel, limestone (marble), and silica (quartz), and small amounts of asbestos, barite, clay, building stone, garnet sand, and talc (soapstone) There appears to be potential for the production of olivine, serpentine, and feldspar sand and for greater amounts of building stone, clay, and soapstone.

It has been mentioned earlier that the igneous rocks play an important part in mineral deposition in the area. In addition to the dioritic rocks being a major source of hydrothermal mineralizing solutions, the ultramafic rocks are potential host rocks for such ores and minerals as chromite, nickel, asbestos, talc, magnetite, olivine, and serpentine.

GEOLOGY OF THE CASCADE RANGE

(By A. B. Griggs, U.S. Geological Survey, Menlo Park, Calif.)

The Cascade Range, which extends from Lassen Peak in northern California through Oregon and Washington, is part of a nearly continuous mountain chain that borders the Pacific slope of North and South America. The segment within Oregon is from 30 to 70 miles wide and 250 miles long. Its crest roughly divides the State into a western third and an eastern two-thirds. In Oregon, the Range is divisible into two distinct north-south belts, the Western Cascades and the High Cascades (Callaghan, 1933; Baldwin, 1964) (fig. 1). These belts differ both in physiographic development and in the kinds and ages of the rocks exposed.

The Western Cascades, which occupy nearly two-thirds of the Range, are made up almost entirely of slightly deformed and partly altered volcanic flows and pyroclastic rocks that range in age from late Eocene to late Miocene. These rocks have been maturely dissected so that the only evidence that remains of the many volcanoes from which they were erupted is an occasional remnant neck or plug that marks a former vent. In contrast, the High Cascades are a relatively narrow plateau built up in Pliocene and later time by coalescing shield volcanoes formed of basalt and basaltic andesite lavas. Although in varying stages of dissection, these volcanoes still exhibit their constructional forms. Upon this plateau was erected a majestic chain of young volcanic peaks. The highest of these within the State is Mount Hood, which attains an elevation of 11,235 feet, over 5,000 feet above the surrounding country. Glaciation has carved their summits into their present shape; in some, alpine glaciers still remain.

With prevailing winds from the west, the Cascade Range forms a distinct weather barrier. Moderate to heavy rainfall is typical west of the crest, whereas the eastern part of the State has a semiarid to arid climate. The Range has been breached only where the Columbia Gorge has been cut through the mountains by the mighty Columbia on its way to the sea. The volcanic rocks that make up the Range are magnificiently exposed on the walls of the Gorge. Elsewhere the relatively few highways that traverse the Range go through passes at elevations of about 5,000 feet and may be closed from time to time by heavy snowfall during the winter and spring months.

The Cascade Range has been a substantial producer of mercury; 60,000 flasks have been recovered from mines along its western margin and adjacent parts of the Coast Range. The western Cascades have also produced nearly $1.5 million in gold and silver since 1858, when gold was first discovered in that region. The gold-producing areas, which are mostly in Tertiary volcanic rocks and are in association with small Tertiary intrusive bodies, are fairly evenly spaced along a north-south alignment extending from Clackamas County on the north to Jackson County on the south (Brooks and Ramp, 1968). They include the Bohemia, Quartzville, and North Santiam districts. Mining activity has been intermittent with the major part of the production prior to 1920, most of which was from near-surface oxidized ores. Production since 1920 amounts to about $½ million from complex gold, silver, copper, lead, zinc sulfide ores.

The resources of the Cascade Range also include great stands of Douglas fir on the west slope and of Ponderosa pine on the east slope, that cover all but the higher peaks. The mountainous, in part glaciated terrain, with numerous sparkling lakes and streams, provides a recreational area of exceptional beauty. An object of unusual interest is Crater Lake. The lake occupies the collapsed crater or caldera of an extinct volcano known as Mount Mazama (Smith and Swartzlow, 1936; Williams, 1942). The eruption that caused this caldera to form took place about 6,600 years ago and scattered volcanic ashes over a wide area in Oregon, Washington, Idaho, and Montana (Fryxell, 1965).

Western Cascades

In the southern part of the State, part of the western fringe of the Range is underlain by a complex of folded and faulted graywacke, siltstone, argillite, and interbedded volcanic rocks that span the interval from Late Triassic to Cretaceous time. Large areas of these rocks have been regionally metamorphosed. They have been intruded by periodotite and serpentine sills and dikes and by plutons which range in composition from gabbro to granite. These older rocks make up much of the adjacent Klamath Mountains and are described in the section of this report on the Klamath Mountains. Similar rocks with similar structural trends are exposed in northeastern Oregon and for this reason these pre-Tertiary rocks are considered to be continuous under the southern part of the Cascade Range forming the basement.

Further north where the Cascades border the Coast Range, marine and estuarine sediments with some interbedded basaltic flows and pyroclastic rocks of Eocene age crop out along the western margin (Diller, 1898; Wells and Waters, 1934; Wells, 1956; Hoover, 1963; Peck and others, 1964). These rocks make up part of the Umpqua and Tyee Formations (fig. 15). Their total thickness is more than 10,000 feet, and they most likely extend for many miles to the north and east under the younger volcanic rocks in the Cascades. The rocks of late Eocene age are predominantly of terrestrial origin. They contain thin coal seams, and near their southern limit grade upward into clastic volcanic rocks of the Western Cascades.

The volcanic rocks of the Western Cascades have been divided into four formational units (Peck and others, 1964) based upon fossil plants, lithologic differences, and erosional breaks plus some deformation. The oldest is named the Colestin Formation (Wells, 1956), and is spottily exposed along the southwestern edge of the Range. Included within this unit are the lower parts of both the Calapooya Formation (Wells and Waters, 1935) and the Fisher Formation (Hoover, 1963). These old volcanics consist of tuffs, flows, and much volcanic sedimentary rocks; all are of andesitic composition and are mostly late Eocene in age. The maximum thickness of these rocks is about 3,000 feet, and they pinch out entirely against a high of pre-Tertiary rocks southeast of Roseburg. They are buried, if present in the northern part of the Range.

Most of the southern part of the Western Cascades is formed of the next younger unit, composed mainly of the Little Butte Volcanic Series. Also included in this unit are the Mehama Volcanics and the

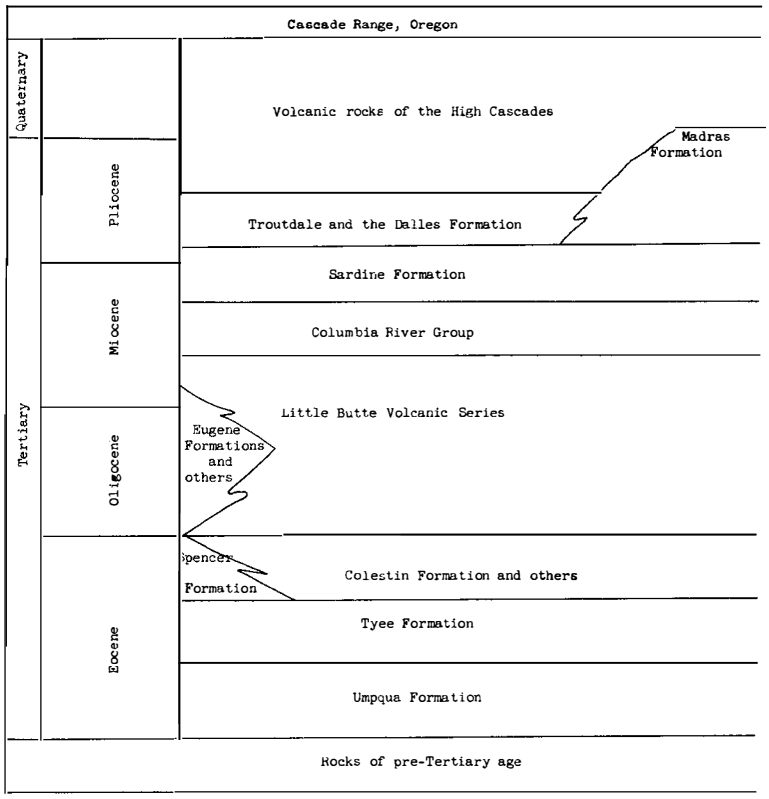

FIGURE 15.—Stratigraphic units in the Cascade Range, Oregon.

lower part of the Breitenbush Series of Thayer (1939), the Molalla Formation and the pre-Butte Creek Lavas of Harper (1946, Oregon State Coll. Master's thesis), the Eagle Creek Formation (Williams, 1916), and the Bull Creek Beds of Barnes and Butler (1930, Oregon Univ. Master's thesis). All of the latter are in the northern part of the Range, where they are exposed along the axes of at least three anticlines. Fossil leaves from localities in all of these rocks are from Oligocene to early Miocene in age. Tuffs, some of them welded, ranging from andesite to rhyodacite in composition, make up more than three-fourths of this unit; basalt and andesite flows and breccia make up much of the remainder. Water-laid tuffs and conglomerate are present locally through the section from place to place. The thickest section of the Little Butte Volcanic Series, 15,000 feet, is exposed along the North Umpqua River. At most other places in the southern part of the Range only half as much, or less, is exposed. In the northern part, where an unknown amount is buried, from 1,500 to 5,000 feet are exposed in the eroded anticlinal crests. Most of the basaltic and andesitic material was erupted from a north-south chain of shield volcanoes

near the western margin of the Western Cascades, whereas the more acidic rocks came from a chain of vents in the central and eastern parts. Intermittent subsidence of this accumulating volcanic pile is evident from the interfingering of marine rocks in the central part of the western margin. These mark the last eastward incursions of the seas into the area of the Cascade Range. The interbedded stream and lake deposits show that the westward flowing streams that drained the Cascades area and the country to the east were dammed by volcanic material from time to time. The many early Tertiary fossil leaf collections from localities scattered over eastern Oregon are typical of warm and humid environments. They show that at no time during this interval had the ancestral Cascades built up sufficiently high to form a climatic barrier.

In the northern part of the State basalt flows of the Columbia River Group crop out along the east and west fringes of the Range, and are exposed continuously through the gorge of the Columbia River. The Stayton Lavas of Thayer (1939) that occur east of Salem, and correlative basalt flows to the south of them are included within the Columbia River Group. The flows of the Columbia River Group lap on to the eroded edges of the older Little Butte volcanic Series rocks. They are considered middle Miocene in age in the Oregon Cascades because they lie on rocks containing fossil leaves as old as early Miocene and are overlain by rocks with middle to late Miocene fossil leaves. The section of flows exposed in the Columbia Gorge is more than 2,000 feet thick. These flows gradually pinch out southward against a high of older rocks in the core of the Range, at about the latitude of the North Santiam River. However, they continue to be exposed at intervals further south along both the eastern and western margins. Volcanic activity within the Oregon part of the Cascades had apparently ceased or was only minor during the outpouring of the flood basalts as no Cascade volcanics are interlayered with them. The same condition also may be true on to the south as the same time interval is represented by an erosional break and by warping of the older volcanics.

Flows, breccias, and tuffs, mostly of hypersthene andesite composition, that conformably overlie the Columbia River Group in the northern part of the Western Cascades and unconformably overlie older volcanics on to the south, have been grouped in the Sardine Formation (Peck and others, 1964). Also included in this unit are the Fern Ridge Tuffs and the upper part of the Breitenbush Series of Thayer (1939), the Rhododendron Formation (Hodge, 1933), and the Boring Agglomerate of Treasher (1942) in the nothern part of the Range, and the Heppsie Andesite (Wells, 1956) east of Medford to the south. Based upon stratigraphic position and fossil flora found in them, these rocks are considered to be mostly middle to late Miocene in age. They cover most of the nothern part of the Western Csacades, but occur only in patches to the south. Some correlative basalt and basaltic andesite flows that are exposed along the west central margin of the Range also are included in this unit. Locally along the North Santiam River as much as 10,000 feet of the Sardine Formation is exposed, but at most places these rocks aggregate 3,000 feet or less. The arching of the Cascade Range probably began towards the close of this episode of volcanic activity. Heretofore in Tertiary time the

Western Cascades had subsided intermittently and irregularly with the piling on of the great mass of volcanics. Erosion had assisted in keeping the area at a general low level. With the arching, westward flowing streams became impeded, and lakes formed east of the mountains. The dissection of the present Western Cascades began then, and the dendritic drainage pattern of today was established.

Conglomerates with some interbedded sandstone, shale, and tuffaceous rocks, all of Pliocene age, mantle the Columbia River Group or Sardine Formation at places along the Columbia River Gorge and are found along both margins of the Cascade Range for 30 to 40 miles to the south. Those on the west side are called the Troutdale Formation (Hodge, 1938a) and those to the east, the Dalles Formation (Piper, 1932). They may be as much as 1,500 feet thick, but are generally less. Similar rocks, but containing more interbedded tuff and flows, are exposed along the eastern margin of the Range to the latitude of Bend where they are called the Madras Formation (Stearns, 1930; Williams, 1957). These latter rocks are in part correlative with the Dalles Formation, but in part are younger. A relatively long period of volcanic quiescence preceded the deposition of the conglomerates, during which a thick lateritic soil formed on rocks of both the Columbia River Group and the Sardine Formation along the western margin of the Range. The arching of the Western Cascades continued well after the deposition of the conglomerates. In part synchronous with the arching, but in part preceding it, was the subsidence of the basins in which much of the Troutdale and the Dalles Formations accumulated. Also, during this episode and following it the Columbia River maintained its course, cutting the Columbia Gorge through which it now flows.

High Cascades

The High Cascades are made up predominantly of basalt and basaltic andesite, mostly in the form of flows. These rocks built up a chain of broad, coalescing shield volcanoes that cover the eroded eastern margin of the Western Cascades, form the crestal plateau, and underlie the narrow eastern slope of the Range (Williams, 1933, 1942, 1944, 1962; Thayer, 1936, 1937; Walker, 1966). Eruptions of these rocks began early in the Pliocene Epoch and continued into Holocene time. The constructional form of even the older volcanoes is still evident although eroded to varying degrees. The volcanoes developed on an uneven terrain, and the younger ones formed on the eroded remains of the older to aggregate a thickness of several thousand feet in many places. As a closing phase of many of these volcanoes, cinder cones formed at the top and on the flanks or on adjacent areas. Many of the more recent of these dot the crestal area of the Range. Isolated volcanoes of the High Cascade type developed here and there on the Western Cascades. The Boring Lava in and east of the Portland area is the remains of a number of relatively small volcanoes that are a part of the High Cascades group (Treasher, 1942; Trimble, 1963). More fluid flows of olivine basalt that were emitted mostly from fissures around the flanks of the shield volcanoes streamed down the eastern and western sides of the Range. In the Western Cascades they flowed down valleys, filling some to depths of many hundreds of feet. To the

east, in addition to filling valleys, they spread across the alluvial fans, where they are interbedded with gravels and tuffs.

Superimposed along the crestal area are the large composite volcanoes that dominate the skyline of the Range. The more prominent of these are Mounts Hood, Jefferson, and McLoughlin, and the Three Sisters. Mount Mazama, whose caldera is now occupied by Crater Lake, was probably the most impressive of all in Oregon before its cataclysmic eruption and collapse. The flows and ejecta with which they were built up are mostly of andesitic composition, and for some are entirely so. Others have erupted a wide variety compositionally, ranging from rhyodacite to basalt. Glacial debris, interlayered at intervals well down in their volcanic pile, show that they came into being early in Pleistocene time, and were intermittently active throughout most of that period. Others in the Cascade chain, like Mount St. Helens to the north in Washington and Lassen Peak to the south in California, have even been active in historic time.

Eruptions of basaltic material continued during the time the great andesitic cones were forming. Whereas the andesitic volcanoes formed isolated peaks, basaltic shield volcanoes and cinder cones formed all along the chain of the High Cascades. Both types of volcanism continued through Pleistocene time and into Holocene. Some of the older basaltic cones, like the older andesitic peaks, are strongly sculptured by glacial erosion. Younger cones are only slightly modified by ice, and the very youngest, perhaps on the order of a thousand years old, have little or no vegetation on them. The lava field surrounding the Belknap cones north of McKenzie Pass are a striking example, with black, slaggy, craggy, lava fields that stretch for miles (Taylor, 1965). Volcanic activity in the High Cascades is quiescent at present but may be merely dormant.

Glaciers have modified all but the more recent volcanic peaks in the High Cascades. Some, like Three Fingered Jack, Mount Washington and Mount Thielsen, that are among the older of the shield volcanoes, have been so deeply eroded that only a steep, tall spire—the more resistant neck-filling lava—remains (Walker and Greene, 1966). The intermittent battle between volcanic buildup and glacial erosion on the great andesitic volcanoes has continued to the present. Today, although retaining much of their cone-shaped forms, the volcanic peaks are scarred by deep cirques and large U-shaped canyons. Some of the latter are still occupied by glaciers. Morainal deposits and U-shaped profiles of the upper parts of the valleys show that glaciers advanced as much as 30–40 miles down some of the major streams such as the North Santiam, McKenzie, and Rogue Rivers. These glaciers originated in the snowfields that surrounded the highest peaks at the maximums of the Ice Age. Many of the higher peaks in the Western Cascades are also scarred by small glacial cirques.

Intrusive Rocks

In addition to the many fine-grained intrusive rocks in the form of plugs, domes, dikes, and sills closely akin to the associated volcanic rocks, there are a number of small stocks, or irregular bodies that intrude the volcanic rocks of the Western Cascades (Buddington and Callaghan, 1936). Although exhibiting a variety of compositions, these

stocks are dominantly medium-grained diorite, and are almost uniformly porphyritic in habit. They are mostly in the northern part of the Range, where they are scattered throughout a relatively narrow north-south belt. The largest covers an area of about eight square miles in Still Creek and Zigzag River southwest of Mount Hood. Two other intrusives, one along the valley of the McKenzie River and another exposed in the North Santiam River near Detroit Dam occupy about four square miles and two square miles respectively. The respective ages of these last two stocks, determined from the lead-alpha ratios in zircon, were 35 ± 10 and 23 ± 10 million years (Jaffe, 1959). The Still Creek intrusive appears to be much younger (Corcoran, 1968, oral communication). Broad zones tens to hundreds of square miles in extent surround these intrusives in which the intruded rocks have been altered to chlorite-albite-epidote. Quartz veins containing precious metals and base metal sulfides are associated with some areas of altered rock. Some of these quartz veins cut the intrusives as well as the surrounding country rock (Callaghan and Buddington, 1938).

Structure

The volcanic rocks of the Oregon Cascades form a sequence more than 10,000 feet thick, of which at least half is now depressed below sea level. General downwarping, which was intermittent through much of the Cenozoic Era, gently folded the rocks into a series of anticlines and synclines of north to northeast trend. A broad arching that occurred late in the deformational history of the Cascades has affected rocks as young as the Pliocene conglomerates. It is well displayed in the walls of the Columbia Gorge, where in the central part the Miocene basalts have been bowed 2,000 feet or more above their positions at the east and west margins of the Range.

A series of parallel fractures of northerly trend that penetrated deeply into the crust of the earth have been postulated as channelways through which the magma was extruded to form the volcanic pile of the Oregon Cascades. These postulated fractures would explain the marked linearity of the centers of volcanism and the alignment of the small dioritic intrusives. The oldest fractures provided the channels through which the rocks of the Little Butte Volcanic Series were extruded near the western margin of the Cascades. The youngest were responsible for the large volcanic cones along the crest of the Range to the east.

Few faults have been recognized in the Oregon Cascades. This paucity of recognized faults may result in part from the small amount of detailed mapping so far completed. Most of those that have been recognized trend northwest to north and dip steeply. South of Crater Lake the eastern margin of the Range is bordered by the Klamath graben, which also marks the northwest limit of the Basin and Range Province. Eastward tilted blocks are bounded by northwest-trending faults at several places along the northeast edge of the Range in Oregon. Knowledge concerning the time of movement along most of these faults is vague, but some has involved rocks as young as Pleistocene. Each of these structural elements; the folds, deep through-going fractures, and the faults, have trends that are at variance to one another. The intersection of faults and fractures may have localized some of the vents.

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GEOLOGY OF THE DESCHUTES–UMATILLA PLATEAU

(By R. C. Newcomb, U. S. Geological Survey, Portland, Oreg.)

The extensive plateaus of north-central Oregon are a part of the Columbia Plateau physiographic province (Fenneman, 1931). The unit of plateau and canyon topography defined as the Deschutes-Umatilla Plateau by Dicken (1950) includes a 100-mile-long strip of east sloping piedmont along the base of the Cascade Range and a main part in which the surface descends generally northward from the 3,500- to 4,000-foot levels in the mountains of Central Oregon to the 400- to 1,000-foot altitude along the Columbia, Umatilla, and Walla Walla Rivers (fig. 1).

This 150-mile-long by 10- to 70-mile-wide main body of the plateau unit is the largest part of Oregon devoted predominantly to the growing of small grains. Annual precipitation ranges from about 30 inches in the highest parts next to the Blue Mountains to 7 inches in the lowlands along the Columbia River.

Besides the Columbia River, which follows the principal structural downwarp from Wallula Gap to the Cascade Range (Newcomb, 1967), the John Day and Deschutes Rivers are the other large rivers that flow from outside this plateau unit. They traverse the plateau largely in canyons and gorges. Streams within the area flow in canyons that trend down the regional slopes and around the minor anticlinal warps which characterize the general regional surface.

The oldest rocks are schists and gneisses. They have been bared by erosion in the steeper part of the north slope of the Blue Mountains and occur within this plateau unit only in stream canyons south of Pendleton. Their age is unknown but probably is equivalent to that of some of the Mesozoic or Paleozoic rocks exposed father south. These rocks had been intruded by plutonic magma and the whole exposed by erosion before deposition of the Clarno and John Day Formations (Tertiary) (Hogenson, 1964, p. 18–19), as shown at the bottom of figure 16.

The Clarno Formation, of Eocene and Oligocene age, consists of shale, sandstone and tuff, and of dacitic, andesitic, and basaltic lavas. An eroded surface on the Clarno Formation was covered by tuff of the John Day Formation in Oligocene-Miocene time. Both of these Tertiary formations are more widely exposed south of the western part of the Deschutes-Umatilla Plateau, along the crest and brow of the mountains of Central Oregon.

The principal rock unit of the plateau is the volcanic sequence now named the basalt of the Columbia River Group but more briefly referred to herein as the Columbia River basalt. It consists of Miocene and early Pliocene, accordantly layered, dark basaltic lavas with some interbedded tuffs near the top. The greatest total thickness of basalt beneath these plateaus is estimated as 3,000 feet. It thins to the south, where relatively small areas of the underlying rocks are exposed within this plateau.

The Columbia River basalt is the greatest unit of lava on the continental areas of the world. The extrusion consisted of successive flows of very liquid lava that spread great distances from fissures and nonelevated orifices. The main body of the basalt extends west from the

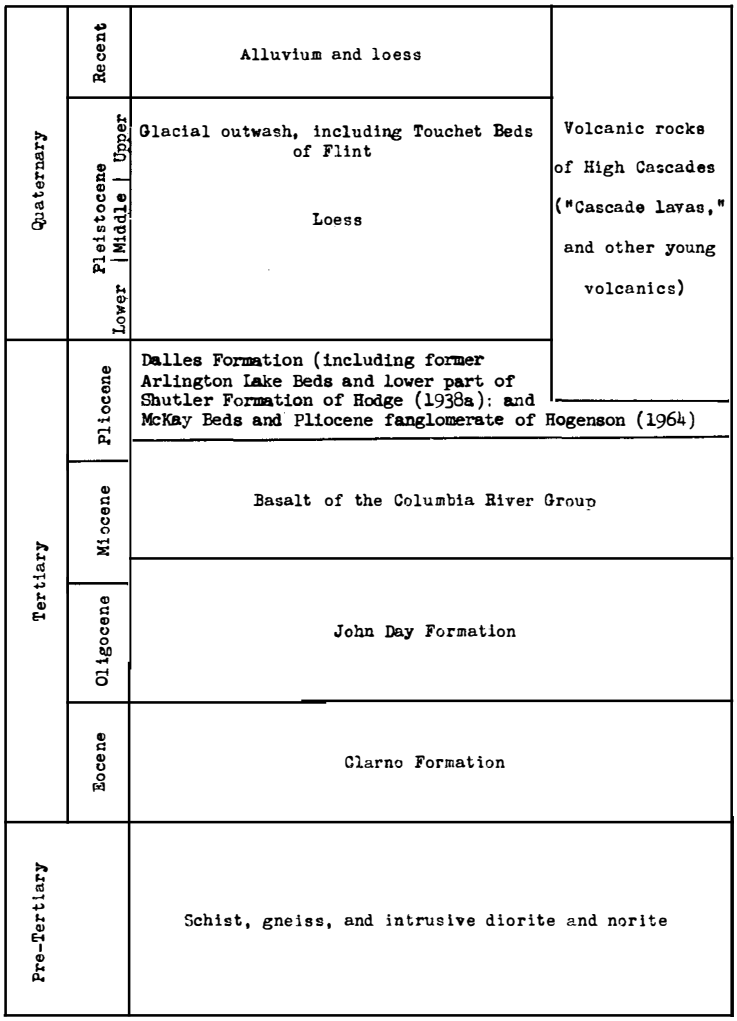


FIGURE 16.—Deschutes-Umatilla Plateau Geologic Column.

Rocky Mountains to the Cascade Range and south from the Okanogan Highlands, in northern Washington, into the mountains of Central Oregon. In parts of its vast area the basalt has been warped and faulted in Pliocene and Quaternary time as earth movements of regional extent elevated the mountains of Central Oregon and the Cascade Range and depressed the fault blocks like those underlying the Snake River and Grande Ronde valleys.

The surface of the basalt, little changed from the original stratigraphic top of the lava accumulation, is the north-sloping surface of

the consolidated rock beneath most of this plateau. Over part of the plateau the basalt is overlain by a relatively thin covering of sedimentary deposits.

The sedimentary materials that overlie the basalt in the broad east-west synclinal trough between The Dalles and Pendleton consist of: (1) tuff, conglomerate, silt, and sandstone of the Dalles Formation (Pliocene); (2) silt, sand, and gravel of upper Pleistocene glaciofluvial deposits; (3) alluvium of Pleistocene and Holocene age along the streams; and (4) loess of middle Pliocene to Holocene age (Newcomb, 1966). Beneath wide areas of the plateau the total thickness of the sedimentary cover on the basalt ranges from more than 1,000 feet southwest of The Dalles to less than 200 feet east of the Deschutes River.

The volcanic rocks of the High Cascades (Pliocene to Holocene), more briefly referred to as "Cascade lavas," overlie the Dalles Formation at the western edge of the Deschutes-Umatilla Plateau. This group of volcanic rocks includes one outlying cinder cone and lava flow just east of the Deschutes River a few miles above its mouth.

The upper Pleistocene glaciofluvial deposits consist of the water-laid gravel and sand that underlie the lower benches adjacent to the Columbia River and wide areas in the lowermost part of the Umatilla River valley, as well as the silt and sand lakebed deposit that was laid down in proglacial Lake Lewis (Allison, 1933). As a thin blanket, this silty lakebed deposit (the Touchet Beds of Flint (1938)) once extended up to about 1,150 feet altitude but has been greatly eroded and in many places has been reworked by the wind.

Loessial soils occur generally, except beneath the steepest slopes and the most eroded surfaces, eastward from longitude 121°00. The loess occurrence is eastward from the area underlain by the volcanic debris facies of the Dalles Formation. The loess exceeds 3 feet in thickness over large areas of the plateau unit and in a few places is several tens of feet thick. At least some of the oldest parts of the loess have been derived from local windworking of the fine-grained silt and tuff of the post-basalt Tertiary strata. Some of the youngest soils, the type called Sagemoor soils, include wind-worked materials from the upper Pleistocene glaciofluvial lake beds.

The crustal deformation that has framed the large structural and physiographic characteristics of the Deschutes-Umatilla Plateau resulted from broad open folding in Pliocene and Pleistocene time. This folding is most readily discerned by the tilt and altitude of the once-horizontal Columbia River basalt. The master structure is the broad Dalles-Umatilla syncline, whose axial trough extends 160 miles from the Cascade Range to the intersection of the Horse Heaven anticline with the Blue Mountains anticline east of Pendleton (Newcomb, 1967) (fig. 17). This great east-west downwarp, especially because of its connection with the east end of the Columbia Gorge through the Cascade Range, is a major transportation route to the interior of the Pacific Northwest.

The Deschutes-Umatilla Plateau consists essentially of the southern limb of this broad syncline; the basalt dips from ½ to 3° north from the Blue Mountains to the 10-mile-wide axial trough. The main exceptions to this structural singularity of the plateau include a small

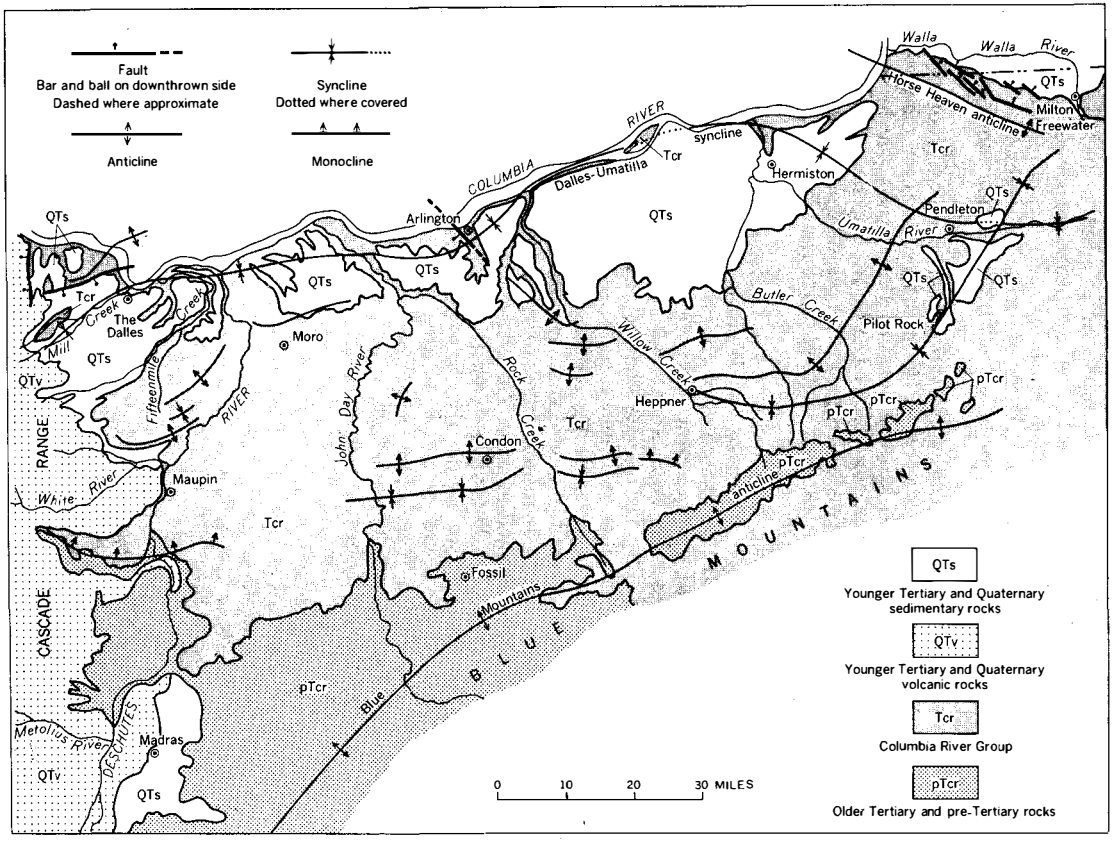


FIGURE 17.—Structural geology of the Deschutes-Umatilla Plateau.

part of the Horse Heaven anticline north of Pendleton and a small part of the Walla Walla syncline in the northeast corner as well as parts of the Columbia Hills anticline and Mosier syncline west of The Dalles. Minor warpings within the syncline mostly trend parallel to the large structures. These subordinate warpings form minor buttes, ridges, and valleys.

The broad trough of the Dalles-Umatilla syncline locally plunges into shallow sag areas along its trend; the principal sags are centered at Umatilla, The Dalles, and Mission (east of Pendleton). In the sags at Umatilla and The Dalles, the top of the basalt stands only about 200 feet above sea level. Between these sags the top of the basalt in the synclinal trough rises to the 900-foot altitude that extends from Arlington westward beyond the Deschutes River.

The Columbia River was diverted into the Dalles-Umatilla syncline in Pleistocene time, when it carved the Wallula Gap and took over, enlarged, and deepened the channel and course of an ancestral Umatilla River. Its natural channel, now submerged in a series of hydroelectric reservoirs, descends from about 300 feet in Wallula Gap, to about sea level near The Dalles. Its channel was largely a graded course except for the 50-foot falls and rapids at Celilo and for several other rapids in which the river plunged over the edge of particularly resistant layers of the basalt. Some of these rapids occurred closely upstream from where faults or minor warps cross the river.

The Walla Walla, Umatilla, John Day, and Deschutes Rivers, the secondary streams of the Deschutes-Umatilla Plateau, flow partly or entirely across the plateau in deeply canyoned channels which are rudely graded to the level of the Columbia River. The headwater canyons of the Walla Walla and Umatilla drainages lead from the Blue Mountains upland. The mainstems of these rivers flow in canyoned courses in the mountain section and cross alluviated synclinal basins to reach the Columbia River. The entirely canyoned courses of the John Day and Deschutes Rivers are oriented, in consequent fashion, down the regional slope of the plateau and make subordinate side swings around minor anticlinal warps.

The largest creeks drain areas on the upland and slopes of the Blue Mountains or the Cascade Range and are only partly graded water courses. The channels of Butter and Willow Creeks, as well as Mill Creek near The Dalles, have generally even but steep gradients of 50 to 200 feet per mile. Other creeks, like Fifteenmile Creek near The Dalles, have incised courses that in places flow gently in wide canyons, where the creek is base leveled on resistant layers in the basalt, and in places descend steeply.

The small intra-plateau creeks also flow along canyoned courses which have both base leveled and cascading segments. The smallest stream courses, and their storm-water continuations, extend upslope into all parts of the plateau surface where they provide complete drainage, devoid of lakes or ponds. Their drainage courses allow varying degrees of aggressive and sporadic water erosion to threaten the soil mantle. In the summer these streams flow only where springs emerge from the basalt, generally along the axes of synclines.

Mineral Resources

The Deschutes-Umatilla Plateau contains very little in the way of metallic minerals or carbonaceous fuels, the common concept of mineral resources. It does have large areas of loessial soil; great amounts of road metal and common rock; access to large amounts of good quality water; and minor amounts of other usable mineral materials.

The loessial soils are farmed to wheat under the summer-fallow system in which a crop is planted every other year. Most of the wheat farms range in size from several hundreds to many thousands of acres. Land in some of the higher areas along the mountain slopes receives enough precipitation to permit limited annual planting, which may include rotation with other crops such as peas. Small amounts of the farmland is irrigated where water is available from streams or from wells. Depending in general on the altitude, rainfall, soil characteristics, and variety planted, the dry land wheat yields range from 15 to 60 bushels per acre. Cattle are grazed on the rocky slopes. Diversified farming is practiced on the plains and benches that are irrigated in the valley areas. These irrigated lands are extensive along the Walla Walla and Umatilla Rivers.

The growing-season flow of the Walla Walla and Umatilla Rivers and most of the creeks of the plateau is used for irrigation in the adjacent valley plains. The only storage of surface runoff for irrigation is in Cold Springs and McKay Reservoirs in the Umatilla River basin and in a few scattered farm reservoirs.

Ground water occurs in permeable zones at the top or bottom of some of the layers of the bedrock basalt, in some of the gravelly beds of the Pliocene sedimentary strata, in sand and gravel beds of the glaciofluvial deposits of the lower part of the Umatilla River basin, and in gravelly layers of some of the alluvial deposits along the streams.

In the higher parts of the plateau, ground water perched on the basalt furnishes rural, domestic, and stock-water supplies for wells and springs. Large withdrawals, at relatively small pumping lifts, are made from wells in synclinal areas of the basalt. Most of the towns and cities obtain public water supplies, or at least supplementary supplies, from wells in the basalt. Industrial water, as well as irrigation water for several thousand acres of land, is obtained from the basalt by wells in the lower areas.

The gravel layers of the alluvial deposits in the Walla Walla River valley and in the lowest part of the Umatilla River valley contain ground water extensively withdrawn for irrigation.

The Columbia River basalt affords an easily available and nearly limitless source of good quality road metal, riprap, rock fill, and common stone. Large block rock, of jettystone dimension, is available in the young lava ("Cascade lava" type) which once filled the Deschutes River canyon 3 miles above the river mouth. Red scoriaceous lava stone is taken from cinder cones along the east side of the Cascade Range; the larger blocks are used for decorative stone walls and the finer "cinder" for decorative roofs, driveways, and walks.

Some layered tuff and tuffaceous sandstone, durable enough for limited use as dimension stone, is obtained from the Dalles Formation.

Some colored tuffstone is cut from the John Day Formation at a few places where it crops out beneath the Columbia River basalt in this plateau section. Clayey materials suitable for burning common brick and tile are available in the loess and the Pliocene sedimentary deposits. Volcanic ash of andesitic and dacitic types is present in places in both the surficial deposits and the Tertiary formations. One 30-foot thick bed of relatively pure volcanic ash, occurring near the top of the Pliocene sedimentary strata 7 miles south of Arlington, was used as a pozzuolana admix to the concrete for the John Day Dam. Semiprecious stones (mostly agate, chalcedony, and common opal) are associated with silicified wood in the lava rocks.

Minor economic minerals of little present value include small amounts of methane gas in a few of the water wells in the Columbia River basalt, noncommercial coal in the Clarno Formation at the southern edge of the plateau, and some specimen minerals like those of the zeolite group.

GEOLOGY OF THE JOSEPH UPLAND

(By R. C. Newcomb, U.S. Geological Survey, Portland, Oreg.)

The area of plateau and canyon lands north of the Wallowa River valley, west of the canyons of the Snake and Imnaha Rivers and east of the Grande Ronde River upstream from Palmer Junction, was termed the Joseph Upland by Dicken (1950) (fig. 1). The 225 square-mile area is a part of the region termed by Fenneman (1931) the Blue Mountains section of the Columbia Plateau physiographic province. The altitude ranges upward from the 1,500-foot level of the Grande Ronde River at the State boundary to 5,350 feet; large areas of the upland surface lie above 4,500 feet.

The upland is in a partial rain-shadow cast by the Blue Mountains and the Wallowa Mountains; hence, despite its relatively high altitude, the area receives an average annual precipitation of only 15 to 18 inches. The precipitation comes most y as snow and rain during the colder period, October to March, with a secondary rainy season in May and June of some years. The summers are dry and cool; the frost-free growing season averages less than 100 days.

Logging is the main industry. Ponderosa pine, Douglas fir, hemlock, larch, and spruce are the main trees harvested. The logs are trucked chiefly to sawmills at Elgin and Enterprise. The whole area is grazed by cattle, most of which are brought to the upland in summer from ranches in the nearby valleys. Small grains, mainly wheat, are raised on a few thousands of acres by dry-farming methods; most of the grain is grown near Flora and on scattered farms at the west side of the upland. Recreation—chiefly hunting, fishing, and scenic enjoyment—is important and is a potential major use of the area.

Geology and Physiography

The basalt of the Columbia River Group, Miocene and early Pliocene in age, underlies virtually the entire Joseph Upland. This accordantly layered sequence of dark basaltic lava has a total thickness of from 1,000 to 3,000 feet. The base of the basalt is exposed in the

Imnaha and Snake River canyons farther east and the Wallowa Mountains to the south, where older metamorphosed rocks underlie the basalt. About 15 cones of volcanic tuff and cindery basalt, of possible Pliocene age, lie upon the Columbia River basalt in the southeastern part of the Joseph Upland.

The Columbia River Group beneath the upland lies essentially horizontal, in contrast to its folded and faulted displacements in the Wallowa and Blue Mountains. Only a gentle east-west arch through the center of the upland, with resultant gentle dips (1°–3°) southward to the Wallowa River valley and northward to the Grande Ronde valley, relieve the uniform horizontal attitude of the basalt.

The deep dissection of the plateau of this upland resulted from the development of the youthful V-shaped canyons that cut headward from the Snake River, the base drainage of the region. Prior to that dissection an undulating plain existed on the constructional surface of the basalt after its extrusion ended in early Pliocene time and after the local and later extrusions that formed small volcanic cones such as Roberts, Haskin, and Greenwood Buttes, Elk Mountain, and Findley and Harl Buttes.

The great canyon of the Snake River to the northeast is cut 3,500 feet below the general 5,000-foot level of the upland. Within the upland area, the 2,500-foot deep canyon of the Grande Ronde River has been eroded along a syncline. Joseph Creek and Sheep Creek canyons are more precipitous V-shaped declivities of nearly equal depth. Headward extensions of these canyons reach, with progressively lesser depths, to within about 5 miles of the heads of the creeks leaving only small parts of the upland as the old undulating plain. Much of this remainder of the old undissected surface lies 5 to 10 miles north of the Wallowa River valley. In that part of the upland, shallow northward-trending creek valleys, such as those of Swamp and Crow Creeks, indicate that their former headwaters were captured and diverted by the downwarp of the syncline that the Wallowa River follows westward. Appreciable depths of soil occur mainly beneath these remnants of the old plain. Elsewhere the soils are shallow and rocky.

Mineral Resources

The almost universal prevalence of basalt of the Columbia River Group limits resources to peat, common stone, road metal, siliceous deposits—as agate, chalcedony, and common opal—and small amounts of interbedded tuff and volcanic ash. To the present time only road metal has been put to a substantial use.

The volcanic cones of post-Miocene age, such as Findley Buttes, are possible sources of colorful clinkery rock, decorative stone, and red roofing-type cinders.

The water resources of the Joseph Upland consist of: (1) the Grande Ronde River and main tributaries of the Imnaha River flowing through the northwestern and southeastern part of the upland, (2) the intra-upland drainage of creeks, (3) very small amounts of water that enter the upland as ground water precolating north from the higher parts of the Wallowa River valley, and (4) locally infiltrated water that recharges the soil water or transfers to ground water.

The open, gently graded swales of the old upland plain are potential water-storage areas for floodwaters diverted from places of excess, such as the Wallowa Mountains. Recreation, irrigation, electric power, and some other possible developments for water of the through-flowing and intra-upland streams now are largely untapped.

GEOLOGY OF THE BLUE MOUNTAIN REGION

(By T. P. Thayer, U.S. Geological Survey, Washington, D.C., and N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg.)

The Blue Mountains are a complex of mountain ranges and intermontane basins and valleys which occupy an area of about 21,000 square miles in the northeastern corner of Oregon. The maximum relief is almost 8,000 feet, from 2,000 feet altitude in the Snake River Canyon to nearly 10,000 feet on the peaks of the Wallowa Mountains 20 miles to the west. Over much of the region the relief ranges between 2,000 and 5,000 feet, from altitudes of 2,500 to 4,000 feet in lowlands to 4,000 to 8,000 feet along the mountain crests. The rainfall ranges from 12–15 inches in the valleys to 30 or 40 inches in the high mountains. In the ranges that stand above 8,000 feet, the heads of the larger valleys have been glaciated down to altitudes of about 5,000 feet.

Although the Blue Mountain region is widely regarded as a subdivision of the Columbia Plateau (Freeman, Forrester, and Lupher, 1954), actually it separates, or is a broad transition zone between, the Columbia Plateau (of which the Deschutes-Umatilla Plateau is the southern part) and the Basin and Range geologic provinces (fig. 1). The northwestern boundary of the region follows the crest of the Blue Mountain front, which is a monoclinal fold that extends 180–200 miles southwestward from north of the State line to the vicinity of Prineville. From a steep rise of 3,000 feet in 6 miles at the State line, the monocline broadens southwestward and becomes indistinct in the vicinity of Fossil. Erosional remnants show that the basalts of the Columbia Plateau once extended about halfway across the present mountain region. The mountains have no definite southern border, but merge irregularly with the fault-block structures and folds of the High Lava Plains. The boundary has been taken, therefore, as the approximate southern limit of exposures of pre-Tertiary rocks. On the east, for about 60 miles along the Snake River the Blue Mountains merge with the mountainous section of central Idaho. The Blue Mountains, in fact, hold the answers to some of the geologic riddles of the highly metamorphosed rocks surrounding the Idaho batholith.

Chronologically, the rocks of the region fall into two major groups: pre-Tertiary and Tertiary. The pre-Tertiary formations comprise a wide variety of volcanic and sedimentary units that were deposited mostly under marine conditions, have been intruded by at least two major groups of plutonic rocks, and have been strongly deformed and variably metamorphosed. The Tertiary and younger formations consist almost entirely of volcanic rocks erupted under continental conditions, and erosional debris derived from them and the pre-Tertiary rocks.

Pre-Tertiary Rocks

SEDIMENTARY AND VOLCANIC ROCKS

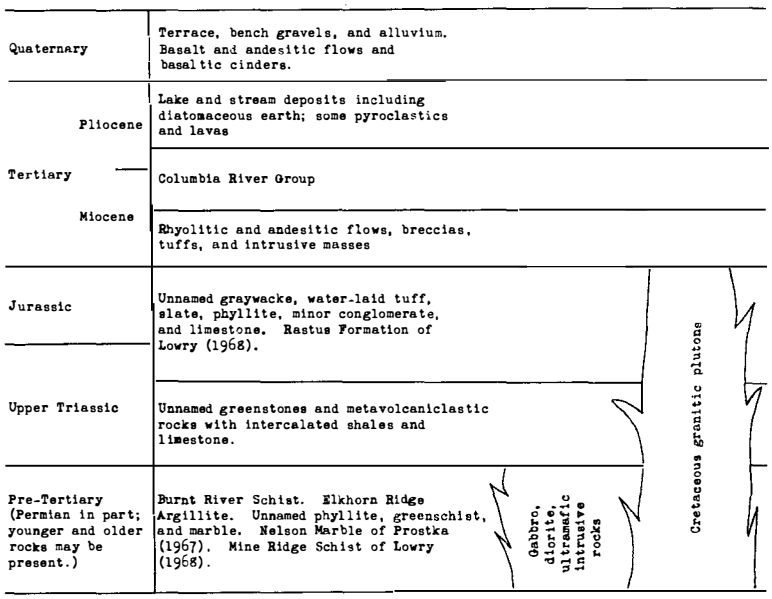
The pre-Tertiary sedimentary and volcanic rocks are divided into three main groups: old rocks, partly highly metamorphosed, of Paleozoic age; a thick sequence of late Middle Triassic to Upper Jurassic rocks; and middle Cretaceous sedimentary beds (figs. 18 and 19). Angular unconformities and major time breaks separate the three groups.

The oldest rocks of known age are unmetamorphosed limestones, shales, and sandstones of Devonian and Mississippian age, and conglomerates, sandstones, and siltstones that contain plant remains of Pennsylvanian age (Buddenhagen, 1967); they are exposed only in a small area 60 miles southwest of Canyon City. The next youngest formations are submarine volcanic flows and tuffs, muddy sandstones and argillites, chert, and subordinate lenticular limestones, or their schistose derivatives, which are exposed in many parts of the region. Their total thickness is unknown but must be at least many thousands of feet. These rocks have been described in areas near Baker as the Burnt River Schist, Clover Creek Greenstone, and Elkhorn Ridge Argillite (Gilluly, 1937). They are believed to be mostly of Permian age, but Late Triassic fossils show that in places younger rocks are included (Prostka, 1962, 1967).

Rocks of late Middle Triassic to early Late Jurassic age are markedly uncomformable on and are less metamorphosed than the Paleozoic rocks even where they are tightly folded (Vallier, 1967, The geology of part of the Snake River Canyon and adjacent areas in northeastern Oregon and western Idaho: Oregon State University doctoral thesis, 267 pp.). Volcanic flows and pyroclastics, volcanic graywackes, mudstones, and shale constitute the bulk of these Mesozoic rocks. The only major limestone unit of known Mesozoic age is the Martin Bridge Limestone, which is exposed in the vicinity of Eagle Creek in the southern Wallowa Mountains; it is 1,500 feet thick (Prostka, 1962). The Nelson Marble, of similar thickness, has been correlated with the Martin Bridge (Prostka, 1967) but may be older (Brooks and Vallier, 1967). It has been traced about 30 miles in an east-west belt from the southeastern part of the Baker quadrangle (Gilluly, 1937) to the Snake River. The Mesozoic rocks are estimated to be 10,000–15,000 feet thick in the Wallowa Mountains and are known to be at least 50,000 feet in maximum aggregate thickness in the Aldrich Mountains and nearby areas (Dickenson and Vigrass, 1965, p. 13; Brown and Thayer, 1966a). Rapid lateral variations in facies and thicknesses of beds, local unconformities, and submarine slide breccias show that the rocks were deposited rapidly in local basins while faulting, folding, and volcanism were going on. Because the Triassic beds, especially, contain few fossils, it is possible that some beds of Early Triassic age may be present but have not been identified.

Intertonguing continental fluviatile and marine deposits of middle Cretaceous age, which total 9,023 feet in thickness, have recently been described (Wilkinson and Oles, 1968) near Mitchell in southwestern Wheeler County. The deposits are interpreted as material derived from a rising land mass on the north and transported by a major river

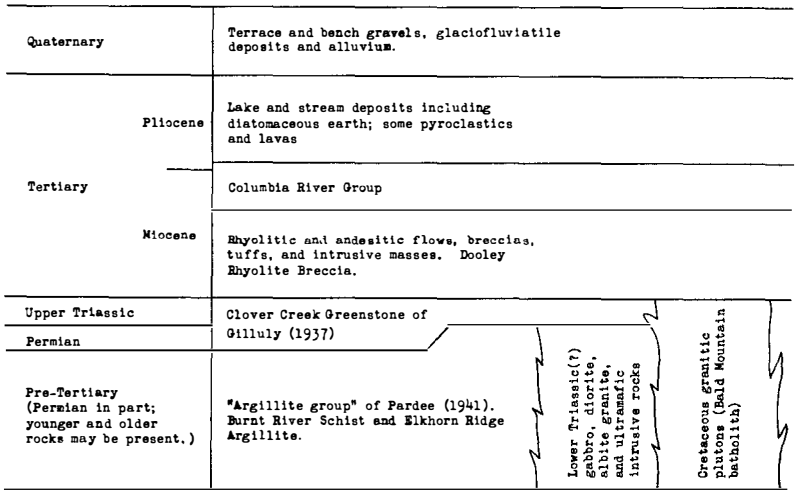
Southern Baker and northern Malheur Counties and upper Snake River Canyon



Adapted from Prostka (1967), Lowry (1968), Wagner, Brooks, and Imlay (1963), and unpublished data by Howard C. Brooks, Ernest Wolff, and R. E. Corcoran.

FIGURE 18.—Stratigraphic units commonly recognized in the eastern part of the Blue Mountains Province and the Snake River Canyon (compiled by Howard C. Brooks, Oregon Department of Geology and Mineral Industries).

Eastern Grant and western Baker Counties (Sumpter and Baker quadrangles)



Modified after Pardee (1941), Gilluly (1937), Taubeneck (1955), and Bostwick and Koch (1962).

FIGURE 19.—Stratigraphic units commonly recognized in the western part of the Blue Mountains Province (complied by Howard C. Brooks, Oregon Department of Geology and Mineral Industries).

system that emptied into a broad shallow-marine estuary on the south. Scattered patches of conglomerate and fossiliferous sandstone show that the shoreline, which appears to have fluctuated widely, at times lay east of the longitude of Canyon City (Brown and Thayer, 1966b).

PLUTONIC INTRUSIVE ROCKS

Two major sequences of plutonic intrusive rocks are now recognized in the Blue Mountain region: a Permian and Triassic suite that ranges from peridotite to albite ranite, and a Lower Cretaceous suite that ranges from gabbro to granodiorite (Thayer and Brown, 1964). The Lower Cretaceous intrusive unquestionably predominate in the northeastern part of the region, but the full extent of the older intrusive rocks is uncertain beneath extensive sedimentary cover (fig. 3). The relationships of the pre-Upper Triassic magma series are best known in the Canyon Mountains Complex in Grant County (Thayer, 1963) and in the Baker-Sparta area (Gilluly, 1933b; Prostka, 1962). The peridotite and gabbro were intruded together and were cut successively by quartz diorite or trondhjemite and albite granite. Part of the albite granite appears to have been intruded as magma, but brecciation and alteration by solutions accompanying the magma also produced large volumes of rock of albite granite composition from gabbro, diorite, and volcanic country rock. The Upper Triassic formations contain albite granite erosional debris and lie unconformably on it in places.

Several large granitic masses of the region, including the Wallowa and Bald Mountain batholiths (Taubeneck, 1957, 1964) are outliers of the Idaho batholith; the sizes of such outliers decrease rapidly toward the west (fig. 3). They intrude Triassic and Jurassic rocks, have radiogenic ages of 99 to 145 million years, and are overlain in places by middle Cretaceous beds. The batholiths range in composition from gabbro (norite) to granodiorite and have formed wide contact halos in which invaded rocks have been strongly foliated and metamorphosed to amphibolite and pyroxene granulite facies (Taubeneck, 1957, 1964).

TERTIARY AND QUATERNARY ROCKS

Volcanic rocks of Tertiary age once blanketed the Blue Mountains and buried parts of them to depths of several thousand feet. Basaltic to rhyolitic flows and breccias and bedded sedimentary rocks of the Clarno Formation (Eocene and lower Oligocene) still cover large areas in all but the northeastern corner of the region. The John Day Formation of Oligocene and early Miocene age, however, is preserved only in the old John Day basin, a relatively low area west of 119°. The basalt flows of the Columbia River Group (middle Miocene-lower Pliocene), which covered the northwestern half of the region, were erupted from known swarms of dikes in the Wallowa Mountain-Snake River area, in the vicinity of Monument, and possibly from others still concealed. In the southeastern part, in contrast, the later Tertiary rocks consist of a complex series of basaltic to rhyolitic flows, breccias, and ash, which interfinger with debris washed into the lowlands between cones built up around eruptive centers (Thayer and Brown, 1966). Vertebrate fossils in the basin deposits indicate that the main volcanism ended during early Pliocene time. Quaternary

basalt flows are scattered here and there along the southern margin of the Blue Mountains, and many of the larger valleys contain a few to several hundred feet of late Tertiary and Quaternary filling (Hampton and Brown, 1964).

Geologic Structure

The rocks in the Blue Mountain region have been folded and faulted repeatedly, and the structure of those of pre-Tertiary age is so complex and incompletely known that generalizations on a regional scale mean little. For example, fold axes and faults in the Mesozoic rocks of the Aldrich Mountains (Brown and Thayer, 1966a, 1966b) nearly box the compass and locally differ greatly from those in the Paleozoic rocks. The pre-Tertiary deformation was much more intense than any in the Tertiary, especially during the Permian and Triassic interval before and during intrusion of the Canyon Mountain Complex and related rocks. The Mesozoic stratified and volcanic rocks generally are much more metamorphosed in the eastern part of the region than farther west, probably as a result of deformation accompanying intrusion of the Cretaceous batholiths.

There were two major Tertiary episodes of folding and faulting, the first during the early Oligocene, the second in early middle Pliocene time. During early Oligocene time the Clarno Formation was faulted and locally folded to angles as high as 60°, and some of the present major structural units probably originated then. In the Aldrich Mountains and along the Blue Mountain Front, for example, there is evidence that when the John Day Formation was laid down, ranges or uplifts stood at least several hundred feet high where the present mountains are. The John Day Formation was folded gently and eroded before the basalts of the Columbia River Group completely buried it and the post-Clarno mountainous landscape. During the early middle Pliocene, the second and better known major deformation raised the modern Blue Mountains, probably partly by renewed uplift along older Tertiary fold axes. On the north, the basalts were folded up to form the northeast-trending Blue Mountain front, at or along which all other folds and faults die out. Along the southern border, northwest-trending Basin and Range-type fault blocks merge with a series of east-west anticlines and synclines by swinging westward through angles of about 60° (Brown and Thayer, 1966b). Taken together, the Ochoco, Aldrich, and Strawberry Mountain Ranges, the Ironside Mountain unit, and Juniper Mountain uplift appear to outline an east-west structural zone 160–170 miles long (fig. 3). At least the Aldrich-Strawberry Mountain segment is believed to have originated during the post-Clarno folding, but its present relief is due entirely to Pliocene and Pleistocene deformation. In the triangle bounded by the Ochoco-Juniper Mountain structural zone on the south, the Blue Mountain front on the northwest, and the Baker Valley on the east (fig. 1) a series of major anticlinal mountain ridges and synclinal valleys appears to swing from nearly east-west trends north of the John Day Valley to northwest in the Elkhorn Mountains. All these folds, like the faults along the Upper Grande Ronde Valley and Wallowa Mountains, die out southeast of the crest of the Blue Mountain front. It seems significant that the major differences in

deformational patterns and nature of volcanism essentially coincide; namely, west to northwest-trending folds in the basalts of the Columbia Plateau type, and block faults in the area of basaltic to rhyolitic volcanoes. The normal faults that block out the Baker and Upper Grande Ronde Valleys and Wallowa Mountains, on the basis of their orientation, numbers, and displacements of as much as 5,000 feet (Hampton and Brown, 1964), represent the northernmost extension of Basin and Range structure in Oregon. Oversteepening along the foot of the fault scarp at Hot Lake, 8–9 miles southeast of La Grande, indicates that faulting probably still is going on.

Mineral Resources

Mineral deposits of demonstrated or potential economic importance occur in rocks that range from the youngest to the oldest in the region. Beginning with the youngest geologically, the list includes Pleistocene to Holocene placer deposits from which notable amounts of gold and some platinum group minerals have been recovered and a bog from which peat is now being shipped for soil conditioning. The placers were widely distributed throughout the region, but the largest and richest were in streams crossing or flowing from areas of pre-Tertiary rocks. Comparatively little unworked ground remains. The peat bog is in the Enterprise Valley on the flank of an accumulation of alluvial and glacial debris from the Wallowa Mountains.

Mineral resources of Tertiary age include principally: (1) various of the volcanic rocks themselves such as perlite, cinders, zeolitized tuffs, and rock usable as decorative dimension stone; (2) diatomite, gypsite, and clays which are mostly interlayered with lake beds and tuffaceous sediments; (3) remnants of Eocene and Miocene gold-bearing placers; and (4) vein or impregnation-type cinnabar and gold-silver lode deposits. Additionally, the Tertiary rocks are the sources of vast amounts of semiprecious gem stones of which agate, opalite, cryptocrystalline quartz, and petrified wood constitute the principal varieties.

Lode gold historically is the best known of the pre-Tertiary mineral resources: however, cement- and chemical-grade limestone reserves are large and very important. Gold and silver occur in hydrothermal veins in the older, more metamorphosed sediments and greenstones and also in the intrusive granodiorites, albite granites, serpentine, and gabbro. The hydrothermal activity is generally regarded as being Cretaceous in age. The principal limestone deposits are of Triassic and Permian age, but small lenses and thin, local interbeds occur also in the Devonian and Jurassic sediments. Gypsum and anhydrite were mined from Triassic beds near the Snake River northeast of Huntington over the turn of the century, but today only remnants, chiefly anhydrite, remain unmined. Chromite and chrysotile asbestos have been mined from deposits in pre-Upper Triassic peridotites and serpentines, mostly from the Canyon Mountain Complex and nearby masses in the John Day area.

Copper, cobalt, molybdenite, scheelite, manganese, stibnite, and quicksilver also form deposits of economic interest in the pre-Tertiary rocks. The principal copper occurrences are irregular veins, pods, and

disseminated deposits of sulfides in albitized granite and Permian and Triassic greenstones in Baker County, and veins and disseminations of copper and gold-bearing cobalt and iron sulfides in similar intensely brecciated and albitized greenstones in the Quartzburg area of Grant County, north of Prairie City. Small contact metamorphic and pegmatitic deposits containing molybdenite and scheelite have been prospected in the Wallowa Mountains. In addition, small amounts of scheelite and molybdenite occur separately in quartz veins and veinlets in various other parts of the region. Manganese oxides form kidneys and irregular bunches usually associated with quartz in narrow veins and shears in the Elkhorn Ridge Argillite and Burnt River Schist, almost exclusively in Baker County. Native quicksilver and cinnabar are scattered in small occurrences from the Snake River north of Huntington to the Aldrich Mountains in Grant County; although the host rocks are pre-Tertiary in age, the mercury mineralization is believed to have been Tertiary. Apart from incidental occurrence as accessories in many gold veins, stibnite and antimony oxides are known to occur in a few gash veins in grandodiorite or in other rocks near granitic intrusives.

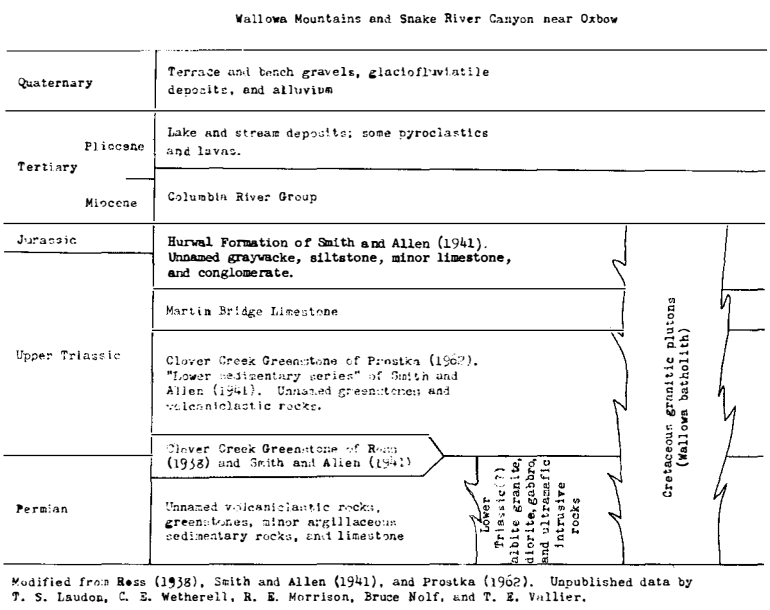
GEOLOGY OF THE SNAKE RIVER CANYON

(By H. C. Brooks, Oregon Department of Geology and Mineral Industries, Baker, Oregon)

At Farewell Bend near Huntington, Snake River leaves the relatively flat Snake River Plain and from there northward for more than 150 miles flows in a deep, narrow, V-shaped canyon marking the Oregon-Washington and Idaho border. The upper part of the Canyon, between Farewell Bend and Oxbow Dam has an average depth of between 2,000 and 3,000 feet. The slopes are cut by long, steep flanked side canyons and are generally soil covered. From Oxbow north to the Washington border and beyond, the Canyon ranges from about 3,000 feet to more than a mile in depth as measured from the western rim and is 8 to 10 miles wide. This part of the canyon is no less spectacular, topographically, than the Grand Canyon of the Colorado River. Only its somber colors make it less attractive than the more famous Arizona gorge. From promontories such as Hat Point which overlooks Hells Canyon, one sees a vast panorama of angular erosional features falling away in giant rocky steps toward the river about 5,600 feet below. Across the Canyon in Idaho the highest peaks of the Seven Devils tower nearly 8,000 feet above the river.

River level elevation is 2,077 feet at Farewell Bend and about 860 feet at the Washington line. Three dams, Brownlee, Oxbow and Hells Canyon, impound the waters of the upper canyon.

The rocks in Snake River Canyon are divisible chronologically into two groups, pre-Tertiary and Tertiary (fig. 20). The two groups are separated by a major structural and erosional unconformity. The older group comprises a heterogeneous assemblage of volcanic, sedimentary and intrusive rocks of Paleozoic and Mesozoic age. The



Modified from Ross (1938), Smith and Allen (1941), and Prostka (1962). Unpublished data by T. S. Laudon, C. E. Wetherell, R. E. Morrison, Bruce Wolf, and T. E. Vallier.

FIGURE 20.—Stratigraphic units recognized in the Wallowa Mountains and Snake River Canyon near Oxbow.

younger group is almost entirely made up of basaltic lava flows which flooded most, if not all, of the area now traversed by the canyon in middle Tertiary time when the Columbia Plateau was formed. Above the mouth of Powder River most of the rocks exposed in the canyon walls are representative of the pre-Tertiary group; small patches of Tertiary basalt are found locally. Between the mouth of Powder River and Oxbow Dam the canyon is carved mainly in Tertiary basalt which is more than 2,000 feet thick at Brownlee Dam. Pre-Tertiary rocks appear only as small inliers surrounded by the basalt. North of Oxbow Dam to the Washington border and beyond, the river has cut through the thick sequence of plateau basalt flows which underlie the Joseph Upland and on into the pre-Tertiary basement rocks beneath. In most places the irregular contact between the younger and older rocks is from 1,000 to 2,500 feet above the river. The profile of the old land surface on the canyon walls indicates that the region was mountainous at the time the lava began to pour forth. Since Jurassic strata are locally involved in the folds of the old mountains and since most of the plateau lavas are of Miocene age it is evident that much of the topography beneath the lavas was developed after Jurassic and before Miocene time. Dating of the lavas also proves that the canyon has been carved since Miocene time. Livingston (1928) and Wheeler and Cook (1954) discussed the origin of the canyon and suggested that in late Tertiary time Snake River followed a far different course than the present one.

Pre-Tertiary Rocks

No geologic maps of the canyon between Hells Canyon Dam and the Washington State line have been published; there are no roads along the river and the area has had few visitors. The stratigraphy of the pre-Tertiary rocks is almost unknown except in a 20-mile section including the mouths of the Imnaha and Salmon Rivers which was mapped by R. E. Morrison (Oregon State University Ph.D. thesis, 1963). Above Hells Canyon Dam the pre-Tertiary rocks exposed in the canyon are lithologically and structurally continuous with formations in the eastern Blue Mountains (Brooks and Vallier, 1967). Probably the oldest rocks are a thick, badly contorted sequence of siliceous to pelitic phyllites, massive to schistose greenstones, and marble that occupies a broad belt extending several miles upstream from the mouth of Powder River. Contiguous rocks several miles to the west were named the Burnt River Schist and Elkhorn Ridge Argillite by Gilluly (1937). The age of the Burnt River Schist is unknown. The Elkhorn Ridge Argillite is partly Permian but may include both older and younger rocks. Thick unnamed sequences consisting mainly of greenstones and associated volcaniclastic rocks of both middle Permian and Late Triassic ages, including Ladinian, are well exposed along the river in the Oxbow-Hells Canyon Dam area. Upper Triassic greenstones and volcaniclastic rocks also occur in the Huntington area at the upper end of the canyon. North of Huntington the greenstone-volcaniclastic sequence is overlain by a thick series of interbedded graywacke, slate, and phyllite which contains Early Jurassic fossils. Probably Upper Triassic rocks are also present. Limestone equivalent to the Martin Bridge Limestone of the Wallowa Mountains forms a bold outcrop at Big Bar about midway between Oxbow and Hells Canyon Dam.

Two groups of plutonic rocks and a multitude of dikes cut the pre-Tertiary rocks. The older group of plutonic rocks includes gabbro, diorite, quartz diorite, and serpentinized ultramafic rocks of Permian and Triassic age. The younger plutonic intrusives consist mainly of granodiorite and are probably related to the Idaho and Wallowa batholiths of Cretaceous age.

The bedded rocks and older intrusives have been folded and metamorphosed to the greenschist facies. Rocks of higher metamorphic grade are found near the margins of plutonic bodies.

The pre-Tertiary strata have a general northeasterly trend and the river has cut diagonally across them. The prevailing strike of bedding, planes of schistosity, and major fold axes is northeasterly and dips are generally steeply northwest. Many large and small faults complicate the structure.

Tertiary Rocks

The Tertiary lava series consists mainly of a great number of superimposed flows. Most of the rocks are brownish olivine basalts. Volcaniclastic units, many of them light colored, are sparsely distributed through the sequence. The Tertiary rocks have in most places been only gently warped and are relatively little altered. In places they are cut by steeply dipping faults of predominantly northwest trend.

GEOLOGY OF THE HIGH LAVA PLAINS PROVINCE

(By G. W. Walker, U.S. Geological Survey, Menlo Park, Calif.)

The High Lava Plains province of central and south-central Oregon consists of a middle to upper Cenozoic volcanic upland nearly 160 miles long and about 50 miles wide that extends eastward from the Cascade Range to the eastern margin of the Harney Basin (fig. 1). The province is dominated by a west-northwest-trending zone of en echelon normal faults (fig. 3) here informally termed the Brothers fault zone, that extends for most of the length of the province. Eruptive centers for both basaltic and rhyolitic volcanic rocks are concentrated in the zone of faults and in some nearby subsidiary fault zones.

The High Lava Plains are contiguous with and gradational into the Basin and Range province to the south, and many upper Cenozoic volcanic rocks and fault structures are common to both provinces. The boundary separating the High Lava Plains from the Blue Mountain province to the north, is taken as the southern limit of pre-Tertiary rocks that have been brought to the surface in the Blue Mountain-Ochoco Mountains uplift.

Except for small areas of older Cenozoic volcanic and tuffaceous sedimentary rocks exposed along the northern margin of the High Lava Plains that represent parts of the Columbia River Group and the John Day and Clarno Formations (Walker, Peterson and Greene, 1967), the oldest rocks are non-porphyritic olivine basalt flows of late Miocene or, more likely, early Pliocene age (fig. 21). These flows are exposed along the southern margin of the province, where they are overlapped by widespread sheets of ash flow tuffs; in a few places the ash flow tuffs and olivine basalt flows appear to be interbedded. Radioactive ages of several of the earliest ash flow tuffs in the sequence indicate that they were erupted about 9 to 10 million years ago and spread laterally over several thousand square miles of the ancestral Harney Basin. Eruption of these tremendous volumes of rhyolitic ash and ash flows apparently permitted some crustal collapse into the evacuated magma chamber and this collapse was partly responsible for the development of the large structural depression of Harney Basin. The depression was subsequently filled with younger ash flow tuffs, tuffaceous sedimentary rocks, and local basalt flows—all of late Cenzoic age (Piper, Robinson, and Park, 1939; Baldwin 1964). In places, the tuffaceous sedimentary rocks are diagenetically altered to bentonitic clay minerals, zeolites, and potassium feldspar, particularly where the sediments were deposited in ancient lakes that filled the lower parts of the structural depression. In the western part of the province, the middle to upper Cenozoic basalt flows, ash flow tuffs and sedimentary rocks are mostly buried beneath younger upper Pliocene, Pleistocene, and Holocene basalt flows (Williams, 1957; Oregon Department of Geology and Mineral Industries, 1965; Walker, Peterson, and Greene, 1967) that erupted non-explosively from widely scattered cones, shield volcanoes, and fissures. Charcoal from a tree inundated by one of the youngest of these flows on the northwest flanks of Newberry Volcano has been dated as about 6,000 years old (Oregon Department of Geology and Mineral Industries, 1965, p. 9). Throughout much of the western part of the province, rocks only slightly older are mantled with a widespread but discontinuous sheet of unconsolidated coarse to

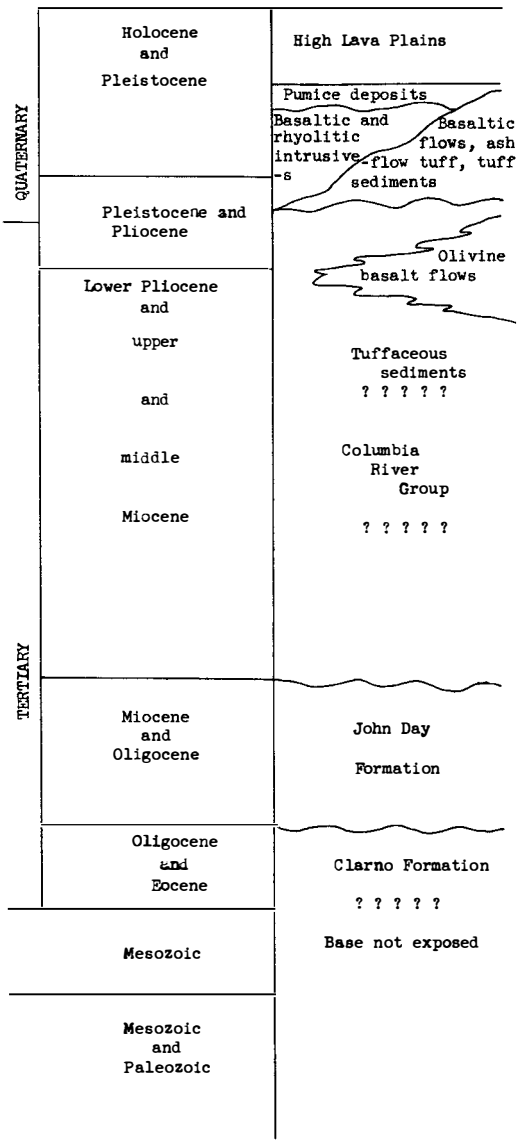


FIGURE 21.—Generalized stratigraphic column of the High Lava Plains.

fine pumice fragments erupted about 7,000 years ago from Mount Mazama, a large prehistoric Cascade volcano that collapsed to form the caldera now occupied by Crater Lake.

The total thickness of Cenozoic volcanic and tuffaceous sedimentary rocks in the province is not known. Estimates based on fragmentary data, however, indicate that the thickness is more than 5,000 feet in

most places and that a minimum total volume of basaltic and rhyolitic volcanic material erupted to the surface within the province must be on the order of 8,000 cubic miles. This widespread and thick sequence of volcanic rock was erupted from several different kinds of vents that are concentrated in the Brothers fault zone or in subsidiary fractures. Dome complexes, such as Glass Buttes, Wagontire, Pine, Sheep, and Iron Mountains, China Hat, and Hampton Butte, mark the vents for some of the rhyolitic volcanic rocks; some of the widespread rhyolitic ash flow tuff sheets of the Harney Basin erupted from giant fissures in the Brothers fault zone. Most of the basalt flows are associated with broad shield volcanoes of low relief, although many basaltic eruptions in the high lava plains occurred sporadically along fissures; local flows of basalt and basaltic cinder cones resulted. In places the rising hot basalt magma encountered water, which caused fragmentation of the basalt and violent steam explosions. Where the explosions were of moderate intensity basaltic tuff cones, tuff rings, and tuff ridges formed; examples of these features are found at Fort Rock, Table Mountain, St. Patrick Mountain, and Seven Mile Ridge, all either within or marginal to Fort Rock and Christmas Lake Valleys. More violent steam explosions blasted out prominent craters, including such features as Hole-in-the-Ground.

One of the largest and most spectacular eruptive centers is Newberry Volcano near the western end of the province. On this comparatively young basaltic shield volcano, which is about 40 miles long and 25 miles wide, a caldera has developed that contains East and Paulina Lakes; the walls of the caldera expose several varieties of both basaltic and rhyolitic rocks, indicating a more complex volcanic history than most of the other shield volcanoes in the region (Williams, 1935; Higgins and Waters, 1967).

The structural pattern of the High Lava Plains province is dominated by the northwest-trending Brothers fault zone. From several lines of evidence, this zone appears to be one of the fundamental elements of Oregon. It is continuously exposed for nearly 150 miles through south-central Oregon and suspected extensions of the zone have been recognized that indicate it may be much longer. Throughout the High Lava Plains, the zone is dominated at the surface by closely spaced en echelon normal faults of moderate to small displacement that localized many basaltic and rhyolitic vents mostly of Pliocene and Pleistocene age, but including some of the possible late Miocene and early Holocene age. The abundance and age distribution of vents indicates that crustal breaking has recurred along the zone for a considerable span of time. Also, many northeast-trending structures in the region, including several of the large normal faults that bound major grabens (fig. 3), terminate at this discontinuity or, in places change direction and seem to merge into it. Apparently both the normal faults of the zone and the many volcanic vents along the zone represent only the surface manifestations of deformation on a large, deeply buried structure, the exact nature of which is not known. The pattern of normal faults within and near the Brothers fault zone and the relation of many small monoclinal folds to the faults suggests, however, that the zone overlies a deeply buried fault with lateral displacement; the normal faults denote only adjustment of surface and near surface volcanic and tuffaceous sedimentary rocks.

GEOLOGY OF THE OWYHEE UPLAND PROVINCE

(By R. E. Corcoran, Oregon Department of Geology and Mineral Industries, Portland, Oreg., and G. W. Walker, U.S. Geological Survey, Menlo Park, Calif.)

General Setting

The Owyhee Upland of southeastern Oregon occupies most of Malheur County, the northeast corner of Harney County, and extends into adjacent parts of Idaho and Nevada (fig. 1). It is a moderately to deeply dissected region with few perennial streams but, in contrast to the adjoining Basin-Range province, there are few basins having interior drainage. Malheur and Owyhee Rivers, the principal streams, both empty into the Snake River a few miles apart near the northeastern corner of the province.

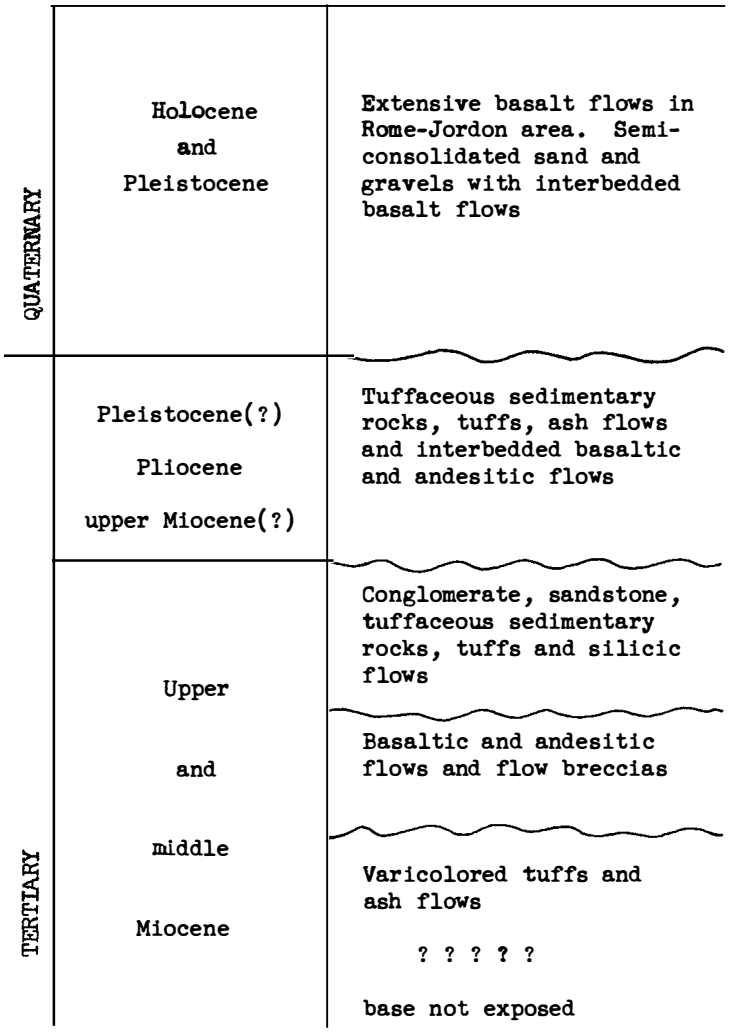
The Owyhee Upland is essentially a plateau region developed on several widespread extrusive basaltic, andesitic, and rhyolitic sheets with associated pyroclastic and sedimentary rocks of middle to late Cenozoic age. The varied landscape includes deep gorges where the major streams have cut through resistant lava and ash flows into softer, more easily eroded sediments and tuffs, open basins underlain by thick sequences of continental beds, and broad upland regions capped by thin sheets of lava or welded tuff. Elevations range from 2,230 feet on the Snake River to 5,000–6,000 feet along the western and southern borders of the province.

The province merges with the Basin-Range and High Lava Plains to the south and west, and some of the geologic and geomorphic features characteristic of these provinces extend into the Owyhee Upland. Extensions of the block fault mountains of the Basin-Range in the Owyhee Upland are neither as large nor as well defined separate blocks as those to the southwest. The established drainage pattern and more mature topography distinguish the Owyhee Upland from the geologically younger plains regions both to the west and east. The southern Blue Mountains, which are underlain by intensely deformed pre-Tertiary marine sedimentary rocks and metavolcanic rocks, mark the northern boundary of the Owyhee Upland. The province extends eastward to the broad Snake River Basin, which has been filled with several thousand feet of upper Tertiary and Quaternary terrestrial sediments and lavas.

No pre-Tertiary rocks are exposed within the province, although marine sedimentary beds of Mesozoic age or older, which crop out to the north in the Blue Mountains and dip southerly, presumably lie below the Tertiary cover. By the close of the Mesozoic era in Oregon, the seas had retreated from the region east of the Cascade Range, and all the Cenozoic sediments are continental deposits.

Stratigraphy

The oldest known rocks are exposed in the hills along the eastern margin of Malheur County, both north and south of Jordan Valley, and in the southern part of the province (Corcoran and others, 1962; Walker and Repenning, 1966). These consist of upper Miocene tuffaceous continental sedimentary rocks and air-fall tuffs with thick and widespread sections of basalt and rhyolite flows, separated by several small erosional and angular unconformities (fig. 22). Total thickness



Generalized from
Walker and Repenning 1966

FIGURE 22.—Generalized geologic column of the Owyhee Upland.

of these rocks varies considerably from one depositional basin to another, but a maximum is probably about 6,000-7,000 feet. A late Miocene age for the entire series is based on vertebrate fossils collected in the sedimentary rocks and on several K–Ar dates from lavas and ash flow-tuffs within the section (Evernden and James, 1964; Evernden and others, 1964).

Stratigraphically above the Miocene rocks and separated from them in many areas by large erosional and moderate angular unconformities is a series of lower Pliocene to Pleistocene(?) continental sediments, air-fall tuffs, basaltic lavas, and welded ash-flow tuffs, all considered part of the Idaho Group (Bowen and others, 1963; Lund, 1966; Newton and Corcoran, 1963). Rocks of the groups are widely distributed in the province and show considerable variation in lithology; hence, they have been given several different formational names by geologists working in both Oregon and adjacent parts of Idaho (Malde and Powers, 1962; Kittleman and others, 1965). In the eastern part of the Upland the Idaho Group consists of unconsolidated to semiconsolidated clay, silt, sand, volcanic ash, diatomite, fresh-water limestone, and conglomerate with several interlayered basalt flows. These flows are generally distinguishable from older Miocene flows by higher olivine content and, in the central and northern part of the province, by a more coarsely crystalline texture. In general the individual lava sheets are thinner and more widespread than those of the Miocene. In the western part, distinctive ash-flow tuffs are intercalated in the sedimentary section and underlie some of the high plateaus in the upper Malheur River drainage.

The Pliocene section is thickest on the east side of the province where it merges into the Snake River Plains. A well drilled by El Paso Natural Gas Co., 10 miles south of Vale, penetrated about 4,500 feet of Pliocene sedimentary rocks and lavas before encountering rocks considered to be Miocene or older (Newton and Corcoran, 1963).

Most of the rocks younger than middle Pliocene in age are unconsolidated terrace gravels and valley fill of Quaternary age; in the southern part of the province, some fine ash layers and interbedded basalt flows of Pleistocene age are present in and marginal to the Rome basin. Gravels cap many of the low-lying hills and broad divides bordering the major stream valleys. The clasts are mainly basalt, with lesser amounts of rhyolite, quartzite, and granite. The coarser interbedded sand layers show well-developed cross-bedding, and indicate torrential stream deposition, probably resulting from large volumes of water during the Pleistocene.

Some very young olivine basalt flows west and northwest of Jordan Valley are late Pleistocene or Holocene in age and may be some of the youngest extrusive basalts in the entire State. The basalt surface is little modified by erosion or weathering and is marked by collapsed lava tubes and pits, pressure ridges, tumuli domes, and spatter cones.

Structure

The Miocene sediments and lavas in the Owyhee Upland have been moderately deformed, and broken into a number of separate fault blocks. These blocks are not as large nor as continuous as those in the adjacent Basin-Range province, and the amount of movement along any particular fault has not been as great. Pliocene sediments and lavas fill many of the troughs produced by the post-Miocene deformation. Rocks of the Idaho Group (Pliocene and Pleistocene) also have been deformed, but the amount of displacement in most places is considerably less than in the older rocks. Pleistocene rocks of the Rome basin are only slightly deformed.

The well-defined northeast trend of the faults in the Basin-Range province is seen only in a few places in the Owyhee Upland, mostly in the southern part of the province. The pattern tends to die out to the north and east, and in most of the Owyhee Upland the predominant trends are northerly or northwesterly. The change in direction of the fault zone may reflect a deep-seated change in the subcrustal tectonic pattern in this region.

The northwest-trending Snake River Basin appears to be a major structural feature, the development of which began at least by middle Miocene time. Older Tertiary units cropping out on both sides of the basin show considerable block faulting and indicate that the basin is a broad, depressed region filled with later Tertiary and Quaternary sedimentary and volcanic rocks.

Mineral Resources

More than 20 wildcat holes have been drilled in northeastern Malheur County, along the western border of the Snake River basin, exploring for oil and gas. Several wells produced small but significant flows of gas from shallow sands in the Idaho Group (Pliocene and Pleistocene), which has been used by ranches in the Snake River Plains for domestic heating and lighting (Newton and Corcoran, 1963).

One of the more important nonmetallic minerals in the Owyhee country is gem-quality chalcedony (agate) that is much prized by "rockhounds" throughout the country. Some of the well known areas where agatized material has been found are along Succor Creek and the Owyhee Reservoir (moss agate and thunder eggs), in Stinkingwater Mountain (petrified wood and agate), and in the Buchanan area (thunder eggs). Other potentially important nonmetallic minerals found within the Owyhee Upland are the diatomite and pumicite beds at Harper and Drewsey, perlite deposits near Jordan Valley, optical calcite veins along the west side of the Owyhee Reservoir, salt brines near Vale and bedded potassium feldspar and zeolite deposits near Rome.

GEOLOGY OF THE BASIN AND RANGE PROVINCE

(By G. W. Walker, U.S. Geological Survey, Menlo Park, Calif., and N. V. Peterson, Oregon Dept. of Geology and Mineral Industries, Grants Pass, Oreg.)

The part of the Basin and Range province that lies in southern Oregon extends eastward from the Cascade Range to the eastern limits of the Trout Creek Mountains, or from near 122° to 118° west longitude, a distance of about 200 miles (fig. 23). Southward the province extends great distances through Nevada and northeastern California to Arizona and New Mexico (Baldwin, 1964b). To the north it is bounded by and gradational with the High Lava Plains province of south-central Oregon (fig. 1).

In Oregon, the province is dominated by Cenozoic volcanic rocks that are intricately broken by two prominent fault sets—one striking N. 20–40 E. and the other N. 20–35 W. (fig. 3). (Donalt, 1958). Displacements of large magnitude on some of these normal faults have resulted in north-trending fault block basins or grabens bounded by

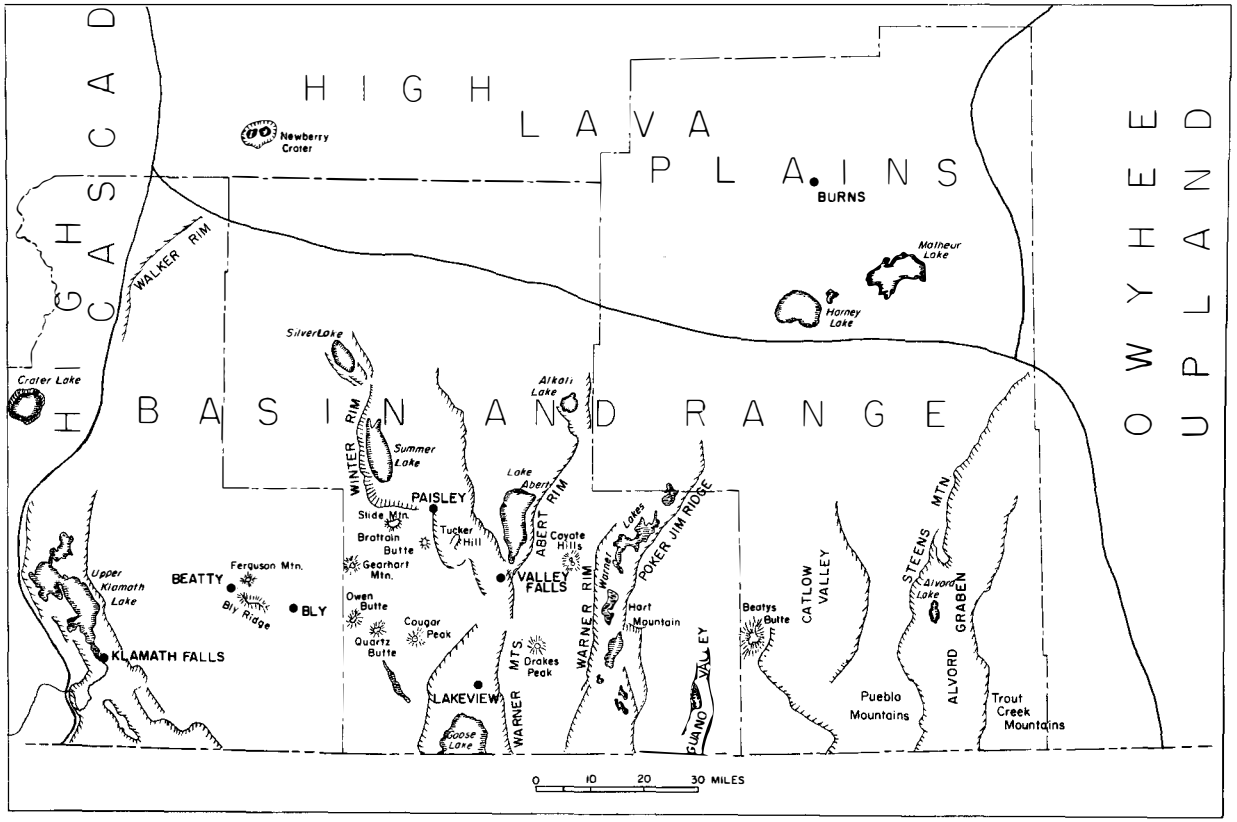


FIGURE 23.—Basin and Range province in Oregon.

high mountain ranges representing giant tilted fault blocks or horsts (Fuller and Waters, 1929). There are seven prominent structural basins or tectonic depressions and innumerable minor grabens within and between the major structures. From west to east they are the Klamath graben, Goose Lake Valley, the composite Summer Lake-Abert Lake graben, Warner Valley, Guano Valley, Catlow Valley, and the Alvord graben. Steens Mountain, with an eastward facing fault scarp over 5,500 feet high, is the dominant, intervening fault block range of the province; impressive fault scarps several thousand feet high also are present on other tilted fault blocks at Walker Rim north of Klamath Falls, Winter Ridge just west of Summer Lake, Abert Rim, Hart Mountain and Poker Jim Ridge, the east face of the Pueblo Mountains, and both the east and west margins of the Trout Creek Mountains (fig. 23).

Slickensided fault plane surfaces of the large normal faults are especially well displayed along both sides of Klamath Lake and at the bases of other fault blocks in Klamath graben (Peterson and Groh, 1967). Here, the fault planes have a general strike of N. 25° W. and dip 60° into the basin; nearly all of the grooves and large troughs on fault surfaces show vertical movement only and little or no evidence of horizontal movement. In this part of the province, hot springs and upper Quaternary explosive volcanic deposits are localized along some of the faults, indicating that some movement is quite recent, although most faults bounding grabens show evidence of recurrent movement.

Both faulting and volcanic activity have played an important role in the development of the giant horst and graben structural pattern. The tectonic depressions result partly from crustal collapse following eruption to the surface of vast volumes of basalt and rhyolitic ash flows and tuff. A stress pattern related to deeply buried structural elements, probably including several northwest-trending faults with horizontal movement, apparently existed in the province before most and perhaps all of the Cenozoic volcanism; this stress governed, in part, the development of the fracture system which localized many of the large volcanic vents, and the ultimate distribution of volcanic rocks.

Pre-Tertiary rocks are exposed in only two places in the Oregon part of the Basin and Range province. The largest area of outcrop occurs in the Pueblo Mountains and the other is about 10 miles to the east in the Trout Creek Mountains, both in southeastern Harney County (fig. 3). In the Pueblo Mountains metamorphosed sedimentary and volcanic rocks, presumably of Permian or Triassic age, are intruded by quartz albite rock (or keratophyre) and by diorite. These rocks form the crystalline core of the mountains. Partly foliated granodiorite in one small area north of Cottonwood Creek in the western Trout Creek Mountains represents the northern extension of a larger Mesozoic intrusive exposed extensively south of the Oregon-Nevada border. Very little is known of the pre-Tertiary basement throughout the rest of the province and only meager data are available to establish the depth to basement rocks and the thickness of the overlying cover of volcanic and continental sedimentary rocks of Cenozoic age. A profound unconformity separates these older crystalline rocks from the overlying volcanic and sedimentary rocks (fig. 24).

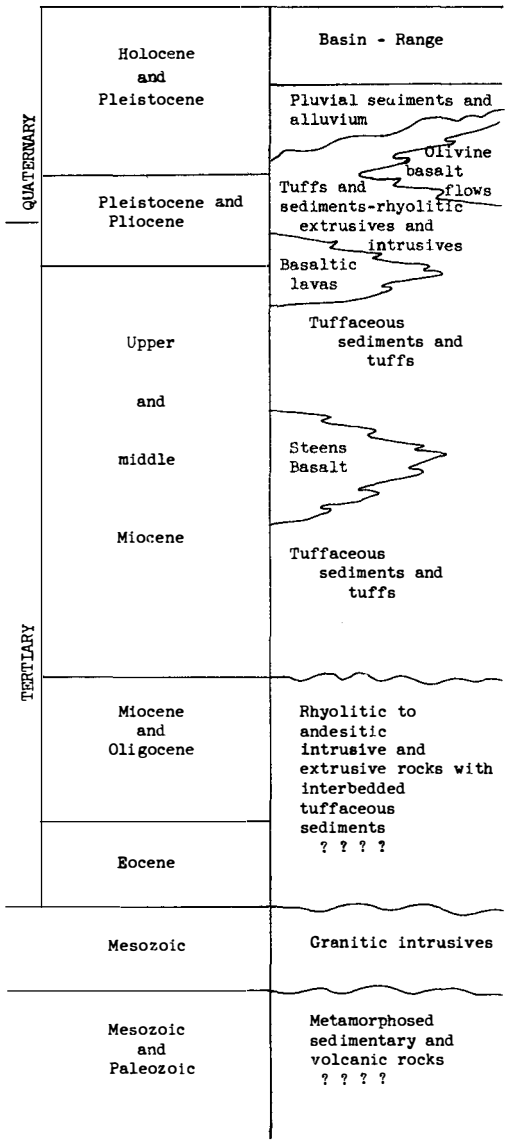


FIGURE 24.—Generalized stratigraphic section of the Basin and Range province in Oregon.

Probably the oldest Tertiary rocks in the region include andesite flows and breccias and some interbedded tuffaceous sedimentary rocks that are deformed and unconformably overlapped by rhyolitic tuffs and tuffaceous sedimentary rocks in in several places near Paisley south of Summer Lake (Walker, 1963). These older rocks may correlate with

the Clarno Formation (Eocene and Oligocene) of central Oregon, but their precise age is not known. The tuffaceous sedimentary rocks locally contain vertabrate fossils of late Oligocene or early Miocene age that indicate temporal equivalence with the John Day Formation of central Oregon. The Pike Creek Formation (Fuller, 1931), at the east base of Steens Mountain, and rhyolitic tuffaceous sedimentary rocks exposed on the west face of Hart Mountain are comparable in lithology to the rocks dated as late Oligocene or early Miocene near Paisley and probably are of about the same age. Rhyolitic tuffs, andesite flows and breccias, and volcanic sediments low in the Warner Range fault block also are of about the same age. In several places, the volcanic ash of the rhyolitic tuff and sedimentary rocks have been intensely altered to bentonite or to zeolites, principally clinoptilolite, mordenite, and phillipsite.

Basalt and some andesite flows of middle (?) and late Miocene age extend over several thousands of square miles from Abert Rim to the eastern margin of the province (Walker and Repenning, 1965) and in places attain a thickness of more than 3,000 feet; the name Steens Basalt (Fuller, 1931) has been applied by some geologists to all or parts of this flow sequence. High alumnia basalt appears to be the dominant petrographic type in the sequence, although alkali olivine basalt flows also are common. The flows emerged as fissure eruptions partly from scattered dikes, but mostly from dike swarms concentrated in the broken zones along margins of some of the tilted fault blocks. Probably the largest concentration of feeder dikes is on the east scarp of Steens Mountain, although many dikes also are present on the southern extension of Abert Rim.

Some ash-flow tuffs and widespread, poorly bedded, mostly fluviatile flood plain deposits, composed largely of volcanic ash and fine pumice fragments, overlie the sequence of basalt flows, in places lapping on the basalts and elsewhere apparently interfingering with basalt flows. In many places, the flood plain deposits contain vertebrate fossils signifying a late Miocene (Barstovian) age. A few isotopic ages of minerals from the fossiliferous sedimentary rocks and from uppermost flows in the underlying basalt sequence indicate that these units overlap in time and are both about 13 to 15 million years in age.

Olivine basalt flows occur above the Miocene tuffaceous sedimentary rocks throughout much of the province and in places form the rims at the tops of several of the large precipitous fault scarps. The flows have not been precisely dated and may be either of late Miocene or early Pliocene age.

Pliocene olivine basalt flows and an intervening unit of stratified tuffaceous sedimentary rocks—the Yonna Formation of Newcomb (1958)—dominate the western part of the province in the upper Klamath River basin near Klamath Lake. East of Klamath Falls the Yonna Formation contains, in addition to much volcanic debris, fairly extensive bedded deposits of diatomite admixed with clay minerals (Moore, 1937, pp. 34–51). The olivine basalt flows erupted mostly from cinder and lava cones and from shield volcanoes, although some fissure eruptions occurred on fracture zones bounding grabens.

Some of the basalt of Pliocene and early Pleistocene age in this part of the province erupted explosively into lakes or wet sediments. This

resulted in ver large volumes of palagonite tuff and fragmented basalt now found in broad tuff rings and in thick layered lenses of tuffaceous sediments.

Large parts of the province north of Lake Abert and Warner and Catlow Valleys are covered by widespread rhyolitic ash-flow tuff sheets of Pliocene age that emerged from fissures in the Brothers fault zone, a zone of northwest-trending en echelon fractures that transects the High Lava Plains province to the north (Fig. 3). The ash-flow tuffs represent southward extensions of parts of the Danforth Formation (Piper, Robinson, and Park, 1939) that is mostly confined to the Harney Basin; several isotope ages on minerals and volcanic glass from some of the oldest of these ash-flow tuffs indicate an age of 8.5 to 9.7 million years.

Large silicic volcanic centers, characterized mostly by steepsided domes and closely related viscous flows, were the source for much of the rhyolitic volcanic rock of the province. They are widely distributed and include Ferguson Mountain and Bly Ridge near Beatty; Gearhart Mountain, Quartz Butte, Owen Butte, and Cougar Peak west of Lakeview, Slide Mountain, Tucker Hill, and Brattain Butte near Paisley; Coyote Hills, Hart Mountain, and Drakes Peak near Warner Valley; Beatty Butte and Hawkes Valley south of Catlow Valley, and several small rhyolite domes along the margins of Alvord graben. Several kinds of metallic mineral deposits have been found associated with these silicic volcanic centers, notably those of mercury (Williams and Compton, 1953) and uranium (Peterson, 1959b), and several of the centers contain large volumes of perlite.

The great volcanic activity during Miocene and Pliocene time apparently was followed by minor outpourings of Pleistocene basalt mostly around local cinder cones or small lava cones in the western part of the province. Heavier than normal precipitation related to Pleistocene glacial periods resulted in many partly connected pluvial lakes that filled most of the large structural depressions. Obvious evidence of these ancient lakes is afforded by prominent shoreline features on the lower walls of many of the closed basins; included are gravel bars, spits, wave-built terraces, and wave-cut benches. Many of the large basins are floored with sediments deposited in these ancient lakes or with fanglomerate and alluvium. In areas above the prehistoric lake levels, extensive sheets of pediment gravels and some fluvioglacial deposits are present locally. Violent eruption of Mount Mazama in the Cascade Range about 7,000 years ago resulted in the formation of a spectacular caldera or crater now occupied by Crater Lake and the burial of much of the western part of the Basin and Range province under a blanket of pumice fragments and ash. Wind and stream erosion has stripped the pumice from many of the ridges and hills, redepositing it in sand dunes and in soils in the lower valleys.

MINERAL RESOURCES

THE MINERAL INDUSTRY OF OREGON

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash., and H. M. Dole, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Like most Western States, Oregon's mineral industry had a golden beginning, although the early emigrants who made the arduous trek over the Oregon Trail did not come in response to the lure of gold. They were attracted by reports of rich agricultural lands to be had for the taking in the Willamette Valley and elsewhere in the Oregon Territory. Their objective was to establish homes, not to win quick wealth from the creeks. Soon after the discovery of gold in California, however, prospectors moved northward into Oregon and by 1850 had discovered gold in Josephine County in southwestern Oregon. This was followed in 1851 by the discovery of rich placers in Jackson County, and in 1861 by the discovery of placer gold deposits near the site of Baker in northeastern Oregon. The virgin placers were rich and generously rewarded those fortunate enough to find them. Prospecting increased and other discoveries were made. Just how much gold was won during the first years of mining is not accurately known. It may have been as much as $20 million. Although not large by our standards today, this new capital was a tremendous stimulant for the development of a sparsely populated and struggling pioneer country. There were other effects, too. The exploration of these early miners and prospectors helped to open up large areas of the Territory, and many miners remained to become permanent settlers. The establishment of mining districts with their rules and regulations helped bring law and order to the Oregon Territory. Many of the present rules governing water rights date from these early miners' regulations.

The total value of all minerals that have been produced in Oregon is estimated at about $1.3 billion. This amount compares favorably with the $1.8 billion estimated value of the mineral production of Washington and is about half that of Idaho ($2.6 billion). In 1966, Oregon's mineral production was valued at $107.8 million, placing it 32d among the States with respect to the value of its mineral output. It was ranked between Nevada with a production of $112.6 million and North Dakota with a production of $101.8 million. It was not far behind Idaho, which with a production of $114.9 million was ranked 30th, and was considerably ahead of Washington, which was ranked 34th with a production of $89.1 million. Oregon has produced at one time or another 13 metallic and at least 12 nonmetallic commodities. In contrast to Idaho, but similar to Washington, it is predominantly a producer of nonmetallic minerals. During the period 1960 to 1968 about 76.1 percent of the value of its mineral production came from nonmetallic minerals and only 24.9 percent from metals. This ratio

has varied considerably from time to time, but a rough estimate indicates that about three quarters of the value of Oregon's production has come from nonmetallic minerals, mostly construction materials. It is, nevertheless, the country's only producer of nickel. It customarily ranks about fourth among the mercury-producing States and is one of the few States which has produced chromite. In the past, its production of gold has been substantial, but its gold mining industry is now essentially dormant. The State has produced some uranium, as well as minor amounts of silver, lead, zinc, copper, tungsten, antimony, and manganese.

Mineral production in Oregon separates into three distinctive phases: a short but rich period ending about 1874 when most of the richer placer gold deposits had been exhausted and lode mining was beginning; a long period of very gradual growth ending with the economic depression of the early 1930's; and a period of vigorous growth that is still continuing. Gold was the dominant mineral produced in the earliest period, and was still the principal metal throughout the gradual growth period, however dredging replaced the earlier hand methods of placering and lode mining became important. The nonmetallic minerals became of increasing importance, and such prosaic materials as sand and gravel soon far exceeded the value of the State's gold production. During this period production of mercury began and, under the stimulus of World War I, there was a small production of tungsten, antimony, manganese, and some base metals, and chromite mining began. The present period of phenomenal growth beginning about 1935 is marked by a tremendous increase in production of construction materials. In part, this stemmed from the installation of large hydroelectric projects, but to a much larger extent it represents the overall industrial growth these projects helped foster. Gold mining flourished through the depression until halted by events during World War II, resumed briefly after that, but ceased because of rising costs and fixed selling price. Nickel mining began at the Riddle mine in 1954, and is now an important industry in the State. The total value of Oregon's nickel output in this brief period exceeds that of all the gold it has produced in the past 117 years. Uranium production began in 1956.

Figure 25 shows the three periods quite plainly. The lower curve shows the unadjusted value of the annual mineral production; the upper curve shows the same figure adjusted to the purchasing power of 1957–1959 dollar. The graph also shows the relative proportion of nonmetallic to metallic mineral production by 10-year periods since 1930, and this clearly illustrates the dominance of nonmetallic minerals over metallic minerals. Because of this heavy dependence on nonmetallic minerals the value of the State's overall mineral production has not undergone the violent fluctuations which have so markedly affected the mineral production of Montana and Idaho (Weissenborn, 1963, figure 1; 1964, figure 1). Production of individual commodities has fluctuated widely, but even during the depression of the 1930's and the heavy demands for strategic minerals during World Wars I and II and the Korean conflict, the total value of the annual production of minerals was affected only to a moderate degree.

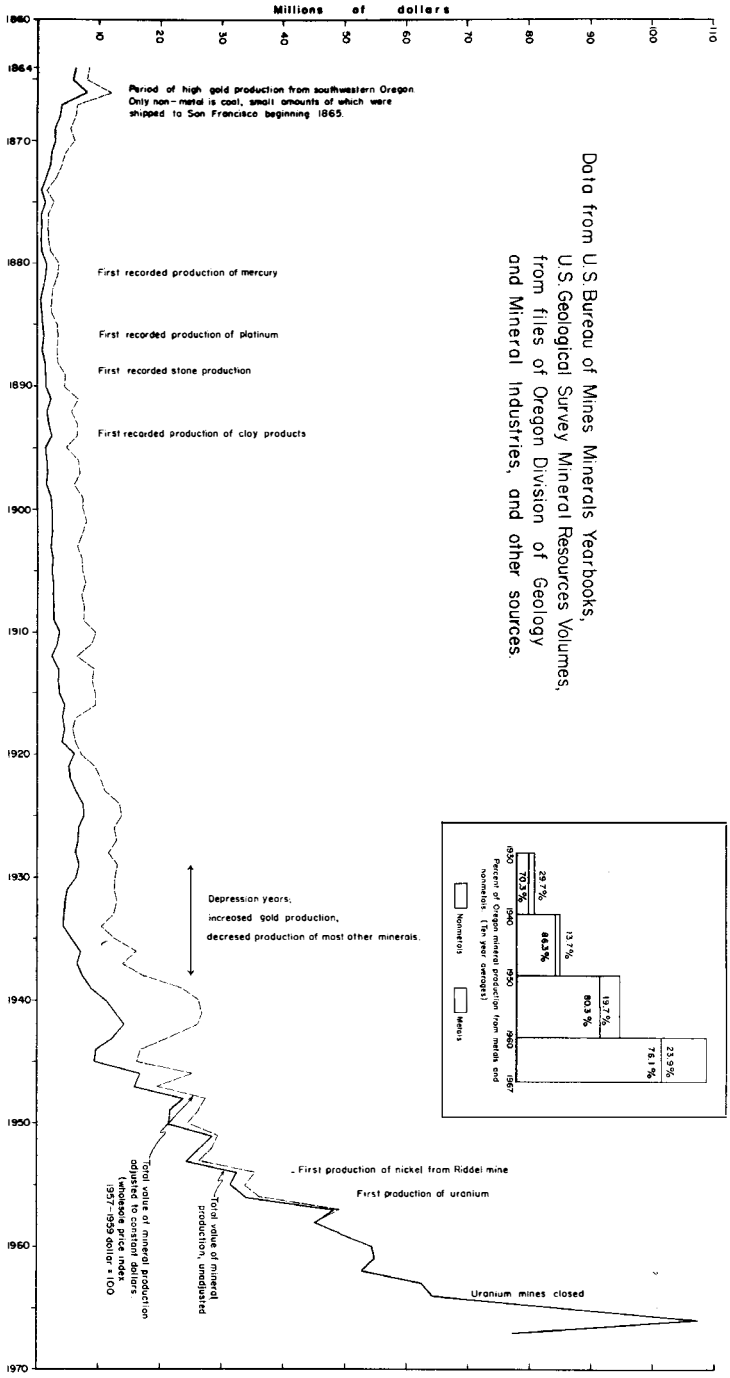


FIGURE 25.—Mineral production of Oregon 1864–1967.

A marked decrease in production in 1968 from 1967 is explained by decreases in consumption of sand and gravel as several large construction projects neared termination.

Figure 26 shows graphically the relative value of the more significant nonmetallic and metallic commodities that the State has produced. It again brings out in striking fashion the importance of the nonmetallic industry to the State, particularly since the nonmetallics production represents fewer years than the metals. It also shows that nickel, which has been produced in the State only since 1954, now exceeds gold in total value of metal produced.

With steadily increasing population, Oregon's mineral industry can look forward to continued dominance of nonmetallic over metallic products. Some decrease in dam construction is probable as the major dams on the Columbia are completed, and this may result in a temporarily lessened demand for sand and gravel. Other construction,

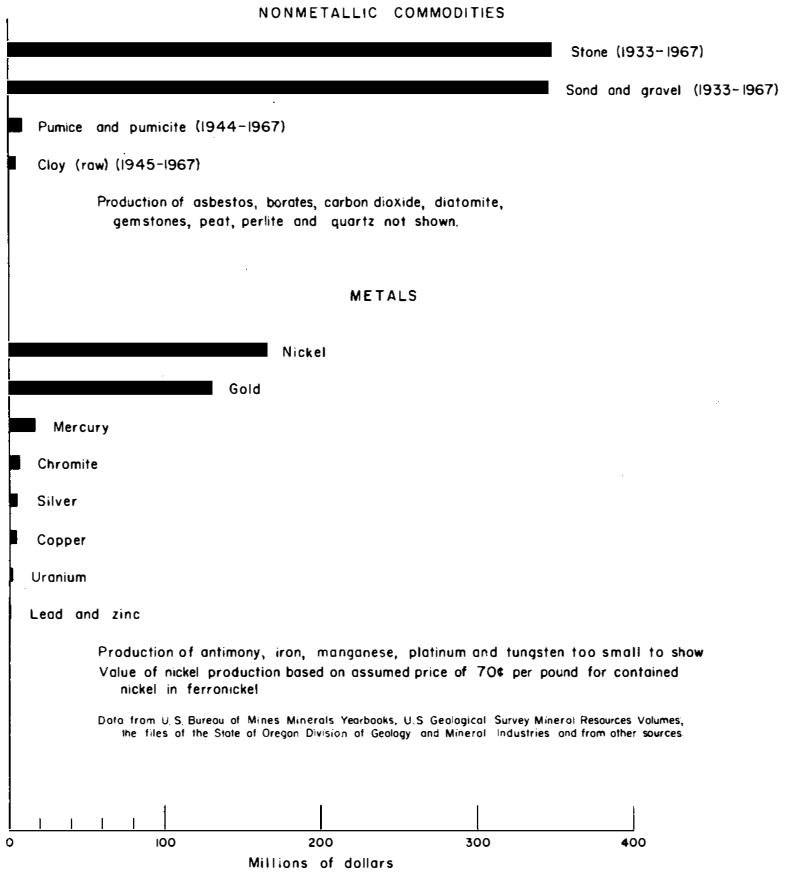


FIGURE 26.—Oregon's mineral production by commodities.

including highway improvement, should take up much of the slack. In the metallic field nickel will continue to dominate. Oregon has a considerable potential for the production of gold, but only at price levels considerably higher than now prevail. Mercury production decreased in 1965 from 1964 as existing reserves became depleted, but present high prices for mercury are expected to continue. This should encourage prospecting and there is a probability of discovering new deposits and developing additional reserves in existing properties. The production of copper, lead, and zinc has been small, and the base metal industry has been dormant for many years. As a consequence comparatively little attention has been paid to Oregon's potential for these metals. With the use of modern techniques the possibility of discovering disseminated deposits of copper or molybdenum associated with some of the granite intrusive rocks in northeasten Oregon should not be discounted, a possibility pointed out by Gilluly years ago (Gilluly, 1933).

A great disappointment in Oregon's mineral industry has been the lack of success to date in the search for oil and gas. Although exploration drilling began in 1902, sustained commercial production has yet to be found. Considering, however, the many thousands of square miles within the State that have marine sedimentary rocks at the surface, and that fewer than 50 of the exploration holes thus far drilled can be considered valid tests of specific horizons and structures, further testing is needed. Of particular interest in the past few years has been the exploration offshore. This work has demonstrated the presence of a large and thick sedimentary basin on the Continental Shelf.

Recent work under the Department of the Interior's Heavy Metals program off the southwestern Oregon Coast has indicated the existence of anomalous concentrations of black sands. These findings should soon attract the interest of industry and will open up a new frontier to Oregon's mineral industry. This, it is felt, demonstrates that the mineral industry in Oregon which started long before it became a State still holds much promise for the future.

In the succeeding sections, the specific nature of Oregon's mineral resources have been summarized, outlining the available information on known distribution of each commodity and suggesting where the further search for additional resources might be directed.

METALLIC MINERAL RESOURCES

Antimony

(By N. S. Wagner and Len Ramp, Oregon Department of Geology and Mineral Industries, Baker and Grants Pass, Oreg.)

Antimony is a brittle, silver-white metal with a low (630° C) melting point and the unique capacity of expanding when resolidifying from a melt. It also adds strength, hardness, and toughness to certain other metals when alloyed with them. These properties account for major industrial applications in the manufacture of storage batteries, type metal, antifriction bearings, cable sheathing, and solder, each of which uses involves lead and tin-based alloys. Antimony metal is also used extensively in making munitions. In nonmetallic compound form

it is used in the manufacture of ceramics and glass, plastics, pigments, and cartridge primers. Another use of increasing consequence derives from the fire-retardant properties of some antimonial compounds.

The United States depends on imports for its antimony needs. In fact, nearly half of the world output of newly mined antimony is consumed by United States industries, and only 2 percent of domestic requirements comes from domestic sources. Red China, the Republic of South Africa, the U.S.S.R., and Mexico, in that order, have been the leading producers during recent years. At the present time, domestic production of primary antimony consists almost entirely of by-product antimony from lead-silver mines rather than production from ores valuable chiefly for antimony. However, 50 percent or more of domestic industrial requirements are met regularly by antimony reclaimed from scrap (chiefly storage batteries). This secondary antimony constitutes a vital supplement to the domestic supply from other sources, and its reclamation represents a long-established and well organized example of conservation practice. The dependency of the United States on both imports and reclamation is illustrated graphically in figure 27. Note especially that United States mine production

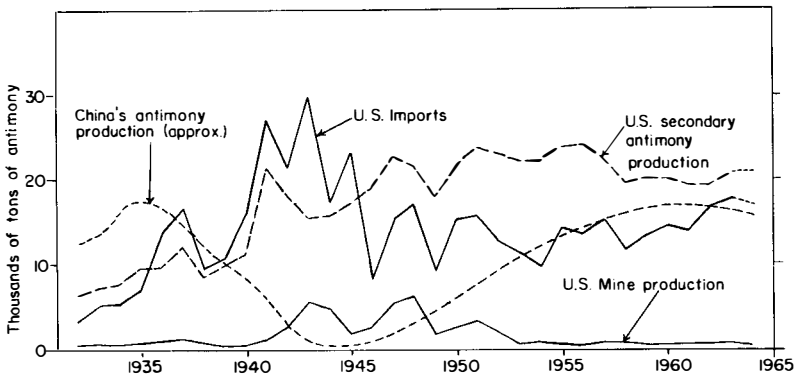


FIGURE 27.—Trends in United States production and imports of antimony.

is appreciable only during periods of wartime emergency, whereas the level of output of reclaimed, secondary antimony is consistently great.

Most antimony is recovered from ores in which antimony sulfide (stibnite) and various of the antimony oxides (stibiconite and valentinite) are the dominant ore minerals. However, some is obtained as a by-product from ores mined primarily for lead, gold, silver, quicksilver, and tungsten. In such ores the antimony may be present in the form of stibnite and the oxides in minor amounts, or it may occur along with copper, lead, and silver in complex base-metal sulfide minerals such as tetrahedrite, jamesonite, and pyrargyrite. In either case, epithermal (low temperature) fissure veins and replacement-type deposits constitute the characteristic mode of occurrence.

In Oregon, antimony commonly occurs as a minor metal in gold veins. There are, however, five known occurrences which have been worked primarily for antimony (fig. 28). Three of these reportedly

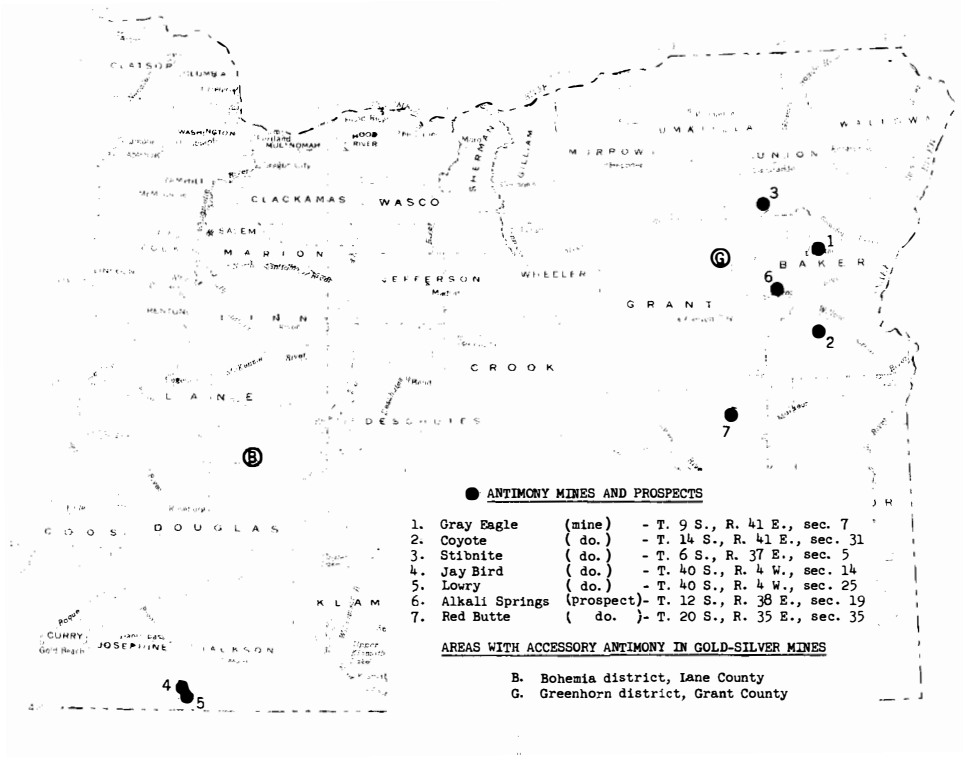


FIGURE 28.—Antimony mines and prospects.

yielded sorted, shipping-grade ore during the first World War, and two others are credited with similar production in 1907 and 1908. Only fragmentary records exist concerning the grade and tonnage of material produced during these periods. Between 1941 and 1946, under the emergency demands of World War II, a small but critically needed production of antimony ore was obtained from the Gray Eagle mine in Baker County and from the Jay Bird mine in Jackson County. Only work of an exploratory nature has been performed on these properties since 1946. Mines that are primarily valuable for other metals (gold and silver) but which contain some antimony as a minor metal are mostly in the Bohemia district of Lane County and the Greenhorn district of Grant County (Callaghan and Buddington, 1938; Oregon Department of Geology and Mineral Industries, 1941). These districts are indicated in figure 28, and are described in the section on gold (p. 125).

The Gray Eagle mine in the Virtue district, Baker County, is the largest and best known antimony occurrence in Oregon (fig. 28). Production began in 1907 and includes at least 73 tons of metal during World War I and 245 tons during World War II. This last production included 140 tons of sorted, high-grade lump ore that averaged 49.2 percent Sb (antimony) and 2,040 tons of fines (grizzly undersizes), which assayed 8.13 percent Sb and 0.26 ounces per ton in gold. Oxide minerals accounted for a calculated 82 percent of the antimony contained in the fines. The ore occurs in a strong, steep shear zone in altered gabbro-greenstone of Permian to Early Triassic age. The vein, in places as much as 6 to 8 feet wide but normally less, was developed by adits and shafts to a vertical depth of approximately 150 feet. Within the vein the antimony minerals occur variously as pods, kidneys, tabular partings, and zones of interlacing stringers spaced erratically over a strike distance of approximately 650 feet. The workings were extensively rehabilitated in 1965 and 1966, but no new production has as yet been attempted. Stibnite is known to have been encountered in several long-inactive gold mines located in the Virtue district near the Gray Eagle. These occurrences reportedly range from clusters of crystals embedded in quartz to veinlets and occasional pods of massive sulfide. In all instances, however, the stibnite is described as minor in comparison with that at the Gray Eagle.

The Jay Bird mine in the upper Applegate district, Jackson County, located in 1939, yielded 111 tons of sorted ore averaging approximately 47 percent Sb from 1941 through 1944. Some additional production may have been made in 1945 and again in 1965, but the records are not available. Massive bladed stibnite ore occurs mostly as replacement bodies in a steeply dipping shear cutting Upper (?) Triassic metasedimentary and metavolcanic country rock of the Applegate Group. In places stibnite also occurs disseminated in the wall rock adjacent to the shear. Kermesite and various of the yellow-colored oxides of antimony are frequently evident but are not abundant. The mine is developed by two adits with interconnecting raises. Stoping extends from the lowest adit to the surface, approximately 80 feet vertically, along a strike distance of about 150 feet.

At the Lowry mine 3 miles southeast of the Jay Bird, the ore also is enclosed in metasediments and metavolcanics of the Applegate Group. Small shipments of hand-sorted ore and possibly of concen-

trates recovered from a mine dump were reported in the 1920's and 1930's. Stibnite has been found at several places on the property and in the surrounding area, but no single, clear-cut, persistent vein has been recognized. The stibnite evidently occurs as scattered pods and short veins. There is no record of any significant amount of new work having been done on the property since 1945.

The Coyote mine on the south slope of Cow Butte, Malheur County, approximately 14 miles west of Brogan shipped two railroad cars of selected high-grade stibnite to the Selby smelter, California, in 1908, and another carload of similar material was produced in 1917. Data are not available on tonnage and grade for this, the only known production from the property. Stibnite occurs alone and with quartz in narrow veins on the contact of Tertiary basalt dikes which cut biotite granodiorite country rock of probable Cretaceous age. Exploration done during the 1940's and again during the 1950's under a Defense Minerals Exploration Administration (DMEA) exploration contract disclosed more stibnite, but not in minable widths.

Stibnite veins in Cretaceous granodiorite are found at the Stibnite mine (also known as the Parker mine) on the north flank of the Elkhorn Mountain Range in Union County. The stibnite occurs here in a steeply dipping, narrow (1 foot or under) vein reportedly developed originally as a gold prospect during the early 1900's. Other smaller stibnite-bearing veins have been found nearby as a result of later work. Available records indicate that the stibnite occurs most commonly as clusters of needles embedded in a quartz gangue rather than as massive, readily sortable pods, partings, or segregations. However, some sortable stibnite evidently existed in the original workings. During World War I, three carloads of ore were recovered from a comparatively shallow trench. During the 1940's and again in the 1950's, the surrounding terrain was extensively explored by bulldozing and stripping in search of other occurrences, but no attempt was made to explore the original vein at depth.

At several localities, stibnite needles occur in Tertiary sediments but in specimen quantities only. There are, however, two known occurrences where stibnite is present in massive form in Tertiary rocks. At Alkali Springs west of Hereford, Baker County, stibnite is associated with hot-spring activity localized along a fault (Brooks, 1963, p. 212). The country rock is an intrusive dacite of Eocene (?) age (Gilluly, 1937). Several short stibnite veins 1 to 8 inches wide have been prospected extensively by bulldozer and back-hoe trenches, but no significant increase in vein widths was encountered to the depths explored.

The second prospect, near Red Butte, Harney County, is in an area occupied chiefly by Pliocene clastic volcanics and minor basalts of the Drewsy Formation of Bowen and others (1963). About a ton of fairly massive stibnite, in chunks 15 to 18 inches in diameter and assaying 33 percent Sb, was extracted in 1958 from a 40-foot vertical shaft. Some localizing bedrock structure such as a vein, shear, pipe, or dike contact must exist to account for the development of stibnite in bunches of this size; however, when the prospect was visited by the senior author in 1958, the shaft was so tightly lagged and the surrounding surface was so covered by dump material and natural soil-rock rubble that it was impossible to do more than confirm the authenticity of the discovery.

Oregon's past production of antimony has been small, and there are no known measurable ore reserves. Neither is there any available data to suggest that ore can be developed at any given occurrence in the future in amounts substantially greater than, or in some cases even equal to, those produced in the past. The Gray Eagle is one possible exception in that under favorable economic conditions exploration at depth is rendered logical by the well defined nature of the vein and the strike distance over which antimony-gold mineralization has been demonstrated to exist. The area surrounding the Jay Bird and Lowry properties also merits mention in that over the years stibnite samples have been reported (Oregon State Assay Service records) from numerous places, principally in secs. 14, 23, 24, 25, and 27. Since these samples originated mostly from raw, undeveloped prospects, systematic investigation in this area would seemingly be justified. No other specific recommendations can be made at this time. It should be realized, however, that there has been virtually no interest in searching for antimony in the United States except during periods when imports from foreign sources have been severely curtailed. Under the circumstances, it is entirely possible that other currently undiscovered prospects may exist in Oregon, especially in northeastern and southwestern parts of the State.

Much of the information in this chapter has been abstracted from Wagner's (1944) report on antimony, supplemented and updated by unpublished information in the files of the Oregon Department of Geology and Mineral Industries.

Bauxite

(By R. E. Corcoran, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Bauxite is an ore of aluminum containing gibbsite, boehmite, kaolinite, and other hydrated aluminum oxides. The process by which bauxite is formed by the weathering of aluminum-bearing rocks is known as "laterization." Laterization is essentially a desilication process in which the alkalies and alkali earths are leached out along with most of the silica. The other constituents of the parent material, chiefly aluminum, iron, and titanium oxide, remain behind as principal components of the resulting laterite. The formation of the Oregon bauxites has been discussed by Allen (1948), who postulates that the parent basalt was first altered to clay and then to bauxite by a two-stage process of weathering. The aluminum laterites of Oregon are high in iron compared to most commercial bauxites, and the term "ferruginous bauxites" is used to distinguish them from the low-iron bauxites. In his investigation of the Antrim, Ireland, laterites, Eyles (1952), also uses "ferruginous bauxite" when describing the material developed on basalt similar in composition and age to the Oregon bauxite.

Deposits of high-iron bauxite in northwest Oregon were discovered by the Oregon Department of Geology and Mineral Industries in the Tualatin Hills (Washington County) in 1943 (fig. 29). Following the discovery, the Department mapped and test drilled these and several other deposits in order to determine their size and quality. Based on results of the preliminary survey (Libbey, Lowry and Mason, 1944 and

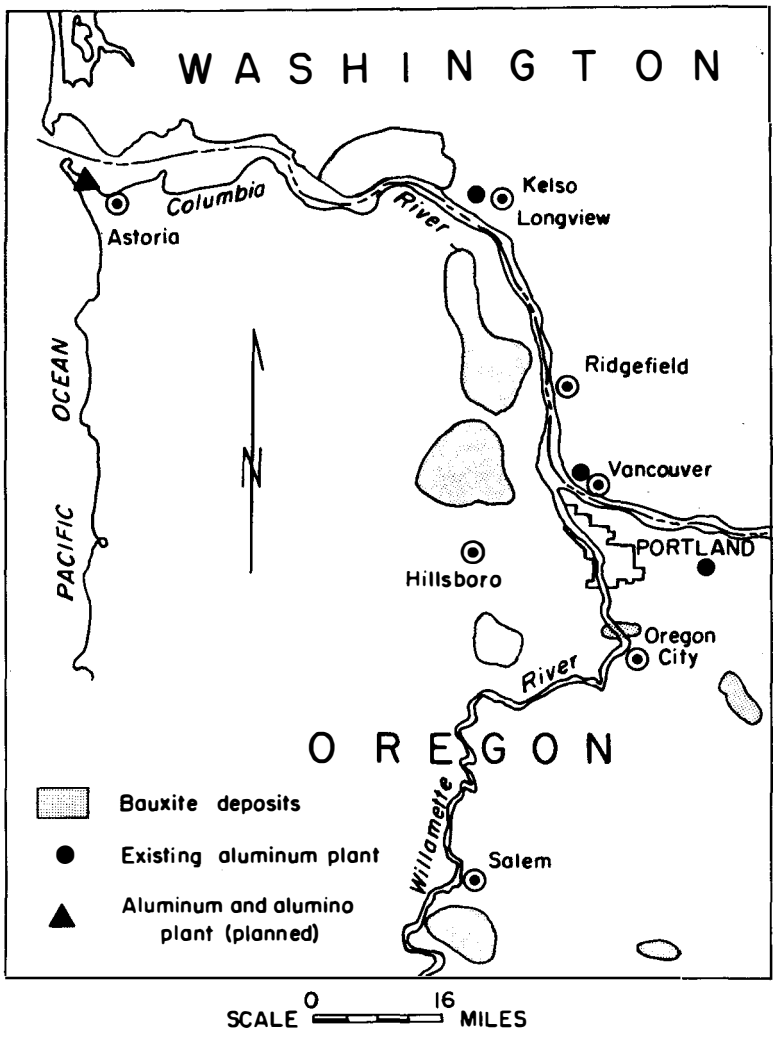


FIGURE 29.—Ferruginous bauxite deposits of Oregon and Washington.

1945) Alcoa Mining Company, beginning in 1945, conducted a long-range exploration and drilling program in northwestern Oregon and an inspection of adjoining parts of Washington.

Farther to the south, in the Salem Hills, the Department later carried on a program of exploratory drilling similar in scope to the work that had been done in Washington County (Corcoran and Libbey, 1956). The Salem area has subsequently been investigated by Aluminium Laboratories, Ltd., Harvey Aluminum Co., and Reynolds Metals Co.

Other deposits of ferruginous bauxite are known to occur in several widely separated areas along both sides of the Willamette Valley, but have not been explored sufficiently to determine their economic importance.

Basalt flows, basaltic breccias, and tuffs of probable Miocene age underlie most of the hilly upland areas where the bauxite deposits are known to occur (Wells and Peck, 1961). The lavas have been termed "Columbia River basalts" (Libbey, Lowry and Mason, 1945), "Salem lavas" and "Stayton lavas" (Thayer, 1939), but all are probably part of the Columbia River Group as suggested by Waters (1961).

The color of the Oregon bauxite varies from dark reddish brown in Washington and Columbia Counties to light yellowish brown in the Salem area. Varieties range from hard oolitic or pisolitic type characteristic of the Washington County deposits to a porous granular or earthy type found in the Salem Hills. Chemical analyses show that the better grade of lateritic material usually contains 33–36 percent Al_2O_3, 30–33 percent Fe_2O_3, 5–7 percent SiO_2, and 5–7 percent TiO_2. High-grade gibbsite nodules are scattered through the soil zone above the bauxite section in many of the laterite areas. Nodules as much as 3 feet across are especially common in the Salem Hills area, and these residual boulders average approximately 55 percent Al_2O_3, 8 percent Fe_2O_3, and 3 percent SiO_2.

Results of exploration drilling in the laterite areas by private companies have never been released to the public. On the basis of widely spaced auger holes put down by the Department in the Tualatin Hills (Washington and Columbia Counties) an estimated area of 8,000 acres is underlain by laterite as much as 30 feet thick, averaging approximately 34 percent Al_2O_3 and less than 8 percent SiO_2. In the Salem Hills (Marion County) 27 exploratory holes drilled in an area of 1,200 acres showed the laterite section to be as thick as the Tualatin Hills deposit and that it averaged 35.0 percent Al_2O_3 and 6.7 percent SiO_2. Total resources of ferruginous bauxite in Oregon probably exceed 50 million tons. This figure could be increased considerably if the cut-off point for contained silica (8–10 percent) is raised or if some of the unexplored deposits which lie outside the main areas prove to be larger than now indicated.

According to Williams (1965) the United States is the world's largest consumer of bauxite, but produces only 15 percent of domestic requirements. Almost all of the bauxite mined in this country comes from Arkansas, where reserves, averaging 52 percent Al_2O_3, are estimated to be about 50 million tons. Most of the imported bauxite comes from Jamaica and Surinam, with lesser amounts from Guyana (formerly British Guiana), Haiti, and French Guinea. Extensive deposits now being explored in both Australia and French Guinea may eventually provide a large share of our imports.

Aluminum metal is produced in two steps requiring two distinct operations. First, bauxite ore is treated by the so-called Bayer process to produce pure aluminum oxide, or alumina as it is called. The second step is the reduction of the aluminum oxide to aluminum metal by electrolysis in a cryolite bath. As a consequence, aluminum reduction plants are located near cheap and reliable sources of electric power such as in the Columbia River area where several large hydroelectric plants have been installed. At present all Bayer plants are in the

Middle West or South because of their proximity to the Arkansas bauxite and the Caribbean region. Thus alumina used in Northwest reduction plants must be shipped across the country or brought in by water transport.

The percentage of alumina in the ferruginous bauxites of northwest Oregon is fairly low compared to that of most imported ores which range from 45 percent to 60 percent Al_2O_3. For this reason, the unit cost of producing alumina from Oregon laterites using the Bayer process would be higher than from either Arkansas deposits or foreign sources. Oregon bauxites, however, have the advantage of a favorable location close to several large aluminum reduction plants along the Columbia River. This would offset to a large extent their higher processing costs. The total annual metal capacity of these plants is now in excess of 340,000 tons. With the addition of the Northwest Aluminum Co. plant now under construction at Warrenton, Oregon, and the extra pot lines being completed at Reynolds' Longview and Troutdale smelters, the total annual capacity will exceed 600,000 tons (table 2).

TABLE 2.—CAPACITY OF ALUMINUM REDUCTION PLANTS IN THE PACIFIC NORTHWEST

Company	Location	Year reduction plant built	Primary annual capacity (short tons)	
			Jan. 1, 1967	Planned
Plant along the lower Columbia River:				
Alcoa	Vancouver, Wash.	1940	100,000	
Reynolds Metals Co.	Longview, Wash.	1941	65,000	185,000
Do.	Troutdale, Oreg.	1942	91,500	131,500
Harvey Aluminum Co.	The Dalles, Oreg.	1958	87,000	
Northwest Aluminum Co.	Warrenton Oreg.	(1)		120,000
Other plants in the Pacific Northwest:				
Kaiser Aluminum & Chemical Corp.	Spokane, Wash.	1942	193,000	
Do.	Tacoma, Wash.	1942	41,000	82,000
Alcoa	Wenatchee, Wash.	1952	125,000	175,000
Anaconda Aluminum Co.	Columbia Falls, Mont.	1955	100,000	175,000
International Aluminum Co.	Bellingham, Wash.	1966	76,000	228,000

[1] Under construction.

The Northwest Aluminum installation will include a Bayer processing plant as well as an aluminum reduction facility. Reduction plants in the Pacific Northwest have a total capacity of almost 880,000 tons per year and supply almost 30 percent of the United States' aluminum metal. In the next few years, planned increases in plant capacity will boost the total for the Northwest to 1,476,500 tons.[3]

Extensive metallurgical testing has been done on Oregon bauxite by Alcoa, and reportedly the ore is amenable to treatment by a modification of the Bayer process. Another method for treating the laterites is the Pedersen process which was originally developed on a commercial scale in Norway. In this procedure, the ore is smelted with carbon and limestone to produce pig iron or a ferroalloy, and calcium-aluminate slag, which is further treated to produce alumina. The U.S. Bureau of Mines in Albany, Oregon, has conducted plant tests on the ferruginous bauxites of the Northwest and has shown that the Pedersen process can be used successfully on these ores to recover pig iron as well as alumina (Fursman and others, 1968).

[3] Information on production capacity supplied by Bonneville Power Administration, Department of Marketing Research.

SUMMARY

The Oregon ferruginous bauxites are the United States most important known potential resource of low-silica aluminous raw material. The deposits are favorably located near existing aluminum reduction plants. The deposits are amenable to low-cost mining methods. The ferruginous bauxites have a low silica content, and may be processed to recover alumina more economically than such other potential source materials as clay and other aluminum silicate minerals. The iron content of the ferruginous bauxites may provide an important by-product with enough value to offset the lower alumina content it has compared to presently used bauxite ores. In the event that imported supplies of bauxite or alumina were cut off or seriously reduced, as occurred during World War II, Oregon bauxite might very well fill a critical, perhaps crucial, need in supplying bauxite to aluminum plants.

Black Sands

(By H. E. Clifton, U.S. Geological Survey, Menlo Park, Calif., and R. S. Mason, Oregon Department of Geology and Mineral Industries, Portland, Ore.)

"Black sands" are natural concentrations of minerals having a specific gravity substantially greater than quartz, the dominant mineral in most sands. As a result of this high specific gravity, waves and currents readily segregate the heavy minerals from the lighter grains of the sediment. These heavy mineral concentrates may be a source for such diverse commodities as chromium, titanium, iron, zirconium, rare earths, and precious metals. Because the most aboundant heavy minerals are dark and opaque, the deposits commonly are referred to as "black sands", although owing either to original composition or to subsequent weathering the sand may not be truly black. Table 3 lists the heavy minerals found in the Oregon black sands, their specific gravity, and relative abundance.

TABLE 3.—HEAVY MINERALS OBSERVED OR REPORTED FROM COASTAL BLACK SANDS OF OREGON (AFTER TWENHOFEL, 1946)

[A=abundant, C=common, R=rare, Tr=trace]

Mineral	Specific gravity	Relative abundance	Mineral	Specific gravity	Relative abundance
Actinolite	2.9 – 3.5	R	Leucoxene	3.5 – 4.5	R
Andalusite	3.1 – 3.2	Tr	Magnetite	5.1 – 5.18	A
Apatite	3.15– 3.23	R	Monazite	4.9 – 5.3	Tr
Augite	3.2 – 3.6	C	Olivine	3.27– 3.5	R
Chromite	4.3 – 4.6	A	Platinum group	12.0 –19.0	Tr
Clinozoisite	3.25– 3.37	R	Rutile	4.18– 4.25	R
Cummingtonite	2.85– 3.2	Tr	Sillimanite	3.23– 3.25	R
Diopside	3.11– 3.42	R	Spinel	3.6 – 3.8	R
Enstatite	3.1 – 3.5	R	Spodumene	3.1 – 3.2	Tr
Epidote	3.25– 3.5	C	Staurolite	3.65– 3.77	R
Garnet	3.5 – 4.3	C	Titanite	3.4 – 3.56	R
Glaucophane	3.0 – 3.15	R	Topaz	3.4 – 3.6	Tr
Hornblende	3.0 – 3.3	C	Tourmaline	2.98– 3.3	R
Gold	15.0 –19.3	Tr	Tremolite	3.0 – 3.3	R
Hypersthene	3.2 – 3.5	A	Zircon	4.5 – 4.7	R
Ilmenite	4.5 – 5.0	A	Zoisite	3.25– 3.37	Tr
Kyanite	3.56– 3.68	R			

Most of the heavy minerals in the Oregon black sands formed as a result of igneous activity or metamorphism. The minerals subsequently have been freed during erosion of the source rocks and transported seaward by streams. Black sands form locally where these streams winnow the lighter minerals away, although most heavy minerals ultimately reach the sea. Black sands accumulate on beaches, where they are concentrated by wave swash. Wind also can effect small concentrations in dunefields bordering the coast, and offshore currents conceivably can concentrate heavy minerals on the continental shelf. Twenhofel (1943) discusses the origin of black sands on the coast of southwest Oregon.

The configuration of black sand deposits reflect their depositional environment. Most occur in lenticular bodies, although highly irregular deposits are not uncommon. Beach deposits tend to be elongate parallel to the present or former shorelines, and they generally are larger and show greater lateral persistence than stream deposits.

Scattered small black sand deposits of Mesozoic or Tertiary age occur in the Coast Ranges in the Illinois River drainage (fig. 30). During the Pleistocene Epoch, fluctuations in sea level as the result of glaciation, tectonism, or a combination of both produced shoreline deposits on terraces than range in elevation from 1500 feet above present sea level to unknown depths offshore (Griggs, 1945, p. 117). The emergent terraces contain numerous and locally extensive black sand deposits and similar deposits could be expected to occur on submerged terraces on the continental shelf.

Utilization of the various minerals found in the black sands has progressed considerably since they were first mined solely for gold 125 years ago. Chromite is the principle ore of chromium and is also used as a refractory, and for various chemicals and pigments. Zircon is the source of the element zirconium, and rutile and ilmenite are ores of titanium. Magnetite, an iron oxide mineral, is commonly used as an iron ore. Garnet, in the sizes available in the coastal black sands, has found limited usefulness, but small quantities of garnet sand have been sold for sand blasting and as an abrasive in dimension stone quarry gang and wire saws. Olivine is in increasing demand as a refractory. Although studies have been made over the years to find markets for the quartz grains which accompany the black sands, no success has been reported. Most of the quartz grains have been freed from any enclosing matrix, but unfortunately, many of the grains have cracks or fractures which contain iron oxide films. The iron cannot be removed by any simple washing or acid leaching treatment, thus precluding the use of the quartz for glass making. No other markets have been considered. Details on the commercial aspects of these commodities are given in other sections of this report.

Other commonly associated black sand minerals include hypersthene, hornblende, epidote, and augite. Although these components have no commercial application at the present time, any beneficiation of the other salable black sand fractions would in effect make at least a rough concentrate of these minerals. Future changes in technology conceivably could create markets for them.

Investigation and exploitation of black sands in Oregon has been largely confined to the southwestern coast where the Klamath-Siskiyou

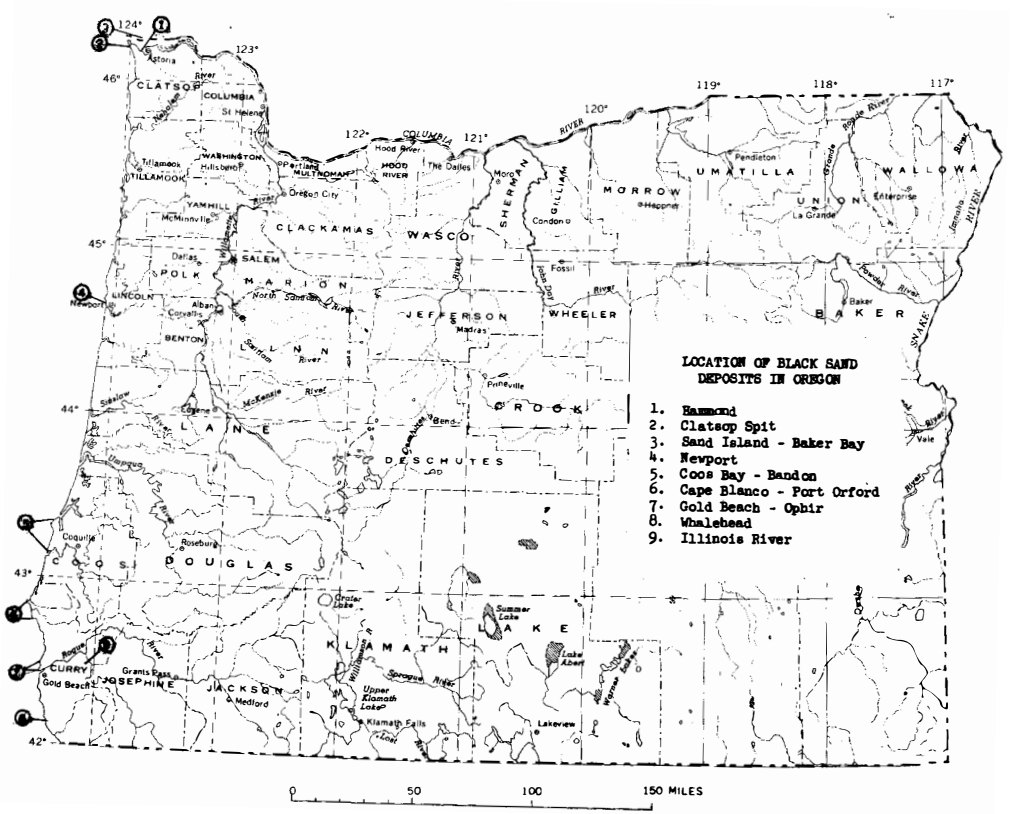


FIGURE 30.—Black sand deposits in Oregon.

Mountains provide a source for valuable heavy minerals. Gold and platinum were found on the beaches there shortly after the beginning of the California Gold Rush (Blake, 1854). For a number of years in the late 1850's and early 1860's beach placers were extensively mined along the Oregon Coast (Hornor, 1918, p. 7). Initially, the associated platinum was regarded as waste material, but as the importance of the silvery grains was recognized, recovery of platinum also was attempted. The amount of gold and platinum extracted by the early miners is unknown. Butler and Mitchell (1916, pp. 48–50) describe recovery attempts around the turn of the century.

It was not until 1926, however, that any serious attention was given to the associated "heavy blacks" in the sands along the active coastal beaches and the elevated terraces immediately shoreward from them. First exploitation of the deposits occurred during World War II when the demand for chromite made it economically feasible to concentrate the richer portions of some of the terrace deposits. A total of 46,500 tons of semi-finished concentrates left over from the war-time activity were subsequently upgraded, and five fractions containing chromite, magnetite, garnet, ilmenite, and zircon were produced.

Despite the relatively small production of black sands from southwestern Oregon there has been a long history of investigation of the deposits. Originally reported on by Diller in 1901 in the Coos Bay Folio of the U.S. Geological Survey Geologic Atlas, the deposits have been examined by private, State and federal organizations.

Interest in exploiting Oregon's black sands is tied almost completely to the need for chromite during periods of national emergency. Currently the United States has no domestic production of this strategic commodity, but world production in 1965 totalled nearly 5.4 million short tons. Chromite has been produced in California, Oregon, Montana, Alaska, and Texas. Almost all domestic production has come from hard rock mines; only in Oregon have chromiferous sands been mined. Recovery and beneficiation methods for chromite-bearing black sands are described in Dasher and others (1942), and Hundhausen (1947).

The Oregon black sand deposits are found at numerous places along the coast (see fig. 30). Most attention to date has been directed toward the terraces lying between Coos Bay and the mouth of the Coquille River in Coos County, an area roughly 5 miles wide and 25 miles long (fig. 30, No. 5). Here the coastal terraces of southern Oregon reach their maximum development and contain numerous black sand bodies (Diller, 1914, p. 124–125; Hornor, 1918, pp. 14–25, Pardee, 1934, pp. 28–29; Griggs, 1945). The largest black sand deposit, The Seven Devils (Last Chance) mine (Griggs, 1945, pp. 132–135), was originally nearly a mile long, 150–1,200 feet wide and averaged between 14 and 20 feet thick. Early studies (Day and Richards, 1906, pp. 1208–1210) showed these deposits to be enriched in chromite, ilmenite, garnet, zircon, gold and platinum. Mining for chromite has been restricted to deposits in the terraces of this area. Kauffman and Baber (1956, p. 12) summarize the chromite mining operations and Kauffman and Holt (1965, pp. 21–22) discuss the present potential for zircon in these deposits.

Other areas that have been considered for black sand exploitation are shown on figure 30. They include: (1) the Hammond deposit in Clatsop County, a small but fairly well concentrated deposit in the

south bank of the Columbia River estuary that has not been productive. (2) Clatsop Spit, where the Bunker Hill Company in early 1963 drilled a series of 34 holes ranging in depth from 40 to 86 feet, to determine the iron content. The top 10 feet contained the highest concentrations of iron but the average content was only 22.6 pounds per ton. The company had 2000 acres under lease from Clatsop County, the State of Oregon, and the federal government. (3) Sand Island-Baker Bay. Recent attempts have been made near the mouth of the Columbia River to recover heavy minerals. (4) Newport. A small amount of gold and platinum was recovered many years ago from the active beach; little if any activity has been conducted recently. (6) Cape Blanco-Port Orford. This area ranks second to the deposits lying north of Bandon in the production of gold and platinum. Most of the recovery has been from the active beaches, with lesser amounts coming from elevated terraces not far from the coast. Aside from one or two small beach placers there has been little activity since the middle 1930's. (7) Ophir-Gold Beach. The active beaches near the mouth of the Rogue River have produced gold but very little platinum over the years. Most of the placering was done years ago when rich concentrations of gold were worked along the active beach. During World War II several attempts were made to concentrate chromite in the black sands but they were not successful. (8) Whalehead. A rusted skeleton of a concentration plant at Whalehead Cove attests to an early attempt to mine the extensive black sand there. (9) Horsesign Butte-Illinois River. Small outliers of black sand of Tertiary age (Baldwin, 1967, written communication) occur west of the Illinois River south from Agness.

Prospective producers of Oregon black sands face numerous problems. As has been mentioned, many deposits occur in unconsolidated or poorly cemented Pleistocene terrace deposits. Some occur near the surface, but others have been found at depths of 60 feet or more. The rank vegetative growth makes prospecting difficult. Even old test pits are difficult to find once they are abandoned.

Black sands on the active beaches of the area present several unique problems to the prospective miner. Most of the "wet sand" areas have been reserved for public use by the state, and an additional adjoining strip of "dry sand" is currently being surveyed by the state for eventual inclusion in the public use area. Certain small sections of the active beach are privately owned and presumably could be leased or purchased. Regardless of the status of the land and the possibilities for mining from a legal standpoint, there is an over-riding difficulty in the continual hazards of wind, wave, and tide along the littoral zone. The destructive effects of storm winds and wind-driven waves are well known. Less well appreciated are the recurring changes in the sand deposits caused by normal wave and wind action from day to day. These changes make it difficult to plan an orderly and efficient mining program. Numerous attempts to recover black sands from the active beaches have ended in failure.

Offshore black sand deposits along the southern Oregon coast present further problems. The amount of black sand, gold and platinum that has been washed down from the Klamath-Siskiyou Mountains is probably very large, but whether or not the material has been sufficiently

concentrated offshore remains to be determined. The U.S. Geological Survey in 1966 under its heavy metals program began studies to identify areas on the continental shelf containing concentrations of heavy minerals.

Under a joint research contract, the Office of Marine Geology and Hydrology of the U. S. Geological Survey and the Department of Oceanography of Oregon State University are investigating the possibility for black sand deposits on the sea floor off southern Oregon. To date, more than 600 nautical miles of acoustical subbottom profiles have been run. These profiles indicate the distribution and thickness of marine sediment, the location of possible submerged river channels and the nature and geologic structure of bedrock underlying the continental shelf. More than 250 marine sediment samples have been taken using box corer, piston corer and grab sampler; these samples currently are being analyzed for their heavy mineral and heavy metal content. Magnetometer surveys across areas of particular interest show local positive magnetic anomalies that may represent black sand bodies on or beneath the sea floor.

Preliminary results show anomalous concentrations of gold in surface sediments, particularly offshore from the mouths of major streams. In nearly all cases the gold is associated with a relatively high proportion of heavy minerals. The heavy minerals either may be concentrated by contemporaneous bottom currents or, perhaps more likely, may be derived from partly buried relict beach sands that formed at a previous low stand of the sea. Gold at the surface of these deposits occurs as very fine flakes mostly less than 0.005 mg in mass (Clifton and others, 1967). Exploitation of gold from offshore deposits not only requires development of new mining techniques, but also may require new techniques to recover such extremely fine gold.

Potential resources of black sand in southwestern Oregon remain to be adequately determined. Most of the investigations have been made during periods of national emergency and were directed primarily towards discovering the most readily mined deposits. No comprehensive examination of the entire district has been conducted. The U. S. Geological Survey began an onshore test drilling program along the coast north of Bandon in 1966. Any peace-time exploitation of the deposits will depend on the use of all or nearly all of the various "heavy blacks." At present, it is questionable whether even as by-products the various minerals can compete with other known deposits. Changing markets and prices, coupled with improved mining and beneficiation costs and techniques will be the critical factors in determining the cut-off grade of the deposits, the tonnage available, and ultimately the feasibility of conducting any mining program.

Exploration of the potential onshore black sand deposits can be done at relatively low cost. The area is accessible the year around, the climate is characterized by fairly heavy rainfall, but very little snow or sub-freezing weather. Drilling and trenching would require standard equipment for penetrating poorly consolidated sand. The Coos County deposits are located adjacent to rail, highway, and deep water transportation and cities of Coos Bay, North Bend, Coquille, Bandon, Empire, and Charleston, located around the periphery of the area, can supply labor, materials, services, and supplies.

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Chromite

(By T. P. Thayer, U.S. Geological Survey, Washington, D.C., and Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg.)

Chromite, the only commercial source of chromium, is indispensable for several major industrial uses. It is a chromium-bearing member of the spinel group. Its composition can be expressed by the general formula $(MgFe)O \cdot (CrAlFe)_2O_3$. The relative proportions of chromium, magnesium, and iron may vary widely, and variation in composition affects directly the uses to which it can be put.

CONSUMPTION, TYPES OF ORES, AND USES

In the 10 years 1956–1965 the United States annually used approximately 1,250,000 long tons of chromite ore containing about 545,000 long tons of Cr_2O_3. about 59 percent of the ore was used in ferroalloys, principally in stainless steel, and about 28 percent was used for refractory linings in high-temperature furnaces. The chemical industry consumed the remaining 12–13 percent, mainly for dyes, tanning, and chromium plating. In terms of Cr_2O_3, the metallurgical industry consumed 65 percent, refractories about 22.5 percent, and chemicals about 12.5 percent of the total.

Since about 1880 (see fig. 31) the United States has had to rely on imported chromite, and even when imports were limited by war it has been able to obtain only half its needs from domestic deposits. The total domestic production of 1.9 million long tons of ore, disregarding problems of grade, would be equivalent to about 16 months' needs at the 1965 rate, and Oregon's total production of 147,000 long tons would last about 6 weeks.

The composition and, to a considerable extent, the uses of chromite ore depend upon two factors: the composition of the chromite mineral itself and the ratio of chromite to gangue minerals. Chemically, there are three general classes of chromite ore (Thayer, 1962): high-chromium, high-iron, and high-aluminum. The SiO_2 content may differ somewhat between classes, but in all it must be below 8 percent.

High-chromium ores contain 46 percent or more Cr_2O_3, have a Cr:Fe ratio of 2:1 or more, and are used mainly for metallurgy. High-iron ores contain between 40 and 46 percent Cr_2O_3 and have Cr:Fe ratios of 2:1 or less; they are used for chemical purposes and also in increasing amounts for metallurgy and refractories. The high-alumina ores contain 20 percent or more Al_2O_3, 60 percent or more Cr_2O_3 and Al_2O_3 combined, and not more than about 12 percent Fe; they are used principally in refractories. Lumpy ores are best for metallurgical and refractory uses, whereas fines and concentrates are preferred for chemicals. Off-grade ores can be used by blending, or directly, with loss of efficiency. If the composition of the chromite is suitable, low-grade materials can be concentrated to commercial grade by grinding and separating the chromite from gangue minerals by gravity methods, flotation, or electrostatically.

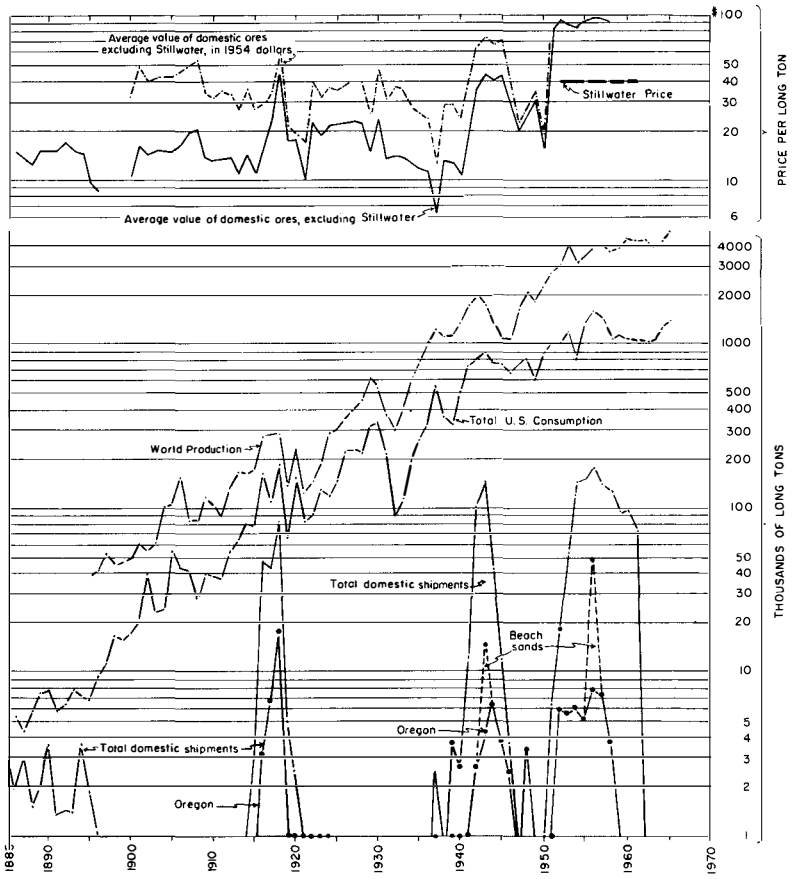

FIGURE 31.—Production of chromite in Oregon since 1885 in relation to total United States production and consumption, world production, and domestic price. Dots indicate production, but less than 1,000 tons (most data from U.S. Bureau of Mines Minerals Yearbooks).

GEOLOGY OF DEPOSITS

The chromite deposits in Oregon are of two kinds:

(1) Irregular to tabular bodies of the podiform type (Thayer, 1964) in peridotite and serpentine. They occur in the Blue Mountains in the northeastern part of the State and in the Klamath Mountains in the southwestern part (fig. 32).

(2) Minable concentrations of chromite in beach sands along the coast in Coos and Curry Counties.

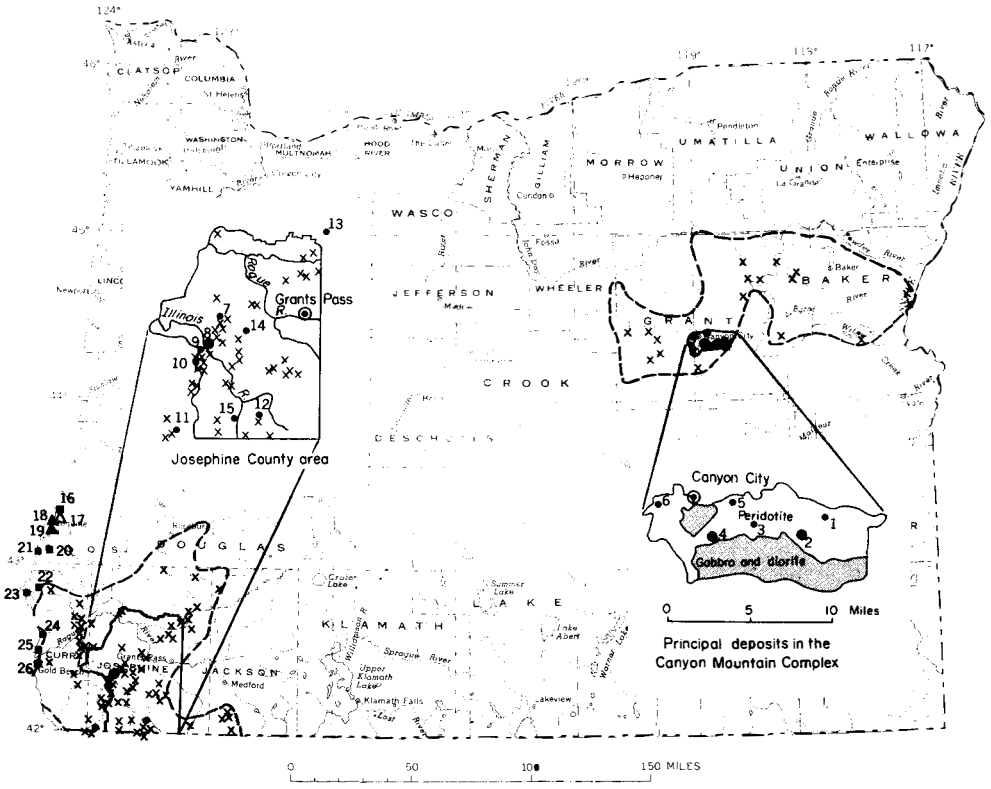

FIGURE 32.—Chromite districts and principal deposits in Oregon.

Geologic type	Size: Production plus remaining resources, in terms of shipping ore and concentrates, in long tons			
	More than 100,000	10,000-100,000	1,000-10,000	Less than 1,000
Podiform		●	•	x
Beach sands	▲	△	▪	

Key to principal mines, deposits, or closely grouped deposits

Podiform deposits

1. Dry Camp (and 5 others)
2. Chambers (5 deposits)
3. Haggard and New (and 4 others)
4. Iron King
5. Ward
6. Potato Patch (4 deposits)
7. Shady Cove, Violet, Buster
8. Oregon Chrome
9. Deep Gorge, Chrome King, Young's Dailey Dozen
10. McCaleb group (Sourdough No.1 and No. 2)
11. Sourdough
12. Chollard (Golconda)
13. Starveout (Black Boy, Gray Boy)
14. Big Bear
15. Esterly

Beach sands

16. South Slough area, unexplored deposit
17. South Slough area (8 deposits)
18. Seven Devils Terrace (12 deposits)
19. Pioneer Terrace and Lagoons (6 deposits)
20. Unexplored deposits (2)
21. Present beach
22. Butler mine (3 deposits)
23. Present beach
24. Ophir beach
25. Present beach
26. Rogue River beaches

The known podiform chromite deposits in the State (Allen, 1941; Ramp, 1961; Thayer, 1940) range in size from a few pounds to nearly 100,000 tons. Many deposits are of massive ore and have sharp boundaries, but most of the larger ones are of disseminated ore that grades into barren rock. The ore bodies occur individually and in clusters scattered more or less randomly in the peridotite or serpentine. All of the known podiform deposits have been found by surface exposures or by exploration and mining close to known ore bodies. Despite long-continued research, no reliable economic method has been devised for finding "blind" deposits concealed just below ground, especially in areas of moderate or high relief.

Podiform deposits in southwestern Oregon

Chromite is more or less widespread in ultramafic rocks of the Klamath Mountains (fig. 32). More than 250 separate occurrences have been described in southwestern Oregon (Ramp, 1961). Most of these occurrences produced only small amounts of massive lump ore from float and near-surface lenses. A few of the deposits worked were of low-grade disseminated ore that required milling and concentration.

Mapping of igneous platy flow structures, including chromite schlieren, in ultramafic rocks has shown that the major chromite occurrences lie in certain horizons within intrusive bodies. Considerable banding, flowage folding, and stretching out of the chromite segregations have taken place during intrusion of the peridotite magma. These relations suggest that the magma was largely crystallized (a crystal-mush) before being injected into its present position. Characteristics

of alpine-type ultramafic rocks such as these have been described by Thayer (1964).

Chromite deposits of the area occur as thin streaks or schlieren that pinch out and occasionally reappear along the strike, as flow-banded disseminated bodies, and as pods or lenses of massive chromite that are normally strung out in some linear arrangement.

The lode chromite deposits shown on the accompanying map (fig. 32) have been described by areas (Ramp, 1961). A few mines in the Central Illinois River, Pearsoll Peak, Chrome Ridge, Waldo, and Sourdough-Vulcan Peak areas have contributed a major portion of the State's chromite production (table 4).

The largest bodies of massive metallurgical-grade ore mined in Oregon were from the Robertson (Oregon Chrome) mine (fig. 32, No. 8) in the Central Illinois River area, where single lenses as much as 15 to 20 feet thick and groups of closely spaced smaller bodies of massive chromite have yielded more than 5,000 tons each. Total production from this mine, Oregon's largest chromite producer, has be n about 32,000 long tons of ore which averaged near 46 percent Cr_2O_3, with 2.7 :1 Cr :Fe ratio. Development work has been carried to a depth of about 500 feet.

TABLE 4.—PRODUCTION OF THE LARGER CHROMITE MINES IN SOUTHWESTERN OREGON

Mine and index No. on fig. 32	Map area	Production (long tons)	Average grade	
			Approximate percent Cr_2O_3	Cr:Fe ratio
Oregon Chrome (8)	Central Illinois River	32,000 (lumpy)	46	2.7
Deep Gorge (9)	do	2,000 (lumpy)	46	2+
Shady Cove (7)	Chrome Ridge	2,000± (part conc.)	45–50	2.7
Sourdough (11)	Sourdough-Vulcan Peak	1,567 (part conc.)	44	2.8
Chrome King (9)	Central Illinois River	1,400 (lumpy)	42–45	2.5
McCaleb (10)	Pearsoll Peak	1,200 (conc.)	50	2.5
Violet (7)	Chrome Ridge	940 (conc.)	52	2.4
Chollard (12)	Waldo	3,500 (mill ore)	10–35	2.1
Esterly (15)	do	2,300 (mill ore)	20	2.1
Buster (7)	Chrome Ridge	2,000 (mill ore)	20–30	2.3±
Big Bear (14)	Grants Pass district	900 (lumpy)	45–50	3
Black Boy (Starveout Group) (13)	Southern Douglas County	900(?) (lumpy)	45	2.5

No very large deposits of disseminated (low-grade) chromite have been found in southwestern Oregon, although a few chromite-bearing zones 8 to 19 feet wide have been described. Mines such as Young's Dailey Dozen (No. 9) and the McCaleb mine (No. 10) in the Pearsoll Peak area, which are in zones of disseminated chromite about 12 feet wide in altered dunite, together have potential reserves of about 70,000 tons of milling-grade material containing between 20 and 50 percent chromite. There are no known reserves of shipping-grade metallurgical chromite in southwestern Oregon, because all exposed ore was mined out during the stockpile purchasing program that ended in 1958. Small tonnages of disseminated milling-grade ore can be projected from exposures that remained in a few mines, but these mines would have to be trenched or drilled to establish any reserves. The following known occurrences are not of sufficient size to support profitable mining operations without a significant increase in price: the Sourdough mine (No. 11) near Baldface Creek in southern Curry

County; the Signal Buttes area reported on by Allen (1941) about 8 miles east of Gold Beach; the McCaleb mine (No. 10) about 1½ miles south of Pearsoll Peak; Young's Dailey Dozen (No. 9) about 1½ miles east of Pearsoll Peak; the Violet mine (No. 7) on Chrome Ridge; and the Gray Boy (No. 13) prospect near the head of Starveout Creek in southern Douglas County.

Exposures of ultramafic rocks in which chromite may be found cover roughly 400 square miles in southwestern Oregon, and should a successful geophysical method of prospecting for chromite be developed the area would present a large potential for exploration.

Podiform deposits in northeastern Oregon

Probably at least 200 chromite mines and prospects could be identified in eastern Oregon; their total production is about 30,000 long tons. Most of the prospects are in Grant County (Thayer, 1940, 1956) and concentrated in two areas; in Canyon Mountain, south and southeast of John Day, and in the Fields Creek-Deer Creek belt 20 miles to the west (fig. 32). All seven of the mines that have yielded more than 1,000 tons each are in peridotite of the Canyon Mountain Complex, which has yielded at least 90 percent of the production from the region. The Canyon Mountain Complex is 12–13 miles long by 4–5 miles wide; the northern part consists of chromite-bearing peridotite, and the southern half of gabbroic and dioritic rocks. Three of the largest deposits or groups of deposits, the Iron King, Haggard and New-Present Need Group, and Chambers, are near the gabbro (Thayer, 1956), but the others are scattered at random. All the larger deposits are now accessible from maintained forest roads. Possibly half a dozen mines outside the Canyon Mountain Complex have yielded more than 100 tons apiece.

The eastern Oregon deposits range from high-chromium ore containing at most about 55 percent Cr_2O_2 and having a maximum Cr:Fe ratio of 3.25:1 to high-alumina ore containing about 32 percent Cr_2O_3, 32 percent Al_2O_3, and having a Cr:Fe ratio of about 1.75:1. Except for about 13,500 tons of low-grade, high-alumina ore mined in 1916–17, mining has been limited to high-chromium ores that met specifications of the Government purchase programs.

Beach sands

Chromiferous black sands occur in the present beaches and on raised marine terraces along the coast in Coos and Curry Counties (fig. 32) (Griggs, 1945). The black sands occur in lenses and layers from a few inches to 42 feet thick, from a few tens of feet to 1,000 feet or more wide, and from a few hundred feet to more than a mile long. The overburden ranges up to 75 feet of sand, clay, and gravel. Besides chromite, the minerals of possible economic interest in the sands are zircon, ilmenite, garnet, magnetite, and rutile, together with minute quantities of gold and platinum. The proportion of chromite in the sands varies widely from place to place. Although some high-grade layers contain as much as 26 percent Cr_2O_3 (53 percent chromite), the average grade of minable sand is believed to be about 5 percent Cr_2O_3, or 10 percent chromite. The chromite in the black sands originally was eroded from peridotite and serpentine in the Klamath Mountains, distributed by along-shore currents, and concentrated by wave action. The chromite

is believed, however, to have been deposited first in Tertiary sedimentary rocks, then released by erosion and redeposited in the beaches (Griggs, 1945, p. 122).

Systematic exploration of the sands was undertaken in 1940 by the State of Oregon Department of Geology and Mineral Industries and the U.S. Geological Survey, and later by the U.S. Bureau of Mines, which also investigated means of recovering the chromite. In 1943 the Humphreys Gold Corp., with the newly invented Humphreys spiral, and the Krome Corp. by conventional tables, recovered about 78,000 long tons of rougher concentrates averaging 24–25 percent Cr_2O_3 from nearly 450,000 tons of crude sand. From part of the rougher concentrates a special plant erected at Coquille by the Defense Plant Corp. produced 10,641 tons of final concentrates in 1943, averaging 39.3 percent Cr_2O_3 with a Cr:Fe ratio of approximately 1.6:1. In 1955 and 1956, 40,813 tons of concentrates averaging about 37 percent Cr_2O_3 was recovered from the remaining rougher concentrates and smelted to ferrochromium for the National stockpile. Separation of the chromite from magnetite and ilmenite is difficult because the magnetic properties and densities of the three minerals overlap within a restricted range. Electromagnetic and electrostatic methods were used in 1955 and 1956.

RESOURCES AND HISTORY OF PRODUCTION

The chromium resources of Oregon as of 1956 were estimated by T. P. Thayer and E. D. Jackson of the U.S. Geological Survey (Dept. Interior press release, 1957) to be on the order of 350,000 long tons of Cr_2O_3 in the ground. Of this total, 250,000 tons is believed to be in the beach sands, and 100,000 tons in podiform deposits. In terms of shipping ore and concentrates, disregarding losses in mining and milling, these resources are equivalent to 650,000 tons ranging between 35 and 40 percent Cr_2O_3 with Cr:Fe ratios between 1.6:1 and 2:1, and 75,000–100,000 tons of high-chromium ore averaging more than 45 percent Cr_2O_3.

Podiform deposits

Although many miners may disagree, the most accurate basis for estimating the potential production of high-chromium (metallurgical) chromite from podiform deposits in the United States and in Oregon is the history of production during World War II and 1951–1958. The complex geology of individual ore bodies and uncertainties of wartime purchase programs preclude exploration more than a few months ahead of actual mining. Measurable ore reserves, in the sense used by the mining industry, are insignificant at any given time. For example, although the Oregon Chrome mine has produced nearly 32,000 tons of high-grade ore (W. S. Robinson, personal communication, 1958), it is unlikely that as much as 5,000 tons was ever blocked out ahead of mining. An estimate of 40,000–50,000 long tons on Cr_2O_3 in high-chromium podiform deposits in the State (equivalent to about 100,000 tons of ore and concentrates), is based on the geologic premise that concealed deposits of this magnitude lie within reach of mining and will be found under sufficiently high price stimulus.

Except for 1948 when 2,755 long tons was shipped from the Oregon Chrome mine, chromite has been mined in Oregon only during three wartime periods. Production has not kept up with price in terms of 1954 constant dollars despite improvements in technology and access between period of mining (see figure 31). In 1918, an average price of about $58 (1954 $) induced a peak production of 18,100 long tons, compared to 6,600 tons in 1944 at about $67 per ton, and 7,900 tons in 1956 at $94 per ton. To state it another way (in 1954 $), a base price of $87 in the period 1945–1944, for lumpy ore containing 48 percent Cr_2O_3 and having a 3 :1 Cr :Fe ratio, yielded peak production of 6,600 tons whereas a base price of $113 in 1952–1957 yielded a peak of 7,900 tons; the 30 percent price increase led to only 20 percent more production. Furthermore, most of the later production was of concentrates, which are less desirable than lumpy ores. The domestic subsidized prices during World War II and the Korean War were twice to three times world market prices. No major new podiform chromite deposits have been discovered in the State since 1917, although extensions or faulted segments of known ore bodies have been found. It seems probable, nevertheless, that an increase of 30 to 40 percent in real price (constant dollars) above the 1951–1957 base would stimulate production of a few thousand tons a year for several years. Production of as much as 10,000 tons a year of chromite containing 45 percent or more Cr_2O_3 at any foreseeable price, however, should be regarded as unlikely.

Two deposits in Grant County contain 50–60 percent of the estimated resources in podiform deposits. They were explored by the U.S. Bureau of Mines (Hundhausen and others, 1956) and the U.S. Geological Survey (Thayer, 1940) in 1939–43. The average grade of the ore in the ground is about 22 percent Cr_2O_3. The highest grade of concentrates attainable by gravity methods is 33–38 percent Cr_2O_3, with a Cr :Fe ratio of 1.5 :1–1.7 :1, with recovery of 68–75 percent of the Cr_2O_3 in the ore. Flotation tests indicate that 90 percent of the Cr_2O_3 could be recovered in concentrates grading between 36 and 42 percent Cr_2O_3, with a Cr :Fe ratio of about 2 :1 (Sullivan and Stickney, 1960). The estimated tonnages of chromite might yield 75,000–80,000 tons of flotation concentrates, but the cost and grade would prevent their use when standard ores are available.

Beach sands

The production of nearly 52,000 tons of concentrates from the beach sands showed that, although they contain a substantial amount of chromite, many problems of extraction need to be solved. The reserves measured and indicated by drilling in explored deposits containing more than 3 percent Cr_2O_3 were estimated at about 180,000 long tons of Cr_2O_3 in 3,125,000 tons of sand (Griggs, 1945, p. 126). Increasing this figure by a third or thereabouts to allow for unexplored areas gives a total of 250,000 tons of Cr_2O_3, equivalent to 625,000 tons of concentrates containing 40 percent Cr_2O_3. Minability of the material by large scale open-pit methods is a major advantage. In 1943, however, only 56–58 percent of the chromite was recovered in the rougher concentrates from relatively high-grade sands; recovery of 85 percent of the Cr_2O_3 in the rougher concentrates, as achieved in 1956, would result in an over-all recovery of less than 50 percent. Until methods of treat-

ment are greatly improved, substantial production of chromite from the beach sands should not be expected, even in time of emergency. The low grade of concentrates, not more than 40 percent Cr_2O_3 and Cr:Fe ratio of 1.5:1–1.6:1. precludes competition with commercial high-iron foreign ores.

COBALT

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Cobalt is a hard, gray, magnetic metal closely related chemically to iron and nickel with certain unique properties which make it essential for some uses, and substitutes for certain other uses are either more expensive or less efficient. The more important of these uses are: in permanent magnets, in alloys and steels requiring high-temperature strength, as a binder (cemented carbides and ground-coat frit), as a catalyst (in driers, etc.), in trace amounts for animal feeding, and as radioactive cobalt (Cobalt Information Center, 1960, pp. 53–69).

The average annual United States consumption for the period 1961 to 1965 was 11,127,600 [4] pounds. The average amounts for different uses were:

Metallic:	Percent	Nonmetallic:	Percent
High-temperature alloys	24.3	Ground-coat frit	5.1
Magnet alloys	22.8	Pigments	1.9
High-speed tool steels, etc	9.4	Salts and driers [1]	11.0
Alloy hard-facing rods, etc	6.5	Other	4.7
Cemented carbides	4.1		
Other miscellaneous	10.2	Total	22.7
Total	77.3		

[1] Lacquers, varnishes, paints, inks, enamels, etc.

United States production of cobalt is far below domestic consumption. Only in 1958, when deposits in Missouri, Idaho, and Pennsylvania were in full production, did domestic output reach as high as 64.2 percent of the amount consumed. Since 1961, with Pennsylvania the only domestic producer, the amount produced within the United States has amounted to only about 4 to 5 percent of that used. Thus under present conditions the United States is almost entirely dependent upon imports. Of the free world production outside the United States, about 77 percent comes from Africa, 12 percent from Canada, and 10 percent from Germany.

About 22 ppm of cobalt is present on the average in the rocks of the earth's crust. Ultramafic rocks average between 150 and 240 ppm cobalt; mafic rocks about 50 ppm. The cobalt content of intermediate and felsic rocks becomes progressively lower, accompanying the decreased amounts of magnesium and iron. In granites it is generally below 1 ppm. Sedimentary and metamorphic rocks normally are low in cobalt, except for some special types—manganese oxide deposits (as in the nodules found offshore) and some organic deposits.

Concentrations of cobalt of economic, or possible future economic importance, occur in numerous types of deposits. The most important of these, in descending order of importance, are:

[4] Data from U.S. Bur. Mines Minerals Yearbooks.

A. Bedded deposits in sedimentary rocks, the so-called "strata-bound" deposits (Katanga and Zambia in Africa; the southeastern Missouri lead district in the United States);

B. Segregated sulfide deposits in or near mafic igneous rocks (Sudbury, Ontario; Lynn Lake, Thompson Lake, in Manitoba; Petsamo in northeastern Russia);

C. Laterites developed on ultramafic and mafic rocks under tropical conditions (Cuba, New Caledonia, Indonesia, New Guinea, the Philippines;

D. Hydrothermal veins and contact deposits associated with mafic intrusions (Bou Azzer, Morocco; Ergani, Turkey; Temiskaming, Ontario; Cornwall, Pennsylvania);

E. Other hydrothermal deposits (Erzgebirge, Germany; Outokumpo, Finland; Blackbird, Idaho).

Cobalt minerals which may be abundant enough in some deposits to have commercial value are:

	Maximum Percent Co
Cobaltite (Co,Fe)AsS	32.36
Erythrite $(Co,Ni)_3(AsO_4)_2 8H_2O$	26.28
Glaucodot (Co,Fe)AsS	31.64
Heterogenite, CoO·OH	56.63
Linnaeite series $(Co,Ni)_2(Co,Ni,Fe,Cu)S_4$	48.78
Safflorite $(Co,Fe)As_2$	18.58
Skutterudite $(Co,Ni,Fe)As_{3-x}$	20.89

Other minerals especially pyrite, pyrrhotite and pentlandite may contain small amounts of cobalt in some deposits. If large tonnages of these minerals are used in the production of other elements, considerable cobalt is produced as a by-product. Sphalerite, arsenopyrite and manganese oxide minerals in some localities contain enough cobalt so that under changing technologies they could become sources of by-product cobalt.

The cobaltiferous deposits of Oregon are limited to four geologic types: (1) Segregated sulfides in ultramafic sills; (2) Hydrothermal copper deposits in serpentine or at the contact of serpentine with greenstone; (3) Nickeliferous laterites; (4) Hydrothermal veins with gold, copper, and cobalt, near a quartz diorite intrusion.

The Shamrock mine, Jackson County, (No. 4, fig. 33) contains disseminations and some solid masses of pyrrhotite, pentlandite, and chalcopyrite in ultramafic sills that intrude schistose greenstone (Hundhausen, 1952). The ore body is broken by thrust faults. Average grade is 1.3 percent nickel, 1.1 percent copper, and 0.07 percent cobalt. Although 1,500 feet of workings in 4 adits and 3,420 feet of diamond drilling in 11 holes have been put into the deposits, figures on reserve tonnage are not available. Where similar ores are mined in Canada, the cobalt present is recovered during refining.

Four copper mines—the Queen of Bronze, the Lyttle, the Lilly, and the Waldo—in the Takilma-Waldo district, Josephine County (No. 3, fig. 33), are in greenstone close to sepentine masses. The ore bodies are irregular lenses containing pyrite, chalcopyrite, cubanite, pyrrhotite, and minor sphalerite. The Cowboy mine, in the same district, is entirely within serpentine. In addition to the above minerals, cobaltite is an accessory mineral at the Cowboy mine. Shenon (1933 b)

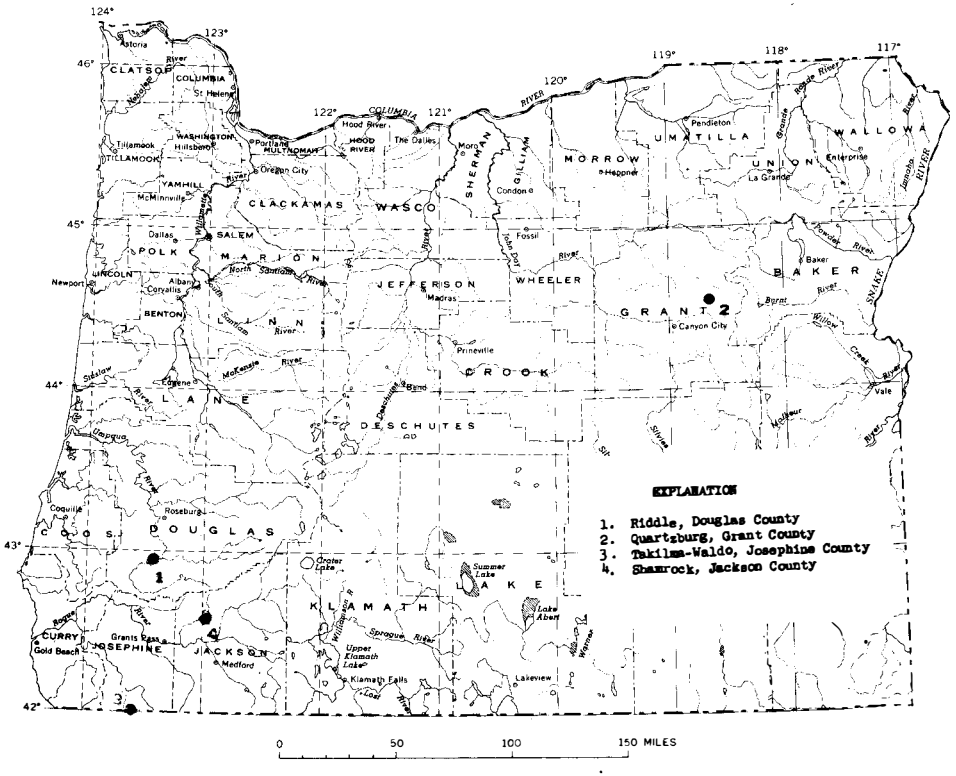

FIGURE 33.—Cobalt occurrences in Oregon.

lists an analysis of typical ore as 18.65 percent copper, 0.24 percent zinc, 0.15 percent cobalt, and 0.11 percent nickel. Because of their similar mineralogy, ore from the other mines probably carries some cobalt. Although the mines of the Takilma-Waldo district have produced copper with a total value of about $1,700,000 (Hundhausen, 1956) almost no reserves are known because of the irregular shapes of the lenses of ore.

In the Collier Creek district, Curry County (Butler and Mitchell, 1916, pp. 99–100), there are a number of copper deposits in serpentinized ultramafic intrusions. These are somewhat similar to the deposits in Takilma-Waldo district. These so-called "boulder deposits" contain magnetite, chalcopyrite(?), bornite, and chalcocite; cuprite. native copper, malachite, chrysocola, and erythrite are reported in the oxidized zone. A primary cobalt mineral has not yet been identified. The ore bodies are scattered through the serpentine with no apparent structural control. They are therefore difficult to find underground, and very little copper has been produced from them in the past.

In the Quartzburg district, Grant County (No. 2, fig. 33), cobalt has been reported at several deposits. Geochemical and geological studies in the 1950's by the author and J. W. Hosterman showed, however, that copper-cobalt-gold deposits are restricted to veins around the Standard Mine and to a pipelike deposit nearby on the Copperopolis property.

The country rocks of these deposits are metamorphosed Permian(?) volcanic rocks, intruded by a granodiorite stock a short distance northeast of the Standard mine. About 16 veins on the Standard hillside, east of Standard Creek, trend on the average N. 70° E. and dip steeply. Many of them are exposed only as gossan zones, some having in addition secondary copper minerals. Relatively few have been tested by underground work, and of these only the Standard vein has had any appreciable production—approximately 10,000 tons.

The Standard vein has been exposed intermittently over a distance of about 2,200 feet and between altitudes of about 4,525 and 5,200 feet above sea level. Widths are from a few inches up to about 5 feet. The primary ore minerals are chalcopyrite, glaucodot, and gold, with minor amounts of safflorite and cobaltite. The copper-rich and cobalt-rich parts of the vein are in separate ore shoots, and most of the gold content of the deposit occurs with the cobalt minerals. The gangue is mostly quartz with some pyrite, dolomite, calcite, and tourmaline. In many places the vein is bordered by alteration zones several feet wide consisting of fine-grained tourmaline and quartz; this is true also of some of the other veins exposed on the hillside.

Resources in the Standard mine and in the other nearby veins are unknown. If this property is to be worked successfully, all three metals—copper, cobalt, and gold—must be recovered and marketed, something which has not been possible in the past, because the copper refineries have not paid for the cobalt in the copper concentrates, and the cobalt refineries have not paid for the gold or copper. If separate concentrates of copper and cobalt-gold could be made and if all three metals were paid for, this deposit might possibly be operated successfully.

An adit on the Copperopolis property explores a pipelike mass of

quartz-tourmaline rock about 40 feet in diameter. Small amounts of chalcopyrite, pyrite, and cobaltite are scattered through the mass. Reserves are not known, but the over-all grade is probably very low.

Some of the ultramafic rocks in the Klamath Mountains province were exposed to semitropical weathering during much of Tertiary time, and deep laterization resulted. These laterites, some of which contain significant nickel and cobalt, now occur as remnants on high benches or on flat-topped uplands (fig. 42 Nickel in Oregon). An important deposit at Nickel Mountain, Douglas County, has been mined for nickel since 1954. The ore mineral is a hydrous nickel silicate, commonly referred to as garnierite. Cornwall (1966, p. 49) reports about 16 million tons assaying 1.5 percent nickel. The cobalt content is about 0.05 percent. During the production of ferronickel at the refinery, most of the cobalt is lost, as the ferronickel assays 45.94 percent nickel but only 0.5 percent cobalt (Bogert, 1960).

Other occurrences of nickeliferous laterite, mostly in Josephine and Curry Counties, contain little if any garnierite, the nickel probably being present in the iron oxides and the cobalt mostly in the manganese oxides. Cornwall (1966, table 5) estimates that these deposits contain about 30.3 million tons averaging 0.8 percent nickel. The cobalt content probably averages about 0.03 percent. Under present economic conditions, material of this grade must be considered submarginal. A fuller discussion of the lateritic nickel deposits is given on page 164.

Copper, Lead, and Zinc

(By R. G. Bowen, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Copper, zinc, and lead in that order follow iron and aluminum in tonnage and value of all metals produced. These three base metals are used extensively in many phases of modern civilization. Worldwide production of copper totaled 5½ million tons in 1965, almost double what it was in 1950. In the U.S., mine production of copper was over 1¼ million tons in 1965 and has been in excess of a million tons for several years. The total U.S. production from the earliest available records through 1965 has been almost 53 million tons.

This increase in the production and demand for copper is attributed directly to the development of electric power and expansion of the brass and bronze industry. Domestic consumption of electricity has doubled every decade during this century, and increased generation and transmission facilities are required to meet our near-future needs. Worldwide, with the industrialization programs now in progress in the hitherto underdeveloped nations, the present and projected future demands for copper can only increase.

The United States is the largest consumer of copper in the world. Since 1883, when it displaced Chile as the world leader, it has also been the largest producer. Prior to World War II domestic production exceeded domestic needs, but we now import about a quarter of our needs. Projections of industrial growth and increased population and per capita consumption suggest we will continue to rely on imports.

Most United States production comes from ores of lower grade than worked elsewhere, but by using methods such as open pit mining and

large scale underground breakage where thousands of tons of ore are mined and milled daily, unit costs are reduced to the point where U.S. ores are competitive with the rest of the world. Copper is a widely occurring metal, but only five principal producing areas contain 93 percent of the world's measured and indicated reserves. These are: (1) Chile and Peru, (2) western United States, (3) Zambia and Congo, (4) Russia, and (5) Canada. United States reserves are estimated at 86 million tons (Everett and Bennett, 1967), some 41 percent of the world's reserves.

Lead and zinc follow copper in production and consumption. Lead is particularly vital to the transportation industry where it is used in storage batteries, bearing metals, and tetraethyl gasoline. Smaller amounts are used as type metal, solder, and in the glass and chemical industry. Zinc's main use is in galvanizing, followed by die castings, photoengraving plates, and dry-cell battery cases.

The United States is the largest consumer of lead and zinc. At one time it was also the largest producer of these metals but is now the fourth largest producer of lead and the second largest producer of zinc.

Figure 34 shows the areas of copper, lead, and zinc production and significant occurrences of these elements in Oregon. Table 5 lists the districts that have had appreciable production. Areas considered significant but having little or no production are shown in table 6.

The production of copper in Oregon has been small, but its potential is probably greater than the past production of 24,000,000 pounds would indicate. By present-day standards this is small indeed when compared, for example, to the daily production of about 1,400,000 pounds from Utah Copper's West Mountain mine at Bingham Canyon, Utah. Oregon's copper production has come from vein and irregular replacement bodies along shear and fault zones, largely from one mine, the Iron Dyke, located on the Snake River near Homestead in Baker County. Next in importance and producing about half as much copper was the Queen of Bronze, located in Josephine County in the opposite corner of the State. These two mines accounted for a little over 21,000,000 of the 24,000,000 pounds of copper produced in Oregon from 1902 to 1965. Both the Iron Dyke and the Queen of Bronze were operated primarily as copper mines. The remaining 3,000,000 pounds came as ancillary to gold and silver mining.

Oregon's recorded production of lead and zinc has been small; only 1,320,000 pounds of lead and 380,000 pounds of zinc. These production figures represent the lead and zinc reported by the smelters. They are only a minimal figure as most of the Oregon ore has gone to the A.S. & R. smelter in Tacoma which is primarily a copper smelter and does not report zinc. Consequently, there was no recorded zinc production unless the ore was shipped to a zinc smelter.

Complex sulfide ores containing significant percentages of lead, zinc, and smaller amounts of copper are found in the Cascade Mountains of Oregon in addition to the other mining areas in northeastern and southwestern Oregon. The bulk of the lead and zinc production has come from the Bohemia district where it occurs in quartz-bearing veins and shear zones where diorite and quartz diorite intrusives have invaded the Tertiary lavas and pyroclastic rocks.

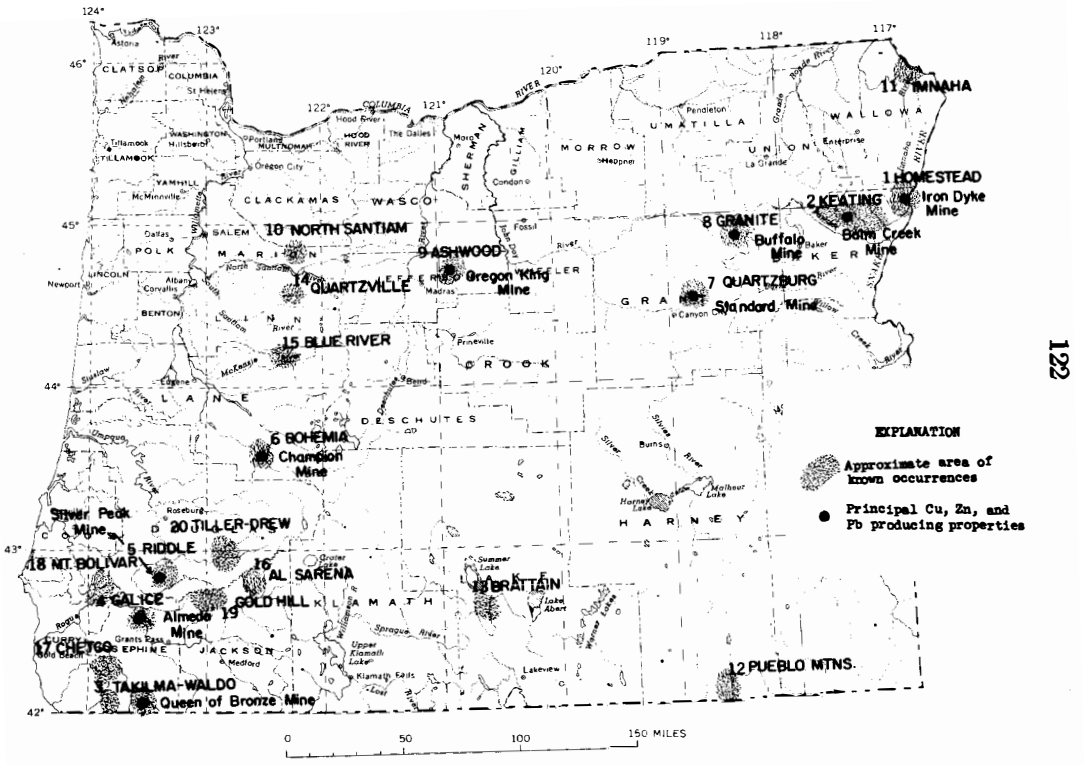

FIGURE 34—Copper, lead, and zinc in Oregon.

TABLE 5.—PRINCIPAL COPPER, LEAD, AND ZINC PRODUCING AREAS IN OREGON

County, district, and index No. on Fig. 34	Production in pounds			Principal mine and generalized description of ore occurrence in district[1]	References
	Copper	Lead	Zinc		
Baker:					
Homestead (1)	14,417,920			Iron Dyke mine. Massive pyrite and chalcopyrite in shear zones in Permian(?) chloritized lava flows.	Lindgren, 1901; Swartley, 1914; Parks and Swartley, 1916; Oregon Dept. Geology and Min. Ind. Bull. 14–A, 1939.
Keating (2)	1,047,000			Balm Creek Mining Co. Pyrite and chalcopyrite impregnate and replace Permian and Triassic greenstones along shear zones and fractures. Secondary minerals include copper oxides, minor native copper, chalcocite and bornite.	Lindgren, 1901; Gilluly, 1933a.
Josephine:					
Waldo-Takilma (3)	6,882,274	72,295		Queen of Bronze mine. Copper sulfides in irregular deposit associated with greenstone-serpentine contacts.	Diller, 1914; Shenon, 1933b.
Galice (4)	259,800	71,200		Almeda mine. Massive copper sulfide replacement and fissure fillings. Associated with dacite sills near greenstone-slate contact. Also podiform barite and complex sulfide masses near greenstone and metasediment contacts with associated porphyritic dikes.	Diller, 1914; Shenon, 1933a; Libbey, 1967.
Douglas: Riddle (5)	[2] 593,000			Silver Peak mine. Massive and disseminated sulfides in schist associated with shears along the contact between metavolcanics and metasediments.	Shenon, 1933a
Lane: Bohemia (6)	393,059	605,883	237,200	Champion mine. Quartz and complex sulfides with gold and tourmaline as cavity fillings and replacements in shear zones and breccia associated with Tertiary intrusives in lower Tertiary volcanics.	Callaghan and Buddington, 1938; Taber 1949
Grant:					
Quartzburg (7)	328,614			Standard mine. Quartz veins in Permian(?) altered volcanic rocks brecciated and intruded by Cretaceous(?) granodiorite.	Gilluly, Reed and Park, 1933; Vhay, 1960
Granite (8)	[2] 50,000	260,071	[2] 43,000	Buffalo mine. Quartz and calcite veins with pyrite, chalcopyrite, sphalerite and galena in Permian(?) metamorphosed shales near contact with Jurassic and Cretaceous granodiorite.	Koch, 1959; Pardee, 1941
Jefferson: Ashwood (9)	59,000	110,000		Oregon King mine. Quartz and various sulfides including cinnabar occur in breccia zone in sheared Tertiary volcanics and sediments.	Libbey and Corcoran, 1962
Marion: North Santiam (10)	41,172	40,700	100,063	Amalgamated and Ruth mines. Quartz veins with complex sulfides in Tertiary andesite adjacent to diorite intrusives.	Callaghan and Buddington, 1938

[1] Main producing property named but smaller amounts were produced by other mines in the district.

[2] Estimated.

TABLE 6.—AREAS OF SIGNIFICANT BASE METAL OCCURRENCES WITH LITTLE OR NO PRODUCTION

County, district, and index No. on Fig. 34	Type of occurrence	Reference
EASTERN OREGON		
Wallowa County: Imnaha (11)	Fissure fillings of hematite and chalcopyrite in granodiorite.	Libbey, 1943.
Malheur County: Pueblo Mountains (12).	Siliceous "reefs" up to 25 feet wide in Tertiary and pre-Tertiary volcanic rocks contain small amounts of chalcopyrite, schwatzite, and cinnabar.	Williams and Compton, 1953.
Lake County: Brattain (13)	Replacement and cavity fillings with chalcopyrite, galena, and sphalerite in Tertiary volcanics.	Oregon Dept. Geology and Mineral Industries files.
CASCADE MOUNTAINS		
Linn County:		
Quartzville (14)	Quartz veins carrying complex sulfides in Tertiary andesite adjacent to diorite intrusives.	Callaghan and Buddington, 1938.
Blue River(15)	Complex sulfides in breccia zones in Tertiary volcanics adjacent to diorite intrusives.	Callaghan and Buddington, 1938.
SOUTHWESTERN OREGON		
Jackson County: Al Sarena (Buzzard) (16)	Altered and bleached volcanic rocks containing veins of complex sulfides, little quartz.	Callaghan and Buddington, 1938.
Curry County: Chetco (17)	Podiform sulfides at the contact between greenstone and serpentine.	Parks and Swartley, 1916.
Coos County: Mount Bolivar, (Thompson mine) (18).	Mineralized shears along a major serpentinized fault zone between sediments and metavolcanics.	Parks and Swartley, 1916
Jackson County: Gold Hill (19)	Gold-bearing quartz veins in metasediments and metavolcanics associated with diorite intrusives.	Parks and Swartley, 1916
Douglas County: Tiller-Drew (20)	Quartz veins and shear zones in metavolcanics and metasediments adjacent to dioritic intrusives.	Parks and Swartley, 1916 Shenon, 1933a.

The Iron Dyke deposit (No. 1, fig. 34) is in Permian greenstones. Mineralization is associated with a broad shear zone in which the rocks have been brecciated, hydrothermally altered, and locally silicified. The ore minerals, consisting mainly of pyrite and chalcopyrite with very little quartz as gangue, occur as tabular replacement bodies up to 6 feet thick along shear planes and as stringers and small irregular masses disseminated through the intervening country rock. The ore zone in the lower levels of the mine was about 140 feet wide and 210 feet long. The mine operated almost continuously from 1915 to 1928. The 239,075 tons of ore produced averaged 3 percent copper, 0.14 ounces gold, and 1.07 ounces silver per ton.

The Queen of Bronze mine (No. 3, fig. 34) is in Triassic greenstones near serpentine contacts. The ore occurs in shear zones in the greenstone that are filled with quartz and sulfides. The main period of activity at this mine was from 1903 to 1910 when about 20,000 tons of ore averaging 8½ percent copper was mined. Later lessees shipped about 15,000 tons of ore. The mine closed in 1930.

Other properties that shipped more than 100,000 pounds of copper are: the Balm Creek mines in the Keating district of Baker County (No. 2, fig. 34), Silver Peak mines in Douglas County (No. 5), the Champion mine in the Bohemia district of Lane County (No. 6), the Standard mine of the Quartzburg district of Grant County (No. 7), and the Almeda mine in the Galice district of Josephine County (No. 4). Table 5 describes these properties as well as the other principal producers of base metals in the State.

Oregon has the potential to produce a larger amount of base metals. Most of the known copper, lead, and zinc in Oregon was found during

the search for gold between the years 1850 and 1900. At that time there was little interest in base metals unless the deposits were extremely rich. Those found were vein type deposits and only with the low-cost labor at that time could they be profitably worked by underground mining. Current base metal exploration targets tend to be large areas of disseminated mineralization suitable for mechanized mining, where the large tonnages handled make it possible to mine lower grade ore than is acceptable in vein or podiform type deposits. These disseminated deposits have been found in other areas by diligent search using exploration techniques that will uncover hidden mineralization. Such exploration generally starts from areas of known mineralization which may or may not have been productive in the past.

The geologic literature of Oregon describes numerous localities where relatively large areas of sulfide dissemination have been reported (fig. 34). At the time of the reporting the metal values probably were too low for exploration by methods then in use, but using today's techniques of exploration and mining a new look should be taken at many of these properties; under existing conditions some of these may present attractive opportunities for exploration. Examples of properties where potential disseminated deposits have been reported by competent geologists are: the Quartzburg district of Grant County, where Gilluly, Reed, and Park (1933) report a replacement body of quartz, tourmaline, and chalcopyrite which extends along a fracture zone over a distance of about 1,000 feet long by 75 feet wide on the Copperopolis property. Reports by Lindgren (1901) and Gilluly (1933a) on the Keating district of Baker County describe "widespread" copper prospects in the Triassic greenstone in the foothill belt of the Wallowa Mountains from North Powder to Homestead, a distance of about 55 miles. Lindgren (1901, p. 630) describes an ore body of disseminated chalcocite and native copper in altered basalt at the Cooper Union (Burkemont) property. Libbey's (1967) report on the Almeda mine in Josephine County summarize several earlier reports that point out the likelihood of a good sized body of base metals that may be of sufficient grade to be worked by today's methods. Shenon (1933a) points out the possibility of sulfide mineralization in the Silver Peak area in Douglas County.

In summary, base metal mining in Oregon has been dormant for many years and the total production of these metals from the State has been small. In spite of this there are areas in the State where application of modern methods of prospecting and exploration could result in the discovery of base metal deposits, particularly copper, that can be mined profitably under present day conditions. Recent interest shown by several exploration companies in base metal deposits in Oregon is an encouraging sign.

Gold and Silver

(By H. C. Brooks, Oregon Department of Geology and Mineral Industries, Baker, Oreg., and Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg.)

Gold and silver have been prized among men and nations since earliest times. These metals are universally accepted standards of wealth and prosperity and for centuries have been used in world monetary systems. Because of their beauty, workability, resistance to corrosion,

and their scarcity, gold and silver are widely used in the decorative arts. Gold has limited but important and expanding uses in industry, dentistry, medicine, and scientific research. Silver finds its most extensive use in photography but has other important industrial uses. Gold and silver are discussed together in this report because nearly all the silver produced in Oregon has been a by-product of gold mining.

The search for gold and silver has been a major factor in the advancement of civilization in several parts of the world, including the United States. The American gold rush which began in 1849 greatly accelerated settlement of the western States, including Oregon, and the gold mining industry was an important element in the developing economy of many areas. During the latter half of the 1800's, the United States led the world in gold output and for many years thereafter was second only to the Union of South Africa. It now ranks a poor fourth in world production. Since World War II, the domestic gold mining industry has been caught in a squeeze between increasing costs of production on the one hand and a fixed price of $35.00 per ounce for gold on the other. United States mine output dwindled from 4.9 million ounces from 5,393 lode mines and 4,176 placer mines in 1940 to 1.5 million ounces from a total of 355 mines in 1964, the lowest peacetime output in 100 years. Production increased slightly to 1.7 million ounces in 1965 and 1.8 million ounces in 1966 due to new production from the Carlin gold mine in Nevada.

For several years gold consumption by arts and industry in the United States has far exceeded domestic output. Consumption steadily increased from 1.05 million ounces in 1940 to an all-time high of 6.9 million ounces in 1966. This growing supply-demand deficit is balanced by withdrawals from gold stocks of the U.S. Treasury. While United States production has dwindled, world output has steadily increased. Average world production in 1955–59 was 33 million ounces. The 1966 output was 48.1 million ounces. Most of the increase has come from South African mines, which more than doubled production since 1954.

Silver production in the United States also lags far behind consumption. Mine output ranged from 35 million ounces in 1961 to 43.7 million in 1966. During the same period, net industrial consumption increased steadily from 105 million to 150 million ounces. Requirements of the photographic industry alone are nearly equal to the United States production. In recent years, industrial drain on silver stocks of the U.S. Treasury has resulted in legislative action which drastically reduced the amount of silver used in coins, and the treasury policy of selling silver at the monetary value of $1.29 per ounce has been terminated.

The total output of gold and silver from Oregon is not known precisely because statistics for the period 1850–1863 are not available and for succeeding years to 1880 are estimates based on incomplete records. Figures presented in the U.S. Bureau of Mines Minerals Yearbooks place Oregon gold production through 1966 at 5,796,767 troy ounces, which is about 1.8 percent of total United States gold production. Estimates of early-day output for eastern Oregon by Lindgren (1901, p. 571) and for southwestern Oregon by Pardee (1930) and Libbey (1963) suggest a considerably higher figure. Distribution of lode and placer gold and silver production by counties since 1902 is given in table 7. Statistics were not separately reported prior to 1902, but it is

TABLE 7.—OREGON GOLD AND SILVER PRODUCTION BY COUNTIES, 1902-1965, IN FINE TROY OUNCES

County	Gold			Silver		
	Lode	Placer	Total	Lode	Placer	Total
Baker	835,226	423,753	1,258,979	2,172,145	93,568	2,265,713
Grant	98,817	250,787	349,604	937,908	37,573	975,481
Josephine	88,140	162,390	250,530	94,950	20,703	115,653
Jackson	41,232	162,790	204,022	29,672	22,538	52,210
Lane			34,624			71,820
Malheur			31,827			13,669
Other			56,192			[1] 356,858
Total	[2] 1,108,957	[2] 1,076,821	2,185,778	[2] 3,670,646	[2] 180,758	3,851,404

[1] Mostly from the Oregon King mine in Jefferson County.
[2] State total; includes production from Lane, Malheur, and "other" counties.

Source: U.S. Bureau of Mines statistics.

estimated that about 40 percent of the total gold production came from lode gold mines. The remainder was mainly from placers. Oregon silver production has been about 5,463,000 ounces, most of it as a by-product of lode gold mining. By-product output of gold and silver from base-metal mines has been very small (about 50,000 ounces gold and 300,000 ounces silver), mostly from copper deposits in the Homestead and Keating districts in Baker County and the Takilma-Waldo district in Josephine County.

HISTORY OF GOLD AND SILVER MINING IN OREGON

The history of gold and silver mining in Oregon and the geology of the gold and silver deposits have been discussed by Brooks and Ramp (1968). C. A. Spreen has discussed the early history of placer mining in the State.[5] The first recorded gold mining in the State was in the summer of 1850 at the confluence of what is now Josephine Creek and the Illinois River in Josephine County, but Oregon's gold rush really began in December 1851 with the discovery of rich placers near the present site of Jacksonville in Jackson County. In the fall of 1861 gold was discovered in northeastern Oregon near what is now Baker in Baker County. The virgin placers were locally very rich, and the first few years after discovery mark the high point of gold production in Oregon. According to Browne and Taylor (1867, p. 9), output in 1865 may have been as high as $20 million. Due to the great influx of miners, the cream of the placers was skimmed off within a few years, and production declined to less than a million dollars annually during 1882–1888. Lode mining developed rapidly in the 1890's and from then until 1921 was the chief source of Oregon gold and silver, although production fluctuated markedly (fig. 35). A steam-powered bucket-line dredge was built on the Right Fork of Foots Creek in Jackson County in 1903. It was converted to electric power in 1905, the power being obtained from Gold Ray dam near Gold Hill. Dredging began in Sumpter Valley in Baker County in 1913 and at John Day in Grant County in 1916. The success of these operations stimulated use of mechanized equipment for placer mining in other areas. As a result, between 1921 and 1954 placer output exceeded that of lode mines.

[5] Spreen, Christian, August 1939. A history of placer gold mining in Oregon, 1850–1870: University of Oregon thesis, unpublished.

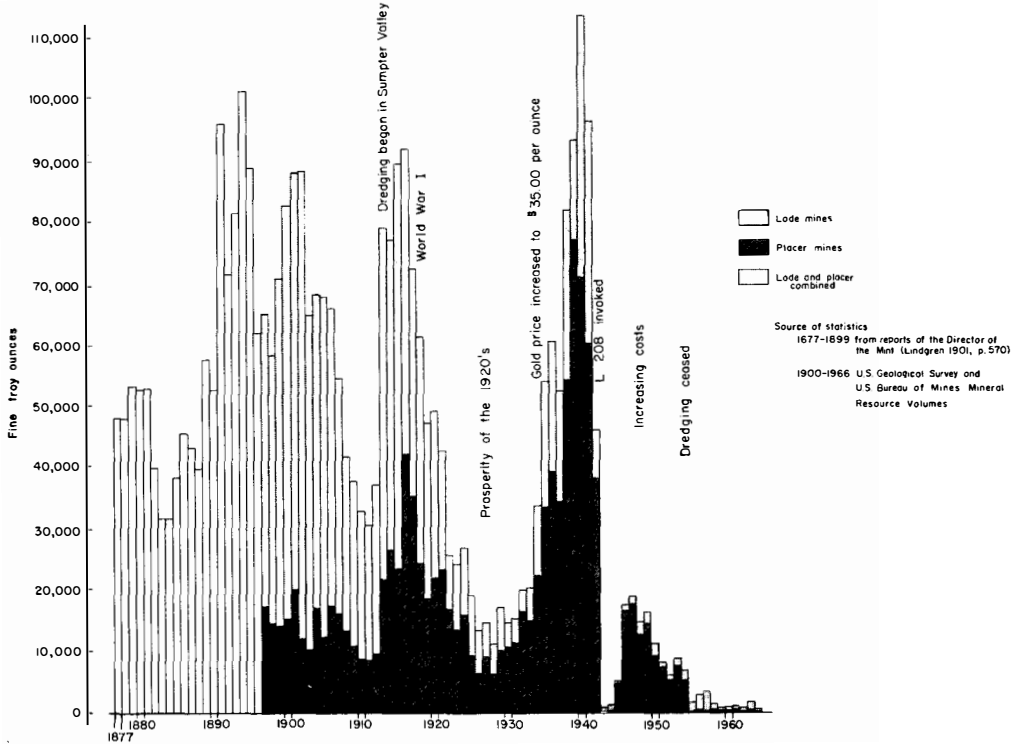

FIGURE 35.—Trends in Oregon gold output, 1877–1964, and by various mining methods, 1897–1964. (In fine troy ounces)

Inflation of costs during World War I and the 1920's caused a sharp decline in production. The trend was reversed by the great depression of the early 1930's. Then when the price of gold was increased from $20.67 to $35.00 per ounce in 1934, production expanded rapidly (fig. 35). Output for the seven years, 1935–1941, averaged about $3 million per year. The 1940 production was valued at $4,124,883, the highest figure since the heyday of placer mining in the 1860's. Output amounted to 41.825 ounces gold and 206,317 ounces silver from 112 lode mines and 71,577 ounces gold and 12,795 ounces silver from 192 placer mines. Of the latter, 29 used floating dredges and 29 used nonfloating mechanized washing plants.

With the curtailment of gold mining caused by War Production Board Order L–208 in 1942, Oregon gold and silver production virtually ceased, and few mines were successfully reactivated after the order was rescinded in 1945. Production reached its postwar high in 1947 of 18,979 ounces gold and 30,379 ounces silver valued at $691,000, only 17 percent of the 1940 output. Ninety-three percent of this came from placer mines, mainly dredge operations. Since 1947, production has followed a generally diminishing trend and in 1966 totaled 281 ounces gold and 343 ounces silver from scattered intermittently operated placer mines. Of the 24,081 ounces of gold produced by lode mines during 1945–1966, more than 60 percent came from the Buffalo mine in the Granite district in Grant County. Production from this mine has been very small since 1958. Dredging in the State ceased with the closure of the Sumpter Valley dredge in 1954.

GOLD AND SILVER DEPOSITS IN OREGON

Gold and silver usually are associated in nature, though typically there are wide variations in the relative amounts of the two metals present in different localities. Gold occurs chiefly as the native metal. In ores it is commonly in particles too small to be seen with the unaided eye. Silver is always alloyed with the gold, and in many primary deposits silver sulfides or their oxidation products are also present. Gold and silver tellurides have been found in a very few deposits in Oregon.

Oregon's gold and silver deposits are concentrated in two widely separated areas: the eastern Blue Mountains in the northeastern part of the State and the Klamath Mountains in the southwestern part (fig. 36). Mines in the Blue Mountains, mostly in Baker and Grant Counties, have contributed about 70 percent of the gold and 74 percent of the silver produced in Oregon since 1880. Deposits in the Klamath Mountains, chiefly in Jackson and Josephine Counties, account for most of the remainder. Small amounts of gold and silver have been recovered from districts in the western Cascades and from scattered occurrences elsewhere, mainly in the central and southeastern parts of the State.

Production data and salient geologic features of the lode gold and silver bearing areas and some of the mines are summarized in table 8. Because production records are incomplete, the figures given can only be considered as crude approximations. Early-day placer production data are too incomplete to permit tabulation by district or county; available figures and estimates are presented in the column entitled "Remarks." This information has been abstracted from a treatise on gold and silver in Oregon by Brooks and Ramp (1968).

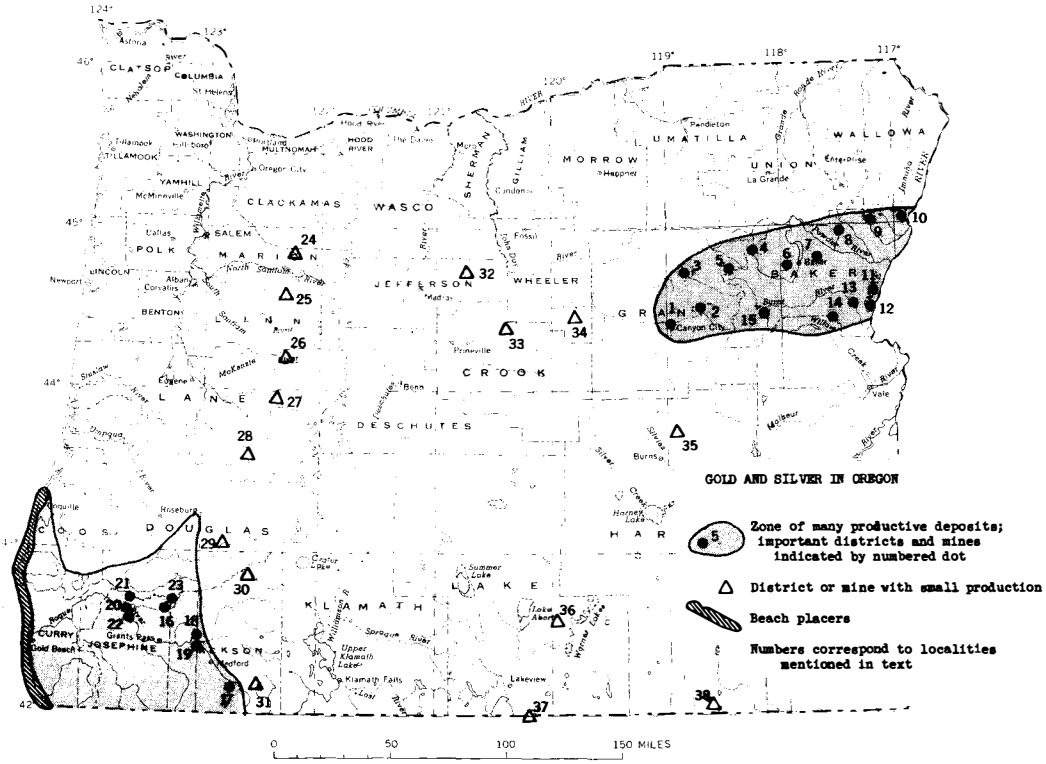

FIGURE 36.—Gold and silver in Oregon.

TABLE 8.—SUMMARY OF LODE GOLD AND SILVER DISTRICTS AND SELECTED MINES IN OREGON

Index No. on fig. 36, district or mine, county	Manner of occurrence	Remarks	Lode production	References
EASTERN BLUE MOUNTAINS				
1. Canyon district, Grant County	Small quartz veins with hematite and calcite in gabbro, ultramafic rocks, greenstone, meta-argillite, and graywacke.	Large production from placers along Canyon Creek and adjacent gulches and hillsides. Early output may have been as much as $15 million. Dredges later produced minimum of 120,000 ounces gold and 13,000 ounces silver.	Records scarce. Probably 5,000–20,000 ounces gold. Low silver content.	Lindgren, 1901, p. 712–720; Swartley, 1914, p. 200–209; Parks and Swartley, 1916; Oregon Dept. Geology and Mineral Industries, 1941 ,p. 17–39.
2. Quartzburg district, Grant County.	Quartz veins and sulfide replacement bodies mainly in altered andesitic and basaltic lavas, breccias, and tuffs. Gold, copper, and cobalt have been produced.	Placer mining on Dixie Creek began in 1862. Lower part of the creek has been dredged. Total placer output probably between 50,000 and 100,000 ounces gold. Chief lode mines are the Dixie Meadows, Equity, Present Need, Cougar, and Standard.	Records scarce. Probably 10,000–20,000 ounces gold. Low silver content.	Lindgren, 1901, p. 708–712; Swartley 1914, p. 194–199; Parks and Swartley, 1916; Gilluly, Reed and Park, 1933, p. 85–105; Oregon Dept. Geology and Mineral Industries, 1941 p. 108–128.
3. Susanville district, Grant County.	Quartz veins and replacement masses in schist, slate, quartzite, greenstone, and serpentinized peridotite and gabbro. Some veins related to aplite dikes associated with the Greenhorn batholith.	Elk Creek and nearby placers were discovered in 1864. By 1914 had produced about $600,000 in gold. Later dredge operations on Middle Fork of John Day River near Galena produced more than 15,000 ounces gold and 2,800 ounces silver. Tne most productive lode mine is tne Badger.	15,000–30,000 ounces gold	Lindgren, 1901, p. 705–708; Swartley, 1914, p. 168; Parks and Swartley, 1916; Gilluly, Reed, and Park, 1933, p. 105–117; Oregon Dept. Geology and Mineral Industries, 1941, p. 129–148.
4. Cracker Creek, Sumpter, Rock Creek, Cable Cove, and Granite districts, Baker and Grant Counties.	Quartz veins and lodes in argillite and granodiorite along edge of Bald Mountain batholith.	At least 25 lode mines and prospects have been productive. Largest producers were the Nortn Pole-Columbia Lode in the Cracker Creek district, the Baisley-Elkhorn and Highland-Maxwell in the Rock Creek district, and the Buffalo, Cougar, and La Belleview in the Granite district. Placer production probably exceeds 550,000 ounces gold. Dredging in Sumpter Valley during 1913–1942 and 1945–1954 produced more than 325,000 ounces gold and 80,000 ounces silver. Dredging in Granite also yielded large amounts of gold.	Incomplete records. Combined production from Nos. 4 and 5 probably about 650,000 ounces gold and more than 1,500,000 ounces silver.	Lindgren, 1901; Pardee, 1909; Pardee and Hewett, 1914; Swartley, 1914; Parks and Swartley, 1916; Hewett, 1931; Lorain, 1938; Oregon Dept. Geology and Mineral Industries, 1939, 1941; Koch, 1959.

TABLE 8.—SUMMARY OF LODE GOLD AND SILVER DISTRICTS AND SELECTED MINES IN OREGON—Continued

Index No. on fig. 36, district or mine, county	Manner of occurrence	Remarks	Lode production	References
5. Greenhorn district, Baker and Grant Counties.	Quartz veins in argillite, granodiorite, greenstone, and altered mafic to ultramafic intrusive rocks. Deposits occur near the borders of the Greenhorn batholith. Many veins associated with porphyritic granitic dikes.	Bulk of lode mine output has come from the Bonanza, Red Boy, and Ben Harrison mines, although there are many smaller mines and prospects. Output from placers isunknown but probably exceeds 100,000 ounces gold. Parts of Whitney Valley and Middle Fork of John Day River have been dredged.	Incomplete records. See No 4	Lindgren, 1901, p. 692–704; Pardee and Hewett, 1914, p. 114; Swartley. 1914, p. 166; Parks and Swartley, 1916; Lorain, 1938, p. 15; Hewett, 1931; Oregon Dept. Geology and Mineral Industries, 1939, p. 52; 1941, p. 66.
6. Southeastern Elkhorn Ridge, Pocahontas, Auburn, and Minersville districts, Baker County.	Small, discontinuous quartz veins and mineralized fault zones in argillite, greenstone, limestone, and altered gabbro.	Initial discoveries of gold in northeastern Oregon were made here in 1861. Nearly every creek and gulch in the area have been placered extensively. Some are said to have been "enormously" rich. Lode output mainly from rich pockets of free gold.	Records not available. Probably exceeds 10,000 ounces gold.	Lindgren, 1901, p. 649–654; Grant and Cady, 1914, p. 145–150; Swartley, 1914, p. 162–163; Gilluly, Reed, and Park, 1933, p. 80–85; Gilluly, 1937, p. 101–105; Oregon Dept. Geology and Mineral Industries, 1939, p. 14–17.
7. Virtue district, Baker County	Quartz veins along the periphery of small intrusions of diorite into argillite, greenstone, and gabbro.	Principal mine was the Virtue. Other productive mines include the White Swan and Flagstaff. Minor gulch placers.	150,000–175,000 ounces gold. Low silver content.	Lindgren, 1901, p. 721–726; Grant and Cady, 1914, p. 150–155; Swartley, 1914, p. 129–131; Gilluly, Reed, and Park, 1933, p. 71–79; Gilluly, 1937, p. 93–101; Oregon Dept. Geology and Mineral Industries, 1939, p. 102–110.
8. Eagle Creek, Sanger, Sparta, and Keating districts, Baker County.	Gold quartz veins in sandstones, shales, and greenstones in Eagle Creek and Sanger districts and in albite granite, diorite, and gabbro in Sparta district. Copper-and gold-bearing veins and replacement bodies along shear zones in greenstone in Keating district. Deposits probably related to Wallowa batholith.	Lode production dominated by Sanger mine. Small output from Mother Lode copper mine, Basin, Gem, East Eagle, and others. Sanger placers produced $500,000 prior to 1901. Sparta and Eagle Creek placers said to have been very rich locally.	95,000–130,000 ounces gold	Lindgren, 1901, p. 733–740; Swartley, 1914, p. 116–127; Gilluly, Reed, and Park, 1933, p. 57–68.
9. Cornucopia district, Baker County	Quartz veins mainly in granitic rocks of the Cornucopia Stock.	Production almost entirely from Union-Companion and Last Chance veins, 2,500 feet apart and roughly parallel. Many small veins in the district.	Minimum of $10 million in gold and silver. Recorded output 1903–1941 totals 272,777 ounces gold, 1,088,051 ounces silver.	Lindgren, 1901, p. 740–745; Swartley, 1914, p. 22–65; Lorain, 1938, p. 37–40; Goodspeed, 1939; Oregon Dept. Geology and Mineral Industries, 1939, p. 24–33.
10. Iron Dyke mine, Baker County	Copper replacement deposits with associated gold and silver in broad shear zone in greenstones. Sulfides chiefly chalcopyrite and pyrite.	Main period of activity 1915–1928	35,000 ounces gold, 256,500 ounces silver, and 14,418,000 pounds of copper.	Lindgren, 1901, p. 749–751; Swartley, 1914, p. 107–109; Oregon Dept. Geology and Mineral Industries, 1939. p. 60–62.
11. Connor Creek district, Baker County.	Quartz veins and irregular quartz-impregnated fracture zones in slate, phyllite, and metavolcanic rocks.	Lode production almost entirely from Connor Creek mine. Connor Creek produced about $125,000 in placer gold	Minimum of 67,000 ounces gold about 900 fine.	Lindgren, 1901, p. 756–762; Swartley, 1914, p. 213–217; Parks and Swartley, 1916; Gilluly, Reed, and Park, 1933,

		prior to 1914 and has been intermittently active since.		p. 49–54; Oregon Dept. Geology and Mineral Industries, 1939, p. 21–24.
12. Bay Horse mine, Baker County	Silver-bearing tennantite impregnates fault zone in metavolcanic rocks.	Silver deposit. Ore contains practically no gold.	125,459 ounces silver during 1920–1925.	Lindgren. 1901, p. 753; Livingston, 1923; Gilluly, Reed, and Park. 1933. p. 52.
13. Weatherby district, Baker County.	Small, discontinuous quartz veins, mainly in granodiorite.	Several small lode mines. Largest producer was Gold Ridge mine. Placers on Burnt River, Chicken Creek, and various tributaries.	Records scarce. Probably 5,000–10,000 ounces.	Lindgren, 1901, p. 762–767; Swartley, 1914, p. 217–218; Parks and Swartley, 1916; Gilluly, Reed, and Park, 1933, p. 54–57; Oregon Dept. Geology and Mineral Industries 1939, p. 64–74.
14. Mormon Basin district, Baker County.	Quartz veins in slate, phyllite, and metamorphosed igneous rocks. Some veins associated with dikes related to Pedro Mountain Stock.	Principal lode mine is Rainbow. Smaller producers include Humboldt and Sunday Hill. Reputedly large output in early days from extensive gulch and bench placers in Mormon Basin and adjacent Malheur City, Rye Valley, and Clarks Creek areas. Parts of Clarks Creek and Burnt River have been dredged.	125,000-135,000 ounces gold and 75,000–150,000 ounces silver.	Lindgren, 1901, p. 770–773; Swartley, 1914, p. 218–229; Parks and Swartley, 1916; Gilluly, Reed, and Park, 1933, p. 31–49; Oregon Dept. Geology and Mineral Industries, 1939, p. 74 84.
15. Unity (Bull Run) district, Baker County.	Quartz veins and mineralized felsite porphyry and amphibolite dikes. Molybdenite present along with pyrite and chalcopyrite. Country rocks are diorite, serpentinite, and schist.	Record, Orion, and Bull Run lode mines produced small amounts of gold. Parts of Bull Run Creek have been dredged.	5,000–10,000 ounces gold. Silver values small.	Lorain, 1938, p. 40-43; Oregon Dept. Geology and Mineral Industries, 1939, p. 98, 101.
		KLAMATH MOUNTAINS		
16. Greenback mine, Josephine County.	Gold and pyrite in 20-inch, west-striking quartz fissure vein in greenstone.	Faults cut off vein at limits of ore body. Mined to 1,000 feet depth.	About $3½ million between 1897 and 1940.	Diller, 1914, p. 31–34; Winchell, 1914, p. 186–188; Parks and Swartley, 1916, p. 112–114; Oregon Dept. Geology and Mineral Industries, 1952, p. 104–106; Libbey, 1963.
17. Ashland mine, Jackson County.	Gold, pyrite, chalcopyrite in quartz vein in Applegate Group metasediments and diorite.	Vein had two principal ore shoots. Mined to 1,200 feet depth. Workings total about 11,000 feet.	$1.3 million mined from 1886 to 1902 and 1933 to 1940.	Winchell, 1914, p. 114–117; Parks and Swartley, 1916, p. 16; Oregon Dept. Geology and Mineral Industries, 1943, p. 23–26; Libbey, 1963.
18. Sylvanite mine, Jackson County.	Rich ore shoot at intersection of quartz-calcite fissure vein and shear zone in argillite. Ore minerals are galena, chalcopyrite, pyrite, and gold.	Winze in shoot produced $1,000 per lineal foot in 600-foot depth. Some scheelite in vein.	$700,000 produced from rich ore shoot between 1928 and 1939.	Winchell, 1914, p. 166; Parks and Swartley, 1916, p. 219–220; Oregon Dept. Geology and Mineral Industries, 1943, p. 111–112; Libbey, 1963.
19. Gold Hill mine, Jackson County.	Crystallized quartz loaded with gold was found at surface in fissure vein cut by gash vein. Country rock is amphibolite with pegmatite dike on footwall. Rich gold bottomed at 15 feet depth. Molybdenite occurs deeper.	Discovered in 1857, outcropping ore was so full of gold that it "could scarcely be broken by sledging."	$700,000.	Winchell, 1914, p. 167; Oregon Dept. of Geology and Mineral Industries, 1953, p. 70–71; Libbey, 1963.

TABLE 8.—SUMMARY OF LODE GOLD AND SILVER DISTRICTS AND SELECTED MINES IN OREGON—Continued

Index No. on fig. 36, district or mine, county	Manner of occurrence	Remarks	Lode production	References
20. Benton mine, Josephine County	Multiple quartz fissure veins in quartz diorite or granodiorite containing pyrite form ore bodies 2½ to 20 feet thick.	Discovered in 1893. Benton vein developed for 2,000 feet along strike and to 600 feet depth.	Main period of operation from 1935 to 1942 produced $549,414.	Winchell, 1914, p. 193–194; Youngberg 1947, p. 31–33; Libbey, 1963.
21. Gold Bugmine, Josephine County	Quartz, free gold, pyrite, and chalcopyrite occur in a mineralized shear zone in greenstone.	Most of the mining was done before 1913.	About $750,000	Diller, 1914, p. 52–53; Winchell, 1914, p. 195–197; Youngberg, 1947, p. 17–18.
22. Almeda mine, Josephine County	Broad, altered, mineralized zone associated with dacite dike at contact of altered volcanics and slate. Disseminated pyrite, chalcopyrite, barite replacement, minor galena, and sphalerite.	Discovered 1874; sometimes called Big Yank Lode. Major mining activity was from 1905 to 1911.	$123,000, largely from matte smelted at the mine.	Diller, 1914, p. 72–81; Winchell, 1914, p. 207–214; Shenon, 1933a, p. 24–35; Libbey, 1967.
23. Forget-Me-Not, Douglas County	300-foot wide mineralized zone in greenstone bounded by serpentine zone in silicified rock with some pyrite, minor chalcopyrite, and gold.	Richer areas in altered zone have been worked to a limited extent.	$1,300 milled from 400 pounds of high grade.	Oregon Dept. of Geology and Mineral Industries, mine file report, 1945.
		WESTERN CASCADES		
24. North Santiam district, Clackamas and Marion Counties.	Andesite and rhyolite lavas with subordinate interbedded tuffs are intruded by small dacite and diorite bodies. Veins strike northwest and dip steeply. Carbonate gangue minerals common. Chalcopyrite, sphalerite, pyrite, galena, and gold are the metallic minerals.	Discovered in 1896. Most properties were located by 1903. An areal temperature zoning is apparent. Veins scattered; ore bodies small.	From 1896 to 1947: gold 454 ounces; silver 1,412 ounces; copper 41,172 pounds; lead 40,700 pounds; zinc 110,063 pounds.	Parks and Swartley, 1916; Callaghan and Buddington, 1938; Oregon Dept. Geology and Mineral Industries, 1951, p. 113–132.
25. Quartzville district, Linn County	Lavas and tuffs intruded by scattered dikes and plugs of dacite. Veins strike northwest, dip steeply, carry mixed sulfides; pyrite and sphalerite most common. Gold concentrated in oxidized zone.	Discovered 1863; 24 properties described. Lawler mine largest producer.	Production mainly before 1896. Gold 8,557 ounces; silver 2,920 ounces. Lawler produced about $100,000.	Parks and Swartley, 1916; Callaghan and Buddington, 1938; Oregon Dept. Geology and Mineral Industries, 1951, p. 96–109.

26. Blue River district, Linn and Lane Counties.	Like Quartzville district, andesitic lavas, some rhyolites and tuffs intruded by dioritic dikes and plugs. Veins strike northwest. Quartz is the dominant gangue mineral and occurs with pyrite, sphalerite, galena, and chalcopyrite.	Principal mine is the Lucky Boy discovered 1887. Production from oxidized portion of veins.	About $200,000 mostly from Lucky Boy mine. Largely gold and silver, some copper and lead.	Do.
27. Fall Creek district, Lane County	Tuffs with some andesitic lavas intruded by plugs and dikes of augite diorite and dacite porphyry. Areas and zones of rock alteration, silicified rock, and pyrite impregnation. A few quartz veins with pyrite—low grade.	Six prospects are described; none have had significant production, area discovered in 1901.	Not reported (Ironsides mine operated for several years).	Callaghan and Buddington, 1938; Oregon Dept. Geology and Mineral Industries, 1951, p. 84–87.
28. Bohemia district, Lane County	Layered tuffs, andesites, and rhyolites intruded by dikes, plugs, and stocks of dioritic rocks and cut by northwest-trending fissure veins of brecciated, altered rock with cherty to drusy crystalline quartz and sulfides including sphalerite, galena, chalcopyrite, and pyrite. Gold is enriched in oxidized zone. Some veins have been traced for half a mile and are up to 20 feet wide.	Most important of Western Cascades districts. Discovered in 1858. Champion, Musick, Helena, and Noonday largest producers. Large number of known properties.	Over-all production, largely gold with some silver, copper, and lead, is about $1 million.	Diller, 1900; Stafford, 1904; Parks and Swartley, 1916; Callaghan and Buddington, 1938; Taber, 1949; Oregon Dept. Geology and Mineral Industries, 1951, p. 53–83.
29. Zinc Creek area, Douglas County	Tuff breccia cut by augite diorite dikes. Zones of altered volcanic rock with disseminated pyrite and occasional lenses of sphalerite and less common galena and chalcopyrite. Some calcite and marcasite; very little quartz.	No important mines. Other areas of rock alteration nearby.	None reported	Callaghan and Buddington, 1938, p. 130–131; Oregon Dept. Geology and Mineral Industries, 1940, p. 130.
30. Al Sarena mine, Jackson County	Bleached, altered, tuff breccias and dikes of rhyolite and andesite; vein contains altered rock, gouge, and cherty quartz, with streaks of sphalerite, pyrite, and galena.	Discovered 1897; first ore shipped 1909. Over 4,000 feet of workings in mine.	1909–1918 production was about $24,000, chiefly gold, some silver and lead.	Callaghan and Buddington, 1938, p. 131–132; Oregon Dept. Geology and Mineral Industries, 1943, p. 195–197.
31. Barron mine, Jackson County	Tuff breccias, andesite and basalt flows, dikes of andesite and dacite. Vein lies in northwest-striking belt of altered rock. Consists of altered rock, gouge, cherty quartz, and stringers of sphalerite with some galena, chalcopyrite, pyrite, and arsenopyrite; occasional stibnite and realgar.	Early history lost. Patented 1883. Not extensively developed.	Production since 1917 about $9,000.	Winchell, 1914, p. 123; Callaghan and Buddington, 1938, p. 134–136; Oregon Dept. Geology and Mineral Industries, 1943, p. 26–28.

TABLE 8.—SUMMARY OF LODE GOLD AND SILVER DISTRICTS AND SELECTED MINES IN OREGON—Continued

Index No. on fig. 36, district or mine, county	Manner of occurrence	Remarks	Lode production	References
		CENTRAL AND SOUTHEASTERN OREGON		
32. Oregon King mine, Jefferson County.	Silicified fault breccia zone in Tertiary andesitic rocks.Contains quartz, pyrite, chalcopyrite, galena, sphalerite, cerargyrite, (silver chloride) and native silver. Lenticular ore shoots range from a few feet to 20 feet in width.	Deposit discovered in 1898. Sporadic development and production. Last operated during 1962–1965.	Roughly 300,000 ounces of silver and 3,000 ounces of gold.	Parks and Swartley, 1916, p. 172; Libbey and Corcoran, 1962.
33. Howard district, Crook County	Broad, intensely altered, fracture zones in Tertiary andesite cut by quartz-carbonate sulfide veinlets, which are usually thin but locally enlarge to shoots of minable width.	Largest mine is Ophir-Mayflower lode. Small placer output from Scissors Creek.	About $80,000 in gold between 1885 and 1930.	Parks and Swartley, 1916, p. 167; Gilluly, Reed, and Park, 1933, p. 124.
34. Spanish Gulch district, Wheeler County.	Quartz fissure veins in pre-Tertiary greenstones, argillite, and limestone. The veins contain pyrite, sphalerite, galena, and gold.	----------	No record	Parks and Swartley, 1916, p. 38, 198, 232, and 296.
35. Harney (Idle City) district, Harney County.	Small, discontinuous quartz veins formed along fractures in sheared and altered zone about 1 mile long in Tertiary andesite.	Production mainly from placers	About $50,000 in gold between 1891 and 1916. No later records.	Parks and Swartley, 1916, p. 224, 273.
36. Lost Cabin district, Lake County	Limonitic clay and quartz veinlets in Tertiary andesite and rhyolite locally contain small amounts of gold and copper-oxide minerals.	District was discovered in 1906. Very little development work has been done.	No record	Parks and Swartley, 1916, p. 292.
37. High Grade district, Lake County	Small quartz veins in Tertiary volcanic rocks.	----------	do	Do.
38. Steens-Pueblo district, Harney County.	Silicified fault zones in both pre-Tertiary and Tertiary lavas and related rocks contain copper and mercury minerals and locally small amounts of gold.	----------	do	Williams and Compton, 1963, p. 47.

Oregon's principal primary deposits occur in fissure veins and associated replacement bodies near the edges of felsic to intermediate intrusive bodies. Characteristically the veins consist mainly of quartz with lesser calcite and altered country rock. Small amounts of pyrite and the sulfides of copper, lead, and zinc are commonly present, and the gold and silver minerals often are intimately associated with them. The veins vary considerably in extent and value. Ore shoots at most of the important mines had average widths of 1½ to 5 feet. Several deposits have been mined to depths of 1,000 to 1,500 feet below the outcrop. Maximum depth attained is about 2,500 feet on the North Pole-Columbia Lode in the Cracker Creek district in Baker County. Ore mined in the past generally contained between 0.2 and 1 ounce per ton gold with varying amounts of silver.

Most of the streams and gulches that drain the lode mining areas have been mined for placer gold. The principal placer deposits were along present streams and adjacent terraces. Gold has been recovered from present and ancient coastal beach placers in Coos and Curry Counties (Pardee, 1934) and from ancient stream gravels in the Sumpter quadrangle in Baker and Grant Counties (Pardee and Hewett, 1914, pp. 39–40; Pardee, 1941). The silver content in placer gold produced in Oregon averages about 16 percent.

Many lode deposits have produced more silver than gold, particularly in Baker and Grant Counties. However, because of the wide differences in price, gold is the more valuable metal in all but a few small deposits. More than 20 percent of Oregon's recorded silver output was produced from the Cornucopia district (No. 9 on fig. 36 and table 8). Important contributions were also made by the North Pole-Columbia Lode in the Cracker Creek district and several mines in the Granite (No. 4) and Greenhorn (No. 5) districts, including the Buffalo, La Belleview, and Ben Harrison. Two deposits in Oregon that have been mined chiefly for silver are the Oregon King (No. 32) in Jefferson County and the Bay Horse (No. 12) in Baker County.

Eastern Blue Mountains

The eastern Blue Mountains gold belt (fig. 36) has been by far the dominant lode gold and silver producing region in Oregon and also contains the most productive dredge mining areas. Principal mining districts are in Baker and Grant Counties, although some mining has been done in adjacent parts of Malheur and Union Counties. The districts and most of the mines and prospects have been described by Lindgren (1901), Swartley (1914), Parks and Swartley (1916), and the Oregon Department of Geology and Mineral Industries (1939 and 1941).

The deposits are associated with Lower Cretaceous batholiths and stocks and occur in both the intrusive rocks and older sedimentary and igneous rocks. The rich placer deposits in the Baker area (No. 6, Fig. 36 and table 8) first attracted attention to the gold and silver deposits of the Blue Mountains. The greatest concentration of both lode and placer mines is in the Elkhorn and Greenhorn Mountain Ranges west of Baker. The area includes the Cracker Creek, Sumpter, Rock Creek, Cable Cove and Granite districts (No. 4), and the Greenhorn district (No. 5). Incomplete records indicate that gold output

from these districts probably totaled about 1,300,000 ounces, about equally divided between lode and placer mines. Silver production has been at least 1,500,000 ounces. More than 60 of the lode mines and prospects described by Pardee and Hewett (1914) and Hewett (1931) have been active at one time or another. The veins that have been most productive occur in tightly folded and fractured argillite of Permian age near the edges of the Bald Mountain and Greenhorn batholiths. Numerous small veins are found in the granitic rocks and in older greenstones, altered gabbro, and ultramafic rocks. The North Pole-Columbia Lode near Bourne in the Cracker Creek district produced about $8 million in gold and silver between 1894–1916. Subsequent production has been relatively small. The lode, varies from 10 feet to nearly 300 feet in width, over a productive strike length of about 12,000 feet. Ore shoots averaged 4 feet in width. The ratio of silver to gold in the ore ranged from about 3 : 1 to less than 1 : 1. Total depth of mining has been about 2,500 feet. Much of the lode remains unexplored. Other important mines in the Elkhorn and Greenhorn Mountains region are the Bonanza, Red Boy and Ben Harrison near Greenhorn, the Buffalo, Cougar and La Belleview north of Granite, and the Baisley-Elkhorn and Highland-Maxwell in the Rock Creek district (No. 4). The Buffalo (Koch, 1959) has been almost continuously active in a small way since about 1880. Production during 1903–1965 totals 33,142 ounces gold and 252,893 ounces silver from 42,246 tons of ore. Records of pre-1903 production are not available. The mine develops four productive parallel quartz veins 80 to 220 feet apart, mainly in argillite. The veins range from 1 to 6 feet in width. Sulfide minerals, which contain most of the values, make up 8 to 10 percent of the ore. Ore produced at the La Belleview and Ben Harrison mines contained as much as 50 ounces silver to 1 ounce gold.

The Virtue mine in the Virtue district (No. 7) about 10 miles east of Baker was almost continuously active during 1864–1884 and 1893–1899. Production from this mine totals about $2,200,000, mostly in free gold which averaged over 920 fine. This and several smaller deposits in the district occur on the periphery of small intrusions of diorite into argillite, greenstone, and gabbro. The Virtue mine is said to expose eight veins, only one of which has been explored at depth.

In northeastern Baker County, gold and silver deposits occur on the south slope and in the adjacent foothills of the Wallowa Mountains, which are carved largely from granodiorite of the Wallowa batholith. The Cornucopia mine (No. 9) in the northeastern part of the area ranks first among the lode mines of Oregon. Total output during several periods of operation has been at least $10 million in gold and silver. Most of the production was from two of several roughly parallel veins, chiefly in granodiorite of the Cornucopia Stock. These are the Union-Companion and Last Chance veins, which are 2,500 to 3,000 feet apart horizontally, dip 45°, and in the stoped areas averaged 4 or 5 feet in width. Vertical extent of mining was about 3,000 feet. Ore mined and treated during 1938–1941 averaged 0.48 ounces gold, 2.2 ounces silver, 0.1 percent copper, and 0.025 percent lead. The Sanger mine in the Eagle Creek district (No. 8) worked a quartz vein in Upper Triassic sandstones and shales. The principal vein was discovered in 1870 and worked more or less continuously through 1897; total output was $1.5 million. Placers along Eagle

Creek and in the vicinity of Sparta and the Sanger mine were productive in early days. The gravels of Pine Creek below Cornucopia remain largely unworked and may contain considerable gold. The gravels occur in a deep narrow channel and contain many large boulders which have hampered mining.

Occurences of copper minerals and associated gold are widely scattered in the southern foothills of the Wallowa Mountains and along Snake River to the east. The deposits occur in irregular bodies impregnating and replacing greenstones and related rocks along shear zones, faults, and fractures (Gilluly, 1933). Only two of the deposits have made any appreciable output. Operated mainly during 1915–1928, the Iron Dyke mine (No. 10) at Homestead on Snake River produced 34,967 ounces gold, 256,489 ounces silver, and 14,417,920 pounds of copper. The Mother Lode near Keating (No. 8) produced about 8,000 ounces of gold and 1 million pounds of copper during 1935–1938.

In the Connor Creek (No. 11), Weatherby (No. 13), and Mormon Basin (No. 14) districts in southeastern Baker County, numerous gold-quartz veins are associated with a northeasterly aligned group of stocks, dikes, and irregular masses of granodiorite intruded into phyllites, slates, massive to schistose greenstones, and mafic intrusive rocks of Paleozoic and Triassic age. The most productive lode mines are the Rainbow mine in the Mormon Basin district and the Connor Creek mine in the Connor Creek district (Gilluly, Reed, and Park, 1933). Production from the Rainbow from its discovery in 1901 through 1919 was more than $2,323,000. The Rainbow mine worked two quartz veins, one on the footwall and one on the hanging wall of a steep, northeast-trending fault zone which cuts slate, greenstone, and old intrusive rocks, and into which a premineral diorite porphyry dike was intruded. Output from the Connor Creek vein, which is in slatey rocks, totals about $1,250,000; the principal period of activity was between 1880 and 1890.

Early-day output from placers in the area was probably quite large; among the most productive were those near Malheur and at Rye Valley. The latter are said to have produced $1 million from terrace gravels along Dixie Creek. Placers in Mormon Basin and along Burnt River, Chicken Creek, and Connor Creek were also productive. A small dredge operated on Clark's Creek and Burnt River near Bridgeport during 1917–1936.

Probably the most productive early-day hydraulic placers of the entire Blue Mountains region were those along Canyon Creek (No. 1) near John Day in Grant County. Part of the area was later dredged. Placers in the Quartzburg (No. 2) and Susanville districts (No. 3) were also worked extensively, first by hand and hydraulic methods and later with dredges. Veins and associated replacement bodies up to 70 feet wide occur along shear zones in greenstones in the Quartzburg district (Gilluly, Reed, and Park, 1933). Although production has been small, the area constitutes a potential source of copper, gold, and cobalt.

Klamath Mountains

More than 75 percent of the gold produced in the Klamath Mountains has been derived from placer mines. Prior to 1900 most of the

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gold was won by sluicing and hydraulic operations. Subsequently, bucket-line dredges were operated on Foots Creek and Pleasant Creek in the Gold Hill area in Jackson County and on Graves Creek in the Greenback area in Josephine County. Dragline dredges and mechanical washing plants were used in many places. Virtually all the streams in the Klamath Mountains province have been placered to some degree. Flush production of the first 10 years following the 1851 Jacksonville rush nearly equalled that of the next 100 years (Libbey, 1963).

Gold was discovered on the beaches of southwestern Oregon about 1852 (Pardee, 1934) (Spreen, C. A., 1939, Univ. of Oregon master's thesis), and mining flourished for a few years. Mines such as on Whiskey Run, about 7 miles north of Bandon at the mouth of the Coquille River, and others along the beach near Cape Blanco and Gold Beach showed good returns. Mining was conducted at various places on elevated beach terraces as well as on active beaches. Thin transitory concentrations of black sand deposited during storms were skimmed up and hauled to higher ground, where the gold and platinum content were recovered in sluices. The very fine particle size of the gold and abundance of other heavy minerals such as chromite, magnetite, ilmenite, zircon, garnet, olivine, etc. made its recovery difficult. Early-day gold production from the beach mines is not reported, but they are said to have been good producers for a few years. Pardee (1934, p. 26) reports a value of $60,615 in gold and platinum produced from Coos and Curry County beach placers between 1903 and 1929.

At least 150 lode mines in the Klamath Mountains have been productive at one time or another (Diller, 1914; Winchell, 1914; Parks and Swartley, 1916). Six mines have supplied the bulk of lode production. These are the Greenback (No. 16) ($3½ million); Ashland (No. 17) ($1,300,000); Sylvanite (No. 18) ($700,000+); Gold Hill Pocket (No. 19) ($700,000); Benton (No. 20) ($550,000), and Gold Bug (No. 21) ($500,000). Fourteen other mines in the area produced between $100,000 and $500,000. Of these 20 mines, seven are in metavolcanic rocks ("greenstone"), six in metasediments (argillite, slate, quartzite), three in diorite, three in metagabbro, and one in serpentine.

The Greenback (No. 16) and Ashland (No. 17) veins were worked down dip to depths of 1,000 feet and 1,200 feet, respectively. The Greenback quartz vein is in greenstone derived from andesite; the vein had an average thickness of 3 feet and was productive for about 600 feet along strike. The main period of activity was during 1897–1908. The Ashland vein is in metasediments of the Applegate Group that are intruded by granodiorite. The mine operated from 1886 to 1902 and again from 1933 to 1939. Value of ore and size of ore shoots are said to increase with depth. The Sylvanite mine (No. 18) worked high-grade ore formed in a complex zone of shearing and alteration along the contact between meta-igneous and metasedimentary rocks. The rich Sylvanite ore shoot produced $1,000 per lineal foot of winze in sinking 600 feet (Oregon Department of Geology and Mineral Industries, 1943, pp. 110–112). The Sylvanite veins and ore shoots carry gold and sulfides including galena, chalcopyrite, and pyrite in a gangue of quartz and calcite. The richer ore shoot formed at the intersection of a fracture zone and vein.

Rich, near-surface "pockets" were almost commonplace in parts of

Jackson and Josephine Counties generally west of Medford and east and south of Grants Pass. Several produced many thousands of dollars worth of gold from very small areas. The pockets were found in surface or subsoil outcrops of quartz-filled fissure veins, particularly near intersections of two or more veins. Exhaustion of the deposits within a few feet of depth was typical. The Gold Hill pocket (No. 19), discovered in 1859, is said to have been so rich that $400,000 was taken out the next year. The outcropping rock was so full of gold it could scarcely be broken by sledging. The gold in this pocket went down only 15 feet (Diller, 1914, p. 46). The Steamboat, Revenue, Town, and Roaring Gimlet pockets, all in western Jackson County, are credited with production of from $40,000 to $350,000 each.

A few mineralized areas of potentially large tonnage, low-grade material are known in the Klamath Mountains area. In the Mount Reuben district (of the Galice area) the Benton mine ore zone (No. 20), which consists of multiple sulfide-bearing quartz veins in sheared mineralized diorite, has been stoped to widths of 20 to 30 feet. The Almeda mine (No. 22) mineralized zone on Rogue River downstream from Galice is about 200 feet wide (Diller, 1914, pp. 74–75). It is associated with a dacite porphyry sill or dike that has intruded along the contact of altered volcanic rocks of the Rogue Formation and slates of the Galice Formation (Shenon, 1933a). Almeda mineralization is characterized by barite, pyrite, and chalcopyrite with minor amounts of sphalerite and galena (Libbey, 1967). The Forget-Me-Not (No. 23) mineralized zone in southern Douglas County contains disseminated pyrite and low-grade gold mineralization in altered greenstone for about 300 feet width. Mining has been localized on a few narrow high-grade seams that occur in the broad altered zone.

Mineralization of strong persistent shear zones seen in a few of the gold-producing areas represents another potential area of exploration for large low-grade deposits. A few examples of highly sheared, iron-stained, talcy serpentinite containing low gold values have been found in the Klamath Mountains area.

Western Cascades

Gold and silver production from mining districts in the Western Cascades has totaled approximately $1,500,000 since 1858, when gold was first discovered in the region. The main production was before 1920, and periods of mining activity were sporadic. The bulk of this production was derived from near-surface ores that were residually enriched by oxidation and easily treated in stamp mills. Production since 1920 has amounted to about half a million dollars in total value of gold, silver, copper, lead, and zinc, mainly from complex sulfide ores below the zone of oxidation. The ratio of silver to gold in some of these deposits is quite high, although the average for all ores produced has been about 2 to 1.

The areas of mineralization are more or less evenly distributed along a north-south line running through the center of the Western Cascades Tertiary volcanic rocks (Nos. 24–31, fig. 36). Each of the mineralized areas is associated with small dioritic intrusive bodies that are believed to be genetically related to the mineral deposits. The largest and most persistent veins are found in the Bohemia district

(No. 28). Some of the veins exceed half a mile in length and 20 feet in width (Callaghan and Buddington, 1938; Taber, 1949). Sulfide minerals found in the veins and mineralized zones of the Western Cascades include pyrite, sphalerite, chalcopyrite, and galena. The common gangue minerals include quartz, calcite, and in places, barite. Large areas of propylitic rock alteration related to the period of diorite intrusion are widespread in the Western Cascades. The typical Western Cascades vein is made up of an altered, brecciated rock cemented by microcrystalline to vuggy, coarse crystalline quartz and containing scattered sulfides. The veins crosscut virtually all rock types—lavas and tuffs as well as the dioritic rocks.

The Bohemia district (No. 28) is the largest and leads other western Cascade areas in production. The Champion, Musick, Helena, and Noonday mines each with more than $100,000 production were the largest in the district. Some of the larger producers outside the Bohemia district include the Lucky Boy mine in the Blue River district (No. 26) with a record production since 1902 of 7,737 ounces of gold and 12,844 ounces of silver; the Lawler mine in the Quartzville district (No. 25) with a production of about $100,000; and the Al Sarena (No. 30) or Buzzard mine in northern Jackson County with a recorded production of 1,081 ounces of gold between 1909 and 1918. Minor production has been recorded from the North Santiam district (No. 24) in Clackamas and Marion Counties and from the Barron mine (No. 31) in Jackson County. Gold veins have been prospected in the Fall Creek district (No. 27) in Lane County and in the Zinc Creek area (No. 29) in Douglas County.

Very little placer mining has been done in the Cascade Range because the values contained in placer deposits are low and the gold particles extremely fine and difficult to recover.

Future potential of gold mining in the Western Cascades province will depend on extracting all values from the complex sulfide ores. Exploration at depth of some of the large areas of pyrite-impregnated, altered rock may prove the presence of other sulfides and accompanying gold and silver values.

Occurrences in central and southeastern Oregon

The Oregon King mine (No. 32) (Libbey and Corcoran, 1962) near Ashwood in eastern Jefferson County was discovered in 1898 and has been worked intermittently, the latest period of operation and development being 1962–1965. The mine has produced more than 300,000 ounces of silver and 3,000 ounces of gold from a quartz vein in andesitic rocks of Tertiary age. According to Gilluly, Reed, and Park (1933), the Howard district (No. 33) in Crook County produced about $80,000 in gold between 1885 and 1930. The mineralized ground consists of intensely altered andesite of Tertiary age cut by narrow quartz veins an inch or so thick, which locally enlarge into high-grade shoots, especially at junctions or intersections. The largest lode mine in the district is the Ophir-Mayflower. In the Spanish Gulch district (No. 34) in Wheeler County, small amounts of gold and silver have been produced from quartz fissure veins in pre-Tertiary greenstone, argillite, and limestone, which have been invaded by dikes and small irregular masses of granodiorite and related rocks. The veins contain pyrite, sphalerite, and galena.

Placer deposits were found in the Idle City (Harney) district (No. 35) in 1891, and approximately $50,000 in gold was produced up to 1916 (Parks and Swartley, 1916, pp. 224, 273). There has been small and intermittent placer mining activity in the district since that time. Primary mineralization is associated with discontinuous quartz veins along fractures in Tertiary andesite porphyry. Small gold occurrences have been explored to a very limited extent in the Lost Cabin (No. 36), High Grade (No. 37), and Pueblo Mountains (No. 38) districts. No records of production are available. The occurrences in the Lost Cabin and High Grade districts are in Tertiary volcanic rocks. In the Pueblo Mountains district, gold is locally associated with copper and mercury minerals formed along silicified fault zones in both pre-Tertiary and Tertiary rocks.

FUTURE POTENTIAL

Oregon must be considered a potentially important source of gold despite the fact that production has been very small for several years. There is good geologic evidence that many of the known lode deposits in the State have not been exhausted. A major increase in the price of gold or decrease in production costs probably would result in the reopening of many mines that were active during the late 1930's. Very likely new deposits would be found with the modern methods of prospecting that have since been developed. Under present conditions any appreciable increase in Oregon gold and silver production appears contingent upon the discovery of large precious metal or gold- and silver-bearing base-metal deposits that are amenable to big-tonnage, low unit-cost methods of mining. Aggressive systematic investigation of known mineralized areas might lead to the development of such deposits, particularly in districts where broad zones of shearing and hydrothermal alteration occur. Beach and off-shore black sand deposits are presently being investigated by the U.S. Geological Survey and the U.S. Bureau of Mines. Large-scale mining of these deposits might result in a considerable output of gold.

Iron

(By R. S. Mason, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Iron ore mined in Oregon has been used for a number of purposes in addition to the production of pig iron. Limonite deposits have been mined for many years to supply industrial pigments. Ore from these same deposits has also been used to make a sulfur-scrubber for treating producer gas. Minor amounts of magnetite have been used for ship ballasting and high density concretes.

The iron resources of Oregon are contained in a variety of types of deposits in widely scattered areas of the State as shown on fig. 37. By far the largest and most important are the Scappoose limonite deposits in Columbia County and nearby areas in the northwestern part of the State, as described by Williams and Parks (1923), Bell (1945), Hotz (1953), and Wilkinson and others (1945). Also in northwestern Oregon the ferruginous bauxite deposits represent a signifi-

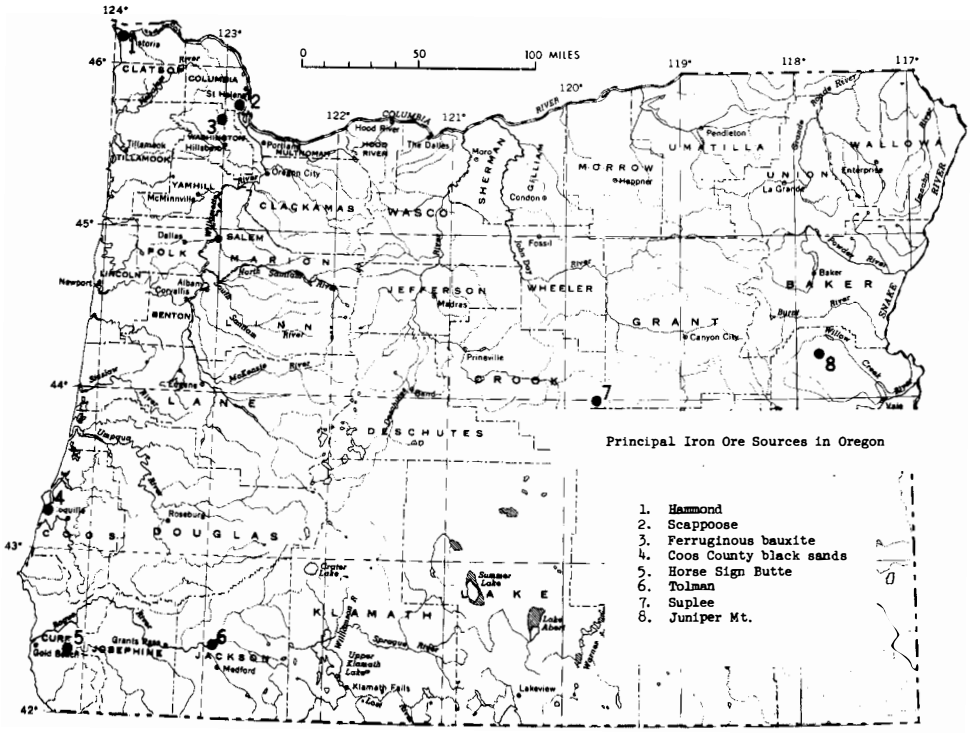

FIGURE 37.—Principal iron ore sources in Oregon.

cant potential resource of both iron and aluminum. Black sands along the coast in southwestern Oregon and near the mouth of the Columbia River also have some potential for recovery of iron in association with other materials. Numerous additional occurrences of iron have been reported in many parts of the State. Most of these deposits are small and consist of magnetite in association with a variety of rock types. Summary data on many of these are given in the *Ore Bin*, February, 1953, published by the Oregon Department of Geology and Mineral Industries.

The Scappoose limonite deposits have been developed in the Tertiary lavas of Miocene age which blanket much of northwestern Oregon. Weathering of the flows, which apparently stood at or slightly above sea level, released iron to nearby bogs and lakes where it was precipitated as limonite. Apparently this process was repeated many times, since individual limonite deposits have been found in successive layers of stratigraphically younger lavas. Subsequent engulfment of the area by younger lavas and ash protected the limonite deposits until comparatively recent erosion stripped away some of the overburden. Post-Miocene arching has elevated the lavas and inaugurated a cycle of fairly rapid stream erosion (Zapffe, 1949; Hotz, 1953).

The Scappoose limonite ore bodies are highly irregular in shape and their geographic and topographic distribution is varied. Exploration of several of these shows that they have widely varying thicknesses, and curving margins. Williams and Parks (1923) suggest that some are fillings of old sluggish stream channels and small bogs or lakes. Other ore bodies have been modified either by contemporaneous interruptions to the deposition of the ore or by subsequent faulting or erosion of the body. Overburden of from 2 to more than 20 feet in thickness, plus thick vegetative cover, have combined to make exploration for the deposits difficult. Most of the work has naturally been conducted in the vicinity of known exposures of the ore and relatively little "blind" drilling and trenching have been conducted. There is considerable geologic evidence, based largely on known occurrences, which indicates the probable existence of additional ore bodies.

The Scappoose ores have a considerable compositional range; analyses given by Williams and Parks (1923) indicate samples range from 48 to 56 percent iron. A composite sample from one property showed 51 percent iron, 7.47 percent alumina, 3.58 percent silica, 14.34 percent loss-on-ignition, 1.24 percent manganese, 0.025 percent sulfur and 0.849 percent phospherous.

Oregon's first and only source of limonite used for making pig iron is the long abandoned Prosser mine, located immediately north of Lake Oswego. A century ago the first pig iron was smelted on the banks of the Willamette River just outside of the city of Oswego (Hotz, 1953; Walsted, 1954). The ore, a mixture of soft, earthy limonite with minor hard, flintlike masses, was enclosed between a series of lava flows and cropped out along the hillside for approximately 1 mile. Workings down the dip developed ore for 600 feet, and outcrops indicated that the deposit was at least half a mile in width. Thickness varied from 2 to 20 feet.

The blast furnace produced both pig iron and cast iron pipe during its 28 years of operation. Apparently the furnace was the limiting factor in the operation. The Census of 1880 states, in the section titled

"Iron Ore West of the One Hundredth Meridian," that although the mine owners estimated that the mine had an annual capacity of 20,000 tons, only 6,225 tons was required by the furnace in 1879.

The following analysis of the Oswego ore is given by Williams and Parks:

	Percent
Metallic iron	30.00–40.00
Silica	7.00–15.00
Magnesia	2.00– 3.00
Manganese	4.00– 8.00
Lime	2.00– 4.00
Phosphorus	0.37– 0.67
Sulfur	0.3– 1.00

Increasing mining costs and variations in the ore, according to Williams and Parks (1923), led to the abandonment of the entire operation in 1894. Subsequently the mine area has seen the steady encroachment of housing development to the point where no future mining can be considered. The remains of the blast furnace and a "skull" from one of the last pours are now featured in a city park.

Another potential source of iron in the State is the ferruginous bauxite of northwestern Oregon, which contains an average of 23 percent metallic iron (Libbey and others, 1945). Any exploitation of the various deposits for the recovery of alumina would necessarily results in a concentration of the iron content to the point where it could conceivably be considered as an economic coproduct, as discussed in more detail on page 101.

The iron content of both the onshore and offshore "black sands" of southwestern Oregon comprises a resource which in the future may be of considerable economic importance (Kelly, 1947). Exploitation of such material is dependent upon many variables, as discussed in the chapter on "black sands" (p. 102). Considerable interest has been shown for a number of years in the iron content of the Columbia River sands. Aside from the test drilling by The Bunker Hill Company at the mouth of the river, there has been no intensive exploration.

The numerous small pods and lentils of magnetite, hematite, and limonite found in many parts of the State apparently contain too limited a tonnage to make them economically important. Minor amounts of ore will very probably be used from time to time for special purposes discussed above.

An unusual iron deposit in the Agness district of Curry County contains a small amount of vanadium. An unpublished report prepared by Allen and Lowry [6] incorporates a portion of an earlier examination (Butler and Mitchell, 1916). Magnetite-impregnated sandstone crops out for 650 feet along on a ridge and is bounded by two greenstone dikes approximately 100 feet apart. Allen and Lowry estimated the reserves at roughly 225,000 tons to a probable depth of 35 feet.

Analysis of a composite sample gave the following:

	Percent
Fe	54.94
S	0.114
V	0.37
TiO_2	2.70
P	0.004

[6] Horse Sign Butte iron deposit. Unpublished manuscript in files of Oregon Department of Geology and Mineral Industries.

No vanadium minerals were identified in any of the samples taken, and almost no vanaduim was reported in the nonmagnetic fractions after separation. The vanadium apparently is intermixed with the magnetite. Exploitation of the deposit would depend primarily upon a market for vanadiferous magnetite, since the separation of the vanadium from the iron would be difficult.

The small size of the deposit, plus its remote location, make any mining unattractive. Detailed examination of the surrounding terrain has been insufficient to rule out the possibility of additional deposits or an extension of the limits of the original ore body.

The Tolman iron deposit, located about 2 miles north of the town of Gold Hill, Jackson County, consists of a series of lenses and stringers lying within a mineralized zone from 20 to 60 feet wide and approximately 4,600 feet in length. In an unpublished report (1903) H. V. Winchell and Fred T. Green estimated that there were 760,000 tons of ore to a depth of 50 feet. Analysis of the ore was: iron—51.63 percent, silica—8.67 percent, sulfur—0.208 percent, phosphorus—0.060 percent, and titanium—none.

The property was explored by a series of tunnels, pits, and trenches in the early 1900's. A dip needle survey was conducted by Hodge (1938c, pp. 59–68). A minor amount of excavation with a bulldozer was performed in 1953. An examination of the deposit was made by Ramp [7] in 1960. In his report Ramp states that spectrographic analyses and field evidence suggest a possible sedimentary origin for the deposit. Much of the magnetite has a granular texture. It is interbedded with metasediments of the Applegroup Group (Upper(?) Triassic) including schist, argillite, quartzite, and limestone. A second deposit, the Victory Group, located approximately 2 miles southeast of the Tolman, consists of amphibolite impregnated with disseminated magnetite. Unlike the Tolman, the magnetite when magnetically concentrated contains approximately 5 percent titanium. Insufficient exploration has been conducted to appraise the reserves.

Minor deposits not appearing in the list published by the State of Oregon Department of Geology and Mineral Industries in the February 1953 *Ore Bin* include the following: (1) lenses and laminae of magnetite grains in Pennsylvanian clastic sediments have been reported by Buddenhagen (1967) from the Suplee area of eastern Crook County; (2) high-grade pods of magnetite are reported by Brooks [8] to be enclosed in diorite of Late Triassic age on Juniper Mountain southwest of Brogan in Malheur County; and (3) small streaks of nearly massive magnetite in hornblende diorite over an area a quarter of a mile by half a mile in Chetco mining district of Curry County (Tincup Iron prospect) have been reported by Ramp.[9]

The iron ore resources of Oregon, in terms of any future utilization, are probably restricted to four sources: (1) the Scappoose deposits, (2) the black sands of the southwestern coastal region, (3) the reject iron fraction from the red muds resulting from the beneficiation of ferruginous bauxite to make alumina, and (4) the Tolman iron deposit.

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[7] Ramp, Len, 1960, Tolman iron property (2d supp. rept.) : Oregon Department of Geology and Mineral Industries unpublished report.
[8] Brooks, H. C., 1956, La Rae No. 1 (Magnetite), Malheur County : Oregon Department of Geology and Mineral Industries unpublished report.
[9] Ramp, Len, 1958, Tincup Iron Group : Oregon Department of Geology and Mineral Industries unpublished report.

The Scappoose deposits, as presently explored, contain far too little tonnage to make them economically attractive and occur in a populated area where land values are high. Whether sufficient reserves could be developed with additional exploration remains to be seen. It is unlikely that all or nearly all of the potential deposits have been exposed by erosion or located with the small amount of work done to date. The high sulfur and phosphorus content of the ore is objectionable, but metallurgical tests conducted at the U.S. Bureau of Mines by Walsted (1954) showed that a satisfactory pig iron can be produced.

Consideration of the black sands as a source of iron must be predicated on the concurrent marketability of most of the remaining fractions. A high-grade magnetite concentrate can be produced from the sands with comparative ease. The uneven distribution of the recoverable fractions coupled with their low concentration impose a serious economic barrier during normal times. During periods of national emergency the deposits might be worked, since they would yield, in addition to magnetite, chromite, zircon, ilmenite, and garnet.

Recovery of alumina from the ferruginous bauxites of northwestern Oregon would create an iron-rich coproduct in the form of a red mud. Upgrading of the mud should present no unusual problem and since the cost of mining and transportation to the mill would be borne by the alumina fraction, the finished cost for the iron should be low. No decision to mine and process the bauxite has been announced.

The Tolman iron deposit has a considerable tonnage of fairly high-grade ore located within easy reach of both rail and highway transportation. The presence of sulfide minerals in portions of the deposit would perhaps limit its marketability.

Manganese

(By R. N. Appling, Jr., U.S. Bureau of Mines, Spokane, Wash.)

Manganese is one of the most common metals, ranking tenth in abundance among elements in the earth's crust. It is essential in the manufacture of steel, where it is used to counteract the effects of sulfur; to impart strength, toughness, hardness, or hardenability; and to act as a deoxidizer. In 1965, 95 percent of domestic production went into steelmaking, some 3 percent was used for chemical purposes, and slightly more than 1 percent went into dry cell battery manufacture.

The United States has a large share of the world's subeconomic resources, yet is almost totally dependent on imports to fill its needs. In recent years only about 1 percent of manganese ore consumed is produced domestically, primarily from deposits in Montana, New Mexico, and, occasionally, southern California. Very large deposits are known in Maine, Minnesota, South Dakota, Arkansas, and Arizona; however, all contain less than 10 percent manganese and, therefore, are not economic under present conditions.

The mineralogy of manganese is complex in detail, yet simple in broad outline. More than 100 minerals contain manganese as an essential element; in many cases X-ray analysis and other laboratory studies are needed to differentiate among them. From a practical standpoint, however, field identification can generally be limited to three groups: oxides, carbonates (rhodochrosite), and silicates (rhodonite). Manganese oxides are black to brown in color. They usually

are soft and "sooty," but may be hard as in the "psilomelane type" minerals. Streak is most often black to brownish black. Rhodochrosite and rhodonite are commonly pink or rose red in color, but may grade through tan to brown, often with black oxide coatings on the surface. Rhodonite approaches the hardness of quartz; rhodochrosite is softer.

Most manganese ore production from Oregon has apparently been on a test basis only. Ore has been shipped from a total of 11 deposits in northeastern Oregon but usually production has been limited to 1 or 2 shipments. Largest production has been from the Utah deposit in Baker County, where 450 tons were reportedly shipped in 1917, and 70 tons, averaging 35.5 percent manganese, were shipped in 1953. In southwestern Oregon the Tyrrell deposit in Jackson County was active in 1917, producing 100 to 200 tons of concentrates averaging about 47 percent manganese from a 25-ton concentrating mill on the property. According to local reports, only two carloads were shipped; the balance was stockpiled. In 1950, a 500-ton concentrator was built near the property, but no ore was produced. Although minor occurrences of manganese have been reported throughout the State, all production and nearly all exploration have been confined to the northeast and southwest corners. The manganese deposits of the State have been described in several reports (Appling, 1958, 1959; Hodge, 1938; Libbey and others, 1942; Pardee, 1921; Pardee and Parks, 1918). Rasmussen (1952), Walsted (1955) and Wells and Agey (1947) have reported on metallurgical tests on Oregon ores.

NORTHEASTERN OREGON

Eleven manganese deposits in northeastern Oregon have been explored to a limited extent (fig. 38). Ten are in Baker County; 1 is in

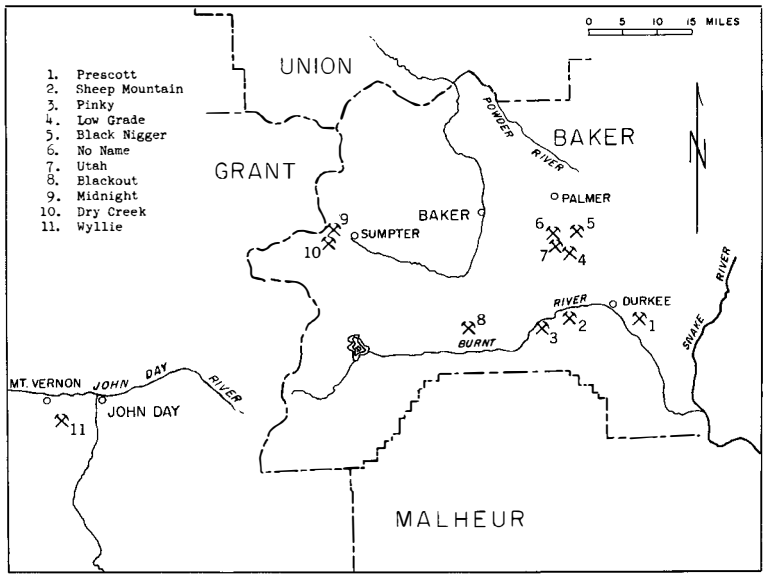


FIGURE 38.—Manganese prospects of northeastern Oregon.

Grant County. Six of the deposits have produced from 20 to 520 tons of ore (Appling, 1959).

The Grant County deposit is composed of rhodonite, altered near the surface to manganese oxides. The deposit is in altered mafic igneous rock, near a serpentine contact.

Most of the Baker County deposits are in schists, argillites, and bedded cherts of the Elkhorn Ridge Argillite of Early Permian to Late Triassic age (Taubeneck, 1955; Gilluly, 1937). Two deposits are in the Burnt River Schist of pre-Carboniferous(?) age. Rocks of both formations have been intensely deformed and structures are complex. In general, folds are tightly compressed, strike westward, and dip to the north and south at high angles.

Manganese deposits in the Elkhorn Ridge Argillite are composed of oxides, intermixed with abundant quartz and chert. They are usually localized along bedding or schistocity planes as irregular, discontinuous pods and bunches ranging in size from several hundred pounds to as much as several hundred tons. Most samples contain more than 30 percent silica; manganese content ranges from 15 to 36 percent in selected samples. Run-of-mine material rarely exceeds 30 percent manganese.

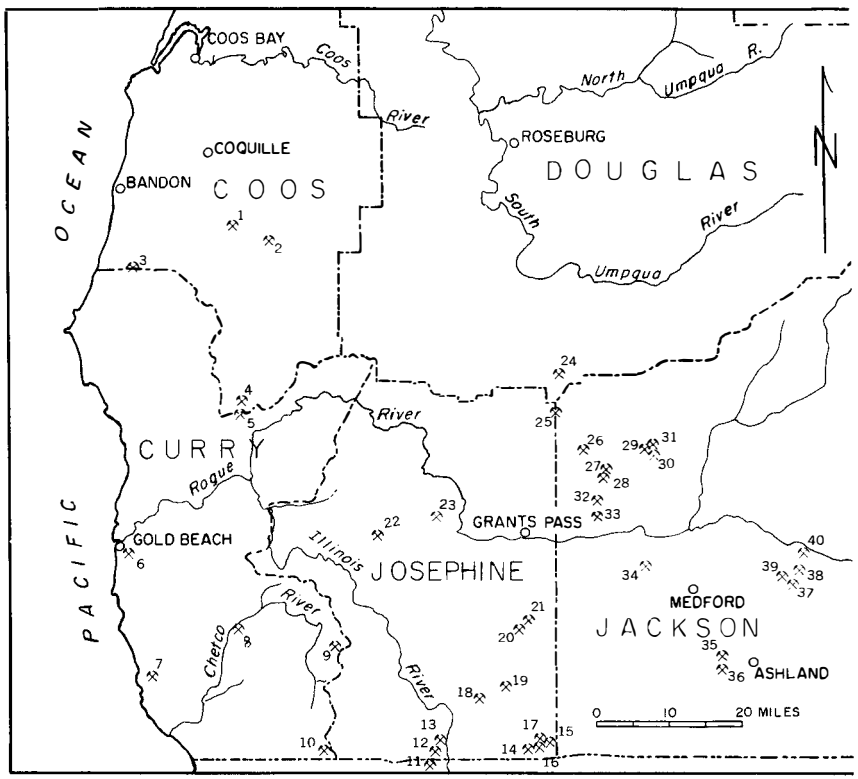
Both deposits in the Burnt River Schist are veins occurring in greenstone schist. Ore minerals are similar to those found in deposits in the Elkhorn Ridge Argillite, except that small amounts of rhodonite were observed at one prospect.

SOUTHWESTERN OREGON

In southwest Oregon, managanese occurs as silicates (rhodonite largely), as mixed oxides, and as both oxides and silicates intermixed with hematite and quartz in deposits that are commonly referred to as manganiferous iron. In general, the oxides are found in the coastal counties, Curry and Coos; manganiferous iron deposits occur in Josephine and Douglas Counties; and silicates are limited to Josephine and Jackson Counties. Notable exceptions are the oxides of the Tyrrell and Newstrom Ranch deposits in Jackson County, and the hydrous managanese silicate, neotocite, of the Smith deposit in Curry County. The total production from the area is probably less than 250 tons (Appling, 1958). The locations of the deposits are shown on figure 39.

In the coastal counties, manganese oxides are usually associated with chert in sandstone or shale layers of the Knoxville Formation (Riddle Formation of present usage) of Late Jurassic age, although occasional deposits occur in the Dothan Formation (Jurassic) and the Paskenta Formation (Cretaceous) (Wells, 1955). Most deposits in this area consist of pods or bunches ranging in size from a few pounds to several tons, or more extensive areas of fractured rock with manganese oxide coatings on fracture surfaces. The latter occurrences are usually very low grade, where-as the pods and bunches may contain as much as 50 percent manganese in small selected samples.

Deposits of rhodonite and manganiferous iron are limited to Josephine County and the western part of Jackson County. Nearly all are in siliceous metasediments of the Applegate Group of Late(?) Triassic age (Wells and others, 1949). Both rhodonite and manganifer-



PROSPECTS

1. Guerin
2. Rookard
3. McAdams
4. Leep
5. Fitzgerald
6. Smith
7. Colegrove
8. Long Ridge
9. Hamaker
10. Black Bear
11. C.M.S. Strategic Metals
12. Black Boy
13. Jack Pot No. 2
14. Hinkle Lake
15. Larkspur
16. No Name
17. Low Gap
18. Oregon Caves
19. Grayback
20. Sunny Mayday
21. Wild Deer
22. Elkhorn
23. Campbell-McAllister
24. Bull Run
25. McTimmonds
26. Starr
27. Neathamer
28. Erickson
29. Big Jim
30. Shamrock
31. Evans Creek
32. Woods
33. Flume Gulch
34. Bailey
35. Burris
36. Taylor
37. Coon Creek
38. Tyrrell
39. Fox
40. Newstrom Ranch

FIGURE 39.—Manganese prospects of southwestern Oregon.

ous iron deposits occur as discontinuous pods and irregular bunches; however, manganiferous iron deposits are usually much larger. Deposits occasionally occur in poorly defined zones oriented with the plane of bedding. The better grade rhodonite deposits vary in manganese content from about 15 to 25 percent; a few selected samples may assay as high as 30 percent managanese. Manganiferous iron occurrences usually contain 5 to 10 percent manganese and 20 to 30 percent iron. Silica may vary from 45 to 75 percent in both types.

Manganese oxides are found in the Lake Creek District, eastern Jackson County, in a series of Eocene flows and interbedded tuffs (Wells, 1939). The manganese occurs as nodules of mixed oxides in irregular areas of a relatively soft brick red tuff of andesite composition. According to Wells, the deposits probably originated through leaching of manganese from overlying lavas, and redeposition in cavities in the underlying tuff beds.

Grade varies both horizontally and vertically, from several percent to nearly 20 percent manganese. Several zones containing an average of 1 to 3 percent manganese over a width of 50 to 150 feet and a length of as much as 500 feet have been noted. Limited concentrations in brecciated areas occasionally contain as much as 18 or 19 percent manganese. Ore was probably mined from similar concentrations and milled to a 47 percent manganese concentrate in 1917. Total production is reported to be from 100 to 150 tons of concentrates.

Although occasional efforts may be made to develop a manganese producer in the State, the chance of success appears slight. Deposits are small, irregular, low-grade, and frequently off-grade because of silica content. Potential is too limited to warrant the high cost of milling facilities necessary to consistently ship a plus 35 percent product, or, in the case of siliceous ores, the smelter necessary to produce silicomanganese or ferromanganese. Transportation costs are too great at present to permit shipping low-grade material for custom processing, and are likely to remain so. If low-grade ore should become attractive for any reason, small deposits such as these are unlikely to be competitive with the very extensive low-grade deposits elsewhere in the Nation.

Mercury

(By H. C. Brooks, Oregon Department of Geology and Mineral Industries, Baker, Oreg., and E. H. Bailey, U.S. Geological Survey, Menlo Park, Calif.)

Mercury, or "quicksilver," as it is popularly called, is a heavy silver gray metal that is liquid at ordinary temperatures. It becomes a malleable solid at $-40°C$ and boils to a colorless vapor at 358°C. Mercury has a multitude of uses because of the unusual properties of the metal, its vapor, and its compounds. Because it expands uniformly over a wide range of temperatures and is an excellent conductor of heat and electricity, mercury is used in a wide variety of control instruments and electrical apparatus such as thermometers, barometers, pressure gauges, batteries, switches and fuses, rectifiers, oscillators, and various vapor lamps. Mercury amalgams are used for dental applications, bearings, solders, and type. Mercury fulminate is an explosive used in munitions and blasting caps. Mercury compounds are used in fungicides, insecticides, and medicinal preparations. Mercury oxide is used

in antifouling paints and in mold and mildew inhibitors. Currently the largest single use is as the metal in the production of chlorine, which is basic for the manufacture of a wide variety of chemicals including plastics.

"Prime virgin quicksilver," the product of the mines, is marketed in cylindrical steel flasks containing 76 pounds. A "flask" is the international unit of trade. Most of the metal entering the market is about 99.9 percent pure, and more than 80 percent is used without further refining. The extraction of mercury from ore is a comparatively simple process, and nearly every mine has its own recovery plant. Usually the ore is roasted in mechanical furnaces or retorts to convert the mercury minerals to mercury vapor. Metallic mercury is then obtained directly from a condensing system through which the vapor is conducted. At some mines the mercury minerals are concentrated before they are roasted.

The principal mercury ore mineral is the red sulfide, cinnabar (HgS). Native mercury, and more rarely metacinnabar, schwatzite, livingstonite(?), chloride, and oxychlorides of mercury have been found in some deposit in Oregon. The iron sulfides, pyrite or marcasite, are common though rarely abundant gangue minerals. Sulfides of other metals are scarce. Calcite and chalcedony are usually present; more rarely opal or fine-grained quartz are found in the deposits.

Mercury deposits throughout the world occur in regions of Tertiary and Quaternary orogeny and volcanism. The mercury minerals are deposited from ascending hot waters, which probably are genetically related to magmatic activity and volcanism. These hot solutions rise along fractures in the earth, and mercury minerals are deposited in the interstices of broken or porous rocks as the solutions are cooled or otherwise changed in character on nearing the surface. Near many deposits the rocks are greatly changed in composition and appearance by the ore-forming solutions, and in some rich mercury deposits the rocks are extensively replaced by cinnabar. Mercury ore bodies probably formed nearer the surface and at lower temperatures than the ores of most other metals deposited from hydrothermal solutions, and few deposits extend to depths greater than a thousand feet.

The world mercury-producing industry is small, and the major sources of supply are concentrated in a few areas. During recent years, the world output has been around 250,000 flasks a year. About half of this was recovered at a single large mine in Spain and a few other mines in central Italy. Most of the remainder was supplied by mines in the United States, the U.S.S.R., China, Yugoslavia, and Mexico. Because of their dominance, Spain and Italy have long been able to control the market price of mercury, though they now work competitively rather than in a cartel as formerly.

United States mercury consumption during 1950–1966 averaged 58,628 flasks annually, with a maximum of 82,000 flasks in 1964. During the same period, domestic mine output averaged 21,875 flasks or about one-third of the consumption. When considered on an annual basis, the ratio of domestic production to consumption varied from lows of 7 percent and 17 percent in 1950 and 1964, respectively, to a high of 72 percent in 1958. Annual price averages ranged from lows of $81 and $225 per flask, respectively, in 1950 and 1963 to highs of

$290 and $570 in 1955 and 1965. Similar price and production fluctuations have characterized the mercury market for over 50 years; as a result, the United States mercury-producing industry has been one of high risk and instability. On the other hand, the demand for mercury both in the United States and the world has been rapidly rising, and because production costs in Spain and Italy are also increasing, one might expect the price of mercury to remain near or above the high levels that prevailed in 1966–1967 (Bailey and Smith, 1964).

Oregon mines have produced about 105,700 flasks of quicksilver, or roughly 3 percent of total United States output through 1966. Of this amount, nearly 102,500 flasks have been recovered since 1927. Oregon output has closely followed the cycles of United States production. The annual output for 1927 through 1945 averaged 4,265 flasks, with a peak of more than 9,000 flasks from 20 mines in both 1940 and 1941. World oversupplies following World War II caused a sharp decline in prices, which resulted in closure of nearly all domestic mercury mines. Oregon's production in 1950 was five flasks. High prices brought about by the Korean conflict during the 1950's revitalized Oregon's quicksilver industry, and 3,993 flasks were produced from eight mines in 1957. Thereafter, output dwindled to four flasks in 1963. As a result of recent price escalation, production reached a high of 1,400 flasks in 1965, but dropped to 700 in 1966. Output for 1967 is expected to be about 900 flasks.

Mercury occurrences are widespread in Oregon (fig. 40). More than 225 deposits in 17 counties have been described or listed (Schuette, 1938; Brooks, 1963). The most productive deposits are concentrated in the southwestern, central, and southeastern parts of the State. More than 90 percent of the production was contributed by five mines: Bonanza (No. 1 fig. 40) in Douglas County; Black Butte (No. 2) in Lane County; Horse Heaven (No. 4) in Jefferson County; and Bretz (No. 8) and Opalite (No. 9) in southern Malheur County. The Bonanza was the largest producer, with an output of about 39,500 flasks. Yield from the other four ranges from 12,000 to 17,500 flasks each. No other mine produced more than a thousand flasks.

More than 99 percent of the mercury produced in Oregon has come from deposits in Tertiary rocks of Eocene, Oligocene, and Miocene age. Included are volcanic flows and volcaniclastic breccias and conglomerates, volcanic plugs, tuffs, tuffaceous lake beds, and marine and nonmarine sandstones. The rocks of volcanic origin are predominantly of andesitic to rhyolitic composition. Although a few mercury deposits occur in basaltic rocks along the western edge of the Cascade Range, the plateau-forming basalts that cover so much of the State east of the Cascades are remarkably unmineralized. Numerous mercury occurrences have been found in pre-Tertiary rocks, particularly in the Klamath Mountains (Brooks, 1963, pp. 83–103), but few have been productive.

In southwestern Oregon most of the mercury deposits lie close to the boundary between the Cascade Range on the east and the Coast Range and Klamath Mountains on the west. Included are the Bonanza and Black Butte mines, which together account for more than half of the State's mercury production. The Bonanza mine (fig. 40, No. 1) is in the Umpqua Formation of Eocene age. The ore occurs in

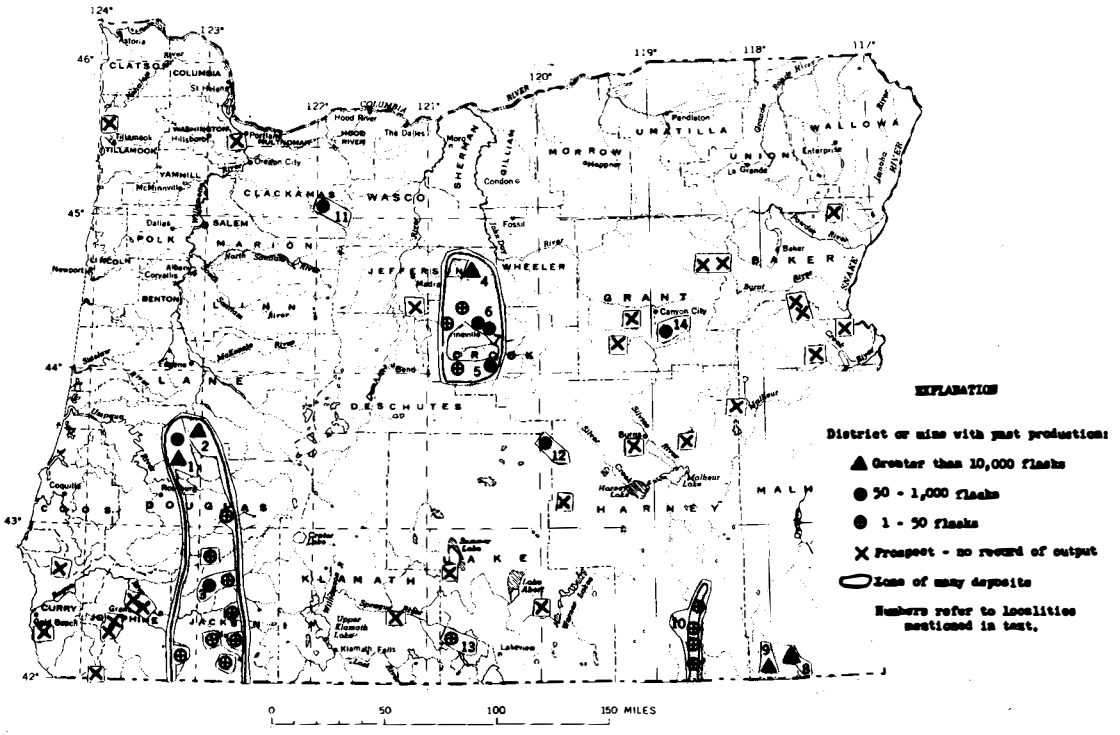


FIGURE 40.—Mercury occurrences in Oregon.

fractured and highly altered tuffaceous marine sandstone overlain by shale. Differential movement during the formation of an anticline developed fractures in the tuffaceous sandstone, which were later mineralized (Brown and Waters, 1951). The average dip of the ore zone is about 45°. Cinnabar was localized primarily along bedding plane shears and beneath an impervious shale capping. The principal ore body of the Bonanza mine is about 800 feet long and has been developed, largely by an inclined shaft, down the dip about 1,450 feet. The ore body in the upper levels was in places as much as 60 feet thick, but it narrowed considerably with depth.

The Black Butte deposit (No. 2) occurs in andesitic lavas, breccias, and tuffs of the Calapooya (or Fisher) Formation of late Eocene and Oligocene age (Wells and Waters, 1934; Waters, 1945). The principal ore zone lies along a normal fault whose surface expression coincides with the crest of Black Butte. The dip of the fault averages about 58°. Subordinate faults are distributed through a wide zone both above and below the fault, and the intervening rocks are extensively brecciated and altered. Veinlets of quartz and carbonates are thickly massed in the fault zone, and, as they are more resistant to erosion than the enclosing rocks, are responsible for the butte standing above the surrounding country. Cinnabar occurs as irregular veinlets and disseminations scattered through most of the brecciated and altered rock. The grade of ore is highest in material that was silicified and brecciated prior to the introduction of cinnabar. The Black Butte mine is developed by adits distributed over a vertical interval of about 1,300 feet. The principal ore shoot has been worked from surface outcrops to the 1,100-adit level, a vertical distance of about 850 feet. In 1967, ore was being mined on the 1,250-adit level. The average recovery from the ore has been about 3½ pounds of mercury per ton.

In the Meadows district (No. 3), about 10 miles west of Trail, the deposits lie within a broad zone of minor normal faults on both sides of a faulted contact between Mesozoic metamorphic rocks and Eocene sediments. The district has produced about 950 flasks of mercury, nearly three-quarters of which was obtained from the Rainier vein at the War Eagle mine, where cinnabar and pyrite fill fractures in a brecciated quartz vein 3 to 10 feet wide in sheared amphibolite. Mercury has also been recovered from small deposits along faults within Eocene sandstone, shale, and lignitic coal.

The principal deposits of central Oregon lie within 35 miles of Prineville. The Horse Heaven mine in eastern Jefferson County (No. 4) is by far the most productive and rates as the second largest producer in the State. Many of these deposits, particularly those in the Horse Heaven and Maury Mountain districts, occur on the margins of volcanic plugs and dikes that are intruded into lavas and tuffaceous rocks of the Clarno and John Day Formations. The ore bodies at the Horse Heaven mine occur in and along the edge of a biotite-rhyolite plug (Waters and others, 1951). As the plug rose, the overlying rocks were domed, and both the rhyolite and the wall rocks were broken and locally converted to breccia. These zones of broken rock were later altered and mineralized. Much of the ore lay beneath an ancient clay soil horizon which developed at the surface of the Clarno Formation. This horizon is now buried beneath younger rock but in many

places is in contact with the southwestward-pitching margin of the plug. Little ore was found at depths greater than 400 feet in spite of extensive deeper exploration.

In the Maury Mountain district (No. 5), in southern Crook County, about 770 flasks have been produced from high-grade ore bodies erratically distributed along normal faults bordering a basalt plug intruded into volcanic tuff of the Clarno Formation. One of the ore bodies yielded 5,000 pounds of mercury from 26,000 pounds of ore. In the Ochoco Creek (No. 6) and Johnson Creek (No. 7) areas east of Prineville, small but rich deposits of cinnabar occur along northeast-trending zones of shear and hydrothermal alteration in the Clarno Formation. Cinnabar occurs in fault breccia and gouge rich in clays, carbonates, and locally silica. Total output from eight small mines has been about 2,200 flasks. Stephenson (1943) made detailed geophysical surveys in the vicinity of some of the mines in the Ochoco and Maury Mountain areas.

In southeastern Oregon, the principal mercury mines are the Bretz (No. 8) and Opalite (No. 9) in the Opalite district. In the same district across the Nevada line, is the Cordero mine, which for many years was one of the Nation's leading producers. The deposits occur in altered tuff and tuffaceous lakebeds of Miocene age. In places adjacent to faults, the tuffs and lakebeds have been silicified to opalite, a light-colored rock consisting of a mixture of chalcedony, quartz, and opal. The Opalite mine ore body occurs in a flat mass of opalite about 1,200 feet long, 800 feet wide, and more than 100 feet in maximum thickness. Yates (1942) deduced that, during a late stage in the hydrothermal activity responsible for the silicification, finely divided cinnabar was deposited with the silica. At the Bretz mine, several small but relatively high-grade ore bodies occur along a fault in lakebeds and tuffs. Nearby masses of opalite contain little or no cinnabar. The Bretz ore bodies have been mined by open pit; the Opalite ore bodies were mined by the glory-hole method. Ore has not been found at either mine below a depth of about 100 feet, although at the nearby Cordero deposit the depth of mining exceeds 800 feet. Deep drilling at the Opalite deposit encountered only massive pyrite.

Many small mercury deposits occur in southern Harney County in a narrow belt extending about 40 miles northward from the Nevada State line along the lower eastern flanks of the Steens and Pueblo Mountains (No. 10) (Ross, 1942; Williams and Compton, 1953). Total production from these deposits has been only about 75 flasks. In a majority of the deposits, cinnabar, schwatzite (a mercurial tetrahedrite), and other copper minerals are contained in long, narrow reefs of brecciated and silicified andesite. These reefs are more resistant than the enclosing rocks and, as a result, form prominent ridges about 25 feet wide and as much as half a mile in length.

On the Oak Grove Fork of the Clackamas River in Clackamas County (No. 11), cinnabar occurs in banded calcite veins in basalt of the Columbia River Group. At Glass Buttes (No. 12) in northeastern Lake County, mercury deposits are scattered over a wide area; most occur in zones of opalitization along faults cutting glassy volcanic rocks (Ross, 1941a). Deposits of the opalite type also occur in the Quartz Mountain area (No. 13) west of Lakeview. At the Canyon Creek mine (No. 14) in Grant County, cinnabar is found along frac-

tures in Upper Triassic sandstones and shales. This deposit, which was discovered in 1963, has yielded about 65 flasks of mercury from intermittent operation.

Recent all-time high prices have generated renewed interest in mercury mining in Oregon, and a few old mines have been reactivated. If prices continue at 1965–67 levels, the revitalized prospecting will probably find new exploitable ore bodies. Areas adjacent to the more productive mines have often proved to be the best targets for exploration, and many "worked-out" mercury mines have been successfully reactivated when high prices stimulated search for new ore. However, some of the more than 60 scattered small mines and prospects that have produced between 1 and 1,000 flasks might, with cautious, well-advised exploration, develop into paying mines. Recently developed mercury detectors and geochemical sampling techniques should be of aid in the search for new deposits, particularly in the Cascade Range or other areas where soil cover is heavy.

Molybdenum

(By R. U. King, U.S. Geological Survey, Denver, Colo.)

Molybdenum is a silvery white metal, somewhat softer than steel. Its melting point is 4,730° F which is higher than all other common metals except tungsten, rhenium, osmium, and tantalum. It has a specific gravity of 10.2, about as heavy as silver or bismuth.

Molybdenum is a metal of primary importance to our modern industrial and scientific community chiefly because of its superior properties as an alloying element in the iron and steel industry, but also because of its versatility in applications to the electric and electronics, missiles and aircraft, metal working, nuclear energy, chemical, glass, and metallizing industries as well as in such uses as lubricants, pigments, catalysts, and agricultural products. Somewhat over 85 percent of the molybdenum produced in the United States is used in the manufacture of high-temperature alloy steels, stainless steel, castings, and special alloys to which it imparts such beneficial properties as increased hardness, toughness, resistance to corrosion and wear, and high-temperature strength.

Commercial production began in the United States at about the close of the past century but continued small and intermittent until about 1914. Probably the first successful industrial application of molybdenum was its use as alloy in steel by the German military during World War I. Since that time production has increased yearly with few exceptions from an annual rate of about 200,000 lb to the current annual rate of about 90,000,000 lb. During the first part of this century, the United States produced only a fraction of the world's molybdenum supplies but since 1925 has ranked first in world production of molybdenum, having reached this level of production with the development of the large molybdenite mine at Climax, Colorado, and the recovery of molybdenum as a by-product from the large porphyry copper deposits in the southwestern States. Since that time, from two-thirds to nine-tenths of the world's molybdenum has been produced in this country. Molybdenum, today, is produced in quantities sufficiently in excess of domestic consumption to supply a sizable portion of the Free World demand, and is the only ferroalloy metal for which the Nation

has a net exportable surplus. According to the U.S. Bureau of Mines, United States consumption of molybdenum in 1966 amounted to slightly more than 75 million pounds whereas mine production was just over 90 million pounds of contained molybdenum. A continued rise in both production and demand for molybdenum is foreseen for the remainder of this century.

Molybdenum is marketed chiefly in the forms of molybdenite concentrates (prices quoted in early 1968 were $1.62 per pound of contained molybdenum, at 95 percent MoS_2) or roasted concentrates (molybdenum trioxide). Concentrates, however, are not normally marketable in small or individual lots, thus limiting the economic potential of small deposits.

Ore-grade molybdenum deposits in the United States range from 0.2 to 0.5 percent molybdenite in large ore bodies mined primarily for their molybdenum content, but molybdenum is profitably extracted as a by-product from copper, uranium, and tungsten ores in which the molybdenum content ranges from 0.01 to 0.1 percent.

Molybdenum is widespread in the crustal rocks of the earth, but concentrations of commercial interest are found chiefly in igneous rocks of granitic composition or in sedimentary rocks closely related to granitic rocks. The abundance of molybdenum in the crustal rocks is variously estimated to be from 1 to 2.5 parts per million (0.0001 to 0.00025 percent). It is present in trace amounts in the oceans, in ground water, soils, and in plant and animal tissues in which it apparently plays a vital role in many organic processes. It does not occur in its native or metallic state, but only in combination with other metallic elements such as arsenic, bismuth, calcium, cobalt, lead, magnesium, tungsten, and vanadium, and the nonmetallic elements sulfur and oxygen.

Some 12 minerals are known to exist in nature that contain molybdenum as an essential element, but only two of these, molybdenite (molybdenum disulfide, MoS_2) and wulfenite (lead molybdate, $PbMoO_4$) have been the source minerals of most of the molybdenum produced to date. Recently, however, two other molybdenum minerals, ferrimolybdite ($FeMoO_3$–nH_2O) and jordisite (amorphous molybdenum disulfide, Mos_2) have been found to occur in sufficient concentrations to be of commercial value for their molybdenum content. Two additional molybdenum minerals, which are of more than passing interest either for their molybdenum content or geologic significance as the demand for this metal continues to rise, are powellite (calcium molybdate, $CaMoO_4$, often associated with tungsten) and ilsemannite (blue, water-soluble molybdenum oxysulfate).

MOLYBDENUM IN OREGON

Molybdenum deposits are scattered sparsely across the State, but are concentrated largely in the Blue Mountains province in the northeastern part of the State and in the Klamath Mountains province in the southwestern part of the State. Although Oregon has not had significant production of molybdenum, some of the deposits were recognized and prospected as early as 1917 (Petar, 1932). The known molybdenum deposits of Oregon are shown on figure 41 and are briefly described in table 9.

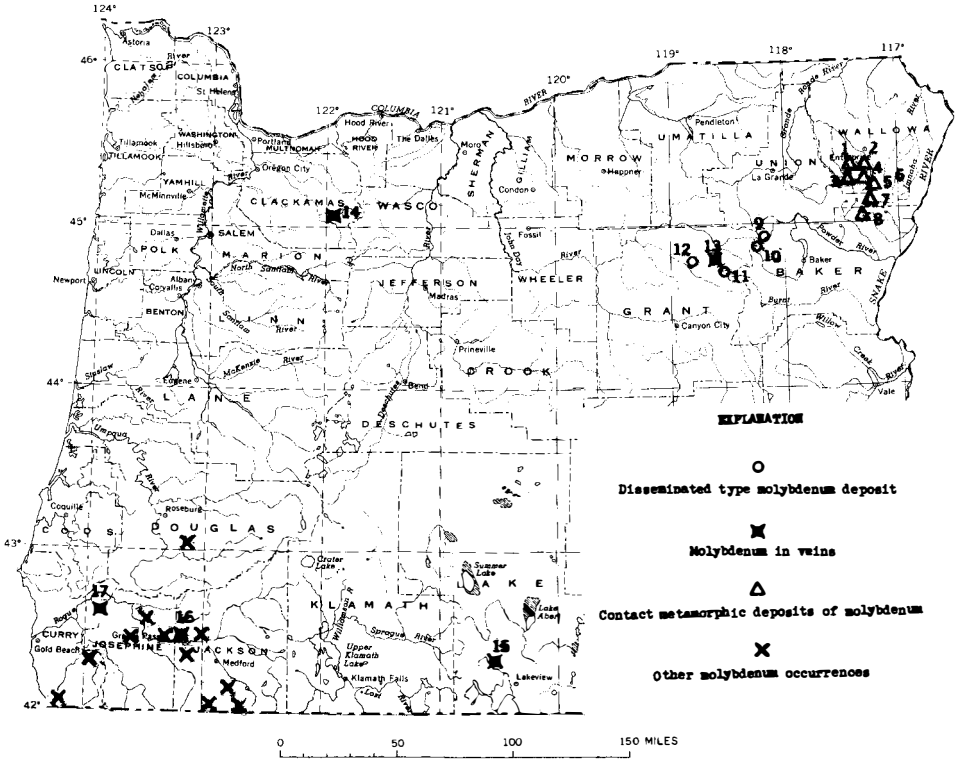


FIGURE 41.—Molybdenum in Oregon.

TABLE 9.—MOLYBDENUM DEPOSITS OF OREGON

Index No.	County and district	Locality	Mode of occurrence	Selected references
	BLUE MOUNTAINS			
1	Wallowa, Wallowa Range	Metzger property	Molybdenite with scheelite along contact between marble and granodiorite.	Wolfe, H. D., and White, D. J., 1951.
2	Do	Le Gore prospect	Molybdenite, pyrite, chalcopyrite, pyrrhotite, and traces of scheelite in tactite between limestone and granodiorite.	Smith, Allen, and others, 1941; Wolfe and White, 1951.
3	Do	Contact mine (Peacock property)	Molybdenite and pyrite in tactite 10 feet wide between siliceous sediments and marble.	Smith, Allen, and others, 1941.
4	Do	Wilmot property (Matterhorn group)	Disseminated molybdenite, pyrite, chalcopyrite, and scheelite in tactite between limestone and granodiorite.	Smith, Allen, and others, 1941; Wolfe and White, 1951.
5	Do	Green group (Copper King, Copper Gem, Mountain Gem).	Disseminated molybdenite, pyrite, and chalcopyrite in quartz and calcite along contact of aplite, basalt, and pegmatite with limestone.	Smith, Allen, and others, 1941.
6	Do	Seeber mine	Molybdenite, chalcopyrite, and chalcocite, in tactite 20 feet wide between limestone and granodiorite.	Do.
7	Union, Wallowa Range	Frasier prospect	Molybdenite, pyrite, chalcopyrite, and scheelite in tactite zone surrounded by quartz diorite.	Hess and Larsen, 1922; Wolfe and White, 1951.
8	Baker(?)	Drum Lummon (Dodson?)	Molybdenite in metamorphosed limestone	Petar 1932.
9	Baker, Elkhorn	Kuehn prospect	Coarse, flaky molybdenite, ferrimolybdite, and silver disseminated in aplite.	Oregon Dept. Geology and Mineral Industries, unpub. file data.
10	do	North Powder River prospect	Molybdenite, ferrimolybdite, pyrite, copper sulfides and native copper in aplite, pegmatite and granodiorite.	Do.
11	Grant, Greenhorn	Bi-metallic (Intrinsic) group	Molybdenite, pyrite, chalcopyrite and tetrahedrite, disseminated in veined and fractured diorite.	Parks and Swartley, 1916.
12	do	Gardner-Murphy prospect	Molybdenite and copper sulfides disseminated in shear zones in granodiorite.	Oregon Dept. Geology and Mineral Industries, unpub. file data.
13	do	Bowman (Molybdenum mine)	Molydbenite in quartz veins cutting biotite-quartz diorite	Oregon Dept. Geology and Mineral Industries, 1941.
	CASCADE RANGE			
14	Clackamas	Kiggins and Nesbit mine	Ilsemannite, jordisite, and calcite with mercury in veins	Staples, 1951; Brooks, 1963.
	BASIN AND RANGE			
15	Lake	White King mine	Ilsemannite and jordisite with uranium in veins in volcanic rocks.	Peterson, 1958.
	KLAMATH MOUNTAINS			
16	Jackson	Irwin molybdenum prospect	Molybdenite, cassiterite, pyrite, chalcopyrite, and bismuth minerals in quartz, veins.	Lowell, 1942.
17	Josephine	Blue Bell prospect	Molybdenite in veins in greenstone	Diller, 1914.

Molybdenum deposits occur in a variety of geologic environments and in various forms or types. The most important deposits economically are the disseminated or porphyry type deposits associated with intrusive rocks of granitic or monzonitic composition that have been fractured and pervasively altered and mineralized. In such deposits molybdenite may be either the principal metallic mineral or only a minor constituent associated with copper sulfides. These deposits commonly have low metal contents but a number are of relatively large size and are therefore economically minable by large-scale low-cost mining methods. More than 95 percent of the domestic reserves of molybdenum are in this type of deposit. They have been by far the most productive of molybdenum in the past and constitute the greatest resource potential of molybdenum for the future. Typical of large porphyry type deposits are those at Bingham, Utah; Morenci, Arizona; Questa, New Mexico; and Climax, Colorado. The first two are copper mines; at the others molybdenum is the chief metal produced. Four small disseminated molybdenum deposits are reported to occur in the Blue Mountains province in northeastern Oregon. At the Kuehn (No. 9, fig. 41) and North Powder River (No. 10) prospects in the Elkhorn Mountains, molybdenite occurs with copper sulfides, traces of silver, and pyrite irregularly disseminated in fine to coarse flaky aggregates in pegmatitic and aplitic rocks and granodiorite. At the Bi-metallic group (No. 11) and the Gardner-Murphy prospect (No. 12) in the Greenhorn Mountains, molybdenite occurs with chalcopyrite, pyrrhotite, pyrite, and silver sulfides in quartz veins and disseminations in shear zones in diorite. The economic potential of these occurrences for molybdenum is not known.

Molybdenum occurs in contact metamorphic deposits and tactite bodies of silicated limestones along contacts between granitic intrusive rocks and lime-rich sedimentary rocks. Ore minerals generally consist of molybdenite, scheelite, chalcopyrite, and powellite in variable amounts, in gangue composed of garnet, epidote, calcite, pyrite, quartz, and other contact metamorphic minerals. Molybdenite has been produced from contact deposits but not in any large quantities, although this type of deposit has yielded significant tungsten. A number of contact deposits are known in the Wallowa Mountains in the Blue Mountains province of northeastern Oregon (fig. 41 and table 9, Nos. 1 to 8).

The most widespead type of molybdenum occurrence is probably in quartz veins, aplitic rocks, and pegmatites, in which it is commonly associated with bismuth, copper, tungsten, or tin minerals. The most common primary molybdenum mineral is molybdenite, which is often accompanied or replaced in the near surface parts of the deposits by wulfenite, ferrimolybdite, powellite, or ilsemannite. The molybdenite is commonly coarsely crystalline, forming large rosettes and irregular masses and books, and thin coatings of "paint" on fracture surfaces. In a finely divided state in thin quartz veinlets, molybdenite is often concentrated along the margins of the veinlets. Powellite is the common molybdenum mineral in deposits containing scheelite, and in many tungsten deposits molybdenum is present as a contaminant in scheelite thus reducing its economic value. High-grade quartz-molybdenite vein deposits containing several percent molybdenum have

yielded considerable molybdenum in the past, particularly in Arizona, New Mexico, and Colorado, but are not likely to be economically minable in the future because of the relative high cost of exploration for and mining of this type of deposit. Molybdenite in quartz veins cutting granodiorite occurs in the Greenhorn district (No. 13, fig. 41) in the Blue Mountains; and in the Klamath Mountains in greenstone (No. 17), and with copper, tin, and bismuth minerals in Paleozoic metavolcanic rocks (No. 16).

Ilsemannite and jordisite occur with mercury minerals and calcite in the Kiggins and Nesbit mines (No. 14) on the Oak Fork of Clackamas River in Clackamas County and with uranium minerals in the White King mine (No. 15) in Lake County. The amount of molybdenum present is very small and would not likely have any economic potential.

The potential for significant molybdenum production from Oregon does not appear to be great. Known deposits are small, and the types of deposits recognized are not generally known to be large producers. However, some production may be possible. Among the more promising areas are the Elkhorn-Greenhorn areas in the Blue Mountains. The Klamath Mountains may contain veins or disseminated deposits of potential value, and the Wallowa Mountains may contain contact type deposits of limited production potential.

Nickel

(By P. E. Hotz, U.S. Geological Survey, Menlo Park, Calif., and Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg.)

Nickel, a hard, silvery white metal, has many uses in science and industry, in addition to its common use in coinage, because of its alloying properties with other metals. Large quantities are consumed in the manufacture of ferrous alloys, but it also is used in combination with other metals, especially copper and chromium. Special-purpose nickel alloys are being developed for use in the rapidly expanding nuclear, rocket, and aircraft industries. To a somewhat lesser but important extent, the unalloyed metal is used in the electroplating industry, for the manufacture of batteries, and in the chemical and electronic industries. The demand for nickel increases annually.

In 1965 the United States used 172,084 tons of nickel, or slightly more than 36 percent of the world production of 472,000 tons (Lynde, 1966). At the same time, domestic production of nickel was only 13,500 tons, or less than 8 percent of the annual consumption. More than 99 percent of the United States imports of nickel are from Canadian sulfide deposits, 86 percent imported directly, and the rest by way of Norway and the United Kingdom. Small amounts are imported from France, West Germany, South Africa, the Dominican Republic, Columbia, and Asia (Lynde, 1966). The only production of nickel ore in the United States is from Nickel Mountain near Riddle in Douglas County, where more than 9 million tons of ore were mined by the Hanna Mining Company between 1954 and 1965. From the mine output the Hanna Nickel Smelting Company produced approximately 277,021 tons of ferronickel containing 136,116 tons of nickel valued at $185 million (U.S. Bur. Mines Yearbooks, 1954–1965). A few hundred ad-

ditional tons of nickel are produced domestically as a by-product of copper refining and from scrap metal.

Deposits of nickel ores are of two main types: (1) sulfide deposits, and (2) lateritic deposits. Productive nickeliferous deposits in Oregon are restricted to the lateritic type.

The lateritic nickel deposits of Oregon are of two kinds: (a) the nickel silicate type, and (b) ferruginous nickeliferous lateritic soils. In ores of the nickel silicate type a significant part of the nickel occurs as green hydrous nickel magnesium silicates, which are commonly referred to under the general name garnierite. The ferruginous nickeliferous lateritic soils are reddish-brown surficial blankets of variable, complex mineralogy in which no specific minerals are discernible. The nickel, invariably accompanied by smaller amounts of cobalt, probably is combined with hydrated iron compounds, clays, and serpentine minerals in the soil.

Lateritic nickel deposits are the products of weathering of ultramafic rock, commonly peridotite or its altered equivalent, serpentinite. Ultramafic rocks contain between 0.1 and 0.3 percent nickel and about 0.01 percent cobalt, which are present as minor constituents in the magnesium-iron silicate minerals. Through natural weathering processes, the rock-forming minerals decompose and the more soluble compounds, principally magnesia and silica, are carried off by downward-percolating rainwater, while less mobile constituents, including hydrous iron oxide, nickel, and cobalt, are concentrated in the residual soil, thus forming the ferruginous nickeliferous lateritic deposits. Under some circumstances nickel is dissolved, removed, and recombined with silica and magnesia and redeposited to form a boxwork of microcrystalline quartz and garnierite below the soil zone, above a substratum of partly weathered ultramafic rock. The resulting deposit is the nickel silicate type.

A natural nickel-iron alloy, josephinite, containing 76 percent nickel occurs as occasional pebbles in placers on Josephine Creek, 3½ miles west of Cave Junction, Josephine County. Its source has never been discovered, although possibly it is derived from the serpentinite, and it constitutes a mineral curiosity rather than a potential resource.

NICKEL DEPOSITS OF OREGON

Apart from a small deposit of copper-nickel sulfides at the Shamrock mine in Jackson County (Hundhausen, 1952) Oregon's known resources of nickel are almost entirely of the lateritic type. The lateritic nickel deposits of Oregon are in the southwestern part of the state, in Josephine, Curry, and Douglas Counties, where there are many bodies of ultramafic rock (fig. 42). The deposits overlie fresh party serpentinized peridotite, and generally they occupy nearly flat-lying to gently sloping areas on broad ridge crests, in saddles, and on benches on the sides of ridges in the thoroughly dissected and deeply eroded mountainous terrain of the Klamath Mountains physiographic province.

The principal deposit, at Nickel Mountain near Riddle, Douglas County, is essentially of the nickel silicate type. It has been studied and described by Kay (1907), Pecora and Hobbs (1942), Pecora,

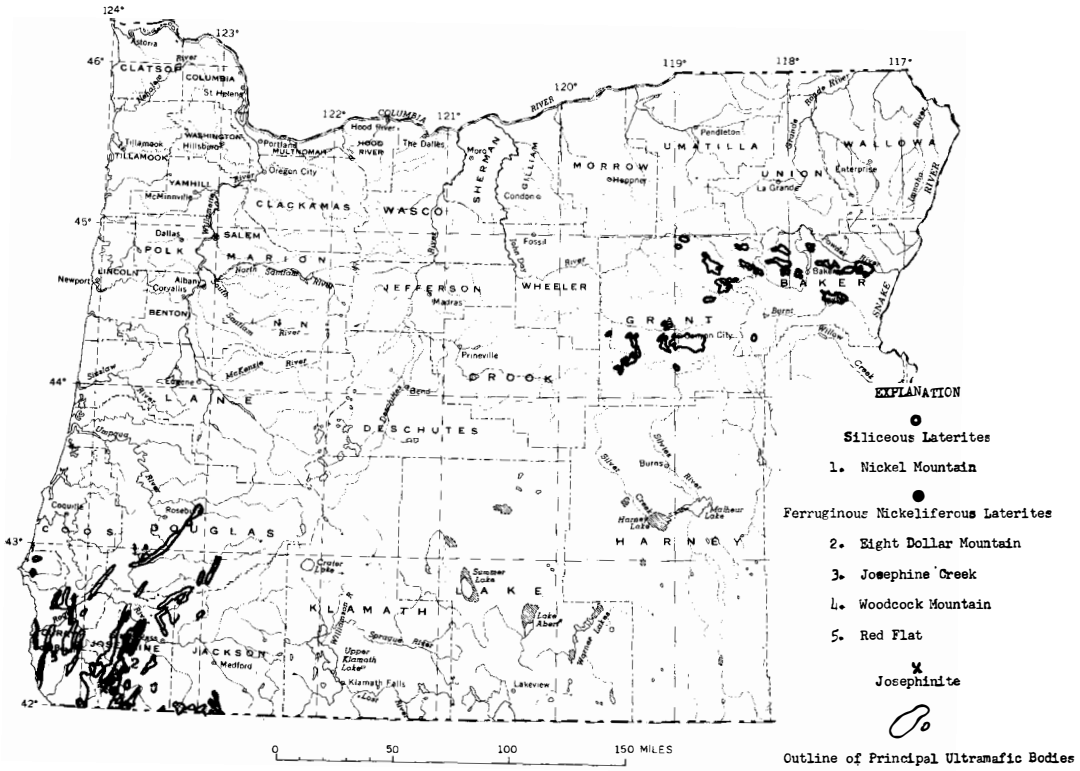


FIGURE 42.—Nickel in Oregon.

Hobbs, and Murata (1949), and Hotz (1964). The deposit occurs in two areas. The largest, which is now being mined, occurs at the top of the mountain; a second, considerably smaller deposit, is on a bench on the southeastern slope of the mountain. Both are underlain by fresh peridotite.

The deposit is overlain by a blanket of reddish brown soil that averages 2 to 3 feet thick. Beneath the surficial layer is the main nickel-bearing zone, which Pecora and Hobbs (1942, p. 217) called the "quartz-garnierite boxwork layer." This layer, of highly variable thickness, but commonly ranging from 5 to 40 feet thick, is a soft, limonitic soil containing a network of veins and veinlets of microcrystalline quartz and garnierite. In its lower part the quartz-garnierite boxwork zone grades downward through progressively less weathered material into fresh peridotite. Nickel occurs throughout the weathered zone but is most abundant in the quartz-garnierite boxwork. The base of the weathered zone is highly irregular and is characterized by pinnacles and "horses" of unweathered peridotite surrounded by soft, weathered rock containing quartz-garnierite boxwork, and rootlike extensions into fresh rock of weathered material containing quartz-garnierite veins. These downward extensions are localized in zones of faulting and fracturing (J. T. Cumberlidge, written communication, 1965). The ore as mined from 1954 to 1963 averaged approximately 1.5 percent nickel; in 1964 and 1965 the average was 1.44 and 1.42, respectively (U.S. Bur. Mines Minerals Yearbook, 1964, 1965).

The other lateritic nickel deposits in Oregon are ferruginous nickeliferous lateritic soils in Josephine and Curry Counties (fig. 42). All are characterized by a reddish brown surficial blanket underlain by yellow orange soil that grades downward in places through yellow brown saprolite into weathered peridotite. Commonly the yellow orange soil contains boulders of partly weathered peridotite. Unlike the Nickel Mountain deposit no nickel silicate minerals are associated with these deposits except for occasional films or veinlets of garnierite in the decomposed peridotite beneath the laterite. In places isolated, residual blocks or boulders of leached barren silica boxwork are scattered on the surface of the lateritic blankets, and chips of microcrystalline quartz occur in the soil and occasionally as veinlets near the base of the soil zone.

The principal deposits in Josephine County are on the west side of the Illinois Valley on Woodcock Mountain and Eight Dollar Mountain near the village of Cave Junction. They occur along the eastern margin of a large body of peridotite and serpentinite. At various times several mining companies have explored the deposits with drill holes and test pits. Exploration of the Woodcock Mountain deposit by geologists of the Oregon Department of Geology and Mineral Industry has been reported on by Mason (1949).

At Woodcock Mountain two blankets of lateritic soil, one approximately 4,500 feet long and from 500 to as much as 1,500 feet wide, and the other approximately 1,000 feet long and 800 feet wide, lie on the summit of a broad ridge at an altitude of approximately 3,200 feet. Two lateritic deposits occupy a bench on the southeast side of Eight Dollar Mountain, one of which is approximately 4,800 feet long by from 1,500 to 1,800 feet in width; dimensions of the other deposit are

approximately 3,000 feet long and from a few hundred to 1,000 feet wide. Exploratory pits and drill holes at both deposits show that the lateritic blanket is highly variable in thickness, ranging from 20 to as much as 100 feet. Nickel content is estimated to average 0.8 percent.

Some deposits of lesser importance occur approximately 3½ miles west of Cave Junction, where four small areas of lateritic soil mantle narrow terraces on the lower slopes west of Josephine Creek. The soil is thin, probably not exceeding 10–15 feet, with an average nickel content of 0.8 percent.

In Curry County the Red Flat lateritic deposit, approximately 8 miles southeast of Gold Beach, has been examined by geologists and engineers from several mining companies. It has been reported on by geologists from the Oregon State Department of Geology and Mineral Industry (Libbey, Lowry, and Mason, 1947; Dole, Libbey, and Mason, 1948) and by the U.S. Bureau of Mines (Hundhausen, McWilliams, and Banning, 1954). The deposit, which occupies a small area at the southern end of a long, narrow body of periodotite and serpentinite, is more than 5,000 feet long and averages approximately 1,000 feet in width. Exploration by drilling and trenching showed that the thickness of the deposit is highly variable and averages approximately 25 feet. The nickel content is estimated to average 0.8 percent.

RESOURCE POTENTIAL

In 1963 ore-reserve estimates by Hanna Mining Company placed the life expectancy of the Nickel Mountain deposit at 13 to 15 years, based on the 1962 rate of production (U.S. Bur. Mines Minerals Yearbook, 1963). There may be on the order of 30 million tons of ferruginous nickeliferous lateritic deposits in Josephine and Curry Counties (Cornwall, 1966, table 5) which average 0.8 percent nickel or less. Although it is not now economically feasible to mine them because of their low grade and dispersal among several relatively small deposits, they constitute an important resource that may be commercially exploitable in the future.

Platinum Group Metals

(By Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg., and H.C. Brooks, Oregon Department of Geology and Mineral Industries, Baker, Oreg.)

Metals of the platinum group include platinum, palladium, iridium, osmium, rhodium, and ruthenium. Each of the metals has important industrial applications, but platinum and palladium occur in the greatest abundance and have the largest number of uses.

The industrial applications of platinum and its alloys are based principally on their high resistance to chemical corrosion, heat, and oxidation, and their superior catalytic properties and electrical conductivity. These metals are used in laboratory utensils, special equipment for handling molten glass and drawing fiberglass, spinnerets through which various synthetic fibers are extruded, electrical thermocouples, high-temperature electric-furnace windings, pressure rupture disks, insoluble anodes for electrohydrometallurgical processing, catalytic gauze for oxidation of ammonia, and for the manufacture of

nitric acid, as a catalyst in the production of high-octane gasoline, electrical contacts especially in certain delicate sensing instruments, and in dental and medical devices. The popular use of platinum-group metals for jewelry and decorative purposes has decreased in importance to some extent in recent years due to the higher price of the metals and increasing demand by other industries.

Palladium has uses similar to platinum, and because of lower price and greater availability it has surpassed platinum in total consumption in recent years. Its major application is in the electrical industry. Other metals of the platinum group are used as alloys to improve the hardness and various other properties of platinum and palladium. Osmium and ruthenium are alloyed to make phonograph needles, tips for ball-point pens, and fine machine bearings (Ryan, 1960, p. 646).

The industrial consumption of platinum-group metals in the United States is shown in the following table:

PLATINUM GROUP METAL CONSUMING INDUSTRIES IN UNITED STATES—TROY OUNCES PURCHASED

Industries	1962	1963	1964	1965
Electrical	439,139	452,391	465,520	551,256
Chemical	210,266	290,579	273,981	308,482
Petroleum	14,273	56,918	154,905	118,651
Dental and medical	78,773	62,415	70,367	77,295
Jewelry and decorative	51,763	57,681	63,905	64,587
Glass	50,765	71,182	73,719	31,531
Miscellaneous	21,480	12,028	15,283	34,899
Total	866,459	1,003,194	1,117,680	1,186,701

Source: U.S. Bureau of Mines Minerals Yearbooks.

The price paid for crude platinum depends on the care used in cleaning the concentrate before shipment and on the proportion of the various platinum-group metals present. Hence the value of the crude product is based on the combined value of the metal content less treatment costs. Little information is available regarding the content of the various metals found in Oregon crude concentrates. In 1914, crude placer concentrate (107 troy ounces) from Oregon was estimated to contain about 70 percent metal of which 51 percent was platinum, 30 percent osmiridium alloy, and 3 percent iridium. The remaining metal consisted of iron, gold, and silver. The bulk of the 1914 production came from ocean beach sands near Bullards, Bandon, and Coos Bay, although some was recovered from inland hydraulic operations near Galice, Kerby, and Waldo (Hill, 1916).

Prior to 1903 there was little market for platinum. Beginning about 1900, when mine returns averaged $6.25 per troy ounce, the price of refined platinum increased almost steadily to more than $100 in 1917. When foreign platinum supplies were curtailed during and for a time after World War I, the price continued to rise and reached the record average of $154 per fine ounce in January 1920, as quoted in New York. Prices have fluctuated widely since that time. Present quoted prices (E&MJ, Dec. 1967) for the refined metals per troy ounce are: platinum $215–$220, palladium $38.50–$39.50, iridium $185–$190, osmium $300–$450, rhodium $258–260, and ruthenium $55–$60.

The physical properties of platinum-group metals are quite variable, as shown in the following table.

PHYSICAL PROPERTIES OF PLATINUM-GROUP METALS

	Specific gravity	Melting point (C)	Hardness	Habit
Iridium	22.5*	2200±	6.5	Hexagonal plates.
Osmium	22.6*	2500±	7.0	Hexagonal plates.
Palladium	11.4	1585	4.8	Small octahedrons(?), grains, radial fibrous structure.
Platinum	21.5	1780	4.3	Cubic, grains, scales, nuggets.
Rhodium	12.5	1955	?	?
Ruthenium	12.2	2450	?	?

*A recent report (Englehard Industries, Inc., 1965) gives iridium a higher specific gravity than osmium: Ir=22.65; Os=22.61.

These metals are bright, silvery white, heavy, and relatively hard. They are found alloyed with one another as well as with variable amounts of iron, copper, gold, and nickel. Source minerals for the platinum-group metals are listed below.

SOURCE MINERALS OF THE PLATINUM-GROUP METALS

Platinum (Pt)	Native Pt, braggite, niggliite, cooperite, sperrylite; in chromite.
Palladium (Pd)	Native Pd, stibiopalladinite, braggite, porpezite, potarite.
Osmium (Os)	Native Os, iridosmine, osmiridium, aurosmiridium.
Ruthenium (Ru)	Native Ru, in chromite, laurite.
Rhodium (Rh)	Native Rh, in chromite, rhodite.

The major world production of platinum-group metals is from the U.S.S.R., Canada, and South Africa. Russian production is from placer deposits in the Ural Mountains. In Canada the metals are recovered as by-products of the smelting of copper-nickel sulfide ores. South African production is derived from two major sources; osmiridium is recovered with gold ores from the Rand district, and a flat-lying, platinum-bearing layer about 12 inches thick is mined by cut and fill methods from a chromite- and sulfide-bearing horizon in the ultramafic Bushveld complex in the Rustenburg district.

The United States ranks as fourth in world production of platinum-group metals behind U.S.S.R., South Africa, and Canada. Present United States annual domestic production is about 3 percent of our consumption of the metals.

Most of the United States production has been derived from placer deposits in the Goodnews Bay district of Alaska. The Goodnews Bay Mining Co. dredging operation on the Salmon River in the southwestern part of the Kuskokwim River region, Alaska, is the only mining operation in the United States where platinum is the primary metal recovered. The gravels are nonglaciated stream deposits near two peridotite intrusions. Chromian magnetite and ilmenite are associated with the platinum. The company has produced placer platinum for more than 30 years. Gold placer operations in California and Oregon, at the time of their major activity, contributed small amounts of platinum-group metals. Prior to about 1930, California led the United States in platinum production. Other States that have produced small amounts of platinum include Washington, Nevada, and Wyoming. The Nevada and Wyoming deposits are in sulfide-bearing ores of copper and nickel.

The history of Oregon's platinum production is closely tied to its gold placer mining activity, and little or no production of platinum metals has been recorded since 1942 in spite of increased market price. Diller (1914, p. 128) summarizes the history of platinum production for southwestern Oregon and states that 1906 was a peak production year, but total figures for that year have not been reported.

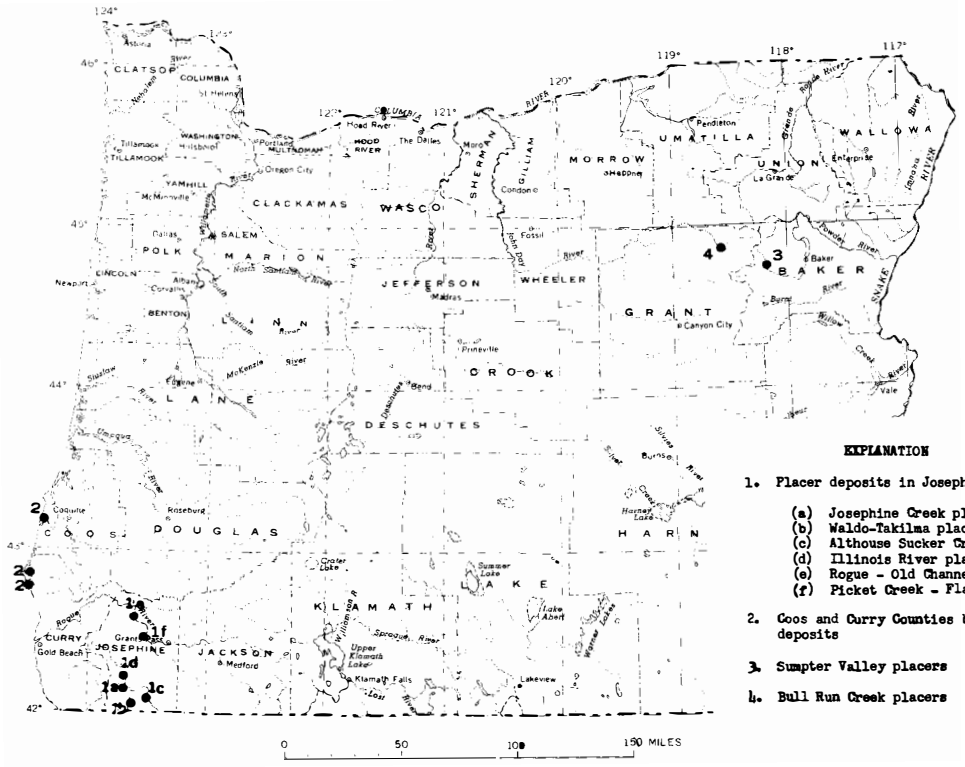
Oregon ranks third in total production of platinum in the United States, trailing far behind Alaska and California with a total recorded production from 1903 through 1945 of 2,018 troy ounces of unrefined platinum concentrates. Records of production prior to 1903 are meager. The first discovery of platinum in Oregon was probably made in the summer of 1850 by a small group of miners who worked a placer on the Illinois River near the mouth of Josephine Creek. It is not known. however, if they recognized the value of platinum at that time, and they may not have saved it.

The occurrence of platinum in the placers of southwest Oregon is mentioned by William Phipps Blake (Blake, 1854, 1855). At that time and for many years afterward there was little or no market for the metal. In describing the gold and platinum deposit of Cape Blanco (Blake, 1854), he states, "I am informed that miners throw out as much platinum as possible as it lessens gold value in San Francisco." Wells and others (1949, p. 21) report the occurrence of platinum in the Kerby area (near Waldo, Josephine Creek, and the Illinois River) and state that the recovered metals contained "about 30 percent platinum, 32 percent iridium, 25 percent osmium, 13 percent ruthenium, and little or no rhodium or palladium." They further report that the ratio of platinum to gold in mines near Waldo is about 1 to 75.

Known sources of platinum production in Oregon, as shown on figure 43, are a number of placer deposits in Josephine County, the black sand beach placers of Coos and Curry Counties (see also p. 102), by-product platinum associated with gold placers in Sumpter Valley, and iridium-rich concentrates from gold placers on Bull Run Creek, near Granite in Grant County. In addition to those, small amounts of platinum may have been recovered from stream placers in Curry County, where drainage areas include ultramafic rocks.

There are no known lode deposits of platinum in the State. Grains of platinum metals found in the placer deposits are presumed to have originated from ultramafic rocks—peridotite and its alteration product serpentine, where it occurs as small discreet particles erratically and sparsely distributed. The chances of locating workable lode concentrations are very poor.

The future potential of platinum production in Oregon is difficult to predict. Deposits of black sand along the coast of Coos and Curry Counties contain small amounts of gold and platinum and represent possible small reserves. Pardee (1934, p. 33) reported that the ratio of gold to platinum (by weight) recovered from black sands at Port Orford and Cape Blanco is about 100 to 1. These black sands also contain considerable chromite and other minerals that would be potentially valuable if separated into pure fractions (see p. —). Possible placer deposits lie offshore of Coos and Curry Counties, but there has been too little work done to evaluate their potential or content (Libbey, 1963; Byrne, 1964).



EXPLANATION

1. Placer deposits in Josephine County:
   - (a) Josephine Creek placers
   - (b) Waldo-Takilma placers
   - (c) Althouse Sucker Creek placers
   - (d) Illinois River placers
   - (e) Rogue - Old Channel placers
   - (f) Picket Creek - Flanagan & Big Four placers
2. Coos and Curry Counties beach placers, black sand deposits
3. Sumpter Valley placers
4. Bull Run Creek placers

FIGURE 43.—Principal platinum occurrences in Oregon.

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Titanium

(By Norman Herz, U. S. Geological Survey, Washington, D. C.)

Titanium, the ninth most abundant element, comprises about 0.6 percent of the earth's continental crust. Its chief use is as titanium dioxide (TiO_2) in pigments, but metallurgical advances over the last 20 years have led to increasing uses of the metal, as well. United States currently consumes about 1.1 million short tons of TiO_2 concentrates annually. Sources of the TiO_2 were ilmenite, rutile, and titanium slag. In 1962, uses were divided as follows: pigments 96.8 percent, welding rod coatings 1.5 percent, titanium metal 1.4 percent, and other uses, including ferroalloys, carbide, and plastics, 0.3 percent (Peterson, 1966).

Industry estimates that consumption of TiO_2 for pigments will increase about 5 percent a year through 1980. Demand for titanium metal is expected to increase at a rate of 10 percent a year until 1970, and at the rate of 15 percent a year from 1970 to 1980 (Stamper, 1965, p. 988).

Titanium dioxide was developed as a pigment for paints because of its high opacity, its chemical and physical stability, and its low specific gravity. By 1963, in the United States, titanium dioxide base pigment far exceeded the production of all other white pigments combined (Stamper, 1965, p. 972).

Titanium is the fourth most abundant structural metal, has the highest strength to weight ratio of any of them, shows little change in physical properties from minus 300° to 1,000° F, and has the greatest resistance to corrosion of any common metal or alloy (Schlain, 1964). These properties explain its increasing use in supersonic jet aircraft, rockets, submarines, desalination plants, and elsewhere in industry where extreme temperatures or corrosion are major problems.

The principal economic minerals of titanium are rutile (TiO_2) and ilmenite ($FeTiO_3$). United States production of rutile in 1964 was 10,500 short tons and of ilmenite in 1966 was 868,000 short tons (Stamper, 1967). Both rutile and ilmenite are found in primary or lode deposits in igneous or metamorphic rocks and in alluvial or eluvial deposits, including placers, beach sands, saprolite, and bauxite. The principal ilmenite deposits, however, are primary, and are associated with anorthosite-gabbro complexes, whereas most of the world's rutile is obtained from beach sands. United States ilmenite production is from anorthosite deposits in New York, saprolite derived from anorthosite and related rocks in Virginia, and beach sands in Florida and New Jersey. Rutile is produced from saprolite in Virginia and beach sands in Florida. Anatase (TiO_2) and other alteration products of ilmenite are also recovered from some placer deposits.

Oregon has no deposits of titanium that are economically exploitable at present. The known resources occur in two forms that may be exploited with technological improvements or in a time of national emergency. The first type of deposit is ilmenite in ferruginous laterite derived from basalt; the second is ilmenite in black sand placers in beach and terrace deposits.

Ferruginous bauxite deposits containing ilmenite occur in a discontinuous 100-mile long belt in Columbia, Washington, Polk, Yamhill and Marion Counties (Roedder, 1956; Libbey, Lowry, and Mason, 1945), as shown on figure 44. The deposits are derived from the

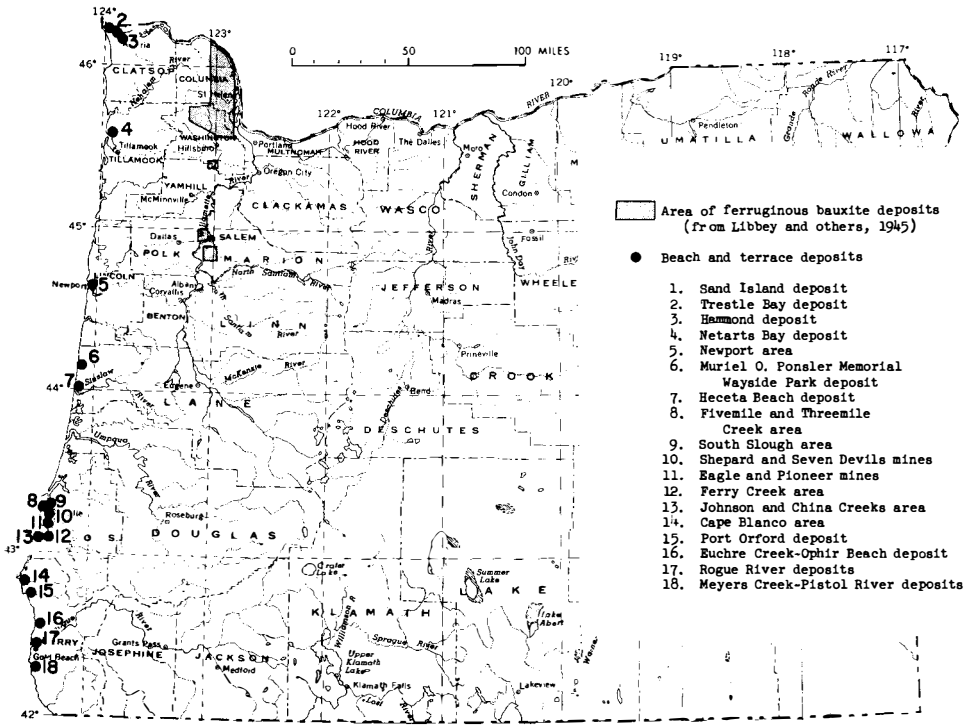


FIGURE 44.—Titanium in Oregon.

weathering and formation of laterite in the upper part of Miocene basalt flows. The ilmenite concentration increased in the laterite by residual accumulation due to the removal of more soluble constituents, such as the silicate and iron oxide minerals. Total resources of TiO_2 in the 50 million tons of ferruginous bauxites (p. 100) are estimated at about 3.25 million tons, assuming an average tenor of 6.5 percent TiO_2. If an operation to produce alumina from Oregon's ferruginous bauxite proved commercially feasible, the ilmenite could easily be recovered from the "insoluble residue" where TiO_2 constitutes 27.2–48.9 percent (Peterson, 1966, p. 37). Assuming all this TiO_2 is in ilmenite, the "insoluble residue" must contain about 45–80 percent ilmenite.

Heavy black sands occur in the beaches and terraces of the Oregon coast (Twenhofel, 1943, 1946; Griggs, 1945). South of Coos Bay chromite is more abundant than ilmenite, but to the north this ratio decreases. Although chromite concentrates were produced from the black sands in 1943, at that time ilmenite could not be marketed. Quantities of ilmenite in deposits checked by the Bureau of Mines have proven to be too low for commercial exploitation except for local concentrations in the Coos Bay area (Peterson, 1966). These placer deposits are shown on figure 44 and itemized in the following table which has been adapted from Rogers and Jaster (1962).

OREGON BEACH AND TERRACE PLACER DEPOSITS CONTAINING ILMENITE

[Numbers refer to map locations on figure 44]

Name of deposit	Principal minerals; accessory minerals	Type of placer
1. Sand Island	Magnetite, ilmenite	Beach.
2. Trestle Bay	do	Do.
3. Hammond	Magnetite, ilmenite; garnet, zircon, rutile	Terrace.
4. Netarts Bay	Ilmenite, chromite; zircon, magnetite, garnet	Beach.
5. Newport Beach and Big Creek Bay	do	Do.
Yaquina Bay	Ilmenite, chromite; zircon, garnet, magnetite	Dune sands.
6. Muriel O. Ponsler Memorial Wayside Park.	Ilmenite, chromite; zircon, magnetite, garnet	Beach.
7. Heceta Beach	do	Do.
8. Fivemile and Threemile Creek area	Chromite, ilmenite; zircon, magnetite, garnet	Beach and inland terrace.
9. South Slough Area	do	Terrace.
10. Shepard and Seven Devils mines area	Chromite, ilmenite; gold, platinum, magnetite, garnet, rutile, zircon, monazite.	Do.
11. Eagle and Pioneer mines (Lagoons) area.	do	Do.
12. Ferry Creek area	Chromite, ilmenite; zircon, magnetite, monazite	Do.
13. Johnson and China Creeks area	Chromite, ilmenite; zircon, magnetite, garnet	Beach and terrace.
14. Cape Blanco area	do	Do.
15. Port Orford	Chromite; ilmenite	Beach.
16. Euchre Creek-Ophir Beach	do	Do.
17. Rogue River	Chromite; ilmenite, magnetite	Do.
18. Meyers Creek-Pistol River	do	Do.

Lawthers (1954, p. 137) estimated the total amount of ilmenite and chromite in the placer deposits at 25,000 short tons, based on the reconnaissance surveys of Twenhofel. Lawthers (1954, p. 139) also estimated the total reserves of some of the better beach deposits north of Coos Bay, where ilmenite presumably is most abundant. This estimate is also based on Twenhofel's work and is given for combined ilmenite and chromite in short tons:

Heceta Beach	3,500
Newport Beach	2,750
Big Creek Bay	12,800
Yaquina Bay	6,300

There appears little likelihood that the Oregon deposits will be exploited for ilmenite in the near future, except as a by-product of chromite in placer deposits, or of bauxite in laterite deposits.

Tungsten

(By S. W. Hobbs, U.S. Geological Survey, Denver, Colo., and E. A. Magill, U.S. Bureau of Mines, Seattle, Wash.)

Tungsten has been a very minor metal in the mineral economy of Oregon, and the total production to date has contributed less than 0.01 percent of the total for the Nation.[10] Known occurrences of tungsten minerals are restricted to two areas—the Medford-Ashland area in Jackson County, southwestern Oregon, and the Wallowa-Blue Mountains area in Wallowa, Baker, Grant, and Union Counties of northeastern Oregon. Most of the recorded production has come from Jackson County. Many of the occurrences reported are in mines originally developed for other minerals—notably gold, although a few of the deposits in the State were discovered and opened for tungsten alone.

Tungsten is an important industrial commodity because of the unique physical and chemical properties of the metal, its compounds and its alloys. These properties include unusual strength, hardness, heat resistance and electrical characteristics. A familiar usage of the pure metal is for filaments in electric light bulbs, but the greatest usage is in alloy steels for high-temperature applications, in nonferrous alloys and in tungsten carbide for cutting tools and other uses where extreme hardness and heat resistance are required. Various chemical compounds are used for dyes, inks, and the fluorescent coatings in lamps.

The pure metal is light gray, very heavy (specific gravity 19.3), and has the highest melting point of all the metals (3,410° C.). It does not occur as a native element in nature but is always combined with other elements in one or another of some 14 minerals of which only scheelite (calcium tungstate) and the gradational members of the wolframite group—ferberite (iron tungstate), wolframite (iron and manganese tungstate), and huebnerite (manganese tungstate)—are commercially important. These minerals occur in pegmatites, quartz veins, contact metamorphic deposits (tactite or skarn), hydrothermal replacement deposits, stockworks or breccia zones, hot spring deposits associated with manganese oxides, and as placer deposits.

Most primary tungsten deposits are closely associated both areally and genetically with rocks of granitic or monzonitic composition. The search for new deposits has in many places successfully utilized this concept to outline favorable areas for prospecting and to eliminate much terrain in which a search would be futile.

Most tungsten ore requires concentration to a product that contains 60 to 70 percent of WO_3 before it is marketable. Imperities of tin, copper, bismuth, antimony, arsenic, molybdenum, phosphorus, sulfur, lead, and zinc must be less than certain tolerances to avoid penalties that reduce the prices received for the concentrate. The price is based

[10] Production data from U.S. Bureau of Mines Minerals Yearbooks.

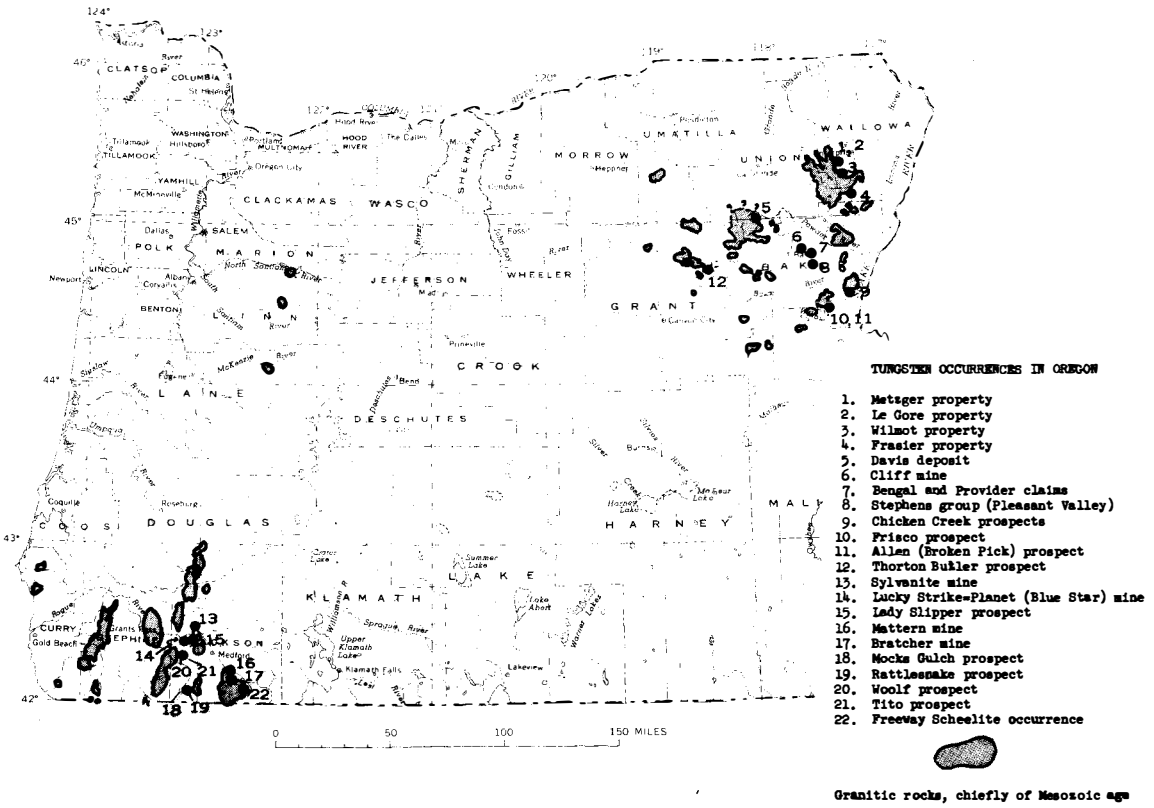
on the short ton unit (20 pounds of WO_3, containing 15.862 pounds of tungsten metal), which has ranged from $2 in the early part of this century to $85 in 1916. At the time of maximum domestic production in 1955 the price was $63; in October 1967 it was approximately $43. Domestic consumption has been in the range of about 12 to 14 million pounds annually since 1960, whereas production has averaged about 8 million pounds.

Most of the known tungsten occurrences in Oregon have been carefully compiled and described by Wolfe and White (1951), and much of the data for this chapter is taken from their work. Other valuable information was obtained from the Oregon Metal Mines Handbook (1939, 1943) prepared by the staff of the Oregon Department of Geology and Mineral Industries, from a compilation of tungsten deposits in the United States by Lemmon and Tweto (1962), and from Defense Minerals Exploration Administration and other reports on individual properties.

Scheelite is the only tungsten mineral identified in the reported occurrences in Oregon. It occurs principally in contact metamorphic (tactite) deposits, in quartz veins and in shear zones. At one place near Pleasant Valley, tungsten is reported to occur with oxide manganese ore in an unknown form. The earliest mention of tungsten in Oregon was made by Lindgren (1901, pp. 644, 725) in his description of the Cliff mine near Baker. It was noted as early as 1909 in placer concentrates from Foots Creek in the Gold Hill area of Jackson County, and in 1916 small amounts were found in the gold-quartz veins of the Sylvanite mine in the same area. Other discoveries followed intermittently, the most notable being those on Pedro Mountain in Baker County, those in the Granite Boulder Creek area in Grant County, and at the Bratcher mine in Jackson County. All these were discovered between 1949 and 1954. The known deposits, some of which are little more than mineral occurrences, are placed in their general geologic setting in the following pages, are located on the map (fig. 45), and are briefly described in table 10. The properties are assigned consecutive numbers by which they are keyed to the map and table.

Deposits in northeastern Oregon are found in two main groups—those in the Wallowa Mountains south of the town of Enterprise, and those in and near the Blue Mountains scattered along a line northwest and southeast of the town of Baker. A lesser area is on the southern slope of the Greenhorn Mountains in Grant County. The Wallowa Mountains deposits include the Metzger property (1), Le Gore Prospect (2), Wilmot property (3), and the Frasier property (4). In all of these scheelite is found in small amounts in tactite formed at the contact of intrusive granodiorite and quartz diorite with limestones in the sedementary rocks of the area. The limestones have been replaced in large part by contact silicate zones comprising garnet, epidote, quartz and calcite which form the host rock for the erratically distributed scheelite as well as for small amounts of molybdenite, pyrite, chalcopyrite and a few other minerals. None of these properties appear to be of economic importance.

The occurrences near Baker include the Davis deposit (5), Cliff mine (6), Bengal and Provider claims (7), Stephens group (8), the Chicken Creek prospects (9), Frisco prospect (10), Allen (Broken



TUNGSTEN OCCURRENCES IN OREGON

1. Metzger property
2. Le Gore property
3. Wilmot property
4. Frasier property
5. Davis deposit
6. Cliff mine
7. Bengal and Provider claims
8. Stephens group (Pleasant Valley)
9. Chicken Creek prospects
10. Frisco prospect
11. Allen (Broken Pick) prospect
12. Thorton Bukler prospect
13. Sylvanite mine
14. Lucky Strike-Planet (Blue Star) mine
15. Lady Slipper prospect
16. Mattern mine
17. Bratcher mine
18. Mocks Gulch prospect
19. Rattlesnake prospect
20. Woolf prospect
21. Tito prospect
22. Freeway Scheelite occurrence

Granitic rocks, chiefly of Mesozoic age

FIGURE 45.—Tungsten in Oregon.

TABLE 10.—TUNGSTEN LOCALITIES IN OREGON

Locality No.	Name	Description	Selected references
1	Metzger property	Small amount of scheelite and disseminated molybdenite in tactite in contact zone between marble and granodiorite.	Wolfe and White, 1951; Oregon Dept. Geol. and Mineral Industries, 1939.
2	Le Gore prospect	Traces of scheelite and sparsely disseminated molybdenite, pyrite, chalcopyrite with minor sphalerite in tactite at contact of limestone and granodiorite. Tactite zone from a few inches to 20 feet wide.	Wolfe and White, 1951; Smith and Allen, with Staples and Lowell, 1941.
3	Wilmot property (Matterhorn group).	Sparsely disseminated scheelite with molybdenite, pyrite and chalcopyrite in small, poorly developed tactite zones along contact of granodiorite with a black shale-limestone sequence. Primarily a molybdenite prospect.	Do.
4	Frasier property	Scheelite, pyrite, chalcopyrite and molybdenite in tactite that borders a semicircular block of marble, several hundred feet in diameter, surrounded by quartz diorite. Scheelite occurs in fractures in the tactite and in quartz lenses along borders, but is very spotty and amount appears limited.	Wolfe and White, 1951; Oregon Dept. Geol. and Mineral Industries 1939; Hess and Larsen, 1922.
5	Davis (Brown) deposit	Very small amount of scheelite in several fractures and gouge seams in both limestone and greenstone near their contact with each other. Exposed in several small open cuts.	Wolfe and White, 1951.
6	Cliff mine	Scheelite reported to occur in a 1- to 3-foot wide quartz vein in altered gabbro. Vein originally mined for gold. Attempts in 1916 and later to mine for tungsten were largely unsuccessful.	Wolfe and White, 1951; Oregon Dept. Geol. and Mineral Industries, 1939; Gilluly, 1937.
7	Bengal and Provider claims.	Very small amount of scheelite in veins prospected for gold. Country rock is "porphyry and granite."	Oregon Dept. Geol. and Mineral Industries, 1939.
8	Stephens group (Pleasant Valley).	Small bodies of manganese oxides along bedding planes or joints in argillite. Believed to be derived from rhodonite and rhodochrosite of hydrothermal origin. Tungsten reportedly discovered during mill test of large composite sample of ore, but subsequent attempts to confirm the analysis have been unsuccessful.	Pardee, 1921.
9	Chicken Creek prospects	Narrow quartz veins and seams in quartz diorite that have been worked for gold. Scheelite appears as incrustations and powdery films in the vein and on vein walls and in narrow fractures in quartz. Although widespread, the amount appears to be extremely small.	Wolfe and White, 1951; Oregon Dept. Geol. and Mineral Industries, 1939.
10	Frisco prospect	Scheelite in and near a small body of almost massive iron sulfides in tactite along a contact between metamorphic rocks and quartz diorite. Tactite in immediate area appears to be limited to a zone about 50 feet in length and less than that in width.	
11	Allen (Broken Pick) prospect.	Disseminated scheelite in tactite zone along contact between quartz diorite and metamorphic rocks. Scheelite occurs in and near a zone of massive iron sulfides. Mineralized zone appears from present work to be limited to a few tens of feet in size.	
12	Thorton-Butler prospect	Contact zone between granite and metasedimentary rocks contains irregular disseminations of scheelite along shears and bedding planes. Placer scheelite also in Lemon Creek in unknown quantities.	
13	Sylvanite mine	Mineralized shear zones in metasedimentary and metavolcanic rocks of the Applegate Group. Main structure trends slightly east of north, dips 45° east; comprises sheared greenstone and slate, some quartz veins and stringers, and fault gouge. Minerals include much pyrite, a little galena, gold, and scheelite. Scheelite occurs in small quartz stringers or as small bands in wider quartz veins. The mine has been extensively worked for gold. A limited amount of exploration was done in 1953 especially for scheelite, but no production resulted.	Wolfe and White, 1951; Oregon Dept. Geol. and Mineral Industries, 1939; Parks and Swartley, 1916.
14	Lucky Strike-Planet (Blue Star) prospect.	Scheelite occurs in metavolcanic rocks of the Applegate Group adjacent to contacts with an intrusive quartz diorite. The metavolcanic sequence comprises altered basaltic and andesitic lavas containing a considerable amount of calcite. Narrow zones of contact silicates including some impure tactites have been developed in the metavolcanics along the borders of the intrusives, and scattered grains of scheelite are found in these contact zones. In 1955 slightly over 4,000 tons of scheelite-bearing rock was mined from an open pit and concentrated in a mill at Eagle Point, Oregon. About 30 units of WO_3 was recovered from the concentrates.	Wolfe and White, 1951

TABLE 10.—TUNGSTEN LOCALITIES IN OREGON—Continued

Locality No.	Name	Description	Selected references
15	Lady Slipper prospect	Scheelite disseminated in zone of metamorphic rocks along the contact of tuffs and amygdaloidal lavas of the Applegate Group with a small diorite intrusive. The lavas contain abundant calcite which has promoted the development of contact silicates and has helped to precipitate the scheelite. Exploration in this zone is limited, but amount of scheelite appears small.	Wolfe and White, 1951
16	Mattern deposit	Scheelite in a contact silicate zone in metavolcanic rocks of Applegate Group near the contact of the Ashland diorite stock. The exposure is in a railroad cut near the portal of the inactive Mattern gold mine. Diorite and narrow granite dikes crop out near the deposit and probably bear on the localization of the scheelite, which is scattered through the tactite exposure and occurs in small local concentrations. The tactite, which has a maximum width of 12 feet, has been explored by a 50-foot long drift from the railroad cut. In 1952 about 500 tons of ore was mined from an underhand stope in the drift. About 250 units of WO_3 was recovered.	Do.
17	Bratcher mine	Scheelite in tactite occurring as inclusions in the Ashland stock, which is a large intrusive igneous rock body comprising quartz diorite, granodiorite, and some porphyritic granite. Main lens of tactite in the Bratcher mine area is 150 feet long and as much as 25 feet wide. Other smaller ones lie within the quartz diorite nearby. The stock intrudes the Applegate Group of metavolcanic and metasedimentary rocks which includes layers and lenses of impure marble. Tactite bodies presumably formed from the contact metamorphism of such limy layers. Banding in tactite reflects the varied composition of the original sedimentary layers, being composed of different proportions of diopside, garnet, quartz, epidote, and wollastonite. In the main body, scheelite is associated with a wollastonite-garnet zone. Scheelite is erratically scattered in the tactite but shows some concentration in the vicinity of fracture zones. Development work consists of a large open cut and considerable bulldozer trenching. During 1949 and 1950 approximately 590 tons of ore yielded about 200 units WO_3. Of this, the first 100 tons yielded 109 units.	Do.
18, 19	Mocks Gulch prospect Rattlesnake prospect.	Scheelite in shear zones in metavolcanic rocks of the Applegate Group. At Mocks Gulch, a 3-foot wide shear zone contains scattered scheelite and small showings of cinnabar in the wall rock. At the adjacent Rattlesnake prospect, scheelite occurs as a very narrow stringer for a distance of about 15 feet on one side of an adit that was driven to explore for cinnabar.	Do.
20	Woolf prospect	Scheelite occurs in narrow quartz veins exposed in a bulldozer cut in metavolcanic rock, which is enclosed in quartz diorite. Scheelite mineralization is erratic, but crystals up to 1½ inches across have been found.	
21	Tito prospect	Scheelite is associated with numerous small quartz veins in quartz diorite. An open cut about 150 feet in length and 30 feet in width, plus a short adit, have explored the occurrence. A small gravity mill was erected on the property, but it is not believed that there was any production.	
22	Freeway scheelite occurrence.	On Interstate 5 about 4 miles south of Ashland, a narrow zone of tactite with scheelite lies along the west side of a 3-foot lens of marble in metasedimentary rocks of the Applegate Group and is exposed in a highway cut. The occurrence is along the eastern margin of the Ashland stock.	Oregon Dept. Geology and Mineral Industries, 1964, unpublished report.

Pick) prospect (11), and the Thorton-Butler prospect (12). In contrast to the tactite deposits of the Wallowa Mountains, these comprise veins and veinlets in greenstone, limestone, granodiorite, or gabbro, or are associated with manganese deposits in the Pleasant Valley area. The gangue is usually quartz in which occur small stringers or specks of scheelite as well as other minerals of economic interest—especially gold. The scheelite is spotty and of small amount, and no records of

production are known. Pardee (1921) cites an assay report that indicates approximately 0.75 percent WO_3 in a mill sample of ore from the Stephens group of claims in the Pleasant Valley manganese district. While this is unusual, the association of tungsten and hydrothermal manganese mineralization is well known in numerous places. In such deposits, the tungsten is thought to be absorbed in limonite or to be a minor component of several of the manganese minerals. However, thorough sampling of the Stephens group failed to confirm the presence of tungsten (F. W. Libby, personal communication).

Known deposits in southwestern Oregon that contain scheelite are all in Jackson County in the vicinity of Medford and Ashland. Country rock comprises the Applegate Group of metavolcanic and metasedimentary rocks described and named by Wells, Hotz and Cater (1949). These rocks comprise gray-green andesitic and basaltic lavas, many layers of which are vesicular breccias bound together by a highly calcareous matrix. Metasedimentary rocks occur as lenticular interbeds in the metavolcanics and include argillite, chert, quartzite, conglomerate, and marble. Numerous irregular granitic bodies have intruded the Applegate Group and have produced contact metamorphic rocks along their borders. The intrusive rocks are predominantly quartz diorite, but include granodiorite, diorite, and some granite. The contact zones range widely in size and mineral composition, the differences depending largely on the composition and physical characteristics of the Applegate Group rocks that have been intruded. The more highly calcareous parts of the country rock are transformed into contact silicate zones, including tactite, and scheelite has been deposited in some of these. Shear zones in the metavolcanic sequence have provided access to mineralizing solutions from the intrusives and constitute another locale for the deposition of ore minerals that include small amounts of scheelite.

Although the scattered occurrences of the tungsten mineral scheelite in northeastern and southwestern Oregon mark these areas as geologic environments favorable for the localization of deposits of this mineral, the history of discovery and exploitation has been disappointing. Tungsten minerals are notoriously spotty and erratic in their mode of occurrence, and this characteristic is well illustrated in the Oregon occurrences, where most of the discoveries are restricted to sparse grains of the mineral widely scattered in the host rock or as very small pockets of higher grade material that have little if any continuity. The failure to exploit any of these discoveries successfully during periods of high price is a measure of their marginal nature.

It should be noted, however, that much of the terrain has probably not been adequately prospected, and in the southwestern part of the State the deep weathering and heavy vegetative cover have deterred any comprehensive evaluation.

Uranium

(By N. V. Peterson, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Uranium, the basic raw material of atomic energy, is a dense, hard, nickel-white, metallic element. It is highly reactive and combines readily with other elements to form a great number of primary and

secondary minerals. It occurs as three radioactive isotopes: U^{238}, the most abundant (99 percent); U^{235} (0.7 percent); and U^{234} (0.3 percent). Uranium has the property of radioactivity, i.e. the spontaneous emission of radiation (energy). It is also fissionable; that is it is capable of easily releasing energy when its nucleus is bombarded with neutrons. A subsequent discovery that neutrons as well as energy are emitted as the U^{235} nucleus is exposed to neutron bombardment led to the first nuclear chain reaction late in 1942. War time accelerated the development of a method for controlling this rate of fission and led to the first atomic bomb tests in July of 1945 and to the first atom bomb used in war less than one month later. Peacetime applications were also visualized, and atomic power for propulsion was introduced for the first time in the submarine "USS Nautilus" in 1955 and in full-scale electrical power generation at Shippingport, Pennsylvania, in 1957 (Baroch, 1966). Nuclear generated electrical power has now become competitive with other sources of electrical power throughout the United States and in many other countries of the world. As a result, the uranium industry is growing much faster than predicted. A sharp revision upward by the Atomic Energy Commission anticipates that by 1980 in the United States there will be an installed nuclear generating capacity of about 150,000 megawatts requiring a cumulaive total of 250,000 tons of U_3O_8 for fuel. The known calculated reserves (those capable of being produced within $8.00 per lb.) as of Jan. 1, 1967, are about 140,000 tons of U_3O_8. The impact of this large anticipated demand is causing a rapid expansion of exploration and development in the uranium industry and the future outlook has never been more promising.

There are over 150 known uranium minerals, but only a few have been found in large enough amounts to be of economic value. They occur in a variety of geologic environments including granitic pegmatites, high-temperature vein deposits, and in several types of low-temperature hydrothermal veins, lodes, and disseminated deposits. Uraninite and pitchblende are primary uranium oxides, and coffinite is a primary uranium silicate. On oxidation these yield a host of brightly colored secondary minerals, the most common of which are carnotite (potassium uranyl vanadate), tyuyamunite (calcium uranyl vanadate), torbernite (copper uranyl vanadate), and autunite (calcium uranyl phosphate) (Page and others, 1956). The Colorado Plateau area centered at the common corners of Arizona, New Mexico, Colorado, and Utah continues to be the most important uranium producing area, although similar stratiform deposits in Wyoming are significant producers. In both the Colorado Plateau and in Wyoming the uranium minerals occur mainly as pore fillings and impregnations in layered sandstones, shales, limestones, and conglomerates (Paone, 1965).

The Atomic Energy Commission's initiation in 1948 of a uranium procurement program of guaranteed minimum prices, discovery bonuses, premiums, and haulage allowances sparked a flurry of prospecting in Oregon, and numerous radioactive occurrences were found (fig. 46) (Matthews, 1955; Schaffer, 1956). Only two, the White King and Lucky Lass, near Lakeview have so far been of economic significance. A three-carload shipment from these two deposits in 1955,

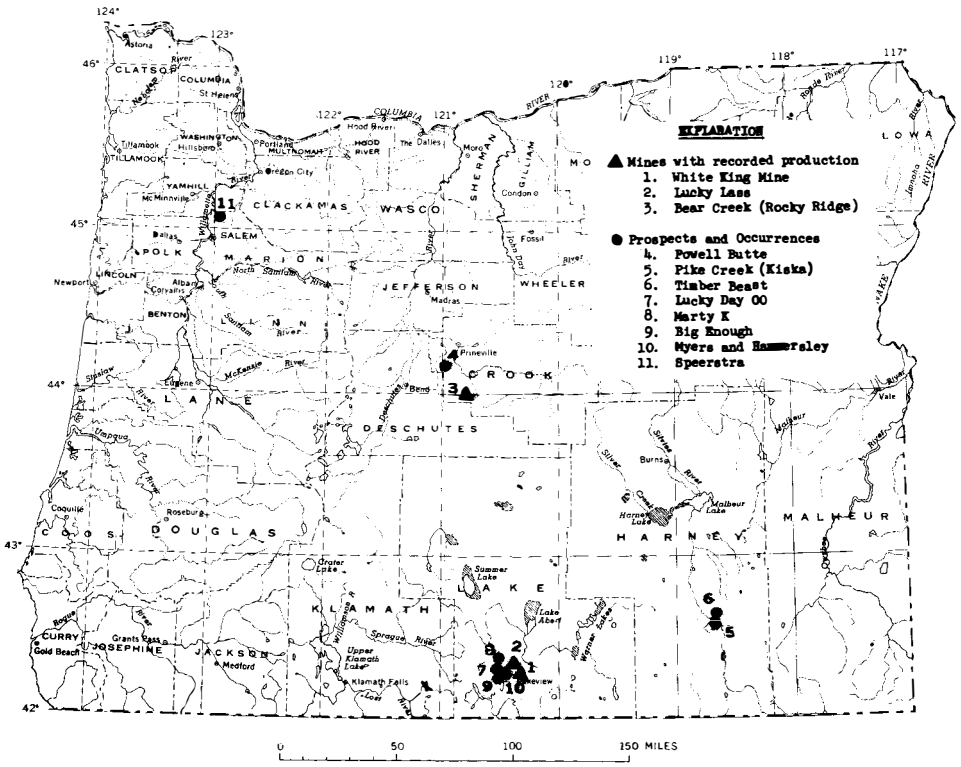


FIGURE 46.—Uranium in Oregon.

shortly after their discovery, was the first uranium ore to be marketed from Oregon. A 210-ton per day processing mill was built in 1958 at Lakeview to process ore from the White King and Lucky Lass mines as well as other amenable custom ores (Peterson, 1958). The Lakeview Mining Co. mill operated continuously until late in 1960 on stockpiled ore from the White King mine and custom ores from Nevada and Alaska. The White King operated as an underground mine and later as an open pit from 1955 until late in 1959. There was also some production in 1962, 1963, and 1965 after the closing of the mill. The Lucky Lass, during its early operation (1956–1958), was mined as an open pit in conjunction with the White King. Production from 1961–1964 has come from deeper parts of the open pit. A 58-ton shipment was made in 1960 from the Rocky Ridge group of claims near Bear Creek in Crook County. Total Oregon production has been about 200 tons of U_3O_8 from 120,000 tons or ore, with the bulk of the production from the White King mine.

The uranium mineralization at the White King appears to be geologically quite recent and is associated with a flow-banded rhyolite dike(?) that has intruded clayey tuffs, tuff breccias, agglomerates, and basaltic lava flows of Pliocene age. Black uranium oxides and associated realgar, stibnite, pyrite, cinnabar, ilsemannite, galena, and chalcedony indicate a relatively low-temperature hydrothermal origin for the deposit. Opalization and clay alteration are prominent in the ore bodies, which tend to be somewhat tabular and are displaced by numerous northwest- and northeast-trending faults. Near the surface, concentrations of a rare, bright yellow-green, secondary uranium mineral, metaheinrichite (barium uranyl arsenate), vivid blue ilsemannite (hydrous molybdenum oxide), and the orange and yellow arsenic sulfides realgar and orpiment make a very colorful and interesting mineral deposit (Peterson, 1958, 1959b).

At the Lucky Lass just a mile to the west the same thin-layered clayey tuffs and volcanic breccias as those of the White King are hosts for both primary and secondary uranium minerals. The mineralization has been controlled by narrow northwest faults and is found in pods and irregular masses in and adjacent to the faults. None of the arsenic, molybdenum, or mercury minerals have so far been found at the Lucky Lass.

In Crook County on the southwest flank of Bear Creek Butte, radioactive minerals occur at the margins of a narrow iron-stained rhyolite dike. This brecciated intrusive-extrusive rhyolite is surrounded by clayey layered tuffs of the John Day Formation of Oligocene and Miocene age. Other occurrences of uranium with possible future importance are shown on the index map and summarized in table 11.

The promising market outlook for uranium through 1980 is certain to encourage future exploration and development in Oregon, especially in the Lakeview area where some reserves are already known. The White King and Lucky Lass mines are presently being revaluated by a major uranium mining company. While this type of hydrothermal deposits is likely to have only moderate reserves, similar deposits could provide appreciable amounts of ore as Oregon's contribution to the future uranium market.

TABLE 11.—SUMMARY OF URANIUM MINES AND PROSPECTS IN OREGON

Map No.	Name	Location	Geologic occurrence	Remarks	Reference
1	White King	Lake County: Sec. 30, T. 37 S., R. 19 E.	Low-temperature, hydrothermal deposit. Primary U minerals in veins and disseminated in clayey tuffs and breccias. Rhyolite mass intrusive into tuffs.	Major production. Associated minerals include realgar, orpiment, stibnite, cinnabar, pyrite, and ilsemannite.	Schafer, 1955. Peterson, 1958, 1959.
2	Lucky Lass	Lake County: Sec. 25, T. 37 S., R. 18 E.	Primary black U mineral and secondary autunite in lenses and masses in and near fault zones in layered clayey tuffs.	Production of about 5,000 tons of ore from large open pit.	Schafer, 1955. Peterson, 1958.
3	Bear Creek (Rocky Ridge)	Crook County: Sec. 13, T. 18 S., R. 16 E.	Mainly autunite in contact zone of Tertiary rhyolite dike with clayey tuffs.	One shipment of 58 tons of ore in 1960.	Peterson, 1958.
4	Powell Butte	Crook County: Sec. 13, T. 16 S., R. 14 E.	Anomalous radioactivity in iron-oxide coatings and stains in flow-banded rhyolite.	No production	Schafer, 1956.
5	Pike Creek (Kiska)	Harney County: Sec. 17, 20, T. 34 S., R. 34 E.	Unidentified U mineral in iron-manganese crusts and coatings in rhyolite breccia adjacent to a fault zone of slight displacement.	do	Peterson, 1958.
6	Timber Beast	Harney County: Sec. 8, 9, T. 34 S., R. 34 E.	Autunite in altered zones of flow-banded dacite adjacent to a basalt dike. Ilsemannite occurs associated with the uranium.	do	Do.
7	Lucky Day 00	Lake County: Sec. 26, T. 37 S., R. 18 E.	Secondary uranium minerals occur in and above thin vesicular basalt flows interbedded with layered tuffs and breccias.	do	Oreg. Dept. Geology and Mineral Industries mine file report.
8	Marty K	Lake County: Sec. 13, T. 37 S., R. 18 E.	High radioactivity in sooty coatings in highly fractured pumice tuff breccia.	do	Matthews, 1955.
9	Big Enough	Lake County: Sec. 32, 33, T. 37 S., R. 18 E.	Apple-green secondary U minerals disseminated and coating fractures in iron-stained ash flow tuff.	do	Do.
10	Myers and Hammersley	Lake County: Sec. 35, T. 27 S., R. 18 E.	Mineralization same as the Lucky Day 00 occurrence	do	Oreg. Dept. Geology and Mineral Industries mine file report.
11	Speerstra	Marion County: Sec. 6, T. 8 S., R. 3 W.	Small concentrations and disseminations of secondary uranium minerals in tuffaceous marine sandstones.	do	Matthews, 1956. Schafer, 1956.

VANADIUM

(By R. P. Fischer, U.S. Geological Survey, Denver, Colo.)

Vanadium is a steel-gray metal capable of taking a very high polish. It is most widely used as a constituent of alloys, especially in steels. Although it is more abundant in the earth than zinc, lead, nickel, or copper, it is not as commonly found in minable concentrations.

The consumption of vanadium in the United States increased from about 2,000 tons in 1960 to nearly 5,500 tons in 1966, according to figures published by the U.S. Bureau of Mines. Of the total vanadium consumed, 75 to 85 percent is used in special engineering, structural, and tool steels as an alloy to control grain size, impart toughness, and inhibit fatigue. The other principal domestic uses have been in nonferrous alloys and chemicals (Busch, 1961).

Four geologic types of deposits have yielded most of the world's supply of vanadium. The bulk of domestic vanadium, and nearly half of the world supply, has come from deposits of vanadium- and uranium-bearing sandstone in southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico. The other principal sources have been a deposit of vanadium-bearing asphaltite in Peru, vanadate minerals from the oxidized zones of some base-metal deposits in Africa, and vanadium-bearing iron deposits in Europe and Africa. These iron deposits and similar ones in many parts of the world contain very large resources of vanadium; they will become increasingly important as sources of vanadium in the future.

None of the four principal types of productive vanadium deposits is known in Oregon. Accumulations of vanadium above trace amounts are known in only two other geologic types of occurrences in the State. These deposits and occurrences are shown on figure 47, and they are briefly described below. None of these is judged to be of significant commercial potential.

Roscoelite, the vanadium-bearing mica, is a minor gangue mineral in some of the gold-quartz veins in Baker County (fig. 47, No. 1) (Lindgren, 1901; Hewett, 1931). No assay data showing the vanadium content of the ore as mined have been found, but the content is assumed to be too low to consider vanadium recovery. Small amounts of roscoelite are common in gold-bearing veins, especially those containing gold-telluride minerals, in other parts of the world.

A deposit of "black sand" in the central part of Curry County (fig. 47, No. 2) is reported to contain about 0.7 percent V_2O_5 (Allen, 1945). The deposit is a sedimentary lens of sandstone, rich in magnetite and with some ilmenite, that probably contains about 225,000 tons of rock. Similar "black sand" deposits along the Oregon coast have yielded gold, platinum, and chromite. Magnetite and ilmenite are also present in these coastal deposits, and they probably contain a little vanadium, but no published analyses showing their vanadium content have been found by the writer.

Almost certainly these deposits offer no economic potential for vanadium; they are probably too small and low grade. However, similar deposits in Japan have been worked for iron and titanium, and during the emergency conditions of World War II they did yield some by-product vanadium (Japan Geological Survey, 1960).

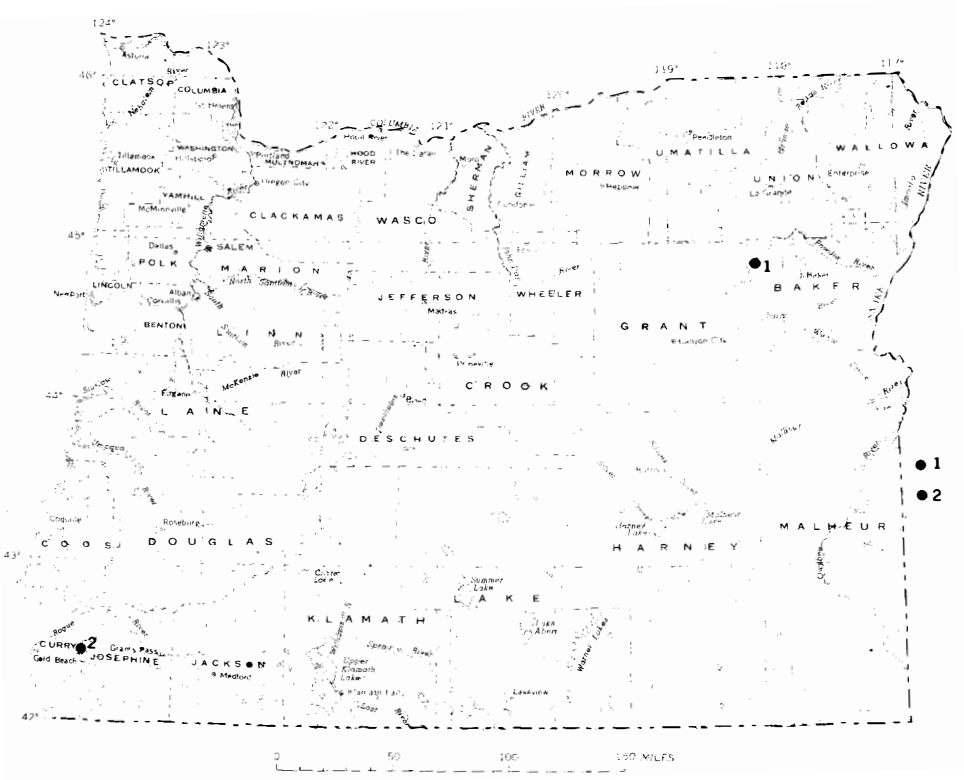


FIGURE 47.—Vanadium in Oregon.

NONMETALLIC MINERAL RESOURCES OTHER THAN FUELS

Asbestos, Olivine, and Other Magnesium Silicate Minerals

(By N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg. and Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg.)

Asbestos, olivine, serpentinite, and diopside are all magnesium silicate minerals and all are associated for the most part with similar rocks and are commonly found in the same general areas. They differ markedly in their physical properties and in the uses to which they are put. Because of their common association, these minerals are discussed together.

ASBESTOS

Asbestos is the name applied to a group of fibrous, noncombustible, magnesium silicate minerals that are useful for a variety of thermal insulation and related applications. All can be separated by mechanical means into fibers of various lengths and thicknesses. Six varieties of asbestos are commonly recognized, which differ in chemical composition and in physical properties. These varieties are the finely fibrous form of serpentine known as chrysotile and five minerals of the amphibole group: amosite, anthophyllite, crocidolite, and the closely related varieties tremolite and actinolite (Jenkins, 1965). The physical properties of these are given in table 12.

Asbestos is most widely known as the mineral that is spun into yarn and woven into unburnable fabric used extensively in various types of fire-fighting gear and for related fire-protective applications. There are, nevertheless, a multitude of other uses. These include friction clutches and molded brake linings, gaskets, shielding for high-temperature industrial furnaces and jet and marine engines, valve packings, and electric cable insulation. Tremendous tonnages are also consumed yearly in the maufacture of roofing materials, asbestos-cement products, floor tile, paper, and, with asphalt, for specialized paving purposes.

The United States is the world's largest consumer of asbestos. An estimated 138,000 short tons of asbestos was produced in 1966 from domestic sources (more than double the 1962 output), but this represents less than 10 percent of United States requirements. Canada is the largest supplier, but special grades are imported from other places, notably Africa.

The big increase in domestic production since 1962 is attributable to the development of large deposits in California and the installation at these deposits of elaborate processing facilities. Now that these facilities are in service, the probabilities are that domestic production will continue to increase. However, the grades of asbestos from domestic sources are usable for only some industrial applications. For the many other grades required, import will always be a necessity unless satisfactory synthetic substitutes can be made.

Long, strong, flexible fibers are necessary for good "spinnability" and are required for many industrial applications. Unfortunately, deposits with this type of material are rare, and mining and milling result in breakage that reduces appreciably the amount of recoverable long-fiber material. Long-fiber asbestos, therefore, commands the high-

21-829 O—69——13

TABLE 12.—PROPERTIES OF ASBESTOS MINERALS (MODIFIED AFTER RICE (1957))

	Chrysotile	Tremolite [1]	Crocidolite	Amosite	Anthophyllite
Color	Green, greenish-yellow, gray, or white.	White, grayish-white, greenish-yellow, or bluish-gray.	Lavender, blue, or greenish	Ash-gray, greenish, or brown	Grayish-white, brownish-gray, or green.
Texture	Soft to harsh, silky	Generally harsh, some soft	Soft to harsh	Coarse, but somewhat pliable	Harsh.
Mineral association	In serpentine, magnetite, antigorite, picrolite, etc.	In serpentine, magnesium limestones, and various metamorphic rocks.	Iron-rich, siliceous argillite in quartzose schists.	In crystalline schists, etc.	In crystalline schists, gneisses, or metaserpentine.
Veining and fiber length	Cross and slip fibers; short to long.	Slip or mass fiber; rarely cross fiber; short to long.	Cross fiber; short to long	Cross fiber; mostly long	Mass or slip fiber; rarely cross fiber; short.
Tensile strength (p.s.i.)	80,000 to 100,000	8,000 or less	100,000 to 300,000	16,000 to 90,000	4,000 or less.
Flexibility	Very flexible	Fairly flexible to brittle	Flexible	Flexible	Mostly brittle.
Spinnability	Very good	Generally poor; rarely spinnable	Fair	Fair	Very poor.
Fusibility	Fusible at 6	Fusible at 4	Fusible at 3	Fusible at 6	Infusible or difficultly fusible.
Acid resistance	Poor	Good	Good	Good	Very good.

[1] Tremolite grades into actinolite by replacement of magnesium with ferrous iron.

est prices, and progressively decreasing prices prevail for the shorter fiber lengths. Current prices range from $1,500 per ton for the longest, crude, grade 1 fiber to $43.50 per ton for the shortest, lowest grade material. For other uses, resistance to heat or acids is important. For many uses in the electrical industry, the asbestos must be electrically nonconductive and its iron content must be low.

Chrysotile is by far the most valuable of the asbestos minerals, accounting for an estimated 95 percent of the world's asbestos production. It is found in serpentinized rock in both cross and slip fiber veins.[11] Fibers range in length from microscopic to three-eighths of an inch and occasionally much more. Good quality fibers are silky, highly flexible, and have a tensile strength ten times that of nylon. In the United States, chrysotile is found in serpentinized peridotite in Vermont, California, and Oregon, and in serpentinized dolomitic limestone in Arizona.

In comparison to chrysotile, the fibers of the amphibole group asbestoses are coarser, less flexible, and commonly are brittle (harsh). All but crocidolite fibers are weaker (table 12). Crocidolite and amosite are industrially important, but no commercially exploitable deposits are known in North America. Tremolite, the most common of the amphibole group, has some limited commercial use. However, world production of tremolite is less than 0.25 percent of the total asbestos production. Tremolite asbestos is found in serpentine, altered magnesium-rich limestones, and in various metamorphic rocks.

Asbestos deposits in Oregon

Prospects of both chrysotile and amphibole asbestos exist in Oregon (fig. 48), and some of these occurrences have been known and worked on in a minor way since early in the century. Production from these sources has been limited to a few small shipments of hand-sorted tremolite from occurrences in the southwestern part of the State (Bright and Ramp, 1965) and to 525 short tons of milled fiber recovered from a pilot plant test of chrysotile from an occurrence near Mount Vernon in eastern Oregon (Wagner, 1963). There is no production from the State at the present time, nor has there been any exploration of major significance on any asbestos prospect since 1964. Most of the amphibole prospects in Oregon occur in shear zones in serpentinized peridotite or in shear zones closely associated with exposures of ultramafic rocks. Without exception, all Oregon chrysotile prospects occur in serpentinite; hence the distribution of peridotite and serpentinite in the State is indicated in figure 48 along with the prospect locations. The known deposits are listed in the following tabulation (table 13). The numbers correspond to numbers shown on figure 48.

As appraised today, none of the currently known asbestos occurrences in the State can be classed as suitable for commerical development. There is either an insufficient tonnage of ore, the asbestos content of the rock is too lean, or there is too low a proportion of the long-fiber, better quality asbestos. Nevertheless, the possibility of develop-

[11] In cross fiber veins, the fibers are transverse to the vein walls; in slip fiber veins, the fibers lie in the plane of the vein.

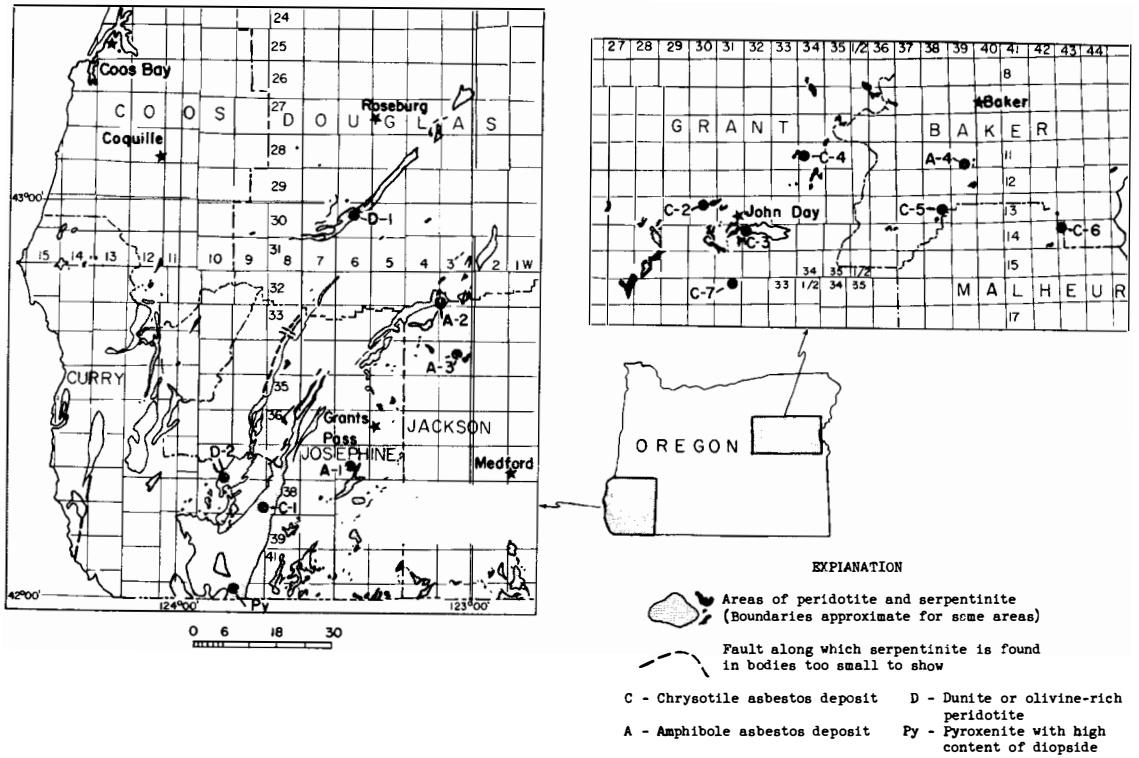


FIGURE 48.—Asbestos, olivine, serpentine, and diopside occurrences in Oregon.

TABLE 13.—ASBESTOS OCCURRENCES IN OREGON

Index number on fig. 48 and name	Location			County	Reference
	Sec.	T.	R.		
CHRYSOTILE ASBESTOS					
C-1 Forster Asbestos	33,36	38 S.	9 W.	Josephine	Files, Oregon Dept. Geology and Mineral Industries.
C-2 Mount Vernon	12, 13, 14	13 S.	30 E.	Grant	Wagner, 1963.
C-3 Spare Time claims	7, 18	14 S.	32 E.	do	Files, Oregon Dept. Geology and Mineral Industries.
C-4 Big Butte Creek	17, 18, 19, 20	11 S.	34 E.	do	Do.
C-5 Rock Creek Butte	22	13 S.	38 E.	Baker	Do.
C-6 Towell claims	7	14 S.	43 E.	Malheur	Do.
C-7 Bear Valley	1, 2, 3, 11	16 S.	31 E.	Grant	Do.
AMPHIBOLE ASBESTOS					
A-1 L.E.J. Asbestos	9	37 S.	6 W.	Josephine	Files, Oregon Dept. Geology and Mineral Industries.
A-2 Liberty Asbestos	36	32 S.	4 W.	Jackson	Oregon Dept, Geology and Mineral Industries Bull. 14-C.
A-3 Raspberry Creek	15	34 S.	3 W.	do	Files, Oregon Dept. Geology and Mineral Industries.
A-4 Pine Creek Asbestos	34, 35	11 S.	39 E.	Baker	Moore, 1937.

ing minable deposits of asbestos in Oregon is by no means hopeless. Each of the chrysotile prospects indicated on figure 48 has been examined repeatedly by geologists from companies recognized as specialists in the evaluation and mining of chrysotile prospects and the processing and marketing of asbestos products. Several of these prospects, particularly the Forster Asbestos, the Mount Vernon, and the Big Butte Creek properties, have been sufficiently attractive to command core drilling or bulk test sampling on more than one occasion. Some of the same companies that have been active in exploration for asbestos within the State are continuing or plan to continue basic geologic investigation of ultramafic rock exposures. Thus, although the results of past exploration have been disappointing, they do not preclude the successful development of asbestos resources of the State.

The foregoing conclusion stems largely from the fact that exploration for asbestos deposits is difficult and costly. The State, therefore, has not been prospected as thoroughly for asbestos as it has for some other minerals. Indeed, several of the currently known chrysotile locations were discovered only recently by local prospectors working under the stimulus and guidance provided by the industry when it was active in the field. Accordingly, many of the areas of ultramafic rock exposure in the State merit more investigation and scrutiny.

OLIVINE

Olivine, also called chrysolite and peridot, is an orthosilicate of magnesium and iron. Its formula is $(Mg,Fe)_2SiO_4$. The end members of the olivine series are forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Olivine has a hardness of 6½ on the Mohs scale and a specific gravity of about 3.3. It is a pale yellowish green to bottle green color, and clear, unfractured varieties (peridot) are used as gems. Olivine occurs in igneous rocks that are generally low in silica and rich in magnesia, such as peridotites, gabbros, basalts. It may also occur in metamorphic

rocks. When olivine is the main constituent of an igneous rock, the rock is called a dunite. Common accessory minerals in dunites are magnetite, pyroxene, and chromite.

Olivine is mined in North Carolina and Washington (Hunter, 1941; Vhay, 1966). The ores are high-magnesian dunites containing 45 to 49 percent MgO. The olivine is used in various refractories, as foundry molding sand, and may be used as a source of magnesium metal and its compounds (Bengston, 1956). Olivine, unlike most silicates, is readily dissolved by acids and is therefore amenable to chemical processing. The principal uses of olivine are shown in the following tabulation:

Olivine products and uses

Product	*Use*
Refractory:	
Forsterite brick	Furnace linings.
Patented olivine mortar	To join refractory brick and patch furnace linings.
Other:	
Olivine sand	Foundry molding sand (Ralston and others, 1938a. b; Schaller and Snyder, 1951); sandblasting.
Crystals	Semiprecious gems.
Potential products:	
Magnesium metal	Castings, lightweight alloys, as reducing agent in producing other metals, powder for fuel.
Magnesium compounds	MgO for refractories (Gee and others 1946); $MgSO_4$ for tanneries, rayon paper, textile pharmaceutical trades, and fertilizer; $MgCl_2$ to make MgO; $MgSO_4 \cdot 7H_2O$ (epsom salts).

Oregon is not yet a producer o f olivine but has potential sources that may some day be exploited. Dunite and olivine-rich peridotite occur at various places in southwestern and northeastern Oregon. Two localities are believed to be worth mentioning. One occurrence is at Nickel Mountain in Douglas County (fig. 48, No. D–1), where dunite underlies a portion of the nickel deposit being mined by the Hanna Mining Co. of Riddle, Oregon. Analyses show that this rock contains about 45 perecnt MgO (Clark, 1888; Hotz, 1964). The other area of dunite and olivine-rich peridotite is located near Pearsoll Peak (fig. 48, No. D–2) at the east edge of Curry County, where very coarse-grained but fractured olivine crystals as much as 2 inches across are common.

SERPENTINE

Serpentine is the common name given to a group of minerals including chrysotile, lizardite, and antigorite. These are all hydrous magnesium silicates that contain about 44 percent silica, 43 percent magnesia, and 13 percent water. Serpentinite is the rock in which these minerals occur, along with variable amounts of accessory magnetite, chromite, calcite, aragonite, or dolomite, and residual olivine and pyroxene. Traces of nickel and cobalt may also be present. The use of pulverized serpentine is described as a source of magnesium in agricultural fertilizer (Oregon Department of Geology and Mineral Indus-

tries, 1945; Burns and Smith, 1965). Williams (1966, p. 628), in reference to Burns and Smith (1965), states that . . . "When serpentine is exposed to moisture, the surface of the crystal ionizes to form hydroxyl and magnesium ions. Magnesium is released at a slow sustained rate making serpentine an effective and efficient source of magnesium for soil. The low calcium content creates a favorable calcium-magnesium ratio. The chromium and nickel content is well below the toxic limits and may be beneficial."

Several blends of finely ground serpentinite and superphophate fertilizers utilized a total of 158,550 tons of serpentinite in the 1964–65 fertilizer year in New Zealand. The two popular blends are a 90 percent superphosphate and 10 percent serpentinite mixture used for aerial application and a 75 : 25 blend which is applied on the ground. Consumption of serpentine-superphosphate fertilizer in New Zealand has increased at an impressive rate in recent years.

Pulverized serpentinites in the State of Washington are being used for diluents in insecticides, as a base for special paints, and for terrazzo chips.

Should any such uses of serpentinite become popular in Oregon, a very large supply of this rock is available in both northeastern and southwestern parts of the State, in the areas shown on figure 48.

DIOPSIDE

The mineral diopside is a calcium magnesium silicate with variable amounts of iron. It is generally a light gray to green color, sometimes white or yellowish, has a hardness from 4 to 6, and a specific gravity of 3.2±. Limited use of this mineral has been developed recently in the manufacture of ceramic tile from a deposit in Arizona (Campbell, 1963).[12]

Pyroxenites in the Whiskey Creek-Oregon Mountain area southwest of O'Brien (fig. 48) contain large percentages of diopside (diallage), and should the demand for diopside develop, these pyroxenites may warrant investigation.

Borates

(By N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg.)

International marketing of borax dates back to at least the 13th century and possibly earlier. It was produced then in Tibet and used by European artisans refining precious metals and making porcelain. Today ceramic and metallurgical uses of borax are not only more numerous and sophisticated than before, but there is also an evergrowing host of other important applications. The more commonly known of these include the use of borax and boric acids in soaps, cleansers and detergents, disinfectants, and preservatives. Great quantities of borax are also consumed by the glass industry to make heat-resistant glass and glass wool and optical glass (Smith, 1966). It is also used in the manufacture of glazed paper, plywood, and paint. In agriculture it is important because minute traces of boron constitute an essential ingre-

[12] Campbell, Ian, 1963, A "State of the industry review." The industrial minerals (exclusive of cement). Presented at an American Mining Congress meeting in Los Angeles, Calif., Sept. 18, 1963.

dient in soils for healthy plant growth, and massive applications serve as an effective weed killer. Boron carbide and tungsten and titanium borides are among the hardest known abrasives. Other boron compounds have industrially important properties as dehydrating agents, solvents, fire retardants, catalysts, and plasticizers and are used in the production of silicones and plastics, in special-purpose fire extinguishers, and as motor fuel additives. Jet-age applications include use in various forms in atomic reactors and solar batteries. In addition, there are potential uses as jet and rocket fuels and as a structural material (boron filament-epoxy mixtures) having many properties of unique and far-reaching significance.

Boron compounds show exceptional promise for use in many fields of industrial endeavor. Because they do, research by both the government and the producing industry can be expected to result in a continuing and possibly major expansion of boron production in the years ahead. Mineral Facts and Problems (Miller, 1965) and the Mineral Yearbook issued yearly by the U.S. Bureau of Mines should be consulted by anyone desiring a more comprehensive review of uses and trends than that given above.

The United States is the world's leading producer and consumer of boron compounds, with more than 85 percent of the known world output of boron-rich raw material originating from sources in California (Miller, 1965). Over the five-year period, 1959–1963, domestic production averaged nearly 332,000 tons of B_2O_3, valued at nearly $49 million per year (Miller, 1965). In 1963 approximately half of the domestic output was exported, chiefly to West Germany, the United Kingdom, France, Japan, and Canada.

Boron is a constituent of several silicate minerals that commonly occur in accessory amounts in certain igneous rocks. It is a constituent of many hot-spring waters of volcanic derivation and of deposits formed by the evaporation of saline waters in volcanic areas. Minable deposits of boron minerals exist almost exclusively in arid regions where natural, boron-rich, hot-spring waters are present and evaporation prevails. In such regions boron occurs in brines and boron minerals form playa encrustations and massive aggregates of crystals exposed either on the land surface or interlayered with clastic lakebed sediments and the precipitated solids of other chemicals (chiefly sodium, calcium, magnesium, potassium) that are also the products of desert sedimentation. The arid climate is important for the preservation as well as the accumulation of the relatively soluble minerals. Such evaporite-type borate occurrences in the United States all represent continental deposition that is Cenozoic (Tertiary to Holocene) in age, and are found only in California, Nevada, and Oregon. Borax, kernite, and to a lesser extent ulexite and colemanite, are the principal borate minerals now mined in the United States. The compositions of these minerals and that of priceite are:

Principal boron minerals	Composition	B_2O_3 content
Borax	$Na_2B_4O_7 \cdot 10H_2O$	36.5
Kernite	$Na_2B_4O_7 \cdot 4H_2O$	50.9
Ulexite	$NaCaB_5O_9 \cdot 8H_2O$	42.9
Colemanite	$Ca_2B_6O_{11} \cdot 5H_2O$	50.8
Priceite	$Ca_4B_{10}O_{19} \cdot 7H_2O$	50.0

Borates are not mined in Oregon at the present time, but two occurrences supported productive mining in the past (fig. 49). The earlier and smaller producer, in Curry County at Cape Ferrelo, about 5 miles north of Brookings, in what is now Boardman State Park, was mined during the summer of 1872 and then again in 1891 and 1892 by the Pacific Coast Borax Company (Staples, 1948). The borate mineral priceite was first named and described from this deposit (Silliman, 1873)[13], the first new mineral ever found in and described from Oregon (Staples, 1948). The priceite occurs in serpentine in the form of irregular masses ranging in size from peasized pellets to nested "boulders" weighing up to 450 pounds. It is also described (Chase, 1873)[13] as filling seams and cavities (?) in slate. Contrary to the general rule that borates occur in arid regions, the priceite is here located in an area noted for abundant rainfall. As this suggests, priceite is relatively insoluble. Although priceite is a comparatively uncommon mineral, it evidently occurred in appreciable quantity, as (Gale 1921)[13] reports the 1891–1892 production at around 580 tons, with some 3,600 to 5,400 additional tons supposedly developed at the time the operation was terminated in 1892 due to litigation. Very few traces of the old cuts and tunnels are now discernible at the original mining site now situated in the State Park; however, some other undeveloped occurrences reportedly exist in the surrounding area (Staples, 1948; Butler and Mitchell, 1916).

The other, more productive, borate occurence is south of Alvord Lake in the Alvord Desert, Harney County, in a geologic setting characteristic of major borax deposits. The climate is semiarid, and the basin has no outlet. Water flow from creeks draining the surrounding countryside is seasonably variable in amount and generally scant. This is supplemented by the discharge from numerous thermal springs, some of which yield water containing boron in the amounts shown in the following table (Libbey, 1960):

Spring	Flow (gpm)	Temp. (° C.)	Total solids (percent)	B_2O_3 (ppm)
1	135	167	0.298	106
2	900	97	0.170	61
3		122	0.155	31
4		198	0.15	56
5	100	198	0.168	33
6	45	136	0.083	4.4
7	30	95	0.015	1.0

Borax was produced here in the 1890's and early 1900's by the Rose Valley Borax Co. Production came from surface encrustations on a playa located adjacent to and west of thermal springs number 2, 3, and 4 (see previous table), of which number 2 is actually a hot lake about 275 yards in diameter (Stearns and Waring, 1937) and numbers 3 and 4 are among a string of springs issuing from a fault extending northward from the lake. Harvesting was seasonal, with the raw material stockpiled for year-round processing while another encrustation developed. The raw material harvested was reported to

[13] The statements relating to Chase, Silliman, and Gale have been paraphrased from Staples due to nonavailability of the original references.

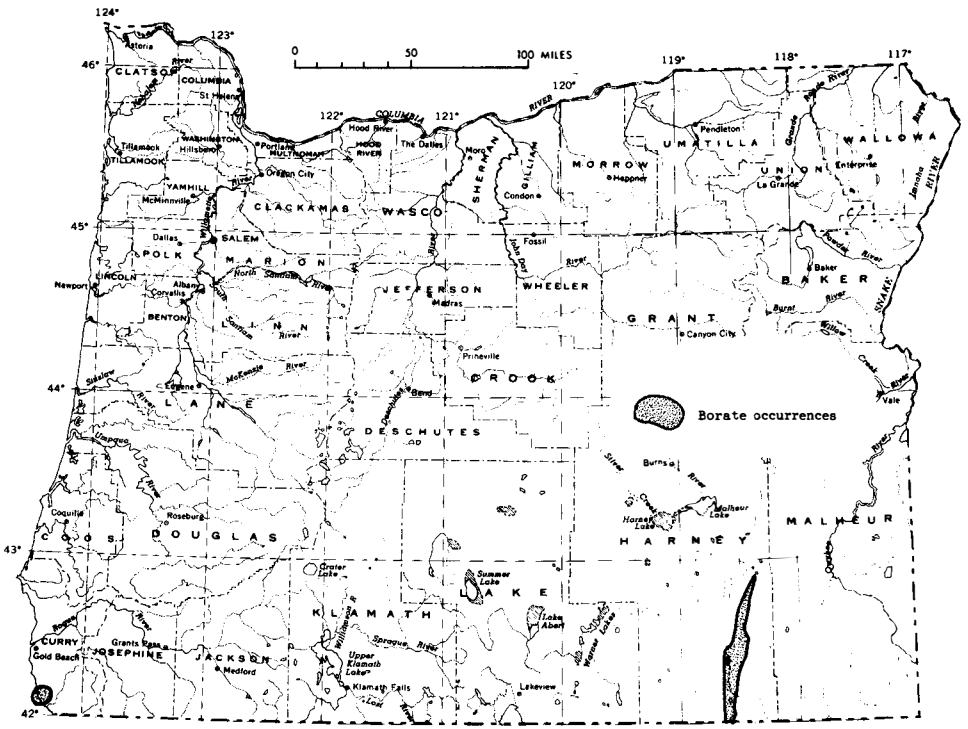


FIGURE 49.—Borate occurrences in Oregon.

be borax, accompanied by sodium carbonate, chloride, and sulfate (Dennis, 1902). In a report for 1901 the yearly output for the "last few years" is given as approximately 400 short tons of refined borax (Struthers, 1902). How much longer production continued is uncertain, as none is listed in "The Mineral Resources of the United States" for 1902 or thereafter, yet in a later report Waring (1909) states that "For the last nine or ten years borax has been shipped. . . ."

During 1958 a grid of holes, 2 to 22 feet in depth, were drilled by the Mohave Mining and Milling Co. close to, and east of, the old mine site. In 1959 and 1960 a number of deep core drill tests (one reportedly 600 feet) were drilled by Boron, Inc., at a location approximately 1 mile south. No information on sampling results was made public, nor has any additional drilling been done since. However, investigation by the Oregon Department of Geology and Mineral Industries (Libbey, 1960) disclosed that the two largest thermal springs in the basin (numbers 1 and 2, previous table) currently discharge 1,035 gpm of water containing approximately 150 tons of B_2O_3 annually.

Borate reserves in California are considered sufficient to meet industrial needs for the next hundred years even with allowance for increased future consumption (Miller, 1965). Because of this there has been little incentive for exploration of new deposits; hence no body of meaningful data has been generated on which to base an appraisal of resources at either Oregon occurrence. Nevertheless, Libbey's spring analyses do bring into focus a pertinent question concerning possible potential in the Alvord Basin: if the present springs have been fairly constant in their mineral content over a long span of time, as it seems reasonable to presume they have, then what has happened to the B_2O_3 discharge over the centuries? Since subsurface accumulations of concentrated brine have developed under similar conditions in other areas, systematic investigation of the Alvord Basin seems a logical undertaking when, and if, the need for developing additional borate reserves should arise.

Carbon Dioxide

(By N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg.)

Carbon dioxide (CO_2) is an odorless, colorless, tasteless, inert, and noninflammable gas which can be converted to a liquid or a solid and held in either state with comparative ease. The solidified material, commonly known as dry ice, has a relatively high specific gravity, a melting point of minus 109° F. and the ability to evaporate back to gas without liquefying.

Commercial and industrial uses exist for carbon dioxide in all its forms. As dry ice it is used as a refrigerant in the storage and transportation of foods, in the shrink fitting of machine parts, and in the hardening of steel alloys. In the liquid state it is used in carbonated beverages, in some types of fire extinguishers and mechanical refrigerators, for food preservation in ways other than refrigeration, and as an explosive. In addition, both the gaseous and liquefied forms are used as packaged power for the inflation of collapsible life-saving gear and for spray application of numerous canned products such as insecticides, and paints.

By far, most of the carbon dioxide gas used commercially originates as an industrial by-product from plants where hydrocarbon fuels are burned, or where lime, ammonia, nitrogen, or alcohol are manufactured. However, nearly 1,300,000,000 cubic feet of carbon dioxide was recovered from natural sources in the United States during 1963 as shown in the following table. New Mexico, Colorado, Utah, California, and Washington, in that order, were the principal producing States.

CARBON DIOXIDE (NATURAL) PRODUCTION IN THE UNITED STATES

	Thousand cubic feet [1]	Value
1963	1,295,545	$178,000
1962	1,144,107	146,000
1961	545,354	82,000
1960	521,167	99,000
1959	485,179	71,000
1958	722,615	102,000
1957	704,276	139,000

[1] Estimated.

Source: U.S. Bureau of Mines Minerals Yearbook, 1960–63.

Carbon dioxide may be generated in the earth's crust when materials containing carbon are subjected to (1) magmatic assimilation, (2) heat, (3) acid groundwater, and (4) the kinds of decay and fermentation that occur during the transformation of buried organic matter to coal and hydrocarbons. Natural occurrences may be found, therefore, in varying degres of concentration in association with coal and hydrocarbon, in areas of recent volcanism, and in areas where limestones or sediments containing organic matter are in contact with heated rocks.

Springs emitting carbon dioxide are known in many places in Oregon (fig. 50) (Wagner, 1959). Some of these discharge directly in rivers and streams. In the vicinity of some of the "soda water" springs, bubbles rising through pools of standing water formed during a hard rain indicate that leakage of CO_2 from subterranean sources is not confined only to the springs; probably unrecognized leakages occur on the dry land surface as well.

There is at present no commercial production of natural CO_2 from Oregon. Between 1945 and 1961, a plant near Ashland converted CO_2 to dry ice (Schafer, 1955; Wagner, 1959). The CO_2 was recovered from water pumped at the rate of about 1,000 gallons per hour from a network of 10 to 12 wells. Total production is unknown, but it is estimated that 470 million cubic feet of gas was recovered up to 1958. The wells, which are 200–300 feet deep, were drilled into a shaly layer in the Umpqua(?) Formation along a line about one-third of a mile in length close to a major fault (Schafer, 1955). Some of the wells and springs in the Ashland area contain unusually high concentrations of lithium, carbonate, chlorine, and sulfur and show a predominance of carbonate over calcium and a low calcium-magnesium ratio (Winchell, 1914, pp. 83–107). This composition is characteristic of water from a volcanic environment (White and Brannock, 1950). Schafer (1955) postulates that the carbon dioxide-rich water was derived from an underlying magma, rose along faults and was mixed with circulatory ground water on its way to the surface.

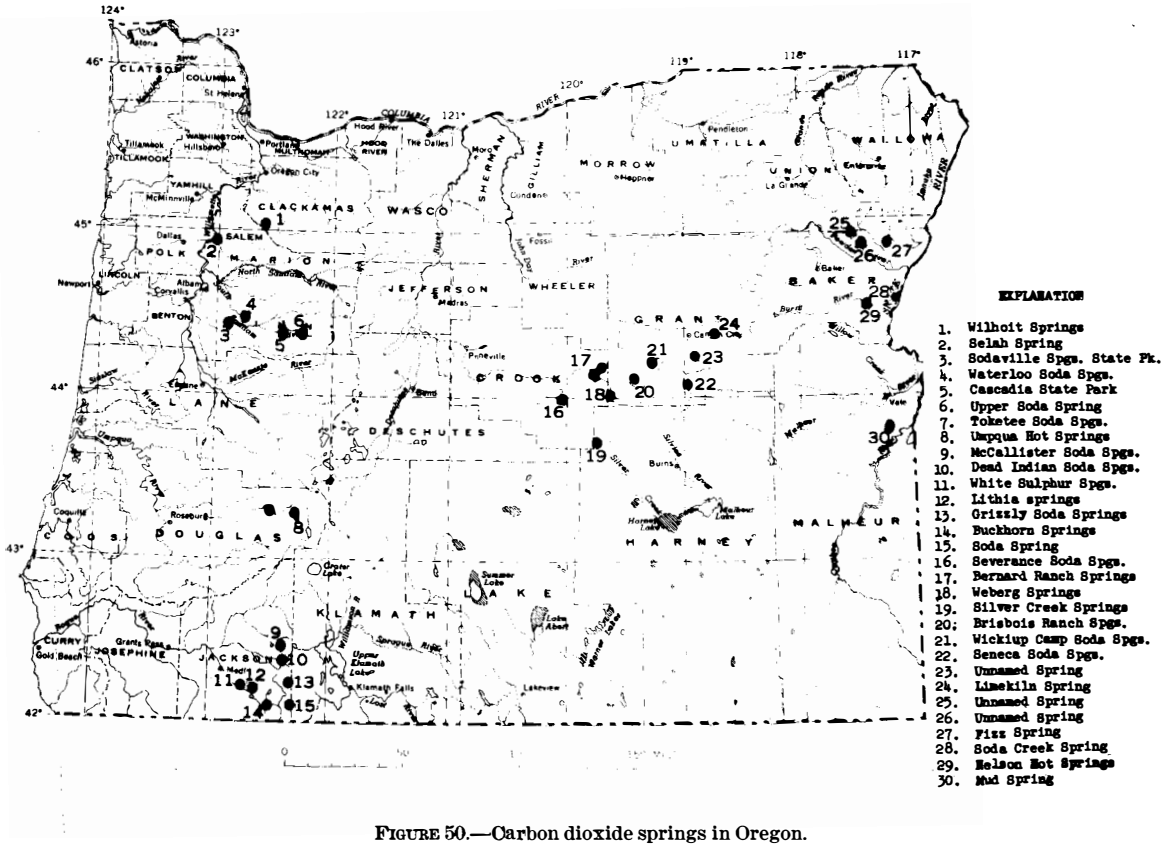


FIGURE 50.—Carbon dioxide springs in Oregon.

Commercial recovery of natural carbon dioxide must face strong competition from by-product carbon dioxide from industrial plants, which provide by far the greater part of the Nation's requirements. Some of the soda water springs shown in figure 50 occur in geologic settings that would appear to warrant investigation should there be at some future time a sufficient demand for carbon dioxide. The most promising of these are Wilhoit Springs, in the vicinity of Sodaville and Cascadia State Park; the springs in the Emigrant Creek area between Lithia Springs and Buckhorn Springs; and those in central Oregon near the Weberg and Brisbois ranches.

Clay

(By R. S. Mason, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Clay very probably has the longest record of continuous use by man of all of the mineral resources. Pottery and art objects made of clay predate the earliest recorded history. Man has been using brick for over 5000 years. The first brick are believed to have been formed in the Tigris-Euphrates valley, but it was not until the art had been adopted by the Etruscans that any reliable history became available. The oldest cities in the world were largely built of sun-dried brick, but clay was used much earlier as a covering over pliant osiers woven into rude hemispherical shelters. Early civilizations developed in arid or semi-arid regions where sun-dried brick served well. Although the Etruscans employed bitumen as a waterproofing agent to protect their brick structures, it was not until fired brick were developed that truly permanent structures became possible. Cultures spreading out from the Tigris-Euphrates valleys eventually reached humid climates where three factors were responsible for the development of the fired brick. First, there was an abundance of wood for fuel in the humid regions; second, there was insufficient sun to properly dry sun-dried brick; and third, the weather rapidly destroyed sun-dried brick. Although seriously challenged by many other building materials in recent years, fired brick were the prime building materials for several milleniums.

Very much the same historical pattern has been followed in Oregon. The earliest structures having any semblance of permanency were log cabins chinked with clay. Shortly afterwards brick and tile, produced from local clays and fired with cordwood came into increasing use.

The uses of clay today show a great expansion over the first sun-dried, straw-strengthened brick cast 5000 years ago. Clays are used in cement, paper, paint, plastics, rubber, pesticides, fertilizers, textiles, inks, medicines and numerous other products. Clays help to bond foundry sand, seal reservoirs and oil wells, bind both stock feed and iron ore pellets, suppress forest fires with a sticky slurry, and sieve out molecular sized impurities in liquids. Clays are fired to make structural units, sanitary ware, whiteware, refractories, stoneware, pottery, artware, and other ceramic products. Certain clays bloat when fired and are sold for lightweight aggregates. Sculptors use clay for modelling but the familiar grade school modelling "clay" is a completely synthetic product.

Some clays or clayey materials may contain sufficient concentrations of aluminum to make them potentially valuable as ore. Bauxite, an ore of aluminum, and limonite, an iron ore, usually contain considerable quantities of clay formed as a result of weathering of the original rock. Some non-bauxitic clays contain a high percentage of aluminum which may some day become economically attractive.

As defined by Murray (1960), clay is a natural, earthy, fine-grained material composed largely of a limited group of crystalline minerals knows as the clay minerals. Although most clays are plastic when wet, not all of them are. The term "clay" may also refer to the smallest of particles, with a maximum size, depending on various scales, of from 2 to 4 microns. Clays have been classified in many ways and no one system seems to work best for all of the various disciplines involved with them. Geologists, agronomists, engineers, ceramists, and others have all established definitions, specifications, and parameters which serve to define and identify the material. Tests for clays are many and varied. Depending upon the clay and the use to which it is to be put a sample may be analyzed chemically; examined petrographically; x-rayed; fired for color, shrinkage, bloating and pyrometric cone equivalency; tested with differential thermal analysis equipment; stained; studied with electron microscopes; or tested with infrared spectroscopy.

Clay minerals may originate in several ways. Simple weathering under generally humid conditions will transform surface rocks of many types into more or less pure residual deposits of one or more clay minerals. Purity of the clay minerals in such deposits depends partly upon the nature of the original source rock and partly on the duration and intensity of weathering. Clays may also be formed by hydrothermal processes beneath the surface. Heated, circulating mineral-bearing water alters existing minerals, and under proper conditions clay minerals are formed at the expense of others. Deposits of clay may be formed by either weathering in situ or by transportation of exposed clay minerals.

Oregon clays have in the past been almost exclusively used for common brick and tile production. Since most of the clays contain a considerable quantity of iron, the fired ware is usually red to dark buff in color. Very little Oregon clay is sufficiently low in iron to produce a light-colored fired product. The manufacture of common, red-firing brick and tile in Oregon dates from the early 1800's when local clay pits supplied material for brick which was sun dried on the ground, fired on the premises, and laid up in a wall not far from the kiln. Numerous commercial kilns and potteries were operating in the 1850's. A total of 68 kilns were active in the State in 1908, the peak year, 29 in 1913, 19 in 1946, and 11 in 1966.

Refractory clay occurs in western Oregon in numerous deposits, as described by Wilson and Treasher (1938). They describe in some detail the four most favorable deposits, all having pyrometric cone equivalents (P.C.E.) of at least 30. These were the Fransen, Ellis, King, and Hobart Butte.

The Fransen deposit, located near Mayger in Columbia County, contains about 430,000 tons of high refractory (Cone 32) plastic clay that when fired has moderate shrinkage and moderately dark color. The

Ellis property, located about 4½ miles southeast of Mollala in Clackamas County, has clay with a P.C.E. value of 30–32 that fires to a tan color, but several attempts to use the clay commercially have been abandoned due to high shrinkage. The clay could possibly be used to improve the workability of less plastic flint clays. At the King clay locality, about 3 miles northeast of Sublimity, Marion County, the raw clay is dead white in color, has a P.C.E. value of 32-plus, and fires to a dark brown. The clay has a high firing shrinkage and also could probably best be used as a plasticizer with flint clays. Approximately 300,000 tons are available.

Hobart Butte is located near the southern boundary of Lane County and about 16 miles south of Cottage Grove. The clay deposit is described by Wilson and Treasher (1938):

> There are three phases of the clay, each having different physical appearances; (1) one at the top of the quarry face is a light-gray, hard, flinty mass with a hardness of 3 and conchoidal fracture, and contains white bodies that look like altered feldspars; (2) below is similar clay, except that it has a slight brownish cast; (3) at the bottom of the quarry is darker-gray, softer clay with hackly fracture and a higher percentage of "white bodies" that are frequently elongated in a parallel direction. This gray clay contains small fragments of carbonized and silicified wood in addition to some realgar, cinnabar, and stibnite. The gray color is due to finely divided carbon that burned out in firing and showed a slightly higher loss on ignition. Realgar, cinnabar, and stibnite volatilize in the physical tests and do not affect the refractoriness.
>
> Small fragments, twigs, and even 10-foot logs of carbonized and silicified wood are found in the gray clay. Some of the logs appear to have been flattened by pressure. The presence of small fragments of wood indicates that the altered rock was originally a pyroclastic instead of a flow. To the westward, the clay grades into more impure material of various colors; some is brick red, grading to dark tan but otherwise having many of the characteristics of the clay in the quarry. The zones of colored clay appear to have vertical extent like strata dipping at steep angles.
>
> The extent of fractures in the clay mass was not determined, and although slickensides occur frequently, they could properly develop in such a mass with very little displacement. In some cases, either realgar or cinnabar, or both, was deposited prior to the fracturing, as these minerals may be smeared along the slickensides.

The clay fuses between Cones 33 and 34, is flinty, and has a light cream color when fired above Cone 20. The addition of Hobart Butte clay to the plastic Willamina black clay produces a satisfactory mix for firebrick. Reserves of clay at Hobart Butte are large; Wilson and Treasher (1938) estimate that 46,200,000 tons are available.

Clays suitable for red-firing brick and tile are abundant in northwestern Oregon, particularly the Willamette and Tualatin Valleys. Distribution of brick and tile plants is shown on figure 51. Most plants are located near or in centers of population, and nearly all obtain their clay close to the kilns. Urban growth over the years since the various plants were established has imposed hardships on some of the operations, particlarly with respect to future pit expansion. There is no real shortage of clay near most of the urban centers, but lack of foresight in reserving suitable deposits by agencies responsible for planning for community growth and development may seriously affect brick and tile production in some areas in the future. Common red-firing brick and tile clay is a low value commodity that cannot be economically transported great distances from pit to plant. Although the value of the fired product is considerably greater than the raw clay, there are

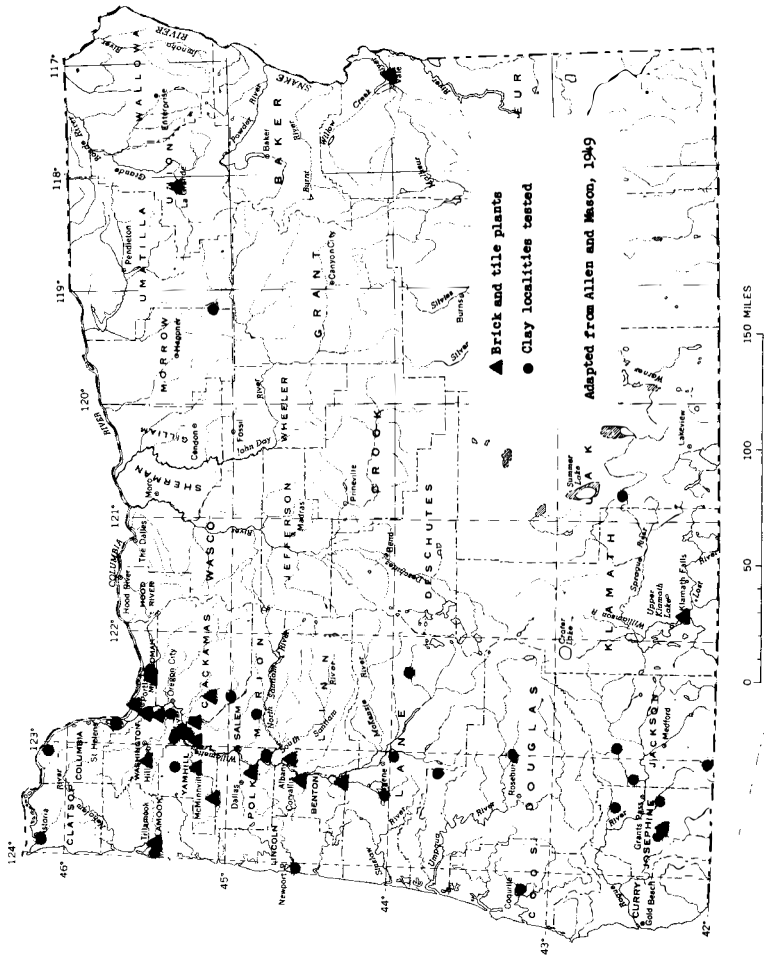


FIGURE 51.—Brick and tile plants in Oregon.

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definite limitations to the market radius for common brick and tile.

East of the Cascade Mountains only three brick and tile plants have had substantial production. Although clays suitable for red-firing brick and tile almost certainly are widely available in eastern Oregon, the distance to urban markets and relatively high cost of fuel and manufacture have severely restricted their utilization. The ready availability of other building materials, including building stone, possibly also has been a factor in limiting the number of brick and tile plants.

With the exception of two deposits, the Hobart Butte flint clay in southern Lane County and the Willamina "black" plastic clay in southern Yamhill County, Oregon is hard pressed for reserves of white-firing clays. Both of the deposits have been reported on by Wilson and Treasher (1938). Some light-colored brick has been fired at the Willamina Clay Products plant located not far from the pit. Some of the brick have been produced from a mixture of Hobart and Willamina clays, and some of the Willamina clay has been shipped to Portland for making stoneware. Several other white-firing clays are known but the deposits are small and have been used sparingly if at all by "art potters."

The paucity of granites and pegmatites in the State explains in part the scarcity of white-firing clays. Generally, the acid igneous rocks weather to form light-firing clays, while the flow rocks such as rhyolite, and the more basic andesite and basalt produce clays having reddish or brownish to blackish colors when fired. The granitic masses found in southwestern and northeastern Oregon are for the most part insufficiently weathered to have formed significant deposits of clay. Deeply buried deposits of white-firing clay may occur in the State but the cost of "blind" exploration coupled with high mining costs effectively prohibit any possibility of production.

Bentonite, a rock composed principally of montmorillonite-group minerals, is formed by the alteration of beds of volcanic ash. Volcanic ash is composed largely of shards of volcanic glass that is readily attacked by ground waters charged with low concentrations of carbon dioxide, sulfuric acid, or organic acids. Central and eastern Oregon contain large quantities of Tertiary volcanic ash which has been partly or wholly altered to bentonite. Only one producer has exploited these reserves. A small open pit operation in eastern Crook County sells dried and crushed ore for sealing stock ponds and canals, and for making slurries for aerial bombing of forest fires. Minor amounts are also sold as a stock feed pellet binder. Exploitation of Oregon bentonite deposits has been hindered by several factors: the deposits are relatively impure when compared to material being imported from out of state; the deposits are at a considerable distance from markets; and no large deposits are known.

Shales suitable for the production of expanded lightweight aggregate are found at several localities in northwestern Oregon. Two producers have been actively mining and bloating Keasey Shale (Tertiary) in Washington County for many years. Keasey Shale is a fossiliferous, gray, expansible rock which increases in volume when fired in a revolving kiln. The feed to the kiln is crushed, screened, and fired to a product having as nearly the correct size as possible. Each fired lump has a characteristic "skin" formed by the softening of the

exposed surfaces in the kiln. The skin helps to prevent water and cement absorption, but even lumps that have been cracked or crushed take up little moisture since the cellular texture consists largely of individual cavities rather than connected tubes.

Expanded shale is used primarily as a lightweight aggregate in concrete products. Large tonnages of the material are used in prestressed concrete members such as architectural beams, Lin-Tees, and piling. Expanded shale is also fine-ground to make a pozzolan for use with portland cement.

Reserves of Keasey Shale suitable for the production of expansible shale are very likely adequate for any future demands. The deposits now being worked are located on paved highways and probably represent the most readily available of all of the known reserves. The remaining reserves, located primarily in Washington, Columbia, and Clatsop Counties, are believed to be large but no detailed examination of them has been made.

High alumina clays in Oregon received considerable attention during World War II when foreign supplies of bauxite were curtailed. An elaborate pilot plant was constructed at Salem to test clays from Oregon and other Northwest deposits, but cessation of hostilities terminated the project and no ore was either mined or milled. The deposit receiving the most attention was located near Molalla in southern Clackamas County. The clay contains approximately 30 percent Al_2O_3 and is composed of a mixture of plastic and semi-flint horizons. The deposit was first examined by Wilson and Treasher (1938). In 1942 and 1943 the property was examined by the U. S. Bureau of Mines. A total of 77 holes were drilled, the deepest being 189 feet. A geological report was made by Nichols (1944) for the U. S. Geological Survey. In his report Nichols estimated the reserves at 49 million dry tons of measured and indicated clay with an available Al_2O_3 content of 26.37 percent. Of this total there are 26 million tons having an Al_2O_3 content of 29 percent. High alumina clays at Hobart Butte and at other nearby deposits have been discussed by Allen and others (1951).

Diatomite

(By N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg.)

Diatomite, kiesselguhr, or diatomaceous earth are the names commonly used to designate an exceptionally light-weight, porous, chemically inert sedimentary material composed principally of the frustules or shells of minute aquatic organisms known as diatoms. More than 12,000 species are known, distinguished mostly by the shape and ornamentation of their frustules which are made of a hydrous form of silica similar to opal. Individual frustules range from a few microns to a few hundred microns in size and they occur in a wide variety of shapes; however, in their natural undeformed state they are hollow and are commonly characterized by an abundance of perforations which give the casing an open lattice-work structure. As a result of this porosity (65 to 85 percent voids), kiln-dried diatomite may weigh as little as 5 to 16 pounds per cubic foot but because of absorbed groundwater the density of pit-run material may be considerably greater.

Diatomite finds its greatest use as a filtration medium. About half of the United States production is accounted for in the processing of beverages, vegetable oils, paints, thinners, lacquers and medicines and other industrial liquids. About one-fourth of the domestic production is used as filler material in batteries, tires and similar goods with the balance distributed between heat insulation and more than 300 other uses such as absorbants, lightweight aggregate, pozzolan, abrasives, pesticide carriers and ceramics (fig. 52). For some of the less demanding uses, diatomite is marketed in a dried, screened, and sized but otherwise unprocessed form, but that marketed for filtration and other higher grade uses is calcined.

The evaluation of diatomite deposits is complex and involves tests of suitability of the material as well as minability. The relative abundance of different diatom species, extent of fragmentation, particle size range and furnacing characteristics are each important in determining potential uses and hence the market value of material. Otherwise, to be minable, a deposit must be large, have few impurities, be well drained and advantageously located with respect to transporta-

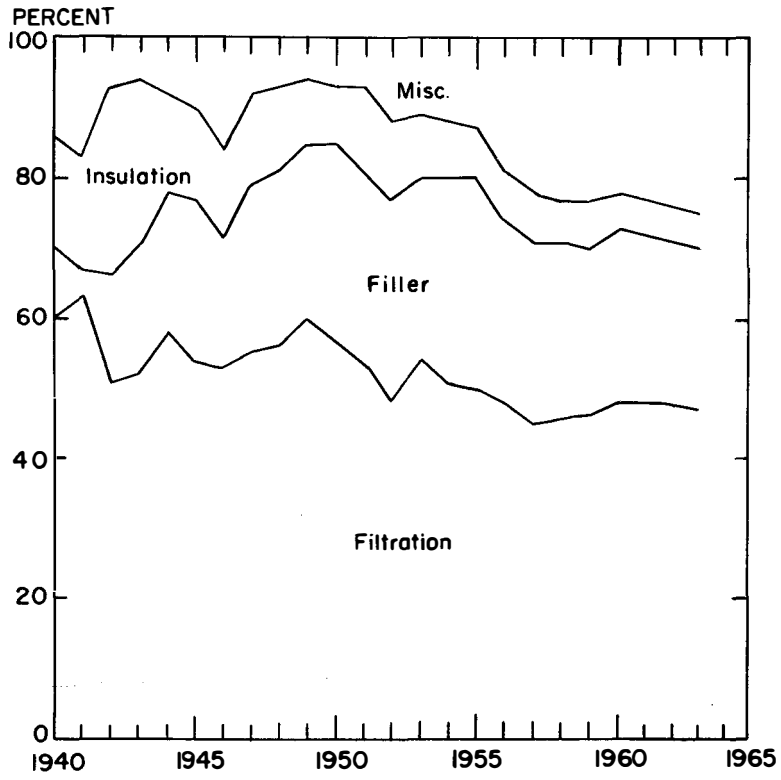

FIGURE 52.—Relative quantity of diatomite consumed in the United States for each principal class of use, 1940–1963. (Compiled from U.S. Bureau of Mines Minerals Yearbook 1963, volume 1).

tion. Intermixed volcanic ash is an especially undesirable contaminant. Sand, silt and clay are also undesirable although separate beds or layers of these or other contaminants can generally be separated if they are not too closely spaced. Organic matter, which may give the diatomite a brown or black color, is less serious in that it can be burned out during calcining. Consequently even though diatomite is found both on the east coast and in many parts of the western United States, minable deposits are by no means abundant.

Diatoms are living today in both the oceans and fresh water lakes, wherever favorable ecologic conditions exist. Diatomite, however, represents the fossil remains of diatoms that lived under conditions in which their shells accumulated in fantastic numbers. How fantastic is illustrated by the fact that a cubic inch of diatomite may contain on the order of 30 to 40 thousand individual frustules; hence the total number of diatoms represented in even a small deposit is virtually beyond comprehension. Studies of living diatoms indicate that ideal conditions for such abundant multiplication entail clear, cool, well-lighted water with a constantly replenished high content of silica to replace that removed from solution by the growing diatoms. Large accumulations are thus almost universally associated with periods of widespread terrestrial volcanism. Lakes impounded behind lava dams provided the necessary habitat, and volcanic ashes and solutions of volcanic origin constituted an abundant source of silica. Similar favorable conditions exist less commonly in marine environments, but only locally in relatively protected areas such as bays and estuaries where the water chemistry is favorable and not subject to excessive dilution from the open sea. With a few exceptions almost all known freshwater diatomite deposits are closely associated with volcanic rocks; a relationship that is less conspicuous with marine deposits. Some diatomite occurrences of pre-Cenozoic age are known. However, most deposits range in age from Tertiary to Quaternary, and all of the commercially important deposits are of late Cenozoic age or younger. Those of marine origin have about the same range of uses as those of freshwater origin but the two types contain distinctively different assemblages of diatom species.

TABLE 14.—DIATOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, 3-YEAR TOTALS

Years	Quantity short tons	Average value per ton
1945–47	640,764	$20.17
1948–50	733,670	25.55
1951–53	908,448	29.97
1954–56	1,105,279	39.21
1957–59	1,349,340	45.73
1960–62	1,446,625	50.08

Source: Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 630.

The United States is the world's leading producer and consumer of diatomite. Russia is the next largest producer. Between them they produced approximately half of the world total of 1,610,000 short tons mined in 1963. In 1963 the United States production (table 14) came from 15 plants operated by 13 companies. California supplied about 80

percent of the total production, with Nevada and Washington next in rank. Minor production came from Arizona, Maryland and Oregon.

Domestic reserves are largely undetermined. Diatomite is found in nearly all the Atlantic Coast States and in some of the Central States as well, but the largest and best of the known domestic resources are in the West. California has extensive reserves; a single deposit near Lompoc extends "over many hundreds of acres with beds reaching 1,400 feet in thickness" (Petkof, 1965). In Nevada it has been said that "diatomite must be considered as occupying large basins rather than be considered as individual deposits" (Olson, 1964). Arizona, Oregon, and Washington also have large quantities of minable diatomite.

DIATOMITE IN OREGON

There are many diatomite occurrences in Oregon (fig. 53). Most are located east of the Cascades where they are associated with volcaniclastic rocks of Miocene to near Holocene age. All are freshwater deposits as are the diatomaceous oozes known to be forming in parts of Klamath Lake today (Moore, 1937). Some of these deposits are prominently and extensively exposed by erosion; most, however, are quite poorly exposed. Indeed, before it was developed, Oregon's most notable producing deposit was almost totally hidden by overlying soils and fluviatile sediments.

Only minor quantities of diatomite have been produced from Oregon sources during recent years. Production from a deposit in Lake County is used for packaged pet litter, and production from a deposit in Baker County is used as one of many ingredients blended into a manufactured soil conditioner. Previously, diatomite was mined extensively from a deposit near Terrebonne, Deschutes County (fig. 53, T) and marketed in natural, calcined and flux-calcined forms for practically all the special-purpose uses for which diatomite is suitable. Much of this was used as a filter medium in the manufacture of sugar and antibiotics.

The Terrebonne deposit was first developed about 1920 but was most productive between 1935 and 1961. The deposit underlay approximately 800 acres and contained a section of usable diatomite beds 22 to 28 feet thick (Drysmid, 1954). Original exposures were limited to small, comparatively unimpressive outcrops along the rim of the steep-walled Deschutes River Canyon; elsewhere the diatomite was overlain by 10 to 30 feet of fluviatile sands and gravels, and locally by basalt. It is believed to be late Pliocene or early Pleistocene in age.

A comparatively small output of non-calcined diatomite produced intermittently between 1917 and 1934 from a deposit near Harper (fig. 53, D) is the only other recorded production from Oregon (Moore, 1937). This came from a large, prominently exposed occurrence of Miocene diatomite interbedded with volcaniclastic sediments, and overlain by Pliocene tuffs, and locally, by basalts.

Most of the deposits shown on figure 53 have been examined and sampled during recent decades by prominent companies identified with the mining, processing, marketing, and evaluation of diatomite. Some have been accorded extensive, follow-up exploration. It is understood, however, that while many of these occurrences were found to

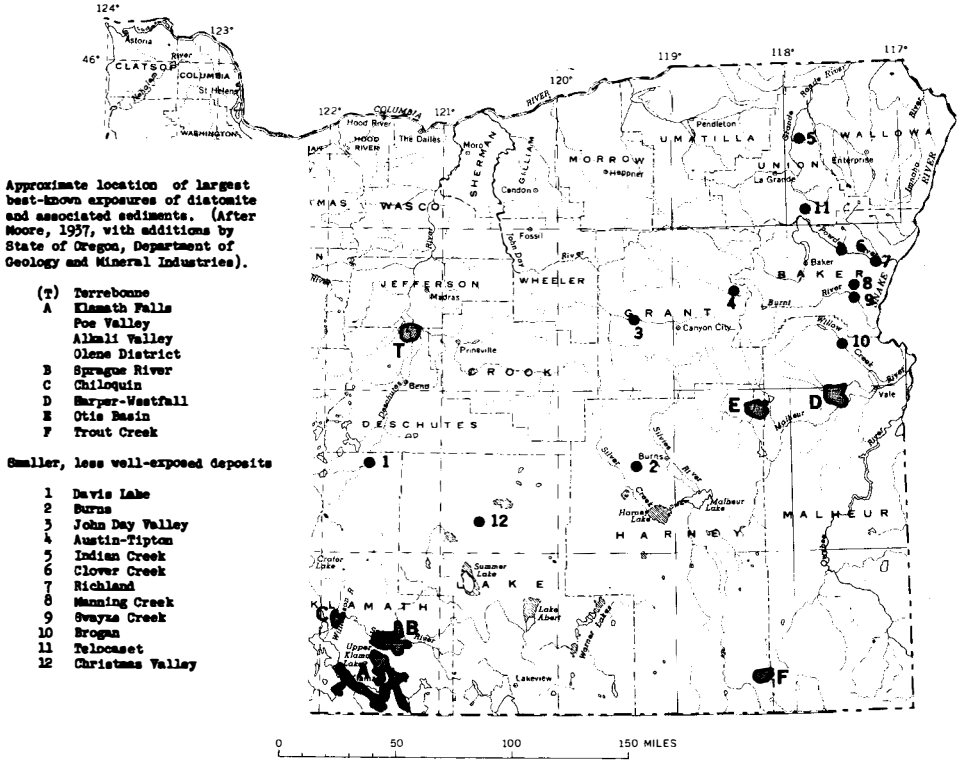

FIGURE 53.—Diatomite in Oregon.

contain diatomite suitable for many industrial uses, most are generally regarded by industry as being deficient in beds containing the kinds of diatoms required for the production of high quality filter media. This condition is believed to apply primarily to deposits of Miocene age and generally less so to the younger Pliocene and Pliocene-Pleistocene deposits. The Terrebonne occurrence represents a notable example of a Pliocene-Pleistocene deposit that contains material eminently suitable for filtration products. Unfortunately, the most impressively exposed diatomites in Oregon are Miocene-Pliocene in age; hence on the basis of the above findings, the material in these deposits is suited for common to intermediate grade uses. On the other hand the potential for finding minable quantities of filter-grade diatomite cannot be regarded as wholly negative. Throughout eastern Oregon, particularly in the High Lava Plains, Basin and Range, and Owyhee Upland provinces (fig. 1) there are many areas that are still in an extremely youthful state of erosion. Some of these areas contain large, structurally undisturbed, and virtually uneroded blocks of upper Pliocene to Holocene sediments in a geologic setting comparable to that at Terrebonne. Inasmuch as the Terrebonne deposit provides precedent for believing that filter grade diatomite may exist in association with the younger sediments, the uneroded basins and plateau surfaces underlain by these Recent sediments must be considered as logical areas for exploration for additional deposits of filter-grade diatomite.

Gem Stones

(By R. S. Mason, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

The quartz family minerals, which constitute the bulk of the semiprecious gem stones found in Oregon, very likely provide the basis for recreation for more people living in the State than any other single natural resource. Since World War II there has been a rapid growth in interest by the layman and his family in the search for, preparation of, and eventual display of the wide variety of quartz family minerals. The "rockhounds," as they are popularly called, are attracted not only by the thrill of discovering a particularly fine specimen, but by the fact that it is a recreational pursuit which knows no season, requires no license, and has no minimum or maximum qualification age for participation. The hobby in its simplest form may entail only the collecting and tumbling or sawing of specimens. More advanced hobbyists often specialize in certain types of minerals or finished materials. The displays sponsored by the numerous "rockhound" clubs scattered across the State reveal the wide appeal that the hobby has and the equally diverse skills and interests of its various members. Displays of jewelry are naturally one of the most popular, with collections of mineral specialties, such as zeolites and petrified wood or laboriously handcrafted objects such as flowers, butterflies, and working models of spinning wheels also finding wide attraction. There are more than 3,000 members of organized "rockhound" clubs in Oregon. The clubs have been active in recent years in standardized displays, conducting field trips, and promoting good outdoor habits. An abundance of printed material has become available on the subject of semiprecious gems,

"rockhounding," gemmology, and related subjects. The following authors have prepared books and articles that are of interest to both the layman and professional interested in semiprecious gems: Fritzen (1959), Frondel (1962), Leechman (1966), Parsons and Soukup (1961), Pearl (1964), Quick (1963), Sinkankas (1961), and Webster (1964).

Semiprecious gems are found in many parts of Oregon. The coast has long been a favorite haunt of the vacationist intent on finding water-polished agates, jasper, and other colorful stones. Numerous stream beds in northwestern Oregon and the Willamette Valley also yield quantities of cutting and polishing material of various kinds. East of the Cascades, collecting areas are scattered from the Columbia River south to the California and Nevada boundaries and eastward to the Idaho line. Maps showing the principal areas in the State where semiprecious gem stones are found have been published by the Oregon Agate and Mineral Society and the Travel Information Division of the Oregon State Highway Department. One of the early publications on Oregon gem minerals, issued by the Oregon Department of Geology and Mineral Industries (Dake, 1941), has been out of print for many years, but Dr. H. C. Dake subsequently authored numerous privately printed books on the subject.

Oregon ranks high among the States in the production of semiprecious gems. Exact statistics on the value and amount of material annually produced are difficult to determine, since a large proportion of the stones are collected by nonprofessionals or by part-time operators. Although regular dealers probably handle a considerable portion of the total, many stones are bought, sold, and traded on an individual basis. The U.S. Bureau of Mines has conservatively set the annual value of semiprecious stones produced in the State at $750,000. In all probability the actual figure is many times larger. In response to a rapidly increasing demand for information on semiprecious stones and localities where they may be obtained, several communities in the central part of the State have created "rockhound" service groups. The Prineville and Crook County Chamber of Commerce has been particularly active in this effort. Visiting "rockhounds" can obtain maps to local digging areas, together with information on Federal rules and regulations, and campsites. In the Crook County area, there are numerous localities available to the "rockhound." Some are publicly owned, others are controlled by the Chamber, and others are privately held. The privately owned areas usually charge a daily fee plus a poundage rate. The popularity of "rockhounding" is such that thousands attend the annual "Powwow" held at Prineville.

The thunder egg is the State stone for Oregon. Of all the semiprecious materials collected in the State, the thunder egg very probably ranks first in quantity collected. The "eggs" were formed in vesicles in Tertiary lava flows which were subsequently filled with silica, both coarse- and fine-crystalline. The method of formation of thunder eggs has been described by Staples (1965). The eventual erosion and weathering away of the lava flows released the more resistant cavity fillings. In some areas the eggs lie scattered over the surface; in others the eggs remain imprisoned in the original matrix and must be dug out. In the latter case, the flows are usually partly weathered, and excavation is somewhat simpler than mining in solid

rock. Most of the commercially run collecting areas strip away the overburden and expose fresh faces from time to time to facilitate recovery by "rockhounds." The thunder eggs range in weight from a few ounces to over 100 pounds.

A recent study by Peck (1964) of the geology of the Antelope-Ashwood area of north-central Oregon includes the following description of the nodule-bearing beds at the widely known Priday Ranch locality located about 20 miles north of the town of Madras. Although thunder eggs vary widely in appearance at the numerous localities, the geologic setting and method of formation are quite similar.

> The spherulites are chiefly in the lower few feet of a weakly welded rhyolitic ash flow * * * at the base of member F of the John Day Formation, but some are in pumice lapilli higher in the ash flow and in the upper few inches of the underlying stony ash-flow sheet (number E). The weakly welded ash flow * * *, which is 10 to 20 feet thick at the deposit, is composed of black perlitic angular lapilli of collapsed pumice in a matrix of shards and ash. Locally the basal part of the ash flow is altered to clay and to less abundant opal. Chalcedony-filled spherulites are widely distributed at this horizon; formerly they were recovered in large numbers from a locality about 1 mile northeast of the present Priday deposit.
>
> The Priday deposit is on a low mesa supported by the resistant ash-flow sheet of member E and is surrounded by the underlying tuffs of member D * * *. The spherulite horizon is preserved in a northward trending graben in which the Priday ash flow has been downdropped about 100 feet. The fault bounding the west side of the graben is exposed about 100 feet (in 1958) west of the pit, where it trends N. 10° E. and dips 80° E. West of this fault the Priday ash flow with its enclosed spherulites has been uplifted and eroded.
>
> The thunder-eggs from the Priday deposits and other localities in Oregon and Idaho have been described in detail and illustrated by Dake (1938), Ross (1941), Renton (1951) and Brown (1957), so that a brief description will suffice here. They are small spheroidal bodies, about 3 inches in average diameter, and have a cauliflowerlike surface crossed by low ridges. Most consist of an outer shell of pale-brown aphanitic rock and a core of white to bluish-gray chalcedony. The outer shell of each thunder-egg is composed chiefly of shards, fine ash, and collapsed pumice lapilli, all of which are altered to radially oriented sheaves of fibrous cristobalite and alkalic feldspar. The chalcedonic cores commonly contain concentric and planar bands and dendritic mineral growths and range in shape from round and highly irregular forms to geometrically regular pyritohedrons and cubes, each face of which is an inward-pointing pyramid (Ross, 1941, pl. 2, fig. d; Brown, 1957, pl. 3, fig. 3). These appear as squares and stars in section.
>
> A reasonable explanation of the origin of the thunder-eggs has been advanced by Ross (1941b, p. 732). He concluded that spherulites formed during cooling of the ash flow and were disrupted by the pressure of volatiles exsolved from the ash; the resultant cavities were later filled by chalcedony during alteration of the enclosing ash flow.

Names applied to the various semiprecious gems reflect a mixture of science, geography, folklore, and fanciful description. Petrographically all the quartz family stones can be divided into two main groups; the coarse-crystalline and fine-crystalline. Table 15 lists the principal gem stones found in Oregon under these two categories. The fine-crystalline stones can be further subdivided into groups represented by chalcedony, agate, jasper, and opal. Chalcedony has a microfibrous texture, whereas agate is distinguished by concentric or planar banding. Jasper is a microgranular type that may have been formed by metamorphic processes. Opal is a submicrocrystalline mineral characterized by variable amounts of nonessential water. A detailed study of quartz and the numerous varieties of both coarse-crystalline and fine-crystalline minerals has been made by Frondel (1962).

TABLE 15.—SEMIPRECIOUS GEM STONES IN OREGON

Quartz family gem stones					Miscellaneous gem stones
Coarse-crystalline, quartz	Fine-crystalline				
	Banded microfibrous, agate	Microfibrous, chalcedony	Microgranular, jasper	Submicrocrystalline, opal	
Rock crystal	"Moss"	Chrysoprase	Bloodstone	Common	"Sunstone".
Amethyst	"Iris"	Enhydros	"Oregonite"		Grossularite.
"Polka-dot"	"Plume"	Carnelian	"Wascoite"		Obsidian.
	Sagenite	Plasma	Tempskya		Rhodonite.
	Petrified wood	Petrified wood			Almandite.
	"Thunder egg"	Sard			Zeolite.
		"Thunder egg"			

Considerable confusion exists in the terminology applied to semiprecious stones by the layman. The distinction between the various types of quartz family stones often can be resolved only by microscopic or other laboratory procedures. In all probability, there will always be some uncertainty identifying a semiprecious stone in the field, but as long as it is recognized as belonging to the quartz family rather than to some other mineral group, there is nothing really too seriously wrong. An excellent guide to the intricacies of identifying and naming the numerous varieties of the quartz family gem stones has been published by Dake, Fleener, and Wilson (1938).

Clusters and crusts of coarse crystals are usually bought and sold "as is," with perhaps a careful cleaning the only processing attempted. The second group comprises by far the larger portion of the semiprecious gems collected. The fine-crystalline type of silica forms the bulk of most of the "thunder eggs," and the numerous varieties of agates and chalcedony. Although lacking in visible crystal form, the fine-crystalline stones possess a wide variety of patterns and colors. Some agates are almost perfectly water clear, whereas others are translucent with colors of every hue. Agates may be banded, speckled, flecked, infiltrated with "moss," "plumes," "iris," or other forms of mineral impurities which impart interesting and unusual patterns, or there may be cavities which given an open-work texture to sawed slabs. One of the rarer types of gem stone found in the State is filled with water. Although most "water agates" (actually chalcedony) or enhydroses are quite small, specimens weighing several pounds have been found. Most enhydroses are found along the Oregon beaches.

Oregon is noted for its petrified (silicified) wood. Excellent material, ranging in size from small agatized limbs to solid logs several feet in diameter and yards long have been found in many parts of the State. Some highly prized material has been recovered from petrified stumps still rooted in the soil that has turned to stone during the millions of years since the trees were buried. The identification techniques used on petrified wood have been described by Eubanks (1960, 1966). An interesting petrified material called Tempskya has been found in limited quantity in the Greenhorn district of eastern Oregon. The Tempskya was originally a fern with a curious false trunk composed of bundles of stems. The jasperlike masses reveal a distinctive pattern when cut and polished. Oregon is also

noted for agatized seeds, nuts, and fruits. The deposits in the Clarno area of Wasco and Wheeler Counties have yielded large numbers of excellent specimens. A detailed study has been made by Scott (1954).

A few small diamonds have been found in Oregon. Their discovery in gold placer concentrates was accidental, and no concerted efforts have been made to find others. A diamond chip about the size of a small fingernail is on display in the Roebling Collection of Native Diamonds in the Smithsonian Institution, Washington, D.C., and bears a label stating that it was found in Curry County, Oregon. Uncut diamonds closely resemble agates, and very likely some diamonds have been mistakenly discarded during placer gold cleanups. Geologically, the ultramafic rocks such as serpentine, dunite, and periodotite that are found in southwestern Oregon and also in the Blue Mountains of the northeastern part of the State could be hosts for diamonds. Recovery of diamonds from stream gravels requires, in addition to regular placer mining equipment, a section of sluice box lined with grease-covered sheet metal. Diamonds possess the peculiar property of not being wet when immersed in water thus when a diamond passes over the grease-covered metal it sticks to the grease, while all other grains and pebbles roll past, protected from the grease by a film of water adhering to their surfaces.

Semiprecious gem resources in the State are probably large. Much of the easily recovered material lying on or near the surface has been found. Future "rockhounds" will continue to discover good material on the surface, but more and more will have to come from excavations of greater and greater depth. In all probability there will be continued growth in membership of "rockhound" groups, which in turn will sponsor more conducted "digs." With the exhaustion of surface deposits and the opening up of commercial digging areas, recreational "rockhounding" will change from a largely freelance activity to a more formal and regulated one. The problems of the exploitation of semiprecious gem stone deposits on public lands have been of growing concern to the "rockhound" organizations, the commercial collector, and the public agencies charged with the administration of the lands involved. In a discussion of some of the problems, the U.S. Bureau of Land Management revealed that it is currently treating recreation mining as a specific component in its multiple-use management classifications, where appropriate (I. W. Anderson, oral communication, 1966).

Gypsum and Anhydrite

(By N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg. and C. F. Withington, U.S. Geological Survey, Washington, D.C.)

The calcium sulfate minerals gypsum ($CaSO_4 . 2H_2O$) and anhydrite ($CaSO_4$) have a long record of use in the building trade industry and agriculture. Pure gypsum is generally white or light gray; impurities may color it dark gray, black, pink, green, or yellow. The most common form is massive rock gypsum, a compact aggregate of small crystals occurring in beds as much as 100 feet thick. Alabaster is a compact, very fine-grained rock gypsum. Other varities, of mineralogic interest only, include satin spar and selenite. Gypsite

is an impure earthy mixture of gypsum (rarely more than 70 percent), sand, silt, and clay formed near the surface in secondary deposits that are seldom more than 30 feet thick and a few acres in extent. The gypsite is generally gray mottled with white, buff or cream; iron may color it pink or red.

Anhydrite is slightly heavier and harder than gypsum. Pure anhydrite may be gray, bluish gray or white; impurities may color the mineral red, pink, gray, or black. Anhydrite may occur as isolated crystals or lenses within a gypsum deposit.

Most commercial deposits of gypsum and anhydrite are found in sedimentary rocks and were deposited as chemical precipitates from saline water, generally in partly isolated arms of the sea. The two minerals are closely associated. In most deposits the calcium sulfate probably was originally precipitated as anhydrite and hydration to gypsum has taken place near the surface by ground and surface water. Consequently, in most deposits gypsum at the outcrop gives way to anhydrite at relatively shallow depth.

Gypsum is the more useful of the two minerals. Most gypsum mined in the United States is calcined to be used as plaster and in the manufacture of wallboard and other prefabricated gypsum products. A less dominant but important application is for making industrial models, patterns, and molds. Uncalcined or raw gypsum is used as a set retarder for portland cement and as a soil conditioner. Gypsite is used extensively as a soil conditioner, especially in California.

According to the Bureau of Mines state-of-the-industry records for 1963 (Barton, 1965), the United States is the world's largest producer of gypsum and also the largest consumer. The domestic industry included 71 mines which produced a total of 10.4 million short tons of crude gypsum. There were 68 domestic calcining plants in service and the value of gypsum products sold or used (including imports) was $414.1 million. Compared to 1890 the annual domestic production had increased 56.8 times and the domestic demand for gypsum products had increased 95.0 times. If the economic growth of the United States continues as expected, annual domestic production of gypsum may reach as much as 13 million tons by 1975, and nearly 20 million tons by 1985. The amount of gypsum imported into this country will also increase. At present, the annual import of crude gypsum, mostly from Nova Scotia and Mexico, amounts to between 5 and 6 million tons. This figure should rise during the next several years and by 1975 may reach 8 million tons.

No figures are available for the amount of anhydrite produced annually in this country, but it probably amounts to only a few hundred thousand tons. As much as 500,000 tons is imported annually. It is used primarily as a soil conditioner—in the southeastern United States more than 200,000 tons is used annually to provide sulfur for peanut crops. Mixed with gypsum it is used as a retarder for portland cement. In Europe and Asia anhydrite is used in making sulfuric acid and ammonium sulfate.

Although deposits of calcium sulfate are not distributed evenly throughout the country, large occurrences of gypsum are known in many States, and the measured resource (domestic) is estimated to be sufficient for many centuries of output at the present rate of production.

However, exploitation of these deposits is governed to a large degree by the location of occurrences with reference to transportation facilities and market areas. Because the demand in the northwest is great, local producers of gypsum would probably find a ready market for their product.

Between about 1896 and about 1926, gypsum was produced from near the Snake River a few miles north of Huntington, Baker County (fig. 54, No. 1). The deposits are on a ridge 1,800 feet above the river in secs. 16, 17, 20, 28, and 29, T. 13 S., R. 45 E. Willamette Meridian. The property was first operated by a local concern known as the Oregon Plaster Company, then later by the Pacific Lime and Plaster Company (about 1911–1919), the Acme Cement and Plaster Company (1919–1923), and the Certain-teed Company (1923–1926). Mining involved both open-cut and underground workings from which the product was delivered a distance of 1⅛ miles by aerial tram to a rail siding adjacent to the river at an elevation 1,800 feet lower than the mine. From here it was initially shipped by rail to a calcining plant at Lime some 10 miles distant, but around 1912 another calcining plant was built at the tram discharge site on the river. Today the dumps of waste rock at the mine constitute a well-known landmark visible for miles, but virtually no trace of the old facilities is to be seen. The lack of maps or reports on the former operation and the inaccessible condition of the working make it difficult to determine the nature of the deposit. However, this is believed to be one of the comparatively unusual types of occurrences in which sulfate waters introduced along fault planes altered calcareous beds to anhydrite and gypsum along a comparatively narrow zone bordering the faults. No data are available on the purity of gypsum mined, but W. C. Riddell (oral communication, 1957) recalled that the gypsum contained a considerable amount of white calcium carbonate that looked like the gypsum, which made mining pure gypsum difficult. In addition, thin seams and grains of chlorite occur scattered through the gypsum, which added to the impurities.

The deposit was worked in three places along three-fourths of a mile of the valley wall; the workings extended into the hill about 300 feet. The gypsum is in lenses or beds as much as 40 feet thick, very similar to the deposits that are 4 miles to the north across the Snake River in Idaho (Lindgren, 1904, p. 111; McDivitt, 1952; Withington, 1964). According to Moore (1937), the minable gypsum has been removed to the extent that remaining reserves consist largely of anhydrite.

These deposits occur in close association with a series of red and green shales and conglomerates with interspersed limestone pods and calcareous subhorizons. Described as the "Gypsum formation" and mapped as part of a larger section of Triassic sediments (Livingston, 1923), these lithologically distinctive beds strike east across the Snake River at a point some 3 miles north of the gypsum mine and thence are exposed along a north-northeasterly trend for many miles in Idaho. Although in Oregon these beds are covered in many places by Tertiary formations, they have been traced intermittently along a south-southwesterly trending arc to Juniper Mountain, Malheur County (an inferred trace distance of approximately 40 miles) beyond which they are again obscured by Tertiary formations. Gypsum occurrs in associa-

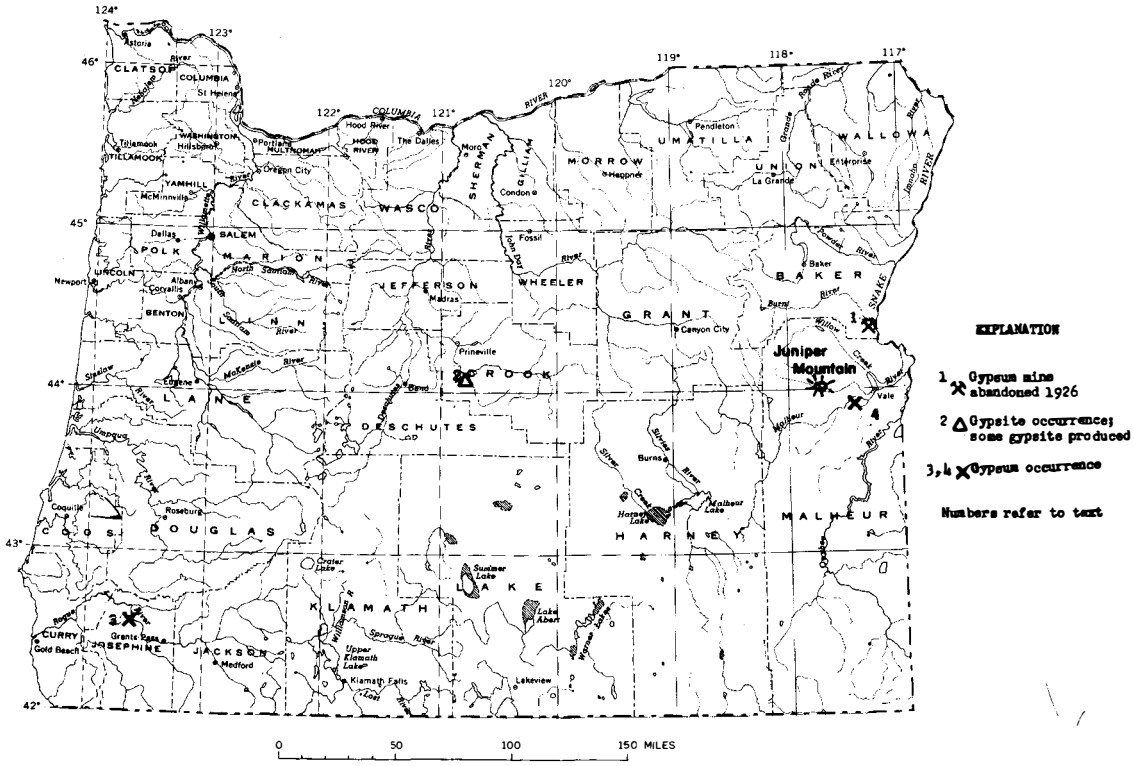

FIGURE 54.—Gypsum, gypsite and anhydrite in Oregon.

tion with these beds at several places in Idaho (Lindgren, 1904; McDivitt, 1952; Withington, 1964) which is one of the contributing reasons for Livingston having named them the "Gypsum formation." However, no additional gypsum deposits are known to occur in association with these beds in Oregon. Brooks (1967) has indicated that the red and green conglomerate may be in unconformable relationship with the red and green shales with which the gypsum is associated. Whether they are, or are not, the remnants of anhydrite and gypsum occurring at, and in the immediate vicinity of the original mine site, constitute the only reserves that can now be described in this area on the basis of available data. Further exploration back from the rim of the valley near the old workings might find additional beds of calcium sulfate. This material would be predominantly anhydrite but might be useful as a set retarder for portland cement.

A desposit of gypsite in sec. 28, T. 18 S., R. 17 E., Crook County (fig. 54, No. 2) was reportedly mined to a limited extent early in the century for local use as a fertilizer (Burchard, 1911; Stone, 1920, p. 236). The gypsite is known to underlie a considerable acreage. Memorandum notes of an examination in 1939 (White Swan prospect, State of Oregon, Department of Geology and Mineral Industries) indicate that the host material is a soft white tuff heavily impregnated with veinlets of crystalline gypsum. This was disclosed in a single shaft that penetrated a 39-foot section of the gypsite before bottoming in 8 feet of highly pyritized blue clay. Although surface evidence is described as indicating that gypsite may underlie a large area, no additional exploration is known to have been undertaken; hence no significant estimate can be made concerning the amount and gypsum content of the occurrence. In as much as the demand for gypsite in California and other Western States is great, this material might possibly be developed for use as a soil conditioner.

Gypsum stringers and clusters of gypsum crystals are commonplace in lake beds and tuffs in many localities in Oregon. Gypsum also occurs as a gangue mineral in many of the vein deposits. Some of these localities provide specimens of selenite and satin spar of interest to mineral collectors, but except for the above-mentioned deposits in the Huntington and Prineville areas, none of these appear to offer any possibility of commercial development.

Peat

(By C. C. Cameron, U.S. Geological Survey, Washington, D.C.)

The peat industry of Oregon is in its infancy, with production having begun only in 1966. The demand for peat as an important soil conditioner and horticultural commodity has reactivated a long dormant domestic industry formerly based on the use of peat as a fuel. Increasing demands for peat in the Pacific Northwest can be the basis for a larger industry in the future, as the peat resources are large although very imperfectly known.

Peat is a partially decomposed vegetable matter that has accumulated under water or in a water-saturated environment. Different types of peat have a wide range of physical and chemical properties. For statistical purposes the U.S. Bureau of Mines has classified peat into

three general types—moss peat, reed-sedge peat, and peat humus. Peat of sphagnum, hypnum, and other moss groups is classified as moss peat; whereas that of reed-sedge, shrub and tree groups is classified as reed-sedge peat. Peat is classified as peat humus when decomposition has obscured its botanical identity and further oxidation of the material has been impeded.

The coincidence of several physical and biological factors required for peat formation and preservation exist in several places in Oregon, namely a moderately moist climate and a soil that favors the growth of plants; a physical setting in which plant debris can accumulate; and a geological setting in which peat, once formed, may be preserved. Humidity is probably the most critical climatic factor in promoting plant growth and in inhibiting decay. Ponds, swamps, and marshes offer sites for rapid immersion of plant debris into a suitable peat-forming environment. Depressions containing quiet or slow-moving water part of the year at depths shallow enough to permit growth of woody and herbaceous plants range in size from small areas in hills and mountains to large areas of low relief in plains and plateaus. On the seaward side of mountains where the rainfall is high, deposits of sphagnum moss may accumulate and form peat independently of flooded conditions. Areas mapped by the U.S. Department of Agriculture (in cooperation with the State of Oregon) as containing peat and areas delineated as probably containing deposits are shown in figure 55. West of the Cascade Ranges, peat has accumulated in old lake beds in the lowlands. A typical example of a peat deposit forming is at Wapato in a valley like depression in which backwater from the Tualatin River stands several feet deep during winter. In places where the organic material is only slightly decayed, 75 to 90 percent of fibrous peat has been reported (U.S. Department of Agriculture, Bureau of Soils, 1920, p. 63). Other smaller peat deposits occur near the communities of Tualatin and Banks in the Tualatin Valley.

The Astoria area (U.S. Department of Agriculture, 1949, pp. 43–44) in northwest Oregon contains large quantities of peat with high organic content, high water-holding capacity, and low degree of fiber decomposition. The marine climate with cool summers and mild winters with abundant rainfall favors accumulation of sphagnum moss up to reported depths of five feet, somewhat above the flood plain of the Columbia River (U.S. Department of Agriculture, [pub. date unknown], p. 32). Thick deposits of reed-sedge, woody and moss peat lie on tidal flats and river flood plains in the Tillamook area (U.S. Department of Agriculture, 1964, p. 61). Peat occurs along streams, lagoons, and in old lake beds in the Coos Bay vicinity (U.S. Department of Agriculture, Bureau of Soils, 1911, pp. 35–57), but varying amounts of river sediment lower the quality.

The Coast and Cascade Ranges and the eastern Blue Mountains, especially the Wallowa Mountains, receive sufficient moisture to facilitate thick accumulations of peat at the sites of former lakes and ponds in deep depressions caused by (1) ablation under ice and snow fields, (2) gouging of bedrock by mountain glaciers, (3) irregular distribution of glacial moraine material, and (4) irregular distribution of volcanic material in the Cascades, as the result of glacial and volcanic activities during several stages of the

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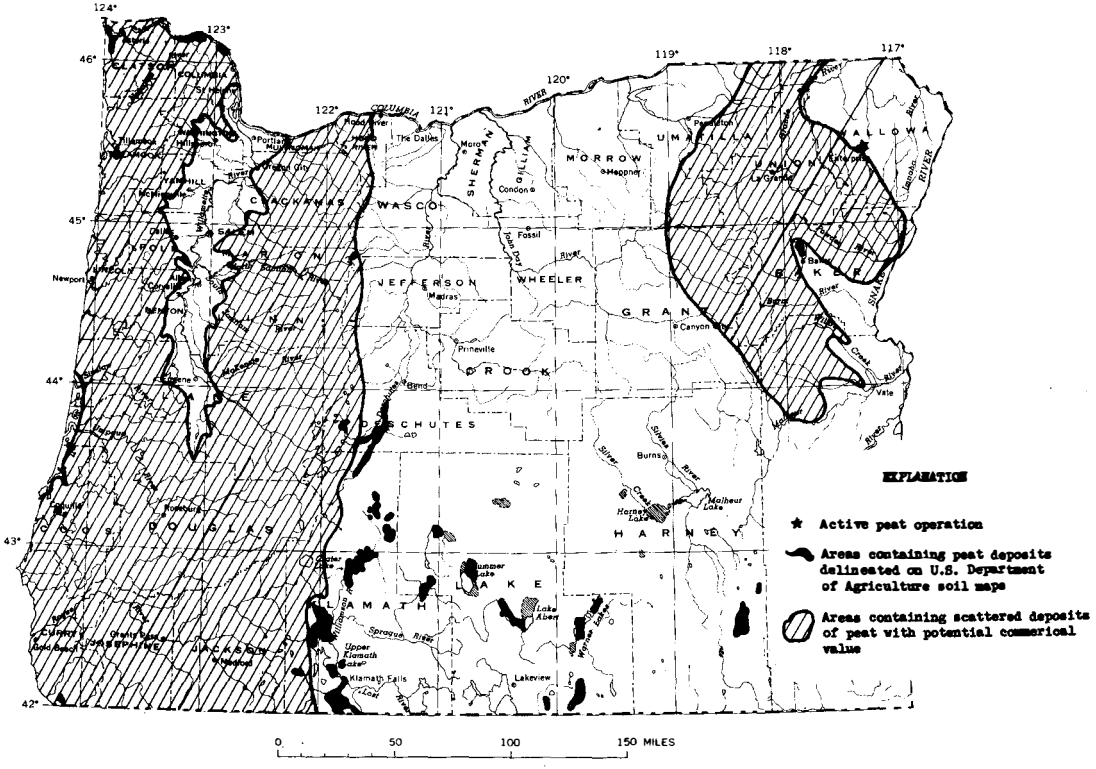

FIGURE 55.—Peat in Oregon.

Quaternary. Deposits in settings such as these offer the best potential for resources in the expanding peat industry. Although only a small part of the total area can be expected to contain commercially significant deposits, many of minable size should exist where glaciation has occurred.

Deposits of peat in the rain shadow east of the Cascades, such as those in the Basin and Range province, occupy old lake beds now covered by grassy marshes fed largely by groundwater. Many of these areas shown on the Soil Survey maps (U.S. Department of Agriculture, Bureal of Soils, 1935, pl. 5, sec. 4) have been exploited for farming and are now unavailable for use by the peat industry. Scarcity of water-fed depressions and low humidity reduce the resource potential in the High Lava Plains and the other plateaus and upland provinces in the rain shadow of the Cascades.

In the United States, production of peat for agricultural and horticultural purposes began about 1904 with about 12 companies producing a few thousand tons of peat annually. Since then the industry has expanded, and in 1965 there were 146 active operations in 26 States (Sheridan, 1967, pp. 265-267). Total production amounted to 604,082 short tons of air-dried peat. Fifty-three percent of the output was reed-sedge peat; about one quarter was humus; and the remainder was moss peat. All peat production is from surface pits. Seventeen percent was sold as excavated, and the remainder was processed. Most operators employ conventional types of excavating and earth moving machinery; these include power shovels, bulldozers, draglines, and front-end loaders which are used on drained bogs; clam shells and dredges are used on submerged deposits. Processing includes air drying by discing and harrowing the peat at the surface of drained bogs, or articificial drying in gas- or oil-fired driers. Before packaging or piling in heaps for bulk sales, the peat is screened and shredded.

Before 1955 most peat was sold locally in bulk. With the development of synthetic films for packaging, it is now practical to distribute large quantities of peat to all parts of the United States. Fifty-one percent of the peat sold in 1965 was packaged, and the remainder sold in bulk. Ninety-six percent of the peat marketed by domestic producers was sold for general soil improvement. Principal consumption was by nurseries and greenhouses for use as mulch for growing plants, shrubs and trees; by landscape gardeners and contractors for use in building lawns and golf course greens, and for transplanting trees and shrubs; and by homeowners for improving lawn and garden soils and for mulching. The remaining four precent was sold for use in potting soils and mixed fertilizers, and for packing flowers and shrubs. Total sales were nearly double the 1957–59 average. Of the total packaged sales, more than one-half was reed-sedge peat produced in Michigan. The remaining packaged peat was produced principally in Indiana, Illinois, California, New Jersey, and New York.

In 1965, sales totaled $6.1 million; the average value per short ton was $10.07. The over-all average for bulk peat was $7.62 per short ton, and for packaged peat was $12.41 per short ton. Imports, chiefly from Canada, amounted to 879,208 short tons of air-dried peat valued at $12 million. World production was estimated at 205 million short tons of air-dried peat, of which an estimated 89 percent was produced by the U.S.S.R.

Peat production in Oregon began in 1966 with 900 short tons of air-dried peat valued at $17,000 produced by Jewell's Mother Earth Company at Enterprise, Wallowa County. Sales in bulk and package averaged $18.89 per ton. The outlook for peat in Oregon suggests increase in consumption due to increased demand by homeowners, landscape gardners, and nurseries in the Pacific Northwest. Oregon peat should be able to compete regionally with foreign peat not only for agricultural and horticultural uses, but for other uses as well. Some of these may be in construction as an insulating material; as a cattle feed when blended with by-products of the sugar industry, as a poultry and cattle litter, as a vegetable storage and shipping material, and as a base for special fertilizers. Peat deposits in Oregon have not been studied for economic development beyond use as a soil for the raising of crops. Known reserves are small compared to other areas (Averitt and Taylor, 1953, p. 38), but resources of peat are very incompletely known. Possibly some of the many small deposits shown on the U.S. Department of Agriculture soil maps might be worked. The most promising potential, however, lies in the unmapped deposits of the Coast and Cascade Ranges and the Wallowa Mountains.

Perlite, Pumice, Pumicite, and Cinders

(By N. S. Wagner, Oregon Department of Geology and Mineral Industries, Baker, Oreg.)

Perlite, pumice, pumicite, and cinders are all types of volcanic rocks derived from material that was once molten. They differ from common dense stony lavas in that they are primarily glasses—the natural end-product of lavas that have cooled quickly under certain special and ideal conditions. The distinctive physical properties of all these rocks result in large part from the water content of the lava from which they were derived. Perlite, pumice, and pumicite form from lavas that are high in silica and generally of rhyolitic composition. Cinders, on the other hand, form from basaltic lavas that contain much less silica and relatively much more magnesium and iron. Perlite, pumice, and pumicite range from white to various tones of gray and tan. Cinders are almost always dark red to black. They are also commonly more stony than glassy.

Pumice, pumicite, and cinders are similar in origin in that all three represent the fragmental debris of lava that solidified for the most part in the air after having been explosively ejected from surface vents. When the parent lavas reach the surface of the earth, the release of pressure allows the contained water to expand and the resultant abundant steam forms a porous froth. If this cellular froth is cooled quickly, it forms a light, porous, glassy rock which is either pumice or cinder depending on the composition of the parent lava. Some pumice contains such a large proportion of cavities, or "fossil" bubble casts, that it is light enough to float on water. Cinders, however, are generally less cellular and proportionately heavier. Pumicite has the same origin, chemical composition, and glassy structure as pumice but lacks the cellular structure characteristic of pumice. This is because pumicite occurs in fragments too small to exhibit the bubble casts. The distinction between pumicite and pumice is thus primarily a matter of particle

size (Klinefelter, 1960) resulting from shattering during formation. Most of such explosively ejected materials, especially the larger chunks, fall back to earth in close proximity to the vent from which they erupted to form part of the cone that normally surrounds such vents; however, smaller sized fragments and ashes fall at progressively greater distances from the vent, in some instances covering large areas with blanketlike accumulations of rubble and shards.

Cinder cones constitute the source of most of the cinders that are exploited commercially, but some cinders form on the topmost layers of basalt flows when the parent lava contained a significant proportion of water. For the most part, however, basaltic lavas contain less water that rhyolitic lavas. They are also more fluid and are erupted at higher temperatures. Consequently, eruptions of basaltic lava are generally less explosive than rhyolitic eruptions, and the resulting cones are usually smaller. Bubble casts in the cindery portion of outlying lava flows tend to have thicker walls than the cinder fragments found in cones. The walls of the bubble casts on the flows also tend to be only partly glassy with the thicker parts grading into semicrystalline, stony basalt.

Under some conditions, rhyolite-type lavas containing water may flow out onto the earth's surface to cool and solidify without the formation of vapor bubbles. Some glassy occurrences of this type show distinctive shrinkage textures that resemble the concentric layers of onion skin, commonly with a small, hard kernel of darker pearly glass in the center. The concentric cracks give the rock a pearly luster, hence the name perlite. When perlite is heated, its chemically retained water expands to form a cellular product much like natural pumice.

Volcanic eruptions that produced pumice, perlite, cinders, and other glassy rocks have taken place throughout geologic time. However, over long periods of time most glassy rocks tend to devitrify. Additionally, the porous types such as pumice may be compressed by younger overlying rock-forming material, thus losing their cellular structure. For these reasons, the most extensive reserves of pumice, pumicite, perlite, and cinders are in the western United States, which contains many areas of comparatively recent volcanism.

Pumice and pumicite have long been used as abrasives for cleaning and fine polishing. Finishing plate glass is one example of this use. Soaps, scouring cleansers, and tumbling barrel grits represent others. In addition, there are many miscellaneous uses, a partial list of which includes use as fillers, and extenders in paints, enamels, varnishes, plastics, paper, and rubber goods, as catalysts and insecticide carriers, as decolorizing and purifying agents, for making special-purpose refractory brick, and for soil conditioning. There is a growing use of both of these materials, and cinders too, as a pozzolanic additive to hydraulic cements, to which they contribute greater workability, increases in strength and durability (see chapter on pozzolan materials), and a chemical ability to counteract excesses of free lime.

Cinders and pumice are both used as aggregate in the manufacture of light-weight, precast, concrete blocks and bulk pours in applications where insulation, fireproofing, and weight saving are important factors. Because of inherent differences in density, cellularity, and color, each imparts differing characteristics to the concretes in which

they are used. Due to its greater density and superior crushing strength, cinder aggregate is used generally in the same capacity as slags and artifically expanded shale aggregate, that is, for the manufacture of prestressed beams and wall panels and blocks where structural loads are appreciable. Cinders are also used extensively as railroad ballast and in highway surfacing mixes. Pumice, on the other hand, is perhaps more versatile in that it makes an even lighter weight concrete with superior insulation properties. Such concrete is suitable for deck and floor pours, for special-purpose, precast partition and roof panels, and for other uses in which low loads exist and the extra weight saving is advantageous. It is also used, commonly as blocks, for construction of homes and modest-sized buildings in which bearing strength is not a critical factor. Large amounts of pumice are used in making acoustic, fire-retardant building plaster.

As stated previously, expanded perlite is for all practical purposes a synthetic pumice. For this reason it is suitable for use in most of the ways in which pumice is used. Thus about 60 percent of the expanded perlite produced in the United States in 1963 was marketed as an aggregate for construction purposes or for loose-fill insulation in competition with pumice. However, with rigid control of furnace-feed sizing, furnacing temperatures, and exposure time in the furnace, perlite can be expanded to beads having a wider range of density and shell characteristics than pumice—from fairly dense glazed beads to a fluffy, ultralight-weight aggregate less dense than most natural pumices. Artifically expanded perlite can also be made to have a greater product uniformity with respect to particle sizes and sealed voids. Consequently, expanded perlite is favored for use in a greater diversity of industrial applications than pumice. Filtration is an illustration of a fast-growing industrial use, with perlite filter aids now competing at an increasing rate with diatomite in the filtering of food products, beverages, chemicals, resins, pharmaceuticals, and other liquids. Other industrial uses relate to expanded perlite's highly effective insulating properties at temperatures below —150°C. Expanded perlite is used extensively for insulating tanks containing liquid oxygen and hydrogen, for insulating steam and refrigeration pipes, for lining refrigerators, refrigerator cars, cold-storage bins, and frozen-food shipping boxes. Still other unusual industrial applications include use for imbedding hot steel ingots during transportation and as a foundry sand to prevent rapid cooling of metal castings in their molds.

Production statistics given by the U.S. Bureau of Mines by May (1965) indicate that in 1963 only 273,000 short tons of perlite were produced in the United States as compared to 2.6 million short tons of "pumice." Yet this small tonnage of perlite is valued as $14.5 million, whereas the much larger output of "pumice" is valued at only $6.6 million. The pumice was worth less than half as much as the perlite even though the tonnage was 10 times greater than that of the perlite.

The explanation of this seeming discrepancy in values for two products having similar compositions, properties, and uses is that for statistical purposes the U.S. Bureau of Mines lumps all production of pumice, pumicite, and cinders under the heading of "pumice," includ-

ing even the tremendous amount of cinders used yearly for railroad ballast and common road rock. Consequently, no comparisons can be made between the output or value of pumice marketed for uses equivalent to those represented by the perlite statistics. However, the combined statistics for pumice, pumicite, and cinders show that the total output and value of these materials has increased greatly since 1940.

Another significant statistic is that in 1963 there were 103 operations (including County, State, and Federal agency road metal pits) in 15 States, with Arizona the leading producer. Perlite has had an equally impressive record considering it was expanded commercially for the first time in 1940 and that commercial production did not assume significant proportions until 1946. By 1963 there were 7 States in which perlite was being mined, and in California, alone, there were 14 processing operations. Marketing was nationwide, with Pennsylvania and Texas having 6 processing plants each, followed by Illinois and New York with 5 each, and Colorado, Florida, Indiana, Iowa, and New Jersey with 3 each, and many other States, including Oregon, with 1 or 2 each.

Perlite, pumice, pumicite, and cinder occurrences are numerous and widely distributed in many western States. Many of these occurrences are impressively large and some, like the pumice accumulations in south-central Oregon, blanket huge areas. Because of this, there is a tendency to consider that reserves are sufficient for many years. This is probably so; however, because these are fairly commonplace materials there is a tendency to take them for granted as resources. Thus, even though most major occurrences have been recognized and catalogued geologically, only a few notable occurrences have ever been studied comprehensively from a mining standpoint. Statistics concerning reserves on a national scale are therefore not available. It should be borne in mind, however, that these are low unit value materials which must be delivered in bulk quantities and that marketing costs constitute one of the major problems facing the industry. As a consequence, occurrences favorably located with reference to marketing areas and transportation facilities are the only ones which can properly be regarded as minable. Another factor not to be overlooked is that all perlite does not "pop" to meet industrial standards, all pumices are not suitable for use as abrasives and aggregate, and only some natural glasses have pozzolanic properties. Devitrification, weathering, and associated impurities negate the commercial potential of many otherwise desirable-appearing occurrences. Thus, even though these resources can be classed as comparatively commonplace, it should not be inferred that reserves of material meeting industrial standards are necessarily as great as might be thought from the widespread geographic distribution of occurrences.

There are noteworthy occurrences of all four of these volcanic glasses in Oregon, especially east of the High Cascades (fig. 56). Shipments of lump pumice originating from the Newberry Crater area in Deschutes County and from several places in Klamath County have been made periodically throughout the present century; however, organized production of pumice, cinders, pumicite, and perlite for the higher levels of use has taken place almost exclusively within the past 20 years. During this time there has been a steady and growing output

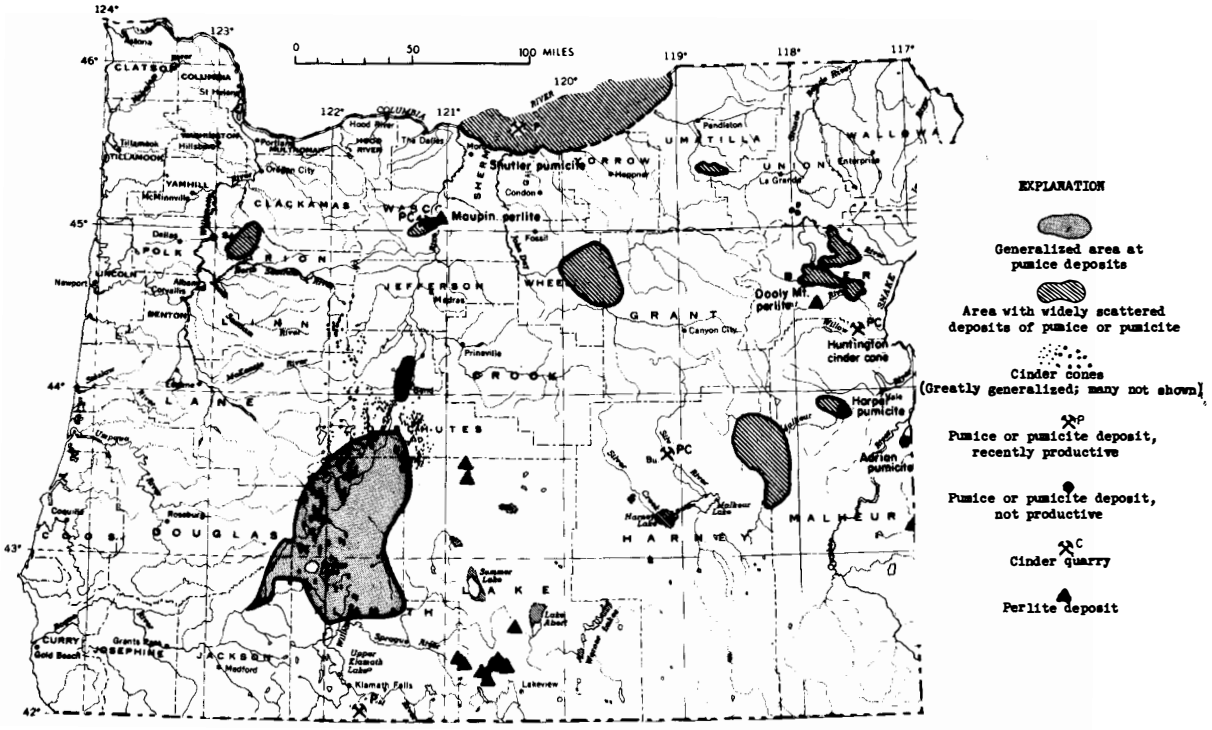

FIGURE 56.—Generalized distribution of pumice, pumicite, perlite, and cinder deposits in Oregon.

of both pumice and cinder aggregate and also periodic production of perlite and of pozzolanic cinders and pumicite. The use of cinders for road work has also pyramided.

Although there was some earlier sporadic production, organized production of pumice and cinder aggregate began with the housing boom which took place at the close of World War II (Mason, 1951). Most of this production has come and is coming from Deschutes and Klamath Counties in a belt paralleling the railroad from Redmond to Klamath Falls. Some aggregate has also been obtained at times from occurrences in eastern Oregon, notably in the Burns area, Harney County. Figures covering the amount of pumice and cinders from Oregon sources marketed annually as aggregate are not available, but in 1966 the combined total output of pumice and cinders sold or used by producers in Oregon for all purposes, including ordinary fill, rail ballast, and road uses, was 714,468 short tons valued at slightly more than $1.25 million according to U.S. Bureau of Mines statistics (personal communication, A. J. Kauffman, Jr.). The rate of increase in the use of these materials is illustrated by comparing with production in 1946, which only amounted to 3,004 short tons valued at $12,500. A large part of the present output consists of cinders consumed in connection with acccelerated highway construction programs, but aggregate represents an important percentage of the total. Both cinder and pumice concrete aggregates and specially sized and blended pumice plaster aggregates have been marketed regularly from two established operations in the Bend area to consumers located between Vancouver, B.C., on the north and central California on the south.

Pumicite from one of several occurrences near Arlington, Gilliam County, and black basaltic cinders form an enormous cone located near Huntington, Baker County (Wagner, 1946), have been used as possolan during recent years. In both cases the material was used as an additive in concrete in hydroelectric dams on the Columbia and Snake Rivers.

Perlite mining was attempted in Oregon on a major scale between 1945 and 1950, when the industry was in a truly pioneering stage of development (Allen, 1946). This operation was located in the Deschutes River Canyon near Maupin, Wasco County. It was conceived as an integrated mining, popping, and fabricating project. Fine, high quality accoustic and insulating tile was produced for a number of years until it became evident that economic operation was best achieved by expanding perlite for general consumer use in a number of small popping plants located in strategic marketing areas rather than at one large integrated facility. Today crude perlite from out-of-State sources is being expanded in Oregon in a plant located in Portland. There has been no production of crude perlite from sources within the State during recent years except for a small tonnage mined from an occurrence on Dooley Mountain, Baker County, and expanded at the Portland plant on a test basis.

On the strength of the mapped wide distribution of pumice deposits in Deschutes and Klamath Counties (Moore, 1937; Walker, 1951; Williams, 1942 and 1957), the reserves of pumice in Oregon can be described as tremendous. Much of this pumice is too hilly located with reference to transportation facilities to be minable under existing, or

presently foreseeable, conditions. Equally important, at many locations where pumice occurs within economic limits of transport to rail sidings, weathering, nonpumiceous sedimentary interbeds, excessive overburden, and/or ground-water saturation are factors which preclude mining. The net result is that, although the quantity of minable material meeting top industrial standards is probably enormous, favorably located occurrences with material of the necessary quality are by no means so numerous or so commonplace that no consideration need be given to the problem of reserves.

Minable-sized occurrences of clean, fresh pumicite exist within reasonable proximity to rail transport in Gilliam County near Shutler, in Klamath County about 8 miles southeast of Klamath Falls, and in Malheur County between Harper and Westfall and a few miles south of Adrian. Apart from the occurrences in the Maupin area, Wasco County, two of the better known perlite deposits in Oregon are located on the south slope of Dooley Mountain, Baker County. Another which has received prospecting attention is located near Sheaville, Malheur County. Additionally, several occurrences have been described from areas within Klamath and Lake Counties (Peterson, 1961). Cinder cones and basaltic scoria are to be found throughout all of eastern Oregon but are probably most prevalent in the central and south-central portions of the State. One notable exception in far eastern Oregon is a very large cone located approximately 13 miles southwest of Huntington, Baker County (Wagner, 1946).

Serious prospecting in the Deschutes-Klamath County area can without doubt result in the discovery of many locations containing large reserves of minable pumice capable of meeting top industrial standards; however, this may entail more searching and prospect testing than may be commonly anticipated. Other occurrences of pumicite, perlite, and cinders can undoubtedly be found in many places throughout the eastern portion of the State. Some of these may well be of minable size and quality; however, successful exploitation will depend upon such economic factors as transportation costs and availability of markets, as well as size and quality of the deposits.

Potassium Feldspar

(By R. A. Sheppard, U.S. Geological Survey, Denver, Colo., and G. W. Walker, U.S. Geological Survey, Menlo Park, Calif.)

Feldspar is the general name for a group of anhydrous aluminosilicates that contain varying amounts of potassium, sodium, and calcium. Both potassium and sodium feldspars are used by the glass and ceramic industries, but the potassium variety ($KAlSi_3O_8$) is preferred. Potassium feldspar can also be used as an abrasive or as a soil conditioner. Most commercial feldspar is mined from pegmatite or granitic rock that can be beneficiated to yield a nearly pure feldspar concentrate. Feldspathic materials are also obtained from quartz-feldspar sands and from aplite and nepheline syenite (Wells, 1965). Discussion in this chapter is limited to bedded deposits of potassium feldspar that are found at several localities in Oregon.

Potassium feldspar occurs as an authigenic [14] mineral in sedimentary

[14] Authigenic—Generated on the spot. Applied to those constituents that came into existence with or after the formation of the rock of which they constitute a part.

rocks that are diverse in lithology, depositional environment, and age (Baskin, 1956; Hay, 1966). These bedded deposits have never been mined by the feldspar industry, although their existence has long been recorded in the geological literature. The authigenic feldspar content of these rocks is generally less than 10 percent, but some altered rhyolitic vitric (glassy) tuffs contain more than 90 percent feldspar (Sheppard and Gude, 1965). Authigenic potassium feldspar is especially common in those tuffs found in saline lake deposits of Cenozoic age. The feldspar typically is monoclinic and contains minor or no sodium or calcium. Potassium feldspar in the altered tuffs occurs as aggregates of irregular crystals that generally range in size from less than 0.002 mm to about 0.01 mm. The feldspar commonly occurs associated with other authigenic minerals such as zeolites, clay minerals, or silica minerals. Most, if not all, of the potassium feldspar formed in the rocks as a result of reaction between zeolite minerals and fluids after the rocks were deposited (Hay, 1966, pp. 93–98; Sheppard and Gude, 1965, p. 4).

Authigenic potassium feldspar has been reported in tuffaceous sedimentary rocks from central and southeastern Oregon. In central Oregon, authigenic feldspar is known to occur near Mitchell (fig. 57, No. 1) (Hay, 1962; 1963) in tuffaceous claystone in the lower part of the John Day Formation of Oligocene and Miocene age, and near Izee (fig. 57, No. 2) (Dickinson, 1962a, pp. 259–260) in tuff of the Trowbridge Formation of Jurassic age. Hay (1962) reported that the authigenic feldspar in the John Day Formation makes up as much as 8 percent of the rock and that the deposit extends over an area of at least 600 square miles. The purity and extent of the deposit near Izee is unknown.

High-grade deposits of authigenic potassium feldspar occur in Pliocene lacustrine rocks near Harney Lake and Rome in southeastern Oregon. The Harney Lake deposit (Walker and Swanson, 1968a) occurs in altered vitric tuffs of the Danforth Formation that crop out on the southeast side of Harney Lake in sec. 30, T. 27 S., R. 30 E. The feldspathic tuffs are 1 to 3 feet thick and contain about 60 percent potassium feldspar. Zeolites, clay minerals, and (or) quartz are locally associated with the feldspar. The Rome deposit occurs in an altered vitric tuff in the upper part of an unnamed formation about 5 miles southwest of Rome in sec. 6, T. 32 S., R. 41 E. The feldspathic bed is 1 foot thick and consists of about 60 percent potassium feldspar. Zeolite (clinoptilolite) and clay minerals are associated with the feldspar. Tuffs rich in zeolites underlie and overlie the feldspathic bed at this locality.

The size and purity of these potentially valuable feldspar deposits are not adequately know for a meaningful appraisal; however, large volumes of vitric tuffs have obviously been replaced by potassium feldspar. Deposits of similar or higher grade may occur in the tuffaceous rocks of other Cenozoic basins in southeastern Oregon. Some of these deposits may have commercial potential for use by the glass and ceramic industries or perhaps as a source of potash for fertilizer (Everest and others, 1964).

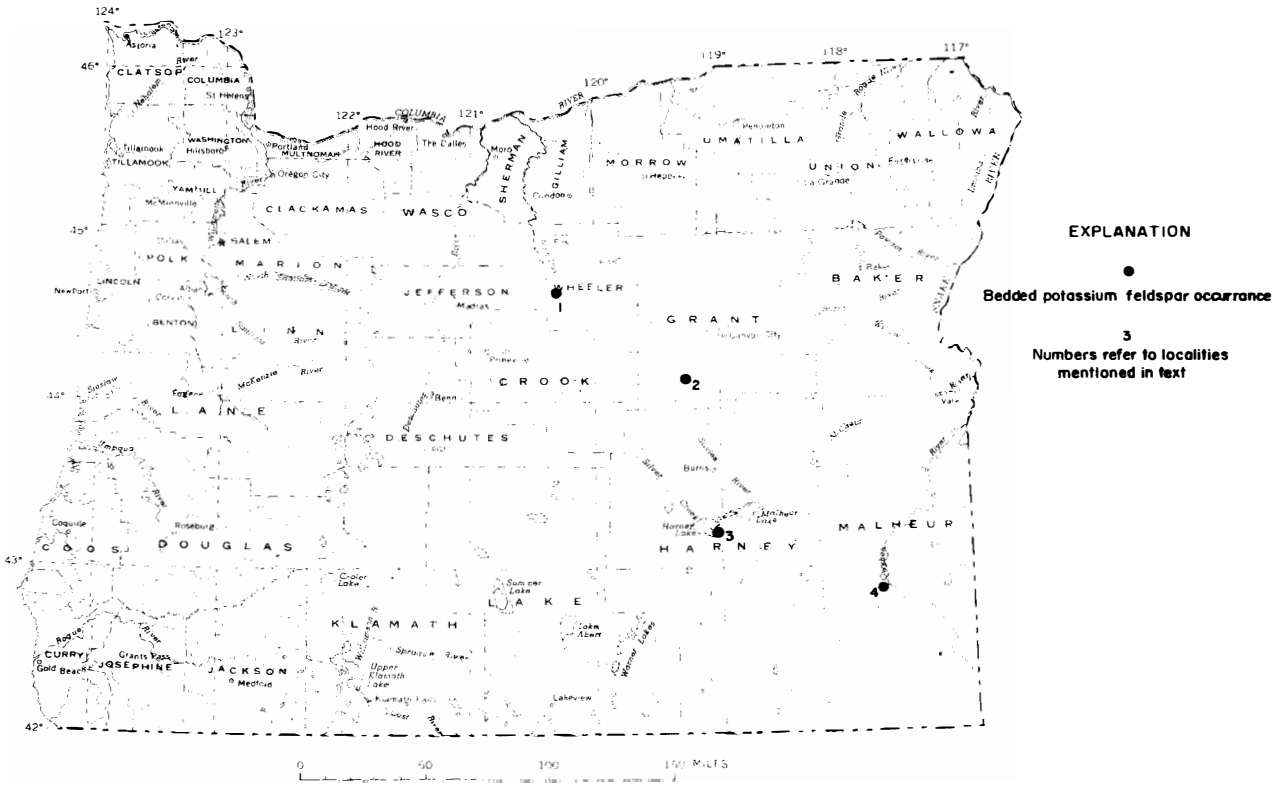

FIGURE 57.—Bedded potassium feldspar deposits in Oregon.

Saline Water

(By V. C. Newton, Jr., Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Saline waters in Oregon occur in sedimentary, metamorphic, and volcanic rocks of all ages. Connate marine and volcanic waters are the two main types of saline water found in the State. Connate marine waters are generally enriched in I, B, SiO_2, Ca, and are low in Mg and SO_4. Volcanic waters typically are high in Li, F, SiO_2, B, S, CO_2 and are low in Ca and Mg (White, 1957a, b). Subsequent diagenesis and mixing with meteoric waters produce variations in composition, and the ground water in sedimentary and volcanic rocks that overlie marine rocks is commonly a mixture of meteoric and connate waters.

In Oregon, saline springs and lakes are found east of the Cascade Mountains, mainly in the southern part of Lake County and in Harney Lake basin and Alvord Desert in southeastern Harney County. Alkali saline springs also occur near Vale in Malheur County (Wagner, 1947).

In western Oregon, saline water originated as connate water in Mesozoic and Cenozoic marine sediments. Wells drilled more than 100 feet deep in unconsolidated alluvium in the western Willamette Valley usually encounter salt water unfit for domestic or irrigation purposes (Piper, 1942). Salt springs are found in Polk County 2 miles southwest of Dallas. These springs issue from middle Eocene marine sedimentary rocks (Baldwin, 1964a). Two other mineral springs are located in the Anlauf Drain area of Douglas County and seep from lower Eocene lavas. Analyses of these springs show them to be typical connate marine water (Hoover, 1963).

Oregon has no known significant deposits of rock salt so that any salt produced would have to come from evaporite deposits or brines. Connate marine brines often contain high concentrations of sodium chloride but they are seldom considered as a commercial source of salt since there are ample reserves of primary deposits in the U.S.

Several attempts have been made in the past to obtain domestic salt from lakes and springs in Oregon. In eastern Oregon a salt plant erected at Alkali Lake in Lake County in the 1920's proved to be uneconomic (Ladoo, 1947). In western Oregon between 700 and 1,000 pounds of salt a day was obtained prior to 1869 from springs in the Umpqua Valley in Douglas County. The Willamette Salt Works is said to have produced 4,000 pounds of salt per day from mineral springs issuing from Oligocene marine sediments at the head of McKay Creek approximately 17 miles northwest of Portland (Phalan, 1919).

Analyses of saline waters collected in Oregon are given in table 16. These analyses are grouped according to whether the waters are moderately saline, very saline, or brine. The places where these analyses are from are shown on figure 58.

TABLE 16. E —SALINE WATERS IN OREGON

[Analyses given in parts per million]

Index number on fig. 58	Name	Location	Well depth (feet)	Water-bearing formation	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Footnote	Total hardness	Reference
MODERATELY SALINE WATERS (3,000–10,000 p.p.m.)																	
1	R. Murphy	NE¼NW¼ sec. 27, T. 1 S., R. 1 W.	314	Miocene basalt			587			510			1,840			3,640	U.S. Geol. Survey Water-Supply Paper 1697, p. 89, 155.
2	E. F. Canty	SE¼NE¼ sec. 21, T. 1 S., R. 2 W.	780	Valley fill		6.0						54	2,000			3,940	U.S. Geol. Survey Water-Supply Paper 1697, p. 95, 155.
3	L. Baags	SW¼SW¼ sec. 23, T. 2 S., R. 4 W.	92	Yamhill Formation	19	1.75	1,980	113	824	12	51	30	5,010		(1)	8,010	U.S. Geol. Survey Water-Supply Paper 1697, p. 120, 157.
4	Crosby	SW¼NE¼ sec. 25, T. 31 S., R. 41 E.	265	Idaho Group	52		195	32	885	19	392	1,620	254	257		3,580	U.S. Geol. Survey Water-Supply Paper 1475–E, p. 172, 166.
5	Goodwin	NW¼SE¼ sec. 33, T. 11 S., R. 4 W.	295	Spencer Formation	15	1.03	324	62	1,450	14	100	1.9	2,956			4,967	U.S. Geol. Survey Water-Supply Paper 890, p. 108, 60–61.
6	(?)	NW¼NW¼ sec. 11, T. 25 S., R. 32½ E.	22	Valley fill			34	58	2,157		2,560	1,141	790			5,810	U.S. Geol. Survey Water-Supply Paper 841, p. 146, 117.
7	Ausmus	Lot 1, sec. 20, T. 25 S., R. 32½ E.	19.5	Valley fill			212	322	1,396		1,081	3,160	505			6,139	U.S. Geol. Survey Water-Supply Paper 841, p. 146, 117.
8	Harney Lake	Harney Lake		(Surface)	29	0	0	6–8	3,604	193	3,007	773	2,771		(2)	10,477	U.S. Geol. Survey Water-Supply Paper 231.
9	Wilhoit Spring	Rock Creek, 25 miles northeast of Salem, Clackamas County.		(Surface)		102	275	779	2,484			83	1,710		(3)	7,180	U.S. Geol. Survey Bull. 32, p. 216–217.
10	Cooper's Spring	Douglas County, 1 mile east of Wilbur		Umpqua Formation			1,615		1,090				2,705			5,987	U.S. Geol. Survey Bull. 32, p. 215, 217.
11	Payton Spring	Douglas County, 2 miles south of Drain's Station.		Umpqua Formation		1,050	980	1,230	960				3,170			7,390	U.S. Geol. Survey Bull. 32, p. 216, 217.
12	F. Haines	NW¼SE¼ sec. 7, T. 24 S., R. 32½ E.	41	Valley fill			106	129	871		1,154	1,166	375			3,230	U.S. Geol. Survey Water-Supply Paper 841, p. 144, 116.
13	U.S. Geological Survey	SE¼SE¼ sec. 15, T. 26 S., R. 31 E.	17	Valley fill		4.5	25	2,640		4,990	299		428			6,370	U.S. Geol. Survey Water-Supply Paper 841, p. 147, 117.
14	Thoreton	NW¼SW¼ sec. 35, T. 26 S., R. 30 E.	25	Valley fill			14	58	1,630		1,804	570	1,148	0.25		4,138	U.S. Geol. Survey Water-Supply Paper 841, p. 147, 117.
15	Vickers	Unsurveyed, T. 26 S., R. 31 E.	18	Valley fill			468	291	615		1,140	2,204	335			4,480	U.S. Geol. Survey Water-Supply Paper 841, p. 148, 117.
16	Haley	NE¼NE¼ sec. 18, T. 26 S., R. 32 E.	21	Valley fill		7.0	2.0	2,840		4,370	1,221		425			7,100	U.S. Geol. Survey Water-Supply Paper 841, p. 148, 117.
17	Bristmayer	SW¼NW¼ sec. 33, T. 36 S., R. 5 W.	285	Applegate Group	35	0.02	694	9.2	1,450	2.7	19	441	3,320	4.2	(4)	6,060	U. S. Geol. Survey Open-file report: D. Hart, Jan. 1954.
18	Pearson	SW¼ sec. 28, T. 36 S., R. 5 W.	201	Applegate Group			998	18	2,230		25	534	4,850		(5)	8,640	U.S. Geol. Survey open-file report: D. Hart, Jan. 1954.
19	H. Dunn	NE¼SW¼ sec. 3, T. 37 S., R. 2 W.	505	Umpqua formation	13		407	1.2	796		24	60	1,878		(6)	3,518	U.S. Geol. Survey open-file report: D. Hart, Jan. 1954.
20	Gas Ice Corp. hot spring	SW¼SW¼ sec. 7, T. 39 S., R. 2 E.	418	Umpqua formation	68	2.1	132	74	1,410	65	2,660	14	1,140	0.9	(7)	4,210	U.S. Geol. Survey open-file report: D. Hart, Jan. 1954.
21	McCredie	Lane County, 8½ miles east of Oakridge		Oligocene volcanics	68	0.07	460	1	1,100	27	236	253	1,990	0	(8)	3,935	Unpub. analysis, U.S. Geol. Survey Quality of Water Br., Portland, 1958.
22	London Springs	London Springs, Lane County		Oligocene volcanics	19	0	480	29	810	8.2	76	1.2	2,100	9.3	(9)	3,500	Do.
23	Watson hot spring	Dexter, Lane County		Oligocene volcanics	47	0.01	726	5.7	1,450	28	27	197	3,420	2.7	(10)	5,930	U.S. Geol. Survey Bull. 32, p. 215, 217.
24	5/1–33A2	5/1–33A2	438	Middle Eocene volcanics	12	0.01	2,310	0	1,410	3.2	13	18	6,190		(11)	9,950	Unpub. analysis, U.S. Geol. Survey Quality of Water Br. Portland, 1957.
25	Miriam Oil	SW¼ sec. 9, T. 8 S., R. 5 W.	1,835	Spencer Formation									3,826			3,826	Oregon Dept. Geology and Mineral Industries file (formation test 1,700–1,835 feet)
26	Lakin	NW¼ sec. 31, T. 10 S., R. 7 W.	400	Tyee Formation									4,545			4,545	Oregon Dept. Geology and Mineral Industries file.
27	R. Mitchell	NW¼ sec. 15, T. 8 S., R. 5 W.	1,347	Spencer Formation									11,118			11,118	Oregon Dept. Geology and Mineral Industries file formation test 70–1,347 feet).
VERY SALINE WATERS (10,000–35,000 p.p.m.)																	
28	Sun Ray Mid-Continent	NW¼ sec. 12, T. 2 N., R. 2 W.	1,666	Goble Volcanic Series									28,900			28,900	Oregon Dept. Geology and Mineral Industries file.
29	Texaco, Inc	NE¼ sec. 19, T. 6 N., R. 4 W.	8,501	Cowlitz Formation									17,400			17,400	Oregon Dept. Geology and Mineral Industries file (formation test 8,000 feet).
30	U.S. Geological Survey	SE¼SE¼ sec. 3, T. 26 S., R. 31 E.	14	Valley fill			717	341	8,510		3,770	11,060	4,850			27,500	U.S. Geol. Survey Water-Supply Paper 841, p. 147, 117.
31	U.S. Geological Survey	Lot 2, sec. 32, T. 26 S., R. 30 E.	13	Valley fill			327	348	3,150		1,172	5,020	2,065			11,490	U.S. Geol. Survey Water-Supply Paper 841, p. 147, 117.
32	A. Sikes	SE¼SE¼ sec. 10, T. 12 S., R. 5 W.	122	Spencer Formation	19	0.86	4,630	22	2,025	18	20	3.5	11,381	0.0		18,102	U.S. Geol. Survey Water-Supply Paper 890, p. 114, 62–63.
33	U.S. Geological Survey	Lot 13, sec. 22, T. 26 S., R. 33 E.	11	Valley fill		5.0	6.1	8,270		2,510	3,530		3,250			20,930	U.S. Geol. Survey Water-Supply Paper 841, p. 149, 118.
34	Aurora Spring	Marion County, 1½ miles west of Aurora Mills.		Valley fill	181	(12)	4,025	169	3,025				7,219			14,636	U.S. Geol. Survey Bull. 32, p. 215, 217.
35	Sommerset Well	SE¼ sec. 24, T. 1 N., R. 2 W.	515	Basalt of Columbia River Group	31		4,920	83	2,350	122	13	64	11,600		(13)	18,500	Unpub. analysis, U.S. Geol. Survey, Quality of Water Br., Portland, 1962.
36	Boswell Spring	NW¼ sec. 21, T. 22 S., R. 5 W.		Umpqua Formation	17	0	7,080	0	3,900	13	6	2.1	18,800	0	(14)	33,000	Unpub. analysis, U.S. Geol. Survey, Quality of Water Br., Portland, 1957
37	Gulf Oil	NE¼ sec. 27, T. 13 S., R. 4 W.	8,471	Spencer Formation			4,794	0	2,440	6	98	0	12,200			19,538	Oregon Dept. Geology and Mineral Industries file (formation test 3,800 feet).
38	Hemble	SE¼ sec. 10, T. 10S., R. 3 W.	4,951	Spencer Formation			4,570	37	2,700	10	16	31	11,870		(15)	19,244	Oregon Dept. Geology and Mineral Industries file (formation test 2,400 feet).
39	Dutch Canyon	NW¼ sec. 17, T. 3 N., R. 2 W.	4,426	Scappoose Formation			1,610	24	8,340	28	16	4.4	15,200			25,200	Unpub. file, U.S. Geol. Survey, Quality of Water Br., Portland.
40	M. Lewis	NE¼ sec. 31, T. 6 S., R. 4 W.	5,549	Spencer Formation	0.01		1,370	309	9,800	33	52	7	18,800		(16)	31,391	Oregon Dept. Geology and Mineral Industries file.
41	Linn County Oil	NW¼ sec. 32, T. 11 S., R. 1 W.	4,929	Eocene—Oligocene marine (?) sediments									13,245			13,245	Oregon Dept. Geology and Mineral Industries file (formation test 2,220–4,520 feet).
42	Oregon Oil and Gas	NE¼ sec. 25, T. 10 S., R. 8 W.	2,630	Tyee Formation									13,100			13,100	Oregon Dept. Geology and Mineral Industries file (formation test 2,160 feet).
43	Reserve	SW¼ sec. 7, T. 12 S., R. 1 W.	8,603	Eocene—Oligocene nonmarine and marine sediments			8,430	305	4,400	40	100	181	21,460		(17)	34,916	Oregon Dept. Geology and Mineral Industries file (formation test 7,100 feet).
BRINES (MORE THAN 35,000 p.p.m.)																	
44	Texaco, Inc	SE¼ sec. 25, T. 1 S., R. 2 W.	9,263	Cowlitz Formation			15,900	10.5	4,180	75	28.1	25.2	35,490			62,340	Oregon Dept. Geology and Mineral Industries file (formation test 3,505–3,534 feet).
45	Texaco, Inc	do	9,263	Middle Eocene volcanics and marine sediments.			15,380	30.6	8,980	608	168	16.5	43,660			71,980	Oregon Dept. Geology and Mineral Industries file (formation test 9,220–9,263 feet).
46	Texaco, Inc	do	9,263	do			17,860	23.9	10,020	412	81.3	21.4	49,660			81,870	Oregon Dept. Geology and Mineral Industries file (formation test 7,862–9,263 feet).
47	Summer Lake	Lake County, northwest of Paisley in secs. 31, 32, R. 17 E.			268				14,529	727		1,452	6,280			36,550	U.S. Geol. Survey Prof. Paper 135, p. 189.
48	U.S. Geological Survey	NE¼NE¼ sec. 27, T. 26 S., R. 33 E.	16	Valley fill			2.9	44	21,810		4,020	30,100	8,560			63,000	U.S. Geol. Survey Water-Supply Paper 841, p. 149, 118.
49	Albert Lake	T. 34 and 33 S., R. 21 E.			165				30,032	1,233	6,700	1,444	27,483			76,323	U.S. Geol. Survey Prof. Paper 135, p. 189. U.S. Geol. Survey Water-Supply Paper 220, p. 13.
50	Alkali Lake	T. 30 S., R. 23 E.					(18)	45	49,849	5,435		49,849	18,263	(19)	(20)	146,100	U.S. Geol. Survey Prof. Paper 135, p. 189.
51	Johnson	Sec. 8, T. 17 S., R. 45 E.	(?)	Payette Formation												56,000	Oregon Dept. Geology and Mineral Industries Ore Bin, v. 9, n. 9, 1947.

[1] Fluoride 0.2, boron 2.1.
[2] B_4O_7 92.8, iodide 0.
[3] Iodide—trace.
[4] Fluoride 0. boron 2.3.
[5] Fluoride 0.
[6] Fluoride 2.1, boron 4.08.
[7] Fluoride 0. boron .40.
[8] Fluoride3.4.
[9] Fluoride0.
[10] Fluoride 2.8.
[11] Fluoride 0.
[12] Trace.
[13] Iodine 2.2, bromide 17, boron 1.1.
[14] Iodide 7.5, bromide 45, boron 7.8, lithium 0.
[15] Iodide 10.
[16] Iodide 20, fluoride 0.5.
[17] Iodide 5.
[18] PO_4 409, B_4O_7 trace.

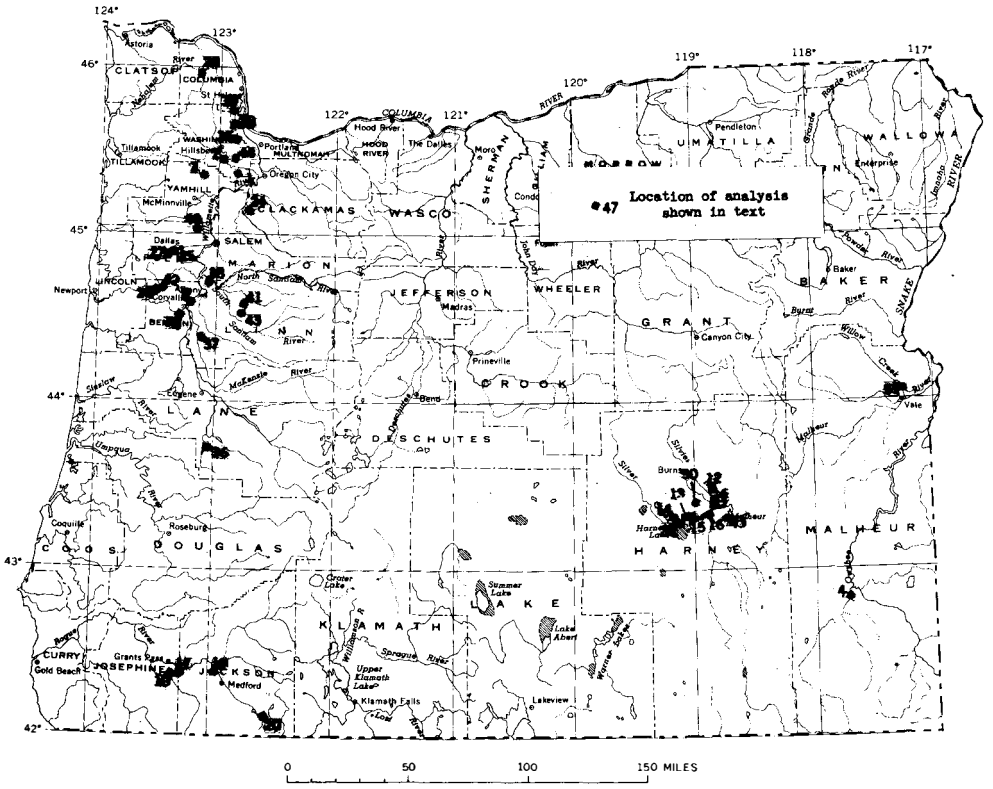

FIGURE 58.—Saline waters in Oregon (analytical data for samples from numbered localities is presented in Table 16)

SAND AND GRAVEL

(By H. G. Schlicker, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

The combined values of sand, gravel, and stone rank first in Oregon's mineral industry. The total sand, gravel, and stone production in 1966, of which sand and gravel is about half, was valued at $83.3 million as compared to $24.2 million for all other minerals (Collins, Gray and Kingston, 1967). The Willamette Valley produces and consumes about two-thirds of the State's total in sand and gravel. Regions like the Willamette Valley which are undergoing rapid industrial and urban expansion and accompanying population growth require more sand and gravel per capita than do other areas.

Sand and gravel are vital raw materials for the construction of highways, bridges, buildings, and airports. As shown on table 17, large quantities are used for fill as well as for asphaltic and portland cement concrete.

TABLE 17.—USE OF SAND AND GRAVEL IN OREGON, IN TONS

Year	Buildings	Road construction	Railroad ballast	Fill	Dam construction	Other	Total minus "Dam construction" and "Other"	Grand total
1960	2,497,749	7,798,207	[1] 37,800	799,014	5,108,086	692,275	11,141,870	16,934,131
1965	3,761,000	15,963,000	[1] 23,000	1,027,000	610,000	261,000	20,774,000	21,645,000

[1] Part of total withheld.

GEOLOGIC OCCURRENCE

Sand and gravel occur in several types of deposits, chief of which are stream channels, floodplains, alluvial fans, and deltaic deposits.

Stream channels and floodplains

The larger streams deposit gravels in the form of bars within their channels and along the inside bank of meanders. The quantity of gravel brought into the valleys from the Cascade Range is now being limited by the high dams built on the Clackamas, North and South Santiam, McKenzie, and Willamette Rivers and their tributaries. These dams do not allow new gravel to move past their ponded areas, and the leveling effect of most of the floods by dams slows the migration of gravels downstream. Flood control dams and placement of riprap along the banks to prevent erosion minimize bank gravels as a source of stream load.

Gravel deposits from Coast Range streams are generally small and of little consequence except locally. In some places the gravel is made up of good quality basalt from small dikes and sills. Eocene lavas are abundant but much of these lavas are badly weathered or altered and produce gravel of poor quality.

Large deposits of sand and gravel occur in the mile-wide floodplain of the Willamette River. These gravels, left by the Willamette River along old meander channels on the floodplain, have been buried by sandy silt to depths less than 10 feet (Schlicker, 1961). Gravel deposits of this type occur along the eastern margin of the Willamette River

from Newberg south to the Eugene area. They merge with gravels similarly deposited by the larger tributaries flowing from the Cascade Mountains.

The Columbia River supplies large quantities of gravel for use of communities along the river. This material is obtained by clamshell dredge and barged to the markets and the construction projects along the river.

Upstream from Portland the hydroelectric dams have deepened the water over many previously exposed gravel bars which will tend to limit utilization of some of the gravel deposits. A large deposit near Scappoose appears to contain abundant gravel accessible to barge traffic for use in the Portland area.

Alluvial fans

Alluvial or glacial outwash fans in the Santiam River drainage between Mehama and Turner have provided a few hundred square miles in area of sand and gravel. Although these gravels are quite thick, the deposits are usually not as clean as floodplain gravels. This is due partly to weathering which has produced some clay in the deposits.

Gravels occurring in wide valleys of small streams in Baker, Lake, and Klamath Counties tend to be small, weathered, and dirty. Production of a good concrete aggregate from these deposits is costly. In eastern Oregon the dry climate is also conducive to producing a coating of caliche on the surfaces of some gravels which is deleterious to portland cement concrete.

Deltaic gravels

Extensive gravels were deposited as deltas in a lacustrine environment in east and southeast Portland, and in the Durham area of southwest Portland. According to Trimble (1963), these gravels were deposited by a fast-moving body of water which surged through the Columbia River Gorge and formed a temporary lake in Portland and the northern part of Willamette Valley during Pleistocene time. As the water spread out and lost its load-carrying capacity, the gravels were dumped, forming stratified deposits with steep torrential foreset bedding. The materials range in size from sand to large boulders and blocks composed primarily of basalt but containing some quartzite and granitic fragments.

COMMERCIAL ASPECTS OF GRAVEL DEPOSITS

Gravel deposits are quite numerous throughout Oregon, but generally only those that are located less than 20 miles from the point of major use can be economically developed because of haulage costs. More distant deposits will be developed as urban expansion approaches within economic limits of haul or as required for special local uses such as for highways, bridges, or dams.

Many gravel deposits are closed to exploitation by urban encroachment before the deposits are completely utilized; thereby part of these resources are wasted. Unfortunately, most gravel deposits lie in the flat ground adjacent to stream, highway, rail transportation and therefore are also prime areas for industrial development.

PRODUCTION AND CONSUMPTION

From 1960 to 1966 the use of sand and gravel related to industrial development and population growth in Oregon increased from 11.1 million tons to 20.7 million tons, an average of about 8.8 percent per year (J. J. Gray, U.S. Bureau of Mines, Albany, Oregon, written communication, Oct. 6, 1967 and March 8, 1968). During this period the population of the State increased about 3.4 percent per year (World Book Atlas, 1965, Rev.). The usage per capita during this period increased from 6.3 tons to more than 10.0 tons. Studies elsewhere indicate an average of about 6 tons of sand and gravel is needed per capita. These figures apparently do not consider the use of trap rock in place of sand and gravel. Production of sand and gravel and crushed quarry rocfk in Oregon is about equally divided.

FUTURE REQUIREMENTS

Aside from major dam construction, requirements for sand and gravel and crushed rock are directly related to population demands. The population of Oregon has for several decades been growing at an increasing rate (fig. 59), and this increase is not expected to diminish. Using a conservative 6.5 tons of sand and gravel per capita, the annual production will be about 20 million tons in 1985 (fig. 60).

Population Curve for Willamette Basin Counties

1870 - 1960: U.S. Bureau of Census, U.S. Census of Population: 1960, Oregon.
1960 - 2010: Preliminary Population Projections, Willamette Basin, 1960 - 2010 Prepared for Task Force, 1963.
1965 - Oregon State Board of Census, Portland State College, Portland, Oregon, July 1965

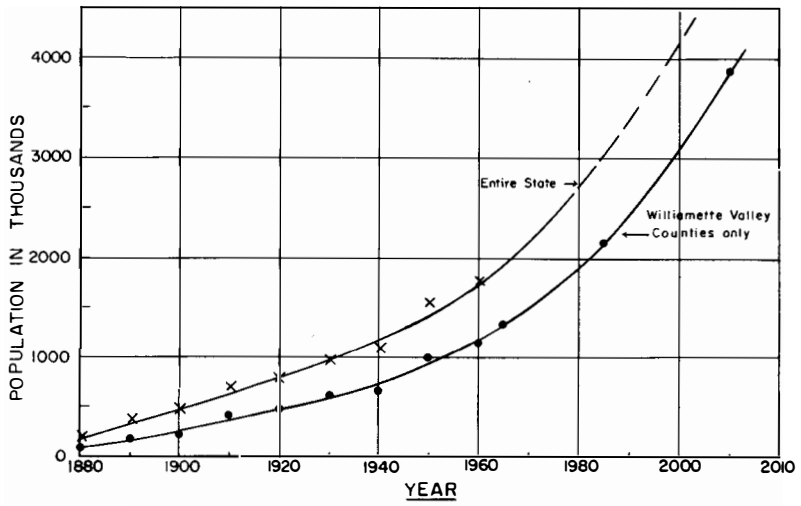

FIGURE 59.—Population curve for Willamette Basin Counties.

In order to visualize the total sand and gravel resources which will be required for the future, cumulative curves have been prepared based on present average consumption per capita and future population projections. In the Willamette Valley, beginning with the 1965 production of approximately 10.5 million tons, 1985 cumulative production will have been almost 300 million tons, and by the year 2010 the amount of sand and gravel used will have been 740 million tons (fig. 61). Assuming gravel extends an average of 30 feet deep, an excavation one-half mile wide by 60 miles long will be required to produce the quantities needed in the Willamette Valley by 2010. The entire State will have used over 1 billion tons by the year 2010.

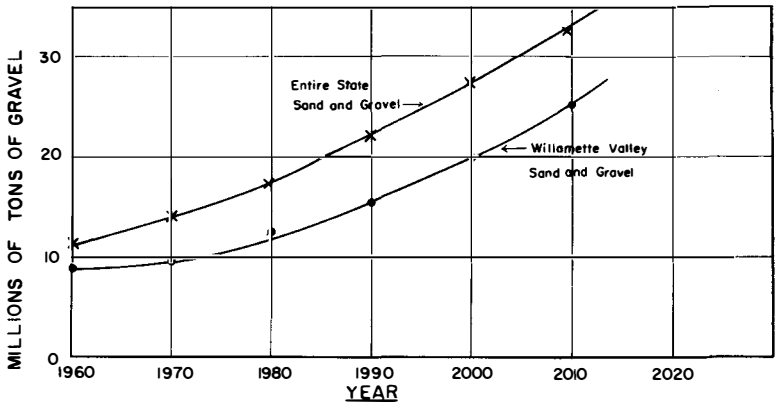

FIGURE 60.—Projected annual gravel production at 6.5 tons per person annually.

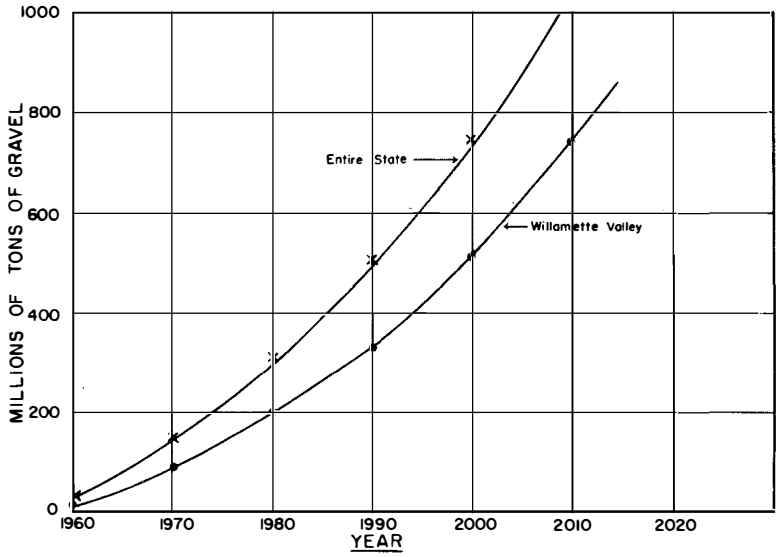

FIGURE 61.—Cumulative gravel-production curve at 6.5 tons per person annually.

The gravel in the Willamette Valley is in an adjacent to the Willamette River and a few major tributaries. Other areas have even a more limited source of supply. It appears likely that most, if not all, of the available gravel will be needed for future development within the source areas. From past experience here and in other places, gravel shortages become critical long before the entire resource can be used. The incomplete utilization of the resource is attributable to several factors previously mentioned in this report. Since gravel is a vital resource in the development of any area and it appears that all of the favorably located gravel deposits will be required, adequate protection by both state and local governmental agencies will be needed to assure its availability for present and future use.

Silica

(By Len Ramp, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg., and R. S. Mason, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Silica is one of the most abundant compounds found in the earth's crust, but large deposits of high-purity silica are not common. The mineral has a low specific gravity, about 2.65, but is quite hard (7 on Mohs' hardness scale) and in some forms is fairly tough and very resistant to abrasion.

The main varieties of industrial silica (SiO_2) are quartz, quartzites, and various microcrystalline forms of chalcedony including chert.

Industrial-grade silica generally contains 97 percent or more of SiO_2 and, for many higher unit value uses may contain only very minor amount of various impurities such as alumina, magnesium, iron, titanium, calcium, arsenic, phosphorus, and sulfur. Some of the more important uses of silica are listed below:

Abrasives:

Scouring and polishing powders and soaps.
Sandpaper, whetstones, grindstones, and sandblast.
Production of silicon carbide (carborundum).
Quartzite pebbles for ore-grinding mills and dimension quartzite for tube-mill liners.

Building:

Roofing granules.
Rubble stone and exposed aggregate for exterior walls.
Aggregate for stucco and plaster.
Insulating material.

Ceramics:

Pottery, glazes, and enamels.
Manufacture of glass and fused-quartz chemical apparatus.

Chemical:

Lining for acid towers.
Filtering medium.
Catalytic agent in petroleum refining.
Cement.
Manufacture of sodium silicate (waterglass), silicones, and other chemicals.

Electronics:

High-purity silica for manufacture of transistors, rectifiers, diodes, etc.; solar cells and atomic batteries.

Metallurgical:

Silicon metal, ferrosilicon, and other silicon alloys.
Flux in smelting basic ores, foundry mold wash, and foundry parting sand.

Mineral fillers:

Inert extender in paint, wood filler, fertilizer, insecticides, rubber, phonograph records, linoleum, etc.

Miscellaneous:

Road-surfacing aggregate.
Landscaping decorative granules.
Chicken grit.

Piezoelectric:

Quartz crystals for cutting oscillator plates.

Refractory:

Silica firebrick and other refractories.

GEOLOGIC OCCURRENCE

Various types of deposits of silica have been exploited to satisfy the many industrial uses. Due to the relatively low market value of silica (except for extremely high-purity quartz and quartz crystal), it is desirable for the deposit to be located close to the market. Five general types of silica deposits are recognized as follows:

1. Sedimentary deposits:
   - (a) Quartz-rich sand and sandstone.
   - (b) Chert (flint or jasper).
   - (c) Diatomite or tripoli.
   - (d) Boulders and pebbles of pure quartz in gravel deposits.
2. Pegmatites:
   - (a) Quartz crystals.
   - (b) Bodies of crystalline to massive quartz relatively free of feldspar.
3. Hydrothermal veins:
   - (a) Relatively pure when oxidized and leached of sulfide minerals at or near the surface.
4. Replacement bodies:
   - (a) Replacement of limestone.
   - (b) Silicified tuffs, etc.
5. Metamorphic:
   - (a) Quartzites (ganister), recrystallized quartz-rich sandstone, chert, or other forms of sedimentary silica.

OREGON DEPOSITS

Four deposits in Oregon have been worked commercially for silica (fig. 62). They are the Bristol Silica quarry in Jackson County, the Quartz Mountain deposit in eastern Douglas County, the Eugene Silica sand, and the Hugo Pegmatite. The first two mentioned are the most important. They occur in very different geologic environments

but appear to have been formed by a similar geologic process—metasomatic replacement.

The Bristol silica deposit (fig. 62, No. 1) is a replacement of limestone belonging to the Applegate Group (Upper (?) Triassic). Some limestone remains around the fringes of the roughly lens-shaped body of massive quartz. The deposit has been producing high-purity industrial silica since 1938 (Oregon Dept. Geol. and Mineral Industries, 1943, p. 55–56). Total production to 1967 is near 1 million tons. The body is faulted and somewhat irregular in shape. It is about 1,500 feet long with an average width of about 250 feet. It is being mined by open-pit methods. The silica is selectively quarried to avoid areas of impure rock, then crushed, screened, and washed before marketing. The silica is used in metallurgical and chemical processes, by the building and landscaping trades, and for various other purposes. The analysis is generally 99.5+ percent silica with small amounts of iron, calcium, aluminum, magnesium, and phosphorus impurities.

The Quartz Mountain deposit (fig. 62, No. 2) is a silicified tuff of the Tertiary Western Cascades volcanic series. Replacement of the tuff by silica is believed to be the result of hot-spring action (Ramp, 1960). The main deposit is roughly 3,000 feet long by 1,200 feet wide and crops out between 4,800 and 5,500 feet elevation on the upper portion of Quartz Mountain. The better grade rock contains from 96 to 99 percent silica. Principal impurities are iron, alumina, titania, and water.

The deposit was located in 1957, and to date its production has been limited mainly to a few hundred tons for the manufacture of ferrosilicon by the Hanna Nickel Smelting Co. at Riddle, Oregon.

A deposit of clay-bearing silica sand at Wallace Butte (fig. 62, No. 3) about 2 miles west of Eugene in Lane County has been used for refractory brick and foundry molding sand. It is believed to be a residual deposit formed by weathering of indurated feldspathic sandstone in the lower portion of the Eugene Formation (Oligocene). The sands when washed produce a naturally bonded molding sand suitable for steel and semisteel castings. The property is currently idle.

A similar clay-sand exposure lies half a mile south of the Wallace Butte occurrence. This deposit, known as the Hawkins locality, has not been worked. The grains have not been as thoroughly weathered as the Wallace Butte deposit, and as a consequence less clay is found. Insufficient exploration has been conducted in the vicinity of these two deposits to determine whether or not sufficient reserves exist to warrant exploitation. Since the area borders on the rapidly expanding Eugene suburbs, there is a question of eventual engulfment and restrictive zoning. Reports by Cook (1923),[15] Lowry and Mason (1943), and Lowry (1943, 1954; Oregon Dept. of Geol. and Mineral Industries, 1951 pp. 88–89) discuss the geology, economics, and industrial applications of the sand.

A small body of quartz-rich pegmatite near Hugo northwest of Grants Pass (fig. 62, No. 5) has produced about 500 tons of quartz that was marketed for sandblasting in 1936 and 1937. The pegmatite occurs in decomposed diorite of the Grants Pass batholith (Oregon Dept. of Geology and Mineral Industries, 1942 pp. 78–79).

[15] Cook, Paul W., 1923. A preliminary report on the geology and economics of the Wallace Butte quartz sand deposit, Lane County, Oregon; an appendix to "A preliminary report on the geology of the Eugene quadrangle, Oregon" by H. G. Schenck: Univ. of Oregon master s thesis.

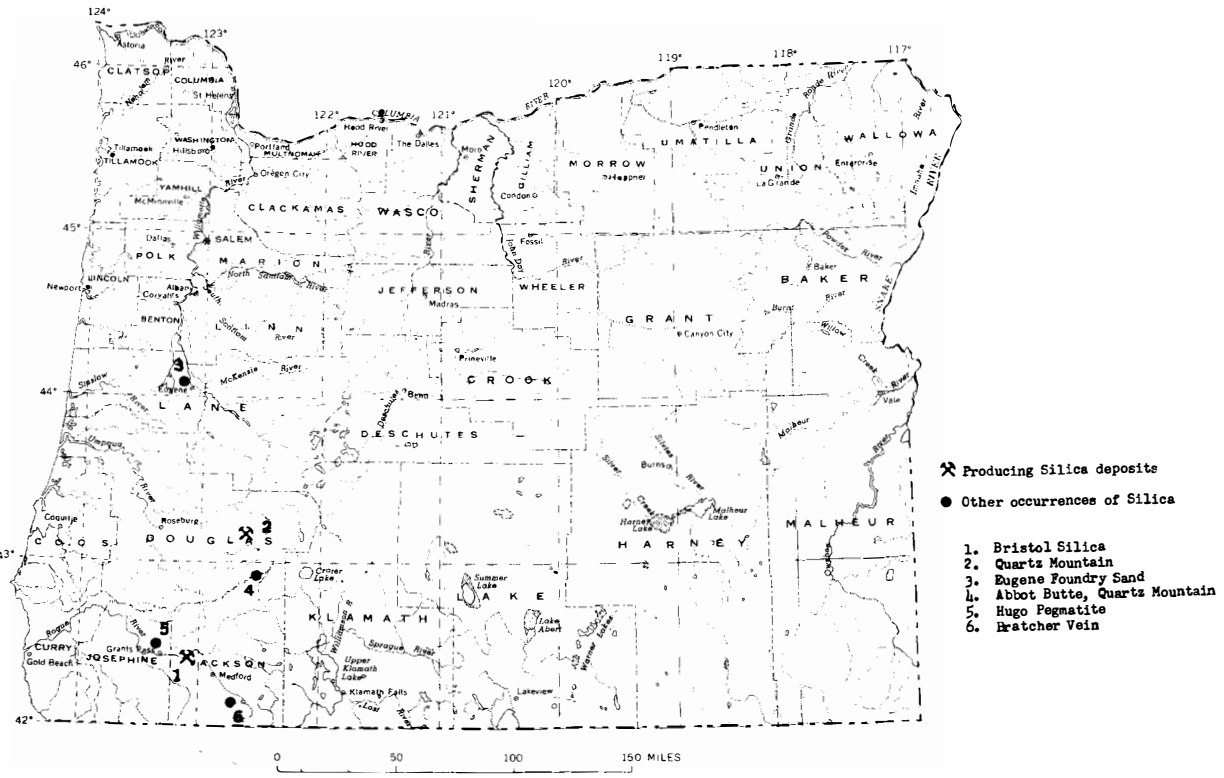

FIGURE 62.—Silica in Oregon.

OTHER POTENTIAL SOURCES OF SILICA IN OREGON

Extensive deposits of chert and impure quartzite are found in both northeastern and southwestern Oregon pre-Tertiary formations. Tough, well rounded quartzite pebbles and boulders derived from the Applegate Group are found in Eocene conglomerate and recent alluvium in the Medford-Ashland area of Jackson County and to a lesser degree in gravels of the Applegate, Illinois, and Rogue Rivers. Quartzite boulders are also common on Pritchard Flat, 15 miles east of Baker, and Pleasant Valley, 12 miles southeast of Baker. Bodies of chert occur in the Applegate Group as well as in the Dothan and Galice Formations in southwestern Oregon and in the Elkhorn Ridge Argillite of northeastern Oregon. These rocks have not been used commercially but represent a large reserve of silica-rich rock.

Other deposits of silicified tuff occur in Western Cascades volcanics. One area with rock similar to that at Quartz Mountain occurs near Abbot Butte on the Douglas-Jackson County line (fig. 62, No. 4). This high point on the county line ridge is also called Quartz Mountain.

Numerous quartz veins and a few pegmatites with bodies of nearly pure silica are known to occur in southwestern and northeastern Oregon.

The Bratcher vein on Horn Gulch southwest of Ashland (fig. 62, No. 6) is an 8- to 12-foot thick pegmatitic quartz vein exposed for about 1,000 feet along the strike. It contains minor amounts of various sulfides at depth but is relatively pure silica at the surface. The vein occurs in decomposed diorite in the western part of the Ashland batholith.

Oregon's coastal dune sands have been tested by the U.S. Bureau of Mines (Carter, Harris, and Standberg, 1964) and found to be a potential source of glass sand.

Diatomite, a hydrous or opaline silica, is described in a separate chapter of this report.

A few isolated deposits of opalite are known to occur in volcanic rocks of the Cascades and central and eastern Oregon. Small amounts of cinnabar are often associated with these opalite deposits.

RESOURCE POTENTIAL

Present known reserves of high-purity quartz, such as the Bristol deposit, which are suitable for metallurgical uses are definitely limited. There are, however, practically unlimited supplies of lower grade silica for various uses that do not require as pure a product. The future market potential for silica rock appears to be growing, and more extensive use will undoubtedly be made of this abundant resource.

Soda Ash

(By R. S. Mason, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Anhydrous sodium carbonate, Na_2CO_3, or soda ash as it is commonly called, is an important industrial chemical. According to the U.S. Bureau of Mines Minerals Yearbook a total of 6.4 million tons of natural and synthetic soda ash was produced in this country in 1965. More than half of this is synthetic, a coproduct of chemical processes.

California, Wyoming, and Texas account for all of the production of naturally occurring soda ash.

Soda ash finds its biggest market in the manufacture of glass. It is also used extensively to make a variety of sodium-bearing chemicals. The pulp and paper industry requires about 10 percent of the output, and alumina and water treatment combined use the same amount. Soda ash is also a raw material in the manufacture of several other sodium compounds, because it is comparatively cheap and reacts readily with most other chemicals. Caustic soda, NaOH, is finding increased use in the manufacture of glass, since it produces more rapid melting at lower temperatures than soda ash.

Soda ash, along with numerous other closely related evaporites, is formed by the evaporation of waters containing dissolved salts. Concentrations of evaporites in sufficient quantities to make them economically attractive have occurred in a few closed basins in areas where surface waters draining into the land-locked lakes or playas are trapped and evaporated by solar energy. The evaporating waters eventually reach the saturation point for each component, which is then crystallized out. Deposition of minerals having successively greater solubilities continues as the brine becomes more concentrated. Variations in the annual rainfall, mean temperature, sunshine, wind, and other factors determine the rate of inflow of surface waters charged with dissolved salts, and the amount of evaporation from the lake or playa surface. Incomplete desiccation of the ponded waters during wet years would result in the deposition of only the less soluble minerals, while those that were more soluble remained in solution. A dry year or series of years would result in the complete evaporation of the basin waters. The net effect, over a period of years, is to build up layers of the various precipitated salts. Due to the vagaries of weather and other variables, the layers may not be uniform in thickness and composition. Recovery of such deposits of salts generally requires a chemical plant where they can be dissolved and separated by fractional crystallization.

Natural soda ash is produced from two types of deposits. Saline lakes which contain high concentrations of dissolved salts have been worked for many years. More recently, attention has been given to buried beds of solid salts. These must be of considerable thickness and purity to make them competitive with surface brines. Producers of both types of natural soda ash face strong competition from synthetic soda ash which is commonly manufactured nearer to the point of consumption.

Deposits of soda ash in Oregon have been known for nearly 100 years. The saline lakes in the basin-and-range country of south-central Oregon have been investigated repeatedly, and several abortive mining ventures have been undertaken. Total production of solid salts has amounted to only a few hundreds of tons. Principal deposits include the following lakes or playas: Summer Lake, Lake Abert, and Alkali (playa) Lake, all in Lake County (fig. 63). By the end of a normal dry summer season, Summer Lake has a considerable playa surrounding it, and Lake Abert develops a fairly extensive playa at its north end. Alkali Lake has thin skims of water only during the winter months. The lakes are in a region of low rainfall, hot dry summers, and cold dry winters. The lakes are more than 4,000 feet above sealevel.

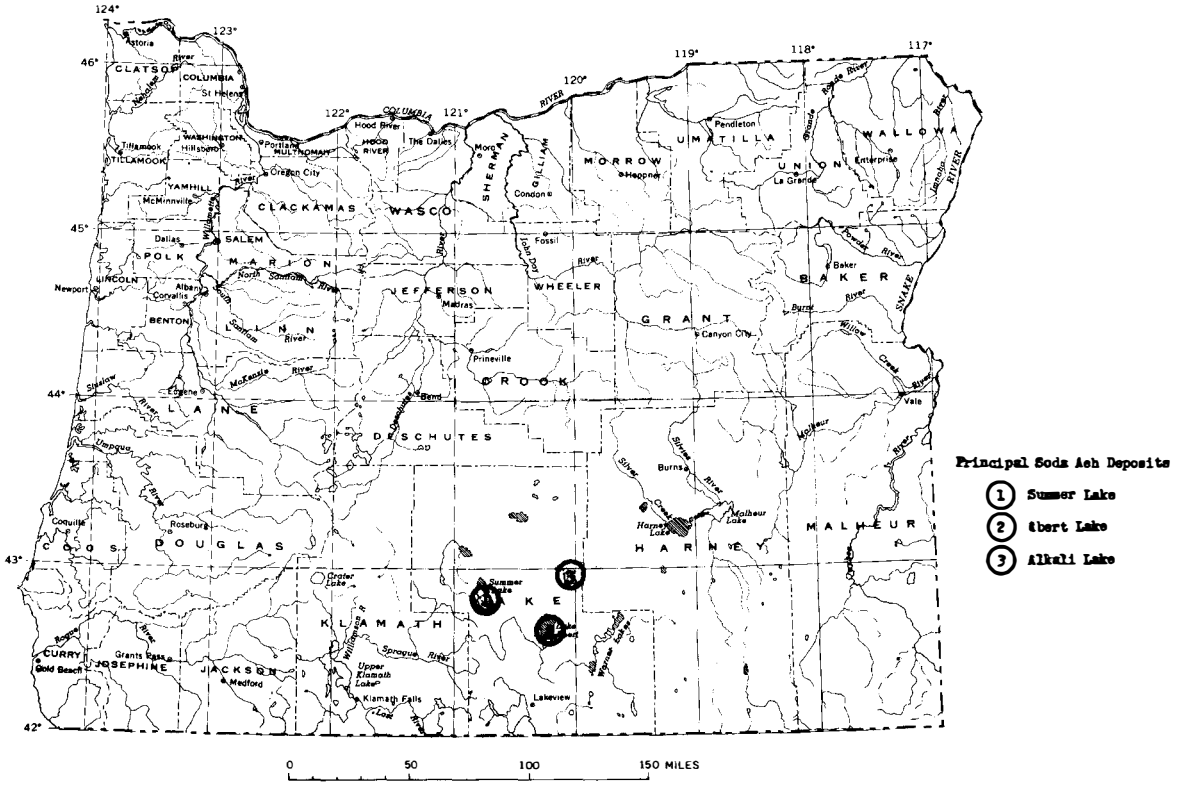

FIGURE 63.—Principal soda ash deposits in Oregon.

Published references to the three saline lake basins and their included deposits of soda ash include the following: Allison and Mason (1947), Chatard (1890), Phalen (1917, 1919), Russell (1884), Stafford (1939), Stanley (1960), Van Winkle (1914), and Waring (1908).

An investigation of Summer, Abert, and Alkali Lakes was conducted by the State of Oregon Department of Geology and Mineral Industries to determine the reserves available. Results of the study (Allison and Mason, 1947) revealed that the salts at Summer and Abert Lakes probably could not be recovered economically. At Alkali Lake it was estimated that there were between 75,000 and 200,000 tons of recoverable saline solids. The three lakes are located at considerable distances from population centers and potential markets. Mining operations would have to contend with rather severe climatic conditions. Periods of freezing and subzero temperatures are common during several of the winter months. Although the area is semiarid, sufficient fresh process water probably could be developed by drilling.

The composition of the efflorescent salts in the three basins is shown in tables 18 and 19.

TABLE 18.—ANALYSIS OF SALT CRUSTS FROM SUMMER AND ABERT LAKE PLAYAS

[In percentages by weight]

	Col. 1 [1]	Col. 2 [2]
Na_2CO_3 (soda ash)	70.80	78.95
$NaHCO_3$ (baking soda)	9.45	.60
NaCl (common salt)	12.12	15.55
Na_2SO_4 (sodium sulfate)	7.83	1.11
K_2SO_4 (potassium sulfate)	1.64	1.40
Water crystallization		n.d.
Total	101.84	97.61

[1] Composite of 3 efflorescence samples from Summer Lake, after desiccation, taken September 1944. Analysis by L. L. Hoagland, Oregon Department of Geology and Mineral Industries.

[2] Platy surface efflorescence, 1/16-inch thick, taken from the flat beyond the north end of Abert Lake, Sept. 4, 1944; total soluble salts 39 percent. Analysis by L. L. Hoagland, Oregon Department of Geology and Mineral Industries.

TABLE 19.—PARTIAL ANALYSES OF CRYSTALLINE SALTS FROM ALKALI LAKE (ADAPTED FROM ALLISON AND MASON, 1947)

[In percentages by weight]

	Columns								
	1	2	3a	3b	3c	3d	3e	4	5
Na_2CO_3	7.53	34.91	43.35	53.00	38.90	35.83	33.49	40.91	18.44
$NaHCO_3$	4.64	3.92	nil	nil	2.01	1.00	.67	.74	1.44
NaCl	5.30	3.67	1.07	1.93	1.49	1.22	1.72	1.49	3.27
Na_2SO_4	3.07	2.49	1.54	1.92	1.33	.91	.77	1.29	1.72
Na_3PO_4	.43	n.d.	.11	.09	.12	.11	.10	.11	.18
$Na_2B_4O_7$	.62	n.d.	.14	.10	.23	.14	.07	.14	.24
KCl	1.48	[1] 1.01	.36	.33	.74	.45	.37	.45	.89
LiCl	nil	n.d.	nil	nil	nil	nil	nil	nil	nil
Br_2	.0033	n.d.	.0018	.0010	.0016	.00078	.00052	.0011	.00052
I_2	.0001	n.d.	.0002	.0004	.0001	.0001	.0001	.0002	.0001
SiO_2	.21	n.d.	.08	.08	.21	.18	.16	.14	.20
Insoluble	n.d.	n.d.	.02	n.d.	n.d.	n.d.	n.d.		n.d.

[1] K_2SO_4 instead of KCl.

NOTES

Columns 1, 3, 4, and 5 by W. P. Smith's Laboratory, Painesville, Ohio; No. 2 recalculated from an analysis by L. L Hoagland, State Department Geology and Min. Ind.

Col. 1: Surface crusts, November 1945.

Col. 2: Composite of 3 samples representing the top 2 feet of solid salts in a "pothole", Sept. 4, 1944.

Col. 3: Lens of salts in a "pothole", November 1945; (a) top 3 inches; (b) 3 to 6 inches; (c) 6 to 18 inches; (d) 18 to 22 inches; (e) 22 to 28 inches.

Col. 4: Average of 3a to 3e inclusive.

Col. 5: Sample from depth of 42 inches in same "pothole" as No. 3.

The concentration of dissolved salts in the three lakes varies seasonally. Total dissolved solids in Summer Lake range from a low of about 1.8 percent in February to a high of more than 3.6 percent in October when the lake level is at or near its lowest point. The dissolved solids in Abert Lake water vary from a low of about 3.2 percent to a high of more than 6.6 percent. Brines collected from a "pothole" at Alkali Lake in the month of September contained 34.7 percent dissolved solids. The brine in the "pothole" was saturated, and crystal growths extending out from the margins and floor of the depression indicated that salts were being crystallized out of the brines. Analyses of the lake waters are given in Allison and Mason (1947).

The volume of brines available in Summer and Abert Lakes varies both seasonally and from year to year, depending upon climatic conditions. Summer Lake has a surface area of about 70 square miles and a maximum depth of about 10 feet. Abert Lake has an area of about 60 square miles, and like Summer Lake, is very shallow. The brines in the "potholes" at Alkali Lake hardly constitute a measurable quantity. Most of the depressions are completely dry for the greater part of the year.

The saline deposits at Summer and Abert Lakes are similar to numerous others located in semiarid regions. At Alkali Lake, however, there are many "potholes" or shallow depressions containing lenticular masses of solid salts scattered over considerable stretches of the playa. The Oregon Department of Geology and Mineral Industries conducted experiments to determine: (1) the origin of the "potholes," (2) whether or not an artificially excavated depression would collect salts similar to the nearby naturally formed depressions, and (3) whether or not the salts in a naturally formed "pothole" would regenerate once they had been excavated. The experimental work, carried out over a period of several years, indicated that natural "potholes" tended to refill with solid salts within a year or two after they had been excavated, and that artificially excavated depressions sloughed in and failed to accumulate any salts. The studies did not succeed in establishing the method of origin of the natural "potholes." Results of the experimental work have not been published but are available for study in the Department's files.

The possibility that beds of salts might lie buried below the lake and playa surfaces of the three basins was investigated by Allison and Mason (1947). Concentration of salts were found to decrease rapidly with depth below the playa surfaces at all three sites. The holes penetrated about 40 feet of plastic mud. Subsequent drilling of two holes which reached depths of 145 and 270 feet below the Alkali Lake playa surface failed to develop any concentration of solid salts. Both holes were terminated upon intercepting fresh artesian water.

The successful development of the Lake County soda ash deposits would require a nearby market outlet which could use the salts in their natural state without costly benefication. The relatively small amount of soda ash available severely limits the capital investment warranted for plant construction. Minor tonnages of the surface

crusts have been used from time to time as a weed killer along local roads and highways. The development of similar uses for both the solid salts and liquid brines could conceivably result in a small but profitable operation.

STONE

(By R. S. Mason, State of Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

The production of stone is used mostly for construction materials and accounts for almost half of the State's total mineral value. Included in this category are limestone, sandstone, building stone, crushed and broken stone, jetty stone, and riprap. Lightweight aggregates such as pumice, volcanic cinders, and expensible shale are discussed on page 222 and page 200.

LIMESTONE

Limestone is one of the more important industrial rocks. Raw limestone is used directly in many ways. Agricultural limestone is applied to fields after grinding, aggregate for roads and concrete is crushed and sized, as is flux stone for metallurgical purposes in blast furnaces. High-calcium or high-magnesium limestones are crushed and washed for the manufacture of glass. Special limestone deposits yield blocks suitable for building stone or sculpture. Large tonnages of limestone are calcined into quicklime, which in turn forms the base for a large number of chemical products. The term lime has become a very general and loosely used term that includes practically all of the finely divided types of raw limestone and the burned forms of limestone. Strictly speaking, lime refers to burned or calcined limestone (quicklime), but it also includes the hydrated form called hydrated lime, slacked lime, or calcium hydroxide.

Limestone is a fundamental ingredient in the manufacture of calcium carbide and many other chemical compounds. Lime is extensively used in the building trades, in soil stabilization, in agriculture, paints, plastics, glass, paper, rubber, glue, and medicines. Water treatment usually requires lime, as do oil well drilling mud, sugar refining, the preparation of insecticides, and sand-lime brick. Large quantities of crushed limestone are consumed in the manufacture of portland cement.

Limestone is quarried in nearly every State in the Union. Generally the stone is used or processed locally, since the unit value of the raw stone is low and will not stand high transportation charges. Limestone is basic to the manufacture of cement and construction lime, and it plays a vital role in competitive community development costs. Cement in recent years has become the principal building material used in this country. An excellent review of the importance of limestone, lime, and cement is given in various chapters of *Industrial Minerals and Rocks*, published by the American Institute of Mining, Metallurgical and Petroleum Engineers, 1960.

Limestone is composed essentially of the mineral calcite, which is pure calcium carbonate. Calcium carbonate is formed in a variety of

ways. The following description by Bowen and Gray (1957) outlines the principal methods:

> Many aquatic organisms, both plant and animal, secrete calcium carbonate for protective and supporting parts. As many of these organisms are colonial or at least gregarious in habit, their limy remains may accumulate and be preserved in large concentrations. Microorganisms may also contribute indirectly to the chemical precipitation of carbonate minerals by upsetting the chemical equilibrium of the aqueous system, by catalytic activity, and so on. Changes of temperature and changes in mineral concentration and composition of ocean and lake waters may also result in precipitation of carbonate minerals without the aid of organisms. The relative importance of purely chemical precipitation as compared with the action or influence of organisms in producing limestone has not been well established, but organisms appear to play the predominating role in limestone formation, and mechanical concentration of pre-existing carbonate detritus as well as inorganic chemical precipitation play lesser roles. . . .
>
> A few deposits of limestone, which are of sufficient size and purity to be of economic importance, have formed by a combination of evaporation and chemical interaction between carbonate-laden spring water and air. Such material, which is known as travertine limestone, grows by accretion around multiple spring vents and occasionally builds deposits aggregating tens of millions of tons. Algae, bacteria, and other organisms may aid the process.
>
> Some sea-floor carbonate deposits also grow by accretion of tiny, interbonded mineral crystals, but the bulk of most marine- and lacustrine-laid limestones are believed to originate as soft, unconsolidated oozes which are compacted and finally lithified long after burial under succeeding strata. Consolidation and lithification of soft oozes generally involves widespread resolution, cementation, dehydration, and crystallization, the ultimate rock having few voids and consisting principally of interlocking crystals. Microscopic examination of some limestones shows that some material forms by dehydration of colloidal carbonate gels without crystallization in early stages of lithification. However, colloidal material probably does not form the major parts of most limestone deposits.
>
> Limestones also accumulate by direct growth of reef-building organisms such as corals or the lime-secreting algae *Lithothamnion*. Reef limestones differ from the accumulations of sea shells in that most of the shell deposits have been transported to some extent by water, whereas the bulk of reef limestone generally is secreted in place by colonial organisms.
>
> Calcareous deposits of considerable size also form in desert climates as the result of evaporation of carbonate-laden groundwater. These calcareous evaporites or caliches, as they are commonly called, may form at or close to the surface or they may form deeper in the pervious mantle above locally developed impervious layers. Caliche was the principal raw material used at the early-day Jamul Ranch cement plant in San Diego County and is used to some extent today at several of the desert cement plants.

Oregon commercially significant limestone deposits are mainly in two areas, one in southwestern Oregon, the other in the northeastern part of the State. In southwestern Oregon large reserves of high-grade limestone, some of which has been partly metamorphosed, are found in the hilly country south of Grants Pass in Josephine County. The deposits occur in a series of lenses or pods in a metasedimentary series of late Paleozoic or Jurassic age. The distribution of the various limestone bodies is shown on the Geologic map of the Grants Pass quadrangle, by Wells (1940). One of the larger deposits on Marble Mountain (fig. 64, No. 37) about 12 miles southwest of Grants Pass has been the source of commercial production for many years. The bulk of the stone was shipped to a cement plant at Gold Hill, with minor amounts being sold for agricultural use and paper manufacture. The plant, operated by Ideal Cement Co., closed in 1967. Near Williams

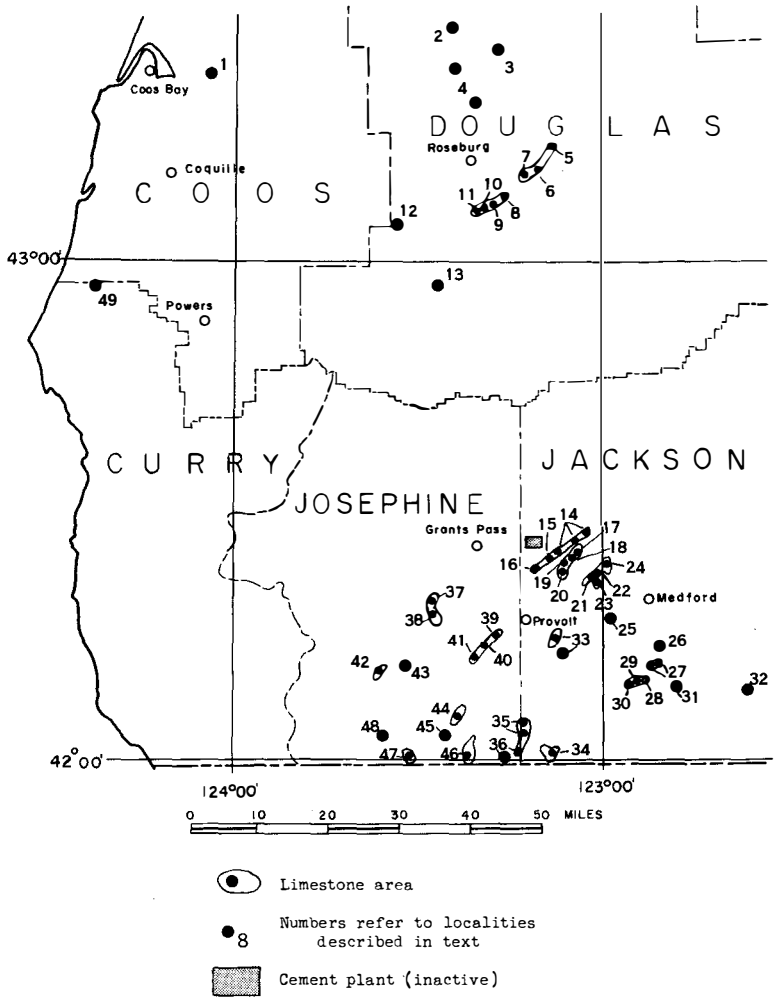

FIGURE 64.—Limestone occurrences in southwestern Oregon.

a relatively small pod of crystalline limes one (fig. 64, No. 41), ranging in color from variegated black and white to nearly pure white, was the source of a small amount of monumental stone. In the mid-1930's an attempt was made to produce burnt lime from a deposit on a ridge south of Powell Creek west of the town of Provolt. About 15 miles southwest of the Williams monument stone quarry and on an extension of the same geological belt of narrow but greatly elongated metasediments lies the Oregon Caves National Monument (fig. 64, No. 44). A fairly extensive system of limestone caverns has been developed as a tourist attraction. Although not presently accessible, a comparable cave complex was discovered many years ago on Marble Mountain during quarrying operations.

The following analyses of limestones from Marble Mountain are typical of the southwestern Oregon limestones (Hodge, 1938b, p. 288).

Constituents	Columns—					
	1	2	3	4	5	6
SiO_2	0.87	0.06	2.31	0.34	1.73	3.20
Al_2O_3	.35	.01	1.72	.06	1.69	.93
Fe_2O_3	.31	.31	.33	.32	.30	.30
CaO	54.60	55.85	54.06	55.44	54.16	54.05
MgO	.80	.33	.41	.25	.40	.36
Ignition loss	43.41	42.09	41.33	42.07	41.57	40.74
Total	100.34	98.65	100.16	98.48	99.85	99.58

NOTES

Col. 1: Body A.
Col. 2: Body B—U.S.E.D. Sample 190A.
Col. 3: Body C—U.S.E.D. Sample 184A, composite from middle and south ends.
Col. 4: Body D—U.S.E.D. Sample 188A.
Col. 5: Body E—U.S.E.D. Sample 182A, composite from middle, north, and south ends.
Col. 6: Body F—U.S.E.D. Sample 186A, south end.

There are many localities in southwestern Oregon where limestone might be mined. The better known occurrences are shown on figure 64 and listed in table 20.

TABLE 20.—LIMESTONE OCCURENCES IN SOUTHWESTERN OREGON

[Adapted from Peterson and Mason, 1958]

Index number on fig. 64 and name	Location	Description	Reference
COOS COUNTY			
1. Morgan limestone	Sec. 35, T. 25 S., R. 12 W.	Small, steeply dipping, bedded deposit. About 85 percent $CaCO_3$.	Hodge, 1938b; Oregon Dept. Geology and Mineral Industries, 1940.
DOUGLAS COUNTY			
2. Green Valley deposit	Sec. 21, T. 24 S., R. 6 W.	Small deposit of fossiliferous, calcareous shale	Diller, 1898; Hodge, 1938b; Williams, 1914.
3. No name	Sec. 3, T. 25 S., R. 5 W.	Small deposit of bluish, shaly limestone	Do.
4. Starr Ranch	Sec. 22, T. 25 S., R. 6 W.	Thin beds of fossiliferous shale	Diller, 1898; Hodge, 1938; Williams, 1914.
5. No name	Sec. 14, T. 27 S., R. 4 W.	Small lentil with abundant microscopic fossils	Diller, 1898.
6. Oden-Hatfield deposit	Sec. 33, T. 27 S., R. 4 W.	Lens 25 ft. wide exposed in small, abandoned quarry from which dimension stone had been sawed.	Diller, 1898; Hodge, 1938b; Oregon Dept. Geology and Mineral Industries, 1940; Ore Bin, v. 5, n. 10, 1943.
7. Hatfield deposit	Sec. 31, T. 27 S., R. 4 W.	Small pod of light colored limestone	Diller, 1898, Hodge, 1938b; Oregon Dept. Geology and Mineral Industries, 1940.
8. Dodson deposit	Secs. 14, 15, T. 28 S., R. 5 W.	Steeply dipping gray limestone 30 feet thick	Diller, 1898; Hodge, 1938b; Williams, 1914; Ore Bin, v. 5, n. 10, 1943.
9. Harrington deposit	Sec. 21, T. 28 S., R. 5 W.	Similar to No. 10	Diller, 1898; Ore Bin, v. 5, n..10, 1943
10. Oregon Portland Cement	Sec. 20, T. 28 S., R. 5 W.	Large lens, steeply dipping, high-purity limestone with interbedded chert. Abandoned in 1935.	Diller, 1898; Hodge, 1938b; Libbey, 1957; Williams, 1914; Oregon Dept. Geology and Mineral Industries, 1940.
11. Fisher property	Sec. 30, T. 28 S., R. 5 W.	Chip sample from small outcrop assayed 97.5 percent $CaCO_3$.	Diller, 1898; Hodge, 1938b; Williams, 1914; Ore Bin, v. 5, n. 10, 1943.
12. Byron limestone	Sec. 5, T. 29 S., R. 7 W.	Small, undeveloped pod, pink to rose limestone, containing about 85 percent $CaCO_3$.	Oregon Dept. Geology and Mineral Industries, 1940. Ore Bin, v. 5, n. 10, 1943.
13. Hammersley limestone	Sec. 20, T. 30 S., R. 6 W.	Irregular mass of calcite in metavolcanic rocks	Oregon Dept. Geology and Mineral Industries, 1940.
JACKSON COUNTY			
14. Gold Hill deposits	Secs. 3, 16, T. 36 S., R. 3 W.; sec. 13, T. 36 S., R. 4 W.	Several small lenses interbedded with argillaceous shale	Diller, 1914; Wells, 1940; Williams, 1914; Winchell, 1914.
15. Rogue River	Sec. 23, T. 36 S., R. 4 W.	Small, elongate lens 100 feet thick. 92 percent $CaCO_3$.	Williams, 1914; Winchell, 1914.
16. Owl Hollow mine	Sec. 26, T. 36 S., R. 4 W.	No information as to size or quality	Wells, 1940; Oregon Dept. Geology and Mineral Industries, 1943.
17. Galls Creek group	Sec. 21, T. 36 S., R. 3 W.	2 undeveloped, narrow lenses of light gray to white crystal-line limestone, 96.3. percent $CaCO_3$.	Wells, 1940; Williams, 1914; Winchell, 1914.
18. Beaver Portland Cement Co	Secs. 20, 29, T. 36 S., R. 3 W.	Quarry furnished limestone for Gold Hill cement plant for few years.	Hodge, 1938b.
19. Eagle limestone	Sec. 30, T. 36 S., R. 3 W.	Undeveloped deposit near Eagle Gold mine	Williams, 1914; Winchell, 1914.

20. Bristol limestone	Sec. 31, T. 36 S., R. 3 W.; sec. 6, T. 37 S., R. 3 W.	Deposit 200 to 600 feet wide and +1,000 feet long. $CaCO_3$ content 97 percent. Inactive since 1941.	Libbey, 1957; Wells, 1940; Oregon Dept. Geology and Mineral Industries, 1943; Ore Bin, v. 5, n. 10, 1943.
21. Lively Quarry	Sec. 2, T. 37 S., R. 3 W	2 small lenses have been worked out and quarry abandoned	Hodge, 1938b; Wells, 1940; Williams, 1914; Oregon Dept. Geology and Mineral Industries, 1943; Ore Bin, v. 5, n. 10, 1943.
22. Baxter limestone	Secs. 1, 2, T. 37 S., R. 3 W	2 lenses of banded limestone quarried by Oregon Limestone Co.; 97 percent $CaCO_3$ reported. Abandoned in 1942.	Wells, 1940; Oregon Dept. Geology and Mineral Industries, 1943.
23. Beeman limestone	Sec. 11, T. 37 S., R. 3 W	Steeply dipping lens of hard limestone with inclusions of metasediments. Better rock said to analyze 96 percent $CaCO_3$.	Wells, 1940; Williams, 1914; Winchell, 1914; Oregon Dept. Geology and Mineral Industries, 1943.
24. Millionaire Mine limestone	Sec. 30, 31, T. 36 S., R. 2 W.; sec. 36, T. 36 S., R. 3 W.	3 elongate lenses reported to average 88 to 92 percent $CaCO_3$.	Oregon Dept. Geology and Mineral Industries 1943; Ore-Bin, v. 5, n. 10, 1943.
25. Ensele quarry	Sec. 6, T. 38 S., R. 2 W	Abandoned quarry in small limestone mass	Wells, 1956; Winchell, 1914; Oregon Dept. Geology and Mineral Industries, 1943.
26. Briner limestone	Sec. 29, T. 38 S., R. 1 W	Discontinuous lens 20 feet wide and 50 feet long, analyzing 92 to 95 percent $CaCO_3$.	Hodge, 1938b; Oregon Dept. Geology and Mineral Industries, 1943; Ore-Bin, v. 5, n. 10, 1943.
27. South Fork Anderson Creek	Sec. 7, T. 39 S., R. 1 W	2 small occurrences reported to be calcareous tufa	Hodge, 1938b.
28. Muddy Gulch limestone	Sec. 23, T. 39 S., R. 2 W	Body 65x500 feet reported to contain 93 percent $CaCO_3$	Do.
29. Bear Gulch limestone	do	Banded limestone interbedded in schist and shale	Do.
30. Wolf Gulch limestone	Sec. 22, T. 39 S., R. 2 W	Similar to No. 29	Do.
31. Bald Mountain	Sec. 20, T. 39 S., R. 1 W	Undeveloped	Oregon Dept. Geology and Mineral Industries files.
32. Shepard Springs	Sec. 28, T. 39 S., R. 2 E	Calcareous tufa	Hodge, 1938b.
33. Applegate River Group	Secs. 23, 24, 26, T. 38 S., R. 4 W	8 closely grouped, steeply dipping short lenses, 50 to 100 feet wide.	Diller, 1914; Hodge, 1938b; Wells, 1940.
34. Seattle Bar group	Secs. 2, 10, 11, T. 41 S., R. 4 W	6 lenses, largest 75 feet thick and exposed for 1 mile along length. Assays 97 percent $CaCO_3$ but contains narrow siliceous bands and included schistose material.	Diller, 1914; Hodge, 1938b; Wells, 1940; Williams, 1914; Winchell, 1914; Oregon Dept. Geology and Mineral Industries, 1943; Ore-Bin, v. 5, n. 10, 1943.
35. Carberry Creek group	Secs. 18, 19, 30, 31, T. 40 S., R. 4 W	6 lenses (largest 50x500 feet) of dark, variegated, siliceous limestone grading into dark, impure quartzite. Analysis shows 71.9 percent $CaCO_3$.	Diller, 1914; Hodge, 1938b; Wells, 1940; Williams, 1914; Winchell, 1914.
JOSEPHINE COUNTY			
36. Whiskey Peak group	Secs. 6, T. 41 S., R. 4 W.; secs. 11, 12, T. 41 S., R. 5 W.	4 occurrences	Wells, 1940.
37. Marble Mountain group	Secs. 19, 30, 31, T. 37 S., R. 6 W.; sec. 6, T. 38 S., R. 6 W.; secs. 25, 36, T. 37 S., R. 7 W.	6 irregularly spaced limestone bodies with large reserves of high quality (95 to 97 percent $CaCO_3$). Major production.	Hodge, 1938b; Libbey, 1957; Wells, 1940; Williams, 1914; Winchell, 1914; Oregon Dept. Geology and Mineral Industries, 1952; Ore-Bin, v. 5, n. 10, 1943.
38. Muck limestone	Sec. 30, T. 37 S., R. 7 W	Light gray limestone exposed for about 1,000 feet in cliffs 150 to 200 feet high. Beds nearly vertical and 150 to 250 feet thick. Chip samples show 95 to 98 percent $CaCO_3$. Property inactive since 1949.	Libbey, 1957; Wells, 1940; Williams, 1914; Winchell, 1914.

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TABLE 20.—LIMESTONE OCCURRENCES IN SOUTHWESTERN OREGON—Continued

[Adapted from Peterson and Mason, 1958]

Index number on fig. 64 and name	Location	Description	Reference
39. Horsehead lime	Sec. 15, T. 38 S., R. 5 W.	At northeast end of limestone belt. Very pure limestone (99 percent $CaCO_3$) interbedded with schist and cut by basic dikes. Inactive since 1950.	Libbey, 1957; Wells, 1940; Oregon Dept. Geology and Mineral Industries, 1952; Ore-Bin, v. 5, n. 10, 1943.
40. Turvey limestone	Sec. 29, T. 38 S., R. 5 W.	Steeply dipping lens 25 feet wide and 400 feet long. Sample assayed 95.3 percent $CaCO_3$.	Oregon Dept. Geology and Mineral Industries, 1952.
41. Jones Marble quarry	Sec. 31, T. 38 S., R. 5 W.	Variegated to pure white marble mass 600 feet wide and 2,000 feet long, with inclusions of shale and schist. Pure marble assays 99+ percent $CaCO_3$.	Diller, 1914; Hodge, 1938b; Libbey, 1957; Wells, 1940; Williams, 1914; Winchell, 1914; Oregon Dept. Geology and Mineral Industries, 1952; Ore-Bin, v. 5, n. 10, 1943.
42. Lime rock	Secs. 11, 12, 14, T. 39 S., R. 8 W.	Gray or white, fine-grained limestone recrystallized to marble in several small bodies. Limestone reported to run 98+ percent $CaCO_3$.	Diller, 1914; Hodge, 1938b; Wells and others, 1949; Oregon Dept. Geology and Mineral Industries, 1952.
43. No name	Sec. 4, T. 39 S., R. 7 W.	Small body similar to No. 42	Wells and others, 1949.
44. Oregon Caves National Monument	Secs. 10, 15, 16, T. 40 S., R. 6 W.	Large mass of limestone in which Oregon Caves were formed. Not available to exploitation.	Diller, 1914; Hodge, 1938b; Wells, 1940; Williams, 1914; Winchell, 1914.
45. Grizzly Gulch	Sec. 29, T. 40 S., R. 6 W.	Small exposure of limestone similar to that in which Oregon Caves were formed.	Wells, 1940; Williams, 1914; Winchell, 1914.
46. Sucker Creek group	Sec. 35, T. 40 S., R. 6 W.; sec. 1, 2, 13, 14, T. 41 S., R. 5 W.	7 limestone lenses grouped around Swan Mountain	Wells, 1940.
47. West Fork Althouse Creek	Sec. 9, T. 41 S., R. 7 W.	2 small undeveloped occurrences	Wells and others, 1949.
48. Elder Creek (Takilma)	Sec. 25, T. 40 S., R. 8 W.	Limestone used as flux for former Takilma smelter	Hodge, 1938b; Wells and others, 1949; Williams, 1914; Winchell, 1914.
CURRY COUNTY			
49. No name	Sec. 29, T. 30 S., R. 14 W.	Fine crystalline, siliceous limestone	Brown, 1942.

In northeastern Oregon large limestone deposits are scattered over parts of Baker, Union, and Wallowa Counties, with minor occurrences in Grant, Malheur, Harney, and Crook Counties, as shown in figure 65. The map has been taken from one by N. S. Wagner, which appeared in the May 1958 Ore Bin. Table 21, which has been adapted from the Ore Bin report, gives condensed information for each of the localities shown on the map. Additional information on the more important deposits appears in Libbey (1957), Moore (1937), and Hodge (1938b). The large deposits represented by those on the Lostine River (fig. 65, No. 3), Black Marble quarry (fig. 65, No. 4), and Hurricane Creek (fig. 65, No. 5) in Wallowa County, and the Baker County occurrences such as those near Lime and the headwaters of Fox, Connor, and Hibbard Creeks (fig. 65, No. 14) are believed to be of Permian and Triassic age.

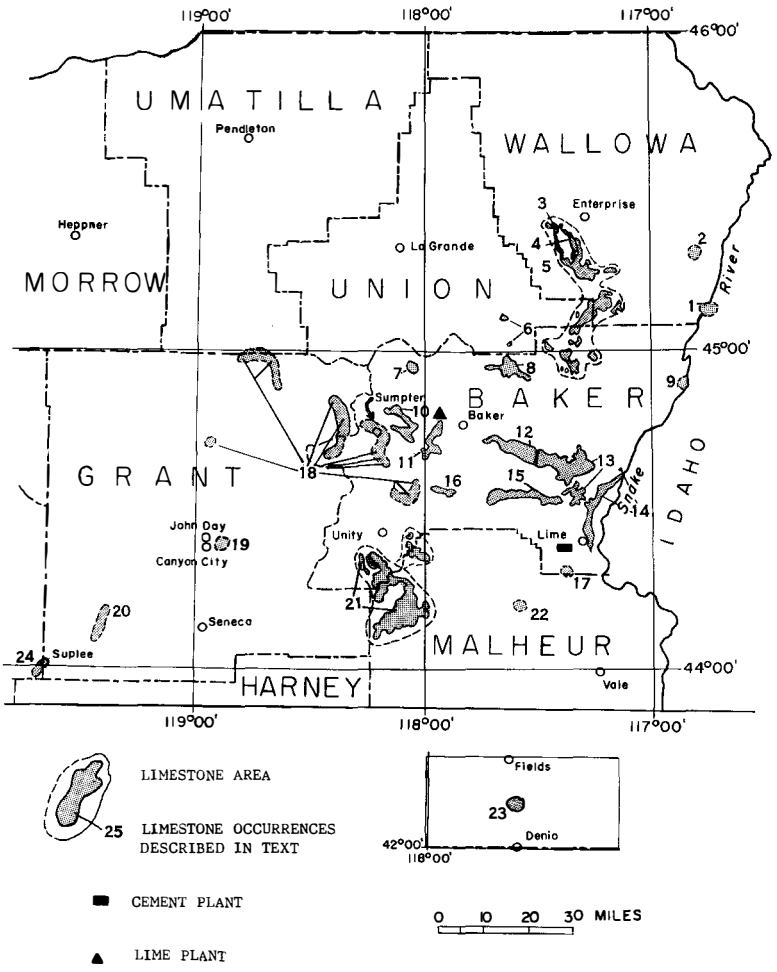

FIGURE 65.—Limestone occurrences in northeastern Oregon.

TABLE 21.—LIMESTONE OCCURRENCES IN NORTHEASTERN OREGON

[Adapted from Wagner, 1958]

Index number on fig. 65 and name	Location	Description	Reference
WALLOWA COUNTY			
1. Big Bar deposit	Sec. 8, 17, 18, 19, T. 5S., R. 49 E.; secs. 24, 25, 26, T. 5 S., R. 48 E., in Snake River Canyon.	Thick beds of massive limestone. Chip samples averaged 53.7 and 52.3 percent CaO.	Unpublished report of U.S. Corps of Engineers.
2. Imnaha River deposit	Secs. 15, 23, T. 3 S., R. 48 E. Partly in Imnaha River Canyon.	Deposit in Imnaha Canyon crops out as 170-foot bluff of thick-bedded, slightly recrystallized, locally silicified limestone. Nearby along river, limestone is noncrystalline and soft. Soft limestone assays 97 percent $CaCO_3$ and 1.1 percent SiO_2.	Moore, 1937, pp. 119, 120.
WALLOWA AND BAKER COUNTIES			
3. Lostine River	Secs. 3, 4, 9, T. 2 S., R. 43 E.	Massive, light-gray, recrystallized limestone formerly burned into quicklime for local consumption. Bed exposed in walls of Lostine Canyon for nearly 6 miles.	Moore, 1937; Ross, 1938; Smith and Allen, 1941.
4. Black Marble quarry	Secs. 19, 20, T. 2 S., R. 44 E.	Well-bedded, dense, dark limestone. Previously quarried for burned lime but later used by Pacific Carbide & Alloys for carbide manufacture.	Do.
5. Hurricane Creek	Secs. 9, 10, 15, 16, T. 3 S., R. 44 E.	Large body of limestone and marble. Varies from low to high purity.	Do.
UNION COUNTY			
6. Catherine Creek	Secs. 24, 25, 26, T. 5 S., R. 41 E.; sec. 24, T, 6 S., R. 41 E.	Several small occurrences. No analytical data available	Wagner, 1952.
BAKER COUNTY			
7. Bulger Hill limestone	Sec. 9, T. 7 S., R. 38 E.	Limestone in two parallel beds. Abundant garnet near contact with diorite intrusive but clean limestone is also available.	Pardee, 1941.
8. Medical Springs occurrences	T. 7 S., R. 41 and 42 E.	Numerous limestone lenses in Permian greenstone. Grade is good but most lenses are small.	Gilluly, 1937.
9. Oxbow limestone	Secs. 4, 8, 9, T. 8 S., R. 48 E. in Snake River Canyon.	Limestone in Permian and Triassic volcanic rocks and in contact with diorite.	Unpublished report of U.S. Corps of Engineers.
10. Elkhorn Mountain occurrences	T. 9 S., R. 38 E., and adjoining townships	145 separate limestone bodies occur as disconnected lenses in pre-Tertiary argillite. Two largest owned by Chemical Lime Co.; estimated to contain 2 million tons averaging 55 percent CaO. Used for burnt lime.	Libbey, 1957; Pardee, 1941.
11. Washington Gulch occurrences	Mostly in T. 9 and 10 S., R. 39 E.	Lenses of limestone in argillite; 45 have been mapped. Sample of largest contained 44.96 percent CaO, 16.54 percent SiO_2, 1.84 percent Al_2O_3, 0.88 percent MgO.	Gilluly, 1937.

12. Pleasant Valley occurrences	Mostly in T. 10 S., R. 41 and 42 E.	Geologic map shows swarm of limestone pods and lenses in argillite. Has been used locally for burnt lime.	Do.
13. Pleasant Valley extension	T. 10 and 11 S., R. 43 E.; T. 10, 11, 12 S., R. 44 E.	Similar to No. 12	Fitzsimmons, J. P., unpublished Univ. of Washington Ph. D. thesis, 1949.
14. Lime-Soda Creek	T. 12 and 13 S., R. 44 E.; T. 11 and 12 S., R. 45 E.	Massive but separate limestone bodies in argillite. Largest deposits are at head of Fox, Conner, and Hibbard Creeks. Potential tonnage very large. Samples show 53.6 to 55.6 CaO content. Occurrence near Lime quarried by Oregon Portland Cement Co., which also controls large reserves on Fox Creek.	Hodge, 1944; Libbey, 1957; Moore, 1937.
15. Durkee-Burnt River occurrences	T. 11 and 12 S., R. 41, 42, and 43 E.	Massive beds of crystalline limestone extend for many miles. Rock from quarry at Nelson Siding shipped to sugar and paper plants. Shipments of "sugar rock" have averaged 98+ percent $CaCO_3$.	Fitzsimons, J. P., unpublished Univ. of Washington thesis, 1949; Gilluly, 1937.
16. Dooley Mountain occurrence	T. 11 and 12 S., R. 39 E.	Twenty-six small lenses in schist have been recognized. No analysis available.	Gilluly, 1937.
17. Limestone Butte	Sec. 30, T. 14 S., R. 44 E.	Dense, recrystallized limestone near granite intrusive. Grade low; many inclusions of shaly material.	Beeson, J., unpublished Univ. of Oregon Master's thesis, 1955.
BAKER AND GRANT COUNTIES			
18. Blue Mountain occurrences		Numerous lenses of crystalline limestone in pre-Tertiary metasediments. Scattered over wide area. No analyses available.	Pardee and others, 1941; Wagner, 1954; Thompson, C. J., unpublished Univ of Oregon Master's thesis, 1956.
GRANT COUNTY			
19. Dog Creek occurrence	Secs. 32, 33, T. 13 S., R. 32 E.	Five small lenses of crystalline limestone in Permian metasediments.	Thayer, 1956.
20. Izee area occurrences	Secs. 20, 30, 31, T. 16 S., R. 28 E; sec. 6, T. 17 S., R. 28 E.	Four massive beds of Triassic age along axis of syncline	Wallace and Calkins, 1956; Dickinson and Vigrass, 1965.
BAKER AND MALHEUR COUNTIES			
21. Ironside Mountain occurrences	Several townships surrounding Ironside Mountain.	Fossiliferous limestone reported interbedded in Rastus Formation. (pre-Tertiary). Limestone beds probably small and widely scattered.	Lowry, W. P., unpublished Rochester Univ. Ph.D. thesis, 1943; Wray, C. F., unpublished Rochester Univ. Master's thesis, 1946.
MALHEUR COUNTY			
22. Brogan limestone	Secs. 9, 10, T. 16 S., R. 42 E.	Gray, crystalline limestone interbedded with Triassic shale	Oregon Dept. Geology and Mineral Industries files.
HARNEY COUNTY			
23. Pueblo Mountain	Sec. 5, T. 40, S. R. 35 E.	Thin beds of marble along eastern flank of Pueblo Mountains	Williams and Compton, 1953.
CROOK COUNTY			
24. Suplee limestone	T. 17, 18, 19 S., R. 24, 25, 26 E., partly in Grant County.	Massive deposits, lenses, reefs, and irregular masses. Grades from nearly pure limestone to calcareous sandstone.	Dickinson and Vigrass, 1965; McKittrick, W. E. unpublished Oregon Agr. Coli. Master's thesis, 1934.

A cement plant at Lime, Baker County, has been in operation since 1910. Limestone has also been quarried near Nelson (fig. 66, No. 15), about 10 miles northwest of Lime, for various industrial and chemical applications. Years ago the Black Marble quarry (fig. 66, No. 4) on Murray Creek about 5½ miles southwest of Enterprise in Wallowa County produced cut stone for monuments. When polished, the stone is a lustrous, velvety black with occasional white fossil shell inclusions. In more recent years the quarry has supplied high-grade stone for the manufacture of calcium carbide and for agricultural use. A lime plant located at Wing, 5 miles northwest of Baker in Baker County, burns lime from quarries high up in the Elkhorn Mountains on Marble and Baboon Creeks (fig. 65, No. 10). There are large reserves of high-grade limestone in northeastern Oregon which are adjacent to or not far removed from both rail and highway transportation. Present markets, with the exception of minor quantities used by agriculture and the refining of beet sugar, are located at considerable distances from the deposits. The cement plant at Lime and the lime plant at Wing both ship most of their products several hundred miles, but their enhanced value permits a much wider marketing radius than that for raw limestone. In recent years barge shipments of limestone from Texada Island, British Columbia, into the Portland area have cut deeply into the movement of cement rock from Baker County.

Analyses of some of the higher grade northeastern Oregon limestones as given by Moore (1937) and Wagner (1958) are shown in the following table:

Constituents	Lostine River (fig. 65, No. 3)[1]	Black Marble quarry (fig. 65, No. 4)[1]	Hurricane Creek (fig. 65, No. 5)[1]	Deposits at Lime (fig. 65, No. 4)[1]	Connor Creek (fig. 65, No. 14)[1]	Elkhorn Mountain (fig. 65, No. 10)[2]
SiO_2	0.92	1.17	0.12	1.99	None	0.38
Al_2O_3	.34	.17	[3]		None	
R_2O_3				.47		.11
Fe_2O_3	[3]	.12	[3]		None	
CaO	54.50	53.15	55.62	54.07	55.65	55.00
MgO	.52	1.23	.28	1.03	.52	.17

[1] From Moore, 1937.
[2] From Wagner, 1958.
[3] Tr.

In northwestern Oregon there are several lenses of limestone which have been quarried for agricultural and cement use. The stone is not as high grade as either the southwestern or northeastern deposits. The following analysis is typical: SiO_2—24.08, $Al_2O_3 + Fe_2O_3$—15.66, CaO—31.58, MgO—2.74, CO_2—20.24. Due to the low quality of the limestone, its use for agricultural purposes is largely restricted to local markets. The stone quarried for cement is shipped to Oswego, where it is mixed with high-calcium stone from British Columbia. The locations of the various deposits are shown on figure 66, and the deposits are briefly described in table 22. Both the map and table have been adapted from an article by R. S. Mason (Peterson and Mason, 1958).

In addition to the deposits mentioned above, there are literally hundreds of pods and lenses scattered over the State which are either too small, too low grade, too far from transportation and market, or too expensive to mine.

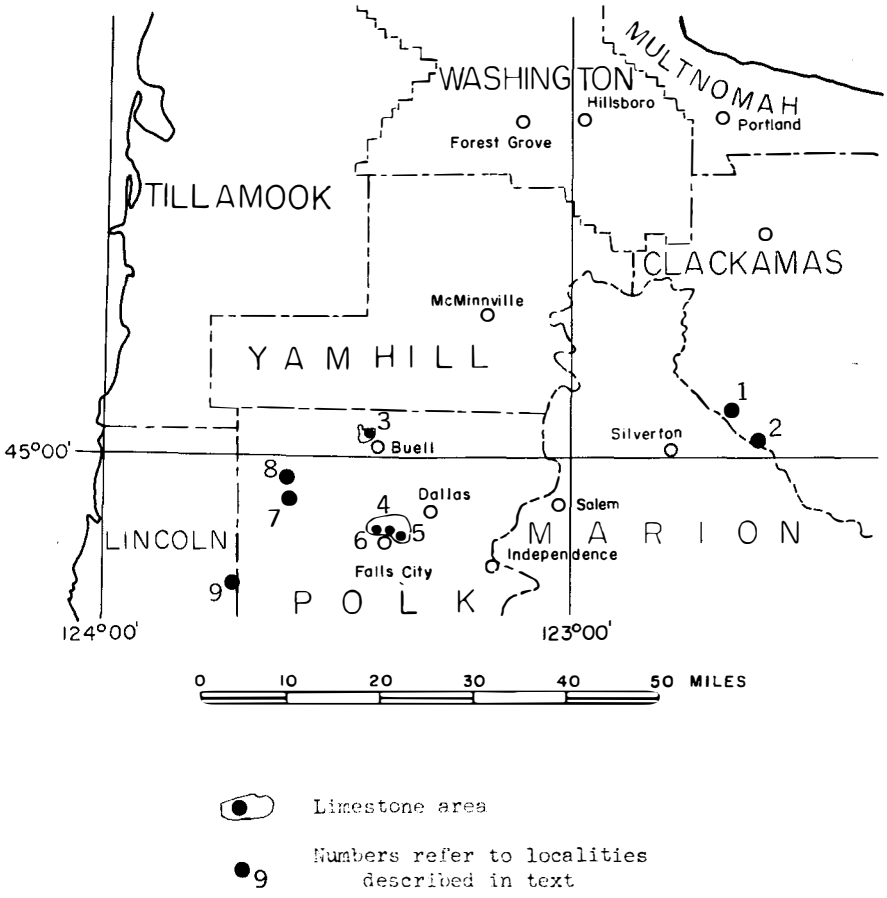

FIGURE 66.—Limestone occurrences in northwestern Oregon.

BUILDING STONE

Building stone is one of the oldest construction materials used by man. The ancients made extensive use of both rough and shaped stone in their temples, public buildings, and somewhat later engineering works such as aqueducts, bridges, and dams. Man gave up living in a tree when his dawning intelligence directed him to a cave, which had better environmental control. Still later it became apparent that loose rock could be fashioned into an adjustable cave which could be adapted to individual or group requirements. From such humble but basic beginnings, the building stone industry has sprung. Today the industry makes use of an exceedingly wide variety of building stones, ranging from blocks of porous coralline limestone to the densest of granites. The choice of materials is dictated by numerous factors, primary

TABLE 22.—LIMESTONE OCCURRENCES IN NORTHWESTERN OREGON

[Adapted from tabulation in Peterson and Mason, 1958]

Index number on fig. 66 and name	Location	Description	Reference
CLACKAMAS COUNTY			
1. Marquam deposit	Sec. 2, 3, T. 6 S., R. 1 E.	Lenses of broken oyster shells in sandy tuffs, grits, and conglomerates. Occurs in 2 deposits covering 10.4 and 4.0 acres. Analyses range from 25 to 65 percent $CaCO_3$.	Libbey, 1957; Oregon Dept. Geology and Mineral Industries, 1951.
2. Beaver Creek	Sec. 19, T. 6 S., R. 2 E.	Undeveloped outcrop of limy tuff. Grab sample showed 50 percent $CaCO_3$.	Oregon Dept. Geology and Mineral Industries files.
POLK COUNTY			
3. Buell limestone	Sec. 19, 20, 29, T. 6 S., R. 6 W.	Twenty-foot bed of massive gray limestone with carbonaceous and clastic fragments. Ranges from 52 to 78 percent $CaCO_3$.	Libbey, 1957; Oregon Dept. Geology and Mineral Industries, 1951.
4. Lime Products Co. quarry	Sec. 11, T. 8 S., R. 6 W.	Similar to No. 5.	Do.
5. Oregon Portland Cement Co. quarry	Sec. 1, 2, 11, 12, T. 8 S., R. 6 W.	Dark gray, tuffaceous, sandy limestone about 50 feet thick. Variable composition but shipments have averaged ±50 percent $CaCO_3$.	Do.
6. Waymire Creek	Sec. 10, T. 8 S., R. 6 W.	Limestone beds 100(?) feet thick exposed for 1 mile along Waymire Creek. Grade probably similar to No. 5. Undeveloped.	Baldwin, 1947.
7. Boulder Creek camp	Sec. 24, T. 7 S., R. 8 W.	Impure beds 50 feet thick; 59 to 86 percent $CaCO_3$. Undeveloped.	Do.
8. Rowell Creek	Sec. 12, T. 7 S., R. 8 W.	Similar to No. 7 but thinner. Grab sample yielded 63 percent $CaCO_3$. Undeveloped.	Do.
9. Sunshine Creek	Sec. 12, T. 9 S., R. 9 W.	Calcareous sandstone 30 feet or more thick. Grab sample showed 44 percent $CaCO_3$. Undeveloped.	Do.

among them is availability, although the history of Stonehenge erected on the Salisbury Plains in southern England tends to refute this. Beauty and utility are obvious requirements. The Taj Mahal is constructed of pure white marble and is considered to be the most beautiful building in the world. In sharp contrast, another equally famous stone structure, the Great Pyramid at Cheops, Egypt, constructed of nummultitic limestone blocks selected primarily for their utility, has resisted weathering and erosion for over 4,800 years. When completed the pyramid was sheathed in smooth limestone, but this has since been removed and used in lesser structures. Much modern construction makes use of ornamental stone facings, which are applied to enhance the appearance of the structure rather than to impart structural strength. In such applications, the attractiveness and workability of the stone is of paramount importance. Criteria for evaluating building stone on the basis of weight and absorption have been suggested by Moen (1967). Built-up roofs covered with various sizes of stone are discussed by Ingram (1963), who gives specifications for the aggregates used. Overshadowing nearly all of the requirements listed above is the cost of the delivered stone. Substitutes for any particular stone are often readily available in another building stone possessing comparable characteristics, and competition from artificial stone is ever present.

Modern uses for building stone include public buildings, retaining walls, footings, curbing, veneering for commercial buildings and private residences, rockeries, landscaping, monuments, statuary, and flagging.

Building stone is sold in several forms. Chunks of rough stone, commonly called rubble, thin sheets of polished veneer, sawed blocks of many sizes, and sawed strips with rough "stone" faces constitute the bulk of the commercially produced building stone. The development of the tilt-up wall has greatly increased the use of rubble. The considerable reduction in cost achieved by this method contrasted to the conventional placement of individual stones permits the erection of rock walls at prices approaching that of standard concrete construction. Stone veneer has been a standard building material for a long time, and its use will probably continue for a long time to come. Veneer sheets usually have a minimum thickness of about 1 inch but may be considerably thicker for very large sized pieces. Marble, grani e, sandstone, limestone, and travertine are most commonly used for veneer. In recent years the use of veneer strips has become very popular. The strips may vary considerably in thickness and length but are uniformly about the width of a brick. The vertical faces are rough surfaces produced by guillotining the sawed slabs into the random-length strips. Placement of the strips is similar to brick laying. Large sawed blocks of stone find limited use in modern building construction. Memorials, mausoleums, and a few government buildings and other structures are built with solid cut stone, but the high cost of the stone plus installation greatly restricts this type of construction.

Building stones are derived from all types of geologic formations and from Precambrian to Holocene age. Stone is the most abundant material on the surface of the earth. The specifications for some types of building stone are extremely rigid while specifications for other

types are very broad and flexible. The applications for building stone are so numerous and varied that practically any stone could be used for some purpose. The highest quality building stone, free from all impurities and flaws and possessing the proper color, texture, density, and workability occurs in limited quantities and commands a premium price. Such stone can therefore be marketed at considerable distances from the quarry. Lower quality stone must sell for less, and even though there are greater tonnages available the market area is curtailed since freight represents a disproportionately large cost. Common field stone and some types of rubble are normally plentiful, but their very low value restricts their use to immediate markets and the tonnage produced is correspondingly small. There is an additional factor involved in building stone which plays an important role in its marketing. Distance lends enchantment to many things, and building stone is one of them. The ultimate consumer of ornamental or monumental stone will more often than not be willing to pay more for material that has come from some far away place, even though equally good and attractive stone is locally available.

Oregon's building stones have been used since early pioneer days when the first permanent structures were erected. Originally the stone was collected locally and used rough or with only minor shaping. Formal production of building stone dates from the late 1880's, when basalt from St. Helens in Columbia County was quarried and shaped. By 1889 the U.S. Geological Survey reported in *The mineral resources of the United States 1889–1900* that Oregon was producing granite, marble, and sandstone. The report stated that granite was produced from Columbia, Multnomah, Clackamas, and Jackson Counties. Almost certainly the granite produced from the first three counties must have come from glacial erratics ice-rafted down the Columbia River from either northeastern Washington or north of the Canadian border. Numerous erratics of granite gneiss and schist have been found in the lower Willamette and Tualatin Valleys and in some areas are still being used for foundation stone. In later years other granite quarries which were opened included: the Ashland granite quarry in Jackson County, the Gold Ray quarry near Tolo in Jackson County, and the Haines quarry two miles east of Haines in Baker County. Of the three, only the Haines quarry had any extended period of production. The quarry was opened before 1900 and shut down in 1960 when the plant was destroyed by fire.

Sandstone

The principal sandstone producer in Oregon was the Pioneer Quarry in Lincoln County, which was most active during the middle and late 1890's. Other sandstone production has come from the Geary quarry southwest of Medford in Jackson County; the Cooper quarry 3 miles south of Sutherlin in Douglas County; the Monroe quarry in Benton County; the Boos quarry 2½ miles northwest of Gaston in Washington

County; Cow Creek quarry about 4 miles west of Riddle in Douglas County; and the Brownsville quarry 4 miles south of Brownsville in Linn County. Only the Pioneer and Boos quarries produced any significant tonage of building stone. The Brownsville quarry has been the source of a small amount of stone used for statuary by sculpture classes at the University of Oregon. The Cow Creek quarry has supplied a limited quantity of fine-grained flagstone.

Limestone

Limestone and marble have been quarried for ornamental stone at several localities in Oregon. Since most of these quarries have been principally used for the production of commercial limestone used by the burnt lime, cement, and calcium carbide industries, they are discussed above in the section on "Limestone" on p. 246.

Volcanic tuffs and flow rocks

Building stone production in Oregon is currently restricted almost entirely to the various volcanic rocks. Tuffs, tuffaceous sandstones, basalt, andesite, and rhyolite are the most common. Tuffs, composed of volcanic ash that has been cemented by minerals dissolved in migrating ground water, are found widely scattered in the State, but principally east of the Cascades. A wide variety of colors, textures, and patterns are available. Welded tuffs are formed from ash flows which issued explosively from vents as large quantities of incandescent volcanic ash, dust, and rocks which became welded together upon cooling, often at considerable distances from their source. Generally the welded tuffs are harder and denser than other tuffs, but a great variation both in color, texture. composition, and density exists.

The Rainbow Rock quarry, located about 5 miles south of Pine Grove in southwestern Wasco County, has been producing brightly colored and banded tuff since 1949. The quarry is located on the nose of a low ridge which stands about 100 feet higher than the surronding countryside. Rock of similar appearance has been uncovered but not developed on the nearby flat east of the quarry. Quarry blocks have been cut with wire saws or traveling circular saws making horizontal and vertical cuts. The saw carriage is mounted on heavy rails. An interesting feature of Rainbow Rock is the deepening of the colors upon firing in a ceramic kiln. When quarried the stone is easily shaped, and various small art objects have been fashioned from it. After firing, the pieces can be given a salt glaze, which produces a hard, impervious, and transparent surface. Past production from the quarry has gone mainly into veneer strips and split-face blocks.

The Willowdale quarry on U.S. Highway 97, about 20 miles north of Madras in northern Jefferson County, has been producing stone from a welded tuff outcrop for many years. Colors available in the well developed quarry range from rose through reddish browns to darker shades. A traveling track-mounted carriage equipped with

vertically and horizontally mounted circular saws cuts out "cants" of various dimensions. The "cants" are then resawed and guillotined in the shop.

An outcrop of green-colored tuff located about 4 miles north of Prineville in Crook County was worked in a small way for a short time. The stone proved to be uneven in composition and hardness. Whether this condition persists much below the shallow depths exposed in the quarry is not known.

A rough, dark red scoria is quarried at Tetherow Butte a few miles north of Redmond and just west of U.S. Highway 97. The butte is a Recent cinder cone several miles in length. Portions of the butte are composed of loose aggregate, which has been extensively used for road ballast. Along part of the southwest flank of the Butte, the scoria has been consolidated sufficiently to permit the extraction of large rough blocks. The blocks, which lack nearly every characteristic of a good building stone, are much used for making rockery walls, planters, and low retaining walls. The blocks can be shaped readily with a borrowed ax and are popular with home owners who like to build their own walls.

The Kah-Nee-Ta stone quarry on the Warm Springs Indian Reservation, Wasco County, produces rough pieces of silicified rhyolite. The rhyolite has been partly infiltrated with silica derived from local hot spring activity. The stone is varicolored with browns, tans, and whites predominating and is quite rough and vesicular.

The Carver quarry, six-tenths of a mile east of Carver in Clackamas County, has produced building stone for many years. The quarry is located at the base of towering cliffs of uniformly gray Boring Lava, which is readily worked. Currently most of the production is going into retaining walls. The old Portland Hotel, one of the landmarks in Portland for many years, was constructed of stone from this quarry.

Near Idanha in southeastern Marion County, a small quarry has produced veneer strips and split-face blocks intermittently over the past two decades. The stone is a buff colored, banded tuff, which works up easily.

Moon Mesa quarry, located about 15 miles south of Baker in southern Baker County, produces building stone composed of thin-banded rhyolite. Colors range from creamy white to almost purplish. Veneer strips and split-face blocks are sold for facings on both domestic and commercial buildings.

Numerous buildings in Baker have been constructed of volcanic tuff obtained from quarries at Pleasant Valley, a railroad siding 13 miles east of town. The tuff covers a considerable area and is at least 100 feet thick were exposed. Joint spacing is such that large blocks can be quarried readily. The tuff is of uniform texture and light gray color. The stone is easily worked when freshly quarried but hardens upon exposure. A detailed report on the Pleasant Valley deposits by Parks (1914) contains the following table showing results of tests on stone specimens.

TESTS OF OREGON VOLCANIC TUFFS

Name and location of quarry	Percentage of absorption	Crushing strength in pounds per square inch			Specific gravity
		Specimen tested dry	Specimen tested saturated with water	Tested after freezing and thawing 10 times	
Grant Quarry, Pleasant Valley, Oreg.	22.68	2,916	2,861	2,816	1.81
Oregon Lava:					
Stone Co., Pleasant Valley, Oreg.	28.96	----------	1,212	----------	1.64
Do.	29.29	1,724	1,160	1,261	1.33

A few miles east of Sublimity, Marion County, there is a tuff quarry which has produced a considerable quantity of light gray stone. The tuff is quite soft and has numerous fragments of pumice and occasional pieces of charcoal, indicating the high temperature of the ash flow. The quarry has been developed for a length of 200 feet along the hillside with a series of benches 36 inches high. The stone is cut with horizontally and vertically mounted circular saws equipped with carbide inserts. Blocks measuring 8 by 16 inches in cross section and of varying lengths are removed to a guillotine where 8- by 8-inch split-face stone is made. The blocks have a high insulating value and have been used in numerous local cold storage plants and meat packing plants. Tests of the Sublimity stone indicate its water absorption is between 23 and 30 percent, its apparent porosity ranges between 31 and 41 percent, and its bulk specific gravity is about 1.35.

A stone quarry on the northeast flank of Rocky Butte, a prominent landmark in northeast Portland, has produced building stone for many years. Rocky Butte is a Pliocene and Pleistocene age volcano that has been somewhat eroded, with a former channel of the Columbia River at its base. The lavas are generally gray, but portions show a pinkish tinge. As early as 1885, stone from the quarry was used to build the south jetty at the mouth of the Columbia River. Other structures using Rocky Butte stone include the nearby Rocky Butte County Jail and the Grotto at the Sanctuary of Our Sorrowful Mother. Over the years the boundaries of the quarry have approached adjacent property lines, and encroaching urbanization has prevented further expansion. The quarry has had limited production in recent years.

In addition to the quarries discussed above, there are literally dozens of outcrops that have been used for ornamental and building stone purposes on an informal and short-lived basis. The great cost of developing a quarry and maintaining a steady market has severely limited the establishment of large, well equipped building stone operations in the State. On the other hand, the current popularity of rubble-faced walls has spurred the use of rock from suitable exposures where it has been loosened by natural processes and can be readily reduced to size. Some of this type of rock is obtained by individuals who wish to erect their own stonework, but masonry contractors also use stone from similar exposures for small jobs.

Table 23 lists the principal stone quarries in the State, together with results of tests for water absorption, apparent porosity, and bulk specific gravity. All tests were performed by the State of Oregon Department of Geology and Mineral Industries, using ASTM procedures.

TABLE 23.—SELECTED BUILDING STONES IN OREGON

Quarry or deposit	Location	Description of stone	Percent water absorption	Apparent porosity	Bulk specific gravity
Banasco Quarry	Sec. 8, T. 37 S., R. 24 E., Lake County, SW of Plush 3 mi.	Dark red scoria lumps up to 18 in. in diameter		(1)	
Breitenbush stone	Sec. 20?, T. 9 S., R. 7 E., Marion County, near hot springs.	Pink tuff with white inclusions	9.95	20.7	2.08
Brownsville sandstone	Sec. 24, T. 14 S., R. 3 W., Linn County, 3.8 mi. S. of Brownsville.	Buif tuffaceous sandstone with dark bands	5.7	12.8	2.24
Butte Creek tuff	Sec. 29, T. 6 S., R. 2 E., Clackamas County, 4.3 mi. SE of Scotts Mills Jct. on Butte Cr. Road.	Buff tuffaceous sandstone containing occasional fossils	12.1	22.4	1.85
Carver Quarry	Sec. 18, T. 2 S., R. 3 E., Clackamas County, .6 mi. E. of Carver.	Gray Boring Lava	3.9	9.7	2.48
Cinder Hill Quarry	Sec. 33, T. 14 S., R. 13 E., Deschutes County, on U.S. 97 just N. of Redmond.	Dark red, highly inflated scoria		(1)	
East Lake Quarry	West end of East Lake, Newberry Crater, Deschutes County.	Lump pumice, buff to light gray, some admixed obsidian		(1)	
Glass Buttes opalite	Sec. 34, T. 23 S., R. 23 E., Lake County, 82 mi. E. of Bend on U.S. Highway 20.	Milk-white opalite chunks up to 12 ins. across with some red cinnabar patches.		(1)	
Hines highway cut	Sec. 31?, T. 24 S., R. 30 E., Harney County, about 2 mi. W. of Hines on U.S. Highway 20.	Pinkish-red tuff with numerous dark red to brown inclusions.	15.8	27.6	1.75
Idanha Quarry	Sec. 10, T. 10 S., R. 6 E., Marion County, near Idanha	Banded buff tuff	13.9	26.3	1.95
Indian Candy Stone Quarry	Sec. ?, T. 7 S., R. 12 E., Wasco County, near Cuchta Corral.	Light colored volcanic tuff with pronounced banding and some dark inclusions.		(3)	
Kah-Nee-Ta Stone Quarry	Sec. 20, T. 8 S., R. 13 E., Wasco County, next to Kah-Nee-Ta Hot Springs resort.	Creamy-yellow siliceous sinter with darker bands and numerous vugs.	6.95	13.8	1.98

McDermitt dendrite	Near McDermitt, Malheur County	Thin-bedded sandstone with large manganese dioxide dendrites resembling ferns on bedding planes.		[1]	
Moon Mesa Quarry	T. 11 S., R. 40 E., Baker County, ½ mi. E. of State Highway 7 near Dooley Mt. summit.	Creamy yellow, thin-banded rhyolite with darker bands	2.34	5.42	2.31
North Fork tuff	Sec. 30, T. 6 S., R. 32 E., Umatilla County, 3.3 mi. upstream from U.S. Highway 395.	Pink to off-white volcanic tuff with darker inclusions. Some salt and pepper coloring.	8.88	16.8	1.85
Ochoco stone	Sec. 14, T. 15 S., R. 12 E., Deschutes County, E. flank of Cline Butte.	Dark brown to gray, flow banded rhyolite		[1]	
Oregon Blue Stone	Sec. 32, T. 30 S., R. 7 W., Douglas County, on S. bank Cow Creek near gauging station.	Dark bluish to greenish fine-grained sandstone. Slabs 2 to 8 in. thick. Dense, hard, heavy.	2.6	5.44	1.98
Oregon Emerald Quarry	Sec. 17, T. 14 S., R. 16 E., Crook County, 3.7 mi. N. of Prineville.	Green volcanic tuff	8.87	15.2	1.71
Oregon Tuff Stone Quarry	Sec. 29, T. 8 S., R. 1 E., Marion County, about 4 mi. NE of Sublimity.	Light gray volcanic tuff with large creamy pumice chunks and occasional inclusions of charcoal.	27.0	36.0	1.35
Rainbow Rock Quarry	Sec. 11, T. 6 S., R. 11 E., Wasco County, about 5 mi. S. of Pine Grove.	Brightly colored volcanic tuff with contrasting bands. Reds, yellows, browns.	16.7	28.3	1.72
Red Rock Mine	Sec. 20, T. 14 S., R. 13 E., Deschutes County, NW side of Tetherow Butte.	Dark red scoria	37.4	45.0	1.20
Rome stone	Sec. 6, T. 32 S., R. 41 E. Malheur County, ½ mi. N. of Bannock War marker on Highway 95.	Light gray, tuffaceous sandstone with dark, fine bands. Somewhat friable, low density.	25.8	39.1	1.52
Sahara Tan Quarry	Sec. 21, T. 14 S., R. 13 E., Deschutes County, 1 mi. S. of Terrebonne.	Brown to off-white silicified tuff. Brittle and fairly dense		[1]	
Snowbird Quarry	Sec. 24, T. 27 S., R. 1 E., Douglas County, on Snowbird Road.	Red banded rhyolite with whitish bands	14.5	27.7	1.94
Sorenson Quarry	Sec. 37, T. 5 S., R. 12 E., Wasco County, on Wamic Road	Dark red scoria		[1]	
Stayton Flatrock Quarry	Sec. 11, T. 9 S., R. 1 W., Marion County, E. edge of Stayton on Highway 222.	Platy andesite, gray on fresh fracture but with tan weathered surface.		[1]	
Willowdale Quarry	Sec. ?, T. 9 S., R. 15 E., Jefferson County, 2.6 mi. S. of Willowdale on U.S. Highway 97.	Rhyolite tuff in various shades of pink, brown, and with purplish tints. Some color banding.	21.9	31.6	1.66

[1] Not tested.
[2] Not tested (similar to Red Rock Mine).
[3] Not tested (similar to Rainbow Rock).

CRUSHED STONE

Crushed stone leads in the annual value of all mineral commodities produced in Oregon, closely followed by sand and gravel. Community growth and development depend on stone and no substitutes are available for most of the many uses to which it is put. Sand and gravel and crushed stone supply the irreplaceable aggregate for a host of construction projects. Roads, highways, dikes, earthen and concrete dams, and concrete in all of its multitudinous forms require stone in sizes ranging from sand to boulders. Crushed stone is a low-cost commodity and is commonly produced and used locally. Although the State has an abundance of excellent stone suitable for crushed aggregate, there are certain areas where demand is rapidly exhausting the supply. In these areas, usually in the western part of the State, spreading urbanization has already checkmated stone deposits and operating quarries and removed them as a source of supply of a vitally needed resource. Specifications for concrete aggregate are becoming steadily more exacting as technologies improve. Aggregates that were suitable for concrete prior to World War II may very well be substandard today.

Due to the double effects of urbanization and increasingly stringent specifications, the reserves of suitable and available stone are diminishing. Adequate planning for the exploitation of stone deposits has not been adopted in the State. Studies by Schlicker (1961) and Schlicker and Deacon (1967) discuss problems related to the pressing need for mineral construction materials in areas with rapidly developing urban populations. Any program for quarrying stone must include provisions for: (1) efficient and economical production of the commodity, secondary use of the abandoned site for sanitary fill or other use, and (2) a minimum of dislocation of local activities and land values, (3) (4) final revamping of the site to the highest possible level compatible with the economics, public need, esthetics, and longrange objectives of the area.

Basalt is the principal rock type quarried for crushed stone in Oregon. Lavas of Tertiary age occur widely over the State and are quarried in most of the 36 counties. Characteristically, the lavas are either exposed or have only a thin overburden. The economic production of crushed stone depends on many factors. Physical characteristics of the rock of prime importance that are usually tested if the stone is to be used in road, riprap, and jetty construction include: abrasion resistance, specific gravity, weight loss with sodium sulphate, degradation, and asphalt stripping. Additional tests for use as concrete aggregate usually include determination of reactivity of the rock with the cement to be used. The joint patterns in a quarry often determine the most economical use: Widely spaced joints permit the freeing of large blocks suitable for jetty and riprap construction, closely spaced jointing requires minimum crushing for road aggregate. Quarries located on hills usually are free of ground water and flooding problems, and the road grade to markets is usually downhill. Quarries located on flat ground may have thick soil overburden, and weathering may increase quarrying costs due to high rejection of inferior rock.

Low-cost crushed stone cannot be hauled very far economically, although more efficient hauling equipment, better roads, and the growing scarcity of deposits tend to extend the haul radius. Spreading urbanization and ever tightening regulations regarding air and water pollution present real problems to quarry operation.

The production of crushed stone is one of the better indices of community growth. The following table, adapted from U.S. Bureau of Mines Minerals Yearbook volumes, shows the production of stone, unit value, and total value for the years 1945 through 1966. The enormous growth of the crushed stone industry in the State is strikingly brought out.

CRUSHED STONE IN OREGON 1945–66

Year	Short tons	Value	Unit value (per ton)	Year	Short tons	Value	Unit value (per ton)
1966	33,288,000	$48,335,000	$1.46	1955	7,741,937	$9,417,834	$1.22
1965	21,212,000	27,301,000	1.29	1954	5,872,353	8,617,795	1.46
1964	16,120,000	19,296,000	1.20	1953	4,939,080	6,301,639	1.28
1963	19,692,000	24,197,000	1.23	1952	6,250,849	8,893,368	1.42
1962	18,258,000	20,977,000	1.15	1951	8,722,000	10,831,000	1.24
1961	17,455,000	21,202,000	1.21	1950	3,837,000	5,559,000	1.45
1960	16,864,000	19,620,000	1.16	1949	4,397,000	6,479,000	1.47
1959	13,341,000	16,126,000	1.21	1948	3,682,000	5,734,000	1.56
1958	15,077,000	15,621,000	1.03	1947	3,002,000	4,425,847	1.47
1957	10,311,000	11,405,000	1.11	1946	1,472,000	2,008,374	1.36
1956	6,098,000	7,890,000	1.30	1945	1,498,160	1,898,073	1.27

Crushed stone is produced in nearly every community in the State. No attempt will be made here to enumerate either the various deposits currently producing crushed stone or to depict the areas where the quarries are located. Many quarries are opened up to supply a specific, short-term need, such as the construction of a highway or dam. Other quarries are operated for long periods of time and serve the general needs of a community or industry. Many quarries are operated on an intermittent or irregular basis in response to seasonal needs or during periods of emergency when dike and fill materials are needed. Some "abandoned" quarries are in reality only on a stand-by basis awaiting the needs of the community. The growing practice of producing stone on a batch basis by contractors equipped with portable quarry plants has been a factor in holding unit costs down. The use of such equipment relieves the quarry owner of the high capital cost needed to properly equip a quarry for low-cost operation, and the contractor is able to operate his high-volume equipment more hours per month by working a succession of quarries in the area.

Oregon has enormous reserves of excellent stone suitable for crushing and riprap and their distribution with respect to present markets is for the most part good. In the northwestern part of the State, diminishing sources and expanding demand sooner or later will create local problems. These can be minimized by immediate adequate comprehensive planning, but no such programs have yet been adopted. In the long run, crushed stone will necessarily have to be quarried from less desirable deposits, and the stone will have to be beneficiated to a greater extent than at present. The cost of longer hauls to market can be partly

offset by more efficient and larger haulage equipment and better roads, but the unit cost of the delivered product will show substantial increases over present levels.

Zeolites

(By R. A. Sheppard, U.S. Geological Survey, Denver, Colo., and G. W. Walker, U.S. Geological Survey, Menlo Park, Calif.)

Zeolites are crystalline hydrated aluminosilicates of the alkalies and alkaline earths. They have a framework atomic structure that encloses interconnected cavities occupied by the relatively large cations and water molecules (Smith, 1963). The cations and water have considerable freedom of movement which gives the zeolites their cation exchange and reversible dehydration properties. The porous character of the zeolites enables them to act as molecular sieves for the separation of molecular mixtures based on the size and shape of the molecular compounds or for the selective absorption of gases.

These unique properties of the zeolites lead to diverse industrial uses in processes such as purification and drying of liquids and gases, chemical separations, catalysis, and decontamination of radioactive wastes (Brown, 1962). Zeolitic rock can be used as a pozzolan in cement (Mielenz, 1950, pp. 5–7) or as a soil conditioner to increase the effectiveness of chemical fertilizers (W. W. Sproul, Jr., 1966, written communication). Industry now uses synthetic zeolites almost exclusively, but as economic methods are developed to convert natural material into a commercial product (Barrer and Makki, 1964), large natural deposits may become important.

Zeolites occur chiefly as cavity fillings in igneous rocks and as authigenic rock-forming constituents in sedimentary rocks, particularly altered rhyolitic vitric tuffs (Hay, 1966). The bedded deposits are a potential resource because they are extensive and high in purity. Most, if not all, of the potentially valuable zeolite deposits in Oregon are of this type. They occur in Cenozoic continental tuffs and tuffaceous sedimentary rocks that originally consisted of rhyolitic vitric ash. The zeolites formed in the postdepositional environment mainly by reaction of the vitric ash with interstitial water, which may have originated as either meteoric water (Hay, 1963) or connate water of a saline lake (Hay, 1964). Of the more than 30 natural zeolites, only seven commonly occur in bedded deposits. These include analcime, chabazite, clinoptilolite (an alkali- and silica-rich variety of heulandite), erionite, laumontite, mordenite, and phillipsite. Laumontite, unlike the other zeolites listed above, characteristically occurs in rocks that have been deeply buried. The zeolites occur in nearly monomineralic beds or, more commonly, occur associated with other zeolites, clay minerals, silica minerals, or feldspars.

Bedded zeolite deposits have been reported chiefly from the central (table 24 and fig. 67, Nos. 2–6) and southeastern (Nos. 8–13) parts of Oregon. Zeolite deposits outside these areas include clinoptilolite and mordenite in the Western Cascade Range (No. 1) and erionite near Durkee (No. 7). The latter occurrence in the abandoned Durkee opal mine is the type locality for erionite described by Eakle in 1898 (Staples and Gard, 1959).

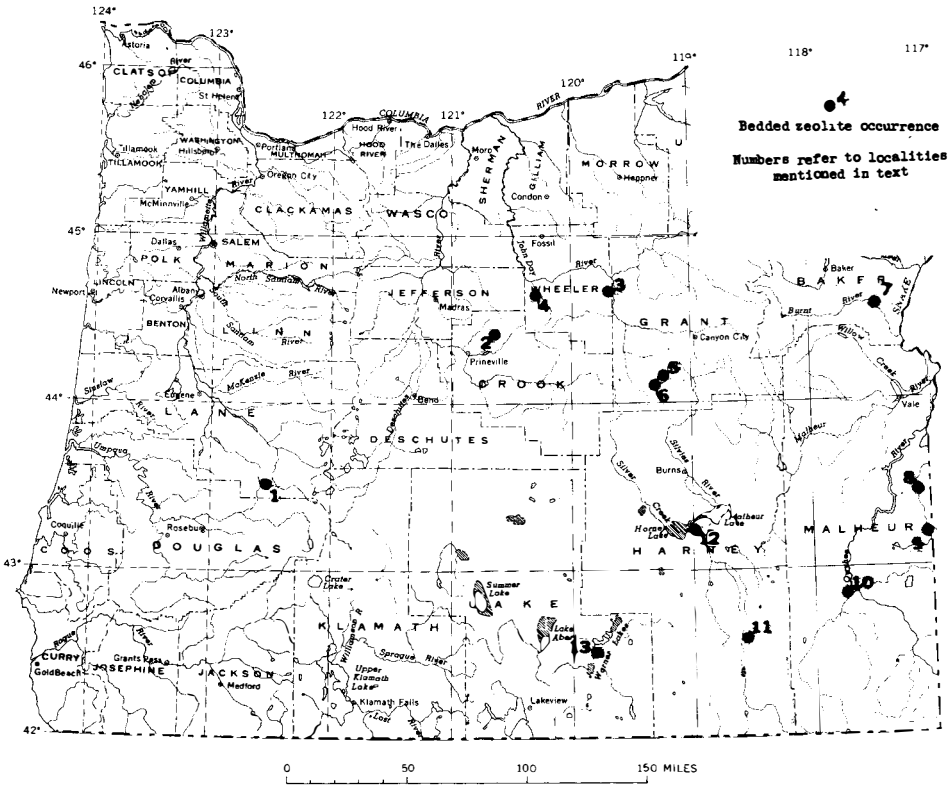

FIGURE 67.—Bedded zeolite deposits in Oregon.

TABLE 24.—BEDDED ZEOLITE DEPOSITS IN OREGON

Index number on fig. 67 and location	Zeolites	Occurrence	References
1. Sec. 36, T. 23 S., R. 2 E., near Bearbones Mountain, Lane County.	Clinoptilolite, mordenite	Tuff and lapilli tuff in the Little Butte Volcanic Series of Oligocene and Miocene age.	Moore and Peck, 1962, p. 188; Peck and others, 1964, p. 15, 40.
2. Sec. 30, T. 13 S., R. 18 E., vicinity of Stein's Pillar, Crook County.	do	Welded tuff in the John Day Formation of Oligocene and Miocene age.	Waters, 1966.
3. Secs. 35, 36, T. 10 S., R. 25 E., vicinity of Deep Creek, Wheeler County.	Clinoptilolite	Tuff in the lower part of the John Day Formation of Oligocene and Miocene age.	Fisher, 1962, 1963; Wilcox and Fisher, 1966.
4. Sec. 31, T. 10 S., R. 21 E., and sec. 36, T. 10 S., R. 20 E., vicinity of Painted Hills, Wheeler County.	do	Tuff and claystone in the lower part of the John Day Formation of Oligocene and Miocene age.	Hay, 1962, 1963.
5. 3 to 4 miles northeast of Flagtail Mountain, Grant County.	Laumontite	Tuffaceous rocks in the Aldrich Mountains Group of Late Triassic(?) to Early Jurassic age.	Brown, 1961; Brown and Thayer, 1963, 1966.
6. Sec. 18 T. 17 S. R. 29 E. along Lewis Creek Grant County.	Heulandite, laumontite	Tuffaceous rocks in the lower part of the Trowbridge Formation.	Dickinson 1962a 1962b.
7. Sec. 36 T. 11 S. R. 43 E. near Durkee Baker County.	Erionite	Welded tuff of Tertiary age	Eakle 1898; Staples and Gard, 1959.
8. Sec. 28 T. 24 S. R. 46 E. along Sucker Creek Malheur County.	Clinoptilolite	Tuff and tuffaceous sandstone in the Sucker Creek Formation of Miocene age.	Kittleman and others 1965, p. 6, 32, 33.
9. Sec. 1 T. 28 S. R. 46 E. near Sheaville Malheur County.	do	Tuff probably equivalent to part of the Sucker Creek Formation of Miocene age.	A. J. Gude, 3d, 1966, oral communication.
10. Sec. 6 T. 32 S. R. 41 E. near Rome Malheur County.	Mordenite, erionite, clinoptilolite, phillipsite chabazite.	Tuff and tuffaceous sandstone in an unnamed lacustrine formation of Pliocene age.	Eberly, 1964; Regis and Sand, 1966.
11. W½ T. 34 N., R. 34 E., east face of Steens Mountain, Harney County.	Clinoptilolite	Tuff in the Pike Creek Formation of Oligocene(?) and Miocene age.	Walker and Repenning, 1965.
12. Sec. 13, T. 27 S., R. 30 E., near Harney Lake, Harney County.	Clinoptilolite, erionite, phillipsite	Tuff and tuffaceous, sedimentary rocks in the Danforth Formation of Pliocene age.	Walker and Swanson, 1968a.
13. West face of Hart Mountain, Lake County	Clinoptilolite, mordenite, phillipsite	Tuff and tuffaceous sedimentary rocks of late Oligocene or early Miocene age.	Walker and Swanson, 1968b.

Zeolite deposits in central Oregon occur in the John Day Formation of Crook, Wheeler, and Grant Counties (Nos. 2–4), and in Triassic(?) and Jurassic rocks of southwestern Grant County (Nos. 5–6). Original vitric material in tuff and claystone in the lower part of the John Day Formation is commonly replaced by clinoptilolite. Clinoptilolite and mordenite occur in an altered welded tuff of the formation in northern Crook County (No. 2). Hay (1963, p. 213) suggested that zeolitic rocks of the John Day Formation extend throughout an area of about 2,200 square miles in central Oregon. Although the clinoptilolite in the formation is generally associated with clay minerals and opal, as well as crystal and rock fragments, nearly monomineralic beds are reported. Fisher (1962; 1963) described several altered tuffs that are up to 30 feet thick and contain as much as 95 percent clinoptilolite.

Laumontite replaced vitric material in marine graywacke, volcanic breccia, and tuff of the Aldrich Mountains Group in southwestern Grant County (No. 5). The laumontite commonly occurs as interstitial material or ovoid segregations; however, some thin tuffs locally consist almost entirely of laumontite. Similar deposits of laumontite occur associated with heulandite in tuffaceous rocks of the Trowbridge Formation near Izee (No. 6).

High-grade deposits of zeolites occur in altered vitric tuffs of several Tertiary formations in southeastern Oregon. Zeolitic tuffs interbedded in an unnamed lacustrine formation of Pliocene age crop out over several tens of square miles near Rome (No. 10). Some beds are nearly monomineralic and consist of erionite (Eberly, 1964), mordenite, or phillipsite (Regis and Sand, 1966); but other beds consist of two or more zeolites and clay minerals or quartz. Nearly pure beds of clinoptilolite occure east of Harney Lake (No. 12) in a lacustrine part of the Danforth Formation of Pliocene age. Phillipsite and erionite occur locally with the clinoptilolite in some tuffs (Walker and Swanson, 1967a). Clinoptilolite is abundant in older Tertiary tuffs north of Jordan Valley (Nos. 8–9), on the east face of Steens Mountain (No. 11), and on the west face of Hart Mountain (No. 13). At the Hart Mountain locality, a few thin tuffs consist of 90–95 percent clinoptilolite. Some tuffs also contain minor mordenite and phillipsite associated with clinoptilolite and clay minerals (Walker and Swanson, 1967b).

Although the size and purity of the above deposits are not adequately known, large volumes of rhyolitic vitric tuffs have obviously been altered to zeolites. Large additional volumes of zeolitic tuff probably occur in other Tertiary basins of southeastern Oregon, such as those near Juntura and Harper. As of 1967, none of the deposits have been commercially exploited, although preliminary exploration and sampling have been done on several. The bedded zeolites are a future potential resource of Oregon, but study to determine their size and value await further industrial development and the establishment of suitable markets.

FOSSIL FUEL RESOURCES

Coal

(By R. R. Mason, Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Coal has been mined in Oregon since pioneer times when many seams were opened to provide fuel for purely local consumption. In the period 1888 through 1911 an average of more than 60,000 tons per year was mined in the Coos Bay field. During this time there were four years when production exceeded 100,000 tons. Shipments to California reached a peak shortly after 1900 and declined rapidly with the discovery of the prolific California oil fields. Large tonnages of coal were also used for firing steam locomotives. Following a brief period of renewed activity during World War II, coal production in the State has declined almost to the vanishing point (fig. 68).

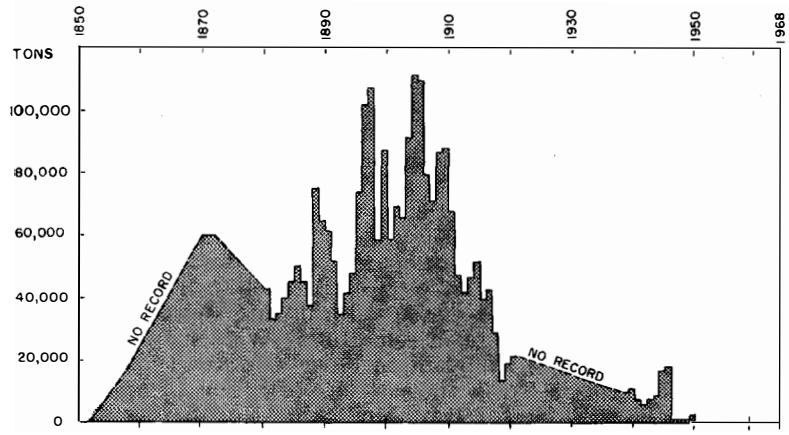

FIGURE 68.—Coal produced in Oregon 1854 to 1966.

Competition from other thermal energy sources has always been severe in Oregon. Wood and wood by-products, fuel oil, coke, low-cost hydroelectrical energy, and more recently, natural gas, have been favored over coal for heating purposes.

For many years a small quantity of coal has been mined in Clackamas County, mostly for use as a soil amendment.

Consideration has also been given to the utilization of the high volatile Coos Bay coals for the production of by-products. A report by M. D. Curran (1944) discusses this as well as the beneficiation of the Coos Bay coals.

The important coal fields of Oregon include: the Coos Bay field, the Eden Ridge field, and the Rogue River field (fig. 69). Other areas in which small tonnages of coal either have been or could be developed include: The Vernonia coals of Columbia County, the Wilhoit area of Clackamas County, the Waldo Hills area of Marion County, the Eckley and Squaw Basin coals of southern Coos County, and the Shasta Costa coal of Curry County. Other counties in which thin seams of low-grade coal are known to crop out include Tillamook, Lincoln, Yamhill, Douglas, Grant, Morrow, Wheeler, and Wasco.

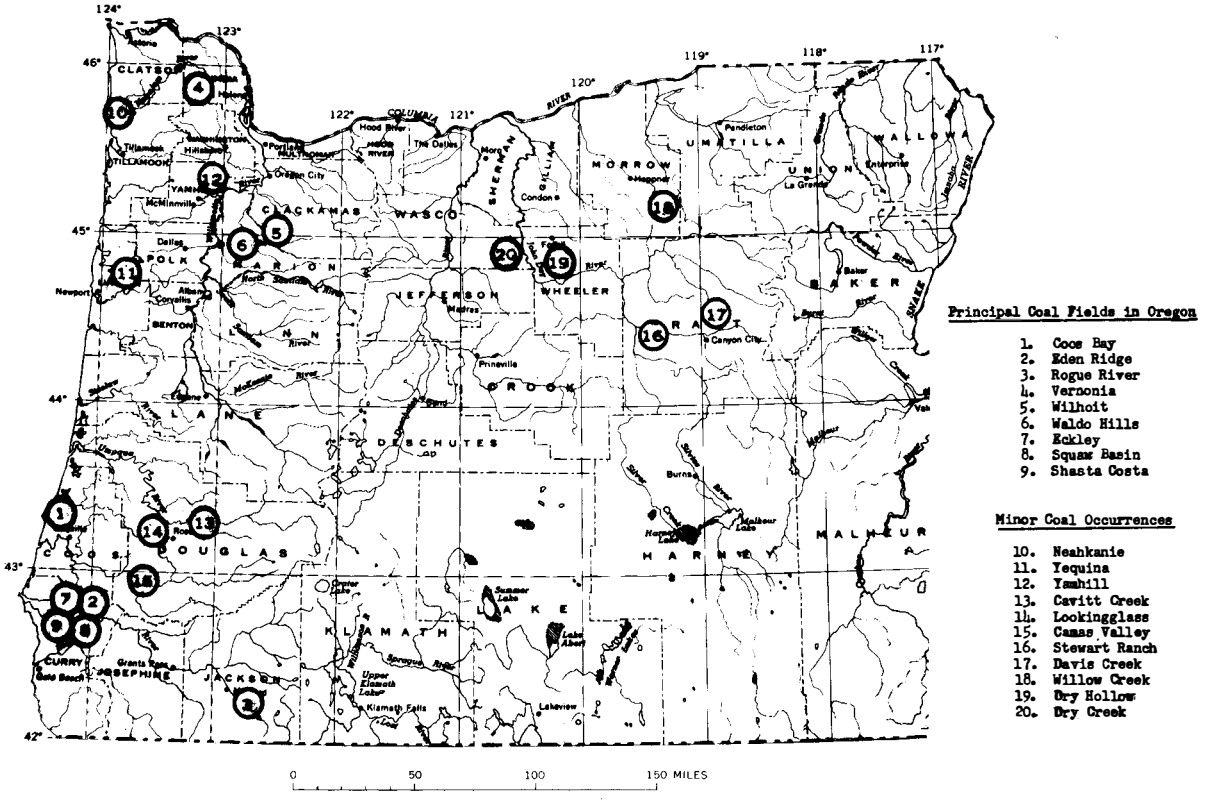

FIGURE 69.—Coal in Oregon.

Coos Bay Field

The Coos Bay coals have been investigated many times in the last 70 years. The first published geological report on the Coos Bay area was by J. S. Diller (1896). This was followed by further reports (Diller, 1899, 1901, 1914; Diller and Diskell, 1911). A comprehensive study of the field was conducted by the Oregon Department of Geology and Mineral Industries in cooperation with Coos County in 1943–44. Results of the work, which, in addition to geologically mapping the area, included detailed mapping of many of the mines, sampling of unmined exposures, and hand and power augering of possible strip mine areas, were published (Allen and Baldwin, 1944). At about the same time the U.S. Bureau of Mines and the U.S. Geological Survey deep-drilled several areas to determine possible reserves. (Toenges and others, 1948; Duncan, 1955). Other pertinent publications on the Coos Bay area include Libbey (1938), Yancey and Geer (1940), and Weaver (1942). Coal occurrences to the south in Curry County were included in some of Diller's investigations and were also discussed by Butler and Mitchell (1916).

Allen and Baldwin (1944, p. 1) summarize the geologic setting for the Coos Bay coals as follows:

> About 6,000 feet of upper Eocene Coaledo sediments are confined to a complex structural basin occupying the central portion of the quadrangle. The lower and upper Coaledo members consist of medium-bedded tuffaceous sandstones made up largely of basaltic glass, separated by the middle Coaledo member consisting of as much as 2,300 feet of dark tuffaceous shale of more acidic composition. The principal coal beds occur in the upper and lower sandstone members of the Coaledo formation.

Duncan (1953, p. 53) condenses the structural relationships of the basin:

> The Coos Bay Coal field occupies a structural basin about 15 miles wide and 30 miles long, elongate north-south. Tertiary sedimentary rocks in the basin have been deformed into several steep, and almost parallel folds which trend northward. One of these folds, the Beaver Slough syncline, underlies most of the map area of this report and the coal-bearing sequence is exposed mainly along the flanks of the syncline. Northward-trending faults in the northern part of the map area are interpreted to be high-angle thrust faults. Several smaller west-, northwest-, and northeast-trending faults with displacements of less than 100 feet offset the coal beds in the mined areas. These faults and adjacent sheared zones have limited the size of several of the smaller mines and prospects in the area.

The Coos Bay coals characteristically have sound roofs which have required little or no support during mining. In some mines rooms remain open for years after operations have ceased. Despite the fact that the Coos Bay area has a heavy annual rainfall, the mines are almost without exception dry, even in cases where the workings have been carried far below sea level. Very little if any gas has been encountered in most of the mines and open flame lamps were used prior to World War II. The Overland mine produced a little gas which was disposed of by driving pipes into the breast and lighting the escaping gas. One of the greatest difficulties encountered in the mines was the faulting which offset the seams vertically as much as several feet. The presence of these "jumps" as they were called locally, necessitated the construction of rock tunnels to reach the offset blocks. In some mines the seam was not thick enough to permit normal height gangways and slopes and portions of the roof had to be "brushed" to give headroom. Nearly all of the seams in the district had one or more clay partings.

Normally the clay was firm enough to permit removing and gobbing.

Almost without exception the mines in the Coos Bay field are abandoned and caved. Portals of many mines have been purposely blocked to prevent access. Maps of the workings of nearly all of the mines in the field have been reproduced in Allen and Baldwin (1944), together with typical coal sections, a history of the operation, and production figures. There is excellent access to all parts of the field but heavy vegetative cover has obscured nearly all of the workings. The unmined portions of the various seams are situated for the most part downslope from the old workings. Various estimates have been made of the remaining reserves. The estimates differ widely due to a variety of factors. In some cases only coal that could be mined economically at the time of the survey or in the immediate future was considered. Other studies included "geologic" coal resources which, based upon available geologic and engineering data, very probably exist in the study area. Some estimates were based on the "geologic" coal but made allowances for losses incurred in mining plus a safety factor for possible breaks in the continuity, thinning of the seams, or lowering of the grade.

Campbell (1913) estimated the reserves at one billion tons. Allen and Baldwin agreed with this figure but felt that certain reservations should be made on the basis of economics. Duncan split the reserves up into the various beds and other factors, with a total of 56.5 million tons for the Beaver Hill bed and an additional 6.2 million tons in the coals overlying the Beaver Hill. Of this total of 62.7 million tons, Duncan estimated that from 25 to 50 percent could be recovered depending upon the type of mining. No coal deeper than 1,500 feet below sea level was considered as minable by Duncan. An estimate prepared by the Oregon Department of Geology and Mineral Industries in 1953 (Libbey, 1953, letter to Oregon Development Commission) divided the reserves in the Coos Bay field into eight areas. The study showed that a total of 51.4 million tons of minable coal were available. Various recovery percentages, ranging from as low as 30 percent for the deeper portions of the Beaver Hill bed, to 100 percent for the Englewood, Southport, Thomas, and Riverton stripping areas, were used in arriving at the reserve figure. The following table from Mason and Erwin (1955) summarizes the Coos Bay reserves:

COAL RESERVES, IN THOUSANDS OF SHORT TONS, IN PARTS OF THE COOS BAY FIELD

[Southport and Thomas, and Beaver Slough reserve figures are included in Duncan's estimates]

	Average thickness (feet)	Measured	Indicated	Inferred	Total
Areas: [1]					
South Slough			263	2,362	2,625
Englewood		[2] 219	[2] 85		304
Riverton		[2] 50	[2] 15		65
Lillian				132	132
Beds: [3]					
Beaver Hill	4.9	17,245	26,636	12,611	56,492
Bed D	3.3	3,628			3,628
Bed E	2.7	1,404			1,404
Bed H	3.6	738			738
Bed J	2.9	475			475
Total		23,759	26,999	15,105	65,863

[1] After Allen and Baldwin, 1944, p. 54.
[2] Stripping coal.
[3] After Duncan, 1953, p. 70.

The Coos Bay field has produced approximately 2.5 million tons of subbituminous *C* coal. Although estimates vary widely there are probably an additional 50 million tons of recoverable coal in the field. Whether any of this coal will be mined depends on many factors. Local energy requirements are presently supplied largely by petroleum products delivered by ships. At some future time natural gas may be provided by extending present pipelines from the Willamette Valley. The discovery of either offshore or upland oil and gas should be considered. All of these factors place the mining of Coos Bay coal under a distinct handicap. The exploitation of the coals for the production of coal tars and other by-products is a possibility but would require moderately heavy capital expenditures.

EDEN RIDGE FIELD

The Eden Ridge field in the extreme southern part of Coos County was first reported on by Mendenhall (1903), followed by Lesher (1914), Campbell and Clark (1916), Daniels (1920), and Wayland (1964). Little exploration was conducted in the area until the middle 1950's when the various seams were intensively drilled. The coal has been classified as bituminous *C*. It it high volatile and does not slack readily. The B.t.u. content per pound averages as high as 11,000. Eden Ridge lies at an elevation of about 3,000 feet above sea level in fairly rugged, forest-clad mountains. The seams are gently dipping and range in thickness from 4 to 8 feet. Due to the steepness of the terrain there would be little coal that could be stripped. Preliminary estimates indicate that there are about 50 million tons in the three seams that have been drilled. A possibility exists that other coal may lie below the lowest known seam. Immediately south of Eden Ridge there are coal exposures in Squaw Basin (Williams, 1914). The correlation of the two coals has been made by Wayland (1964). Only minor exploratory work has been done in Squaw Basin.

Compared to the Coos Bay and Eden Ridge fields, all of the other coals in Oregon are of little economic importance. A review of the Rogue River, Eckley, and John Day Basin areas together with some additional occurrences (Mason and Erwin, 1955) summarizes them as follows:

ROGUE RIVER FIELD

The Rogue River field is located in southwestern Oregon in Jackson County. Coal occurs in a long narrow belt extending south from Evans Creek in the northwestern part of the county to a point about 10 miles south of the Oregon-California State line, a distance of approximately 100 miles.

The coal area has been described by Diller (1909, 1914) and by Winchell (1914). The results of analyses of various coal samples are included in a publication by Yancey and Geer (1940).

The coal of middle to early Eocene age and occurs in sandstones and shales of the Umpqua Formation that have been covered by extensive lava flows. It is a subbituminous *A* or *B* rank and contains a large number of partings and bands of impurities.

Exploration has not been extensive enough to determine the geologic structure of the area, and the fact that the Eocene sedimentary rocks interfinger with lava flows makes it difficult to determine the extent

of the coal beds. Diller (1909, p. 402) noted that at most places in the field the beds dip gently northeastward and that the quality and quantity of the coal increases to the northeast.

There has been prospecting for coal throughout the area, and in many places the coal has been mined for local use. In the northern part of the field, on Evans Creek, beds as much as 8 feet thick have been found, but the coal contains a number of clay and sandstone partings. The coal found in the central part, although of better quality, is generally less than 1 foot thick. The coal found in the southern part is very thin and contains a large percentage of sulfur.

ECKLEY AREA

The Eckley area, which has been described by Diller (1903), includes approximately 20 square miles in southern Coos and northern Curry Counties. The area is located near the Sixes River in a heavily timbered mountainous area, about 45 miles south of the Coos Bay field.

The coal in the area is high volatile *C* bituminous and occurs in rocks of the Arago group of Eocene age. The coal-bearing strata consist of shale and soft sandstone that have a thickness of approximately 50 feet and are exposed only in a few places. Where observed the beds are folded and faulted. The thickness of the coal beds differs greatly from place to place and as a result of folding and faulting the coal occurs locally in irregular masses. The coal contains many layers of carbonaceous shale. Diller (1903, p. 4) has indicated that the best coal crops out along the southern border near the head of the Middle Fork of the Sixes River, and near the mouth of Shasta Costa Creek. There has been no production of coal from this area.

JOHN DAY BASIN AREA

The John Day Basin is in the north-central part of Oregon and includes parts of Grant, Wheeler, Gilliam, Morrow, and Umatilla Counties. Topographically the region is a plateau formed by a series of basalt flows.

Collier (1914) has described the coal-bearing rocks in the area. Bituminous coal, subbituminous coal, and some lignite occure in the Mascall formation of Miocene age. Most of the coal is impure, however, and yields low B.t.u. values.

Widely scattered exposures of bituminous coal with large amounts of impurities occur in the Clarno formation of Eocene age from northwestern Wheeler County northeastward to the central part of Morrow County. Some prospecting has been done in southeastern Morrow County, where coal beds have been found at seven different horizons. The coal ranges in thickness from a few inches to about 3 feet. The rocks enclosing the coal beds are composed largely of tuff with interbedded flows of andesite and other igneous material. The rocks have been highly faulted and folded, making it impossible to trace the coal outcrops for any distance.

The coal found near the John Day River in central Wheeler County and in central Morrow County represents the best coal from the Clarno formation. The beds are thin and discontinous, however, and contain a large amount of impurities.

Several outcrops of lignite are found in the Mascall formation near

the John Day River, but these beds also are irregular in thickness and contain so many partings of bone and other impurities that they are of little value.

OTHER COAL-BEARING AREAS

Other small areas of coal-bearing rocks in Oregon have been described, for the most part, in publications by Diller (1896, 1914).

In northwestern Oregon coal has been found in Multnomah, Marion, Clackamas, Lincoln, Columbia, Yamhill, Clatsop, and Tillamook Counties. The coal in these counties is subbituminous and occurs in rocks of Oligocene and late Eocene age. The largest area known to contain coal in this part of the State includes about 20 square miles on the upper Nehalem River in Columbia County (Diller, 1896, p. 491). The coal beds are from 1 to 10 feet thick, but the thicker beds consist mostly of carbonaceous shale. Coal has been found in an area of about 10 square miles in the west-central part of Lincoln County, but the thickest bed reported from this area contains only 3 feet of impure coal. Coal also occurs in southern Clatsop County in the lower Nehalem River area, but no bed thicker than 22 inches has been reported.

In southwestern Oregon, near Comstock in the north-central part of Douglas County, thin impure coal beds occur in the Spencer formation of late Eocene age. Small outcrops of subbituminous coal are also found in the Lookingglass and Camas Valley districts, and on Little River, all in Douglas County (pl. 1).

A small amount of lignite occurs in the northeastern part of Malheur County in the eastern part of the State.

Little is known about the coal deposits in any of these areas because the exposures and prospecting have not revealed coal that is promising enough to encourage commercial development.

Oil Shale

(By V. C. Newton, Jr., Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

Oil shale is a fine-grained sediment having a high percentage of macerated organic debris, chiefly remains of plants (algae, spores, pollen, resin, and waxes) and lower order water animals. It is termed "oil shale" because the rock contains kerogen, a mineraloid or solid hydrocarbon. Oil is not produced until the shale is heated above 350° C., and for this reason the material is referred to as a pyrobitumen. Kerogen is believed to form as residual resin set free by oxidation and decay of vegetal matter. It occurs as yellow to brownish yellow spheroids and as irregular reddish yellow, dark brown, and black irregular streaks in the shale. Shales with high content of kerogen break with a conchoidal fracture (Levorsen, 1954; Steuart, 1912). Kerogen shales are very similar to and grade imperceptibily into cannel coals. Cannel coals are made up of spores, pollen grains, and comminuted remains of lower order plants and animals. Shale oil resembles petroleum in that it is composed of hydrocarbons with small amounts of sulfur, nitrogen, and oxygen derivatives from hydrocarbons. However, shale oil differs from petroleum in its content of larger amounts of nonhydrocarbons, particularly nitrogen and oxygen compounds (Hellwig and others, 1967).

Rock is considered an oil shale when it has a yield between 10 and

100 gallons of oil per ton. Low grade is considered to be less than 10 gallons per ton; marginal grade between 10 and 25 gallons per ton; and high grade over 25 gallons per ton. The average Rocky Mountain oil shale yields 26.7 gallons of oil per ton of shale. The oil content of high-grade oil shales in the Green River Formation of Utah, Colorado, and Wyoming is estimated at 80 billion barrels; total resources in this deposit are 2 trillion barrels (Spragins, 1967). This forms the bulk of United States oil shale resources. The United States has 42 percent of the world oil shale reserves (Duncan, and Swanson, 1965). These high-grade deposits are found in Tertiary (Eocene) lacustrine deposits. Large deposits of low- and marginal-grade organic marine shale occur in the Upper Devonian and Lower Mississippian of the eastern United States and in the Mesozoic marine shales of northern Alaska (Oil and Gas Journal, Jan. 17, 1966, p. 41).

OREGON DEPOSITS

Thus far only one small deposit of oil shale is known in Oregon; this is the Shale City deposit in sec. 16, T. 38 S., R. 2 E., Jackson County. It is a good commercial-grade shale testing 36 gallons per ton (see table 25). The Shale City deposit was retorted in two or three commercial ventures in the 1920's, but none of these attempts were able to show a profit. Sulfur encrustations on the shale are presently being collected and are sold for medicinal purposes. The Oregon Department of Geology and Mineral Industries has investigated the property on three occasions and estimates the shale body to contain 150,000 tons of high-grade shale.[16] The shale occurs in a white, fine-grained rhyolitic tuff which is part of the Oligocene and Miocene volcanics of the Western Cascades. The shales probably represent lacustrine sediments deposited in the interlude between volcanic eruptions. The thickest shale member is 3 to 4 feet thick and is interbedded with tuffaceous sandstone. Many other thinner shale layers occur in the 30-foot section exposed in a pit on the property.

The shale parts into thin plates and occurs in two colors, dark

TABLE 25.—KEROGEN CONTENT OF OREGON SHALES[1]

Formation	Location	Weight percent			Gas +loss (percent)	Specific gravity of oil	Gallons per ton	
		Oil	Water	Spent shale			Oil	Water
Astoria	N½ sec. 9, T. 8 N., R. 9 W., Clatsop County.	0	11.3	87.3	1.4	----------	Trace	27.1
Nye	Sec. 9, T. 11 S., R. 11 W., Lincoln County.	0	12.5	86.1	1.4	----------	Trace	29.8
Yaquina	E½ sec. 15, T. 11 S., R. 11 W., Lincoln County.	0	11.7	87.2	1.1	----------	Trace	28.1
Oligocene[2]	SE¼ sec. 9, T. 38 S., R. 2 E., Jackson County.	13.8	7.0	76.0	3.2	0.904	36.6	16.8
Elkton Siltstone Member of Tyee (shale unit).	SE¼ sec. 24, T. 28 S., R. 7 W., Douglas County.	.2	4.5	94.2	1.1	----------	.5	10.9
Goshen beds	SE¼ sec. 14, T. 18 S., R. 3 W., Lane County.	0	5.3	94.7	0	----------	0	12.6

[1] U.S. Bureau of Mines Laboratory, Laramie Petroleum Research Center; assays of air-dried samples by the modified Fischer retort method, 1965–67.
[2] X-ray diffraction studies showed a relatively large amount of cristobalite, some quartz, montmorillonite, and pyrite.

[16] State of Oregon Department of Geology and Mineral Industries unpublished reports:
Thommes, N. P., and Treasher, R. C., 1943.
Dole, H. M., and White, D. J., 1950.
Peterson, N. V., and Newton, V. C., 1966.

mahogany brown and dull black. When struck with a hammer it gives off a sulfury bituminous odor. The mahogany-colored shale weathers to a whitish brown on the exposed surfaces and exhibits penecontemporaneous folding.

Testing of organic shales in Oregon thus far has not uncovered any other kerogen shales of even marginal quality. Washburne (1914 p. 53) reported that, "The Astoria shale at many places will yield minute traces of oil by distillation. . .", but recent tests show only a trace of kerogen in samples tested (see table 25). Dark carbonaceous shale of the Elkton Siltstone Member of the Tyee Formation (Baldwin, 1961) was tested for kerogen content and found to contain 0.5 gallons per ton. Plant-bearing black carbonaceous shale of the Goshen beds near Eugene was also tested, as the depositional history of these beds appeared to be that which would produce kerogen. The Goshen samples showed no trace of pyrobitumens.

Recent hydrogenation studies related to retorting kerogen shales indicate recoveries 120 to 125 percent greater than retorting in air (i.e., 37.1 gallons per ton versus 30 gallons per ton) (Schlinger and Jesse, 1967). Sophistication of refining methods may ultimately make use of all the hydrocarbon in the shales.

Carbonization tests on coals have yielded liquid hydrocarbons in amounts equalling the range of marginal grade of oil shales and offer prospects for low-grade petroleum reserves.

YIELDS FROM CARBONIZATION TESTS ON COALS[1,2]

[In gallons per ton]

	Tar and oil	Neutral oil
Coal (average)	16	5
Coal (high)	27	11
Oregon coal	17	11

[1] Walters and others, 1967.
[2] Chemical & Engineering News, June 12, 1967, p. 96.

The U.S. Office of Coal Research has contracted several pilot projects which are now under way to investigate the recovery of liquid hydrocarbons from coals by multistage heating and hydrogenation. Several available processes produce synthetic gas at a price comparable to that of natural gas. Gasoline can also be produced from coal and within the next 5 or 10 years will very likely compete with liquid fossil fuels (Cochran and Staber, 1967). Subbituminous coals in the Coos Bay area have yielded as much as 28 gallons per ton of liquid hydrocarbons in low-temperature carbonization tests (450° to 700° C.). These coals should give good yields with the hydrogenation process (Allen and Baldwin, 1944). Further investigations of the carbonaceous shales in Oregon will doubtless be made but the prospect of finding significant oil shale deposits in the State is remote.

Petroleum and Natural Gas

(By H. C. Wagner, U.S. Geological Survey, Menlo Park, Calif., and V. C. Newton, Jr., Oregon Department of Geology and Mineral Industries, Portland, Oreg.)

More than 35 million barrels of crude oil and refined petroleum products (exclusive of road materials) are used in Oregon each year,

and of these products, gasoline, gas-oil, distillate fuel oil, and residual fuel oil amount to more than 5 million short tons (Newton, 1965). These materials must presently be brought into the State by freighters and pipelines at considerable cost to suppliers as well as to consumers. These factors have been responsible in part for providing the incentive to many wildcatters and major oil companies in their attempts to discover producible oil deposits in Oregon. The economy of the State would be bolstered in many ways if petroleum was found within its boundaries in sufficient quantities to supply these needs.

Roughly one-fifth of the State of Oregon contains sedimentary rocks that satisfy one or more of the following geologic characteristics that are associated with the accumulation of commerical quantities of petroleum and natural gas:

(1) An adequate source of petroleum-generating material in the form of abundant marine (and occasionally nonmarine) animal and plant life.

(2) The presence of reservoir rocks in which important amounts of oil and gas can accumulate and from which they can be made to flow to wells for production at satisfactory rates.

(3) Suitable structural or stratigraphic traps that provide a means of localizing and entrapping the oil or gas in the reservoir rocks. Whether these three characteristics are to be found in a combination that will provide commerical production of petroleum in Oregon has yet to be determined.

There are numerous indications of the presence of petroleum in Oregon. Geodes, vesicles, and crevices containing crude oil occur at the surface in the central and western parts of the State, and shows of oil or gas have been reported in more than 50 of the 183 exploratory wells that have been drilled in Oregon and adjacent offshore areas. Unfortunately, none of these indications has proved to be commercial, and few of the reported oil shows in test wells could be verified. The exploratory efforts have not, however, been fruitless since the drilling of these wells has provided much-needed geologic data on subsurface stratigraphy and structure. This geologic information has been supplemented by data gained from drilling about 50 coreholes, and from several hundred stratigraphic holes put down to furnish near-surface geological information. The total of this information provides a sounder basis for selecting drilling sites in future oil exploration.

Of the wells drilled to sufficient depth to be classed as definitive tests, about 35 were drilled deeper than 5,000 feet, and 6 exceeded 10,000 feet. Five of these deep tests penetrated through the thick Cenozoic sedimentary and volcanic section into rocks of Mesozoic or older age, and an additional 5 drilled a thousand or more feet into lower to middle Eocene volcanic rocks prior to abandonment. Relatively few of the wells were drilled on well defined geologic structures.

The earliest recorded drilling activities that resulted in initiating the search for oil and gas in Oregon occurred in 1902 in two widely separated parts of the State. In that year A. C. Churchill and Associates drilled two wells near the town of Newberg in Yamhill County, western Oregon, from which they succeeded in obtaining a small flow of nonflammable gas. Also in 1902 A.F. Boyer, in drilling a water well near Ontario in Malheur County, eastern Oregon, ob-

tained sufficient flammable gas to supply lighting jets and a cooking range for more than 7 years (Stewart and Newton, 1965). In 1903 some gas and a trace of oil were reported from a well drilled near Dallas in Polk County, and by 1910 at least 40 holes had been drilled in Malheur, Polk, Harney, Tillamook, and Wasco Counties. Although small quantities of high-methane gas were encountered in many of the wells, the flow was of low volume and pressure. Drilling activity continued slowly for about 45 years, only a few wells being drilled each year, until 1955. Since 1955 more than 60 wells have been drilled, and whereas most of the wells in the early period were indiscriminately located and were too shallow to be definitive tests, the majority of those since 1955 were drilled to considerable depth and many were drilled on sound geologic bases.

The deepest exploratory well in the State, the SINCLAIR Federal-Mapleton well in Lane County, was drilled in 1955 to a total depth of 12,880 feet. A positive hydrocarbon cut and black tarry oil were reported. Another deep test, the HUMBLE Thomas Creek well in Lake County, was spudded in 1960 and was drilled 12,093 feet, entirely in Tertiary volcanics and continental sediments, before abandonment. Two offshore wells also were drilled to depths greater than 12,000 feet. The STANDARD-UNION Nautilus in the Siletz Block was taken to a total depth of 12,625 feet, and the UNION Fulmar in the Florence Block went to 12,285 feet. No shows were reported. The LINN Co. DEV. Barr well, which was drilled to 4,529 feet in Linn County, reportedly had the most favorable oil show of any recent well in Oregon, but an attempt to complete the well as a producer was unsuccessful.

In addition to data gained from exploratory drilling, many surface geologic studies have been undertaken by governmental agencies to evaluate the petroleum resources of Oregon. As early as 1911, the U.S. Geological Survey began to study Oregon's oil and gas prospects (Washburne, 1911a, 1911b, 1914). Between 1945 and 1955 the U.S. Geological Survey conducted extensive reconnaissance and detailed geologic mapping in the Tertiary marine rocks of western Oregon and published a series of reports on its findings (Warren, Norbisrath, and Grivetti, 1945; Snavely and Vokes, 1949; Vokes, Norbisrath, and Snavely, 1949; Vokes, Snavely, and Myers, 1951; Baldwin and Roberts, 1952; Vokes, Myers, and Hoover, 1954; Baldwin, 1955; Baldwin and others, 1955). Later, the results of paleogeologic research and details of aeromagnetic and gravity surveys were published (Snavely and Wagner, 1963; Bromery and Snavely, 1964; Bromery, 1965). Snavely and Wagner (1964) summarized the geology of northwestern Oregon, and Snavely, Wagner, and MacLeod (1965) reported on the compositional variations in basaltic rocks in western Oregon. To date the U.S. Geological Survey has published 9 oil and gas maps, 2 bulletins, and 5 special study reports relating to the petroleum geology of Oregon.

The Oregon Department of Geology and Mineral Industries and its earlier counterpart, the Oregon Bureau of Mines and Geology, have published 3 bulletins, 4 miscellaneous papers, and 2 volumes of micropaleontological correlations to assist in the exploration for oil and gas. In 1920 the Oregon Bureau of Mines and Geology contracted a consulting firm to investigate the petroleum prospects of western

Oregon and published a report on this investigation in one of its bulletins (Harrison and Eaton, 1920). A similar investigation was undertaken the following year by J. P. Buwalda in eastern Oregon (Buwalda, 1921). In 1954 the Oregon Department of Geology and Mineral Industries assembled and made available all known records of oil and gas tests as well as references to oil and gas indications throughout the State (Stewart, 1954). This report has subsequently been twice updated and revised (Newton, 1960; Stewart and Newton, 1965). The Department also published results of studies of the Western Snake River Basin (Newton and Corcoran, 1963) and issued gravity and magnetic maps of parts of the State in 1966 and 1967 (Emilia, Berg, and Bales, 1966; Berg and Thiruvathukal, 1967a, b, c; Dehlinger and others, 1967) in cooperation with the Oceanography Department of Oregon State University. The Department also has published in its monthly bulletin, The Ore Bin, articles related to the geomorphology of the continental shelf region adjoining the State (Byrne, 1962) and data concerning oil and gas investigations (Newton, 1965, 1967). Detailed geologic mapping investigations of the pre-Tertiary marine inlier in central Oregon were undertaken by Dickinson and Vigrass (1965) and Buddenhagen (1967) with the intent of making available a good geologic base from which petroleum exploration companies could launch specific investigations in that area.

In order to discuss the petroleum possibilities of the State, four general areas characterized by rocks of different geologic origin or age have been delimited as shown on figure 70. These four areas are the Tertiary marine area, Tertiary nonmarine area, Paleozoic-Mesozoic area, and Cenozoic lava area. Figure 70 also shows the locations of wells drilled for oil and gas between 1900 and 1967 (locations taken mainly from Stewart and Newton, 1965). In the descriptions of these areas the writers have drawn heavily upon published reports, and upon data gained through discussions with colleagues.

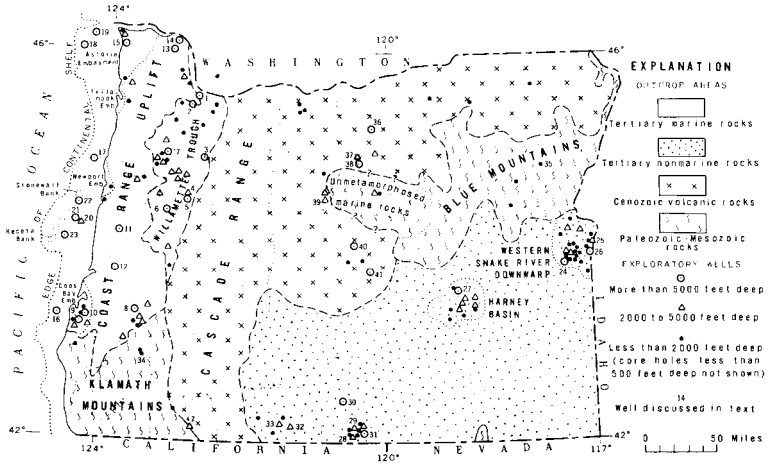

FIGURE 70.—Outcrop areas of major rock types and locations of exploratory wells.

TERTIARY MARINE AREA

The Tertiary marine area includes all of western Oregon west of the Cascade Range and north of the Klamath Mountains. Within this area of about 15,000 square miles more than 25,000 feet of marine sedimentary rocks of Tertiary age have accumulated. The area has many similiarities to oil-producing areas of southern California in that both have (1) deep structural basins in which thick sequences of Tertiary marine strata accumulated, (2) wide belts of intertonguing nearshore and offshore marine and continental sediments, (3) locally thick sand units that formed along the shorelines of ancient seas, and (4) linear structural belts containing folds and faults that could have formed traps for the retention of petroleum. Major differences between the two areas are: (1) the lower Tertiary sedimentary sequence of Oregon contains a much greater amount of volcanic material, and (2) many oil seeps, tar pits, bituminous sandstone deposits and other significant surface indications of the presence of oil are found in southern California but very few in Oregon. At the present time the only recorded surface indications of oil in the Tertiary marine area of western Oregon consist of (1) the organic-rich shales near Newport, Lincoln County, that give off a petroliferous odor when freshly broken, and (2) the free oil reported in vesicles and cracks in Eocene basalt near Florence, Lane County (Harrison and Eaton, 1920; Stewart and Newton, 1965).

The Tertiary marine area in Oregon is subdivided geologically into the Willamette trough, the Coast Range uplift (including the coastal embayments at Coos Bay, Newport, Tillamook, and Astoria), and the continental shelf.

Willamette trough

The Willamette trough comprises one of the more attractive areas for petroleum exploration in Oregon. It includes an area of more than 3,000 square miles which extends from the Columbia River on the north to the junction of the Cascade and Coast Ranges on the south. The Willamette trough has been a separate structurally active downwarp since Oligocene time but prior to that was the eastern fringe of the lower Tertiary eugeosyncline (Snavely and Wagner, 1963).

Geology.—Basement rocks of pre-Tertiary age have not been found at the surface in the Willamette trough nor have they been encountered in test drilling for oil and gas. The oldest rocks known in the region are a series of basaltic submarine lava flows and breccias of early to middle Eocene age. The thickness of this volcanic pile probably exceeds 20,000 feet in the northern part of the trough (Bromery and Snavely (1964), and because of its great thickness and character the unit serves as an effective basement rock to petroleum exploration. It also forms the surface onto which as much as 25,000 feet of sedimentary rocks were deposited in the central part of the trough (Snavely and Wagner, 1964). A large part of this stratigraphic thickness is made up of marine shales and sandstones of Eocene, Oligocene, and Miocene ages. The upper Eocene sedimentary rocks locally have good porosity and permeability (Schlicker, 1962). Near the southern and eastern borders of the downwarp, marine sediments of late Eocene age intertongue locally with continental sedimentary and volcanic rocks, and

stratigraphic traps may be present in the area of intertonguing. In the center of the basin tuffaceous marine sediments, which could possibly be source beds or reservoir rocks, form the major part of the sequence. In the part of the downwarp south of Eugene approximately 5,000 feet of middle Eocene sandstone and siltstone underlies more than 10,000 feet of upper Eocene and Oligocene marine sandstones and shales. The Oligocene sediments intertongue southward with about 7,000 feet of andesitic fragmental volcanic debris (Vokes and others, 1951). Eastward the boundary of marine Oligocene deposition roughly parallels the low foothills of the Cascade Range where marine strata intertongue with continental deposits consisting of dacitic and andesitic tuff, and volcanic breccia and lava flows of andesitic and basaltic composition (Peck and others, 1964). Shoreline sandstone deposits in the marine sequence indicate that the shoreline fluctuated across a distance of 15 miles or more (Vokes and others, 1951). Intertonguing marine sediments and non-marine volcanic and sedimentary rocks occur along most of the eastern margin of the downwarp, but in much of that area the shoreline is covered by lava flows and sediments of Miocene age.

Volcanoes in the Cascade Range were active throughout most of Eocene, Oligocene, and Miocene time, and volcanic ash was supplied in large quantities to the marine environment, thus forming a considerable thickness of ashy clay. The organic material in these marine clays was considerably diluted by the great quantity of ash carried in by stream and wind action. The ash also filled the interstices between sand grains, thus reducing the porosity and permeability of the sandstone deposits. Only along the shorelines of the sea, where the winnowing action of the waves could remove this ashy filling, were clean sands deposited. Much of the Oligocene shoreline area now lies beneath volcanic rocks along the western edge of the Cascade Range, and the existence and location of the belt of permeable sandstone can be determined only by drilling. In the northern and central parts of the Willamette downwarp, where organic-rich marine shales are thickest, a few hundred to nearly two thousand feet of Pliocene and Pleistocene nonmarine sediments overlie the marine Tertiary deposits. In most places the younger rocks effectively obscure any structural complications in the older rocks that might be of interest to petroleum geologists.

Subsurface exploration.—Exploratory wells have tested these Tertiary marine strata along both the western and eastern margins of the Willamette trough and near the center of its southern half. In the northwestern part of the trough, in Multnomah County, the RICHFIELD Barber well (1)[17] tested a large anticlinal structure, the Portland Hills anticline, to a depth of 7,885 feet. The well was spudded in middle Miocene basalt and penetrated Oligocene marine sandstones and shales at 865 feet. Upper Eocene sedimentary and volcanic rocks were entered at 2,055 feet, and volcanic agglomerates and related lava flows and breccias were drilled from about 3,070 to 7,885 feet. No significant oil or gas shows were reported. About 10 miles to the southwest the TEXAS Co. Redding-Gasnor well (2), in Washington County, was drilled to

[17] Number in parentheses identifies well shown on figure 70.

a total depth of 9,263 feet in a test of the Cooper Mountain anticline. This well also was spudded in middle Miocene basalt, went into Oligocene marien sediments at 1,039 feet, and was in fossiliferous sandstones and shales, with occasional thin beds of coal, to 2,840 feet at which depth basaltic agglomerates and breccias as well as shales, sandstones, and thin conglomerates of late Eocene age were encountered. These upper Eocene rocks were drilled from 2,840 to 4,270 feet where basaltic sandstones and conglomerates of early late Eocene age were cut. At 9,206 feet agglomerates and flows of early to middle Eocene age were drilled. The well flowed 700 barrels per day (B/D) of salt water during a formation test at 7,862 to 9,263 feet, and small gas shows were reported at 8,694 and 8,830 feet. The well was plugged and abandoned at 9,263 feet.

Along the eastern flank of the Willamette trough, several deep wells have been drilled presumably to test the possible productivity of nearshore sands, fault traps, and folds in the area. In Marion County, the HUMBLE Wicks well (3) was spudded in upper Oligocene to lower Miocene marine beds that show beneath the middle Miocene basalt flows. Upper Eocene marine sediments were encountered at about 1,500 feet and Eocene basalts were entered at 2,130 feet. The well was drilled to a total depth of 7,797 feet in these basaltic rocks without encountering any shows of oil or gas. In Linn County, the LINN Co. DEV. Barr well (4), which was drilled to 4.529 feet, had possibly the best oil show of any recent well in Oregon. The well had a gas show at 2,250 feet in a sandstone bed within middle Oligocene(?) nonmarine pyroclastic rocks, and a strong oil show at 4,300 feet in a 20-foot section of sandstone near the top of the upper Eocene marine sandstone and shale section. However, an attempt to complete the well as a producer failed. About 3 miles southeast of this well the RESERVE OIL & GAS Co. drilled their Esmond well (5) to a total depth of 8,603 feet. The Esmond well was spudded in Oligocene to Miocene pyroclastic rocks, drilled Oligocene marine sandstones and shales from 2,660 to 3,960 feet, and was in lower Oligocene and upper Eocene volcaniclastic rocks and lavas from 3,960 feet to the bottom. A 2,000 B/D flow of very gassy salt water was obtained on a formation test at 7,055 feet; the gas contained 77 percent methane, 4 percent ethane, and 17 percent nitrogen (Stewart and Newton, 1965). Another significant deep test in Linn County was the GULF Porter well (6) which was drilled near the center of the Willamette trough in its southern part to a total depth of 8,470 feet. The well drilled through about 7,000 feet of Eocene and Oligocene marine sedimentary and volcanic rocks before entering lower Eocene basalt at 7,085 feet. A show of gas that was 98 percent nitrogen was encountered at 3,811 feet (Stewart and Newton, 1965) and a strong show of methane gas occurred at 5,080 feet.

The west flank of the Willamette trough was also tested in Polk County by the RESERVE Roy-L&G-Bruer well (7), which penetrated 4,500 feet of middle Eocene to lower Oligocene marine sedimentary rocks before encountering lower to middle Eocene volcanic rocks. The well was drilled in these basaltic rocks to a total depth of 5,549 feet. A reported gas show in salt water at 1,540 feet was later retested but failed to provide significant amounts of gas or oil. A second but shallower well, the LEWIS Crossley-Jennings No. 2, was drilled 20 feet

to the south of the Bruer well but it, too, was abandoned as an unsuccessful test.

Coast Range uplift

The mountainous area between the Willamette Valley on the east the Pacific Ocean on the west, the Columbia River on the north, and the Klamath Mountains on the south in effect composes the Oregon Coast Range. The rocks exposed at the surface in the Oregon Coast Range are entirely Tertiary in age and consist mainly of a marine sequence of sandstones, siltstones, mudstones, and volcanic rocks ranging in age from early Eocene to middle Miocene. These rocks are more than 25,000 feet thick, and their geologic history records deep submergence, vigorous submarine volcanism, nearly continuous sedimentation in local embayments, and moderate folding and faulting during periods of uplift (Snavely and Wagner, 1963). As a result of nondeposition and erosion since late Eocene time, essentially no sedimentary rocks younger than middle Eocene remain along the apex of the range. Only in relatively small coastal embayments on the western side of the Coast Range and in the foothills on the eastern side are sedimentary rocks of Oligocene and younger age found.

Geology.—The rocks of the Coast Range uplift are somewhat different in the northern and southern parts. The difference is mainly a function of the degree to which different rock units contribute to the total stratigraphic sequence in the different parts of the range. However, as in the Willamette trough, a lower to middle Eocene group of rocks, made up largely of volcanic flows and breccia and possibly as thick as 20,000 feet near centers of volcanism, forms the basal rock unit throughout the entire Coast Range.

In the southern part of the Oregon Coast Range lower and middle Eocene rocks form an interbedded sequence of marine sedimentary and volcanic rocks more than 20,000 feet thick. The lower part of the sequence is made up of alternating thin siltstones and shales with interbeds of pillow basalt and basalt breccia; the middle part of the sequence is a thick conglomerate-sandstone-siltstone unit; and the upper part consists of rhythmic-bedded micaceous graywackes and carbonaceous siltstones (Baldwin, 1946b). Upper Eocene marine siltstones underlie a large synclinal area between Cottage Grove and Coos Bay (Wells and Peck, 1961), but no rocks younger than late Eocene are found in the southern part of the Coast Range except in the Coos Bay embayment (fig. 70) where Tertiary marine strata as young as Pliocene occur. In the Coos Bay embayment more than 6,000 feet of upper Eocene nearshore marine and nonmarine strata (with coal beds) overlie the lower and middle Eocene rocks and in turn are overlain by about 3,000 feet of thin-bedded marine shale and tuffaceous glauconitic sandstone of latest Eocene and Oligocene age. In places the middle Eocene rhythmic-bedded graywacke unit is missing and nearshore marine and nonmarine coal-bearing strata overlie the lower to middle Eocene pillow-basalt sequence (Allen and Baldwin, 1944; Baldwin, 1966). At Coos Bay about 3,000 feet of massive, poorly bedded sandstone and siltstone of Miocene and Pliocene age form the youngest consolidated marine strata in the southern part of the Oregon Coast Range. Relatively unconsolidated marine terrace deposits

of Pliocene and Pleistocene and Holocene age, overlie the older rocks near the coast.

To the north, between Coos Bay and Newport, a thick accumulation of basalt flows and breccia occurs within a tuffaceous siltstone unit of late Eocene age. Bouguer gravity contours on this accumulation indicate that the volcanic build-up extends seaward onto the continental shelf (Bromery and Snavely, 1964). Farther north in the Newport embayment (fig. 70) upper Eocene siltstones and overlying Oligocene tuffaceous siltstones and shallow-water sandstones and Miocene organic-rich mudstones, basaltic sandstones, and tuffaceous siltstones total as much as 10,000 feet in thickness (Snavely and Vokes, 1949; Snavely and Wagner, 1964). The upper part of the Oligocene sediments consists of an arkosic sandstone unit about 2,500 feet thick that locally has good porosity and permeability (Snavely, P. D., Jr., personal commun., 1961); the organic-rich mudstone in the lower part of the Miocene strata is about 3,500 feet thick and has a petroliferous odor when freshly broken. Such strata as these are of particular interest to the petroleum geologist as possible reservoir rocks and source beds for petroleum. Basalt flows 200 or more feet thick are interbedded in the Miocene sandstone and siltstone strata, and sills of dark-colored gabbro and light-colored syenite intrude the Tertiary sequence in bodies 400 to 500 feet in average thickness (Snavely and Vokes, 1949).

In the northern part of the Coast Range late Eocene volcanism supplied basaltic flows, breccias, and tuffaceous sediments to the marine environment. These volcanic and sedimentary rocks, together with similar rocks of early to middle Eocene age, underlie about one-half of the northern part of the Oregon Coast Range and reach an aggregate thickness in excess of 10,000 feet. Marine upper Eocene and Oligocene strata overlie the lower to middle Eocene rocks in an arcuate belt that extends from the southern part of the Tillamook embayment (fig. 70) northward and eastward around the older rocks to the eastern flank of the Coast Range uplift. These upper Eocene sedimentary rocks consist mainly of basaltic, glauconitic, and quartzose sandstones and tuffaceous siltstones 2,500 or more feet thick and are overlain by relatively shallow-water siltstones and sandstones of Miocene age (Warren and others, 1945). The overlying marine Miocene strata, which are about 1,000 feet thick, intertongue in places with basaltic submarine lava flows 500 or more feet in thickness. Some of these Miocene basaltic flows were extruded from local centers near the present Oregon Coast, but others are part of the extensive flood basalts that were extruded in eastern Oregon and flowed westward to the sea through a broad lowland area that includes the present site of the Columbia River (Snavely and Wagner, 1963). In the Astoria embayment area a thick sequence of fluvial pebble to cobble conglomerates, micaceous sandstones, and clayey siltstones of Pliocene age overlies the Miocene sandstones, siltstones, and basalts.

Subsurface exploration.—Exploration drilling for petroleum in the Oregon Coast Range has thus far been unsuccessful despite the testing of many thousands of feet of marine sediments and several prominent geologic structures.

Approximately 30 wells have tested the Coast Range area itself, and an additional 8 wells have been drilled in offshore areas of the con-

tinental shelf. More than one-half of the 30 wells were drilled in the southern part of the Coast Range in the Roseburg and Coos Bay areas where the deepest test, the UNION Liles well (8), in the southeast part of the range, was drilled through lower Eocene carbonaceous marine shales to a total depth of 7,002 feet. The strata in the well were reported to be badly fractured and faulted and to be dipping steeply. On the west side of the range near Coos Bay two deep wells were drilled. The WARREN Coos County well (9) was spudded in upper Eocene marine strata near the axis of a broad anticline near Coos Bay. Traces of gas and oil and a considerable amount of coal were reported in the well which reached a total depth of 6,337 feet. About 4 miles southwest, the PHILLIPS Dobbyns well (10) was spudded on the same structure in upper Eocene marine sedimentary rocks. Lower Eocene volcanics were encountered at 2,330 feet, and more than 4,500 feet of predominantly volcanic rocks were drilled before reaching the total depth of 6,941 feet. No oil or gas shows were reported but a possible gas zone was encountered at 1,050 feet.

The deepest test well in the State was drilled in the Coast Range in Lane County. This well, the SINCLAIR Federal-Mapleton (11), was spudded in middle Eocene marine sandstones and siltstones, reached lower Eocene shales at 2,700 feet, and reported traces of oil at 5,310 feet. The lower Eocene volcanic sequence was encountered at 6,660 feet, and more than 6,000 feet of these volcanics were penetrated before the well was abandoned at 12,880 feet. The other significant deep test in the central part of the Coast Range, the GEN. PET. Long Bell well (12), was drilled about 25 miles farther south in Douglas County. It was spudded in the middle Eocene sandstone-siltstone sequence about 1½ miles east of the axis of a major north-plunging anticline and bottomed in lower Eocene volcanics at 9,004 feet. A slight gas show was reported at 5,345 feet and traces of oil were noted at 5,590 and 6,050 feet.

Three significant deep test wells were drilled in the northern part of the Coast Range. They were spudded a few miles south of the Columbia River in Clatsop and Columbia Counties. The TEXAS COMPANY drilled two wells in northern Columbia County, their Clark and Wilson well (13) with a total depth of 8,501 feet and their Benson-Clark and Wilson well indicated that the stratigraphic section was predominantly marine sedimentary rocks of middle and late Eocene age, with minor amounts of intercalated basalt. Formation tests were made between 3,000 and 3,300 feet and one interval was reported to have had wet gas, but in insufficient quantity to be producible. The Benson-Clatskanie well apparently drilled through more than 5,000 feet of marine Oligocene and Eocene sedimentary rocks before abandonment in Eocene basalt and basaltic breccia. An oily odor was reported in volcanic breccia at 730–760 feet, and a trace of oil and gas was recorded from core at 1,391–1,401 feet (Stewart and Newton, 1965). In Clatsop County the STANDARD Hoagland well (15) was spudded in upper Eocene to lower Oligocene marine sedimentary rocks; it entered lower to middle Eocene volcanic rocks at about 5,000 feet, and was abandoned at 7,101 feet. Several fluorescent spots were reported on fracture surfaces in a core at 5,465–5,470 feet.

Continental shelf

The continental shelf is generally defined as the gently sloping surface of the sea bottom from the shoreline of the coast to a depth

of 200 meters (656 feet). The continental shelf along the Oregon coast differs somewhat from the average as its outer edge occurs at a depth of 80 to 100 fathoms (480 to 600 feet). The shelf along Oregon is 9 to 40 miles wide and slopes seaward at 0°08′ to 0°43′ (Byrne, 1962). This seaward inclination represents a range from 1.2 to 66 feet per mile and is steeper than the average slope of 0°07′ (1.1 feet per mile) for continental shelves around the world (Shepard, 1948). Two prominent north- to northeast-trending shoals, Heceta Bank and Stonewall Bank (fig. 70) occur on the continental shelf off Oregon approximately midway between the Columbia River and the Klamath Mountains.

Geology.—The continental shelf represents the submerged border of the continent, and in many places the geology of the coastal area can be projected onto the adjacent submarine area with considerable success. In petroleum exploration, the deeper parts of the continental shelf beyond the limit to which onshore geology can be projected, although more difficult and more expensive to map and test, have elsewhere proven to be well worth the added effort and cost of the venture. The continental shelf off Oregon in places has attributes that make it in some ways more attractive to the petroleum geologist than the continental area. For example, (1) the onshore upper Tertiary marine sequence thickens seaward, (2) the thick volcanic units that overlie or interlaminate the marine sediments thin seaward, and (3) the lower Miocene organic-rich mudstone unit that is a possible source bed for petroleum dips westward and would underlie reservoir rocks consisting of Miocene or Pliocene sandstones in offshore areas. It should be noted that significant bodies of Miocene or Pliocene sandstone are not necessarily expectable in areas off the Oregon Coast since shale generally becomes the dominant rock type toward the deeper parts of depositional basins. However, sand deposition could have occurred adjacent to structural highs in offshore areas.

In addition to source beds and reservoir rocks, a third basic requirement in the continental shelf area off Oregon must be fulfilled before oil is found; namely a satisfactory structural trap into which any oil present might migrate and be retained. Topographic highs of the sea bottom in this area, such as Heceta and Stonewall Banks, may reflect anticlinal or domal structures. The possibility that these banks reflect such structures probably provided the encouragement that led the oil industry to engage in the use of seismic and underwater sampling devices for determining subsea structure and stratigraphy through several hundred feet of water. Initial work was undertaken in the area of the Stonewall and Heceta Banks, an area from which marine Pliocene siltstone had already been obtained by dredging (P. D. Snavely, Jr., personal commun., 1960; Byrne, 1962). The work was later extended to cover practically the entire Oregon continental shelf from Coos Bay to the Columbia River.

Subsurface exploration.—More than 30 million dollars was spent in 1964 in leasing the drilling rights on large tracts of offshore lands off the Oregon Coast (Newton and Newhouse, 1964). This plus the cost of seismic surveys and sampling effort and the drilling of seven exploratory wells, resulted in a total expenditure of more than 50 million dollars between 1959 and 1966 (Newton, 1967). In addition to the seven wells drilled in 1965 and 1966 an eighth hole, the PAN AM

Coos Bay well (16) was drilled in 1967 in the Cape Arago Block. The well was spudded in 352 feet of water, and at a total depth of 6,146 feet presumably reached pre-Tertiary rocks. Shows were reportedly tested and found to be uneconomic. The deepest test, the STANDARD-UNION Nautilus well (17), was drilled to a total depth of 12,625 feet in 1965. It was drilled in 425 feet of water in the Siletz Block. Reports indicate that the well had not yet reached the lower to middle Eocene volcanics at its bottom. Four wells were drilled by SHELL, two in the Seaside Block in 1966 (18, 19) with total depths of 8,219 and 10,160 feet, and two in the Florence Block, Heceta Head area, in 1965 (20, 21) with total depths of 3,348 and 8,353 feet. Shows were reportedly tested and found to be uneconomic in one of the SHELL wells (18). STANDARD-UNION-PLAN AM drilled a well to 10,010 feet in 1965–66 (22) in the Stonewall Bank area; and UNION drilled their Fulmar well (23), a 12,285 foot test, in the Florence Block, Heceta Head area in 1966. The deepest water depth in which drilling was done was 470 feet, in the Seaside area by SHELL. The three wells drilled in the Heceta Head area were presumably testing structures located by seismic and acoustical profiling methods on the broad extension of the shelf off Heceta Head. The wells were located about 10 miles east of Heceta Bank, a prominent belt of topographic highs near the outer edge of the Continental Shelf. Sands were reported to be lacking in the holes drilled to date, and shows were reportedly found in only two of these eight test holes.

TERTIARY NONMARINE AREA

Approximately the southeastern one-third of Oregon is underlain by a complexly interfingering series of nonmarine sedimentary and volcanic rocks of late Tertiary and Quaternary age. In most parts of the area sedimentary rocks predominate; in the rest, volcanic rocks are most abundant. Within this region are several downfolded basins and downdropped blocks in which considerable thicknesses of sedimentary and volcanic rocks have accumulated. Deposits of this type fall into the second of the two general categories of continental sediments of Tertiary age defined on the basis of depositional environments (Felts, 1954). The first category comprises suites of sediments deposited in large lakes which in their later histories become saline; the second includes basin fills of stream, marsh, and fresh-water lake beds associated with varying amounts of extrusive volcanics. To sediments of the first type are attributed many of the properties of marine strata. They commonly contain pyrobituminous shales and dolomites, petroliferous shales and limestones, tar sands, and various semisolid or solid bitumens. Oil and gas production has come from such beds and closely associated strata. Sediments of the second type commonly are either lacking in hydrocarbons or contain methane gas which can generally be shown to be entrapped emanations from intercalated lignitic beds or other swamp deposits. Oil production from these beds cannot generally be expected; however, sediments of this type cannot be entirely ignored as potential dry gas producers.

Two large structural basins, the Western Snake River downwarp and the Harney Basin, have been seriously prospected for oil and gas

in the northeastern part of the Tertiary nonmarine area (fig. 70). Many of the test wells in these basinal areas have been drilled to depths greater than 4,000 feet. Several other deep exploratory wells have been drilled in the Tertiary nonmarine area in its southwestern part within the Basin and Range physiographic province. Each of these areas will be discussed separately.

Western Snake River downwarp

The Snake River downwarp, which covers a large area in southern Idaho, extends a short distance into eastern Oregon. The Oregon part of this downwarp is bounded on the north by the Blue Mountains pre-Tertiary rocks and on the west and south by flows of Tertiary lava.

Geology.—Middle Miocene to upper Pliocene nonmarine sedimentary rocks, consisting mainly of tuffaceous shales, sandstones, and conglomerates with intercalated silicic and basaltic lavas, fill the major portion of the western part of the Snake River downwarp. The thickness of these Tertiary rocks in the Oregon part of the downwarp is at least 10,000 feet (Newton and Corcoran, 1963) and may be as great as 15,000 feet. Surface indications of oil occur in the southern part of this region at Sand Hollow, where hard, fresh-water sandstone has a petroliferous odor on freshly broken surfaces.

Subsurface exploration.—A preponderance of the thirty wells drilled in this area had shows of gas, and some of the early tests provided gas for family use for many years. In some wells the gas averages more than 95 percent methane. Although small shows of oil have been reported in some wells, no important showing has been verified. Neither gas abundance nor pressure seems to be related to anticlinal structures (Kirkham, 1935).

Of the seven wells drilled deeper than 4,000 feet in the Western Snake River downwarp the deepest was the El Paso Nat. Gas Federal-Spurrier well (24) which went to a depth of 7,470 feet. The well was spudded in Pliocene and Pleistocene lacustrine sediments and intercalated lavas, and entered upper Miocene lacustrine and subaerial sandstone and conglomerate at 4,440 feet. A few small gas shows were reported in this test well, as is the case in most of the other deep exploratory wells. The most spectacular test with significant gas shows was the Ontario Coop. Oil & Gas Co. well (25) near Ontario, Malheur County, that blew mud and water over the derrick crown while drilling at 1,070 and 2,200 feet. The well reached a total depth of 4,362 feet. Another deep test that contained gas shows was the Riddle Kiesel Estate well (26) drilled in the Nyssa area to a total depth of 5,137 feet. Gassy fresh water was reported from 900 and 5,042 feet.

Harney Basin

The Harney Basin includes an area of about 1,500 square miles in southeastern Oregon (fig. 70). This basin of internal drainage was block faulted in late Tertiary and Quaternary time and was filled with a thick sequence of continental sediments, ash-flow tuffs, and lava flows.

Geology.—The oldest rocks exposed in the Harney Basin consist of about 1,000 feet of siliceous extrusive rocks of possible Miocene age, overlain by as much as 3,000 feet of basalt flows and breccias of definite Miocene age. The basalt flows, which form the Steens Mountain escarpment, are unconformably overlain by about 800 feet of Pliocene rocks

consisting of rhyolitic ash-flow tuffs and flows and stratified siltstone and sandstone, the latter rock types being predominant in the upper part of the sequence. Basaltic tuff, breccia, and sandstone, about 750 feet thick and possibly also of Pliocene age, form the youngest Tertiary unit. These Tertiary rocks are covered in the center of the basin by several hundred feet of Pleistocene and Holocene clay, silt, and volcanic ash, and near the perimeter by sand and gravel (Piper and others, 1939).

Subsurface exploration.—About one dozen exploratory test wells have been drilled in the Harney Basin, but only one was drilled deeper than 5,000 feet. This well, the UNITED Co. OF OREGON Weed and Poteet well (27) was drilled to 6,480 feet. Reconstruction of the paleo-environment as recorded by cuttings and cores from this well indicates that great outpourings of basaltic and andesitic lavas, as flows, breccias, and agglomerates, were accompanied by large quantities of volcanic ash that contributed to and accumulated concurrently with greenish clays and silts in an enclosed basin in middle Miocene to Holocene time. This well had reported traces of hydrocarbons, and several shallower wells in the Harney Basin encountered small flows of gas or traces of oil at shallow depths.

Basin and Range region

In the Basin and Range region, prospecting for oil and gas has been confined to the southwestern part, where a thick nonmarine volcanic and sedimentary rock sequence may overlie pre-Tertiary basement rocks and where gas or hot water has been encountered in water wells at shallow depths. The greatest concentrations of drilling have been in the general areas of Lakeview and Klamath Falls.

Geology.—In the Lakeview area the oldest exposed rocks are continental in origin and early Miocene or older in age. They consist of a series of tuffaceous sedimentary rocks and andesitic lava flows of unknown thickness. They are overlain by a stratigraphic unit, possibly 7,000 feet thick locally and Miocene in age, that is composed mainly of dacitic and rhyolitic tuffaceous nonmarine sedimentary rocks and areally restricted lava flows. Interbedded near the middle of these silicic rocks is a flow sequence of basalt and andesitic basalt that is at least 2,500 feet thick near volcanic centers. Above this thick Miocene unit is a group of Miocene(?) and Pliocene basaltic and andesitic flows which, in conjunction with an interbedded sedimentary unit of semiconsolidated lacustrine sandstone, siltstone, and volcanic ash, compose more than 5,000 feet of rocks. A sequence of younger pyroclastic rocks, lava flows, and nonmarine sedimentary rocks, mainly of Quaternary age, overlies these Tertiary rocks. Disruption by a group of northwest-trending faults has broken the entire area surrounding the Lakeview basin into a series of horsts and grabens of Basin and Range structure (Walker, 1963).

In the Klamath Falls area the exposed rocks consist of about 3,000 feet of basaltic lava flows and interbedded nonmarine sedimentary rocks of Pliocene age. The lava flows, which are predominantly basalt but contain subordinate amounts of andesite, form flow units 200 to 800 feet thick. The flow units occur both above and below a sedimentary sequence that consists largely of fresh water diatomite, stratified sand-

stone, laminated siltstone, and basaltic lapilli tuff and ash. These sedimentary rocks, as much as 2,000 feet thick, appear to have been deposited under lacustrine and volcanic-plain conditions. Alluvial material several hundreds of feet thick overlies the Pliocene deposits in the deeper structural troughs that were formed by block faulting probably in middle or late Pleistocene time (Newcomb and Hart, 1958). Most of the faults trend northwest and dip basinward at high angles.

Subsurface exploration.—Six exploratory wells have been drilled in the Lakeview area. One of these, the STARK Fisher well (28) with a depth of 2,900 feet, reported a strong flow of gassy water in which the gas contained 90 percent methane, 1 percent ethane, and 8 percent nitrogen (Stewart and Newton, 1965). The LAKEVIEW OIL Co. well (29), drilled to a depth of 2,870 feet, also reported gas but in small amount. The deepest test in the Lakeview area, the HUMBLE Thomas Creek well (30), was spudded about 20 miles northwest of Lakeview in Miocene tuffaceous sediments and volcanic rocks. The location falls in an area of general anticlinal upwarp, and the well was drilled through more than 12,000 feet of Tertiary volcanic rocks and continental sediments before being abandoned at a depth of 12,093 feet without gas or oil shows. Gas shows were reported in lake beds(?) at depths of 7,100 to 7,600 feet in a second well by HUMBLE, the Leavitt well (31), which was drilled near the town of Lakeview to a total depth of 9,579 feet.

In the Klamath Falls area the deepest test was the LANGELL VALLEY Bonanza well (32) which was spudded in Pliocene volcanics and nonmarine sediments, struck hot water (200°F.) at 3,850 feet, and went to a total depth of 4,365 feet. The YONNA VALLEY Dairy well (33) also struck hot water (85°F.) before abandonment at about 2,000 feet. The flows of hot water came from depths of 550 feet, 935 feet, and 1,300 feet (Van Orstrand, 1938). None of the other three wells reported hot water, and no gas or oil shows were reported in any of the five wells drilled.

PALEOZOIC-MESOZOIC AREA

Large areas in southwestern and northeastern Oregon are underlain at the surface by sedimentary, volcanic, and intrusive rocks of Paleozoic and Mesozoic age. These pre-Tertiary rocks are as much as 60,000 feet thick in the Klamath Mountains and are more than 35,000 feet thick in the Blue Mountains.

Geology.—The oldest rocks in Oregon are dark-green schists found in the Klamath Mountains. These Paleozoic rocks are possibly Ordovician in age and were derived by metamorphism of iron-rich volcanic tuffs and sedimentary rocks. They are overlain by about 15,000 feet of argillite, quartzite, chert, and marble of Triassic age, upon which were deposited about 40,000 feet of sedimentary and volcanic rocks of Late Jurassic age that now consist of altered sandstone and siltstone, slate, and metavolcanic flows and tuffs. Intruson by serpentine and ultramafic igneous rocks, as well as by granite, accomplished the metamorphism of these rocks and they now have no petroleum potential. They are locally overlain by sandstones, sandy siltstones, and a few conglomeratic beds of Cretaceous age.

In the Blue Mountains area (fig. 70) the pre-Tertiary rocks are more than 35,000 feet thick in the eastern part, and are about 20,000 feet thick in the western part. In the eastern part of the Blue Mountains area large bodies of intrusive igneous rocks occur, and mudstones, siltstones, and volcanic rocks of Permian age have been changed to argillites, schists, and greenstones. Similarly, Triassic and Jurassic limestones, mudstones and black shales have been metamorphosed to hornfels, slate, and argillite. The possibility of the discovery of oil and gas in these rocks in the eastern part of the Blue Mountains is nil.

In the western part of the Blue Mountains area the oldest rocks are of Devonian and Mississippian age (Baldwin, 1964; Buddenhagen, 1967). These oldest rocks, more than 2,000 feet thick, consist of fossiliferous gray limestones, shales, and sandstones that are overlain by Pennsylvanian nonmarine mudstones and conglomerates with plant fossils. A massive crinoidal limestone of early Permian age is the youngest Paleozoic formation present. Triassic and Jurassic rocks consist of conglomerates, sandstones, volcanic siltstones, mudstones, black shales, and graywackes as much as 18,000 feet thick. These rocks are among the least metamorphosed strata of this age anywhere along the Pacific margin of North America, and they are known to contain hydrocarbon indications at the outcrop. A petroliferous Jurassic limestone occurs near the former site of the Suplee post office in Crook County (Oregon Dept. Geol. and Min. Industries), and geologists have reported small quantities of light oil in pre-Tertiary ammonites and brachiopods of Triassic age (Buddenhagen, 1951; Stewart and Newton, 1965). Petroliferous indications, possibly derived from these unmetamorphosed marine rocks, occur as oil-filled geodes and crevices in the overlying volcanic rocks.

A third area of pre-Tertiary rocks occurs in southernmost Harney County (fig. 70). These rocks, which project northward into Oregon from Nevada, consist of a mixed assemblage of silicic grits, metavolcanic rocks, and schistose metasedimentary rocks of Permian or Triassic age and granitic intrusive rocks of Mesozoic age (Walker and Repenning, 1965). They have no petroleum potential.

Subsurface exploration.—Few wells have been drilled in the Paleozoic-Mesozoic areas of Oregon. Of the four wells drilled in the Klamath Mountains area the deepest, the Riddle Dayton well (34) in Douglas County reached only to 1,370 feet. A small flow of gas was reported below 1,000 feet in this well; none of the others reported any shows. In the eastern part of the Blue Mountains area, in Baker County, the deepest well was drilled to 1,700 feet. No shows were reported in this well, but in the Baker Williams well (35), drilled to only 257 feet, small shows of gas and oil were reported. In parts of the Cenozoic volcanic area, however, five deep test wells that were spudded in Tertiary lavas encountered pre-Tertiary rocks before being abandoned (see subsurface exploration—Cenozoic volcanic area).

CENOZOIC VOLCANIC AREA

As here used, the Cenozoic volcanic area covers more than one-third of the State and includes the Cascade Range, Deschutes-Umatilla Plateau, Joseph Upland, and western part of the High Lava Plains

physiographic provinces. This area is characterized by volcanic rocks, many thousands of feet thick, that consist of lava flows, volcanic breccias, and pyroclastic rocks of Eocene to Holocene age.

Geology.—On the western side of the crest of the Cascade Range the volcanic rocks of the Cenozoic volcanic area are as much as 15,000 feet thick, and in the western foothills of the range those of Eocene to Miocene age commonly overlie or intertongue with marine strata. At the south end the volcanic rocks overlie pre-Tertiary igneous and metamorphic rocks. The volcanic rocks of the Western Cascade Range vary from olivine basalt through basaltic andesite and hypersthene andesite to dacite and rhyodacite; those of the High Cascade Range are similar but contain more alumina and less iron oxide (Peck and others, 1964).

East of the crest of the Cascade Range the volcanic rocks vary from basalt to rhyolite. They are about 15,000 feet thick, and in northeastern Oregon presumably overlie pre-Tertiary rocks in most of the area. The volcanic rocks of Eocene age are mainly lava flows and volcanic breccia of andesitic composition; those of late Oligocene and early Miocene age are mainly ash and ash-flow deposits of rhyolitic composition; and those of middle Miocene and younger age are mainly flows of basalt and basaltic andesite. Surface indications of petroleum are found in volcanic rocks in Crook and Wheeler Counties surrounding the unmetamorphosed pre-Tertiary marine rocks. Asphaltic residues, possibly gilsonite, occur in quartz geodes and drusy cavities in quartz veins, possibly derived from some of the underlying marine sediments (Buddenhagen, 1951).

For convenience a thin belt of upper Eocene nonmarine sedimentary rocks (Wells and Peck, 1961) that crop out between the Cascade Range and the Klamath Mountains have been included in the Cenozoic volcanic area. These rocks consist of a thick sequence of interbedded sandstone and shale with subordinate conglomerate lenses, and form a north-northwest-trending belt that is about 6 miles wide and extends northward from the California border a distance of about 50 miles (Wells and Peck, 1961). Samples of the shale from Shale City near Ashland were tested in laboratories of the U.S. Bureau of Mines and are reported to contain 35 to 37 gallons of oil per ton (K. E. Stanfield, written commun., 1965).

Subsurface exploration.—Although more than 15 wells have been spudded in the Cenozoic volcanic area, few data have been provided concerning depth to basement or stratigraphy of the rocks below the Tertiary volcanics. The deepest test, the STANDARD Kirkpatrick well (36) was drilled to a total depth of 8,726 feet in Gilliam County. It was spudded in Miocene basalt, topped Oligocene pyroclastic rocks at 2,440 feet, and entered Eocene volcanics at 3,760 feet. It was reported to have encountered pre-Tertiary marine sediments and volcaniclastic rocks at 6,700 feet and to have had traces of hydrocarbons in cores at 8,628 to 8,678 feet. Two other deep tests, drilled about 25 miles to the southwest in Wheeler County, also spudded in Cenozoic volcanic rocks and bottomed in pre-Tertiary sediments. The OREGON PET Clarno well (37) was drilled to a total depth of 4,250 feet and passed through 3,245 feet of Tertiary volcanic rocks before penetrating pre-Tertiary metasediments. About 1 mile to the south the CLARNO BASIN Burgess

well (38) was drilled to a total depth of 5,000 feet before encountering similar pre-Tertiary rocks. The Burgess well reported some gas containing about 65 percent methane, 5 percent ethane, and 30 percent nitrogen in several zones (Stewart and Newton, 1965), but no oil shows were reported in either well. About 40 miles farther southwest, in Jefferson County, the NORTHWEST-CENTRAL Morrow Bros. well (39) was spudded in Pliocene and Pleistocene volcanic rocks on the Haycreek anticline about 5 miles from a structural window of Mesozoic and Paleozoic metamorphic rocks. The well entered Miocene basalt at 1,080 feet, reached Oligocene volcaniclastic rocks at 2,330 feet, and drilled into Eocene lavas and pyroclastic rocks at 2,850. At 3,200 feet pre-Tertiary shale was encountered and 100 feet of shale was drilled before the well was abandoned at a depth of 3,300 feet. No shows were reported. Two other significant wells, both in Crook County, were spudded in the Cenozoic volcanic cover with the underlying pre-Tertiary rocks as objectives. The SUNRAY-STANDARD Bear Creek well (40) was spudded in middle Miocene basalt, entered marine Mesozoic sediments at about 3,000 feet, penetrated into Paleozoic rocks at 7,800 feet, and bottomed at 7,919 feet. Gas shows were reported in the interval 3,980 to 4,020 feet. The STANDARD Pexco-State well (41) was drilled through nearly 5,000 feet of Tertiary lavas and volcaniclastic rocks and 2,500 feet of pre-Tertiary(?) marine and interbedded volcaniclastic rocks before reaching the total depth of 7,594 feet. Traces of oil were reported in cores at 6,900 and 7,400 feet.

Seven wells are recorded as having been drilled in the belt of nonmarine upper Eocene sedimentary rocks near Medford in Jackson County (Stewart and Newton, 1965). The deepest of these wells, the TRIGONIA OIL Co. well (42), went to a total depth of 2,257 feet and reported unconfirmed oil and gas shows (Kellogg, 1921).

SUMMARY AND CONCLUSIONS

Of the four areas discussed in this report, the Tertiary marine area probably has the best possibilities for oil or gas production in commercial quantity in Oregon for the following reasons: (1) Source beds in the form of thick organic-rich marine shales of Oligocene and Miocene age are present on the western side of the Coast Range and in the northern part of the Willamette trough. (2) Sandstone and siltstone units, which could serve as reservoir rocks, occur in the overlying strata. The sandstone and siltstone units are, however, very tuffaceous (ashy), which reduces their porosity and permeability measurably. Only locally have porosity and permeability been found to be adequate for movement of fluid as required in petroleum production. (3) Anticlinal structures are present in many parts of the area, and although many of them remain untested, most of those recognized in possible wedge-edge locations in the Willamette trough and in areas of thick marine beds in the coastal embayments have been tested.

The results of the test wells drilled on the continental shelf have yet to be released, but pertinent conclusions can be drawn on the basis of cancellation and retention of lease blocks adjacent to the tracts tested. For example, cancellations occurred following the drilling of deep holes in the Alsea, Siletz, and Heceta blocks, whereas leases were re-

tained in the Stonewall Bank and Heceta Bank areas. Depth of holes drilled thus far off the Oregon Coast demonstrates that sediments are at least 15,000 feet thick, and some reports suggest thicknesses in excess of 20,000 feet. However, siltstones and mudstones are found to be the dominant rock types, with occassional tuffaceous sandstones. Apparently geologic conditions found to date in the offshore search are partly encouraging and partly discouraging (Newton, 1967).

The Tertiary nonmarine area is underlain by fluvial, swamp, and fresh-water lacustrine sediments associated with thin lignitic coal beds and varying amounts of extrusive volcanics, and has a history of many wells drilled, nearly all of which had small quantities of gas. Sediments of this type generally cannot be expected to furnish commercial production of oil, but they cannot be completely ignored as potential dry gas producers. Organic matter in sufficient quantity could, under favorable structural and permeability conditions, provide commercial quantities of gas.

The Paleozoic-Mesozoic area includes in the western part of the Blue Mountains a large region of unmetamorphosed pre-Tertiary marine strata and interbedded volcanics. Although production has not been obtained from any well drilled to date, the presence of petroleum indications in the few test wells that have been drilled through the Cenozoic volcanic rocks into these pre-Tertiary rocks, as well as minor surface indications of hydrocarbons, suggests that this area of older rocks may be worthy of additional study and exploratory tests.

Lava flows, breccias, and pyroclastic rocks of the Cenozoic volcanic area are in themselves incapable of furnishing oil or gas in commercial quantities. The only possibility of commercial production from these rocks lies in encountering petroleum accumulations that have migrated upward into the volcanic rocks, or in tapping pools of oil or gas in the underlying marine sedimentary rocks. In this respect, two areas are of particular interest. One area lies along the eastern flank of the Willamette trough, where shorelines of the Eocene and Oligocene seas extended eastward to a position later covered by lava flows and pyroclastic rocks of late Eocene to late Miocene age. Stratigraphic traps may be present along these shorelines, but attempts to locate these shorelines have been unsuccessful in the two wells drilled thus far. The other area is that underlain by unmetamorphosed marine strata of Mesozoic or Paleozoic age. In this area wells drilled through the lava cover into the pre-Tertiary rocks, although unsuccessful to date, have nevertheless had small petroliferous indications.

Oregon is known to contain source beds, reservoir rocks and structural and stratigraphic traps within its sedimentary rock sequence. The reported oil and gas shows indicate that petroleum products have been generated and that some have accumulated into small local deposits. However, the complete absence of significant surface indications in the form of oil seeps or large tar deposits, or important subsurface accumulations of petroleum, is not encouraging. Nevertheless, in view of the fact that only an average of one well per 300 square miles has been drilled in the most promising areas, and that only 35 of the holes drilled to date were deep enough to explore adequately the existing sedimentary sections, Oregon cannot yet be excluded from the ranks of potential producing areas.

Geothermal Energy

(By L. H. Godwin, U.S. Geological Survey, Los Angeles, Calif., and N. V. Peterson, Oregon Department of Geology and Mineral Industries, Grants Pass, Oreg.)

The use of the earth's natural heat (geothermal energy) in the form of steam and hot water for the generation of electrical power, residence heating, and other industrial processes is becoming more and more important. The utilization of geothermal energy is not new; apparently the Romans used natural steam and hot water throughout central Europe 2,000 years ago. With the fall of Rome, hot springs and fumaroles became curiosities again until the 19th century, when health resorts such as Hot Springs, Arkansas, became fashionable and appeared around most of the accessible hot springs. Finally, in 1904, at Larderello, Italy, the first well was drilled to produce geothermal steam for the generation of electricity. Present Italian geothermal steam production capacity is estimated to be about 350,000 kilowatts (kw).

Almost half a century later New Zealand became the second country to develop steam for electrical power generation. In 1950, power plants using natural steam began generating electricity at Wairakei, New Zealand. The proven potential of the Wairakei steam field in 1964 was about 182,000 kw. Ten years later the United States became the third country to exploit geothermal steam for electrical power. In 1960, at The Geysers steam field in northern California, the Pacific Gas and Electric Co. began using natural dry steam to generate electricity (McNitt, 1963). Production from three units presently in operation is about 53,000 kw. A fourth unit rated at 27,500 kw is scheduled for completion in 1968. By the end of 1967, power plants using naturally heated steam were also operating in Matsuo Village, Japan, and in Russia; a pilot power plant was in operation at Cerro Prieto, Baja California, Mexico; and the United Nations Organization was sponsoring development of geothermal energy in several smaller countries. Iceland, richly endowed with geothermal energy, has used this natural heat for domestic and industrial heating for many years (Bodvarsson and Zoëga, 1964), but has not yet used it for generation of electricity.

Present United States production of electricity by geothermal steam is about 0.02 percent of the total electric power produced. The current power production in the United States is about 250 million kw (Lake, 1967). With our rapidly expanding population, the demand for electrical power is expected to double every 10 years. Thus, in 20 years this projected increase would require four times the power produced today, or 1 billion kw by 1987. In Rome, Italy, in 1961 at a United Nations conference concerning new sources of energy, it was stated that geothermal energy was probably the cheapest source of energy available. Kaufman (1964) calculated that natural steam can generate electrical power for 2 to 3 mills per kw-hr, compared with conventional fossil fuel or nuclear generation at 5.47 to 7.75 mills.

The geothermal steam industry is new in the United States, and Federal and State laws governing the exploration and exploitation of this energy are nonexistent or inadequate. The rapidly increasing technical skills and relatively low cost suggest that a greater utilization of geothermal energy will take place in the near future if the new laws presently being formulated provide a profitable climate.

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One major economic consideration today in the utilization of a steam field is the proximity to population centers or transmission facilities, since the latter are required to transport the electricity from the power plant to the consumers. As more "clean air" laws are passed and the emission controls become more stringent, conventional fossil fuel generating plants become more costly to operate in population centers. Geothermal steam lacks objectionable fumes and should therefore receive more attention as a possible source of power for the generation of electricity. However, impurities in the steam such as fluorine, boron, arsenic, and other salts may create effluent problems and require treatment or subsurface disposal of waste fluids to prevent pollution.

For a general discussion of geothermal energy and a fairly comprehensive bibliography, see U.S. Geological Survey Circular 519 (White, 1965). The economic aspects of geothermal power have been evaluated by Kaufman (1964), and some of the engineering problems have been summarized by Smith (1964).

GEOLOGIC OCCURRENCE

The earth is a huge reservoir of thermal energy, most of which is presently unusable by man. At the surface, the temperature of the earth is generally near the mean annual air temperature. The temperature of the crust of the earth increases downward as a function of depth and the "geothermal gradient" or the rate of temperature change. The average geothermal gradient is about 1° F. per 100 feet of depth, but it varies from place to place in the earth's crust. In some areas, mainly those where recent volcanoes have been active, the gradient is much higher, and there are usually surface indications in the form of hot springs or fumaroles.

When ground water comes in contact with rocks whose temperature has been elevated, heat is transferred to the water by conduction. Convective transfer of fluids and heat occurs, and the warmer water moves upward and allows the cooler water to become heated. Generally hot water escapes to the surface, losing heat to the walls of the conduit on its trip upward. Frequently it also mixes with cooler ground water, so that when it arrives at the surface it has a lower temperature than the buried reservoir.

In his discussion of the most favorable environment for a geothermal steam reservoir, White (1966) included three citeria: (1) a potent heat source, such as a magma chamber 2 to 5 miles deep; (2) a reservoir rock with adequate volume, permeability, and porosity at a depth of 2,000 to 5,000 feet; and (3) a cap rock with low permeability that inhibits loss of fluids and heat. A fourth, an adequate fluid recharge, might be added.

White (1966) also classified geothermal reservoirs into two types: those with conduits to the surface allowing hot water or steam to escape through hot springs and fumaroles, and deep insulated reservoirs with impermeable cap rocks and little or no indication of heat at the surface. The second type are generally discovered accidentally.

Most of the geothermal systems so far discovered and studied are dominated by liquid water, commonly above 212° F. because of the high pressures at depth. In such systems, steam can only form near the

surface as pressure is decreased. Only two dry steam areas have been found: The Geysers, California; and Larderello, Italy. In both localities the temperature is so high and the rate of flow of water so low that the water is converted to steam even at pressures in excess of 300 psi.

OCCURRENCES IN OREGON

Oregon, along with the other western states, is within the zone of volcanic activity which surrounds the Pacific Ocean. At present, Oregon is enjoying an inactive volcanic stage, but according to Peterson and Groh (1964) volcanism in Oregon should not be considered extinct, but dormant.

Cooling igneous rocks are probably the major source of heat in the geothermal areas. In Oregon, late Cenozoic volcanism was confined to four contiguous physiographic divisions: The Cascade Range, the High Lava Plains, the Basin-Range, and the Owyhee Upland (Groh, 1966). It is not surprising therefore that almost 80 percent of the thermal springs known in Oregon occur within these divisions.

The potential geothermal areas in Oregon are shown on figure 71 and listed in table 26. Three of these areas have been tested for geothermal energy: Klamath Falls, Lakeview, and Crump Valley. As they appear to be the most favorable areas for commercial utilization, they are described briefly below.

Just north of Lakeview a group of hot springs known as Hunters Hot Springs (fig. 71, No. 1) occurs at the base of a steep fault escarpment on the east side of the Goose Lake graben. Tertiary volcanic rocks crop out in the escarpment, but in the valley near the hot springs several hundred feet of alluvium and Pleistocene lake beds are present. A shallow well drilled in 1923 has continued to erupt as "Old Perpetual" geyser. The 200° F. water from a shallow well heats a motel and resort, and other shallow wells nearby are used to heat residences. Nevada Thermal Power Co. drilled a wildcat test well on the east edge of this thermal zone but abandoned it about 650 feet depth because of drilling problems, so the steam potential is as yet untested.

At Crump Valley, Oregon (fig. 71, No. 2), in a similar geologic environment at the base of a steep fault escarpment, the Nevada Thermal Power Co. drilled another hole 1,684 feet deep. The well was tested and abandoned because the water temperature was only 170° F. Within a few days the well began to erupt large quantities of steam and water, and the eruptions continued for over a year (Peterson, 1959a). Tufa, sinter mounds, and other small hot springs scattered for 2 miles along a narrow elongate northwest-trending zone indicate thermal activity along the fault zone.

At Klamath Falls, Oregon (fig. 71, No. 3), hot water from springs and shallow wells has been used for over 50 years by the local residents. The hot water occurs in an elongate northwest-trending zone about half a mile wide and several miles long adjacent to prominent normal faults within the broad Klamath graben. The underlying rocks are Pliocene and Pleistocene lacustrine sediments with intercalated lava flows and pyroclastic rocks. This sequence is relatively impermeable, and only where it is broken by faulting does the hot water leak to the surface. The underlying rocks are believed to be fractured, scoriaceous

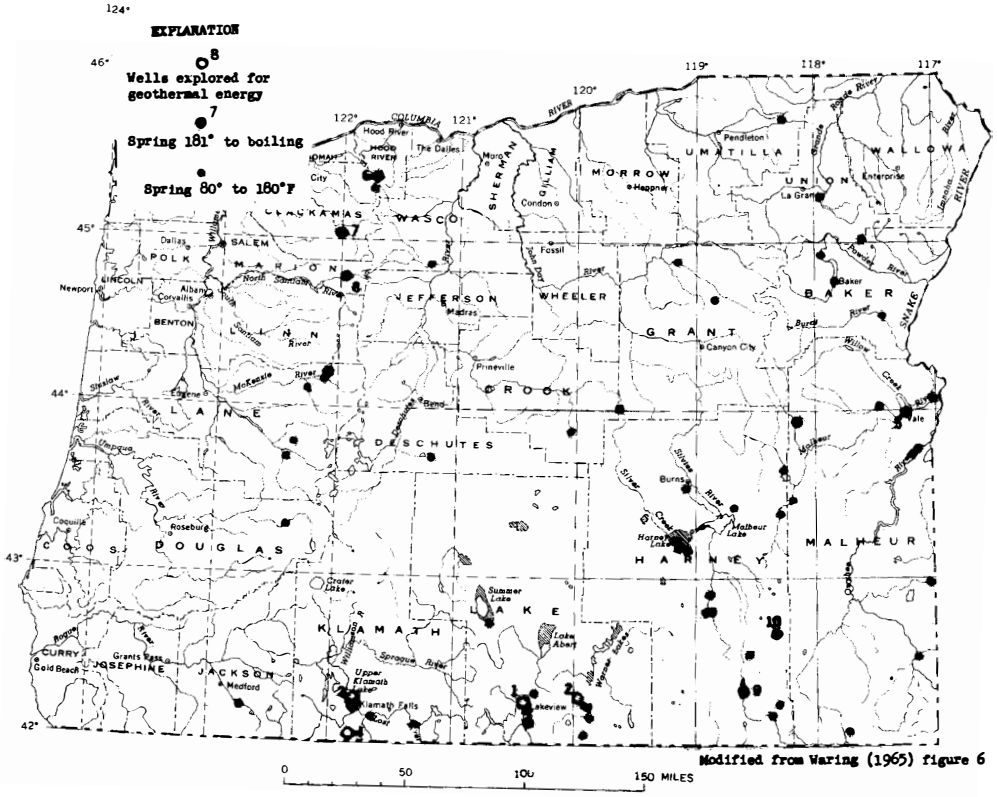

FIGURE 71.—Thermal springs and wells drilled for geothermal energy.

TABLE 26.—POTENTIAL AREAS FOR DEVELOPMENT OF GEOTHERMAL ENERGY IN OREGON

Index number on figure 71 and thermal area	Location	Wells drilled for geothermal energy	Maximum depth (feet)	Maximum temperature °F		Dates drilled	Remarks and references
				Subsurface	Surface springs		
1. Lakeview	Sec. 33, T. 38 S., R. 20 E., W.M., Lake County	1	650	133.5	185	1959	Nevada Thermal Power Co. (Magma Power Co.). Geyser erupts every 10 seconds to 50 feet high; resort; space heating and bathing; temperature 230° F.
2. Crump Valley	Sec. 34, T. 38 S., R. 24 E., W.M., Lake County	1	1,684	230–250	200±	1959	Nevada Thermal Power Co. (Magma Power Co.). Bottom hole temperature survey not taken because hole bridged. 2 days after well abandoned it began to erupt as a geyser. (Waring, 1965; Peterson, 1959a).
3. Klamath Falls	Secs. 28, 29, 32, 33, T. 38 S., R. 9 E., W.M., Klamath County.	350±	[1] 100–1,800	140–240			About 350 drilled wells tap 140°- to 240°-water at depths ranging from 100 to 1,800 feet. Heat is taken from the wells by a variety of heat exchange methods to provide space heating for schools, apartments, and industrial buildings and processes (Peterson and Groh, 1967).
4. Klamath Hills	T. 40 S., R. 9 E., W.M., Klamath County	3	300				Several wells; large volumes of water are pumped to reservoirs, cooled, used for irrigation.
5. Vale Hot Spring	Sec. 20, T. 18 S., R. 45 E., W.M., Malheur County	1	140	230?	198	?	1 spring; bathing resort; well also has hot water (Waring, 1965).
6. Mount Hood	Sec. 29, T. 2 S., R. 9 E., W.M., Clackamas County				194		Several small springs (Waring, 1965).
7. Carey Hot Springs	Sec. 30, T. 6 S., R. 7 E., W.M. Clackamas County				196		Several springs; bathing; sulfur odor (Waring, 1965).
8. Breitenbush Hot Springs	Sec. 20, T. 9 S., R. 7 E., W.M., Marion County				198		Resort; several springs (Waring, 1965).
Alvord Valley:							
9. (a) Hot Lake	Sec. 3, T. 37 S., R. 33 E., W.M. Harney County				198		Sinter cone is arched; total solids in solution 0.15–percent, B_2O_3 56 ppm (Libbey, 1960; Waring, 1965).
10. (b) Mickey Springs	Sec. 13, T. 33S., R. 35 E., W.M. Harney County				198		Several vents, pools, and sinter cones; activity formerly great (Waring, 1965; Libbey, 1960).

[1] Average, 300.

lava flows of the Western Cascade volcanic series. About 350 wells have been drilled in and near Klamath Falls, and large amounts of hot water at 200° F. are found at about 250 to 300 feet depth. Very few of the hot wells are pumped. Instead, city water is circulated through a simple "U" coil heat exchanger immersed in the hot wells, and the hot city water is used to heat schools, businesses, and private residences.

In the Klamath Hills area (fig. 71, No. 4) a few miles to the south in a similar geologic environment, wells also encounter large volumes of hot water at 250 to 300 feet depths. Preliminary geologic studies of these geothermal areas have been made (Peterson and Groh, 1967), but deeper drilling and additional detailed exploratory work are needed to determine the geothermal potential of these areas.

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MINERAL AND WATER RESOURCES OF OREGON

SECTION 2

WATER RESOURCES AND DEVELOPMENT

PREPARED BY

UNITED STATES GEOLOGICAL SURVEY

AND

UNITED STATES BUREAU OF RECLAMATION

AND

BONNEVILLE POWER ADMINISTRATION

SECTION II

WATER RESOURCES AND DEVELOPMENT

WATER RESOURCES

(By K. N. Phillips, U.S. Geological Survey, Portland, Oreg.)

Introduction

Oregon has a large supply of water, but it is unevenly distributed with respect to both area and time. Damaging floods occur every few years, and they are not limited to the wetter parts of the State; shortages of water are frequent in eastern Oregon and are not unknown in the more humid western section. Some rivers that lie almost side by side differ markedly in their patterns of flow. Likewise, ground water varies greatly from place to place in quantity and in quality. Most of this diversity results from differences in topography, climate, and geology.

Several ranges of mountains exert a great influence on the distribution of precipitation and serve to divide the State into drainage basins. The Coast Range extends from California northward into Washington, its crestline in Oregon at 1,000 to 4,000 feet altitude lying 20 to 40 miles inland from the Pacific Ocean. The much higher Cascade Range lies parallel to the Coast Range, about 90 miles farther inland, and reaches a maximum altitude of 11,235 feet at Mount Hood. The valley areas in the basins of the Rogue, Umpqua, and Willamette Rivers lie between these mountain ranges. Farther east, the Blue Mountains of central Oregon reach altitudes of 6,000 to 9,000 feet, and the Wallowa Mountains in the northeast range from 6,000 to nearly 10,000 feet. In the southeast quarter, fault-block ridges that have a general north-south trend and range from 1,000 to 4,000 feet in relief, break up that arid sector into a series of landlocked lake basins. All these mountains are barriers which the prevailing westerly winds must cross. The mountains induce greater precipitation, especially on the windward side and on the steeper slopes. At altitudes above 3,500[1] feet, the approximate mean altitude of the State, most of the precipitation falls as snow.

The climate of the western third of Oregon is characterized by moderate temperatures, wet winters, and dry summers; about 78 percent of the annual precipitation occurs in the period October to March. The eastern two-thirds of the State has greater extremes of temperature but less seasonal variation in precipitation; about 65 percent of the precipitation occurs in the period October to March.

The average annual precipitation ranges from about 200 inches at places in the Coast and Cascade Ranges to less than 10 inches in parts of north-central and southeast Oregon (fig. 72). The statewide average

[1] Computed in 1967 from 1966 edition of 1 : 500,000-scale Oregon base map with contours.

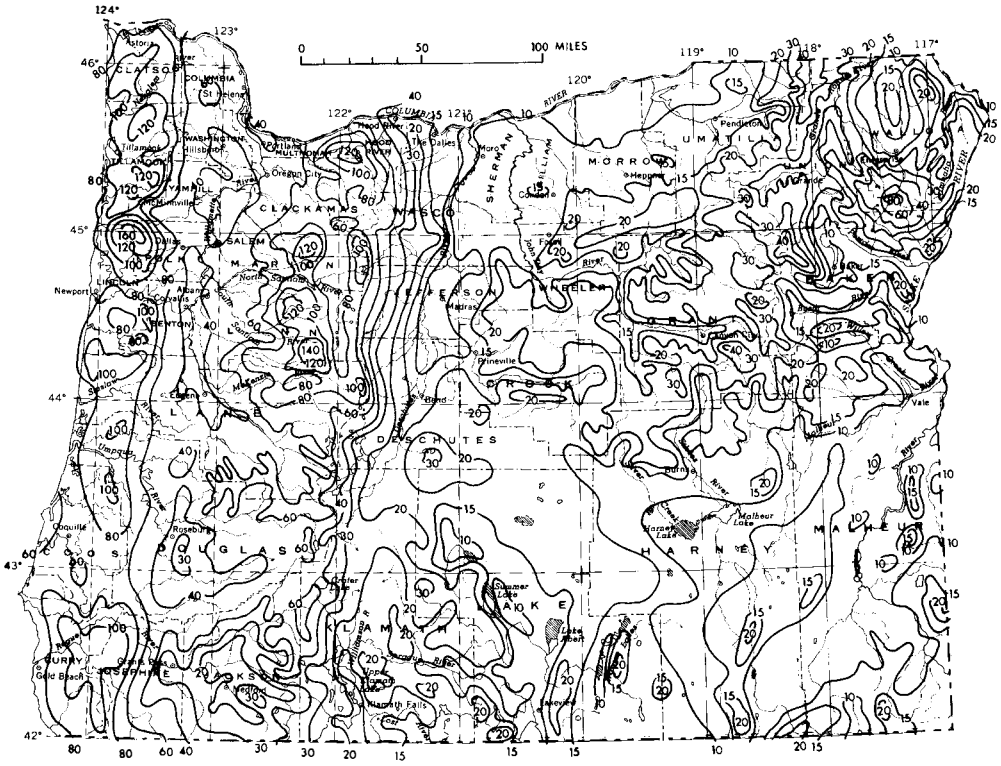


FIGURE 72.—Average annual precipitation, in inches.

is about 27 inches per year, equivalent to 139 million acre-feet. The average precipitation at selected stations is shown in table 27.

Several agents intervene between the falling moisture and the flowing stream. Vegetation intercepts some water, and in the growing season evaporation and transpiration may consume 20 inches or more. Also, decaying plant and tree roots provide passages that increase infiltration into the soil and subsoil. Porosity and permeability determine the capacity of the underlying geologic formation to store and to transmit the water that forms the base flow of streams beween periods of rain. The chemical quality of the stream water depends in part on the nature of the soluble materials in the soil and rock through which the percolating water has passed. The amount, distribution, and quality therefore vary greatly from one basin to another in Oregon.

The chief industries of the State are related to forest products, agriculture, and tourism, and water is vital to each of them. In some respects their uses of water are compatible; for example, irrigation reservoirs are used to a great extent for angling. In other respects their uses are in conflict: a stream depleted for irrigation has less value for recreation than a natural stream; unregulated discharge of waste products from a sulfite-process papermill reduces dissolved oxygen in the river and may promote growth of algal slime.

Water is also used extensively in the mineral industry. Aluminum and nickel production, gold-placer mining, and the processing of exotic minerals use about 100 cfs (cubic feet per second), on the average; and the production, washing, and treatment of nonmetallic building materials (cement, sand, gravel, stone, and clay products) at least as much.

Water is consumptively used in ever larger amounts to meet the demands for agriculture, industry, and municipal and domestic needs, and nonconsumptively for power development, recreation, transportation, fisheries, and dilution of wastes. Agriculture consumes the greatest quantity; its needs are greatest in the dry areas of eastern Oregon and in the dry summer season, the place and time when water often is in short supply. The approximate amounts of water used in 1965 for purposes that require diversion are shown in table 28.

Recreational use of water is increasing rapidly. Parks for public enjoyment all depend on water supply, and most of them are water oriented. Hundreds of picnic areas, campgrounds, and other recreation facilities are maintained on public lands by Federal agencies. Bonneville Dam on the Columbia River attracted 947,000 visitors in 1966; Crater Lake had 552,000 visitors in the short 1966 summer season. The State park system has more than 200 public parks, of which 38 have frontage on the Pacific Ocean, 17 on lakes or reservoirs, 47 on large streams, and many more on small streams; 11 parks feature waterfalls; more than 60 offer facilities for water sports; and 32 have boat-launching ramps. These State parks had a registered attendance of more than 19 million persons in 1967.

Water problems are widespread in Oregon. Flooding and drought are due to natural causes and have been alleviated in some areas by storage, drainage, diking, and irrigation. In some places ground water is too highly mineralized for most uses. Other problems are caused or intensified by man's activities. Evaporation from reservoirs reduces

TABLE 27.—AVERAGE MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, AT SELECTED SITES IN OREGON[1]

Basin	Station	January	February	March	April	May	June	July	August	September	October	November	December	Year
Closed lakes	Burns	1.62	1.27	0.97	0.75	0.89	0.88	0.34	0.29	0.50	0.86	1.16	1.43	10.96
Do	Lakeview	1.84	1.71	1.52	1.15	1.51	1.28	.22	.17	.58	1.21	1.37	1.88	14.44
Snake	Baker	.98	.88	1.05	.87	1.44	1.41	.48	.38	.60	.82	1.00	1.06	10.97
Do	Enterprise	.92	.86	1.19	1.22	1.72	2.19	.60	.59	1.01	1.17	1.07	1.00	13.54
Do	Vale	1.09	.98	.81	.68	1.03	.80	.17	.24	.46	.77	.85	1.00	8.88
Lower Columbia	Hermiston	1.18	.93	.81	.62	.66	.75	.19	.13	.44	.87	1.05	1.14	8.77
Do	The Dalles	2.55	1.80	1.37	.53	.62	.66	.08	.16	.47	1.17	2.02	2.36	13.79
Do	Hood River	5.04	3.62	3.41	1.49	1.10	.92	.15	.27	.86	2.62	4.77	5.44	29.69
Willamette	Eugene	6.33	4.97	4.32	2.38	2.14	1.42	.27	.40	1.27	3.83	5.62	6.61	39.56
Do	Hillsboro	5.95	4.51	4.02	1.89	1.85	1.46	.38	.50	1.44	3.31	5.54	6.97	37.82
Do	McKenzie Bridge	10.48	8.42	8.39	4.75	3.91	2.93	.52	.72	2.25	6.61	9.62	11.84	70.44
Do	Portland	6.34	4.90	4.78	2.45	2.05	1.68	.39	.69	1.74	3.89	6.04	7.42	42.37
Coastal	Astoria	11.71	9.89	8.92	5.18	3.20	3.02	1.27	1.49	3.13	7.78	11.20	13.65	80.44
Do	Brookings	13.16	11.07	10.19	5.42	4.30	2.46	.58	.58	1.84	7.27	10.75	13.78	81.40
Do	Newport	10.01	8.38	8.38	4.16	2.93	2.39	.81	.92	2.31	6.12	8.80	11.02	66.23
Do	North Bend	10.29	8.35	7.63	3.87	2.77	1.69	.43	.52	1.73	5.49	8.56	10.49	61.82
Umpqua	Roseburg	5.51	4.21	3.42	1.93	1.85	1.50	.21	.31	1.00	3.02	4.46	5.69	33.11
Rogue	Ashland	2.78	2.15	2.06	1.30	1.74	1.20	.34	.27	.78	1.84	2.53	3.00	19.99
Do	Grants Pass	5.82	4.50	3.20	1.69	1.63	.91	.26	.18	.71	2.71	3.94	5.52	31.07
Do	Medford	3.14	2.40	1.78	1.06	1.47	1.02	.21	.18	.60	1.94	2.60	3.38	19.78
Do	Prospect	6.60	4.94	4.55	2.90	2.73	1.80	.33	.30	1.06	3.95	5.67	6.86	41.69
Klamath	Crater Lake	11.29	9.02	8.16	4.62	3.55	2.49	.61	.70	2.03	6.46	8.13	11.68	68.74
Do	Klamath Falls	2.11	1.56	1.24	.84	1.15	.95	.31	.33	.60	1.15	1.61	2.21	14.06

[1] Data from publications of U.S. Weather Bureau.

TABLE 28.—CONSUMPTIVE USES OF WATER IN OREGON IN 1965

[In thousands of acre-feet]

Purpose	Approximate annual volume		Remarks
	Withdrawn	Consumed	
Public supplies	290	65	
Rural use	66	59	Includes use for livestock.
Irrigation	5,800	2,500	
Hydropower	240,000	0	Some evaporation from reservoirs.
Fuel-electric	6	0	
Industry	1,200	54	Excludes use from public supplies.

the available water supply. Sudden changes in flow below a dam may create problems—low flows may kill fish, whereas high flows create hazards for anglers. Repeated use of water for irrigation tends to increase the concentration of dissolved minerals. Return flows of water used for agricultural and some industrial purposes contain mineral nutrients that stimulate undersirable algal growths in rivers and lakes. Municipal and industrial wastes at times deplete the natural supply of dissolved oxygen in streams and thus block the passage of migrant anadromous fish so that they die before reaching their spawning grounds. Blocking may also be due to naturally high water temperatures which occur at times, and in the future may result from uncontrolled use of stream water for cooling at thermal- or atomic-energy plants. One of the most difficult problems is to balance the divergent interests of those who would prefer to maintain streams in a near-natural condition and those who recognize the growing needs for use and control of the State's water supplies.

GENERAL CHARACTERISTICS OF THE WATER SUPPLY

Surface-Water Resources

RIVERS

Interstate streams form a significant part of the State's water supply. The Snake River, Oregon's eastern boundary for 216 miles, and the Columbia River, Oregon's northern boundary for 309 miles, derive most of their flow from other States. The Owyhee River rises in Nevada and enters Oregon from Idaho; Twentymile Creek flows from California into Warner Valley in Oregon; and small tributaries of the Rogue River rise in California. The Klamath, Grande Ronde, and Walla Walla Rivers rise in Oregon and carry significant flows into other States. Small tributaries of Smith River in northwestern California rise in Oregon. Goose Lake lies astride the Oregon-California line; its larger tributaries are in Oregon. Large volumes of water are diverted in Oregon each year from the Owyhee River to irrigate land in Idaho, and from the Klamath River to irrigate land in California. Interstate agreements are in effect between Oregon and California on the use of the waters of the Klamath River and Goose Lake.

Streams in Oregon range in size from small rills that cease to flow at times, up to the Columbia River, the largest stream in western America. Figure 73 shows the approximate average discharge of the

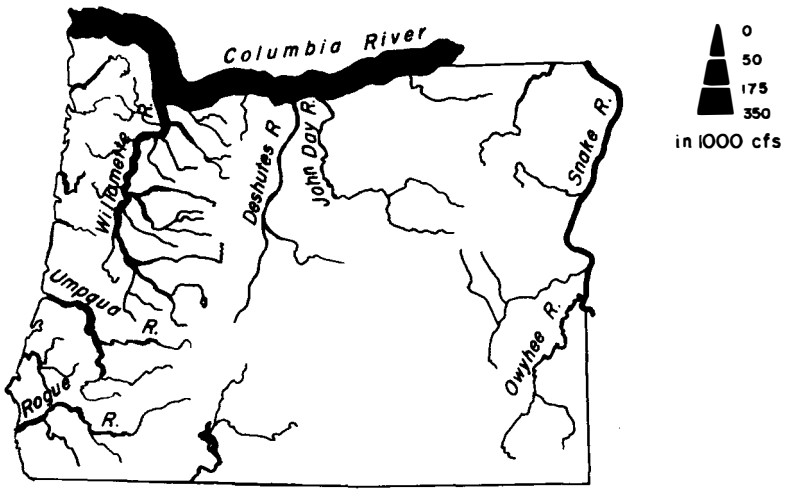


FIGURE 73.—Average discharge, in cubic feet per second, of principal rivers.

larger Oregon streams. Columbia River has an average annual discharge of about 195,000 cfs at The Dalles and about 270,000 cfs at the mouth, mostly derived from upstream States and Canada.

Runoff, the flow that appears in streams, over a period of years is practically equal to the volume of precipitation less evaporation and transpiration. The average annual runoff of all streams in the 96,981-square-mile area in Oregon is about 85 million acre-feet, enough to cover the State to a depth of 16 inches; as shown on figure 74 it ranges from less than 1 inch in semidesert areas of Lake, Harney, and Malheur Counties to more than 100 inches in places on the western slopes of the Coast and Cascade Ranges in northwestern Oregon.

The average annual flow varies considerably from year to year, even on large streams with fairly steady flow. For example, as shown in figure 75, Columbia River at The Dalles has ranged from 314,000 cfs in water year 1894 to 118,000 cfs in 1926, and Willamette River at Albany from 24,200 cfs in 1894 to 7,980 cfs in 1931. The relative range is much greater on small streams in arid regions: Silvies River near Burns, for example, has ranged from 415 cfs in 1904 to 15 cfs in 1934.

Seasonal variability is even more marked. As shown in figure 76, the Siletz River, a stream typical of those that drain the west slope of the Coast Range, has more than 50 percent of its annual flow in the months of December, January, and February, but only 3 percent in the period July to September. In contrast, Columbia River at The

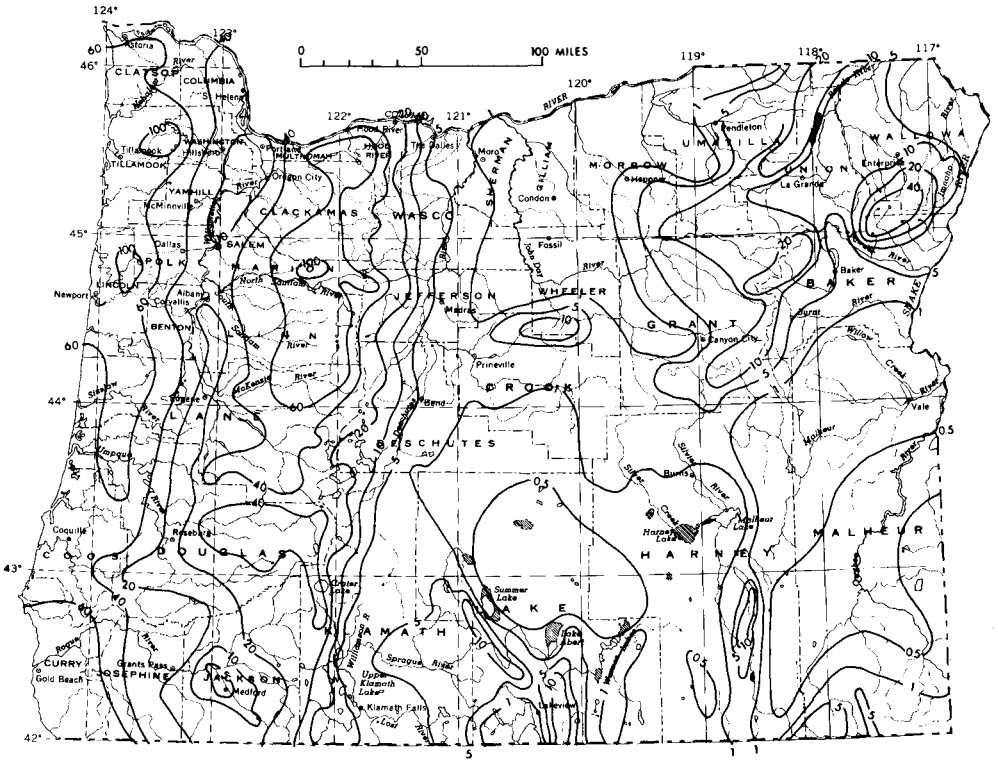


FIGURE 74.—Average annual runoff, in inches.

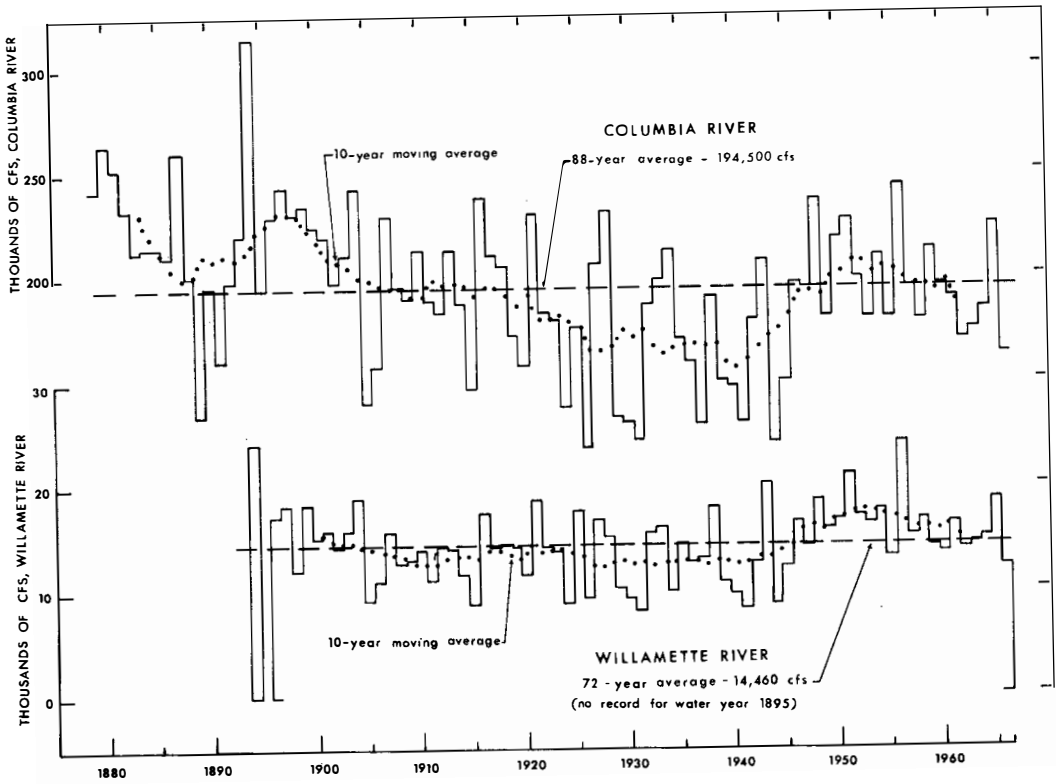


FIGURE 75.—Observed annual flowof Columbia River at the Dalles and Willamette Rivers at Albany.

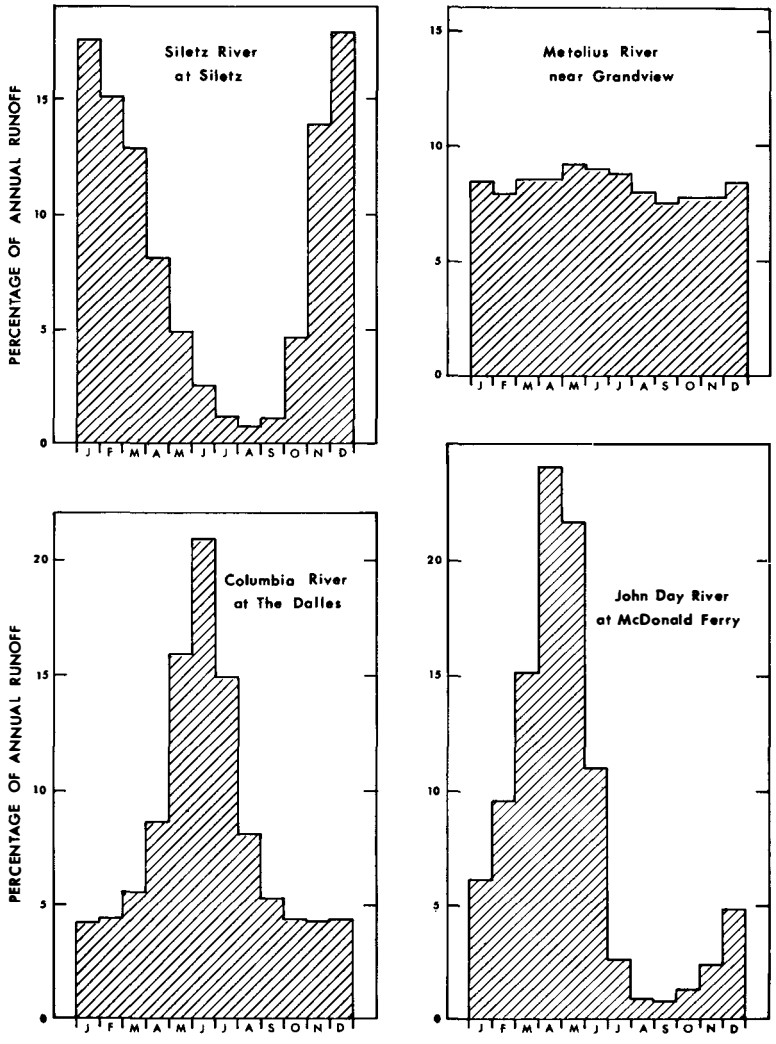


FIGURE 76.—Monthly distribution of runoff for four Oregon rivers.

Dalles has 51 percent of its flow in the period May to July and only 13 percent in the period December to February. That marked difference in seasonable distribution has the favorable effect of tending to reduce the fluctuations in the statewide total supply. The Metolius River has only a very slight seasonal change because of large springs with steady flow that rise from thick, permeable volcanic aquifers. Other streams sharing that characteristic to a notable degree include the tributaries of the Deschutes, Santiam, Umpqua, Rogue, and Klamath Rivers. The John Day River has 61 percent of its flow in the period March to May and only 3 percent August to October. Such a regimen is typical of

many streams that rise in mountain areas where the snow melts in the spring and natural ground-water storage is small.

LAKES AND RESERVOIRS

Lakes are an important hydrologic feature of Oregon. Most lakes overflow; to some extent they store water naturally during periods of high flow and release it gradually in dry periods when water demands are the greatest. Some lakes lose water by leakage that nourishes springs. Many lakes in the high plateaus of south-central Oregon lose water only by evaporation, and several large lakes have thus become moderately to highly saline; examples are Harney, Summer, and Abert Lakes. The water resources of most lakes are undeveloped and the lakes are used chiefly for recreation.

There are at least 1,400 named lakes in Oregon. More than half of these lie in volcanic or glacial depressions near the broad summit of the Cascade Range; about 70 lie in depressions between sand dunes, within 3 miles of the ocean; and nearly 100 small glacial lakes are clustered in secluded pockets in the Wallowa Mountains.

Goose Lake is the largest lake. Most of it lies in California. When filled to its overflow level, 4,716 feet, it covers 194 square miles (126 in California) and has a maximum depth of 24 feet. It overflowed into the North Fork Pit River in 1868 and again for a few hours during a strong north wind in 1881. It was dry at times in 1926 and 1929–34. Future overflow is unlikely because of diversions for irrigation.

Upper Klamath Lake, the largest natural lake wholly in Oregon, covers 90,000 acres. A low dam at its outlet regulates the lake level and controls the release of about 440,000 acre-feet between the levels of 4,137 and 4,143 feet.

Crater Lake, 1,932 feet deep, is the deepest lake in the United States, and contains 14 million acre-feet (4.2 cubic miles) of water. It has a leakage rate of about 90 cfs and a computed evaporation loss of about 23 inches of depth per year. Other deep lakes are Waldo (420 ft), Wallowa (283 ft), and Odell (at least 279 ft). Waldo Lake contains about 800,000 acre-feet of water.

Oregon has 61 reservoirs of more than 5,000 acre-feet capacity that when filled cover 280,000 acres and contain more than 10 million acre-feet of water, of which about two-thirds is controlled storage. Reservoirs of notable size include Owyhee Reservoir and four interstate reservoirs (Brownlee, McNary, The Dalles, and Bonneville). A group of 12 reservoirs operated by the U.S. Corps of Engineers provides flood protection, navigation, power, recreation, and other benefits in the Willamette River basin.

SNOWFIELDS AND GLACIERS

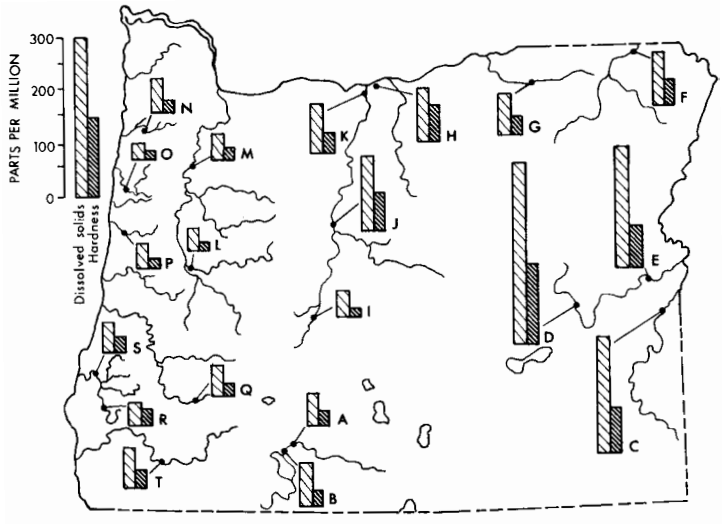
Fields of snow and rivers of ice at high altitudes play a significant part in regulating the flow of the Snake and Columbia Rivers. The larger glaciers are in Canada or in States other than Oregon; but small glaciers exist on the slopes of Mount Hood, Mount Jefferson, and Three Sisters, covering about 8,000 acres and extending down to about the 6,000-foot level. Streamflow from glaciers has several unique characteristics: (1) precipitation in winter is stored for release in the

warm, dry summer period, with little depletion from evaporation or other losses; (2) storage occurs over a long period of wet years, and maximum release occurs during a warm, dry cycle; (3) the melt water contains much suspended sediment or "glacier flour," that may be abrasive to turbines, sprinklers, and the like; and (4) the rate of melting has a pronounced daily fluctuation.

Snowfields that never melt completely cover high-altitude areas that are larger than the glaciers and have similar characteristics of seasonal storage and release. The snowfield melt water does not carry "glacier flour," however, and the diurnal fluctuation in streamflow is less pronounced because of the wider distribution of the snowfields. Still larger areas are covered at times with snow that usually melts during the period February to May. Some streams that drain high mountain areas have well-sustained flows in the dry months of late spring and early summer, when water demand for irrigation is at its peak.

QUALITY

Surface water in Oregon is generally of excellent chemical and physical quality for use in irrigation, industrial processes, or municipal supplies. The dissolved-solids concentration of most streams in western Oregon is less than 100 ppm (parts per million) and in eastern Oregon less than 250 ppm as shown schematically in figure 77. Most



A. Sprague River near Chiloquin
B. Williamson River near Chiloquin
C. Owyhee River below Owyhee Dam
D. Malheur River at Drewsey
E. Malheur River near Hope
F. Grande Ronde River at Troy
G. Umatilla River at Pendleton
H. Columbia River near Rufus
I. Little Deschutes River near Lapine
J. Crooked River near Culver
K. Deschutes River at Moody
L. McKenzie River near Eugene
M. Willamette River at Salem
N. Nestucca River near Blaine
O. Siletz River near Siletz
P. Alsea River at Tidewater
Q. South Umpqua River at Tiller
R. South Fork Coquille River near Powers
S. Coquille River at Coquille
T. Rogue River at Grants Pass

Figure 77.—Chemical quality of typical Oregon streams.

of the waters are of the calcium magnesium bicarbonate type. Streams in western Oregon have less than 60 ppm of hardness and are classed as soft water. Those in eastern Oregon range in average hardness from 20 to 150 ppm, with greater hardness at times because of return flows from irrigation.

The allowable dissolved-solids content of a water varies considerably depending on the particular water use. For drinking-water supplies, the U.S. Public Health Service recommends that waters containing more than 500 ppm not be used if other less mineralized supplies are available.

Hardness of water is a measure of the amount of soap needed to form a lather and is expressed as an equivalent amount of calcium carbonate, in ppm. Calcium and magnesium are the principal ions that cause hardness but ions such as aluminum, iron, and manganese also contribute to hardness. In U.S. Geological Survey publications, water of 0 to 60 ppm is considered to be soft, that of 61–120 ppm is moderately hard, that of 121–180 ppm is hard, and that of more than 180 ppm is very hard.

Data on sediment transport are meager, but most streams are clear and relatively free of sediment at low and medium flows. Notable exceptions are the Hood and Sandy Rivers, and Squaw Creek in the Deschutes River basin, which receive glacier melt water that has not been clarified by passing through mountain lakes. In periods of flood, all streams carry considerable sediment, and a few concentrations exceeding 100,000 ppm of suspended solids were observed in north-central Oregon during the severe flood of December 1964. Such concentrations no doubt occur also in flash floods of the "cloudburst" type that occasionally strike local areas in eastern Oregon. However, these floods are of such short duration and so infrequent that it seems better in this report to express sediment production in terms of total movement by streams in acre-feet per square mile per year.

Figure 78 is a generalized map of annual sediment production in Oregon. Nearly all western Oregon has a low rate of sediment production (0.1 to 0.2 ac-ft per sq mi per yr), in spite of having high annual runoff (fig. 3). Slightly higher rates in several places result from local land-use practices or other special conditions. About 80 percent of eastern Oregon has even smaller sediment production, owing in part to the low rates of runoff. The highest rates occur in areas that (1) have considerable slope, (2) have little or no forest cover, (3) have light, erodible soils, (4) are intensively farmed and, (5) are subject to occasional cloudburst storms.

The temperature of running water has a bearing on its utility for irrigation, fisheries, recreation, and some industrial applications. The average temperature and monthly range in temperature of four Oregon streams are shown in figure 79. (The temperature of Willamette River at Salem may be affected in some months by release of water from upstream reservoirs; other streams shown in figure 79 are unregulated.) The smaller streams, Umatilla and Tualatin Rivers, have a greater monthly range in temperature than do the larger ones, and this difference is probably typical. On small unregulated streams not fed by local springs, temperature variations of more than 20° F. in a single day have been observed, whereas the daily range on large spring-

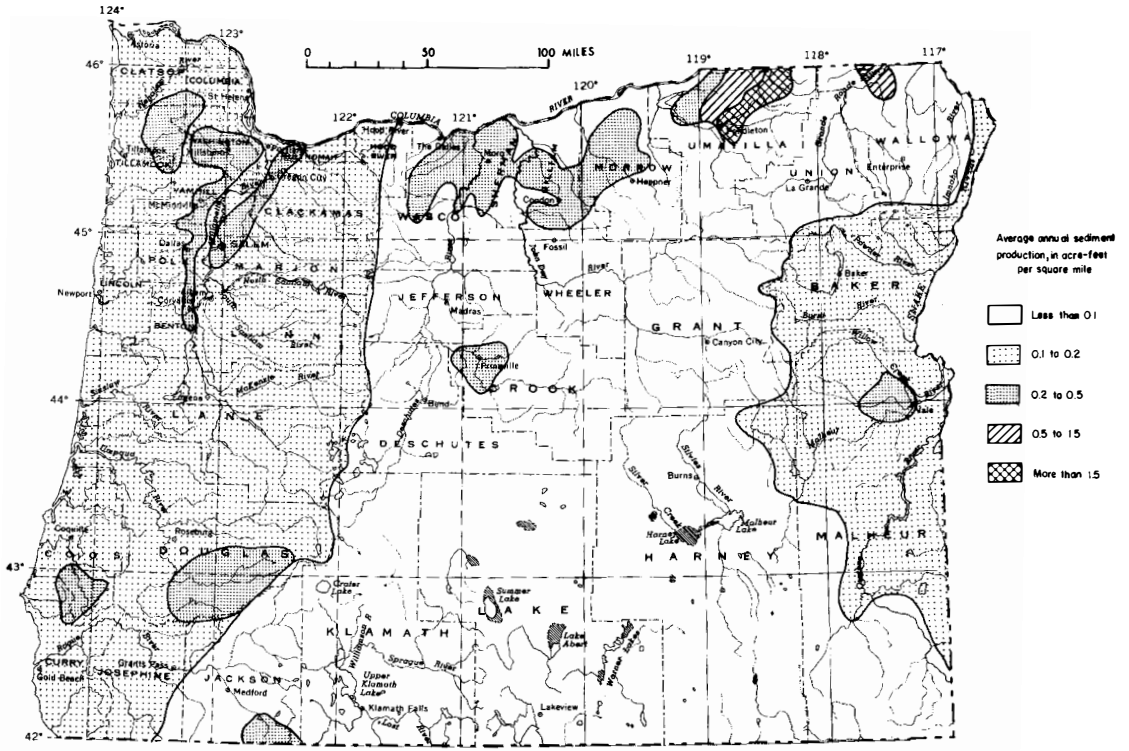


FIGURE 78.—Generalized map of sediment production in Oregon (after Flaxman and High, 1955).

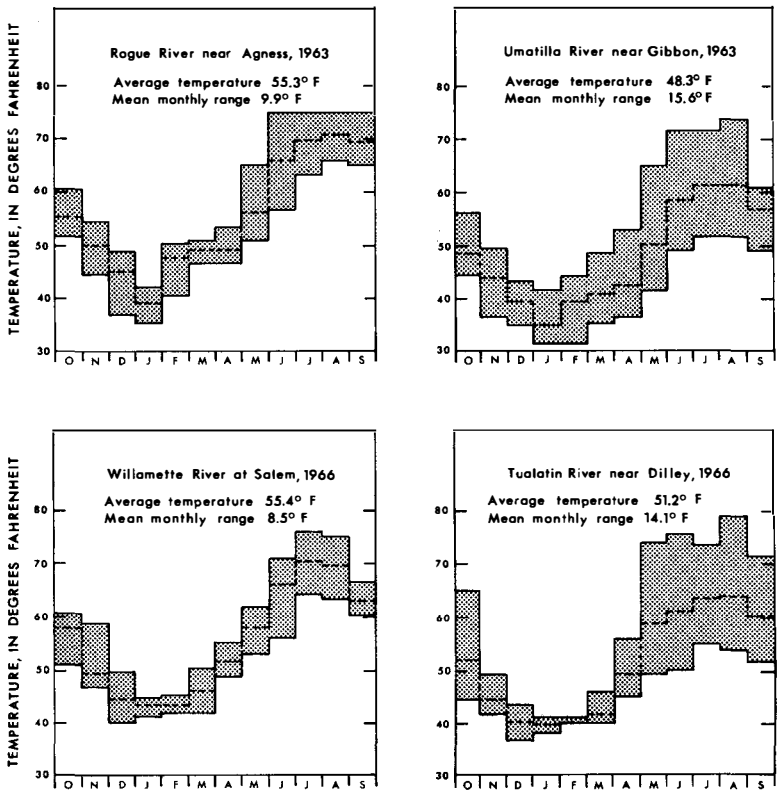


FIGURE 79.—Typical monthly range in temperature of four Oregon rivers.

fed streams seldom exceeds 6° F. Average winter temperatures of the streams are usually higher than basinwide air temperatures, because the temperature of flowing water usually does not fall below 32° F. In most reservoirs, temperature stratification occurs in summer, and the depth at which water is released affects monthly downstream temperature by as much as 8° F. (Moore, 1967, table 3.)

GROUND-WATER RESOURCES

PRINCIPLES OF OCCURRENCE

Ground water occurs in the saturated zone of an aquifer (a permeable formation of consolidated or unconsolidated rock material). In places it may be confined under hydrostatic pressure by less permeable overlying strata (in which event the pressure will cause water to rise in a well or even to flow at the surface), or it may be unconfined (water level in the well the same as in the aquifer).

A ground-water body is fed by infiltration of rain and snowmelt, or by leakage from a lake, river, or watered tract, and is drained by outflow to springs, by evapotranspiration, by diffuse seepage into

streams, or by the pumping or artesian flow of wells. The water table rises in periods of excess supply and falls in periods of drought or heavy draft. An aquifer is thus a natural storage reservoir. Springs that drain an aquifer form the base flow of streams in dry periods. There is, therefore, a continuing and complex interplay between what we, for convenience, call surface water and what we know as ground water.

AVAILABILITY

For economic withdrawal, the availability of ground water depends on the depth to water, the nature of the rock in which it occurs, the thickness of the zone of saturation, and the volume, porosity, permeability, and annual recharge of the aquifer. In Oregon, alluvial sand and gravel and Holocene and some Tertiary lavas usually yield water readily to wells that penetrate saturated zones. Pyroclastic and marine sedimentary rocks generally yield smaller amounts because of their lesser permeability. Wells in any locality or aquifier may differ

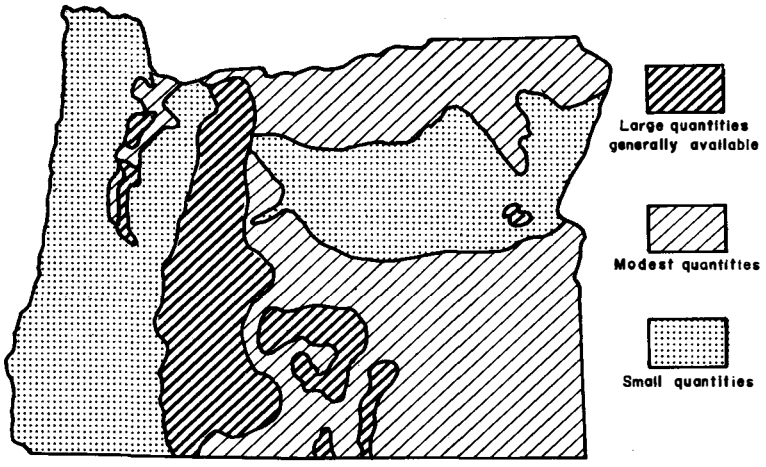


FIGURE 80.—Availability of ground water.

greatly in yield because of nonuniformity of the aquifer itself or because of differences in construction of the wells. The general availability of ground water in the State is shown in figure 80; many local exceptions exist.

The average annual recharge to aquifers in the State is estimated to be about 23 million acre-feet, equivalent to about one-sixth of the average Statewide precipitation. The recharge is about equally divided between eastern Oregon and western Oregon. About a quarter of the total recharge occurs in the basin of the Deschutes River.

The volume of ground water within 500 feet of the surface is estimated at about 250 million acre-feet, or three times the annual runoff of all the streams in the State. At least 80 percent of that total lies in eastern Oregon, where the annual natural recharge is only about 11 million acre-feet. The sustained yield economically recoverable from any aquifer is usually, as a practical matter, considerably less than its annual recharge.

Very large springs fed by ground-water bodies rise from volcanic rocks in the basins of the Deschutes, Klamath, Rogue, Umpqua, McKenzie, and Santiam Rivers, giving each of these streams a large, steady base flow of clear water in dry periods. On the Deschutes River alone, the combined flow of springs is about 4,000 cfs. Smaller springs are common in other areas.

QUALITY

Ground water generally contains somewhat more dissolved solids than do streams in the same area. Typical values for dissolved solids and hardness of water obtained from various geologic formations in Oregon are shown in figure 81.

Ground water from most sources is of the calcium magnesium bicarbonate type, having dissolved solids between 100 and 300 ppm and hardness between 50 and 150 ppm. Such water is suitable for almost any commercial or public purposes. Water from some fault zones, from marine sedimentary rocks, and from the alluvium of closed basins, is more highly mineralized.

The temperature of ground water is usually about the same as the mean annual air temperature at the site, plus 1.8° F. for each 100 feet of depth of its occurrence below the first 100 feet. Many exceptions to this generality exist, such as the many thermal springs in the State. Oregon has at least 105 thermal springs, of which 14 are used for resorts and 73 are used for other purposes (Stearns and others, 1935, p. 96). The potential use of these for the production of power is discussed on page 299. Some houses and other buildings in Klamath Falls are heated by natural hot water. Well drillers have reported water temperatures at depth along fault zones near Klamath Falls and Lakeview as high as 220° F. (data in files of Geological Survey, Portland, Oreg.). Other springs flow at only about 60° F., or 10° F. warmer than the mean annual air temperature. Some thermal springs have very small flow. The largest is probably the group of springs that feed Ana River near Summer Lake; they discharge about 90 to 100 cfs at a temperature of 66° F.

Ground water is preferred to surface water for some uses because of its near constancy in chemical and physical quality and its freedom from surface contamination and sediment.

PRINCIPAL DRAINAGE BASINS OF OREGON

The principal drainage basins are shown in figure 82. For convenience in discussion, Goose Lake is here considered as being in the basin of closed lakes, although overflow into the North Fork Pit River has occurred (p. 334). The Willamette River basin is considered separately from other Columbia River tributary basins because of its large concentration of population and water use and its distinctive water problems. Likewise, the basins of the Umpqua and Rogue Rivers are discussed individually because they differ from other Pacific coast basins in water production, water use, and water problems.

The tables that are presented in the following sections show observed flow of selected streams not adjusted for the effects of upstream storage, diversion, or consumptive use.

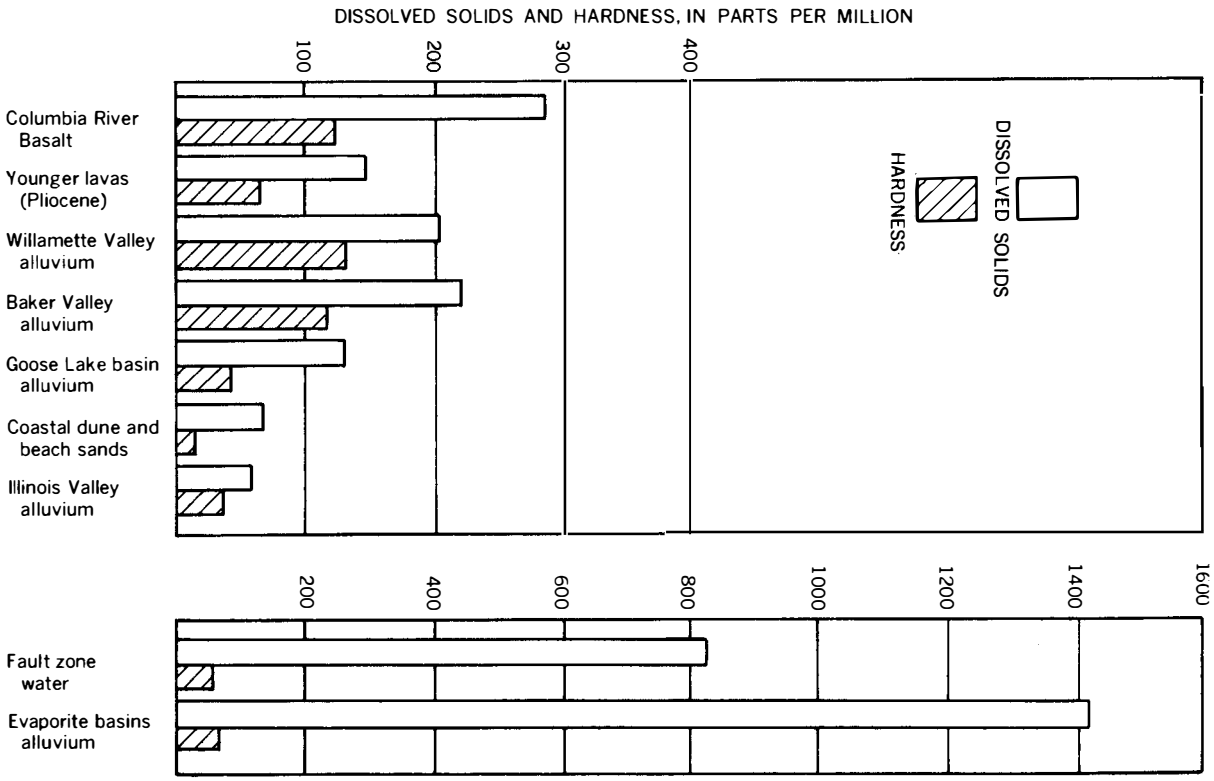


FIGURE 81.—Chemical quality of ground water.

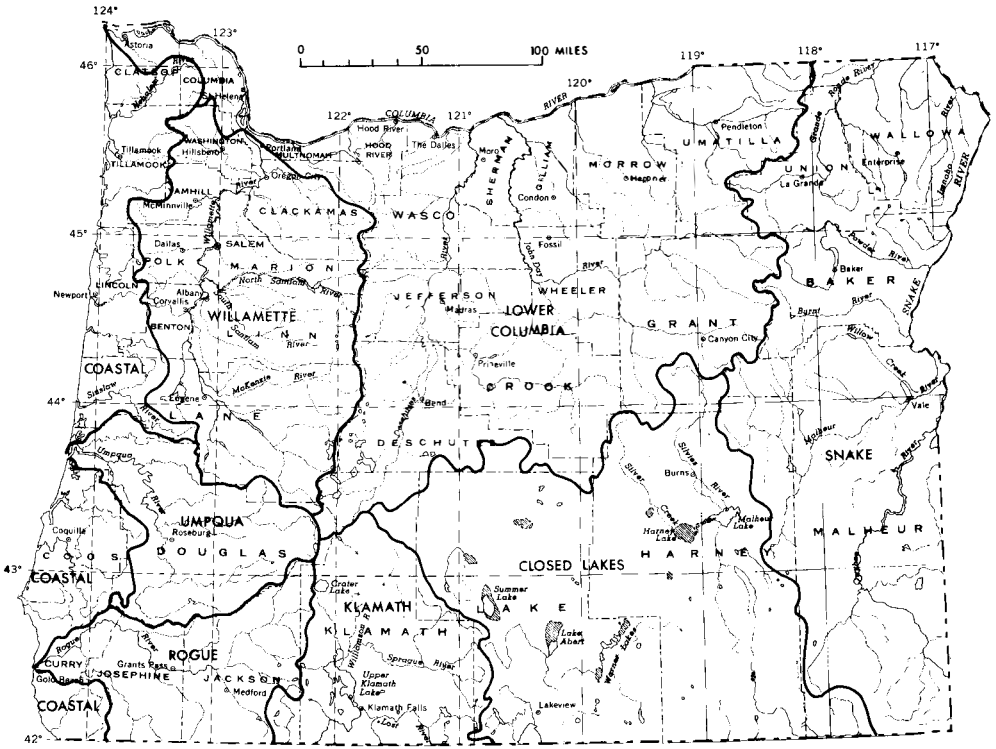


FIGURE 82.—Principal drainage basins of Oregon.

Closed-Lake Basins

WATER QUANTITY

An area of about 18,300 square miles in south-central and southeastern Oregon has no drainage outlet to the sea. All the streamflow not consumptively used is dissipated by evaporation from many shallow playas and several large lakes, including Goose, Abert, Summer, Silver, Malheur, and Harney Lakes, and a chain of 11 smaller lakes in Warner Valley. These lakes and many others lie in shallow basins between fault blocks in volcanic terrane.

The area is semiarid. Average annual precipitation ranges from less than 8 inches in some valleys to 30 inches or more on the slopes of the higher mountains. Many of the smaller streams have little or no flow except in periods of melting snow. The larger streams have been measured, and their records of flow are summarized in table 29. The annual runoff ranges from about half an inch in depth to about 10 inches. The streams listed drain only about one-seventh of the total area in the basins, but their combined flow is half the estimated total runoff of 1.1 million acre-feet per year.

TABLE 29.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN CLOSED-LAKE BASINS

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
Twentymile Creek near Adel	194	31	49.0	35,470	3,670	0
Deep Creek above Adel	249	38	121.0	87,600	9,420	1.7
Drews Creek near Lakeview	212	35	68.6	49,660	3,000	0
Chewaucan River near Paisley	275	51	138.0	99,910	6,490	0
Ana River near Summer Lake	(1)	18	92.7	67,110	188	6.0
Silver Creek near Silver Lake	180	54	28.2	20,420	1,800	0
Silvies River near Burns	934	53	163.0	118,000	4,960	0
Donner und Blitzen River near Frenchglen	200	36	119.0	86,150	2,750	6.4
Trout Creek near Denio	88	35	14.5	10,500	470	.1

[1] Spring fed.

Ground-water aquifers consist of alluvial and lacustrine deposits near the various lakes, and Tertiary volcanic rocks. Saturated zones within 500 feet of the surface contain a volume of water that is probably many times the annual runoff. About 0.8 million acre-feet per year is naturally discharged from these aquifers by springs and seeps that provide the base flow of streams. The largest springs occur in the basin of the Donner und Blitzen River.

WATER QUALITY

Streamflow water in the closed-lake basins is of good quality for irrigation. Dissolved-solids concentration ranges from about 100 ppm for the Chewaucan and Donner und Blitzen Rivers to more than 200 ppm for some streams in periods of low flow. Water temperatures are commonly 70° F. or higher in late summer and near freezing from November to April. Sediment transport is low except in periods of

high runoff. Some streams that drain large marshy areas have a brownish color from organic matter.

The larger lakes have a wide range in chemical quality. Because of frequent overflow into Harney Lake, the water of Malheur Lake is relatively fresh; it is commonly used for stock watering, and freshwater plants grow in the shallower parts of the lake. Harney Lake, with no outflow, is highly saline, as are Summer and Abert Lakes. Goose Lake has only about 1,000 ppm of dissolved solids, even though its overflow within the last 99 years has been negligible. Silver Lake, which appears to lose some water by seepage, is relatively fresh. Crump and Hart Lakes, in Warner Valley, are frequently freshened by overflow, and their waters are suitable for irrigation. In all the lakes, the mineral concentration is increased as evaporation reduces the lake volume. For example, Abert Lake at a low stage in 1939 contained 94,900 ppm of dissolved solids, whereas at a high stage in 1958 it contained only 18,700 ppm.

The water from large springs that rise from Tertiary basalt and feed the Donner und Blitzen River is soft, cool, and of excellent quality. Most smaller springs yield water that is moderately mineralized, containing 200 to 500 ppm of dissolved solids; most wells in alluvial and volcanic formations have water of similar quality. Deep wells and springs that rise from great depths yield water warmer than the mean annual air temperature, and some springs that appear in fault zones near Lakeview are boiling; most such thermal water contains dissolved solids in excess of 1,000 ppm. In Harnev Basin, some shallow wells in alluvium contain 5,000 to 63,000 ppm (Piper and others, 1939, p. 114–119), but other wells and springs in the same general area are entirely suitable for irrigation and for stock water. Alluvium near Goose Lake yields water of excellent quality.

WATER USES

Water in the closed-lake basins is used chiefly for irrigation of hay and small-grain crops. About 261,000 acres of land is irrigated (less in dry years), using more than 500,000 acre-feet of water and consuming more than 300,000 acre-feet per year. About one-tenth of the water used is ground water. No water is diverted into or out of the basins. Reservoirs store water on Drews, Cottonwood, and Silver Creek.

Wells supply water for Burns, Lakeview, and several smaller communities. Livestock and game depend on water from streams, springs, playas, and thousands of stock ponds and tanks. The forest-products industry uses a small amount of water for log ponds, quality control, and fire protection.

The streams and reservoir provide recreation for thousands of anglers. The marshes of Summer Lake, Warner Valley, and Harney Basin are feeding, resting, and nesting areas for large numbers of local and migratory waterfowl. The Malheur Migratory Waterfowl Refuge on the Donner und Blitzen River and around Malheur and Harney Lakes is a haven for birds on the Pacific Coast flyway. The Hart Mountain Antelope Refuge, east of Warner Valley, is the largest area in the State dedicated chiefly to the protection and increase of wildlife.

WATER PROBLEMS

The chief water problem in the area is the lack of enough water to irrigate all the arable land available. Some land is irrigated only in wet years.

The variability of flow, even in the larger and more dependable streams, is illustrated by the extremes of flow listed in table 29. Floodflows inundate thousands of acres of arable land, sometimes for periods of months or years, including the beds of lakes that have been dry farmed at other times (Silver, Flagstaff, and Malheur Lakes, for example). Streams have only small flow or none in late summer.

There is a lack of detailed knowledge of ground water—its depth, quantity, quality, and recharge rate—that is due in part to economic factors (the cost of drilling deep wells in volcanic rock is high) and in part to the diversity of geologic conditions in deposits cut by many large faults.

Snake River Basin

WATER QUANTITY

Tributaries of the Snake River drain more than 19,100 square miles of eastern Oregon. From the Powder River basin southward, much of the area is a high semiarid dissected plateau, mostly between 2,500 and 5,000 feet altitude, that merges into the higher peaks of the Blue Mountains and other isolated ridges. Annual runoff in that part of the basin ranges from about half an inch to 5 inches or a little more. To the north, the Wallowa Mountains rise steeply to about 10,000 feet altitude, and there the alpine-area runoff exceeds 40 inches in places. Thus, although the Grande Ronde River drains less than 20 percent of the area it contributes more than 60 percent of the total runoff to the Snake from Oregon.

The gaged areas listed in table 30 include half the total Snake River drainage area in Oregon and their combined flow is equivalent to about 90 percent of the 3.6 million acre-feet annually contributed to the Snake River from the State. The Snake River flows about 8 million acre-feet per year at the point where it first becomes Oregon's eastern boundary, and about 15 million acre-feet more where it leaves the State; three-fourths of that increment comes from streams in Idaho.

TABLE 30.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE SNAKE RIVER BASIN

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
Snake River near Murphy, Idaho	41,900.0	53	10,760.0	7,790,000	47,300	3,900.0
Owyhee River near Rome	8,000.0	17	830.0	660,900	33,500	42.0
Owyhee River below Owyhee Dam	11,160.0	34	319.0	230,900	22,900	0.0
Malheur River near Drewsey	910.0	40	174.0	126,000	12,000	0.0
North Fork, Malheur River, above Agency Valley Reservoir	355.0	30	125.0	90,500	3,970	12.0
Burnt River near Hereford	309.0	38	81.7	59,150	2,220	0.0
Powder River near Baker	219.0	49	111.0	80,360	1,820	0.0
Eagle Creek above Skull Creek, near New Bridge	156.0	9	316.0	228,800	2,690	44.0
Imnaha River at Imnaha	622.0	38	497.0	359,800	6,650	16.0
Grande Ronde River at La Grande	678.0	58	378.0	273,700	14,100	3.9
Wallowa River at Joseph	50.9	39	130.0	94,120	1,200	0.0
Grande Ronde River at Troy	3,275.0	22	3,136.0	2,270,000	42,200	418.0
Snake River near Anatone, Wash	92,960.0	8	32,630.0	23,620,000	128,000	6,010.0

The average annual runoff of the Snake River has been depleted by evaporation from upstream storage and by consumptive use for irrigation of 3 million acres of land above the gaging station near Anatone, Wash. Further depletion will occur as additional land is irrigated, but much of the water used for irrigation returns gradually to the streams, so that the minimum flow is not expected to be reduced and is more likely to be increased thereby.

Occasional torrential downpours occur locally at times in summer. Their volume is small and of little significance as a source of supply.

Natural recharge and outflow to springs and seeps probably exceed a million acre-feet per year. Tertiary lavas form the principal groundwater aquifers. Saturated alluvium occurs in stream valleys and lacustrine deposits in the Willow Creek and the Middle Grande Ronde River basins. Wells near La Grande yield small to moderate quantities of water from unconfined aquifers in alluvial-fan and valley-fill deposits and larger amounts from basalt or confined aquifers in alluvium. For example, a public-supply well drilled to 655 feet at Elgin penetrates a confined basalt aquifer and yields 500 gpm (gallons per minute) by artesian flow, and up to 1,100 gpm when pumped.

WATER QUALITY

Water in streams in the Snake River basin is generally of satisfactory quality. The Owyhee and Malheur Rivers are suitable for irrigation, their dissolved-solids concentration ranging from about 150 ppm in periods of high flow to 500 ppm or more in periods of low flow. The Grande Ronde River is much less mineralized (fig. 77). Stream temperatures generally range from 32° to 45° F. in the period November to March, and into the middle 70's in late summer, except below reservoirs in which temperature stratification occurs. Sediment transport is generaly moderate except locally near Vale and in the northern Grande Ronde River basin, where occasional intense storms cause local floods that have large concentrations of sediment for periods of a few hours or days.

The chemical quality of ground water generally ranges from fair in the south (Owyhee and Malheur Basins) to excellent in the north. Wells in alluvial gravel at Ontario yield water with 400 to 800 ppm of dissolved solids and more than 200 ppm of hardness. The water in Cow Valley (Owyhee River basin) has a hardness of about 100 to 150 ppm. Most wells in Baker Valley alluvium yield good water, having low salinity and low alkali hazards for irrigations; those in a small tract 8 to 10 miles northwest of Baker have high salinity and alkali hazards. In the Grande Ronde River basin near La Grande, water from the valley fill is of excellent quality.

Thousands of small springs and seeps provide the base flow of streams between periods of rainfall or snowmelt. Most springs that rise in valley fill or in volcanic rocks are similar in quality to well waters of the area. About 30 thermal springs exist, many of them rising from lava rocks near fault zones. Vale Hot Spring (198° F.), at a bathing resort half a mile east of Vale, rises from Tertiary lakebeds; a well 140 feet deep at the site also produces hot water. Hot Lake Spring (180° F.), 10 miles southeast of La Grande, has also been used as a public resort.

WATER USES

Irrigators of about 450,000 acres in the basin divert about 1,900,000 acre-feet of water per year, of which about 780,000 acre-feet is consumed. Nearly half the total irrigated area lies in Malheur County, and the principal water source is surface water from the Owyhee and Malheur Rivers and their tributaries. About 150,000 acres is irrigated in Baker County, mostly from the Burnt and Powder Rivers. Wells furnish ground water to irrigate about 25,000 acres in the basin. Fruit, hay, grain, and grass seed are important crops in the area.

In addition, water is diverted from the Owyhee River at Owyhee Dam to irrigate land near Homedale in Idaho.

Forest-products, food-processing, and building-materials plants are the chief industrial water users. The lumbering activity is centered near Baker and La Grande, and the food processing, including a large beet-sugar refinery, near Ontario. In general, forest-products plants use surface water; food-processing plants use ground water. Average industrial use of self-supplied water in the area is about 40,000 acre-feet per year.

About 35,000 people in the area are served by public water supplies, mostly derived from springs or wells. The town of Union uses water from Catherine Creek; Baker and La Grande (combined pop. more than 19,000) use surface streams in part.

Storage reservoirs on the Owyhee, Malheur, Burnt, and Powder Rivers supply water for irrigation. A dam at the outlet of Wallowa Lake is used to regulate the outflow for irrigation. On the Snake River, Brownlee Reservoir provides almost a million acre-feet of storage to control floods, produce power, and increase the low flows; Oxbow and Hells Canyon Dams have run-of-river powerplants. The reservoirs are also widely used for recreation, as are many natural lakes in the headwaters of the Powder, Imnaha, and Grande Ronde Rivers.

WATER PROBLEMS

Water supply is inadequate to irrigate all the arable land in the basins of the Owyhee and Malheur Rivers, even though four reservoirs with a combined capacity of 1,400,000 acre-feet provide some carryover storage in most years. The reservoirs fail to fill in some years because the combined average annual upstream runoff is only 60 percent of their capacity, and in dry years the flow is much less.

Seasonal variability of flow is marked. Except for some snow-fed streams in the Wallowa Mountains, unregulated flows are very low in midsummer, when the need for water is greatest. Floods caused by general rains or melting snow commonly occur in late winter or spring; cloudburst storms in summer cause intense floods and severe erosion, but usually are limited to a few square miles in area.

The preservation and planned increase of salmon and other migratory fish on the Snake River and its tributaries, the Powder, Imnaha, and Grande Ronde Rivers in Oregon, are currently receiving much attention. Natural spawning areas sometimes are destroyed by dams and reservoirs. Dams present barriers to upstream-bound adults and may cause a loss of seabound fingerlings. Water temperatures become stratified in deep reservoirs; the adult fish below such a pool,

preferring the cool water released through powerplant outlets, may refuse to climb a fish ladder that uses warmer surface water.

The irrigation of land removes some soluble minerals from the soil, and the return flows carry those minerals to the nearest stream. Successive diversion and use increases the concentration. Thus, the dissolved-solids concentration of rivers used for irrigation tends to increase downstream. Concentrations of more than 1,000 ppm have been observed near the mouths of the Owyhee River, the Malheur River, and Willow Creek, and no doubt occur elsewhere at times (Laird, 1964, table 1).

Lower Columbia River Basin

Tributaries of the Columbia River in Oregon, except the Willamette River, are included in this subsection. The basin covers 25,700 square miles, extending from the Walla Walla River, which enters the Columbia above McNary Dam, to the Youngs River at Astoria. In that distance of 314 miles, the river drops only 340 feet, yet it passes through a wide range of climatic conditions (from 8 to 80 in. annual precipitation) and water-use patterns.

WATER QUANTITY

The average annual runoff from this area in Oregon to the Columbia River is about 13 million acre-feet. Table 31 shows the observed discharges of the principal rivers from areas totaling 21,200 square miles. The streams vary greatly in their characteristics. In their lower reaches, the Walla Walla, Umatilla, and John Day Rivers traverse arid regions and commonly receive less water than is diverted from them. Tributaries of the Deschutes River, except Squaw Creek and the Crooked River above Prineville Reservoir, are fed by very large springs with nearly constant flow. Water for irrigation in the Deschutes River basin is stored in four large upstream reservoirs, and water for power is stored in a reservoir downstream from irrigation diversions. The Hood and Sandy Rivers drain the humid slopes of Mount Hood. The Clatskanie and Youngs Rivers are typical of the small streams that enter in the low-altitude humid reach downstream from the Willamette River.

Flows of the Columbia River have been progressively regulated during the periods of record, and further regulation will ensue from dams now under construction. The regulated low flow at The Dalles is now about 90,000 cfs, and the maximum seldom exceeds 700,000 cfs. Increasing irrigation use upstream from The Dalles has depleted the average flow there by about 4 percent, and further depletion is expected as more reservoirs are built and more water is diverted. The average flow at the mouth of the Columbia has been computed as 272,500 cfs in water years 1943–57; the average flow for the period since 1878 is about 265,000 cfs.

The natural recharge of ground-water aquifers that later appears as base flow of streams in periods of no direct runoff is about 7.5 million acre-feet per year. About 5.4 million acre-feet of that total occurs in the Deschutes River basin, where, on the eastern slope of

TABLE 31.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE LOWER COLUMBIA RIVER BASIN

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Maximum (c.f.s.)	Minimum (c.f.s.)
			C.f.s.	Acre-feet per year		
South Fork, Walla Walla River near Milton	63.0	45	175	126,700	2,530	72.0
Columbia River below McNary Dam	214,000	16	185,900	134,600,000	818,000	50,600.0
Umatilla River above Meacham Creek, near Gibbon	131	33	221	160,000	4,910	16.0
Umatilla River near Umatilla	2,290	39	434	314,200	19,800	0
John Day River at Prairie City	231	28	113	81,810	2,400	2.0
North Fork, John Day River, near Monument	2,520	41	1,198	867,300	33,400	6.0
John Day River at McDonald Ferry	7,580.0	61	1,998	1,446,000	42,800	0
Deschutes River at Benham Falls	1,759.0	49	1,413	1,023,000	5,000	363.0
Squaw Creek near Sisters	54.8	54	106	76,740	1,980	14.0
Crooked River above Prineville Reservoir	2,400.0	6	292	211,400	19,700	.2
Crooked River below Opal Springs	4,300.0	5	1,530	1,108,000	6,660	972.0
Metolius River near Grandview	316.0	46	1,483	1,074,000	7,530	1,080.0
Deschutes River near Madras	7,820.0	43	4,425	3,204,000	15,800	1,200.0
Deschutes River at Moody, near Biggs	10,500.0	62	5,825	4,217,000	75,500	2,400.0
Columbia River at The Dalles	237,000.0	88	194,500	140,800,000	1,240,000	35,000.0
Hood River near Hood River	329.0	51	1,099	795,600	34,000	165.0
Sandy River below Bull Run River	440.0	41	2,356	1,706,000	84,400	45.0
Clatskanie River near Clatskanie	53.0	5	130	94,120	2,000	3.0
Youngs River near Astoria	40.1	31	178	128,900	4,750	3.3

the Cascade Range, moderate to heavy annual precipitation falls in a large area underlain by permeable surface materials and deep aquifers of large storage capacity.

The saturated gravelly fan of the Walla Walla River near and downstream from Milton yields water readily to shallow wells. The water table in the fan has a seasonal range of 5 to 30 feet, rising to its peak during or soon after the period of high flow in the river, and reaching its low point in autumn or early winter. Wells and springs near Pendleton yield water from a structural valley in basalt filled with alluvium, to supply that city of 16,000 people. Sand and gravel deposits in the Crooked River valley near Prineville form a confined aquifer that yields water to wells at rates in excess of 500 gpm. Ground water occurs in basalt at The Dalles; its level is somewhat below the water level of the adjacent Columbia River, and has recently been declining at a rate of about 3 feet per year. Alluvium close to the Columbia River from Troutdale downstream is the source of several large municipal and industrial supplies.

WATER QUALITY

Both surface and ground water in the semiarid region east of Hood River generally are more highly mineralized than that in the more humid area farther west. The natural mineralization is increased by the return to the rivers in the semiarid zone of water that has been used for irrigation and contains mineral constituents leached from the soil, including mineral products applied as fertilizers. The greatest observed concentrations of dissolved solids and hardness were 507 and 262 ppm, respectively, in low-flow samples from Walla Walla River near Touchet, Wash.; but high-flow samples from the same site had only about 100 ppm of dissolved solids and 40 ppm of hardness (Santos, 1965, pp. 10–12). Surface water in the Umatilla, John Day, and

Crooked River basins is slightly less mineralized than that in the Walla Walla River. The Deschutes River and its west-bank tributaries and the Hood and Youngs Rivers usually have less than 100 ppm of dissolved solids even at low flow. All the waters are of the calcium magnesium bicarbonate type.

The temperature of Columbia River water is affected by both air temperature and temperatures of inflowing streams. (See figs. 83 and 84.) In midsummer the cool water passing Revelstoke, B.C., is gradually warmed as it flows downstream. The water temperature drops abruptly at Coulee Dam because the water released from the bottom of the reservoir is usually cooler than the inflow. In early winter, water released from the reservoir is usually warmer than the inflow, but the river cools gradually downstream as it is exposed to air temperatures that are near or below freezing. The effect of using part of the river water for cooling future thermal-energy plants is uncertain and is being studied.

Sediment concentration is low on the Deschutes River and on streams farther west. The basins of the Umatilla, John Day, and Crooked Rivers, and Willow Creek are subject to occasional severe erosion by water under two differing conditions: (1) localized torrential summer downpours that cause local floods of great intensity but short duration; and (2) sudden warm winter rains falling on large areas of tilled or bare frozen ground that cause rapid thawing and quick loss of the light volcanic-ash soil. Under the second condition, a single sample from Willow Creek at Heppner during the flood of December 22, 1964, contained 125,000 ppm of suspended solids, and on that day John Day River at McDonald Ferry transported 3.8 million tons of sediment. But even those streams are normally not heavily charged with sediment; for example, the John Day River transported only 760,000 tons in a 12-month period ending in August 1912 (Van Winkle, 1914, p. 73).

Radioactivity in the Columbia River is naturally low. Water from the river is used for cooling the plant of the Atomic Energy Commission at Hanford, Wash., and returned to the river containing a very small amount of radionuclides. The radioactivity decreases downstream from Hanford (Santos, 1965, pp. 58–61).

Because of tidal movement of water in the estuary, salt water extends upriver for at least 16 miles from the mouth. Mixing is not complete, and salinity usually is greater near the bottom of the river. Salt water has not been observed at a test site 24 miles from the mouth (Santos, 1965, p. 56).

WATER USES

About 1.8 million acre-feet of water is used annually to irrigate 360,000 acres of land in the area, in years when water supply is adequate. About 10 percent of the land is irrigated with ground water. The rate of water use is high in the Umatilla River basin because much of the soil there is highly permeable, and also in the Deschutes River basin, where long canals in permeable volcanic rocks have high conveyance losses. Forest-products, building-materials, aluminum, and food-processing industries are the chief industrial users of water. Especially in the reach from Cascade Locks downstream to Portland, water is the focal point for recreational activity at dozens of public

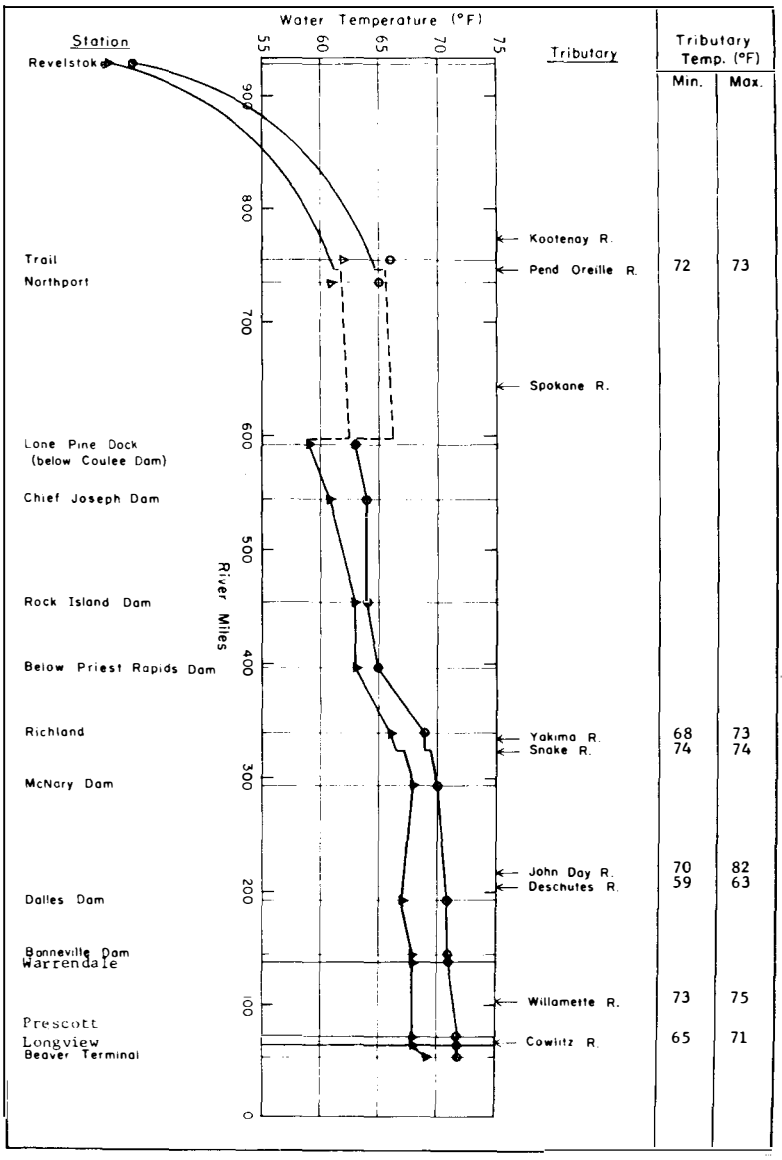


FIGURE 83.—Profiles of maximum and minimum water temperature in the Columbia River, August 8–14, 1967. Abrupt change in profile represents estimate of effect of tributary or of storage release. Dashed lines represent estimates of stream temperatures excluding the effects of the reservoir on impounded water. Extremes of temperature in reservoir are not known.

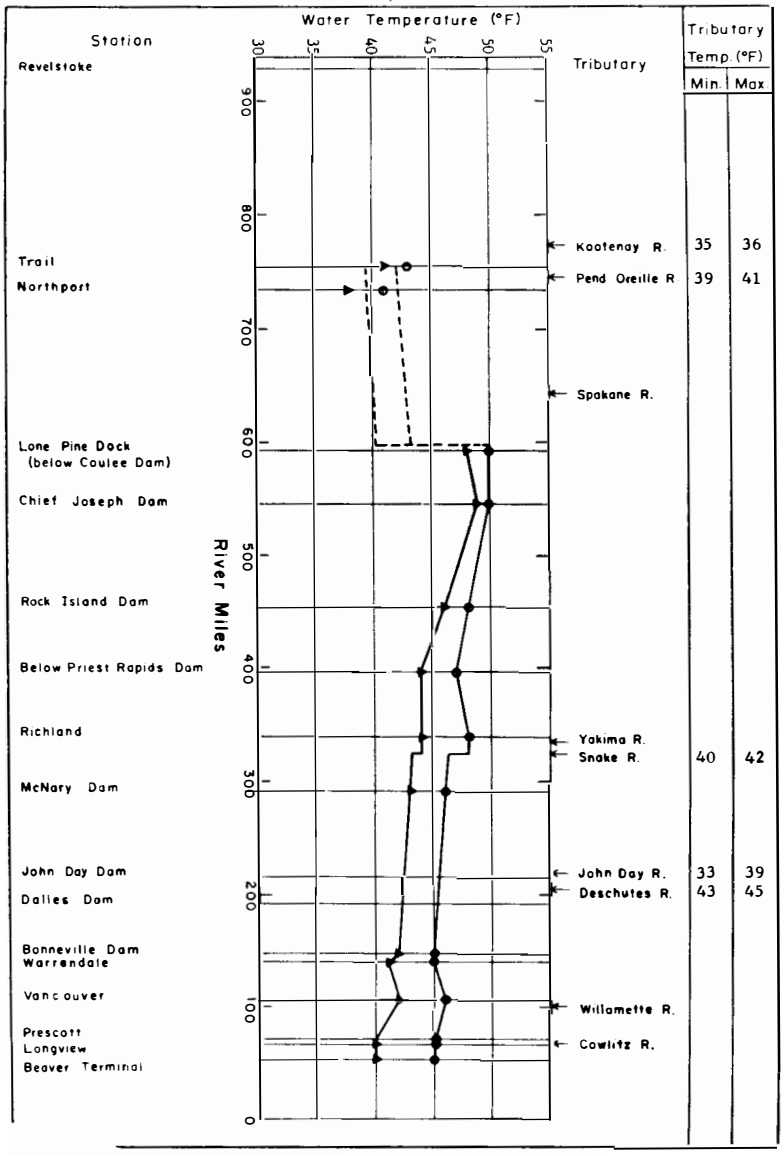


FIGURE 84.—Profiles of maximum and minimum water temperature in the Columbia River, December 12–18, 1967. Abrupt change in profile represents estimate of effect of tributary or of storage release. Dashed lines represent estimates of stream temperatures excluding the effects of the reservoir on impounded water. Extremes of temperature in reservoir are not known.

parks and private marinas; a single State park at Rooster Rock had more than 500,000 visitors in 1967. The downstream 100-mile reach of the Deschutes River and all the small streams in the Columbia Gorge are reserved for recreational use.

Public supplies serve about 63,000 people in the area. Pendleton, Heppner, Hermiston, Arlington, and Troutdale use ground-water supplies. Bend diverts water from Bridge and Tumalo Creeks; Astoria uses water from Bear Creek. The cities of Hood River, The Dalles, and Scappoose use a combination of surface- and ground-water supplies.

The Columbia River is increasingly used for navigation. A 40-foot channel is maintained from the mouth up to the Willamette River, and a 27-foot depth from that point to the head of tide at Bonneville. Slackwater is provided by Bonneville, The Dalles, John Day, and McNary Dams, all with locks of 14-foot draft or more for river steamers and barge tows. Upstream barge cargo consists chiefly of petroleum products; the same barges are commonly used to carry grain from Umatilla and other ports downstream to Portland for milling or trans-shipping. Log rafts are towed downstream for processing. Lockage at Bonneville Dam has recently exceeded 4.9 million tons in a single year. Between the Willamette River and the mouth, river and oceanbound traffic exceeded 25 million tons in 1965. Much of the incoming cargo consists of petroleum, building products, and alumina; forest and agricultural products are the chief exports.

The only Oregon stream open to licensed commercial salmon fishing is the 140-mile reach of the Columbia from Bonneville to the sea. Catches of the famed chinook, silver, blueback, and chum salmon (including salmon caught at sea) in 1965 amounted to 17 percent of the State's total catch of 61 million pounds of fishery products, and 37 percent of their value. Fishing is regulated to ensure release of adequate numbers of adults bound upstream; in 1966, more than 550,000 such adults passed up the Oregon ladder at Bonneville Dam—at times more than 20,000 in a single day.

WATER PROBLEMS

Most of the agricultural land in the area east of the Hood River basin is dry-farmed because an adequate water supply has not been available, and the natural flow of the Walla Walla, Umatilla, and John Day Rivers and many smaller streams is inadequate in some years even for the land now under irrigation. Cheap electric power for pumping from the Columbia River may warrant irrigation of part of this area. Even in the humid area northwest of Portland, the natural stream flows are very low in dry periods, and irrigation by pumping from the Columbia River is increasing.

The water of the Hood River in late summer contains much abrasive sediment derived from the glaciers of Mount Hood, that tends to clog diversions and rapidly erodes sprinkler heads. The Sandy River water is similar, but it is used for sprinkler irrigation much less than is the Hood River water.

In the Redmond-Bend-Sisters area, ground water is not readily available, and many rural users depend on surface-water diversions

for domestic supply. However, bacterial pollution, as indicated by coliform count, is generally low (Santos, 1965, pp. 25–27). Algae are present, however, especially in late summer.

Releases of wastes from pulp and paper mills have created serious problems in the reach downstream from Camas, Wash. The wastes contain nutrients for algal growths, and substances that have a high biochemical oxygen demand; hence they are deleterious to fishery resources. The industries and State agencies concerned are cooperating to find a solution.

Soil erosion and sediment movement are problems on Crooked River above Prineville and at occasional intervals in all the eastern part of the basin because of localized cloudburst floods and sudden thawing of frozen ground by warm rain. On June 14, 1903, a flash flood with a peak flow of about 36,000 cfs and a duration of less than an hour swept down Balm Fork and Willow Creek, destroying much of the town of Heppner and causing the loss of 225 lives. On the Umatilla River, Furnish Reservoir (drainage area, 1,280 sq mi) was built in 1910 with a capacity of 3,900 acre-feet; it was filled with sediment and abandoned by 1934.

Willamette River Basin

WATER QUANTITY

The Willamette River drains about 11,200 square miles and has an average discharge of about 34,000 cfs at its mouth. Seventy percent of the population and a large part of the industry of the State are concentrated in the basin.

None of the basin is arid, but rainless periods occur frequently—one of 72 days' duration occurred in 1967—and at such times streams that do not draw upon a large reserve of ground water dwindle to a trickle or are completely diverted for use. Table 32 lists the principal streams and their flow. In general, streams that drain the west slope of the Cascade Range (the Middle Fork Willamette, McKenzie, Santiam, and Clackamas Rivers) have an average flow of 3 cfs or more per square mile and a low flow that is well sustained by ground water issuing from productive volcanic aquifers. Some of the rivers that drain the less permeable east slope of the Coast Range have comparable average flow (the Luckiamute and South Yamhill Rivers, for example); but all of them, and those that drain the valley floor, have extremely low flows in summer.

A network of multipurpose reservoirs listed in table 33 is operated by the Corps of Engineers, U.S. Army, to control floods, produce electric energy, and increase low flows for improvement of navigation and abatement of pollution.

The operation of the reservoirs tends to reduce maximum flows and increase minimum flows. The extreme flows listed in table 32 are those observed in the various periods of record and should not recur on streams now regulated. For example, the low flow of Willamette River at Albany is now generally maintained at more than 4,000 cfs.

The central lowland of the Willamette Valley covers nearly 3,000 square miles and ranges from 30 to 450 feet in altitude. A permeable alluvial fill that ranges from a few feet to 300 feet in thickness covers

TABLE 32.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE WILLAMETTE RIVER BASIN

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
Middle Fork, Willamette River below North Fork	924.0	44	2,734.0	1,979,000	81,800	322.0
Fall Creek below Winberry Creek	186.0	31	582.0	421,400	24,700	1.5
Middle Fork, Willamette River at Jasper	1,340.0	23	4,067.0	2,944,000	94,000	366.0
Coast Fork, Willamette River below Cottage Grove Dam	104.0	27	285.0	206,300	5,910	0
Row River near Cottage Grove	270.0	27	759.0	549,500	21,400	.2
Coast Fork, Willamette River near Goshen	642.0	22	1,732.0	1,254,000	58,500	36.0
McKenzie River near Coburg	1,337.0	22	5,966.0	4,319,000	88,200	1,080.0
Long Tom River at Monroe	391.0	43	780.0	564,700	19,300	0
Calapooia River at Albany	372.0	26	923.0	668,200	32,700	3.9
Willamette River at Albany	4,840.0	72	14,460.0	10,470,000	340,000	1,840.0
Santiam River at Jefferson	1,790.0	36	7,790.0	5,640,000	197,000	260.0
Luckiamute River near Suver	240.0	32	930.0	673,300	32,900	.6
South Yamhill River near Whiteson	502.0	26	1,745.0	1,263,000	47,200	7.0
Willamette River at Wilsonville	8,400.0	18	29,030.0	21,020,000	339,000	3,600.0
Molalla River near Canby	323.0	34	1,134.0	821,000	43,600	20.0
Tualatin River at West Linn	706.0	38	1,487.0	1,077,000	29,300	11.0
Clackamas River at Estacada	671.0	58	2,701.0	1,955,000	86,900	50.0
Johnson Creek at Sycamore	28.2	26	53.9	39,020	2,620	.1

TABLE 33.—MULTIPURPOSE RESERVOIRS IN THE WILLAMETTE RIVER BASIN, 1967

Reservoir	Stream	Drainage area (square miles)	Usable capacity (thousand acre-feet)
Hills Creek	Middle Fork, Willamette	389	249
Lookout Point	do	991	349
Dexter	do	1,000	(1)
Fall Creek	Fall Creek	184	115
Cottage Grove	Coast Fork, Willamette River	104	33
Dorena	Row River	265	78
Cougar	South Fork, McKenzie River	207	165
Fern Ridge	Long Tom River	252	101
Detroit	North Santiam River	437	340
Big Cliff	do	450	(1)
Green Peter	Middle Santiam River	273	333
Foster	South Santiam River	492	34

[1] Reregulation.

most of the valley and in places yields water copiously to wells. Each summer the water table falls from 5 to 20 feet in places because of the combination of pumping and natural drainage to streams. The alluvium is recharged each winter by local precipitation and runoff. Bedrock formations that underlie the alluvium in the central plain are poorly pervious; some wells in marine sedimentary rocks tap water with high mineral concentration. Near Portland, several wells yield up to 1,000 gpm, chiefly from gravel and basaltic aquifers.

In the entire basin, the natural recharge to ground-water aquifers is about 7 million acre-feet per year. Much of the recharge occurs on the west slopes of the Cascade Range and is released naturally through springs and seeps that maintain the base flow of the larger streams such as the Middle Fork, McKenzie, Santiam, and Clackamas Rivers. The alluvial fill of the central plain receives more than a million acre-feet of recharge per pear. Scanty recharge in the acquifers on the east slope of the Coast Range is responsible for the low base flow of streams in that area.

WATER QUALITY

The natural chemical and physical characteristics of surface water throughout the basin are excellent. All surface water is of the calcium magnesium bicarbonate type. Water from the Willamette River at Salem contained 41 to 83 ppm of dissolved solids in samples taken from August 1910 toAugust 1912 and 38 to 73 ppm in samples taken from October 1951 to September 1964. Eleven samples taken from the Portland harbor from October 1959 to September 1960 ranged from 44 to 65 ppm in dissolved solids. Suspended sediment at Salem (1910–12) ranged from 1 to 88 ppm and water temperature (1963–66) from 38° to 76° F. The larger east-bank tributaries, the McKenzie, Santiam, and Clackamas Rivers, have even less mineral content and transport less suspended sediment.

From a biological standpoint, the natural high quality of the Willamette River and some of its tributaries has been impaired by the discharge of cannery waste, sewage, and sulfite-liquor waste from papermills. Further pollution occurs in Portland whenever storm runoff reaching the sewer system exceeds the capacity of the treatment plant.

Most ground water in the basin has two to four times the concentration of disolved solids as surface water. Piper (1942, pp. 60–63) and Madison (1966, pp. 32–37) listed dissolved-solids concentrations and hardness of water from many wells in the basin. Several wells tap lenses of highly mineralized water in marine sedimentary rocks. For example, water from a well in Tertiary shale 2½ miles south of Corvallis contained 18,100 ppm of dissolved solids; another well near Yamhill contained 8,450 ppm; and three others in Linn, Marion, and Washington Counties contained 1,930 to 4,870 ppm. In those analyses, chloride content ranged from about 50 to 60 percent of the dissolved solids. Several wells in Washington County and one each in Benton and Yamhill Counties contain more than 10,000 ppm of chloride. Some wells in the valley floor north of Salem contain excessive iron for some uses. However, most wells are in alluvium and volcanic rocks and yield good water containing 30 to 400 ppm of dissolved solids and 10 to 150 ppm of hardness.

The copious springs in the Cascade Range are similar in quality to the streams they feed. Most springs in the valley floor drain alluvial aquifers and yield water low in mineral content, but thermal springs are more highly mineralized and have large percentages of sodium and chloride. For example, water from McCredie Hot Springs (164°F.) in the southeastern part of Lane County contains 4,310 ppm of dissolved solids, including 1,100 ppm of sodium and 1,990 ppm of chloride.

WATER USES

Water is vital to irrigation, production of electric power, municipal supply, industrial processes, transport, air conditioning, and recreation in the basin. About 200,000 acres of land is irrigated, using 320,000 acre-feet of water per year; about 41 percent of the land is irrigated with ground water. Potentially irrigable land in the basin, including some pasture, exceeds 1.5 million acres. Most of the irrigation is by

sprinkler, and about two-thirds of the water used is consumed. Industrial processes and air conditioning use more than 200,000 acre-feet per year. The end products of such use include processed foods, forest products, building materials, chemicals, and metals. Western Oregon, including the Willamette River basin, is the center of the United States soft-wood timber industry; lumber, plywood, pulp, and paper are produced in large quantities. Public water systems supply about 181 gallons per person per day to more than a million people in 190 municipalities in the basin. The source for the principle cities are given in table 34.

TABLE 34.—PRINCIPAL MUNICIPAL WATER SYSTEMS IN THE WILLAMETTE RIVER BASIN

Municipality	Estimated population served (includes suburban water districts)	Springs	Wells	Streams
Albany	13,000			South Santiam River.
Beaverton	7,000		X	(1).
Corvallis	23,000			Rock Creek, Willamette River.
Cottage Grove	5,500			Layng and Prather Creeks.
Dallas	7,200			Rickreall Creek.
Eugene	72,500			McKenzie River.
Forest Grove	7,000			Clear and Gale Creeks.
Hillsboro	19,000			Sain Creek, Tualatin River.
Lebanon	6,600			South Santiam River.
McMinnville	8,600			Haskins Creek.
Milwaukie	11,500		X	
Newberg	6,100	X	X	
Oregon City	9,600			South Fork, Clackamas River.
Oswego	9,200		X	(1).
Portland	582,000			Bull Run River.[2]
Salem	60,000			North Santiam River.
Silverton	6,000			Abiqua and Silver Creeks.
Springfield	27,000		X	McKenzie and Willamette Rivers.
Tigard	5,100		X	(1).

[1] Portland system provides some water for Beaverton, Oswego, and Tigard.
[2] Tributary to Sandy River.

The Willamette River from near Albany downstream is used for transportation of log rafts to mills. In 1965, such traffic accounted for 758,000 tons, or almost 60 percent of the total river traffic above the locks at Oregon City. The fresh-water port of Portland has a 40-foot channel to the sea and serves ships bound to all parts of the world. Port clearances in 1965 totaled 11,476,000 tons. The principal exports are forest products, grain, and fruit.

Ground water is used for air conditioning for many buildings in the basin. In Portland, reversed refrigeration with well water is used for space heating of several large structures, including the Equitable, Oregonian, and Sheraton Hotel buildings.

WATER PROBLEMS

Too much water is a frequent problem on about 175,000 acres of land that is subject to overflow in an average year along streams that are not controlled, including the Marys, Luckiamute, Yamhill, Tualatin, Pudding, and Clackamas Rivers, and Johnson Creek. The greatest recent flood, in December 1964, inundated and eroded far

more land than in an average year, including industrial and residential parts of Portland and other cities, and caused about $71 million damage and loss of several lives. Operation of seven reservoirs and other control measures prevented much additional flooding and $514 million additional damage in that flood (Corps of Engineers, 1966, pp. 25–91).

Poor drainage is a problem in much of the low-lying land. The problem results from flat topography, impermeable soil, and high water table, or a combination of those factors.

Too little water is a recurring problem. The annual average of 40 inches of precipitation on the valley floor is of no help in a summer period of little or no rain. The land now irrigated needs about 13,000 acre-feet more of water than is available in an average year; most of the shortage is in the Pudding and Tualatin River basins. Full irrigation development will require much storage that is not now available.

Pollution by sewage and industrial waste is a serious problem at times. In warm-weather periods of low flow, coliform bacteria render the water in the lower river unsafe for swimming, and in the Portland harbor area the dissolved-oxygen content falls below the tolerance limit for upstream migrant salmon. Enforced primary treatment of municipal sewage, coupled with the elimination of large flows of waste liquor from sulfite-process papermills, have in recent years given relief; and release of stored water in periods of low flow help to abate the nuisance. But further measures are needed, including elimination of combined storm-domestic sewerage systems.

Problems arise from conflicts of interest among water users. Every diversion for a consumptive use means less water for downstream users. Sudden releases of water for power production create hazards for downstream anglers and swimmers. Recreationists like to see reservoir levels held high until early September; but requirements of power production, flow regulation, fisheries, or preparation for the next flood-storage season may dictate earlier release of stored water. Partial flood control without attendant enforcement of zoning in a flood plain may permit incautious owners to build in the reduced flood zone and lead to later demands for further flood protection.

Coastal Basins

Included in this section are the many short rivers that drain the western slope of the Coast Range, an area of 7,270 square miles. The Umpqua and Rogue Rivers are considered separately, because in large part their basins lie east of the Coast Range. The tidal shoreline extends for 489 miles and includes harbors for oceangoing ships at Tillamook Bay, Yaquina Bay, Coos Bay, and many smaller harbors.

WATER QUANTITY

This area produces more water per unit of area than any other in the State—and few areas in the United States have greater precipitation and runoff. The observed runoff of the principal streams listed in table 35 amounts to about 7.8 million acre-feet per year from 2,314 square miles. The total annual runoff in the area is about 26 million

acre-feet, equivalent to a yield of about 5.6 feet of depth on the entire basin. That yield is not uniform, however, but is greatest on streams like the Siletz and Wilson Rivers that drain areas sloping to the west and southwest, the directions from which most storms come, and that do not drain rain-shadow areas on the lee side of mountain ridges.

TABLE 35.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE COASTAL BASINS

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
Nehalem River near Foss	667	27	2,704	1,958,000	43,200	54.0
Wilson River near Tillamook	161	36	1,210	876,000	32,100	45.0
Trask River near Tillamook	145	29	964	697,900	23,000	37.0
Siletz River at Siletz	202	47	1,580	1,144,000	40,800	48.0
Alsea River near Tidewater	334	27	1,539	1,114,000	41,800	45.0
Siuslaw River above Wildcat Creek	267	9	688	498,100	12,900	20.0
Tenmile Creek near Lakeside	87	9	324	234,600	3,330	4.1
Coquille River:						
South Fork at Powers	169	47	779	564,000	48,900	12.0
North Fork near Myrtle Point	282	20	949	687,000	38,400	4.5

About 97 percent of the area is underlain by bedrock, mostly marine sedimentary rocks that do not yield water readily. Natural recharge is estimated to be about 6 million acre-feet per year, mostly to aquifers in Tertiary lavas, and the outflow forms springs that supply most of the base flow of the streams. Ground water also occurs in about 100 square miles of alluvium near the streams. Sand dunes that cover about 125 square miles and range from sea level to 260 feet in altitude occur in places along the coast, in a narrow strip that is nowhere more than about 3 miles wide. Most of the precipitation that falls on the dunes infiltrates readily; natural recharge to the dune aquifers probably exceeds 300,000 acre-feet per year. The water in the dunes is discharged through springs and seeps to the many small lakes in the dune area, or directly to the ocean.

WATER QUALITY

Surface water is low in mineral concentration. For example, the Siletz River contained only from 32 to 65 ppm of dissolved solids in 37 composited samples taken in the period August 1911 to August 1912 (Van Winkle, 1914, p. 50). Monthly samples from August 1960 to July 1961 contained 31 to 50 ppm. In the water year 1965, once-a-month samples of West Fork of Millicoma River near Alleghany contained 29 to 40 ppm of dissolved solids, and turbidity was low. Other streams have similar chemical quality. The waters are calcium magnesium bicarbonate in type and contain sodium and chloride that may be derived in part from marine sedimentary rocks and in part from airborne ocean spray.

Wells in marine sedimentary rocks yield only small quantities of water, and in places the water is saline. Wells in alluvium yield water of excellent quality. Water in the dune sands north of Coos Bay is low in mineral concentration and is generally slightly acidic. Water from some wells contains excessive iron that may require removal for many

uses. Some shallow wells in poorly drained areas yield water that has objectionable color, odor, or taste.

Most of the area is forested, and suspended-sediment concentration is low except in places where recent logging, roadbuilding, or fire has upset the balance of nature. In 1911–12, the average concentration observed in the Siletz River was 6 ppm and the maximum was 32 ppm. The runoff is so great that the annual erosion is generally more than in the dry areas of eastern Oregon. The average sediment concentration in the forested areas of three small creeks in the Alsea River basin in water years 1959 and 1960 ranged from 9 ppm in Needle Branch to 15 ppm in Flynn Creek, and total denudation for 1.9 years was equivalent to 340 tons per square mile (Williams, 1964, p. 9), or roughly 0.1 acre-foot per square mile per year.

WATER USES

Even in this humid area, water is used to irrigate about 25,000 acres of land, mostly for dairy-herd pasture. Most of the diversion is by pumping from surface streams; distribution is by pipes and sprinklers. About 25,000 acre-feet of water is applied annually.

The principal water-using industries are related to forest and dairy products. Pulp and paper plants at Toledo and Gardiner use about 40 cfs from surface-water supplies; another at North Bend uses water developed within the sand dunes near Hauser. Cheese-making plants near Bandon, Coos Bay, and Tillamook use lesser quantities of water. North Bend, Coos Bay, Waldport, Newport, Depoe Bay, Garibaldi, and other port cities support commercial fisheries and canneries that help to process the State's average annual harvest of about 61 million pounds of salmon, tuna, bottom fish, crabs, clams, and shrimp.

The public systems serving the larger centers of population are mostly derived from surface streams. The Pony Creek diversions serve about 22,000 people in the Coos Bay-North Bend area. The Siletz River and smaller streams supply water for about 10,000 people in Newport and Toledo. Seaside, Tillamook, Myrtle Point, Coquille, Bandon, and Gold Beach use nearby surface sources.

Much of the economy of the area is based on recreation, and that industry is based on the presence of water—water in the streams, water in the sand-dune lakes, and water at the ocean beaches. State parks abound; five of them had a total day-usage of about 4 million visitors in 1966, about one-fifth of the usuage for all the State parks.

WATER PROBLEMS

Although the total water supply is adequate for foreseeable needs, shortages exist at times because of the great seasonal variation in flow of streams. Use of water for irrigation is greatest in the period of low flow, and much more land may in time be irrigated.

Flooding occurs almost every year, and low-lying arable land is often inundated. Flooding may be aggravated by winds and high tides that force ocean water into the bays and estuaries adjacent to the settlements and farmed lands during periods of high flow.

Ground-water supplies are erratic in availability and in places are undesirable in quality.

Umpqua River Basin

The Umpqua River rises on the west slope of the Cascade Range. Below the confluence of the two main branches near Roseburg, the river cuts through the Coast Range and continues westward to the sea at Winchester Bay. The central basin near Roseburg is subhumid; the upper and lower reaches are humid. The basin covers 4,560 square miles. About 80 percent of the land is forested, in part recently cut over, and the area is one of the chief centers of softwood lumber production in the United States.

WATER QUANTITY

Data for selected streams in the basin are given in table 36. The South Umpqua has a larger drainage area than the North Umpqua but less total flow, because the South Umpqua includes more area with moderate rainfall. Lookingglass and Calapooya Creeks drain areas of moderate precipitation and little ground-water storage. Mill Creek is the only stream west of the Coast Range with records of flow, but Smith River near Reedsport is known to be a much larger stream. The average flow at the mouth of the Umpqua River is about 11,000 cfs (8 million acre-feet per year).

TABLE 36.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE UMPQUA RIVER BASIN

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
South Umpqua River at Tillen	449	28	1,033	747,900	60,200	20.0
Cow Creek near Riddle	456	12	922	667,500	37,500	18.0
Lookingglass Creek at Brockway	158	11	316	228,800	35,000	0
South Umpqua River near Brockway	1,670	32	2,887	2,090,000	105,000	36.0
North Umpqua River below Lemolo Lake	170	38	418	302,600	4,680	10.0
Steamboat Creek near Glide	227	10	720	521,300	51,000	31.0
North Umpqua River at Winchester	1,344	23	3,678	2,663,000	119,000	383.0
Calapooya Creek near Oakland	210	11	519	375,700	26,600	0
Umpqua River near Elkton	3,683	61	7,473	5,410,000	265,000	640.0
Mill Creek near Ash	90	7	316	228,800	10,000	1.5

In the North Umpqua Basin, aquifers of Tertiary volcanic rocks feed many large springs with well-sustained summer flow. Similar aquifers are less productive in the South Umpqua Basin, and scarce in the Coast Range. Wells that penetrate marine sedimentary rocks yield only a little water.

WATER QUALITY

The surface water is soft, low in mineral concentration, and low in suspended sediment. In the period August 1, 1911, to August 15, 1912, dissolved solids in 22 samples from Umpqua River near Elkton ranged from 57 to 86 ppm, and suspended matter average 15 ppm; hardness was about 27 ppm. The water in the South Umpqua at Roseburg has slightly more dissolved and suspended matter and hardness; that in the North Umpqua at Glide is less mineralized and carries a lower sediment concentration than at Elkton. The chemical and physical

quality of the surface water has not been significantly changed by the activities of man from 1911 to 1967.

Ground water issuing from Tertiary volcanic rocks in the Cascade Range is clear, cold, and very low in dissolved-solids concentration and hardness. Wells in alluvium in the stream valleys yield water that is somewhat more mineralized but is usable for almost any purpose. Water in the marine sedimentary rocks of the Coast Range and interior valleys is saline in places.

WATER USES

About 16,000 acres of land is irrigated in the basin, parctically all of it by pumping about 24,000 acre-feet each year from streams to adjacent lands. The potential for profitable irrigation is several times larger.

Water rights for mining purposes total about 300 cfs (1958); some of the rights are not in use. The largest continuous mining operation uses as much as 4 cfs from Cow Creek near Riddle for processing nickel ore.

Municipal supplies are mostly obtained from surface streams. A diversion from North Umpqua River at Winchester serves about 15,000 people in the Roseburg area.

WATER PROBLEMS

The chief water problem in the Umpqua River basin is flooding. In recent years, damaging floods occurred throughout the basin in October 1950, January and November 1953, December 1955, and December 1964. The flood of December 1964 was about equal to the historic floods of 1861 and 1890. No flood-control storage has been provided.

Summer flow is not adequate for potential needs of recreation, irrigation, and fish life on streams that rise in areas without high-yield aquifers, including Cow, Olalla, Deer, Sutherlin, Calapooya, and Elk Creeks. It is in those stream basins that most of the potential lies for future irrigation from storage of winter runoff.

Rogue River Basin

Rogue River drains 5,170 square miles, of which about 55 percent is forested. For the purpose of discussing water resources, the basin may conveniently be divided into three subunits. The eastern, or upstream, section of about 1,500 square miles covers the western slope of the Cascade Range. The central valley section contains about half the total basin area, nearly all the agricultural land, and the larger population centers of Ashland, Grants Pass, and Medford. The western part of about 1,000 square miles is a mountainous, forested region extending along the lower 65 miles of the Rogue River and the lower 45 miles of its largest tributary, the Illinois River.

WATER QUANTITY

The flow of the river and some tributaries is shown in table 37. The average annual runoff of the Rogue River is about 8 million acre-feet.

The Rogue River above Prospect and many of the eastern tributaries have base flows that are well sustained by large springs. Elk

TABLE 37.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE ROGUE RIVER BASIN

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
Rogue River above Prospect	312.0	46	810	586,400	22,400	200.0
Elk Creek near Trail	133.0	21	236	170,900	19,200	0.4
Bear Creek at Medford	289.0	46	108	78,190	14,500	0
Rogue River at Raygold, near Central Point	2,053.0	61	2,933	2,123,000	131,000	616.0
Applegate River near Copper	223.0	28	437	316,400	29,000	20.0
Rogue River near Agness	3,939.0	6	6,372	4,613,000	290,000	860.0
East Fork Illinois River near Takilma	42.3	25	185	133,900	15,700	4.6
Illinois River near Kerby	380.0	5	1,326	960,000	92,200	23.0
Illinois River near Agness	988.0	6	4,311	3,121,000	225,000	148.0

Creek, Bear Creek, Applegate River, and East Fork of the Illinois River have no such dependable low-flow sources; in addition, their summer flows are depleted for irrigation. The flow of Bear Creek is regulated by storage at Emigrant Lake, into which about 34,000 acre-feet per year is diverted from tributaries of the Klamath River to generate power and to irrigate lands in the Bear Creek basin.

The northern part of the upstream section of the basin has a permeable pumice cover overlying Tertiary and Holocene lavas. Those formations store and yield large volumes of soft, clear, cold water to springs of steady flow that have become the base flow of the Rogue River and its upper tributaries, including Mill Creek, Red Blanket Creek, Middle Fork, South Fork, Big Butte Creek, and Little Butte Creek. The central and western sections are underlain in part by less permeable sedimentary and metamorphic rocks. The natural recharge to the groundwater reservoir in the entire basin is about 1.7 million acre-feet per year. About 75 percent of that recharge occurs in the in the upper Rogue River section, including Little Butte Creek, and most of the remainder occurs in alluvium along the river and its lower tributaries.

WATER QUALITY

Surface water has good to excellent chemical and physical characteristics. At a sampling site 6 miles southwest of Prospect, Rogue River water below South Fork is soft and clear, has a dissolved-solids concentration of about 60 ppm, hardness of about 20 ppm, and suspended sediment of less than 10 ppm. Bear Creek at Central Point has about 150 to 200 ppm of dissolved solids and up to 250 ppm of suspended sediment. At the gaging station on Rogue River at Raygold, near Central Point, 34 samples taken from September 1911 to August 1912 ranged from 54 to 86 ppm of dissolved solids and from 1 to 156 ppm of suspended sediment. Dissolved solids ranged from 59 to 91 ppm and hardness from 32 to 62 ppm in 15 samples taken from January 1966 to July 1967 at the gaging station on Rogue River above Illinois River, near Agness.

Ground water that issues from springs in volcanic aquifers is similar in quality to the Rogue River below South Fork. Springs that issue from marine-sedimentary and metamorphic rocks in the central

and western sectors are more highly mineralized, and some emit large quantities of carbon dioxide or other gases.

Wells in alluvial and colluvial deposits, and those in weathered granitic rocks yield moderate quantities of water that is suitable for domestic and other uses. Several wells in valley fill north of Medford yield sufficient water of suitable quality to irrigate small tracts. Wells in several localities yield hard water that contains more than 500 ppm of dissolved solids; some wells in marine sedimentary rocks are unusable because the water is saline, with dissolved-solids concentrations as high as 8,600 ppm or boron concentrations as high as 20 ppm.

WATER USES

About 195,000 acre-feet of surface water is used annually to irrigate about 56,000 acres in Jackson County and 22,000 acres in Josephine County. Water for that use is stored in Fish Lake and in Emigrant Lake to supplement the natural flow of the streams; water is also diverted from Fourmile Lake, Howard Prairie, and Hyatt Reservoirs in the Klamath River basin. Medford, Eagle Point, Central Point, and Jacksonville use water from Big Butte Springs diverted through a covered concrete collecting gallery into the Medford pipelines. Ashland uses water from Ashland Creek; Gold Hill and Grants Pass use Rogue River water. Talent, Phoenix, and Cave Junction use water from nearby shallow wells. Log ponds use modest quantities of water. The chief industries are centered around the processing of forest and food products, and are cyclic or seasonal. Some small placer mines are operated in winter and early spring, when adequate water is available in the small streams.

The Rogue River and its tributaries have exceptional potential for recreational use. The Rogue and the Illinois have long been famous for steelhead fishing. The main river below Grants Pass is under active consideration for designation as a Wild River, to be reserved for recreational and conservation purposes, and State law already prohibits dam building in that reach.

The multipurpose Lost Creek Dam, under construction on the Rogue River above Big Butte Creek, is designed to have a usable storage capacity of 315,000 acre-feet, to be used to control floods, generate power, increase low flow, and provide water for irrigation. The recreational and sport-fishery benefits will also be substantial.

WATER PROBLEMS

Floods occur frequently. Although storage in Emigrant Lake (capacity enlarged in 1960 to 39,000 acre-feet) provides some flood protection for Bear Creek valley, the greatest floods of record on Bear Creek at Medford and Rogue River at Raygold have occurred since that reservoir began operation. At nearly all gaging stations, the flood of December 22–23, 1964, was the greatest since records began. Some flood protection for the central sector of the main stem of the Rogue River will be provided when Lost Creek Dam begins operating.

Inadequate water supply in late summer is a common problem on streams in the central part of the basin.

Local problems of siltation occur when logging, mining, or sand and gravel operations are conducted without adequate control measures. Siltation of spawning areas is harmful to fish life.

Water temperatures exceed 70° F. at times, temporarily blocking runs of anadromous fish.

Klamath River Basin

The Klamath River basin in Oregon consists chiefly of a plateau between 4,100 and 5,000 feet in altitude, and the eastern slope of the southern part of the Cascade Range. The adjacent basins of Swan Lake, Yonna Valley, Lost River, and Lower Klamath Lake are usually included, although those basins contribute little water to the Klamath River except that which is artificially diverted from them. Also included is the topographically closed basin of Crater Lake.

In downstream order, the principal stem is called Williamson River, Upper Klamath Lake, Link River, Lake Ewauna, and Klamath River.

At Keno, the Klamath River leaves the plateau and enters the canyon it has cut through the Cascade Range. Its drainage area in Oregon is about 5,680 square miles, of which about 1,600 square miles contributes little water. The average annual flow at the State line is about 1.5 million acre-feet.

An interstate compact on the use of water resources of the Upper Klamath River basin in Oregon and California is in effect.

WATER QUANTITY

The principal streams and their flows are listed in table 38. The flow at each of the sites is affected by diversions for irrigation, and the flows of the Link and Klamath Rivers are affected by storage in Upper Klamath Lake, controlled by a low dam at the outlet.

TABLE 38.—SUMMARY OF STREAMFLOW DATA AT SELECTED SITES IN THE KLAMATH RIVER BASIN

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Cubic feet per second	
			Cubic feet per second	Acre-feet per year	Maximum	Minimum
Williamson River near Klamath Agency	1,290	12	236	170,900	1,590	0
Sprague River near Beatty	513	16	306	221,500	6,980	57
Sprague River near Chiloquin	1,580	45	555	401,800	14,900	50
Williamson River below Sprague River	3,000	49	1,013	733,400	16,100	320
Link River at Klamath Falls	3,810	62	1,603	1,161,000	9,400	17
Klamath River at Keno	[1] 3,920	46	1 678	1 215,000	9,250	26
Klamath River below John C. Boyle powerplant	[1] 4,080	7	1,767	1,279,000	8,830	311

[1] Excluding adjacent basins of Lost River and Lower Klamath Lake.

Ground water is abundant. About 2 million acre-feet per year is naturally recharged to aquifers, chiefly in Tertiary volcanic rocks. Large springs near Chiloquin and Fort Klamath feed the Williamson, Sprague, and Wood Rivers, and Fort, Agency, and Sevenmile Creeks; others emerge beside the Lost River near Bonanza and the Klamath River below Keno. The flow of Big Spring near Lenz station, north-

west of Upper Klamath Marsh, has been measured as high as 86 cfs in September 1954; yet it had no flow from about 1930 to 1950. In contrast, the springs that form Spring Creek, near Chiloquin, maintain a steady flow of 260 to 330 cfs at all times. The large springs at the head of the Wood River discharge 200 to 300 cfs. Other large springs rise beneath the surface of Upper Klamath Lake. Some wells in the Sprague River basin and near Fort Klamath have artesian flow.

Crater Lake lacks a surface outlet loses about 90 cfs (65,000 acre-ft per yr) by leakage. At least a part of the leakage probably helps to feed some of the large springs in the Klamath River basin.

WATER QUALITY

The water in the larger streams and springs is of good to excellent quality, low in suspended sediment and dissolved solids. and is calcium magnesium bicarbonate in type. In the period July 1959 to December 1963, the Oregon State Sanitary Authority made a series of about 35 analysis on each of the streams listed in table 39. The dissolved-solids concentrations and hardness increase from the Williamson River to Keno, owing in part to evaporation in excess of precipitation on Upper Klamath Lake and in part to the addition below Klamath Falls of municipal and industrial wastes and the return of drainage from irrigated tracts and flow from the semiclosed Lower Klamath Lake and adjacent marshes. As most of the water in Crater Lake is derived from precipitation, it is dilute, having only about 80 ppm of dissolved solids.

TABLE 39.—SUMMARY OF ANALYSES [1] OF STREAMS IN KLAMATH RIVER BASIN, 1959-63

Stream	Site	Parts per million [2]					
		Dissolved solids			Hardness		
		Mean	Maximum	Minimum	Mean	Maximum	Minimum
Sprague River	Bridge near mouth	121	188	85	36	55	19
Williamson River	Chiloquin, 1 mile north	107	157	47	25	43	16
Do	Bridge, 4.5 miles above mouth	114	173	73	31	48	24
Link River	Fremont Bridge, Klamath Falls	141	223	83	35	46	24
Klamath River	Keno	221	428	121	72	184	40

[1] Analyses by Oregon State Sanitary Authority.
[2] Numerically equal to milligrams per liter, as listed in report by Oregon State Sanitary Authority.

Sediment movement in streams is insignificant because much of the flow is derived from large springs and the streams have a rather flat gradient down to Keno.

The Williamson River and some other streams drain large marshy areas, and the water at times has a browinsh color derived from the decay of marsh vegetation. Algal blooms occur annually in Upper Klamath Lake.

Ground water in the northern part of the basin is of excellent quality. In the Swan Lake and Yonna Valleys and in the plain south of Klamath Falls, ground water is moderately mineralized and generally is suitable for domestic use or irrigation. Warm or hot water in fault

zones in Klamath Falls and near Lorella and water in the alluvium adjacent to the evaporation basins of Tule and Lower Klamath Lakes are poor in quality because of high concentrations of sodium salts.

WATER USES

Irrigation is the principal consumptive use. About 1 million acre-feet of water is diverted annually to irrigate 295,000 acres, of which about 5 percent is irrigated with ground water. The largest diversion, the "A" Canal, diverts about 260,000 acre-feet annually from Upper Klamath Lake for use on lands on both sides of the Lost River, partly in California. Some water is also pumped from the lake to irrigate adjacent land. Lumbering and forest products account for most of the industrial use. Dairying and meat packing are the chief agricultural processing industries. Public supplies, almost entirely from ground-water sources, serve 29,000 people.

In Klamath Falls, the natural heat in ground water is used for space heating of many residences and some public buildings, and to effect continuous removal of snow and ice on some stretches of pavement.

Preservation of a suitable habitat for wildlife is an important use of water. Wildlife refuges on Upper Klamath Marsh and Lower Klamath Lake, supplemented by large areas of nearby marsh and irrigated grainfields, support millions of waterfowl.

WATER PROBLEMS

Serious flooding is rare, because Upper Klamath Lake on the main stem and Clear Lake and Gerber Reservoirs on the Lost River have large capacities for storage in relation to annual runoff. The flows of Sprague and Williamson Rivers are equalized by spring inflow and natural channel and marsh storage to a marked degree. However, a long period of high flow occasionally fills Upper Klamath Lake and requires release of water down the Klamath River. Such a flood occurred in December 1964 and January 1965, when large areas of lowland were inundated.

In dry years, little water is available to pass down the Klamath River below Klamath Falls, to dilute municipal and industrial wastes or to generate electric power. Some lands along the Williamson and Sprague Rivers are normally irrigated by natural subseepage or by bank overflow in periods of high water; in dry seasons such land is not watered. Also in dry periods, the partly natural and partly controlled flooding of wildfowl is inadequate, and in some years the shortage is believed to have led to the loss of many thousands of birds.

The ground water in the alluvium near the evaporation sumps of Tule and Lower Klamath Lakes and some of the thermal ground water near Lorella and in Klamath Falls are not suitable in quality for irrigation or domestic use.

Evaportation loss from Upper Klamath Lake amounts to almost 300,000 acre-feet per year. Any economical technique for the suppression of evaporation would increase the outflow available for downstream use. Periodic algal bloom in Upper Klamath Lake causes objectionable odor and inadequate dissolved oxygen for fish life.

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WATER RESOURCES DEVELOPMENT

Hydroelectric Power

(By Z. R. Harper and R. B. Gillespie, Bonneville Power Administration, Portland, Oreg.)

Electric power production in the United States from both steam and hydro generation came into commercial use in 1882. In that year Thomas A. Edison opened the Nation's first steam-electric lighting plant, the Pearl Street Station in New York City. Several days later the first hydroelectric plant went into operation at Appleton, Wisconsin, generating 200 kilowatts and transmitting 110 volts over a one-mile line. During the early years, steam-electric generation took the lead, due to low-cost fuel and the ability to build plants close to load centers. With the development of more efficient transmission of electricity at higher voltages over longer distances and a rise in fuel costs, hydroelectric generation became more feasible and competitive with steam-electric generation. By 1965 the installed capacity of hydroelectric generation in the United States had reached over 44 million kilowatts or 20 percent of 220 million kilowatts installed hydroelectric capacity for the world.[1] The first commercial hydroelectric generation in Oregon was in 1888. At that time the Willamette Falls plant, built by Oregon City Electric Company on the Willamette River near Oregon City, was energized. A new plant was put into operation in 1889 by the Willamette Falls Electric Company. Power was transmitted to the City of Portland in the form of direct current for street lighting. Alternating current generators were installed at this plant in 1890, and one of the first long-distance alternating-current transmission lines in the United States connected these machines with Portland, Oregon. Late in 1897, Portland General Electric Company energized three 450-kilowatt generators at Willamette Falls as the first stage of construction of a new powerhouse. This is now their T. W. Sullivan plant.

Following the pioneering efforts at Willamette Falls, private and public interests began developing hydroelectric power throughout the State. Many of the early plants are still in operation today.

Hydroelectric power development in Oregon has reached an installed capacity of 3,051,201 kilowatts over the past 79 years, with 71 existing private, public, and Federal plants. This places Oregon fourth in the nation with seven percent of the national hydroelectric power output following Washington, California, and New York.[2] Table 40 lists the plants and figure 85 locates them on a map of Oregon. Sixty of these are non-Federal plants either publicly or privately owned which total 1,338,501 kilowatts of installed capacity. Additions planned for the existing public and private plants—Brownlee, Oxbow, Hells Canyon, Bull Run, Oak Grove, Winchester, and Prospect No. 2—will add another 377,000 kilowatts of installed capacity. Eight potential non-Federal plants—Trask, Ginger Peak, Eden Ridge, Buzzards' Roost, Aspen Lake, Keno, Bear Springs, and Salt Caves—would add 603,500 kilowatts for a total of 980,500 kilowatts of future capacity for Oregon.

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[1] World Power Data 1965, Federal Power Commission, published in 1967.
[2] World Power Data 1965, Federal Power Commission, published in 1967.

TABLE 40.—HYDROELECTRIC POWER RESOURCES IN OREGON: EXISTING, UNDER CONSTRUCTION, AND UNDER ACTIVE CONSIDERATION, DEC. 31, 1967

Map reference No.	Project	Stream	Ownership	Gross head (feet)	Existing		Ultimate installed capacity (kilowatts)	Date in service initial unit
					Number of units	Installed capacity (kilowatts)		
	Columbia River Basin:							
1	Duncan Ferry	Owyhee	Bureau of Reclamation	182	2	[1] 14,000	14,000	Under active consideration.
2	Baker	Goodrich	Baker, city of	744	1	120	120	1918.
3	Rock Creek	East Fork, Rock Creek	California Pacific Utilities Co.	936	2	800	800	1905.
4	Brownlee [2]	Snake	Idaho Power Co	272	4	360,400	540,600	Aug. 27, 1958.
5	Oxbow [2]	do	do	117	4	190,000	237,500	July 5, 1961.
6	Hells Canyon [2]	do	do	213	1	130,500	522,000	Nov. 5, 1967 (2 units under construction).
7	Mountain Sheep [2]	do	Bureau of Reclamation [3]	585	5	[1] 1,500,000	2,400,000	Under active consideration.
8	Wallowa Falls	East Fork, Wallowa	Pacific Power & Light Co.	1,187	1	800	800	1921.
9	McNary [2]	Columbia	Corps of Engineers	75	14	980,000	1,400,000	Nov. 6, 1953.
10	John Day [2]	do	do	105	16	[2] 2,160,000	2,700,000	Scheduled 1968 (16 units under construction).
11	Bend	Deschutes	Pacific Power & Light Co.	15	3	1,110	1,110	1913.
12	Cline Falls	do	do	50	1	1,000	1,000	1900.
13	Round Butte	do	Portland General Electric Co.	365	3	247,050	247,050	Aug. 7, 1964.
14	Pelton	do	do	152	3	108,000	108,000	Dec. 20, 1957.
15	Tygh Valley	White	Pacific Power & Light Co.	150	3	2,250	2,250	1902.
16	The Dalles [2]	Columbia	Corps of Engineers	86	16	1,119,000	1,807,000	May 13, 1957.
17	Dee	East Fork, Hood	Oregon Lumber Co.	30	1	150	150	
18	Powerdale	Hood	Pacific Power & Light Co.	210	1	6,000	6,000	1923.
19	Bonneville [2]	Columbia	Corps of Engineers	59	10	518,400	842,400	June 6, 1938.
20	Bull Run	Bull Run	Portland General Electric Co.	326	4	21,000	34,000	1912.
21	Hills Creek	Middle Fork Willamette	Corps of Engineers	318	2	30,000	30,000	May 2, 1962.
22	Lookout Point	do	do	231	3	120,000	120,000	December 16, 1954.
23	Dexter	do	do	57	1	15,000	15,000	May 19, 1955.
24	Carmen	McKenzie	Eugene, city of	513	2	80,000	80,000	Aug. 17, 1963.
25	Trail Bridge	do	do	78	1	10,000	10,000	June 20, 1963.
26	Cougar	South Fork McKenzie	Corps of Engineers	434	2	25,000	60,000	Feb. 4, 1964.
27	Strube	do	do	63	1	[1] 4,500	4,500	Authorized.
28	Leaburg	McKenzie	Eugene, city of	90	2	13,500	13,500	Jan. 6, 1930.
29	Walterville	do	do	56	1	8,000	8,000	1911.
30	Scott Young	Minto Creek	Scott Young	100	1	59	59	Aug. 1, 1952.
31	Mineral Springs	Breitenbush	Felix Young	18	1	35	35	
32	Breitenbush	do	Wayne Halseth	7	1	12	12	1929.
33	Detroit	North Santiam	Corps of Engineers	357	2	100,000	100,000	July 1, 1953.
34	Big Cliff	do	do	97	1	18,000	18,000	June 12, 1954.

See footnotes at end of table.

TABLE 40.—HYOROELECTRIC POWER RESOURCES IN OREGON: EXISTING, UNDER CONSTRUCTION, AND UNDER ACTIVE CONSIDERATION, DEC. 31, 1967—Continued

Map reference No.	Project	Stream	Ownership	Gross head (feet)	Existing		Ultimate installed capacity (kilowatts)	Date in service initial unit
					Number of units	Installed capacity (kilowatts)		
	Columbia River Basin—Continued							
35	Marion Investment	North Santiam	Marion Investment	14	1	900	900	
36	Stayton	do	Pacific Power & Light Co	15	1	600	600	1924.
37	Burnice Crewell	Dobbins Creek	Burnice Crewell	52	1	3	3	
38	Green Peter	Middle Santiam	Corps of Engineers	300	2	80,000	80,000	June 9, 1967.
39	Foster	South Santiam	do	113	1	[1] 20,000	20,000	Scheduled 1968 (under construction).
40	John Wills	Wiley Creek	John Wills	30	1	36	36	
41	Lebanon	South Santiam	Pacific Power & Light Co	10	1	144	144	1920.
42	Albany	do	do	36	2	800	800	1923.
43	Willamette Paper	do	Willamette Paper Co	10	1	192	192	
44	Rolla Shelton	Thomas Creek	Rolla Shelton	25	1	15	15	
45	Baker Creek	Baker Creek	McMinnville, city of	230	1	200	200	1908.
46	Sullivan	Willamette	Portland General Electric Co	40	13	15,400	15,400	1897.
47	West Linn	do	Crown Zellerbach Corp	40		13,900	13,900	
48	Oregon City	do	Publishers Paper Co	40	2	1,500	1,500	
49	Oak Grove	Oak Grove Fork	Portland General Electric Co	879	2	51,000	76,500	1924.
50	North Fork	Clackamas	do	135	2	38,400	38,400	Nov. 24, 1968.
51	Faraday	do	do	133	6	34,450	34,450	1907.
52	River Mill	do	do	82	5	19,050	19,050	1911.
53	Lake Oswego	Oswego Creek	Lake Oswego Corp	90	1	522	522	1910.
	North Pacific Slope Basins:							
54	Trask	Trask	Tillamook County PUD	200	1	[1] 76,000	76,000	Under active consideration.
55	Ginger Peak	do	do	100	1	[1] 9,500	9,500	Do.
56	Lemolo No. 1	North Umpqua	Pacific Power & Light Co	752	1	29,000	29,000	July 1955.
57	Lemolo No. 2	do	do	728	1	33,000	33,000	Nov. 1, 1956.

58	Clearwater No. 1	Clearwater	do	651	1	15,000	15,000	June 16, 1953.
59	Clearwater No. 2	do	do	750	1	26,000	26,000	Nov. 30, 1953.
60	Toketee	North Umpqua	do	448	3	42,500	42,500	Jan. 3, 1950.
61	Fish Creek	Fish Creek	do	1,032	1	11,000	11,000	June 30, 1952.
62	Slide Creek	North Umpqua	do	169	1	18,000	18,000	July 18, 1951.
63	Soda Springs	do	do	114	1	11,000	11,000	Mar. 21, 1952.
64	Winchester	do	do	14	1	500	13,400	1912.
65	Eden Ridge	South Fork Coquille	do	1,515	1	[1] 77,000	77,000	Under active consideration.
66	Prospect No. 3	South Fork Rogue	do	720	1	7,200	7,200	1932.
67	Prospect No. 2	Rogue	do	607	2	32,000	48,000	1928.
68	Prospect No. 4	do	do	112	1	1,000	1,000	1944.
69	Prospect No. 1	do	do	495	1	3,760	3,760	1912.
70	Lost Creek	do	Corps of Engineers	321	2	[1] 49,000	49,000	Scheduled 1973 (under construction).
71	Eagle Point	South Fork Big Butte	Pacific Power & Light Co	409	1	2,813	2,813	Nov. 1, 1957.
72	Green Springs	Emigrant	Bureau of Reclamation	1,984	1	16,000	16,000	May 2, 1960.
73	Reader	Ashland	Ashland, city of	425	1	300	300	1909.
74	Gold Ray	Rogue	Pacific Power & Light Co	20	3	1,500	1,500	1905.
75	Gold Hill	do	Ideal Cement Co	25	1	2,500	2,500	
76	Little Boulder Creek	Little Boulder Creek	B. Timaeus	9	1	187	187	December 1946.
77	Smith Creek	Smith Creek	Larry Lucas	285	1	3	3	May 1940.
78	Buzzard's Roost	Illinois	Coos-Curry Electric Corp., Inc	550	2	[1] 200,000	200,000	Under active consideration.
79	Aspen Lake	Aspen Creek	Pacific Power & Light Co	240	1	[1] 36,000	36,000	Do.
80	East Side	Klamath	do	47	1	3,200	3,200	1924.
81	West Side	do	do	49	1	600	600	1908.
82	Keno	do	do	293	2	[1] 100,000	100,000	Under active consideration.
83	John C. Boyle	do	do	466	2	79,990	79,990	Oct. 1, 1958.
84	Bear Springs	do	do	127	1	[1] 25,000	25,000	Do.
85	Salt Caves	do	do	420	2	[1] 80,000	80,000	Do.

[1] Installed capacity is not existing, but is planned for initial installation.
[2] Plant located on a border stream. One-half of the project installed capacity considered in Oregon when tabulating totals.
[3] Decision as to constructing agency currently before the Federal Power Commission.

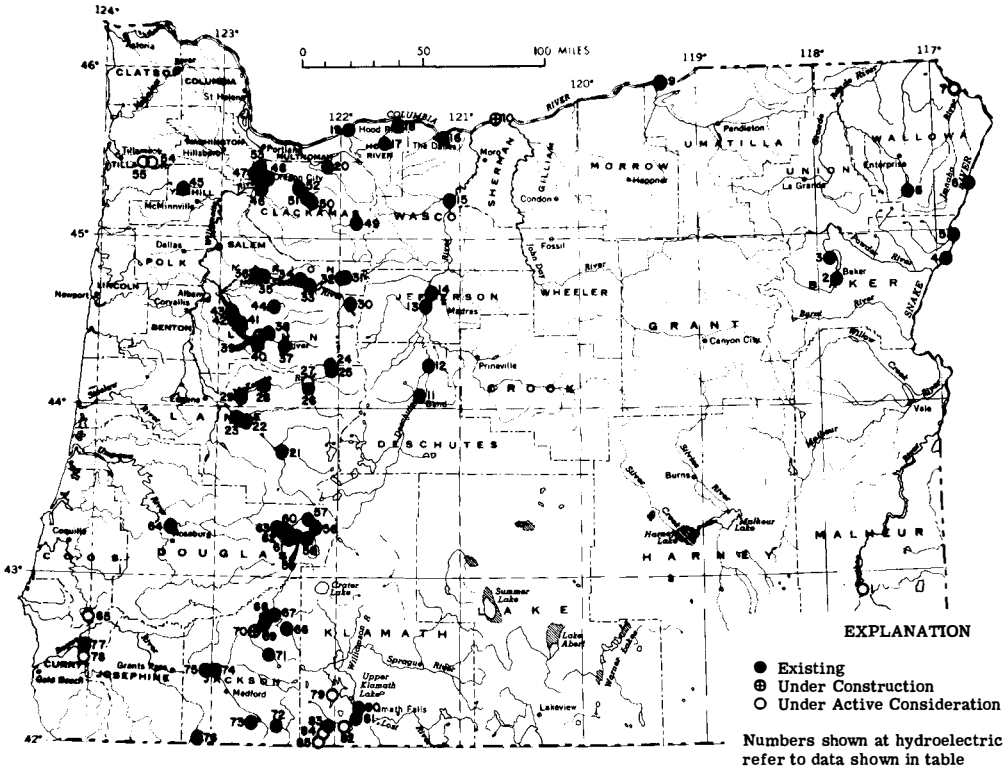

FIGURE 85.—Hydroelectric Power Resources in Oregon; existing, under construction and under active consideration

The Federal Government has eleven existing projects in Oregon for a total of 1,712,700 kilowatts. Of these, the Corps of Engineers has developed ten multipurpose projects combining power with other uses, such as flood control, navigation, municipal water supply, irrigation, etc. These projects are on the Willamette, Santiam, McKenzie, and Columbia Rivers. The Bureau of Reclamation of the Department of the Interior developed Green Springs Plants on Emigrant Creek, which through diversion combines irrigation with power.

Bonneville Dam, energized on June 6, 1938, provided the first Federal generation in Oregon. This dam, located in that part of the Columbia River which forms the boundary between Oregon and Washington, was built by the U.S. Army, Corps of Engineers. Subsequently, the Corps of Engineers completed McNary Dam in 1953, The Dalles Dam in 1957, and now has John Day Dam under construction in the same reach of the Columbia River.

Tabulations of hydroelectric power resources for projects on state boundary streams consider one-half the installed capacities in Oregon. This includes those projects mentioned on the Columbia River and those on the reach of the Snake River where it borders Oregon and Idaho.

The treaty between Canada and the United States of America, relating to Cooperative Development of the Water Resources of the Columbia River Basin, was implemented in 1964. The treaty states that Canada shall provide 15,500,000 acre-feet of usable storage in the Canadian portion of the Columbia River Basin. Coordinated regulation of this storage will improve the flow of the Columbia River and enhance the feasibility of installing additional units at downstream plants. For the State of Oregon, this would justify another power plant at Bonneville Dam and additional units at The Dalles, John Day, and McNary.

The capacity for four Federal projects—John Day, The Dalles, Foster, and Lost Creek—under construction or expansion in Oregon totals 1,493,000 kilowatts. Federal plants under active consideration are Duncan Ferry, Mountain Sheep, and Strube with a total installed capacity of 1,218,500 kilowatts. Future additions planned for the McNary, John Day, Bonneville, and Cougar power plants would add another 677,000 kilowatts. The installed capacity for the existing, under construction, and planned development of Federal generation in the state totals 4,722,200 kilowatts.

The presently contemplated ultimate hydroelectric development in the State of Oregon includes the 85 projects either existing, under construction, or under active consideration listed in Table 40 and located on Figure 85 .The total ultimate installed capacity of these projects is 7,420,201 kilowatts.

To insure usability of the storage available under the United States-Canadian Treaty, Bonneville Power Administration, the Corps of Engineers, and 14 generating utilities executed the 39-year Pacific Northwest Coordination Agreement on September 15, 1964. Three of these utilities are the largest in Oregon: Pacific Power and Light Company, Portland General Electric Company, and the City of Eugene Water and Electric Board. This agreement provides coordinated operation of all the utilities, assures fullest use of the available power re-

sources, and makes savings in operating and transmission costs possible.

Bonneville Power Administration in the Department of the Interior was created during construction of Bonneville Dam. The U.S. Government authorized a Federal agency to market the power from the dam. This took place on August 30, 1937, when the Bonneville Project Act was signed into law by President Franklin D. Roosevelt. The first transmission line built by BPA was 3.4 miles long from Bonneville Dam to the City of Cascade Locks, Oregon, energized at 13,800 volts in 1938.

The Act, later supplemented by amendments and Executive Orders, now designates BPA as the marketing agency for Federal projects in the Pacific Northwest. The Corps of Engineers and Bureau of Reclamation construct and operate the projects.

Bonneville constructs, operates, and maintains the substations and electric transmission lines to deliver the power from the Federal dams to the load centers. Generation and transmission thereby act as a unit. There are now over 10,000 circuit miles of transmission lines in the BPA system operating up to 500,000 volts.

Within Oregon, BPA operates and maintains over 3,000 circuit miles of transmission lines and 91 substations with over 5,570,000 kilovolt-amperes of transformer capacity. These facilities constitute over 30 percent of BPA's physical plant in the Pacific Northwest. All existing BPA substations in Oregon are listed in table 41. Table 42 lists the existing transmission mileage by type of construction and voltage in the state. Figure 86 shows the major substations and transmission lines of 230,000 volts and above.

Through interconnections with all of the generating utilities in the region, the BPA system forms a backbone grid providing greater reliability of service to all and permitting energy in one area to be transmitted to another. The existence of this system made possible the Pacific Northwest-Pacific Southwest Intertie, presently under construction. When completed, this extra-high voltage interconnection will have four high-voltage transmission lines traversing Oregon from north to south. Two lines of 500,000 volts alternating current will extend from John Day Dam to San Francisco and Los Angeles, California. Bonneville has built two lines from John Day Dam to Grizzly Substation near Round Butte Dam and has completed one 500,000-volt line from there to the Oregon-California boundary. Portland General Electric Company will soon complete the other 500,000-volt line from Grizzly Substation to the boundary.

The last two lines of the intertie are designed for 750,000 volts direct current. They will become the first high-voltage direct-current transmission lines in the United States. Each line will total over 800 miles in length with more than 260 miles in Oregon. They will be two of the longest direct-current high-voltage lines in the world. Bonneville Power Administration will build the two 750,000-volt lines in Oregon from The Dalles Dam to the Nevada boundary. One will continue on to Hoover Dam on the Colorado River, the other line terminates near Los Angeles, California.

The intertie will permit exchanges of energy between the regions to take advantage of diversity and peak loads. Through exchange of off-

TABLE 41.—BONNEVILLE POWER ADMINISTRATION SUBSTATIONS IN THE STATE OF OREGON

MAIN GRID SUBSTATIONS

Index No. on fig. 86	Substation	Capacity (as of Dec. 31, 1967) kilovolt-amperes	Date first placed in service
1	LaGrande	33,333	Oct. 10, 1952
2	Roundup	66,666	Oct. 2, 1954
3	McNary	933,333	Nov. 5, 1953
[1] 4	John Day		Sept. 6, 1960
5	Big Eddy	250,000	Dec. 18, 1951
6	Chenoweth		Nov. 7, 1957
7	Troutdale	432,250	Apr. 29, 1942
8	St. Johns	250,000	Dec. 13, 1940
9	D. R. Keeler	250,000	Dec. 15, 1956
10	Wauna	125,000	Dec. 16, 1966
[1] 11	Driscoll		Do.
12	Astoria	12,000	June 30, 1941
13	Oregon City	125,000	July 29, 1941
14	Chemawa	375,000	Dec. 20, 1953
15	Toledo	100,000	Oct. 11, 1946
16	Albany	262,000	Nov. 16, 1940
17	Santiam	75,000	Nov. 7, 1954
18	Detroit	3,000	Sept. 1, 1949
19	J. P. Alvey	256,000	Oct. 6, 1950
20	Lane	250,000	Mar. 9, 1967
[1] 21	Tahkenitch		Oct. 7, 1963
22	Bandon	12,000	Dec. 13, 1950
23	Fairview	250,000	Nov. 1, 1957
[1] 24	Reston		Oct. 23, 1960
25	Hanna	98,000	June 3, 1954
[1] 26	Malin		Oct. 15, 1967
27	Redmond	186,666	Nov. 21, 1952
[1] 28	Grizzly		Oct. 15, 1967

OTHER EXISTING SUBSTATIONS

Substation	Capacity (as of Dec. 31, 1967) kilovolt-amperes	Date first placed in service
Beaver	5,000	Oct. 1, 1946
Blue River	6,000	Nov. 4, 1962
Burntwoods	6,000	July 16, 1964
Cascade Locks	6,000	Sept. 11, 1959
Clatskanie	6,000	Dec. 8, 1950
Coos [1]		Oct. 25, 1950
Cottage Grove [1]		Aug. 14, 1952
Cougar [1]		Oct. 21, 1963
DeMoss	25,000	May 27, 1958
Dexter [1]		May 4, 1955
Dorena	9,375	Sept. 16, 1964
Drain	15,000	May 9, 1946
Eugene	64,500	Oct. 22, 1940
Fern Ridge	12,000	June 28, 1961
Florence	12,000	Sept. 13, 1953
Forest Grove	12,000	Nov. 27, 1939
Fossil [1]		June 18, 1961
Gardiner	33,333	Oct. 15, 1963
Garibaldi	12,000	Dec. 6, 1965
Giesel Monument	6,000	Sept. 8, 1955
Gold Beach	20,000	Oct. 1, 1952
Green Peter [1]		Aug. 2, 1963
Grizzly [1]		Oct. 15, 1967
Hampton	2,500	Dec. 14, 1961
Hanna	98,000	June 3, 1954
Harney [1]		Dec. 22, 1966
Harrisburg	3,000	May 15, 1946
Harvey	321,300	Nov. 8, 1957
Hauser	6,000	Feb. 24, 1954
Hebo	7,500	Dec. 29, 1961
Hood River	8,000	Apr. 4, 1946
Ione	2,500	Nov. 8, 1949
Junction City	2,500	July 11, 1953
Langlois	3,000	Oct. 24, 1957
Lebanon	46,000	Mar. 30, 1950
Lookingglass	6,000	May 10, 1951
Lookout Point [1]		Dec. 16, 1954
Mapleton	12,000	Dec. 24, 1948
McMinnville	52,000	Oct. 18, 1940
Milton	15,000	June 6, 1946
Mohler	7,500	Dec. 29, 1961
Monmouth	9,000	Dec. 4, 1940
Norway	6,000	Dec. 13, 1950
Oakridge	12,000	July 16, 1954
Pendleton	3,000	June 1, 1941
Port Orford	15,000	Oct. 1, 1952
Reedsport	12,000	Oct. 25, 1950
Salem	20,000	May 10, 1940
Salem Alumina	20,000	June 14, 1944
South Bank [1]		June 27, 1941
Springfield	12,000	May 25, 1952
Stateline	3,000	May 26, 1954
Thatcher Junction	20,000	Nov. 19, 1959
The Dalles	28,000	May 24, 1941
Tillamook	33,333	June 13, 1947
Timber	6,000	June 23, 1955
Tongue Point	3,000	Oct. 26, 1941
Tygh Valley	6,000	Sept. 27, 1951
Walnut City	20,000	Jan. 19, 1965
Walton	3,000	July 12, 1949
Warren	3,000	Jan. 15, 1947
Westport	3,000	May 8, 1945
Wren	105,000	Apr. 1, 1947

[1] Switching station.

TABLE 42.—OREGON ENERGIZED TRANSMISSION LINES

[In miles]

Design voltage (kilovolts)	Steel tower	Wood pole	Total
500	110.1		110.1
345	119.0		119.0
287	661.6	1.8	663.4
230	359.0	350.8	709.8
115	212.3	1,133.4	1,345.7
Lower	5.9	71.8	77.7
Total	[1] 1,467.9	1,557.8	[1] 3,025.7

[1] Does not include 267 circuit-miles at 500 kilovolts of the Pacific Northwest-Pacific Southwest interconnection in Oregon.

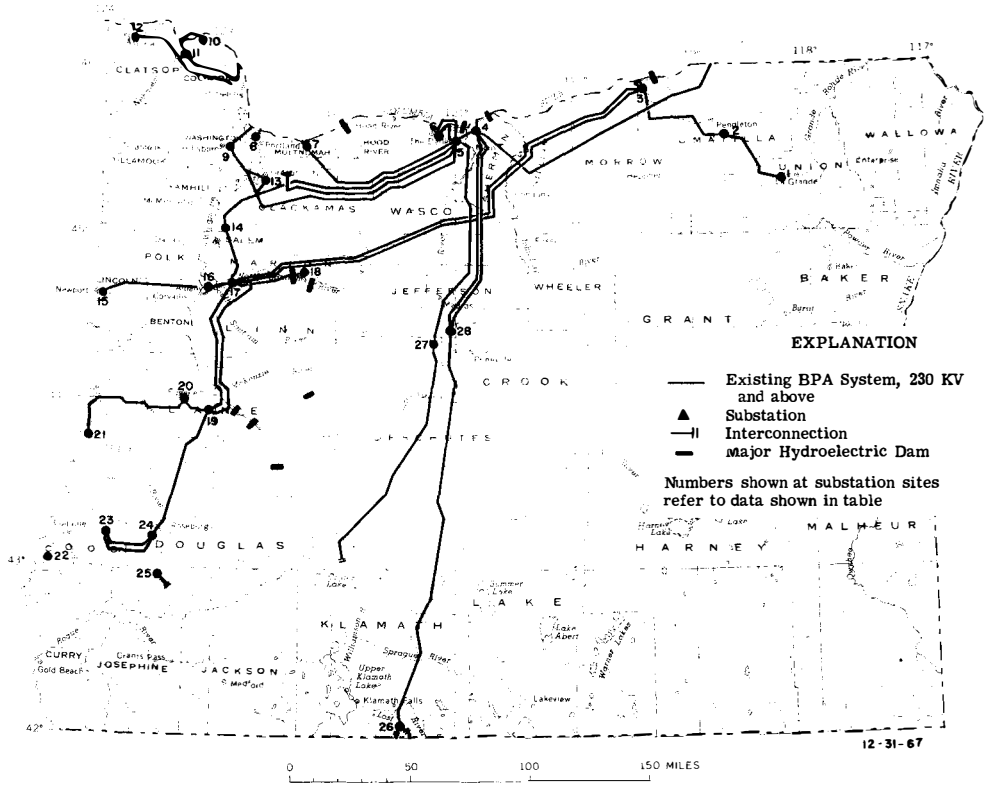

FIGURE 86.—Bonneville Power Administration—main grid in Oregon.

peak energy from the Southwest, Bonneville can firm up some 700,000 kilowatts of secondary energy in the Pacific Northwest. The resulting firm power will be available for sale in the Northwest. Of major importance at present, however, the lines will permit sale in California of Canada's share of Columbia River Treaty power when surplus to Northwest needs.

Those hydroelectric sites which have economic feasibility will be developed, but they will meet only a small part of the power requirements forecast for Oregon. Consequently, other sources of electric power must be sought.

Steam-electric generation has been developed in Oregon on a much smaller scale than hydroelectric. The 45 plants existing at present have a total installed capacity of 322,980 kilowatts. However, Portland General Electric Company proposes building a 1,000,000-kilowatt nuclear-fired steam-electric plant near Rainier on the lower Columbia River in the mid 1970's, the first of its kind in Oregon. Plants of this type may well hold the answer to Oregon's future power development.

POTENTIAL WATERPOWER

(By L. L. Young and J. L. Colbert, U.S. Geological Survey, Portland, Oreg.)

The gross theoretical waterpower at 291 developed and undeveloped sites in Oregon is 11,390 MW (megawatt (MW)=1,000 kilowatts). It has about 9 percent of the United States total and ranks fourth among the states in the extent of this resource as the following table indicates:

Washington	20,000 MW	Oregon	11,400 MW
Alaska	17,000 MW	Idaho	10,700 MW
California	11,700 MW	Montana	4,900 MW

Pumped-storage waterpower sites are abundant in Oregon and will figure prominently in future waterpower developments. Such sites do not add to the gross waterpower resource, however, because they usually consume more energy in pumping than they produce from return gravity flow. Their value is in providing premium energy during periods of high demand.

Gross Theoretical Waterpower

The U.S. Geological Survey is responsible for classification of public lands as to their mineral, water conservation, and waterpower values. To properly classify the water resource value of these lands, the Survey investigates and evaluates potential reservoir and waterpower sites throughout the public land states. Classification prevents disposal of Federal lands valuable for water resources development and the classification process indicates a value to be considered in determining priorities in multiple-use management of the public lands.

The Geological Survey has prepared an inventory of sites in Oregon which its classification studies indicate have a potential for future development. This inventory includes 291 sites for which the mini-

mum theoretical power potential exceeds 1 MW at Q 50 (median stream-flow). The selected sites are shown on a map of the state divided into major drainage basins (fig. 87). Developed and undeveloped sites with a potential power of 20 MW or more with average stream-flow (Q mean) are shown by solid stars (developed) and solid squares (undeveloped). Those sites shown on the map are keyed by number to the list on page 381. Sites with Q mean potentials of less than 20 MW are shown on the map as open stars or open squares but are not listed.

The estimates of the potential waterpower of Oregon are based on criteria defined by the World Power Conference in 1962 as follows:

"*Powersites.*—Waterpower sites, or "powersites," are definite sections of a stream which are developed or are capable of being developed for the production of waterpower.

"*Potential power resources.*—The potential waterpower resources of any country, section, or river basin is the aggregate of the gross theoretical power at all powersites, developed and undeveloped where development may reasonably be assumed to be eventually practicable.

"*Gross theoretical power of powersites.*—The "gross theoretical power" of a powersite is the full potential output at 100 percent efficiency expressed in kilowatts, and is determined by the formula Kw=0.085 Qh when the head "h" is in feet and the flow "Q" is in cubic feet per second.

"*Rates of flow.*—The gross theoretical power of powersites is computed for three different rates of flow, defined as follows: flow available 95 percent of the time (Q95), flow available 50 percent of the time (Q50), and arithmetical mean flow (Q mean).

"*Heads at powersites.*—The "gross head" is the difference in elevation between the water surfaces at the beginning and at the end of the powersite, without reduction for losses."

Figure 88 shows profiles of the important rivers of Oregon on which are indicated the altitudes of the principal sites, also keyed by number to the list on page 381. Highest head is that for the Tunnel powersite, which has been proposed to divert water from Imnaha River through a tunnel to a powerhouse on Hells Canyon Reservoir 2,477 feet below.

Of the total sites meeting the minimum criteria of 1 MW with *Q 50* stream-flow, 52 are developed and 239 are undeveloped. One hundred thirty-five have gross theoretical power of 20 MW or more at *Q mean*. The smallest of these is the Eagle Point plant on the Rogue River, developing 2.45 MW, and the largest is the John Day site under construction on the Columbia River with a planned generating capacity of 1,686 MW. Seventeen sites have a *Q mean* power potential of less than 5 MW and 17 have a potential of more than 100 MW. The distribution of sites by size classes is summarized in table 43.

Tables 43 and 44 are arranged to show the potential capacities in MW at the Q95, Q50, and Qmean flow rates; the existing and installable generating capacities in MW; and the average annual generation in MWH (1,000 kilowatthours) for existing and installable generators,

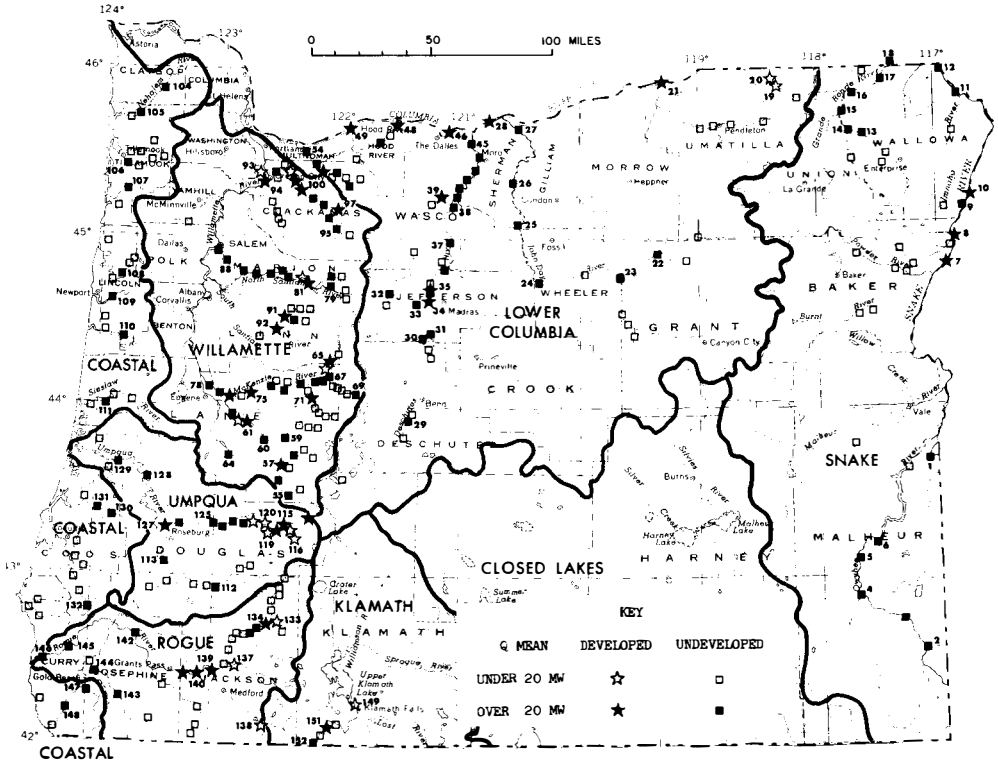

FIGURE 87.—Developed and undeveloped waterpower sites in Oregon.

[Key to figures 87 and 88. Numbers in downstream order identify sites with a Qmean potential of 20 MW or more and 17 smaller developed sites]

No.	Site	Qmean MW
1	Blackjack Butte	[1] 18
2	Three Forks	24
3	Soldier Creek	24
4	Duncan Ferry	20
5	Bogus Creek	32
6	Mohagany	24
7	Brownlee	[1] 202
8	Oxbow	[1] 92
9	Tunnel	39
10	Hells Canyon	[1] 132
11	High Mountain Sheep	[1] 468
12	China Gardens	[1] 89
13	Wallowa	48
14	Little Minam	27
15	Rondowa	75
16	Elbow Creek	75
17	Wildcat Creek	40
18	Wenaha	72
19	Forks	12
20	Milton	5
21	McNary	[1] 644
22	Twomile Canyon	34
23	Kimberly	44
24	Twinkenham	42
25	Butte Creek	56
26	Jacknife	63
27	Tenmile Falls	78
28	John Day	[1] 843
29	Lava Island	25
30	Geneva	24
31	Crooked R. Gorge	54
32	Jefferson Creek	32
33	Metolius Bench	42
34	Round Butte	132
35	Pelton	57
36	Trout Creek	56
37	Whitehorse Rapids	81
38	Maupin	107
39	Tygh Valley	7
40	Sherar Falls	76
41	Oakbrook	36
42	Sinamox	48
43	Reclamation	49
44	Lockit	39
45	Moody	79
46	The Dalles	[1] 714
47	Blue Ridge	26
48	Powerdale	39
49	Bonneville	[1] 496
50	ZigZag	21
51	Marmot	58
52	Bull Run	42
53	Indian John	36
54	Troutdale	28
55	Campers Flat	24
56	Sand Prairie	31
57	Hills Creek	31
58	Salt-Salmon	34
59	Huckleberry Creek	21
60	Uper Lookout Point	73
61	Lookout Point	64
62	Dexter	16
63	Jasper	39
64	Rocky Point	21
65	Carmen	30
66	Trail Bridge	8
67	Belknap	42
68	Paradise	21
69	Mesa Creek	20
70	McKenzie Bridge	41
71	Cougar	34
72	South Fork	37
73	Bear Creek	65
74	Vida	36
75	Leaburg	36
76	Walterville	24
77	Hayden Bridge	36
78	Coburg	25
79	Tom Creek	34
80	Byars Creek	20
81	Detroit	63
82	Big Cliff	17
83	Niagara	77
84	Mehama	25
85	Elkhorn	26
86	Mehama No. 2	42
87	Aumsville	29
88	Turner	32
89	Salem	36
90	Cascadia	23
91	Green Peter	44
92	Foster	28
93	Lake Oswego	13
94	Willamette Falls	177
95	Collawash	43
96	Nowhere Meadows	33
97	Three Lynx	42
98	Fish Creek	42
99	South Fork	41
100	North Fork	31
101	Faraday	30
102	River Mill	19
103	Carver	77
104	Elsie	27
105	Nehalem Falls	72
106	Ginger Peak	20
107	Blaine	20
108	Sunshine Creek	38
109	Elk City	22
110	Scott Mountain	34
111	Swisshome	22
112	Tiller	33
113	Ruckles	28
114	Lemolo No. 1	27
115	Lemolo No. 2	29
116	Clearwater No. 1	9
117	Clearwater No. 2	15
118	Toketee Falls	31
119	Fish Creek	20
120	Slide Creek	13
121	Soda Springs	10
122	Copeland	48
123	Steamboat	32
124	Boundary	43
125	Rock Creek	46
126	Oak Creek	61
127	Winchester	24
128	Kelley-Smith Fry	190
129	Scottsburg	69
130	Tioga Fork	24
131	Dellwood	42
132	Eden Ridge	21
133	Prospect No. 3	11
134	Prospect Nos. 1, 2, and 4	70
135	Cascade	33
136	Lost Creek	31
137	Eagle Point	2
138	Green Springs	8
139	Gold Ray	22
140	Gold Hill	24
141	Savage Rapids	29
142	Ramey Falls	165
143	Falls Creek	59
144	Bald Mountain	102
145	Copper Canyon	402
146	Gold Beach	57
147	Boulder Creek	29
148	Redwood	38
149	Eastside	4
150	Keno	42
151	John C. Boyle	68
152	Salt Caves	63

[1] Site on boundary line; amount is ½ of potential.

TABLE 43.—GROSS POTENTIAL WATERPOWER OF OREGON POWERSITES BY SIZE

Size category	Number of sites	Gross theoretical power, with gross head, 100 percent efficiency and flows at—			Installed and installable (mw.)		Average annual generation (mw.-hr.)		
		Mw. Q 95	Mw. Q 50	Mw. mean	Existing	Existing and/or installable	With existing generators	With existing and/or installable generators	Complete control
State total [1]	291	3,828	7,725	11,390	4,311	15,050	23,700,000	62,500,000	80,000,000
100 mw. or more	17	2,044	3,545	5,027	3,168	6,620	18,430,000	30,200,000	35,300,000
50 to 100 mw	26	550	1,210	1,747	445	2,420	1,870,000	9,300,000	12,250,000
20 to 50 mw	92	877	1,955	2,948	519	4,010	2,500,000	15,200,000	20,750,000
10 to 20 mw	91	277	770	1,255	129	1,500	680,000	5,800,000	8,800,000
5 to 10 mw	48	66	203	345	43	420	175,000	1,650,000	2,420,000
Less than 5 mw	17	14	42	68	7	80	45,000	350,000	480,000

[1] Oregon drainage and ½ potential of sites on State boundary lines.

and for complete equalization of streamflow. Power from sites along State boundaries is divided equally between the States affected. The gross theoretical power shown for developed sites indicates potential only and does not imply that plant enlargements are economically feasible or contemplated, although redevelopment may be desirable at some sites.

Oregon has 4,310 MW installed or under construction at sites whose gross potential at mean flow and 100 percent efficiency is 4,065 MW and whose ultimate installable capacity is estimated to be 5,302 MW. The 4,310 presently installed includes one-half of the capacities of powerplants on State boundaries and excludes powerplants whose potential capacity at Q50 flow is less than 1 MW. Possible future waterpower developments in Oregon amount to about 1,000 MW at plants already partly developed; and 7,000 MW. at sites yet undeveloped.

The potential power based on mean flow represents the maximum obtainable and would require complete stream regulation or power generating installation sufficiently large to utilize the largest possible flows. However, there are very few reservoir sites large enough to afford complete regulation of the stream at the damsite, and it is seldom practical to have plants capable of utilizing the whole range of unregulated flows. Actual output, therefore, will always be somewhat smaller than the theoretical potential. In large integrated power systems it is sometimes possible to achieve almost complete utilization of streamflow by coordinated use of storage reservoirs, reregulating reservoirs, and installation of powerplants capable of utilizing relatively high discharges. When substantial storage can be provided, production during dry seasons and dry years can be augmented. Reregulating reservoirs make possible the production of large amounts of power from upstream storage without undue fluctuations of downstream flows.

An average of 62.5 million MWH (thousands of kilowatthours) of energy might be generated annually under existing flow conditions if generating equipment capable of utilizing water up to twice the Q50 flows were installed at all the powersites studied. This amount of energy would be 78 percent of the 80 million MWH that would

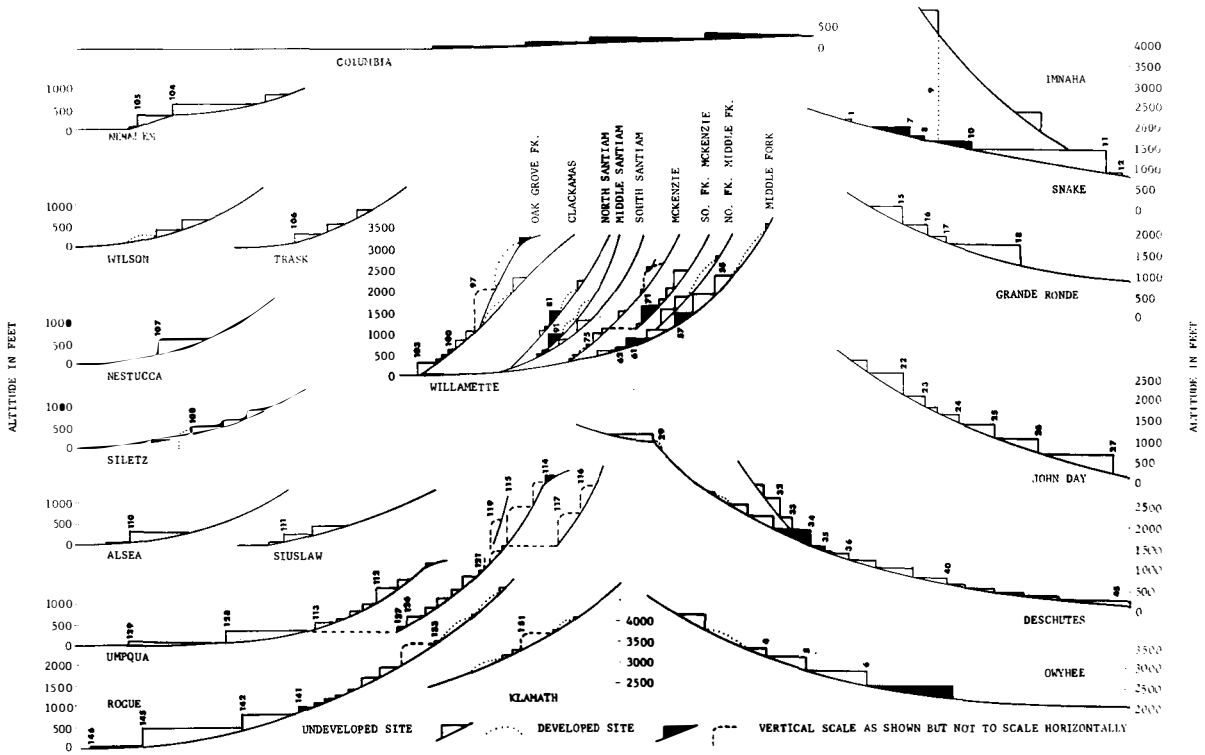

FIGURE 88.—Profiles of principal rivers in Oregon.

be theoretically possible in Oregon through complete utilization of the water at the selected powersites.

The estimate presented here is believed to be conservative. The energy output estimate of 62,500,000 MWH for sites in Oregon where development is assumed to be eventually practicable is about 20 percent of a purely theoretical estimate based upon an average runoff of 85,000,000 acre-feet and an average altitude of 3,500 [3] feet augmented by water originating outside the State and flowing in boundary rivers. The 20 percent for Oregon compares with 43 percent for Sweden, 20 percent for Italy, and 12 percent for Greece as determined by a United Nations study team (United Nations, 1961).

Areal Distribution of Waterpower

This appraisal of the waterpower resources of Oregon is based on the distribution of developed and undeveloped sites within the same principal drainage basins of the State, described in Section II, Water Resources and Development (fig. 87). Except that in this chapter all of the coastal streams are grouped together.

The principal basins and their approximate average altitudes, areas, runoff and percentages of State totals are as follows:

Basin	Average altitude (feet)	Runoff (millions of acre-feet)	Area	
			Square miles	Percent of State
Closed Lake	5,200	1.1	18,300	19
Snake River	4,200	3.6	19,100	20
Lower Columbia	3,200	13.0	25,700	26
Willamette River	1,900	24.6	11,200	12
Coastal	2,700	43.5	22,680	23
Coast Range	(1,300)	(26.0)	(7,270)	(7)
Umpqua River	(2,200)	(8.0)	(4,560)	(5)
Rogue River	(2,800)	(8.0)	(5,170)	(5)
Klamath River	(4,800)	(1.5)	(5,680)	(6)
Average altitude and total	3,500	85.8	96,980	100

The potential power of these basins range from zero in the closed lake basins to 4,510 MW in the lower Columbia basin. The Snake and lower Columbia basin powersites benefit immensely from water derived from other States and, in the case of the lower Columbia, from Canada. The other basins are almost totally inside Oregon and do not receive any material benefit from out-of-State water. The potential power for the principal streams in these drainage basins is shown in table 44 which lists the basins and streams in downstream order. The same data are summarized in figure 89 by amount of potential power for each basin in descending order as follows: Lower Columbia 40 percent; Coastal basins 26 percent; Williamette basin 20 percent, Snake basin 14 percent.

[3] Computed in 1967 from 1966 edition of 1:500,000-scale Oregon base map with contours.

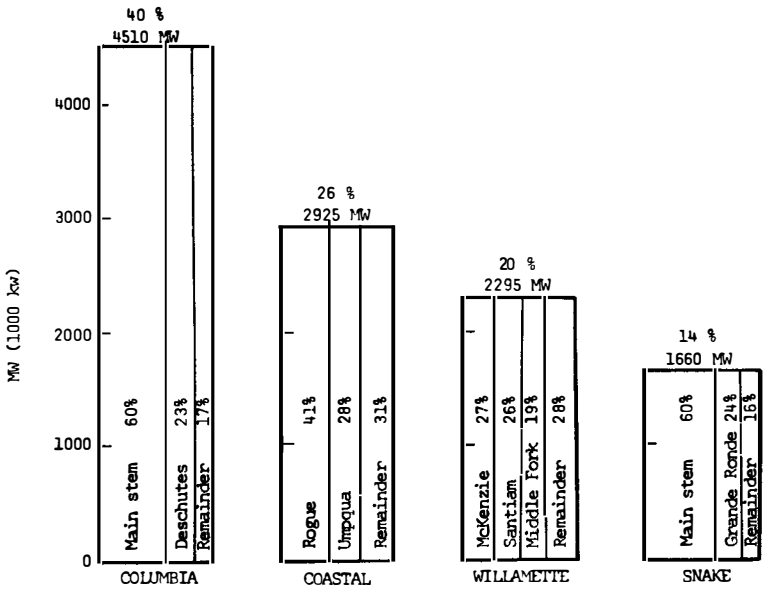

FIGURE 89.—Gross theoretical waterpower of the principal drainage basins in Oregon in megawatts and percentages.

CLOSED-LAKE BASINS

Due to lack of water, this 18,300-square-mile section, 19 percent of the State, has no potential waterpower sites with capacities large enough to be included in the potential waterpower inventory. In the past, when transmission from outside power sources was not feasible, some small waterpower sites were developed, and sites were studied on Deep Creek and Chewaucan River in the southwestern part of the basins and on Kiger Creek and Donner und Blitzen River in the southeastern part. These streams have sufficient fall and discharge in certain reaches to make small waterpower developments possible, but modern technology favors larger developments and has made the smaller sites economically unattractive. The average altitude of the basin in Oregon is 5,200 feet above sea level, ranging from 4,084 feet at Harney Lake to 9,670 feet on Steens Mountain. Average annual runoff from the land surface to the closed lakes is estimated to be 1.1 million acre-feet per year.

TABLE 44.—GROSS POTENTIAL WATERPOWER OF OREGON BY PRINCIPAL DRAINAGE BASINS

Drainage basin	Number of sites	Gross theoretical power, with gross head, 100 percent efficiency and flows at—			Installed and installable (mw.)		Average annual generation (mw.-hr.)		
		Mw. Q 95	Mw. Q 50	Mw. mean	Existing	Existing and/or installable	With existing generators	With existing and/or installable generators	Complete control
Statetotal	291	3,828	7,725	11,390	4,311	15,050	23,700,000	62,500,000	80,000,000
Snake River Basin [1]	35	636	1,120	1,660	470	2,200	2,800,000	9,000,000	11,700,000
Main stem [2]	5	520	813	1,000	470	1,600	2,795,000	6,485,000	7,050,000
Owyhee and Malheur [3]	7	11	35	145	----	60	Small	285,000	1,020,000
Burnt and Powder [4]	7	10	20	47	----	40	Small	160,000	340,000
Pine Creek and Imnaha	4	11	37	78	----	70	----	310,000	550,000
Grande Ronde [5]	12	84	215	390	----	430	Small	1,760,000	2,740,000
Lower Columbia Basin [1]	63	1,990	3,260	4,510	2,786	6,100	15,970,000	28,700,000	31,700,000
Main steam [6]	4	1,216	1,915	2,697	2,397	3,310	14,450,000	18,500,000	19,000,000
Walla Walla	3	10	17	24	3	35	9,000	146,000	166,000
Umatilla	4	3	21	37	----	40	----	158,000	256,000
John Day	12 [7]	20	170	379	----	350	----	1,290,000	2,649,000
Deschutes	27 [8]	668	907	1,053	359	1,900	1,370,000	6,820,000	7,395,000
Hood	3	21	58	82	6	115	48,000	413,000	571,000
Sandy	10 [9]	52	172	238	21	350	93,000	1,373,000	1,663,000
Willamette Basin	89 [10]	667	1,645	2,295	716	3,400	3,000,000	12,000,000	16,000,000
Middle Fork, Willamette [11]	17	111	293	439	165	680	600,000	2,330,000	3,100,000
McKenzie [12]	30	248	466	611	136	920	550,000	3,510,000	4,200,000
Santiam	22	131	420	590	218	900	860,000	3,230,000	4,100,000
Yamhill-Willamette Falls	7	31	160	254	54	300	230,000	520,000	1,800,000
Clackamas	13	146	306	401	143	600	760,000	2,410,000	2,800,000
West Coast Basins	103	535	1,700	2,925	339	3,350	1,930,000	12,800,000	20,600,000
Umpqua	26	225	520	820	187	1,000	1,000,000	3,950,000	5,790,000
Rogue	31	235	710	1,190	68	1,400	430,000	5,400,000	8,340,000
Coast Range Streams	41	35	300	715	----	600	----	2,170,000	5,090,000
Klamath [13]	5	40	170	200	84	350	500,000	1,280,000	1,380,000
Closed Lake Basins	0	----	----	----	----	----	----	----	----

[1] Oregon drainage and ½ main stem.
[2] Oregon's ½ of main stem sites on Idaho-Oregon boundary.
[3] Does not count Vale No. 2 plant, 0.07 MW installed but insufficient practicable potential.
[4] Does not count Baker, Sumpter, Rock Creek, 1.04 MW installed but insufficient practicable potential.
[5] Does not count Morgan Lake and Wallowa Falls, 1.18 MW installed but insufficient practicable potential, and ½ Wenaha and State line undeveloped sites.
[6] Oregon's ½ of main stem developed sites, McNary, John Day, The Dalles and Bonneville.
[7] Does not include Fremont developed site with 1.1 MW installed but insufficient practicable potential.
[8] Does not include Bend and Circle M developed sites with 1.11 and 0.10 MW installed but with insufficient practicable potential.
[9] Does not include Bridal Veil and Rose Moody developed sites with 0.12 and 0.01 MW installed but with insufficient practicable potential.
[10] Includes 19 sites fully or partially developed. An additional 20 small developed sites (installed about 4 MW) are omitted because redevelopment does not appear to be practical.
[11] Includes Row River and Coast Fork Willamette.
[12] Includes Calapooia River.
[13] Does not include West Side plant, 0.6 MW installed but with insufficient practicable potential.

SNAKE RIVER BASIN

The Snake River along the Oregon State line and its Oregon tributaries drain 19,100 square miles (20 percent of the State) and have 1,660 MW potential waterpower (about 15 percent of the State total). The average altitude of the basin in Oregon is 4,200 feet above mean sea level, ranging from about 845 feet on the Snake River at the Washington State boundary to 9,845 feet on Matterhorn Peak in the Wal-

lowa Mountains. The Snake River discharges about 8 million acre-feet per year as it enters Oregon and it is estimated that Oregon drainage contributes an additional 3.6 million acre-feet.

The Snake River forms Oregon's eastern boundary in a 216-mile reach in which the river falls 1,335 feet from altitude 2,180 to 845 feet. Three recently constructed waterpower plants and two potential sites that are in the stages of advanced planning will develop 1,232 feet of this head. The potential power of the reach is 1,967 MW. The half attributable to Oregon (983.5 MW) is 59 percent of Oregon's share of potential waterpower in the Snake River basin. Sites on Imnaha River could be connected by tunnel to sites on the main Snake to create high head for conventional or pump-storage plants. The only Oregon tributary with substantial waterpower is the Grande Ronde River. Capacity of the river in Oregon is 261.5 MW, largely concentrated in a reach extending 70 miles upstream from the State line. A fall of 1,225 feet is potentially developable in the reach.

LOWER COLUMBIA RIVER BASIN

Oregon tributaries of the Columbia River except the Williamette River, drain an area of about 25,700 square miles (about 26 percent of the State). The gross theoretical potential waterpower of this part of the Columbia River Basin is estimated to be 4,510 MW for average discharge and 100 percent efficiency (more than 39 percent of the State total).

The average altitude of the basin in Oregon is about 3,200 feet, varying from sea level along the lower river to 11,235 feet on Mount Hood. Measured runoff at McNary Dam has averaged 134.6 million acre-feet per year and average annual runoff from the Oregon part of the area is estimated to be about 13 million acre-feet. In the 309-mile reach where the Columbia forms the State's northern boundary, the river falls only 340 feet. The average discharge of the stream is so great, however, that it has a gross theoretical potential waterpower of 5,394 MW for average discharge at 100 percent efficiency, 2,697 MW assignable to Oregon (23.7 percent of the State total).

Oregon tributaries to the Columbia River in this basin having the most potential waterpower are the John Day and Deschutes Rivers. John Day River flows westward and northwestward from the Blue Mountains to the Columbia River through many wide valleys in which large storage reservoirs could be built. These reservoir sites might be used for holding Columbia River water pumped into them for later use. Columbia River water might be taken to Central Oregon by pumping it up John Day River from reservoir to reservoir for use in irrigation.

The Deschutes River falls an average of about 18 feet per mile over its 252-mile length. The natural flow of the stream is remarkably constant and, even though a large part of the water flowing in its upper reaches is used for irrigation, an average flow of 4,260 cfs is available for other uses at Round Butte Dam, river mile 111. This flow increases to 5,800 at the river's mouth. Round Butte Dam backs water to an altitude of 1,945 feet and the entire fall of 1,785 feet to the The Dalles backwater at the river's mouth, altitude 160 feet, could be developed.

The potential power of this reach of river, determined by totalling the potential of three waterpower developments and 21 undeveloped powersites, is estimated to be more than 1,000 MW at average discharge and 100 percent efficiency. The stream flows so evenly that plants with capacities sufficient to utilize water up to twice the discharge available 50 percent of the time could produce more than 90 percent of the energy that would be available if the stream were completely controlled.

The State Water Resources Board recently conducted a study of the Deschutes River basin and adopted a policy under the authority of ORS 536.300 in which use of the lower 100 miles of the Deschutes River is restricted to domestic, livestock, recreation, fish and wildlife purposes, and no appropriations of water in this area is to be permitted for any other purpose (State Water Resources Board, 1961). This policy precludes the development of waterpower at the larger undeveloped sites in the basin, for at average flow 70 percent of the potential, and at low-flow 85 percent of the potential are in the restricted reach.

WILLAMETTE RIVER BASIN

From a drainage area of about 11,200 square miles (12 percent of the State) the Willamette River basin has an estimated gross theoretical potential waterpower of 2,295 MW (20 percent of the State). The average altitude of the Willamette basin is 1,800 feet, varying from sea level at the river's mouth to 10,497 feet on Mount Jefferson. The average annual runoff from the basin is about 24.6 million acre-feet and the best powersites are concentrated on tributaries draining the western slopes of the Cascade Mountains as shown in figure 87. The value of these tributaries as potential producers of hydroelectric power lies in the abundant surface- and ground-water supplies originating in their mountainous headwaters areas and in their quick descent to the Willamette Valley floor. Elsewhere in the basin practicable waterpower sites are rare because of low stream gradients and low summertime flows. The McKenzie and Santiam Rivers are each about equally endowed with sites for developing waterpower having 27 and 26 percent respectively of the basin's gross power potential.

COASTAL BASINS

In addition to the Umpqua, Rogue, and Klamath Rivers whose headwaters are in the Cascade Range, the following rivers with headwaters in the Coast Range have potential waterpower sites: Nehalem, Wilson, Trask, Nestucca, Siletz, Yaquina, Alsea, Siuslaw, Coos, Coquille, Floras, Sixes, Elk, Pistol, and Chetco. Coastal streams drain an area of about 22,670 square miles (23 percent of the State) and have a gross theoretical waterpower of 2,925 MW (26 percent of the State). The average altitude of the combined coastal basins in 2,700 feet. Annual runoff is estimated to be 43.5 million acre-feet.

Coast Range Basin

The Coast Range rivers and adjacent streams tributary to the Pacific Ocean drain an area of about 7,270 square miles, 32 percent of the coastal basins total area and 7 percent of the State. The average altitude of the area is 1,300 feet. North of the Umpqua River the

highest mountain is 4,097-foot Marys Peak in the Yaquina and Alsea basins. Between the Umpqua and Rogue Rivers the highest point is 3,661-foot Bone Mountain in the Coquille basin. South of the Rogue River, the highest point is 5,098-foot Pearsoll Peak in the Chetco basin.

The average annual runoff from Coast Range streams is estimated to be about 26 million acre-feet per year. The gross theoretical potential waterpower at practicably developable sites is 715 MW for average discharge and 100 percent efficiency, 24 percent of the potential of the coastal basins, and 6 percent of that of the State. The potential waterpower sites in the area are generally capable of developing less than 20 MW at mean flow. However, the Nehalem Falls site, with a potential at mean flow of 72.5 MW, could utilize a plant with installed generating capacity totalling 60 to 100 MW. Generally, the streams descend rapidly to the coast from altitudes of about 2,000 feet and its is difficult to find reservoir sites large enough to store the heavy water yields of fall, winter, and spring for use during often long rainless summers. The principal exceptions are the Nehalem, which could be quite adequately controlled at the Alsea damsite; the Siletz, which has two or three fair-sized reservoir sites; and the Coquille, which has adequate sites on all tributaries. The site which has received the most study is Eden Ridge on the South Fork Coquille River. A high-head waterpower plant combined with a thermal plant fueled by local coal is planned.

Umpqua River Basin

The Umpqua River Basin drains 4,560 square miles, about 20 percent of the coastal basin's total area and about 5 percent of the State. The average altitude of the basin is 2,200 feet, varying from sea level to 9,182 feet on Mount Thielson in the headwaters of the North Umpqua River. Average annual runoff is estimated to be 8 million acre-feet. The gross theoretical potential waterpower of the basin is 820 MW, 28 percent of the coastal basin's and 7 percent of the State. The North Umpqua and its tributary streams are regulated to some extent from natural storage in pumice and lava fields and possess some attractive waterpower sites. There are nine developed sites on the North Umpqua, eight of which are modern waterpower projects, and additional power is developable. The South Umpqua and the main river could be regulated at reservoir sites making waterpower development more attractive. The whole basin is used enthusiastically by outdoorsmen, however, and they can be expected to resist any plan for constructing waterpower reservoirs.

Rogue River Basin

With a drainage area of about 5,170 square miles (5 percent of the State), the Rogue River Basin has an estimated gross theoretical potential waterpower of 1,190 MW (10 percent of the State). The Rogue basin has 23 percent of the surface area and 41 percent of the potential waterpower of the coastal basins. The average altitude of the basin is 2,800 feet. Mount McLoughlin, at 9,495 feet above sea level in the headwaters of Big Butte Creek, is the highest point. Hillman Peak on Crater Lake rim is 8,156 feet above sea level. Average annual stream flow is estimated to be 8 million acre-feet.

The relatively large waterpower potential derives principally from the fact that natural ground water storage in the Rogue River headwater areas substantially augments the flow for the entire river during low-water periods. Seasonal variations are smaller than for any other Oregon river except the Deschutes, and a substantial increase in flows during dry periods would be possible if the rather spacious reservoir sites were developed. The waterpower site with the largest potential is Copper Canyon on the lower main stem. Effective use of the site would require a dam to raise the water to an altitude of 520 feet above sea level to create a head of 450 feet and a potential power for average discharge at 100 percent efficiency of more than 400 MW.

An obstacle to development of any significant amount of waterpower in the Rogue River basin is the possible interference of dams with passage of anadromous fish. In 1929 the Oregon legislature passed a bill (ORS 542.210) barring any dam on the Rogue River below its intersection with the south line of sec. 27, T. 33 S., R. 1 E. This point is near the mouth of Big Butte Creek 155 miles upstream from the coast. The State Water Resources Board (1959) after making a study of the Rogue River basin reaffirmed the policy of leaving most of the Rogue River in its existing free-flowing state. The river is expected to be one of the first to be designated as a Scenic River.

Klamath River Basin

The Klamath River basin drainage in Oregon amounts to 5,680 square miles, about 6 percent of the State and 25 percent of the coastal basins. The basin has a gross power potential of 200 MW at average discharge and gross head, about 7 percent of the coastal basins' potential, and 2 percent of the State.

The average altitude of the Klamath basin is 4,800 feet, and elevations range from about 2,750 feet on Klamath River at the California State line to 9,495 feet on Mount McLoughlin. Mount Scott, near the east rim of Crater Lake, is 8,938 feet above sea level. The average annual flow from the basin in Oregon is about 1.5 million acre-feet. Potential waterpower sites in the basin are restricted to the reach of river downstream from Klamath Lake. The river falls 1,360 feet between the existing East Side powerplant on Link River and the State line. Two existing waterpower plants and three sites for which development is planned would utilize the entire fall. Due to regulation at Klamath Lake, powerplants with installed capacities sufficient to utilize twice the flow available 50 percent of the time would be able to utilize 93 percent of the runoff.

Pumped-Storage Waterpower

The term "pumped storage" used in association with hydroelectric power development denotes a system in which off-peak power with little value is converted into valuable peaking power by pumping water to an upper storage reservoir with the cheap power and releasing it through hydraulic turbines to produce high value power upon demand. In many modern pumped-storage developments cost savings result if the turbine and generator sets are combined and are reversible, acting as motor-pump units to lift the water and as turbine-generator units

to produce power. Pumped storage may be either seasonal or daily, the first providing storage from certain seasons of the year for use in other seasons and the latter utilizing daily or weekly low-demand periods to provide generating capacity during high-demand periods of the day or week. Pure pumped-storage systems use more energy than they produce, the ratio of input to output being about 1.4 to 1 in modern plants. Feasibility results from using low-value energy to pump and from generating energy when its value is highest.

Although pumped-storage waterpower technology is in its second half century it has been little used in the Pacific Northwest. The addition of pumped-storage plants may be a natural next step for increasing the peaking capacity and overall dependability of the network. Providing pumped storage for daily or weekly peaking purposes does not require large high-level reservoirs but great differences in elevation in appropriate locations are important. The topography of Oregon is ideal for constructing pumped-storage waterpower plants for integration with existing and planned power developments.

The future pumped-storage waterpower plants in this area are expected to have rather large capacities, utilizing thousands of cfs in each turbine. Ten thousand cfs falling 1 foot can produce 680 kw of electric power at 80 percent efficiency. In the discussions that follow no mention will be made of plant capacity but capacity can be easily estimated by multiplying the desired discharge in multiples of 10,000 cfs by the head (in feet) times 680 kw. For example, 10,000 cfs falling 1,000 feet could produce 680,000 kw (1 x 1,000 x 680).

SNAKE RIVER BASIN

A plateau half a mile west of Snake River near the Hells Canyon Dam rises more than 3,300 feet above Hells Canyon powerplant. Water could be pumped from Hells Canyon Reservoir to a small reservoir on this plateau and used to generate peaking power in a pumped-storage installation with a tailrace level with Hells Canyon Plant, 1,510 feet. The head created would be 3,300 feet. At this particular site the upper reservoir could be placed at any altitude desired in a range between 1,700 and 6,000 feet. The highest site directly above the Hells Canyon powerplant would create a head of 5,500 feet through a conduit about 3 miles long. At the High Mountain Sheep site pumped-storage heads of 1,300, 2,500, or 3,500 feet could be developed through conduit lengths of about .5 mile, 2 miles, or 2.5 miles, respectively. A pumped-storage development at the China Gardens site could be operated at heads of 2,100, 2,500, or 3,000 feet. The conduit lengths for these would be about .75 mile, 1.5 miles, or 2.5 miles, respectively.

LOWER COLUMBIA RIVER BASIN

Pumped storage could easily be added at the developed powersites on the Columbia River. Some of the sites present possibilities of utilizing high-level reservoirs with capacities to store large quantities of water so that, should the need arise, the peaking energy would be available for long periods without repumping. Near John Day Dam, for example, a pumped-storage plant whose tailrace altitude would be

about 160 feet above sea level could utilize a large reservoir site on John Day River in which the maximum surface altitude could be 800 or 900 feet above sea level to create a head of some 700 feet. Also, small high-level reservoirs could be constructed directly above the John Day powerplant in Hell Roaring Canyon or on the plateau at either side of it. West of the canyon a reservoir could be located 1,100 feet above the powerplant. Near The Dalles a high-level reservoir located 800 feet higher than the present plant tailrace would require less than 2 miles of connecting conduit. South of Bonneville Dam pumped-storage reservoirs could be located in Tanner Creek or on Tanner Butte. A reservoir on the north end of the butte could create a head of 3,000 feet with a conduit length of about 2 miles. Head could be increased by lengthening the conduit and placing the upper-level reservoir higher on the mountain.

WILLAMETTE RIVER BASIN

Sites in the Willamette basin where pumped storage could be added to existing hydroplants are plentiful. An upper reservoir constructed near Larison Rock, 2.5 miles west of Hills Creek Dam, would create a head of 2,400 feet. A head of 1,600 feet could be created by raising the water to the northwest end of Kitson Ridge east of the dam. A three-fourths-mile-long conduit would reach the upper site. A conduit 1 mile long, either north or south of the Lookout Point powerplant, would create a head of about 1,500 feet for a pumped-storage addition. Newly constructed Green Peter powerplant could be used to pump water to a ridge 1,500 feet higher in elevation utilizing a 1.5-mile-long conduit south of the river. A head of 2,500 to 3,000 feet would be possible if a high-level reservoir were constructed 2.5 miles north of the plant on the slopes of Green Peter Mountain. Cougar Dam on the South Fork McKenzie River lies 1,000 feet below a site suitable for constructing a high-level reservoir. The conduit length would be no more than one-fourth of a mile. The terrain continues to slope upward from this reservoir site eastward toward McLennen Mountain, where a head of 3,000 feet could be realized in about 3 miles of conduit. Detroit Dam on the North Santiam River lies more than 3,000 feet below possible upper-level reservoir sites on Hall Ridge 2 miles northeast from the dam. Tumble Lake, about 2.5 miles in the same direction, could be used as an upper-level reservoir in a pumped-storage development that would have 2,400 feet of head. Tableland north and south of the existing North Fork project on the Clackamas River is suitable for upper-level reservoirs that could be constructed which would require conduits less than half a mile long to create heads of about 700 feet.

COASTAL BASINS

Many of the powersites on coastal rivers would lend themselves to pumped-storage development, and a few examples are cited. A dam at the Elsie site on Nehalem River could raise the water to an altitude of 600 feet, from which altitude it could be pumped an additional 200 feet into a reservoir site in Fishhawk Creek. This reservoir could be connected to a powerplant on the Columbia River side of the divide by a tunnel, thereby utilizing a head of 800 feet in a pumped-storage

development that would require only 200 to 300 feet of pumping. Bluffs as high as 2,000 feet above sea level are near the Nehalem River in its lower reaches, and pumped-storage plants could be added to future hydroelectric or thermal electric plants. A conventional waterpower development has been studied on the Trask River at the Ginger Peak site. Pumped storage could be added by constructing a high-level reservoir in a saddle on Gold Peak ridge south of the river that would create a head of 1,700 feet. A hilltop near the mouth of the Alsea River could be utilized for a pumped-storage reservoir creating a head of more than 1,500 feet and requiring about 1.5 miles of conduit. A combination waterpower and coal-fired thermal power development has been studied on the Coquille River at Eden Ridge. The site has a gross head of 1,800 feet and water could be pumped back to the reservoir through the penstocks and conduits.

The waterpower sites in the lower Illinois and Rogue Rivers lie between mountains on which upper-level reservoirs could be located for creating pumped-storage heads of up to 3,000 feet with conduits less than 3 miles long. The powerplant of the planned Buzzards Roost project on the Illinois River could have a 1,500-foot head pumped-storage addition that would require a conduit only 1 mile to 1.5 miles long depending on the upper-level reservoir site selected. There are excellent sites for adding pumped storage at the powersites on the Klamath River, and the constructed John C. Boyle plant is less than 2 miles east of Hayden Mountain, 5,129 feet in altitude. An upper-level reservoir placed on a plateau south of the peak could have a head of 1,500 feet with a conduit 1.75 miles long. Use of Aspen Lake as a pumped-storage reservoir has been studied. The lake is about 6 miles north of the John C. Boyle plant and more than 1,000 feet higher in elevation.

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WATER RESOURCE DEVELOPMENT FOR IRRIGATION, NAVIGATION, FLOOD CONTROL, AND RECREATION

(By T. B. Lynott and G. V. Schirk, U.S. Bureau of Reclamation, Boise, Idaho)

This portion of the report presents, in summary form, a description of water resource development in Oregon dealing with irrigation, navigation, and flood control, and recreation. The functions of hydroelectric power and municipal and industrial water supply are discussed elsewhere in this report.

To help in the compiling and presenting of information, eight subbasins have been identified in the state. Information and data concerning water resource developments have been presented to show the types and magnitude of major existing developments and to furnish some indication of potentialities yet to be realized.

Introduction

"Oregon Country" was shrouded in a veil of legend even before it had a fur-trading outpost. Mapmakers viewed it as a portion of mystical kingdoms; explorers were drawn to search for the Northwest Passage. The first explorer to view the Oregon coast came because of intensifying European interest in exploration, exploitation, and trade.

In 1788, Captain Robert Gray sent men ashore in what is now Tillamook County. In 1792, he returned and discovered the river the Indians called the Oregon. The land drained by this river became known as the Oregon Territory, but Gray renamed the river the Columbia.

None of the sea traders was much interested in the Pacific Northwest as a living area. They valued its natural resources, especially the fur. They replenished their food supply from its abundant wildlife and repaired their ships with its timber.

The inland portion of Oregon Territory was opened by the 1804–06 expedition of Meriwether Lewis and William Clark. News of their trip had a tremendous impact. Forts and trading posts were soon established. Of these establishments, none had more influence on the development of Oregon than the Hudson's Bay Company. This company formally arrived in Oregon in 1824 in the persons of Dr. John McLaughlin and "Governor" George Simpson. It was about this time that agriculture began to assume its role of importance.

The earliest recorded agricultural activity in what is now Oregon occurred in 1795 when a Captain Bishop observed in his ship's log that his garden's "plantings were doing as well as would be expected." The first known garden to be cultivated and harvested was planted by Nathan Winship in 1810 along the lower Columbia River bottoms.

The influence of the Hudson's Bay Company on commercial agricultural development was initiated in 1828 with establishment of a Company farm in the vicinity of what is now Portland. Other farms soon were established in the Willamette Valley from what is now Scappoose in Columbia County to French Prairie, now a part of Marion County.

The Hudson's Bay Company furnished these farmers with seeds and supplies in exchange for a portion of the crop produced. Many of the species and varieties of livestock, poultry, grains, grasses, berries, and fruits from Europe and elsewhere were introduced to the American pioneers by the Company's overseers and managers. These men helped demonstrate that many European practices of animal husbandry and horticulture were highly adaptable to the Pacific Northwest, which they found similar in climate to that of Northwestern Europe.

Missionary parties of the 1830's and the large migration of the 1840's helped to establish settlements. People in these settlements helped to change the territory's principal economic activity from one of fur trapping and trading to agriculture.

The fertile valleys of the Willamette, Umpqua, and Rogue were the primary areas sought by these early migrants. The next area of settlement was along the coast. Finally, the vast area of the eastern slopes was occupied. These lands were most suitable for livestock, an industry that since has dominated agriculture in central and eastern Oregon. However, the livestock industry received its start in the west-

ern part of Oregon, too. It is believed the first cattle were imported by the Hudson's Bay Company. These cattle were rented; company rules prohibited farmers from either purchasing any of the animals or keeping their calves. To protect this monopoly, the farmers formed a company called the Willamette Cattle Company. This company proved to be a success. Under the influence of these two companies, livestock became the principal agricultural enterprise in Oregon.

Prior to 1837 all of the cattle in Oregon belonged to the Hudson's Bay Company. After that year cattle drives from California and imported breeds from Europe led to a variety of cattle production in the state. In the Willamette Valley and along the coast, the lush pasture was particularly well suited to dairy cattle. Around 1870, eastern Oregon became a great center for beef cattle production.

Generous land laws during the pioneer period led to the development of large farms. The Oregon Donation Land Law of 1850 was the first of a series of these acts and grants designed to stimulate early agricultural activity in the Pacific Northwest. The impact of this act on Oregon can be measured by the census count: in 1850, the year of enactment, Oregon's population was 13,294; in 1855 there were more than 43,000 people, an increase of more than 30,000.

Other acts of Congress including the Linn Bill, the Homestead Act, the Oregon Admission Act, Railroad grants, and others resulted in more than 29,000,000 acres being developed through state and private ownership.

One important acquisition of Federal lands was the Oregon and California Revested Lands, more commonly known as the O & C lands. Between 1866 and 1870, the Federal Government made two land grants totaling about four million acres to companies which became the Oregon and California Railroad. Under terms of the grant, the railroad was to sell the granted lands at a price not to exceed $2.50 per acre, in blocks not to exceed 160 acres to each purchaser, and to sell them only to actual settlers. Because these conditions were not met in the sale of the lands, title to almost three million acres was "revested" by the Congress and returned to the United States in 1916.

The system of timber harvest under the Act of 1916 gave harvesters no incentives to protect the new growth of trees and provided no provisions for adequate supervision of forestry operations. Criticism of this system led to modifications in the 1938 Act. Under this Act, the O & C lands have been administered as forest lands for sustained yield and multiple use. These lands are presently managed by the Bureau of Land Management.

In 1850, there were more than 423,000 acres of farmland in Oregon and the average size of a farm was approximately 370 acres. In 1964 there were 20,500,000 acres of farmland and the average size of a farm was more than 500 acres. Intensive agricultural land use can be found in nearly every county of the state, with some of the heaviest emphasis in the Willamette Valley.

Irrigation has played an important role in the development of Oregon's agriculture. The enactment of the Federal Reclamation Act in 1902 and the development of a State Water Code in 1909 were very important factors. In 1890, 12 percent of the farms in Oregon were irrigated; in 1964 nearly 40 percent of the farms had irrigated crops.

The development of transportation also played an important role in the growth of Oregon. Oregon's commercial trade area, until about 1870, was limited to communities within the State and along the coasts. Although the State had not fulfilled its dream of becoming the "gateway to the Orient" it had entered the world wheat market. In 1875 wheat and flour valued at more than $3,000,000 were shipped from Portland, largely to England and Ireland. All exported wheat grown in Oregon was shipped through Portland because of its advantageous geographical position on the terminus of the Willamette River with the Columbia. Oregon development was dependent upon the waterways; the first mail came by water to Portland and then traveled up the Willamette Valley by boat or horseback, Stagecoach and pack train routes extended south and east from Portland. Railroads began to vie for Oregon's trade; in 1883 the State had its first transcontinental connection via the Northern Pacific. The following year the Oregon Short Line joined with the Oregon Railway and Navigation Company to form a transcontinental link with the Union Pacific Railroad. In 1887 the Oregon-California route was completed, allowing produce from Oregon to reach both eastern and southern markets by land.

THE SETTING

Oregon is bounded on the east by the Snake River and the state of Idaho, on the north by the Columbia River and the state of Washington, on the west by the Pacific Ocean, and on the south by California and Nevada. Oregon contains 96,981 square miles, or more than 61.6 million acres of land.

Rugged mountains, fertile valleys, broad basins, sparkling lakes, many rivers, and an inviting coast are the primary physical features in the State.

An irregular north-south line, immediately east of the Cascade Range divides Oregon into two distinct regions. Elongated north-south ranges and lowlands, moderate to heavy rainfall, mild temperatures and a dense forest cover are characteristics of the area west of this line. Here also are the large urban concentrations. To the east are broad basins, narrow mountain ranges and dissected plateus. Climate is semiarid with a greater annual range of temperature. Population is sparse except in areas where irrigation is practiced.

For purposes of this report, the State has been divided into eight subbasins based primarily upon drainage. Figure 90 shows the boundaries of these subbasins.

A brief look at the physical and cultural highlights of each subbasin follows. The physical description is based primarily on N. M. Fenneman's "Physiography of the Western United States."

Subbasin No. 1—Closed Lakes

This subbasin, which includes the area of interior drainage in Oregon, is largely in the Basin and Range Physiographic Province. Principal physical features are the Steens Mountains and the Abert Rim. Most of this country is flat and has elevations ranging from 3,000 to 5,000 feet with mountains rising nearly 10,000 feet.

Summers are hot and dry; winters are moderately cold and dry. Precipitation is low and erratic; major perennial streams are lacking.

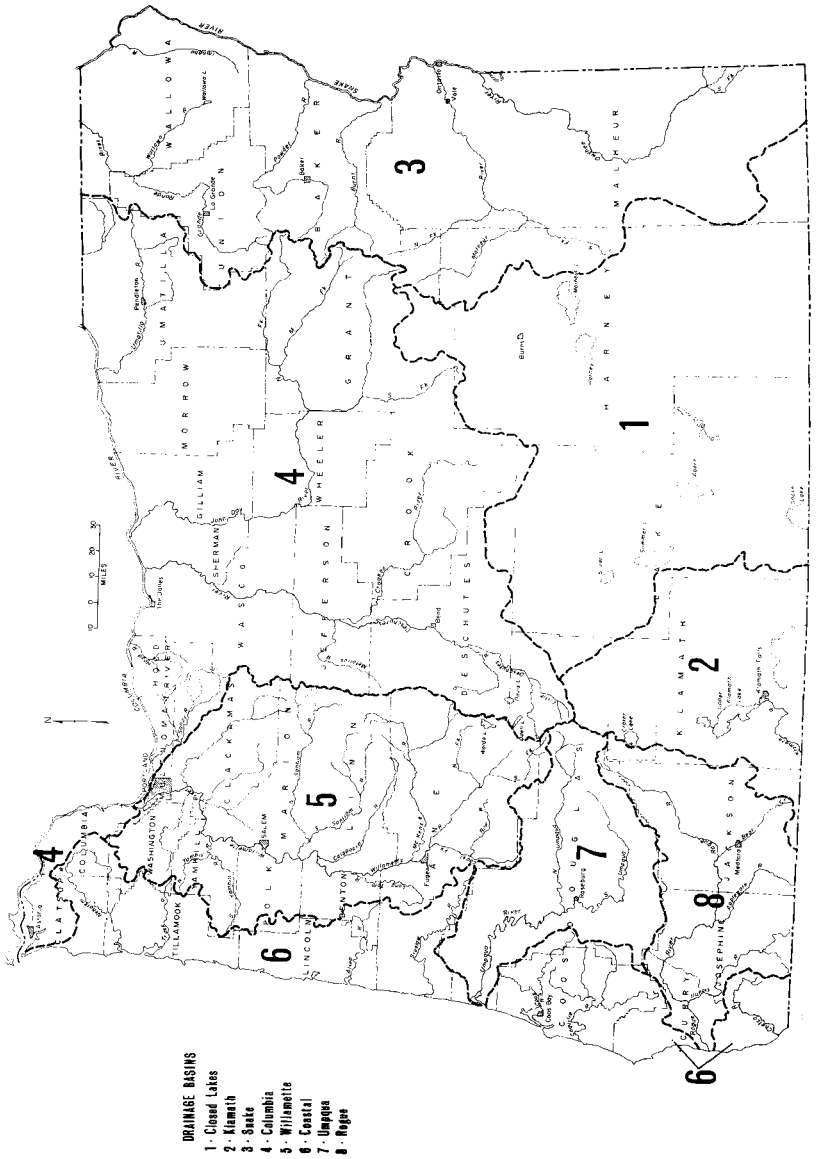

FIGURE 90.—Drainage subbasins.

The drainage is primarily interior; it has no outward surface connection to the sea. Cycles of wet and dry years cause the increase and disappearance of many of the lakes in this subbasin.

The lower country is virtually treeless, and the ground is covered with scattered sagebrush and clumps of bunchgrass. Scattered juniper occur at the 4,000-foot elevation and open groves of Ponderosa pine begin at about 5,000 feet.

Agricultural use of the land is devoted for the most part to livestock grazing and ranching. The largest communities, Burns and Lakeview, have forest product milling industries which receive their supply of logs from the nearby mountains.

Subbasin No. 2—Klamath

This subbasin includes the area of the Klamath River drainage basin which is primarily in the Basin and Range Province.

The climate is characterized by dry, warm summers and dry, moderate winters. Precipitation is low with the majority occurring in winter as snow. The Klamath River is the only major stream draining this area. It flows south out of Oregon across the northwest corner of California to the Pacific Ocean.

Natural vegetation in the mountainous portion is largely Ponderosa pine. Shrubs and grasses can be found at the lower elevations.

Forest products manufacturing, agriculture, and tourism are the principal economic activities. Agriculture is dominated by livestock and specialty crop production primarily on irrigated land. The major portion of the farmland is in pasture, forage and grain crops.

Klamath Falls is this subbasin's largest community.

Subbasin No. 3—Snake

This subbasin includes the drainage areas of all the streams in Oregon which empty into the Snake River. These streams are, from north to south, the Grande Ronde, Imnaha, Powder, Burnt, Malheur, and Owyhee.

The northern portion of this subbasin is generally mountainous, with valleys of varying widths along the streams. The southern portion, part of the Basin and Range Province, is dominated by a rolling high plain.

Annual temperatures and precipitation follow a north-south pattern closely associated with elevation. In the higher, more mountainous north, the annual average temperatures are lower and precipitation is higher than in the south. The entire subbasin has a winter maximum in precipitation, most of which falls as snow.

Each valley lowland in the north has some irrigation. Intensive irrigation has been developed along the Snake, Lower Malheur, and Lower Owyhee Rivers. Forage and specialty crops predominate in these irrigated areas.

Principal cities include Baker, Ontario, Vale, La Grande, and Nyssa.

Subbasin No. 4—Columbia

The drainage area of the rivers flowing north into the Columbia River excluding the Willamette make up the Columbia subbasin. Included among these are the Deschutes, John Day, Umatilla, and Walla Walla Rivers.

This subbasin is dissected by the Coast Range, and the Cascade Range. In addition to these mountain ranges, the gorge of the Columbia River is a dominant physical feature. East of the Cascade Range the subbasin is plateau-like, incised by streams in deep canyons. Its eastern boundary follows the crest of the Blue Mountains.

Climate of this subbasin has a definite east-west pattern. The area to the lee (east) side of the Cascade Range in comparison to the area west of those mountains has: (a) greater annual ranges in temperatures; (b) shorter, but warmer frost-free seasons; and (c) less precipitation.

To the west of the Cascade Range forests abound throughout, especially at the higher elevations. In the lower areas, park-like grasslands predominate. East of the crest, forests are found only at higher elevations. In the lower areas natural vegetation is largely scattered bunchgrass and xerophytic shrubs. In the Cascade Range the pattern of natural vegetation reflects the variations in precipitation. Douglas fir, pine, spruce, and hemlock are found on the west side; Ponderosa pine on the east side. In the higher peaks, some subalpine vegetation can be found; other high areas are entirely devoid of natural vegetation.

Agriculture and lumbering are the main elements in the economy of this subbasin. Two principal types of agriculture are represented—dry-land wheat farming and irrigation.

Portland, Oregon's largest city, is located in this subbasin. Other communities include Pendleton, The Dalles, Bend, Astoria, and Hood River.

Subbasin No. 5—Willamette

The area drained by the Willamette River and its tributaries represents this subbasin. It is a lowland area lying between the Coast Range and the Cascade Range.

A favorable combination of soils, climate, and water has helped to make this subbasin the most populated in the state. Warm, dry summers and mild, wet winters are the dominant climatic factors. Most of the precipitation falls as rain.

A wide range of commodities are produced. Hay, grain, and grass for seed are grown throughout the valley. Since the 1940's irrigation of processing and specialty crops such as vegetables, small grains, fruits, and nuts have assumed a role of major importance in this subbasin. Processing plants for agricultural and forest products are located in most of the subbasin's urban centers.

Many low hills are scattered throughout this subbasin. Some of this hill land is still wooded, although much of it is being cultivated or supporting orchards.

Salem, the state's capital, is located in this subbasin. Other cities of note include Eugene, Springfield, Albany, Corvallis, and Oregon City.

Subbasin No. 6—Coastal

The watersheds of all streams draining to the Pacific except the Umpqua and Rogue represent this subbasin. Dominating this subbasin are forested headlands which rise close to the ocean shore and marine terraces interspersed with sandy beaches and dune areas. The

only truly level areas are the coastal lowlands such as the Tillamook Plain, the marine terraces and the bottom lands along the coastal rivers.

The Coast Range is not a lofty range, reaching its highest elevation of 4,097 feet at Marys Peak near Corvallis, Oregon.

Annual precipitation averages 60–80 inches near sea level and more than 80 inches inland, with wet winter months and dry summer months. The frost-free season is long, 250–300 days; and the marine influence keeps temperatures moderate.

Near the coast, forests of hemlock, spruce, and cedar are interspersed with smaller tracts of grassland, brush and cleared land. Inland, Douglas fir predominates often with an understory of hardwoods. Large "burns" such as occurred near Tillamook in 1933 and logging operations have greatly altered the character of these forests.

Settlements consist of small towns generally located in coastal valleys. They mostly serve forest industries, fishing or tourism. The coastal lowlands provide green pastures of great importance to the dairy industry. Coos Bay is the largest city in this subbasin.

Subbasin No. 7—Umpqua

The watershed of the Umpqua River represents this subbasin. This is an area of rugged topography with the majority of the land undulating and forest-covered. Douglas fir is the primary species.

The climate, which has a definite west to east pattern, is characterized by dry, warm summers and mild, moist winters. Direct factors in local climatic differences include the distance from the coast, elevation, and exposure. Interior basins receive less precipitation, have shorter frost-free seasons, more sunshine and greater annual ranges in temperatures than coastal areas.

Forestry and tourism are the dominant economic factors. Settlements are concentrated in the valleys, basins and isolated coastal lowlands. Roseburg is the largest community in this subbasin.

Subbasin No. 8—Rogue

The drainage basins of the Rogue River and its tributaries represent this subbasin. This watershed is rugged and forested with the only level areas located along the banks of the river.

The climate of this subbasin is similar to that of the Umpqua subbasin. Summers are warm and dry, winters are wet and moderate. Distance from the ocean and elevation have a direct factor in the climatic pattern. Less precipitation, shorter frost-free seasons, more sunshine and greater annual ranges in temperature occur in the interior.

Douglas fir is the dominant species. Some hardwoods can be found in the some humid areas.

Forestry, agriculture and tourism are all important to the economy of this subbasin. Irrigation is practiced throughout the interior. Of note are the specialty crops including pears and apples.

Medford, Grants Pass, and Ashland are the principal urban centers.

Agricultural Regions

Six agricultural regions have been identified in Oregon by the State Department of Agriculture. Figure 91 shows their geographic relationship to the eight drainage subbasins. The numbers and the dashed lines on the maps represent the subbasins; the agricultural regions are named and have a solid line boundary.

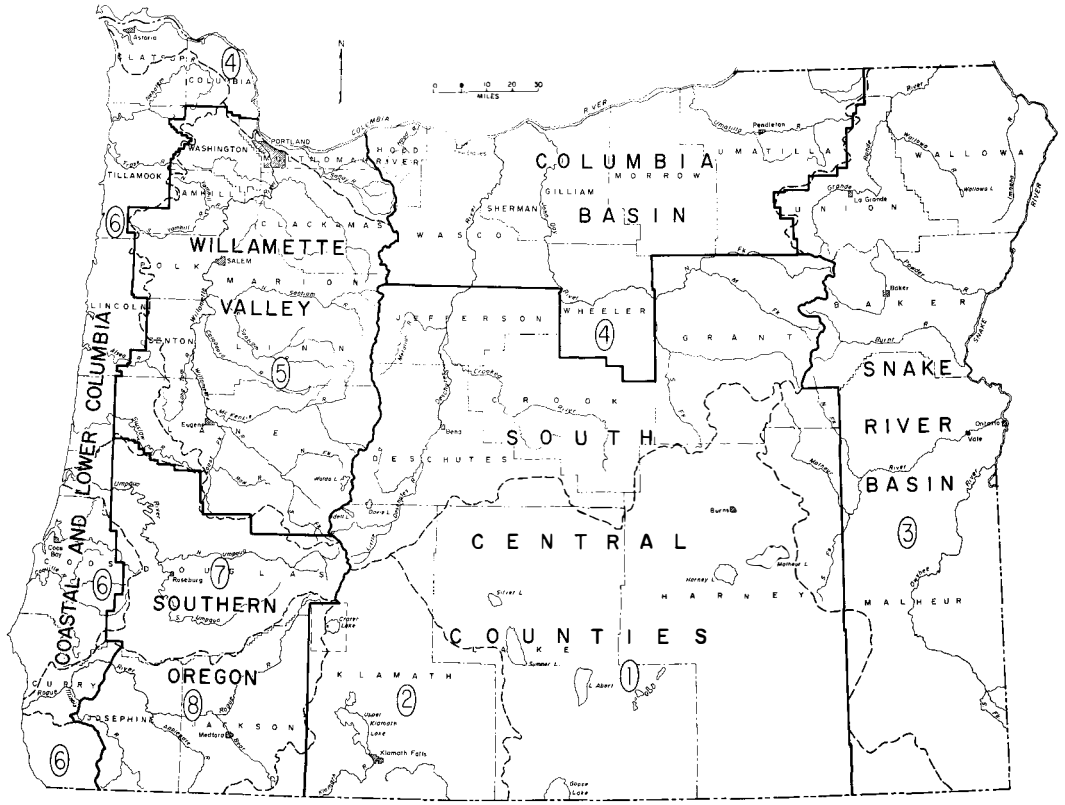

FIGURE 91.—Agricultural regions and drainage subbasins.

Principal products of these agricultural regions are listed as follows:

Coastal and Lower Columbia: Dairying, beef, mink, cranberries, nursery crops, vegetables, small fruits and seeds.

Willamette Valley: Diversified crops and livestock; nursery crops, seeds, poultry, vegetables, berries, and tree fruits.

Southern Oregon: Pears, sheep, dairy and beef cattle, seeds, and mint. Jackson County is a famous pear area.

Columbia Basin: Wheat and barley, fruits, beef, green peas. Hood River County is a major apple and pear area.

Snake River Basin: Beef, dairying, row crops, grain, hay, hops, and some mint.

South Central: Beef, dairying, hay, potatoes and grain.

Existing Water Resource Developments

Oregon's water resources have always been viewed as a means of attracting new industry and aiding in the diversification of industrial production. As early as 1914, Oregon's undeveloped water power resources were being studied. In the early 1930's the Federal Government constructed Bonneville Dam on the Columbia River. This dam, together with other Federally constructed dams built on the Columbia and the Willamette, was multipurpose. Navigation of ocean-going vessels to as far upstream as The Dalles was made possible by the locks at Bonneville and channel improvements. Hydroelectric power generated by Bonneville was made available in 1938 to industry, private utilities, and public agencies through the Federal power marketing agency, the Bonneville Power Administration. As additional Federal power projects were completed, their generated power was marketed by the Bonneville Power Administration. The availability of substantial amounts of low cost power brought to Oregon new manufacturing plants which produced aluminum, ferro-alloys, steel, chlorates, and calcium carbide.

Other functions including irrigation, flood control, municipal and industrial water supply, fish and wildlife conservation and enhancement, recreation and water quality control are also served by many of these projects.

In recent years most of the water resource developments have been analyzed as multiple-purpose projects. All state and Federal agencies coordinate their efforts to provide as many project functions as possible and to obtain maximum benefits from all of these functions.

A summary of existing major water resource developments in Oregon is presented in the following paragraphs under the headings of irrigation, recreation, navigation and flood control. Information on power and municipal and industrial water supply is presented elsewhere in this report.

Irrigation

Agriculture as an industry followed fur trading in the state of Oregon. It developed as a self-sufficient enterprise; each family raised the food and fiber to meet their own essential needs. Even so, limited trading and marketing began during this period.

The economic progress of Oregon has historically received its major contribution from agriculture. During Oregon's first 75 years of statehood, agriculture employed more people than any other activity.

One of the developments that has made a major contribution to the productivity of Oregon farmland is irrigation. This practice dates back to 1852 when Jacob Wagner in Jackson County diverted water from a creek to irrigate his garden. This type of simple creek diversion has grown into the present-day multiple-purpose project with its complex storage, distribution and drainage system. The U.S. Census of Agriculture reports the growth of irrigation by decades as follows:

Oregon land irrigated

Census year	*Acres*	*Census year*	*Acres*
1890	177, 944	1930	637, 967
1900	388, 310	1940	1, 030, 228
1910	(1)	1950	1, 306, 810
1920	(1)	1960	1, 384, 284

[1] Available data not comparable.

The 1964 Census of Agriculture estimates that approximately 1,607,600 acres of land were irrigated in that year.

From the 1850's to the 1890's, irrigation development was, for the most part, carried out by individuals and small groups through simple diversion from creeks and smaller streams.

To increase productivity in the arid areas east of the Cascades, farmers and the Federal Government have actively supported irrigation projects. The Carey Act of 1894 donated arid land to the states with the condition that they settle, irrigate, and cultivate it. Most of the Carey Act lands in Oregon have been reclaimed. With few exceptions, deeds have been issued to the settlers who entered land under its provisions.

The original Carey Act projects in the central Oregon area have been completed. With completion of the few pending projects, a historical and colorful chapter in the reclamation, cultivation and settlement of the central Oregon area will draw to a close.

The economic impact of the 1902 Federal Reclamation Act on the state of Oregon has been recognized by the Legislative Interim Committee on Agriculture in its November 1966 report to the Governor and the 54th Legislative Assembly which stated:

> An agency having had a long and important history of activity in the development of major water resource projects in Oregon is the Bureau of Reclamation. In its 60-year history, Oregon projects completed represent a total capital investment of about $100,000,000.

The Federal Reclamation Act provided for the appropriation of receipts from the sale and disposal of public lands in certain states and territories into a special fund. This money was to be used for survey, construction, etc. of irrigation systems for the reclamation of arid land in those states. Early projects studied included Malheur, Umatilla, Klamath, and those in central Oregon in the Deschutes River Basin.

The Oregon Surface Water Code of 1909 governed the appropriation of the surface waters of the state of Oregon. This water Code set forth a procedure for determining and recording the rights to the

beneficial use of the surface waters within the state which were initiated prior to February 24, 1909.

The doctrine of appropriation provides that the first in time is the first in right to the extent of the quantity of water which has been applied to beneficial use. Subjects of most concern among the water users include: relative date of priority, quantity of water, use to which the water has been applied, and the land to which said water is appurtenant.

Streams of approximately 70 percent of the area of the state have been adjudicated. However, the streams remaining to be adjudicated are in the areas of greatest population concentration. Most of the Willamette River Basin remains to be adjudicated. Other areas requiring adjudication include the remainder of the Klamath River Basin and all the coastal stream systems except the Rogue.

A legal right for an appropriation of ground water initiated after August 3, 1955, can be established only through beneficial use under the provision of a ground water permit issued by the State Engineer. A ground water permit is not required for (1) stock water purposes; (2) watering of lawn or non-commercial garden not exceeding ½ acre in area; (3) single or group domestic purposes in any amount not exceeding 15,000 gallons per day; and (4) any single industrial or commercial purpose in an amount not exceeding 5,000 gallons per day.

Table 45 presents a summary of permits as of June 30, 1966.

TABLE 45.—*Summary of permits as of June 30, 1966*

Summary of applications for permits:		
Pending at the beginning of the biennium		2,355
Filed during the biennium:		
To construct reservoirs and store 531,911.19 acre-feet	521	
To appropriate 172,193.31 acre-feet of stored water only and 4,796.18 cubic feet per second from surface sources, including reservoirs	1,739	
To appropriate 734.30 cubic feet per second from ground water sources	530	2,790
Total in process during biennium		5,145
Total applications approved	3,191	
Total application rejected or withdrawn	290	3,481
Total pending at close of biennium		1,664
Summary of permits issued:		
To construct reservoirs and store 41,670.97 acre-feet		262
To appropriate from surface water sources, including reservoirs 1,370.17 cubic feet per second and 34,724.99 acre-feet of storage for irrigation purposes and 298.35 cubic feet per second and 2,202.75 acre-feet for all other uses		1,586
To appropriate from ground water sources 428.12 cubic feet per second for irrigation purposes and 131.83 cubic feet per second for all other uses		510
To construct and maintain stock water ponds by the Federal Government on lands administered under the Taylor Grazing Act with a total capacity of 1,199.09 acre-feet		833
Total permits issued		3,191

Summary of certificates of water rights issued:

A total of 1,698 certificates were issued in evidence of water rights perfected in accordance with the terms of the permits, summarized as follows:

To store 22,052.13 acre-feet.
To appropriate surface water, including storage:
496.311 cubic feet per second and 7,761.35 acre-feet for irrigation of 32,334.23 acres.
12,856 cubic feet per second for municipal, stock, and domestic.
28.83 cubic feet per second for manufacturing.
183.99 cubic feet per second for fish culture.
6.615 cubic feet per second for power, mining and other uses.

To appropriate ground water:
213.794 cubic feet per second for irrigation of 18,439.73 acres.
45.04 cubic feet per second for all other uses.

Source: 31st biennial report of the State engineer.

Since 1913 the State of Oregon, through the State Engineer, has given extensive cooperation regarding investigations by the Bureau of Reclamation of projects in Oregon. In that year, the Legislature appropriated a $50,000 revolving fund to the State Engineer to be used in cooperation with the Federal Government.

Investigations under this program ended in 1943, when the Legislature enacted legislation stipulating that any moneys paid into the revolving fund be turned over to the State Treasurer, and together with any moneys remaining unexpended, become a part of the General Fund.

The Legislatures in 1933, 1935, 1937, 1939 and 1945 made additional funds available to the State Engineer to be matched on a dollar-for-dollar basis with the Federal Government for the investigation of the Baker, Brogan, Willamette Valley, Grande Ronde Valley, Rogue River Watershed and Goose Lake Projects, respectively.

As a direct result of the State's participation in these programs, many irrigation projects were approved and constructed.

Table 46 presents a listing of the operating irrigation projects constructed as a result of this cooperative program.

TABLE 46.—OPERATING IRRIGATION PROJECTS RESULTING FROM OREGON'S COOPERATIVE PROGRAM

Name of project	Description of works	Irrigable acres
Burnt River Irrigation District	Unity Reservoir	20,000
Eagle Point Irrigation District	Distribution system	10,000
Lower Powder River Irrigation District	Thief Valley Reservoir	7,281
North Unit Irrigation District	Wickiup Reservoir and distribution system	50,000
Ochoco Irrigation District	Ochoco and Prineville Reservoirs and distribution system	18,185
Owyhee Irrigation District	Owyhee Reservoir and distribution system	49,543
Silver Lake Irrigation District	Thompson Valley Reservoir and distribution system	2,616
Summer Lake Irrigation District	Ana River diversion works and distribution system	2,522
Talent Irrigation District	Keene Creek, Emigrant, Hyatt Reservoir, Howard Prairie Lake and distribution system.	14,316
Vale-Oregon Irrigation District	Agency Valley and Warm Springs Reservoirs and distribution system.	34,993
Warm Springs Irrigation District	Warm Springs Reservoir and distribution system	18,398
Total acres		227,854

Note: Warm Springs Reservoir constructed by Warm Springs Irrigation District and half interest sold to Vale-Oregon Irrigation District. Although no appropriations have been made for several years, many of the projects initiated under the cooperative program are still being investigated by the Bureau, or being considered for future development.

Source: 31st biennial report of the State engineer.

In 1955 Oregon Legislative Assembly created the State Water Resources Board to serve as the "single state agency to guide the development of the water resources of the state and to secure maximum beneficial use and control of the state's water resources for all purposes." The Board is composed of seven members appointed by the Governor.

Responsibilities of this board include inventory and studies of existing water resources, and present and future uses leading to the progressive formulation of a state water resources policy. The board is also devising plans and programs for development of, and to encourage, promote, and secure the maximum beneficial use of the state's water resources.

Other activities include reviewing Federal project proposals; participating in Federal flood control projects; holding hearings and rendering decisions upon water use conflicts; and serving as a coordinator between local, state, and Federal water use plans, programs, and projects. The board approves applications for and carries on flood plain identification studies and is responsible for identifying and studying methods of augmenting use of future reservoir sites. They represent the state on certain compacts or agreements authorized by the Legislature concerning the state's water resources.

According to the 1964 U.S. Census of Agriculture, every county in Oregon had some irrigated cropland and some irrigated pasture. Table 47 shows a county breakdown of the number of irrigated farms, the percentage of irrigated farms to all farms, and the irrigated acreage. Figure 92 illustrates the geographic layout of the intensities of irrigated farms as a percentage of all farms.

TABLE 47.—IRRIGATED FARMS AND IRRIGATED LAND IN FARMS, 1964

County	Irrigated farms	Irrigated farms as percent of all farms	Irrigated land (acres)	County	Irrigated farms	Irrigated farms as percent of all farms	Irrigated land (acres)
Baker	643	87.4	126,511	Lane	854	29.5	25,734
Benton	203	23.7	13,000	Lincoln	30	6.0	859
Clackamas	540	13.1	12,572	Linn	656	27.0	27,337
Clatsop	13	2.7	209	Malheur	1,663	95.7	231,151
Columbia	82	7.1	2,539	Marion	1,342	39.6	59,447
Coos	298	28.2	8,756	Morrow	206	60.9	16,131
Crook	291	89.5	64,?00	Multnomah	180	19.6	5,157
Curry	59	22.4	1,763	Polk	205	16.6	9,921
Deschutes	727	93.8	44,482	Sherman	29	13.1	1,395
Douglas	526	27.4	14,379	Tillamook	83	11.6	2,816
Gilliam	49	26.3	4,438	Umatilla	992	66.0	56,082
Grant	215	76.2	45,893	Union	333	41.5	39,431
Harney	210	75,3	140,186	Wallowa	366	69.7	45,524
Hood River	608	94.9	18,756	Wasco	276	46.1	19,184
Jackson	1,147	73.7	50,795	Washington	496	20.1	15,937
Jefferson	360	85.3	55,012	Wheeler	76	58.9	7,934
Josephine	591	71.8	16,871	Yamhill	386	18.8	19,218
Klamath	884	82.5	255,505				
Lake	250	72.9	148,534	State total	15,869	39.9	1,607,677

Source: 1964 U.S. Census of Agriculture.

Subbasin No. 1—Closed Lakes

Approximately 68 percent of all farms in this subbasin were classified as irrigated farms in 1964. The total acreage irrigated in this subbasin in 1964 is estimated to be 262,000 acres.

The livestock industry is the most important agricultural activity and thousands of acres of rangeland are used in this enterprise. Many

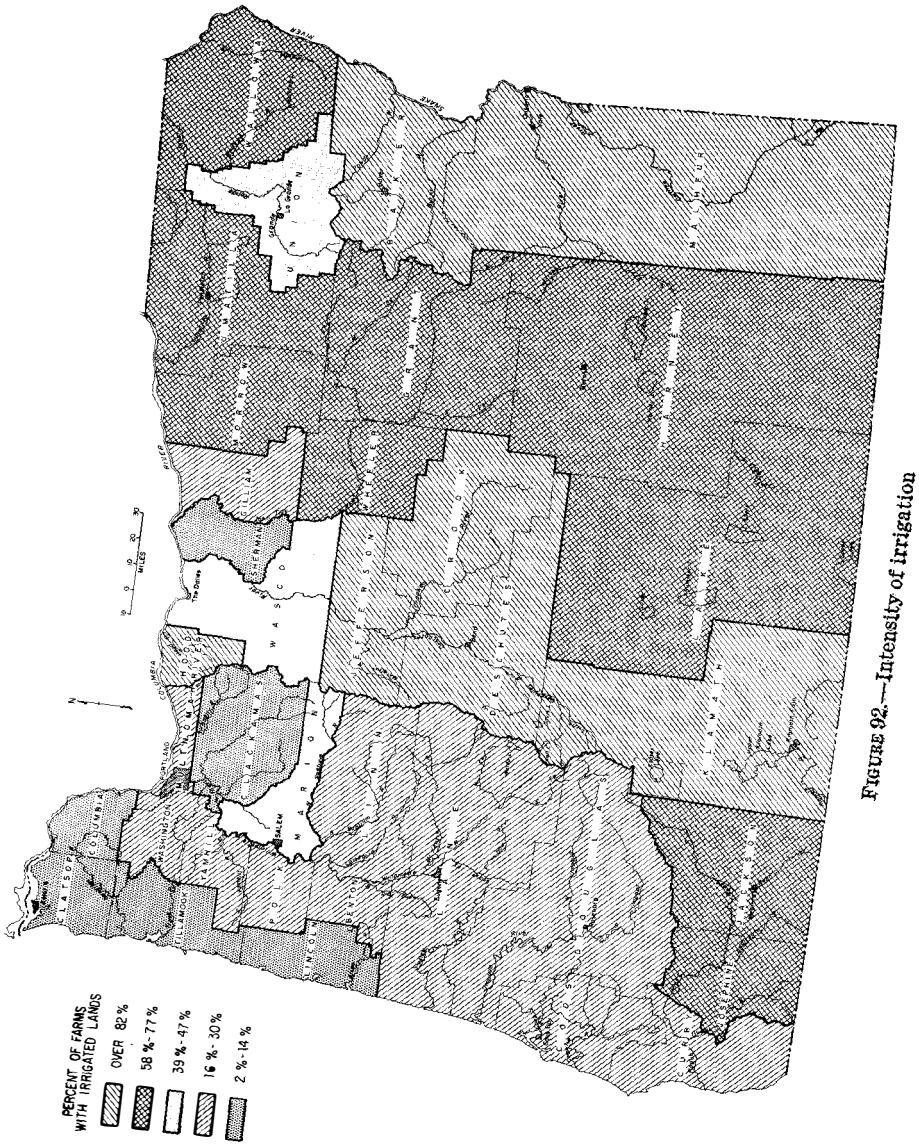

FIGURE 92.—Intensity of irrigation

areas are irrigated; some use ground water as a source. Hay, alfalfa, and wheat are the principal crops grown.

The irrigated lands are for the most part located around the lakes and along the streams feeding into these lakes. In the northern part of this subbasin, an increase in irrigated acreage has recently occurred; here ground water is the primary source.

Subbasin No. 2—Klamath

Slightly more than 87 percent of all the farms in the subbasin were classified as irrigated farms in the 1964 census, making this the leading subbasin in the state in terms of intensity of irrigation. Approximately 253,000 acres were irrigated in that year. Most of the irrigated lands lie along and between the Lost and Klamath Rivers.

Potatoes are the single most important crop grown in this subbasin; Klamath County had more than 20,000 irrigated acres in this crop. Irrigated pasture and grain production help to make beef production also important to the subbasin's economy.

The Bureau of Reclamation's Klamath Project is located, in part, in this subbasin. The remainder of the project is in northern California. A system of storage reservoirs, diversion dams, pumping plants, canals, and laterals provides water to irrigate more than 200,000 acres, the majority of which is in Oregon. Principal crops are potatoes, grain, alfalfa, small seeds, vegetables, and pasture.

Subbasin No. 3—Snake

The Snake River Subbasin, with 79 percent of its farms classified as irrigated farms, is the leading subbasin in terms of total irrigated acreage. According to the Census of Agriculture, in 1964, 473,000 acres were irrigated in this subbasin.

Irrigated pasture and grains and large areas of non-cropped rangeland make livestock production important to this subbasin. Four of the ten leading beef counties in Oregon are within its boundaries. Other irrigated crops include potatoes, sugar beets, sweet corn, peas, onions, seeds, and tree fruits.

In the northern portion of this subbasin, in Union and Baker Counties is the Bureau of Reclamation's Baker Project. The irrigated lands lie along the Powder River. Thief Valley Dam and Reservoir provides a water supply to serve these lands.

Presently under construction is the Upper Division of the Baker Project. When this construction is completed, 18,000 acres will be served either a full or supplemental water supply from storage in Mason Dam and Reservoir.

Also in Baker County, south of the Baker Project, is the Burnt River Project. Its primary feature, Unity Dam and Reservoir, provides a water supply for lands along the Burnt River.

The Owyhee Project, located in Malheur County and in Idaho, serves water to more than 115,000 acres, of which 85,000 are in Oregon. These lands lie west of the Snake River. Owyhee Dam and Reservoir plus a system of canals, laterals, and pumping plants are the principal facilities.

Northwest of the Owyhee Project in Harney and Malheur Counties is the Vale Project. Storage facilities and a distribution and drainage system furnishes water to nearly 35,000 acres of land.

A small portion of the Boise Project is located in Oregon where the Snake River makes its big bend to the north and is entirely within Oregon. About 1,700 acres of irrigated land are located in this area.

Subbasin No. 4—Columbia

The Columbia River subbasin, with nearly 55 percent of its farms classified as irrigated farms, had 342,000 acres irrigated in 1964. Areas of intensive irrigation include lands along the Umatilla, John Day, and Deschutes Rivers.

A wide variety of agricultural products are grown in this subbasin. Some of the Pacific Northwest's finest dryland wheat is produced in Gilliam, Morrow, Sherman, and Wasco Counties. In addition to wheat, other grains are produced. The areas of noncropped rangeland and the irrigated pasture make the production of livestock also economically important.

The major winter-pear producing area in Oregon is in Hood River County. Approximately 14,000 acres of these orchards are irrigated. Wasco County is the nation's number one producer of sweet cherries. They are produced on irrigated orchards near The Dalles and Mosier. In the Hermiston-Stanfield area the domestic irrigated crops include corn, alfalfa, and melons. Around Milton-Freewater apples, prunes, and cherries are the leading irrigated crops.

The Bureau of Reclamation's Umatilla Project, in Morrow and Umatilla Counties, furnishes water to 31,000 acres. Principal facilities include storage dams, diversion dams, and a system of canals.

The Dalles Project pumps water from the Columbia River into a pipe distribution system to provide a full water supply to 3,170 acres and a supplemental supply to 2,250 acres of land adjacent to the City of The Dalles in Wasco County.

Storage on Clear Creek in Wasco County provides a water supply for the 2,100 acres of the Wapinitia Project lying between the Deschutes and White Rivers. Pasture, alfalfa, and wheat are the principal crops grown.

The Deschutes Project is in Crook, Deschutes, and Jefferson Counties. Project lands are in the vicinity of Madras. Principal features include the following dams and reservoirs: Wickiup, Haystack, and Crane Prairie. A distribution system of canals and laterals is also provided. Potatoes, clover seed, wheat, barley, oats, alfalfa, and vegetables are the leading crops produced on the more than 99,000 acres in this project.

The majority of the Crooked River Project's 20,000 acres lie north and west of Prineville. New works include Prineville Dam and Reservoir, a diversion dam, canals, and two pumping plants. The existing Ochoco Dam was rehabilitated. Principal crops are clover seed, alfalfa seed, alfalfa hay, potatoes, wheat, barley, and oats.

Storage on Crescent Creek provides a water supply for the 6,650 acres of the Crescent Lake Dam Project northwest of Bend. This project, originally developed by private interests, was rehabilitated by the Bureau of Reclamation in 1956. The Arnold Project, southeast of Bend, is also a private development for which the Bureau of Reclamation constructed a diversion and distribution system.

Subbasin No. 5—Willamette

Approximately 25 percent of the farms in the Willamette subbasin are irrigated. In 1964 there were 182,000 acres being irrigated, most of it by sprinklers.

The development of irrigation in this subbasin is a recent venture. In 1929 there were only 4,250 acres being irrigated. Thus, in 35 years, irrigated acreage has increased more than 175,000 acres. Nearly all of this has been developed on an individual farm basis with private financing. The early "project-type" developments were of two varieties: (1) a group of farmers organizing into a nonprofit organization or (2) speculative ventures by companies or partnerships.

Pasture, seed production, orchards, small fruits and vegetables, and specialty crops are the leading agricultural activities. Intensive cranberry, strawberry, and vegetable cropping is practiced throughout the subbasin. Many of the canners and packers will not contract for a farmer's crop unless that crop is irrigated. Irrigated pasture is being used by an expanding livestock industry. Poultry production is also important.

Subbasin No. 6—Coastal

Of the farms in the Coastal subbasin, 15 percent were classified as irrigated in 1964. In that year there were 13,000 acres being irrigated.

Most of the farms in this subbasin are located on the river bottom land areas and the adjoining open hill lands. The leading crops are forage, horticultural specialties, and cranberries.

Coos County is the location of the most intensive irrigation in this subbasin. It is one of Oregon's leading dairy counties; irrigated pasture and forage crops help it to assume this leadership. Another leading dairy county is Tillamook, both for fluid milk and cheese production.

The specialty crop industry in this subbasin is rapidly expanding. Principal examples include holly, bulbs, other nursery and greenhouse products, and farm-type forest products.

Subbasin No. 7—Umpqua

In the Umpqua subbasin, nearly 27 percent of the farms were irrigated in 1964. The Census of Agriculture estimates that 14,000 acres were irrigated in that year.

Commercial pear production is important in this subbasin. Prunes, apples, peaches, cherries, walnuts, and filberts are also raised; irrigation plays an important role in their production. Specialty crops such as canteloupe, cauliflower, and vegetable seed are gaining in importance to this subbasin. Most of these fruit, nut, and vegetable crops are sprinkler irrigated.

Most of the irrigation in this subbasin is centered near Roseburg on the rainshadow side of the Coast Range.

Subbasin No. 8—Rogue

The 70 percent of the farms in this subbasin classified as irrigated had 69,000 irrigated acres in 1964. Fruits, forage, and pasture are the leading agricultural products; irrigation has a principal role in their production.

This subbasin is the home of the world famous Rogue Valley pears. Peaches, apples, and cranberries are also important.

The Bureau of Reclamation rehabilitated the Grants Pass Project during 1949 through 1955. This irrigation project was built by private interests in 1920. Principal project features include the Savage Rapids Diversion Dam on the Rogue River and a system of pumping plants, canals, pipelines, and laterals. Approximately 10,300 acres near the city of Grants Pass are furnished irrigation water. Principal crops are alfalfa, clover, pasture, bulbs, hops, and vegetables.

The Rogue River Basin Project is designed to rehabilitate and improve the irrigation facilities of three irrigation districts in the vicinity of Medford. Rehabilitation has been completed on Fourmile Lake Dam, Fish Lake Dam, and the Main Canal.

The Talent Division of this project provided for the construction of Howard Prairie Dam, Keene Creek Dam, Agate Dam, Green Springs Powerplant, and an enlarged Emigrant Dam. The existing distribution system was enlarged and extended. Approximately 24,000 acres are served a supplemental water supply. Tree fruits, specialty crops, and hay and pasture are the leading crops.

SOURCE OF WATER

Most of the irrigated land in Oregon receives its water supply from surface sources, either from diversion of natural streamflows or storage. Ground water pumping is prominent in four general areas: (1) the Klamath subbasin, near Klamath Falls; (2) the Snake subbasin in Cow Valley, Baker Valley, and La Grande Valley; (3) the Columbia subbasin, near Milton; and (4) in the Willamette subbasin north of Salem. Table 48 shows the amount of ground water and surface water irrigation in each of the subbasins for 1959.

TABLE 48.—IRRIGATED ACREAGE, 1959, BY SURFACE AND GROUND WATER

Subbasin	Surface Water	Ground Water	Total
1. Closed Lakes	169,000	17,000	186,000
2. Klamath	205,000	26,000	231,000
3. Snake	345,000	59,000	404,000
4. Columbia	283,000	29,000	312,000
5. Willamette	88,000	63,000	151,000
6. Coastal	16,000	1,000	16,000
7. Umpqua	13,000	0	13,000
8. Rogue	66,000	4,000	70,000
State total	1,185,000	199,000	1,384,000

Source: U.S. Census of Agriculture, 1959.

Figure 93 and table 49 present information regarding the major existing dam and reservoir developments in the State. To help with identification on the map and table, the dams and reservoirs have been geographically segregated by subbasin starting with subbasin No. 1, Closed Lakes.

The State of Oregon through its State Engineer has an active program in both surface and ground water observation as well as a cooperative program with the U.S. Geological Survey. During the 1968 water year, the State Engineer's office operated 142 gaging stations and 161 additional stations were maintained in the cooperative program to monitor surface flow and aid in the distribution of water. In

TABLE 49.—MAJOR EXISTING IRRIGATION, DAM, AND RESERVOIR DEVELOPMENTS

Map No.	Subbasin and name	Year completed	Principal features	Stream	Gross storage (acre-feet)	Irrigated land	Developed by—[1]	Purposes[2]	Remarks

TABLE 49.—MAJOR EXISTING IRRIGATION, DAM, AND RESERVOIR DEVELOPMENTS

Map No.	Subbasin and name	Year completed	Principal features	Stream	Gross storage (acre-feet)	Irrigated land	Developed by—[1]	Purposes[2]	Remarks
	1. Closed Lakes:								
1	Cottonwood	1923	Dam and reservoir	Cottonwood Creek	6,610	5,800	Private	I	Owned by Lakeview Water Users.
2	Drew	1912	do	Drew Creek	62,500	5,800	do	I	Do.
3	Hart Lake	1941	do	Deep Creek (offstream)	52,150	(3)	do	I	Owned by Hart Lake Water Users.
4	Thompson Valley	1923	do	Silver Creek	17,400	(3)	do	I	Owned by Silver Lake Irrigation District.
5	Greaser Lake		do	Twenty-Mile Creek	10,000	(3)	do	I	Owned by Warner Valley Stock Co.
6	Rock Creek	1947	do	Rock Creek	5,800	(3)	do	I	Owned by Miller & Lux, Inc.
7	Silver Creek	1952	do	Silver Creek	8,240	(3)	do	I	Owned by G. V. Moon et al.
8	Riddle Creek		do	Riddle Creek	7,500	(3)	do	I	Owned by R. J. and T. E. Jenkins.
	2. Klamath:								
9	Klamath project	1925	Gerber Dam and Reservoir	Miller Creek	94,300	145,000	USBR	I, R, C	Other storage in California.
10	Upper Klamath Lake		Dam and lake	Link River	873,000	(3)	COP	P, I	Constructed under agreement with USBR.
	3. Snake:								
11	Antelope	1924	Dam and reservoir	Jordan Creek (offstream)	45,000	7,400	Private	I	Owned by Jordan Valley Irrigation District.
	Baker project:								
12	Lower division	1932	Thief Valley Dam and Reservoir	Powder River	17,600	7,300	USBR	I	Operated by Lower Powder River Irrigation District.
13	Upper division	1967	Mason Dam and Reservoir	do	100,000	18,000	USBR	I, FC, C, R	Do.
14	Boise project: Arrowrock division	1950	Storage is in Idaho	Boise River		1,700	USBR	I	
15	Burnt River project	1939	Unity Dam and Reservoir	Burnt River	25,800	15,500	USBR	I, C	Only lands in Oregon shown.
16	Brownlee	1958	Dam, reservoir, and powerplant	Snake River	1,470,000		IPC	P	On Oregon-Idaho boundary.
17	Hells Canyon	1967	do	do	170,000		IPC	P	Do.
18	Oxbow	1961	do	do	52,500		IPC	P	Do.
19	Love	1908	Dam and reservoir	Willow Springs Creek	6,000	(3)	Private	I	
20	Owyhee project	1932	Owyhee Dam and Reservoir	Owyhee River	1,120,000	85,000	USBR	I, R, C	Reservoir named Lake Owyhee.
	Vale project:								
21	Agency Valley	1935	Dam and reservoir	North Fork, Malheur River	60,000	32,000	USBR	I	
22	Bully Creek	1963	do	Bully Creek	32,000	34,000	USBR	I, FC, C	Part of Bully Creek extension.
23	Warm Springs	1919	do	Middle Fork, Malheur River	192,400	32,000	Private	I	
24	Wallowa Lake	1929	Dam and lake	Wallowa River	42,750	(3)	do	I	Developed by Assoc. Ditch Co.
25	Willow Creek No. 3	1911	Damand reservoir	Willow Creek	49,000	(3)	do	I	Owned by Orchard Water Co.
	4. Columbia:								
26	Bonneville	1943	Dam, reservoir, powerplant, and locks	Columbia River	537,000		C of E	P, N, FC, R	First power generated, 1938.
27	Bull Run Lake	1922	Dam and lake	Bull Run River	30,800		Portland	M	Enlarged in 1961.
28	Bull Run Reservoir No. 1	1961	Damand reservoir	do	30,680		do	M	Forms Ben Morrow Lake.
29	Bull Run Reservoir No. 2	1961	do	do	20,990		do	M	
30	Crescent Lake Dam project	1922	do	Crescent Creek	86,000	6,650	Private	I, R	Rebuilt by USBR, 1956.
	Crooked River project					20,400	USBR		
31	Prineville	1961	Dam and reservoir	Crooked River	155,000		USBR	I, R, C	
32	Ochoco	1950	do	Ochoco Creek	46,500		Private	I, R, C	Rebuilt by USBR.
	Deschutes project					50,000	USBR		
33	Haystack	1957	Dam and reservoir	Deschutes River	6,600		USBR	I	
34	Wicklup	1949	do	do	167,300		USBR	I, R, C	
35	Crane Prairie	1940	do	do	55,200		Private	I, R, C	Do.
36	Central Oregon Irrigation District	1905	Crane Prairie Dam and canals	do	55,300	49,000	do	I, R, C	Do.
37	Arnold project	1949	do	do	55,300	4,292	do	I	Do.
38	John Day		Dam, reservoir, powerplant, and locks	Columbia River	2,500,000		C of E	P, FC, N, R, I, C	Under construction.
39	The Dalles	1957	do	do	330,000		C of E	P, N, FC, I, R, C	Forms Lake Celilo.
40	The Dalles project	1966	Pumping from River	do		3,150	USBR	I	First irrigation water, 1965.
41	McNary	1957	Dam, reservoir, powerplant, and locks	do	1,345,000		C of E	P, N, FC, R, C, I	Forms Lake Wallula.
42	Pelton	1957	Dam, reservoir, and powerplant	Deschutes River	36,000		PGE	P	Forms Lake Simtustus.
43	Round Butte	1964	do	do	535,000		PGE	P	Forms Lake Chinook.
	Umatilla project					30,760	USBR		
44	Cold Springs	1908	Damand reservoir	Umatilla (offstream)	50,000		USBR	I	
45	McKay	1927	do	McKay Creek	73,800		USBR	I	
46	Wapinitia project	1959	Wasco Dam and Reservoir	Clear Creek	13,100	2,100	USBR	I	
47	Olive Lake		Dam and reservoir	Lake Creek	6,000		CPU	P	
	5. Willamette:								
48	Big Cliff	1953	Dam, reservoir, and powerplant	North Santiam River	5,930		C of E	P	Reregulates for Detroit Dam.
49	Detroit	1953	do	do	455,000		C of E	P, FC, PA, I	Part of coordinated Willamette River system.
50	Cougar	1964	do	South Fork, McKenzie River	219,000		C of E	P, FC, C, R, I	Do.
51	Dexter	1955	do	Middle Fork, Willamette River	27,500		C of E	P	Reregulates Lookout Point Dam.
52	Lookout Point	1955	do	do	456,000		C of E	P, FC, R, C, I	Part of Coordinated Willamette River system.
53	Foster	1967	do	South Santiam River	61,000		C of E	P, FC, R, C, I	Reregulates Green Peter Dam.
54	Green Peter	1967	do	Middle Santiam River	430,000		C of E	P, FC, R, C, I	Part of Coordinated Willamette River system.
55	Hills Creek	1961	do	Middle Fork, Willamette River	356,000		C of E	P, FC, R, C, I	Do.
56	Blue River		Dam and reservoir	Blue River	85,000		C of E	FC, R, C	Under construction.
57	Cottage Grove	1942	do	Coast Fork, Willamette River	33,000		C of E	FC, C, R, M	Part of Coordinated Willamette River system.
58	Dorena	1949	do	Row River	77,500		C of E	FC, R, C	Do.
59	Fall Creek	1965	do	Fall Creek	125,000		C of E	FC, C	Do.
60	Fern Ridge	1941	do	Long Tom River	101,200		C of E	FC, C, I, M, R	Do.
61	Carmen	1963	Dam, reservoir, and powerplant	McKenzie River	9,000		Eugene	P	Part of Carmen-Smith project.
62	Smith	1963	do	Smith River	15,000		do	P	Do.
63	North Fork	1958	do	Clackamas River	19,000		PGE	P	
64	River Mill	1911	do	do	12,200		PGE	P	
65	Timothy Lake	1956	Dam and reservoir	Oak Grove Fork	65,700		PGE	PS	
	6. Coastal:								
66	Clear Lake		Dam and lake	Offstream			Reedsport	M	Provides a community water supply.
67	Valsetz	1961	Dam and reservoir	Siletz River	5,240		Private	Log pond	
68	7. Umpqua: Lemolo Lake	1954	Dam, reservoir, and powerplant	North Umpqua River	13,900		PPL	P	
	8. Rogue:								
	Rogue River Basin project					31,000	Private and USBR		
69	Agate	1967	Dam and reservoir	Dry Creek	4,600		USBR	I, R, C	Part of Talent division.
70	Howard Prairie	1958	do	Beaver Creek	62,000		USBR	I, R, FC	Do.
71	Hyatt Prairie	1923	do	Keene Creek	16,200		Private	I, R, C	Fish facilities added by USBR.
72	Emigrant	1961	do	Emigrant Creek	40,500		USBR	I, FC	Part of Talent division.
73	Fish Lake	1913	Dam and lake	North Fork, Little Butte Creek	7,980		Private	I	Rebuilt by USBR.
74	Fourmile Lake	1911	do	Fourmile Creek	13,300		do	I	Do.
75	Grants Pass project	1920	Savage Rapids diversion dam	Rogue River		10,300	do	I	Do.
76	Willow Creek	1952	Damand reservoir	Willow Creek	7,500		Medford	M	Provides community water supply.

[1] USBR—U.S. Bureau of Reclamation; C of E—Corps of Engineers; PGE—Portland General Electric; CPU—California Public Utilities; PPL—Pacific Power & Light; COP—California-Oregon Power Co.

[2] I—irrigation; R—recreation; C—fish and wildlife conservation; P—power; PS—power storage; N—navigation; FC—flood control; M—municipal; PA—pollution abatement.

[3] Data not available.

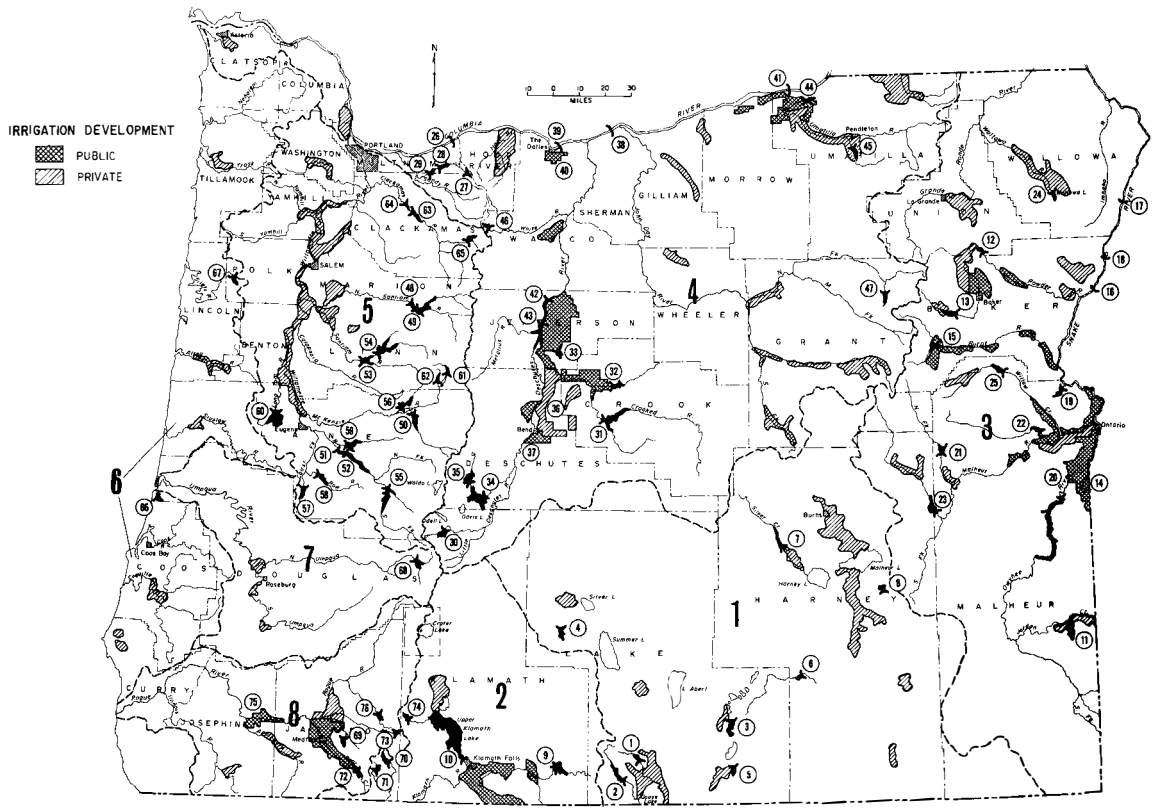

FIGURE 93.—Major dams and reservoirs in Oregon plus irrigated land.

the cooperative work there were 42 wells to observe characteristics of ground water aquifers. Table 50 presents the distribution of these 187 gaging stations and 829 wells operative in the 1964–66 biennium by drainage subbasin. A more detailed discussion of water resources in Oregon is presented in the section beginning on page 325.

TABLE 50.—GAGING STATIONS OPERATED BY STATE ENGINEER AND OBSERVATION WELLS OPERATED UNDER THE COOPERATIVE PROGRAM WITH THE U.S. GEOLOGICAL SURVEY

Subbasin	Gaging stations	Wells
1. Closed Lakes	14	169
2. Klamath	10	57
3. Snake	38	81
4. Columbia	71	186
5. Willamette	15	278
6. Coastal	0	34
7. Umpqua	0	7
8. Rogue	9	17
State total	187	829

NAVIGATION AND FLOOD CONTROL

From the beginning of its modern history, the State of Oregon has been oriented toward trade. At first, this was domestic, involving lumber and foodstuffs carried by sailing vessel to the California gold rush market. Shortly, however, vessels were serving the Hawaiian Islands, and in 1868 the first shipment of grain to the United Kingdom pioneered a trade that has kept the Columbia River in the forefront of export tonnage on the U.S. West Coast.

Portland, as the trade and distribution center for the Oregon territory, became the State's earliest shipping center. Astoria, Coos Bay and other river and coastal harbors soon followed, thriving largely on flour and lumber shipping.

The first port established in the state was the Port of Portland, created in 1891 by an act of the Oregon Legislature. Twenty-five port agencies serve the state today. The oldest is the Port of Portland Commission, the youngest the Marion-Salem-Polk Port Agency.

Seven of Oregon's ports are located on the Columbia River above the head of deep-draft navigation. These inland ports largely serve as grain storage terminals for loading of river barges for transport downstream to deep-water ports. Petroleum storage facilities also are provided at several upstream ports; this commodity is received by barge from Portland.

In recent years, industrial land development has become a major activity of several upriver ports and some coastal and lower Columbia River districts. Attractive plant sites adjacent to plentiful water supplies and low-cost industrial power from run-of-the-river dams, have lured a number of industries to these ports.

Some three-quarters of the total outward water commerce of the state is lumber or forest products and agricultural commodities. Of the latter, grain forms the largest tonnage item. At the present time general cargo shipping between Oregon and California ports is prac-

tically nil. However, approximately 6,000,000 tons annually of petroleum products are brought into Portland by tankers from Southern California. Intercoastal shipping has almost disappeared; most cargoes move by land to San Francisco Bay for transshipment to East Coast ports.

River traffic, principally grain downstream and petroleum, cement, and structural steel upstream, is trending slowly upward. Because of the easy water grade offered by the damming of the Columbia River, port districts such as Umatilla, Arlington, and The Dalles have become major grain distribution centers. Downstream, Portland, and the neighboring cities of Vancouver, Kalama and Longview in Washington, are major grain export harbors. The Columbia River ports have ranked first for many years as the Pacific Coast's leading grain export centers. Coos Bay, because of the proximity of forests and timber processing plants, now ranks as the leading lumber export harbor of the United States.

Typical growth of Portland harbor during the last several years is shown by a comparison of 1956 and 1965 export grain, up from 47,593,147 to 97,102,000 bushels; fresh fruit increased from about 1,200 tons to more than 35,000 tons in the same period. Substantial exports of logs to Japan have added to the economy of Oregon ports, particularly Coos Bay, Astoria, and Portland.

Total dollar value of waterborne commerce, reported by the Oregon Custom District for 1965 through the Oregon Coastal ports and those on the Columbia River, including Vancouver, Kalama, and Longview, Washington, was:

Exports (domestic and foreign)	$484,880,669
Imports (domestic and foreign)	$170,353,994

The Oregon Legislature has directed the State Water Resources Board to represent the state in Federal flood control projects. The Federal law requires that the state's participation include the following assurances:

1. Provide without cost to the United States all lands, easements, or rights-of-way necessary for the construction of the project;
2. Hold and save the United States free from damages due to the construction works; and
3. Maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of the Army.

The State Water Resources Board cannot, at present, carry out state participation in Federal flood control projects because of the Attorney General's ruling that to "hold and save" the United States free from damages due to the construction works would be in violation of the Oregon Constitution. This matter has been presented to the Constitution Revision Commission and other legislative committees many times.

The Board is also directed to maintain Federal flood control projects subsequent to construction; however, to date no funds have been appropriated for this purpose by the Legislature.

In the absence of legal authority to provide these assurances the Board has given assistance in the establishment of local districts to

sponsor bank protection and other water control measures throughout the state.

The Board also performs flood plain identification studies when requested by local governmental units such as cities or county courts. These studies provide basic information which is necessary for local governments in developing effective land use planning.

The Federal Government's flood control and navigation program is carried out primarily by the Corps of Engineers. This agency is charged with the public civil works program to control, regulate and improve river and harbor resources, to administer the laws pertaining to the preservation of navigable waters, and to plan, construct, and operate works for flood control and water resource conservation and development. Existing flood control and navigation projects of the Corps of Engineers are presented in their report, "Water Resources Development, by the U.S. Corps of Engineers in Oregon, January 1967." Locations of these projects and a summary of each are presented in figure 94 and table 51, respectively.

The Watershed Protection and Flood Prevention Act, Public Law 566, authorizes the Secretary of Agriculture to cooperate with states and local agencies in the planning and carrying out of works of improvements for soil, conservation and for other purposes. The State Engineer has been designated to represent Oregon on all matters pertaining to this Act. As of November 1966, 47 applications for assistance had been accepted. Nineteen projects were in various stages of planning and eight had been approved and were being installed as of that date. Figure 95 and table 52 present a summary of these Public Law 566 programs.

At the beginning of the 1964–66 biennium a Watershed Planning Division was started with the State Engineer's office. Initially this Division was engaged in activating stream gaging stations and precipitation recording stations in watersheds partially or wholly devoid of hydrologic history.

This Division also made a channel and flood plain study of the McKay-Rock Creek Watershed in Washington County. Included in this study was a survey of the stream channel and flood plain and potential damsites and hydraulic backwater profiles for flood flows. Other watersheds will be studied in the future.

RECREATION

Having more than 300 miles of rugged, scenic coastline, the snow-capped peaks of the Cascade Range, other mountains, including the Coastal, Siskiyous, Blue and Wallowas, great expanses of basin and range country and many miles of crystal-clear rivers and streams make Oregon a major outdoor recreation area.

Oregon has many nationally known tourist attractions. Crater Lake is one of the most spectacular and beautiful lakes in America. Other beautiful lakes include Diamond, Waldo, Wallowa and Anthony. Some of the largest and most spectacular rivers to be found in North America are located in or on the border of Oregon. Included are the Columbia, Willamette, Snake, Rogue, McKenzie, Umpqua, Deschutes and John Day.

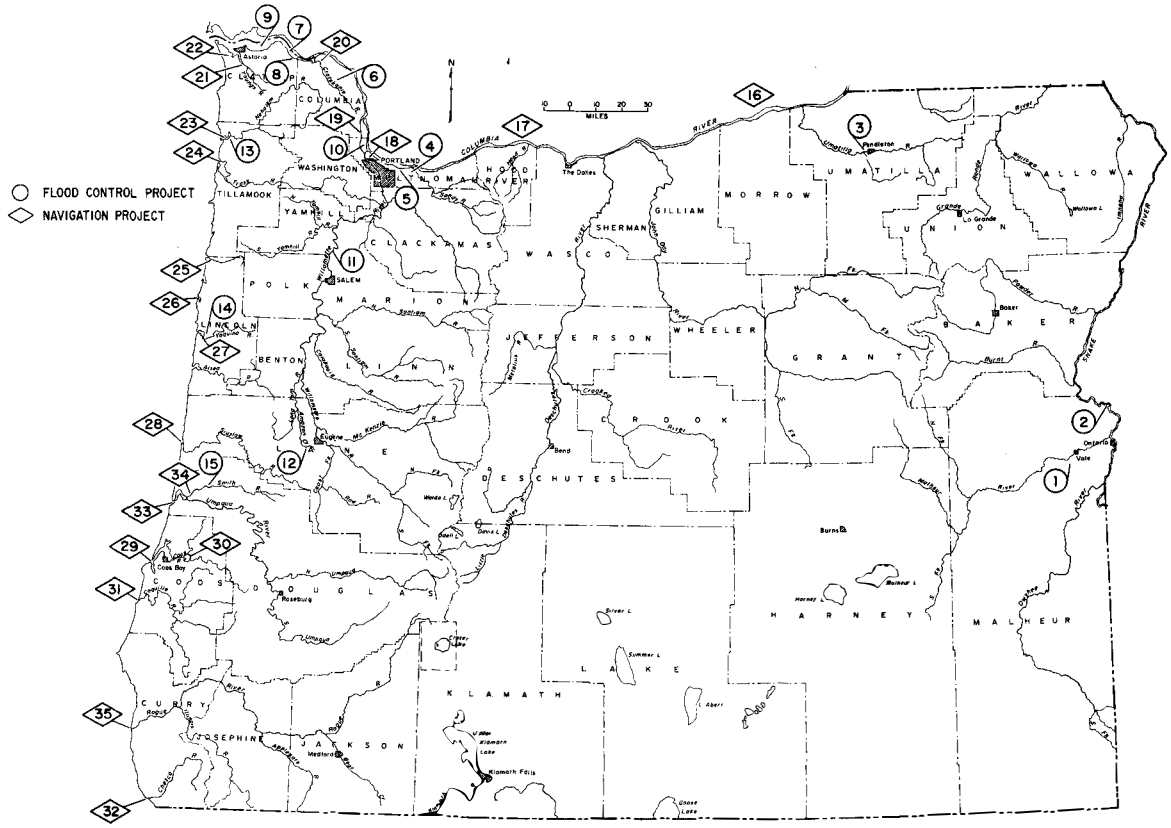

FIGURE 94.—Existing navigation and flood control developments.

TABLE 51.—FLOOD CONTROL AND NAVIGATION PROJECTS COMPLETED (OTHER THAN STORAGE)

Map No.	Subbasin	Name	Principal features	Year completed	Remarks
		FLOOD CONTROL PROJECTS			
1	Snake	Malheur River at Vale	Channel enlargement and levees	1961	Protect city of Vale.
2	do	Malheur Improvement District	Levees	1957	Protect 500 acres of farmland and an arterial highway.
3	Columbia	Umatilla River at Pendleton	Levees and channels	1959	Protect city of Pendleton.
4	do	Sandy Drainage District	Levees, toe drains	1954	Construction, reinforcing.
5	do	Multnomah County Drainage District No. 1	Levee reinforcement, toe drains, tide box	1962	Do.
6	do	Rainier Drainage District	Levees, toe drains, pumping plants	1964	Do.
7	do	Lower Columbia bank protection	Construction of bank protection works		Construction still underway.
8	do	Woodson Drainage District	Drains, pumping plants	1963	Construction, reinforcing.
9	do	Lower Columbia Diking and Drainage District	Levees and revetments, canals		Construction, rehabilitation.
10	do	Sauvie Island areas A and B	Levees, drains, pumping plants, tide box	1962	Construction, reinforcing.
11	Willamette	Willamette River Basin flood protection	Bank protection and channel clearing	1967	Project 91 percent complete.
12	do	Amazon Creek	Channel improvements and linings	1959	Reduce flood damages in Eugene.
13	Coastal	Mill Four Drainage District	Levees with tidegates	1948	Flood protection.
14	do	Nehalem River	Levees	1951	Construction, rehabilitation.
15	Umpqua	Umpqua River and tributaries	Revetments, levees, dikes, channel clearing	1951	Do.
		NAVIGATION PROJECTS			
16	Columbia	Columbia River between Celilo Falls and Kennewick, Wash.	Channel improvements and maintenance		Soon to be slack water channel.
17	do	Columbia River between Vancouver and The Dalles	Channels, boat basins, small boat harbors, breakwaters		3,900,800 tons of traffic, 1964.
18	do	Oregon Slough	Dredging and maintaining channel	1914	681,300 tons in 1964.
19	do	Multnomah Channel	Channels and log removal	1935	1,001,800 tons in 1964.
20	do	Clatskanie River	Navigation channel	1924	89,900 tons of traffic.
21	do	Youngs Bay and Youngs River	do	1939	1,152,400 tons in 1964.
22	do	Skipanon Channel	Channels, turning and mooring basins	1957	205,500 tons in 1964.
23	Coastal	Nehalem Bay	Jetties, channel stabilizations	1918	
24	do	Tillamook Bay and Bar	Channels, jetties, basins, and dike	1958	47,600 tons in 1964.
25	do	Salmon River	Removal of dangerous rock	1948	
26	do	Depoe Bay	Breakwaters, channel, basins	1966	38,000 passengers in 1964.
27	do	Yaquina River	Navigation channels	1914	584,200 tons in 1964.
28	do	Siuslaw River and Bar	Channels and jetties	1929	168,000 tons in 1964.
29	do	Coos Bay	Jetties, channels, basins	1956	Project being modified.
30	do	Coos and Millicoma Rivers	Channel improvements and stabilization	1966	5 ft. deep, 50 ft. wide.
31	do	Coquille River	Jetties and snagging	1933	308,300 tons in 1964.
32	do	Chetco River	Jetties and dredging	1957	Project being modified.
33	Umpqua	Umpqua River	Jetties, channels, basins, wave gage	1964	669,600 tons in 1964.
34	do	Smith River	Channel and passing place	1956	291,300 tons in 1964.
35	Rogue	Rogue River Harbor at Gold Beach	Jetties, channel, turning basin	1965	84,300 tons in 1964, 61,700 passengers in 1964.

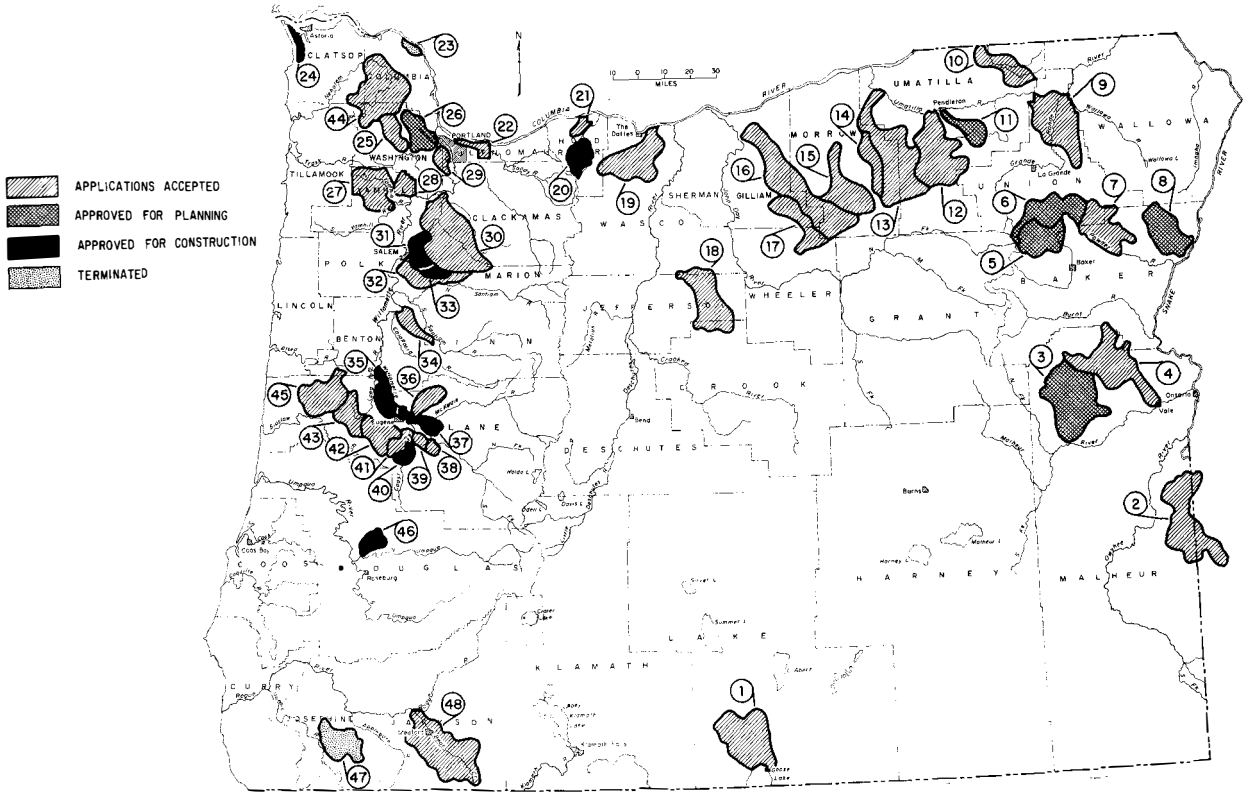

FIGURE 95.—Public Law 566 program.

TABLE 52.—WATERSHED APPLICATIONS FOR ASSISTANCE UNDER PUBLIC LAW 566 (WATERSHED PROTECTION AND FLOOD PREVENTION ACT), OREGON, NOVEMBER 1966

[Symbols are defined as follows: FP—Flood Prevention; LT—Land Treatment; I—Irrigation; MI—Municipal-Industrial Water; D—Drainage; WTC—Water Table Control; R—Recreation; FW—Fish and Wildlife; WQ—Water Quality]

Subbasin	Map No.	Watershed	Area (acres)	County	Sponsors	Date application received	Purposes included	Status of projects				
								Applications accepted	Preliminary investigation initiated	Planning authorized	Plan completed	Installation authorized
Closed Lakes	1	Thomas-Cottonwood Creeks.	207,522	Lake	Lakeview SWCD Lake County City of Lakeview	Feb. 20, 1958	FP-LT-I-MI-FW-R	X	X			
Snake	2	Succor Creek	130,637	Malheur (Oregon).	Adrian SWCD (Oregon)							
			105,000	Owyhee (Idaho)	Owyhee SCO (Idaho)	Apr. 27, 1959	FP-LT-I-R	X	X			
Do	3	Upper Bully Creek	247,000	Malheur	Malheur SWCD	June 9, 1955	FP-LT-I	X	X	X	(1)	(1)
Do	4	Brogan	202,240	do	do	Apr. 8, 1964	FP-LT-I-D-FW	X				
				Baker	Burnt River SWCD Orchard Water Co.							
Do	5	North Powder River	117,760	do	Powder Valley WCD Baker Valley SWCD	Mar. 15, 1955	FP-LT-I-R	X	X	X	X	
Do	6	Wolf Creek	106,240	Union	Union County SWCD Powder Valley WCD	do	FP-LT-I-R	X	X	X	X	
Do	7	Big Creek	181,000	Baker Union	Keating SWDE Union SWCD Big Creek WCD	Dec. 20, 1961	FP-LT-I-R-FW	X	X			
Do	8	Pine Valley	120,000	Baker	Eagle Valley SWCD Pine Valley WCD	June 19, 1958	FP-LT-I-R-FW	X	X	X		
Do	9	Elgin	192,160	Union	Elgin SWCD South Umatilla SWCD Union SWCD	June 15, 1963	FP-LT-I-R-FW	X	X			
Columbia	10	Hudson Bay	112,000	Umatilla	East Umatilla SWCD Hudson Bay District Improvement Co.	Apr. 12, 1962	FP-LT-I-R-FW-MI-WQ	X	X			
Do	11	Tutuilla Creek	40,000	do	South Umatilla SWCD	Mar. 27, 1958	FP-LT-R-FW	X	X	X		
Do	12	Birch Creek	186,000	do	do	Aug. 3, 1955	FP-LT-I-MI-R-FW	X				
				Union								
Do	13	Butter Creek	231,600	Umatilla Morrow	Heppner SWCD West Umatilla SWCD Southern Umatilla SWCD	Jan. 28, 1966	FP-LT-I-FW-R	X				

Do	14	Little Butter Creek	55,000	Umatilla Morrow	Heppner SWCD West Umatilla SWCD Southern Umatilla SWCD	do	FP-LT-I-FW-R	X				
Do	15	Rhea Creek	146,800	do	Heppner SWCD	Aug. 27, 1963	FP-LT-I-R-FW	X	X			
Do	16	Rock Creek	244,987	Gilliam Wheeler	Gilliam SWCD Heppner SWCD	July 13, 1962	FP-LT-I-R-FW	X	X			
Do	17	Lonerock-Six Mile Creeks.	81,468	Gilliam Wheeler	Gilliam SWCD	do	FP-LT-I-R-FW	X	X			
Do	18	Trout Creek	183,640	Jefferson	Trout Creek SWCD Jefferson County Trout Creek WCD	May 29, 1959	FP-LT-I-R-FW	X	X			
Do	19	Fifteen Mile Creek	239,000	Wasco Hood River	Central Wasco SWCD North Wasco SWCD Hood River SWCD South Wasco SWCD	Apr. 18, 1965	FP-LT-I-MI-R-WQ-FW	X				
Do	20	Middle Fork of Hood River.	40,500	Hood River	Hood River SWCD Middle Fork Irrigation District	Apr. 29, 1959	I-LT-R-FW	X	X	X	X	X
Do	21	Oak Grove	20,000	do	Hood River Irrigation District Hood River SWCD	July 13, 1962	LT-I-FP-R	X				
Do	22	Fairview Creek	13,602	Multnomah	East Multnomah SWCD Section Line Drainage District Multnomah Drainage District	Oct. 5, 1963	FP-LT-MI-D-R-WQ	X	X			
Do	23	Rainier Drainage District	3,087	Columbia	Clatskanie SWCD	Mar. 20, 1955	FP-LT-D	X	X	X	(3)	(3)
Do	24	Skipanon River	10,480	Clatsop	Warrenton Dune SWCD Clatsop County Skipanon WCD	Apr. 29, 1958	FP-LT-R-FW	X	X	X	X	X
Willamette	25	West Fork Dairy Creek	50,000	Washington	Washington SWCD	Sept. 28, 1956	FP-LT-I-R-FW-WQ	X	X			
Do	26	McKay-Rock Creek	90,000	do Multnomah	Washington County SWCD McKay Creek WCD. Washington County Multnomah County Tualatin Hills Park and Recreation District. City of Beaverton City of North Plains Sauvie Island SWCD	Dec. 11, 1961	FP-LT-I-MI-R-FW-WQ	X	X	X		
Do	27	North Yamhill River	125,000	Yamhill	Yamhill County SWCD	July 30, 1956	FP-LT-I-MI-R-FW-WQ	X	X			
Do	28	Chehalem Valley	36,800	do	Yamhill County SWCD	do	FP-LT-I-MI-R-FW-WQ	X	X			
Do	29	Fanno Creek	22,800	Washington Multnomah Clackamas	Washington County SWCD Sauvie Island SWCD South Clackamas SWCD City of Beaverton City of Tigard	Aug. 4, 1966	FP-R-D-LT-I-WQ	X				
Do	30	Upper Pudding River	243,000	Marion Clackamas	Mount Angel SWCD Santiam SWCD Silver Creek SWCD	Mar. 20, 1961	FP-LT-I-MI-R-FW-WQ.	X	X			

See footnotes at end of table.

TABLE 52.—WATERSHED APPLICATIONS FOR ASSISTANCE UNDER PUBLIC LAW 566 (WATERSHED PROTECTION AND FLOOD PREVENTION ACT), OREGON, NOVEMBER 1966—Continued

[Symbols are defined as follows: FP—Flood Prevention; LT—Land Treatment; I—Irrigation; MI—Municipal-Industrial Water; D—Drainage; WTC—Water Table Control; R—Recreation; FW—Fish and Wildlife; WQ—Water Quality]

Subbasin	Map No.	Watershed	Area (acres)	County	Sponsors	Date application received	Purposes included	Status of projects				
								Applications accepted	Preliminary investigation initiated	Planning authorized	Plan completed	Installation authorized
Willamette—Con.												
Do	31	Little Pudding River	36,246	Marion	Mount Angel SWCD Santiam SWCD Silver Creek SWCD Lake Labish WCD	May 12, 1955	FP-LT-WTC	(3)	(3)	(3)	(3)	(3)
Do	32	Mill Creek	45,000	do	Santiam SWCD Silver Creek SWCD Beaver Creek WCD Santiam WCD City of Stayton City of Turner City of Aumsville	Oct. 30, 1961	FP-LT-I-R-WQ	X	X			
Do	33	Beaver Creek	19,940	do	Santiam SWCD Silver Creek SWCD Beaver Creek WCD	Mar. 21, 1958	FP-LT-I-R-FW	X	X	X	X	X
Do	34	Grand Prairie	27,700	Linn	Linn County City of Albany City of Lebanon East Linn SWCD Linn-Lane SWCD Grand Prairie WCD	June 5, 1964	FP-LT-I-D-WQ-MI	X	X			
Do	35	Lower Amazon and Flat Creek.	48,880	Lane Benton	North Lane SWCD Benton SWCD Mid-Lane SWCD Upper Willamette SWCD Lane County Benton County Amazon WCD	Dec. 31, 1961	FP-LT-I	X	X	X	X	X

					City of Eugene City of Junction City Junction City WCD River Road Water District Santa Clara Water District							
Do	36	Mohawk River	125,000	Lane	Upper Willamette SWCD	Oct. 12, 1960	FP–LT–I–D	X				
Do	37	Willakenzie Area	16,700	do	do	Feb. 24, 1958	FP–LT	X	X	X	X	X
					Lane County McKenzie WCD City of Springfield Rainbow Water District City of Eugene							
Do	38	Rattlesnake Creek	6,200	do	Upper Willamette SWCD Willamette-Alder Creek Improvement District.	Apr. 15, 1964	FP–LT–I–D–R	X	X			
					Lane County							
Do	39	Cloverdale	22,775	do	Upper Willamette SWCD	Mar. 31, 1964	FP–LT–I–D–R	X	X			
					Lane County							
Do	40	Lynx Hollow Creek	11,720	do	Upper Willamette SWCD	Aug. 6, 1956	FP–LT–I	(3)	(3)	3)	(3)	(3)
					Creswell WCD							
Do	41	Camas Swale Creek	27,900	do	Upper Willamette SWCD	Dec. 18, 1963	FP–I–D–LT–WTC–R–WQ	X	X			
					Mid-Lane SWCD Lane County City of Creswell							
Do	42	Coyote-Spencer Creeks	60,800	do	Mid-Lane SWCD	Jan. 31, 1955	FP–LT–I–D–WQ	X	X			
Do	43	Upper Long Tom River	60,760	do	do	Feb. 4, 1955	FP–LT–I–R–FW–WQ	X	X			
Coastal	44	Upper Nehalem River	229,000	Columbia Washington	Clatskanie SWCD	Apr. 13, 1956	FP–LT–I–MI–R–FW–WQ	X				
Do	45	Lake Creek	144,600	Lane Benton	Siuslaw SWCD Mapleton Water District Port of Siuslaw Lane County Benton SWCD North Lane SWCD City of Florence	Feb. 17, 1966	FP–I–LT–R–D–FW	X				
Umpqua	46	Sutherlin Creek	28,960	Douglas	North Douglas SWCD City of Sutherlin Sutherlin WCD Douglas County	May 20, 1957	FP–LT–I–MI–R–FW	X	X	X	X	X
Rogue	47	Deer Creek	60,800	Josephine	Illinois Valley SWCD	Nov. 24, 1954	FP–LT–I–R	X	X	X	(2)	(2)
Do	48	Bear Creek	234,930	Jackson	Rogue SWCD City of Ashland	June 26, 1957	FP–LT–I–D–WTC–WQ	X	X			

[1] Suspended.
[2] Terminated.
[3] Project completed.

Each river has its own principal attractions. White water boat trips are famous on the Rogue, Snake and McKenzie rivers. Great dams line the Columbia River; here also is the famed Columbia Gorge and Multnomah and Horse Tail Falls. The mile-deep Hells Canyon is the highlight of the Snake River.

Recreation activities are third in the economic picture, behind lumbering and agriculture. In 1960, income from tourist travel was estimated to be $170 million. The 1965 estimated total expenditure for tourism was $250,460,000. Figure 96 shows the income from tourism over the period 1940 to 1965 with an estimate for 1970.

The majority of Oregon's people live in the Willamette Valley. A wide variety of recreational activities are available to them. Within a short time of three to four hours one can be on the coast, doing, among other things, beachcombing or surf-fishing, or in the high mountain country hiking or camping. An excellent state and Federal highway system provides quick access to all the principal recreation areas in the state. Out-of-state visitors can reach Oregon by car, bus, train, or airplane.

Salmon and steelhead fishing and big game hunting are of National interest. Many historical sites are associated with the Indians and westward expansion. Examples include Fort Astoria and Fort Rock Cave which have significant historical value. The following paragraphs list the important existing recreation areas.

Existing Public Areas

One national park, Crater Lake; a national monument, Oregon Caves; and a national memorial, Fort Clatsop, highlight the Federal recreation areas. Oregon has fifteen national forests containing 15,741,971 acres. Included in these forests are more than 500 recreation areas, 17 winter sports areas, 10 wilderness, wild and primitive areas, the Oregon Skyline Trail (part of the Pacific Crest Trail system) and the lower part of the Rogue River Trail.

In addition to the National Park Service, other Federal agencies administer recreation areas. The Corps of Engineers administers recreational activities on certain of its reservoirs. The Fish and Wildlife Service handles the national wildlife refuges. The Bureau of Land Management manages recreation sites on Oregon and California revested railroad lands.

Oregon enjoys the distinction of having the largest number of state park areas in the United States. The State Highway Department's State Parks and Recreation Division is responsible for the development, operation, and maintenance of Oregon's State Parks.

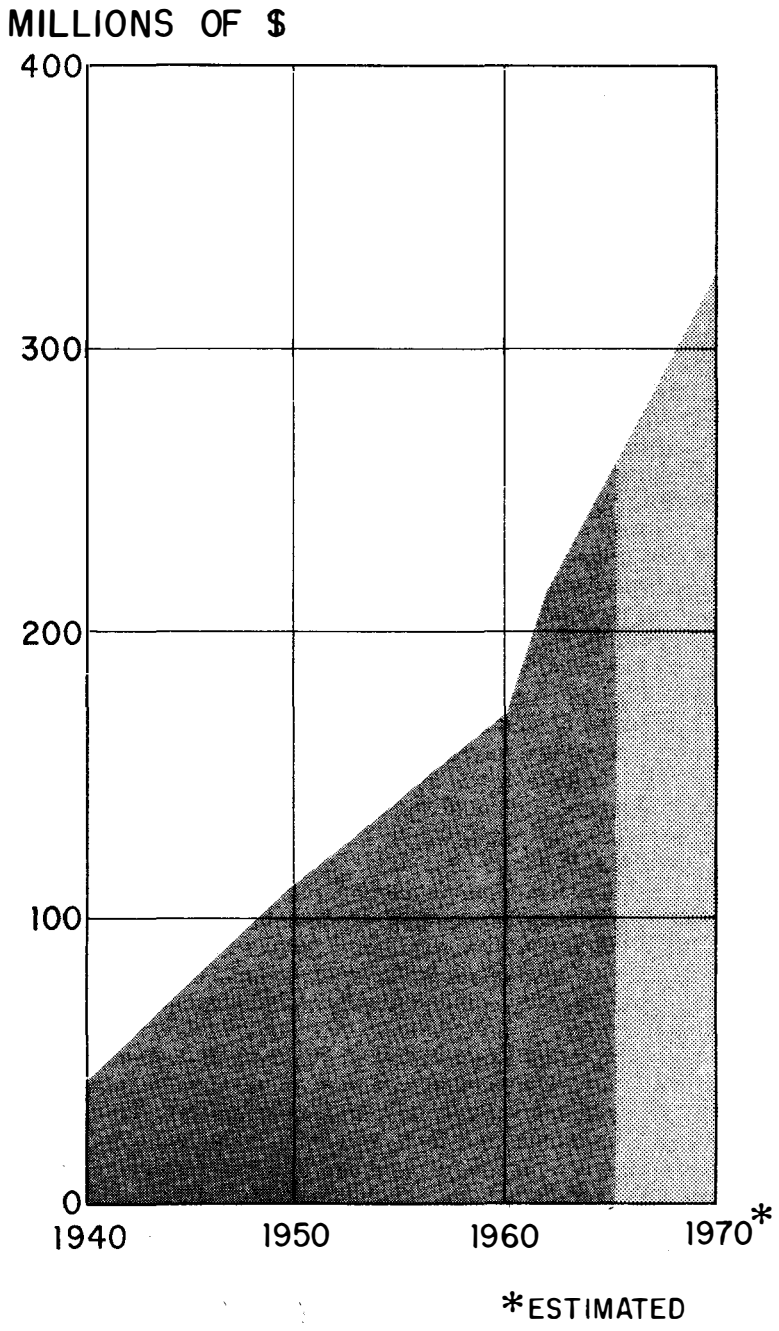

FIGURE 96.—Income from tourism.

Attendance at state parks increases annually. The following tabulation shows the figures for the period 1961–65.

STATE PARK ATTENDANCE

	Day use	Overnight camping	Total
1961	11,487,126	708,210	12,195,336
1962	11,570,313	842,408	12,412,721
1963	13,014,668	877,658	13,892,326
1964	14,256,136	1,003,331	15,259,457
1965	14,784,146	1,127,928	15,912,074

To meet the ever-increasing demand for outdoor recreation, the state of Oregon embarked on an accelerated land acquisition program. Eleven new parks were added, and as of June 1966 there were 200 state parks and waysides in Oregon. Taking full advantage of Oregon's wealth of natural resources, 38 developed parks have frontage on the Pacific Ocean, 17 have lake or reservoir frontage, and 47 are located along rivers with many more on the banks of smaller streams. There are 32 parks with improved boat launching ramps, and over 60 developed parks offer water sports, including swimming, wading, and water skiing. Hiking trails are found in 27 parks, 11 parks feature waterfalls, 30 offer spectacular viewpoints, 20 are of geologic interest, and 18 are historically important.

Sixteen county park departments have developed a combined total of more than 115 parks. Various communities have also developed nonurban parks. Timber companies and private power companies have provided recreation facilities on their lands and reservoirs. These are significant contributions to the state's overall recreation picture.

Figure 97 and table 53 present a subbasin breakdown of the major existing state, Federal and local recreational developments for Oregon.

Two Indian Reservations provide annual recreational attractions of note. The Umatilla, Walla Walla and Cayuse Indians of the Umatilla Reservation in Umatilla County east of Pendleton are featured in the world-famous Pendleton Round-Up. Rodeo contests, parades, reenactments of Old West Indian pageants and dances are featured. Boating, water skiing, fishing, and other water sports along the Columbia River plus fishing and hunting on or near the reservation are principal recreation activities.

On the Warm Springs Reservation in Wasco and Jefferson Counties the Walla Walla and Wasco Indians feature an annual Root Festival, an annual Huckleberry Festival, and ceremonial dances during Thanksgiving, Christmas, and New Years. Boating, camping, and fishing at Lake Simtustus plus fishing on the famous Deschutes and Metolius Rivers are highlights of the recreational activities near this reservation.

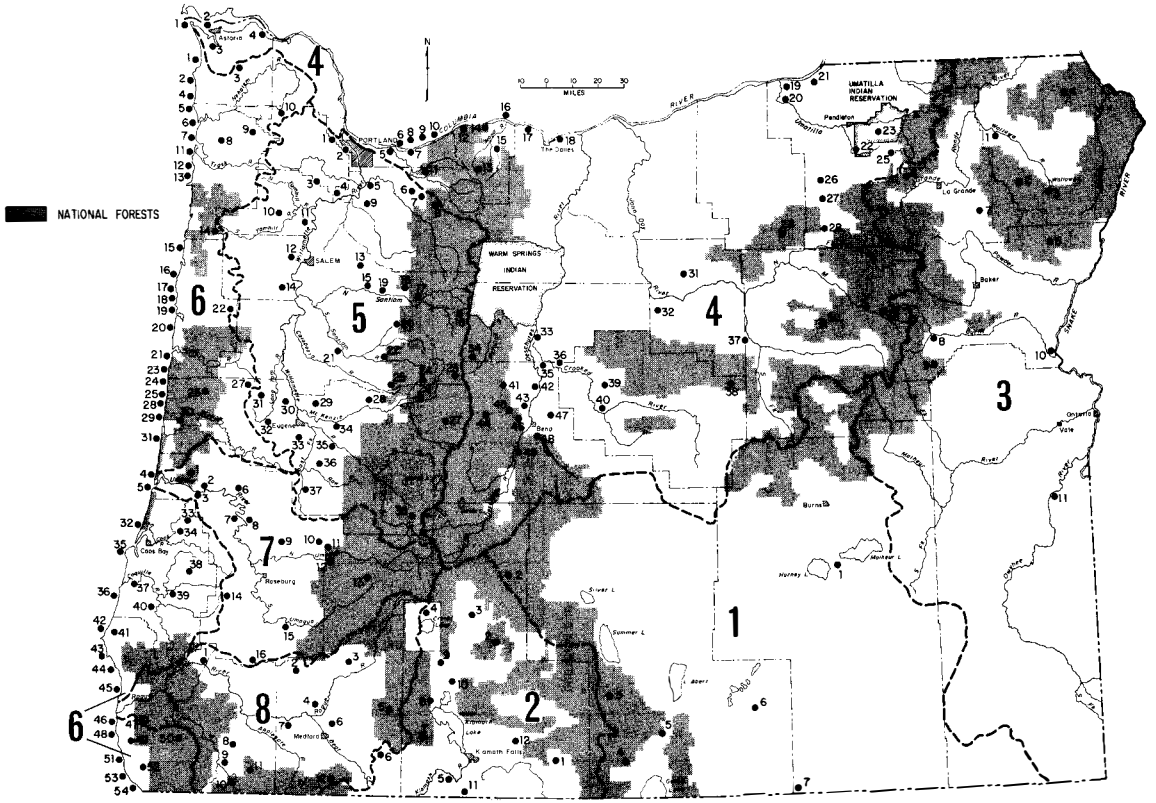

FIGURE 97.—Existing recreation sites and national forests.

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TABLE 53.—RECREATION FACILITIES IN OREGON, EXISTING (AS OF 1963)

Subbasin	Acreage		Type of use				Activities									
	Total land area	Water surface	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness
CLOSED LAKES																
1. Malheur National Wildlife Refuge	184,872	56,000	X				X		X			X	X	X		
2. Winema National Forest	908,963	M	X	X		X	X	X	X	X	X	X	X	X		
3. Fremont National Forest	1,254,608	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4. Booth Wayside	311		X			X	X									
5. Chandler Wayside	59		X			X	X									
6. Hart Mountain National Antelope Refuge	240,664		X						X				X	X		
7. Charles Sheldon Antelope Refuge	628		X						X				X	X		
KLAMATH																
1. Gerber Reservoir	100	5,000	X	X			X		X	X	X	X	X	X		
2. Winema National Forest	908,963	M	X	X		X	X	X	X	X	X	X	X	X		
3. Klamath National Wildlife Refuge	15,226		X											X		
4. Crater Lake National Park	160,290	12,800	X	X	X	X	X	X	X	X	X	X		X	X	X
5. Topsy	40		X				X		X			X		X		
6. Howard Prairie Reservoir	1,980	2,000	X	X			X		X	X	X	X			X	
7. Mountain Lakes Wild Area	23,071	M	X	X	X			X	X			X	X			X
8. Upper Kalamth National Wildlife Refuge	15,226	68,200	X									X	X	X		
9. Jackson Fork Kimball State Park	19		X				X					X				
10. Collier State Park	199		X			X	X									
11. Lower Klamath National Wildlife Refuge	1,340		X						X				X	X		
12. Klamath-Lakeview Wayside	80		X				X									
SNAKE																
1. Wallowa Lake Wayside	314		X				X									
2. Eagle Gap Wilderness Area	216,250	M	X	X	X			X	X			X	X			X
3. Willowa Lake State Park	166	1,600	X	X	X		X	X	X	X	X	X				
4. Willowa National Forest	979,279	S	X	X	X	X	X	X	X			X	X	X		X

5. Whitman National Forest	1,511,613	M	X	X	X	X	X	X	X	X			X	X			X
6. Hilgard Junction State Park	6		X			X	X		X				X				
7. Catherine Creek State Park	160		X				X		X				X				
8. Unity Lake State Park	39	930	X				X			X	X		X				
9. Unity Forest Wayside	85		X				X										
10. Farewell Bend State Park	65	15,000	X			X	X		X	X	X	X	X				
11. Owyhee Lake State Park	730	12,724	X				X		X	X	X	X	X				
COLUMBIA																	
1. Fort Stevens State Park	793	70	X	X	X	X	X	X	X	X	X	X					
2. Fort Astoria Monument	10		X														
3. Fort Clatsop Memorial	125		X		X	X											
4. Bradley Wayside	18		X				X										
5. Blue Lake Park	39	S	X				X			X	X	X					
6. Lewis and Clark State Park	56		X				X			X	X	X					
7. Crown Point State Park	265		X			X											
8. Dabney State Park	79		X				X		X		X	X					
George Joseph State Park	150		X			X		X									
Guy Talbot State Park	241		X			X	X	X									
9. Shepherd's Dell State Park	105		X			X	X	X									
10. Benson State Park	84	S	X			X	X			X	X	X					
John B. Yeon State Park	284		X			X	X	X									
McLoughlin State Park	82		X				X										
Ainsworth State Park	46		X			X	X										
11. Dodge Park	26		X				X				X	X					
12. Lang State Park	162		X			X	X										
13. Mount Hood Wild Area	14,160	S	X	X	X			X	X				X	X			X
14. Lindsey Creek State Park	129		X			X	X										
Seneca Fouts Memorial State Park	199		X				X	X									
Starvation Creek State Park	153		X			X	X	X									
Viento State Park	244		X			X	X		X								
Wygant State Park	691		X			X	X	X									
15. Zibe Diminick State Park	23		X				X						X				
16. Koberg Beach State Park	88	20,700	X				X			X	X	X					
17. Mayer State Park	268	20,700	X				X			X	X	X					
18. Celilo Park	15	9,400	X			X	X		X	X	X	X					
19. Hat Rock State Park	369	38,000	X				X			X	X	X					
20. Cold Springs National Wildlife Refuge	3,117	1,550	X				X					X		X			
21. McNary Reservoir	38,043	38,000	X			X	X			X	X	X					
22. McKay Creek National Wildlife Refuge	1,837	1,286	X									X		X			
23. Emigrant Springs State Park	14		X			X	X	X	X								
24. Umatilla National Forest	1,075,959	S	X	X	X	X	X	X	X				X	X			X
25. Blue Mountain Forest Wayside	2,152		X				X										
26. Battle Mountain Forest Wayside	284		X				X										
27. Battle Mountain State Park	136		X				X										
28. Ukiah-Dale Forest Wayside	2,987		X				X		X								
29. Whitman National Forest	1,511,613	M	X	X	X	X	X	X	X	X			X	X			X

TABLE 53.—RECREATION FACILITIES IN OREGON, EXISTING (AS OF 1963)—Continued

Subbasin	Acreage		Type of use				Activities									
	Total land area	Water surface	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness
COLUMBIA—Continued																
30. Malheur National Forest	1,204,834	S	X	X	X	X	X	X	X			X	X	X		X
31. Shelton Wayside	180		X				X									
32. Painted Hills State Park	13		X				X							X		
33. Cove Palisades State Park	4,533		X	X			X	X	X			X				
34. E. R. Corbett State Park	63	S	X				X	X								
35. Peter-Ogden Wayside	98		X			X	X									
36. Smith Rock State Park	304		X				X	X	X		X	X				
37. John Day Fossil Bed State Park	3,481		X	X	X	X	X	X	X					X		
38. Ochoco National Forest	845,880	S	X	X	X	X	X	X	X			X	X	X		X
39. Ochoco Lake State Park	10	1,080	X				X		X	X	X	X				
40. Prineville Reservoir Recreation Area	300	3,020	X				X		X	X	X	X				
41. Sisters State Park	41		X			X	X									
42. Cline Falls State Park	9		X				X					X				
43. Tumalo State Park	117		X				X		X		X	X				
44. Deschutes National Forest	1,659,380		X	X	X	X	X	X	X	X	X	X	X	X	X	X
45. Robert Sawyer State Park	41		X			X	X					X				
46. Shevlin Park	388		X				X		X			X				
47. Redmond-Bend-Juniper Way	635		X											X		
48. Pilot Butte State Park	101		X			X	X									
49. Lava River Caves State Park	23		X			X	X							X		
WILLAMETTE																
1. Forest Park	3,366		X				X	X								
2. Willamette Stone State Park	2		X													
3. Bald Peak State Park	26		X				X									
4. Champoeg State Park	159		X				X		X					X		
5. Clackamette Park	25		X				X			X		X				
6. Eagle Fern Park	175		X				X	X	X		X	X				

7. North Fork, Eagle Creek	40		X		X		X	X	X			X		X		
8. Mount Hood National Forest	1,115,327	M	X	X	X	X	X	X	X	X		X	X	X	X	X
9. Wagon Wheel Park	15		X				X				X	X				
10. Erratic Rock Wayside	4		X			X								X		
11. Maude Williamson State Park	20		X				X		X							
12. Holman Wayside	9		X				X									
13. Silver Falls State Park	8,259		X	X			X	X	X		X	X				
14. Sarah Helmick State Park	31		X				X		X		X	X				
15. North Santiam State Park	74		X				X			X	X	X				
16. Niagara Park	40		X				X				X	X				
17. Detroit Lake State Park	45	3,600	X	X			X		X	X	X	X				
18. Mount Jefferson Primitive Area	86,700	M	X	X	X			X	X			X	X			X
19. Fishermans Bend	100		X				X		X			X		X		
20. Yellowbottom	40		X				X		X			X		X		
21. Sodaville Springs State Park	1		X													
22. Cascadia State Park	322		X			X	X		X		X	X				
23. Mount Washington Wild Area	46,655	M	X	X	X			X	X			X	X			X
24. Willamette National Forest	1,665,835	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
25. H. J. Morton State Park	24		X				X					X				
26. J. B. Harris Wayside	4		X				X			X		X				
27. Three Sisters Wilderness Area	196,708	M	X	X	X			X	X			X	X			X
28. Dorris State Park	79		X				X			X	X	X				
29. Armitage State Park	41		X				X		X	X	X	X				
30. Fern Ridge Reservoir	9,385	9,360	X				X			X	X	X	X			
31. Alderwood Wayside	80		X				X									
32. Fern Ridge State Park	54	9,360	X				X			X	X	X				
33. Spencer Butte Park	280		X				X	X	X							
34. Hendricks Bridge Wayside	12		X				X				X	X				
35. North Shore Recreation Area	55	1,025	X				X			X	X	X				
36. Baker Bay Park	47	1,900	X				X			X	X	X				
37. Cottage Grove Reservoir	1,580	1,140	X				X			X	X	X				
38. Diamond Peak Wild Area	35,440	M	X	X	X			X	X			X	X			X
COASTAL																
Gearhart Ocean Wayside	286		X				X				X					
Ecola State Park	1,107		X	X		X	X	X			X	X		X		
3. Saddle Mountain State Park	3,054		X			X	X	X	X							
4. Hug Point State Park	1		X				X				X					
5. Oswald West State Park	2,501		X	X		X	X	X	X		X	X				
6. Nehalem Bay State Park	820		X				X				X					
7. Barview Wayside	300		X			X	X		X		X	X				
8. Kilchis Park	600		X				X		X			X				
9. Wilson River Wayside	772		X			X	X					X				
10. Sunset Highway Forest Wayside	1,100		X			X	X									
11. Cape Meares State Park	139		X				X							X		
12. Cape Meares Wildlife Refuge	139	S												X		
13. Cape Lookout State Park	1,451		X	X	X	X	X	X	X		X	X				
14. Van Duzer Wayside	1,507		X				X									

TABLE 53.—RECREATION FACILITIES IN OREGON, EXISTING (AS OF 1963)—Continued

Subbasin	Acreage		Type of use				Activities									
	Total land area	Water surface	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness
COLUMBIA—Continued																
15. Devils Lake State Park	110	M	X				X		X	X	X	X				
Fogarty Beach State Park	104		X				X				X					
16. Boiler Bay Wayside	32		X				X									
17. Beverly Beach State Park	69		X				X		X		X					
Rocky Creek State Park	58		X				X									
18. Devil's Punchbowl State Park	5		X			X	X									
19. Yaquina State Park	32		X				X									
20. Lost Creek State Park	78		X				X				X					
Ona Beach State Park	138		X				X				X					
Seal Rock Wayside	8		X				X				X					
South Newport State Park	163		X				X				X					
21. Beachside State Park	17		X				X		X		X					
Governor Patterson State Park	9		X				X				X					
Lincoln County Wayside	42		X				X				X					
22. Ellmaker State Park	80		X				X									
23. Yachats State Park	3		X				X				X	X				
Yachats Ocean Wayside	9		X				X				X					
24. Neptune State Park	331		X			X	X		X		X	X				
25. M. O. Ponsler Wayside	2		X				X				X	X				
26. Siuslaw National Forest	622,180	M	X	X	X	X	X	X	X	X	X	X	X	X		
27. Blachly Mountain Wayside	80		X				X									
28. Devil's Elbow State Park	97		X			X	X				X	X		X		
29. Joaquin Miller Wayside	112		X											X		
Darlingtonia Wayside	17		X											X		
30. Siuslaw Harbor Park	15		X				X		X	X	X	X				
31. J. M. Honeymay State Park	522	1,123	X	X	X	X	X	X	X	X	X	X		X		
32. Simpson Wayside	24		X				X							X		

33. Golden and Silver Falls State Park	157		X				X	X									
34. Millicoma-Myrtle Grove State Park	15		X				X							X			
35. Sunset Bay State Park	88		X	X			X		X	X	X	X					
Cape Arago State Park	134		X				X				X	X					
Shore Acres State Park	683		X				X							X			
36. Bandon State Park	88		X				X				X						
Bandon Wayside	10		X				X				X						
37. Sweet Myrtle Preserve	16		X											X			
38. Maria Jackson State Park	42		X											X			
39. Norway Myrtle Preserve	57		X											X			
40. Coquille-Myrtle Preserve	7		X				X							X			
41. Port Orford Cedar Wayside	34		X											X			
42. Newburgh Beach Park	1,419		X				X		X		X						
43. Battle Rock Wayside	3		X			X					X						
44. Humbug Mountain State Park	1,821		X	X		X	X	X	X		X	X					
45. Geisel Monument Wayside	4		X			X	X										
46. Buena Vista Ocean Wayside	58		X				X										
47. Kalmiopsis Wild Area	78,530	S	X	X	X			X	X			X	X	X			X
48. Cape Sebastian State Park	1,069		X			X	X	X									
49. Carpenterville-Brookings Wayside	510		X				X										
50. Siskiyou National Forest	1,047,101	S	X	X	X	X	X	X	X	X		X	X	X			X
51. S. Boardman Wayside	1,473		X	X		X	X	X	X		X	X		X			
52. Azalea State Park	26		X				X							X			
Loeb State Park	160		X				X							X			
53. Harris Beach State Park	141		X				X		X		X						
54. Oregon Islands Wildlife Refuge	21													X			
UMPQUA																	
1. Umpqua Wayside	31		X				X			X							
2. Umpqua Myrtle Preserve	5		X											X			
3. Loon Lake	50		X	X	X	X	X		X	X	X	X					
4. Winchester Bay	90		X			X				X		X					
5. Umpqua Lighthouse Park	2,747	S	X	X	X	X	X	X	X		X	X		X			
6. Elk Creek Tunnel Wayside	200		X				X										
7. Hutchison Wayside	6		X				X					X					
8. Tyee	50		X				X	X	X			X		X			
9. Whistler's Bend	160		X				X	X			X	X					
10. R. G. Baker Memorial Park	10		X				X					X					
11. Rock Creek	80		X	X	X		X		X		X	X		X			
12. Susan Creek Park	148		X				X		X		X	X					
13. Umpqua National Forest	983,982	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14. Camas Mountain Wayside	160		X				X										
15. Canyon Creek Forest Wayside	80		X				X										
16. Mackin Gulch Wayside	430		X				X										
Stage Coach Wayside	231		X				X										

TABLE 53.—RECREATION FACILITIES IN OREGON, EXISTING (AS OF 1963)—Continued

Subbasin	Acreage		Type of use				Activities									
	Total land area	Water surface	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness
ROGUE																
1. Rogue River Recreation Area	10,000	S	X	X	X			X	X	X		X	X	X		X
2. Elderberry Flat	40		X				X		X		X	X		X		
3. Casey State Park	80		X			X	X				X	X				
Laurelhurst State Park	272		X				X				X	X				
McLeod Wayside	80		X			X	X				X	X				
4. Tou Velle State Park	35		X				X			X	X	X				
5. Rogue River National Forest	837,235	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6. Prescott Memorial Park	1,720		X				X	X								
7. Ben Hur Lampman Wayside	23		X			X	X			X		X				
Rogue River Bridge Area	169		X				X				X	X				
8. Selmac Lake	320	160	X				X		X	X	X	X				
9. Rough and Ready Wayside	11		X				X							X		
10. Siskiyou National Forest	1,047,101	S	X	X	X	X	X	X	X	X		X	X	X		X
11. Oregon Caves Monument	480		X	X	X	X	X	X								
12. Klamath National Forest	29,795	S	X	X		X			X				X			

Potential Water Resource Developments

The overall economic picture of Oregon provides an excellent base for substantial growth both in the near future and long range. The economy has adjusted to continuing technological advances and diversification in its dominant industry, lumbering. Standard of living increases and population increases are stepping up the demand for agricultural production. Increased leisure time and more "money at hand" are responsible for the ever-increasing demand for tourist and recreation facilities.

Interwoven among these economic activities is the need and desire for abundant, clean water. There is a continuing demand for water resource developments; these developments are an integral part of the plans for economic expansion in Oregon.

Oregon has tremendous amounts of pure water for human and industrial consumption. The importance of this cannot accurately be measured; it suffices to say that with this available water, Oregon has an unlimited opportunity to grow.

This section of the report presents facts and information about the potential for irrigation, navigation and flood control, and recre tion. Information on proposed projects and projects being investigated by Federal and state agencies has been tabulated and summarized by subbasin.

IRRIGATION

It is estimated that by 1980, Oregon will have more than 2,450,000 people. This increase in population plus a moderate rise in per capita consumption of farm products will increase agricultural requirements in the state by 70 to 75 percent.

The West is the fastest growing area in the United States. Considering the population growth and the fact that total acreages actually used for food and fiber production do not exist in unlimited amounts, new and improved methods will be required to meet these agricultural needs.

The increased demand for agricultural products will be met in several ways: (1) by increasing and more intensively using the acreage of land under crop cultivation, particularly through irrigation, (2) by application of technical advances in crop yields and livestock production rates, (3) by a shift in the use of certain farm products, and (4) by changes in the volume of interstate shipments. Future production will be related more to the total national demand and to the population increase in the entire West than to the growth of population in the state.

Though the total acreage in crops including cropland pasture will increase only slightly over the next ten years, irrigated cropland acreages will increase substantially. The adoption of improved technological developments plus the substantial increase in irrigation are indicators that Oregon can meet its agricultural requirements. Some significant changes in major land use will occur; these include: urban encroachment, additional rangelands developed for crop agriculture, farm sizes increasing generally and irrigation increasing substantially. An improved transportation and marketing system will also have an effect on future land use patterns.

About 300,000 acres of land will go out of agricutlural production into such things as urban build-up, highways and industrial developments by 1975. Almost 397,000 acres, however, will come into agricultural use; these lands primarily are Federally owned.

Of the total land area in farms, 20,509,300 acres, only 26 percent or 5,282,000 acres was actually in crops in 1964 according to the Census of Agriculture. The remaining area was divided among pasture and rangeland, woodland, and other land, including house and barn lots and rights-of-way for lanes, roads, and ditches. By 1975, according to the Soil and Water Conservation Needs Inventory, the cropland in Oregon will increase only about 4 percent. Irrigated cropland, however, will increase about 25 percent.

An estimated 8,040,000 acres of arable land in Oregon has some degree of potentiality for irrigation development. Of this total, some 1,608,000 acres were irrigated in 1964. The remaining 6,432,000 acres have physical capabilities of being developed for irrigation. No attempt has been made to determine what portion of this land would be economically capable of supporting irrigation development or whether this development would be financially feasible. Figure 98 shows the general location of these potential arable lands and the existing irrigated land. The following tabulation presents a subbasin breakdown of the presently irrigated land and the arable potential for Oregon.

Subbasin	Arable irrigated	Potential arable	Total
Closed Lakes	262,000	763,000	1,025,000
Klamath	253,000	150,000	403,000
Snake	473,000	733,000	1,206,000
Columbia	342,000	2,461,000	2,803,000
Willamette	182,000	1,835,000	2,017,000
Coastal	13,000	180,000	193,000
Umpqua	14,000	120,000	134,000
Rogue	69,000	190,000	259,000
State total	1,608,000	6,432,000	8,040,000

Subbasin No. 1—Closed Lakes

Most of the 763,000 acres of potential arable land in this subbasin is presently sagebrush and juniper-covered rangeland and plateaus. The potential arable lands are scattered throughout the subbasin with the heaviest concentration in Lake and Harney Counties.

Pasture is the leading crop presently being irrigated in this subbasin; it can be assumed that forage crops would be dominant in future irrigation developments.

In general terms, this subbasin can be described as a water short area; that is, the ultimate water requirements exceed the subbasin's water supply. Some areas, such as around Harney and Malheur Lakes in Harney County and the Warner Valley, Goose Lake Valley, and the Fort Rock area in Lake County, could sustain sizable ground water irrigation developments. However, the ultimate needs can only be satisfied by importing water from another subbasin.

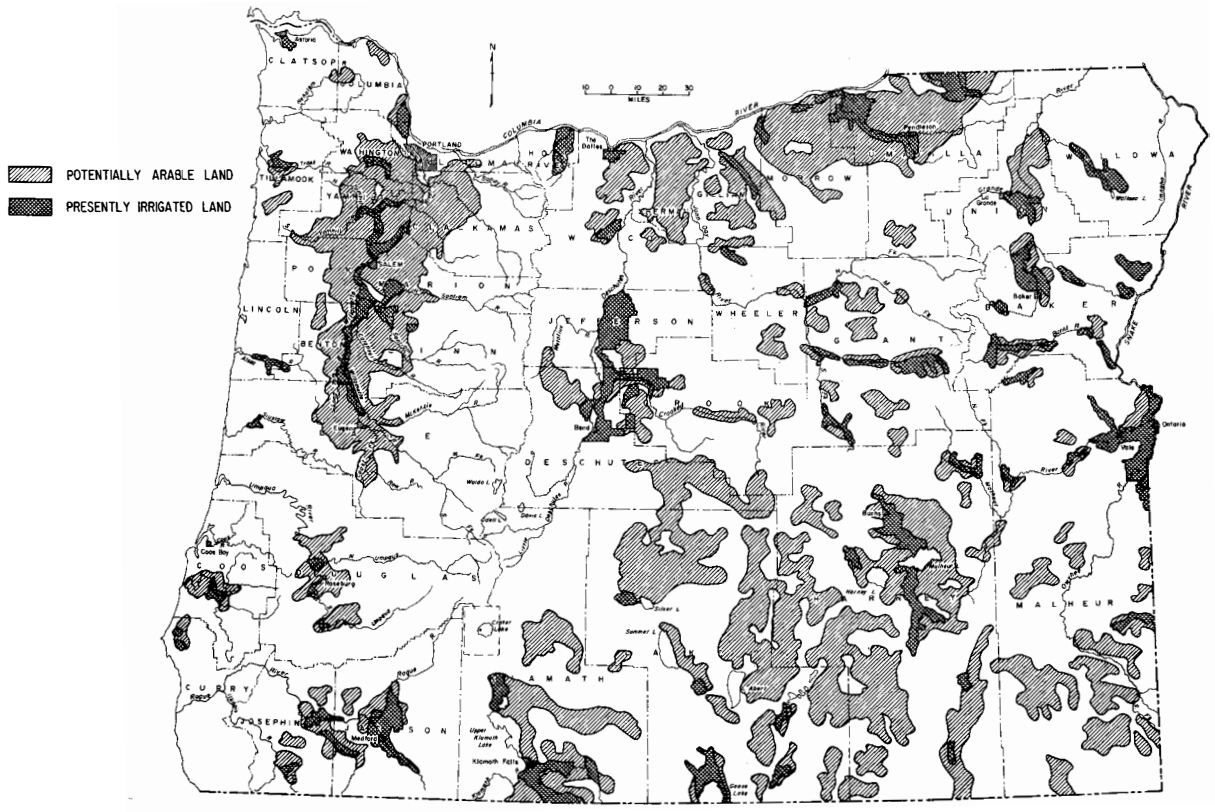

FIGURE 98.—Potential arable land and irrigated land.

Subbasin No. 2—Klamath

As stated earlier, this subbasin leads the state in terms of intensity of irrigation development. Much of this subbasin is mountainous and rolling hill land supporting forests and sagebrush. The most productive agricultural lands are found on former lake beds and alluvial fans. These lands are capable of producing a wide variety of crops. The extensive irrigation development has changed the agricultural pattern from pasturing on open range to cash crops and supplemental livestock feed production.

There are aproximately 150,000 acres of potential arable land in this subbasin. Much of it is located in areas contiguous to existing irrigation development. A possible source of irrigation water is ground water. The Valley of the Sprague River, a tributary of the Klamath, is underlain by some of the most productive ground water reservoirs in the state.

As additional lands are irrigated in this subbasin, it is expected that they will be adapted to the general cropping pattern of the presently irrigated land.

Subbasin No. 3—Snake

Irrigated agriculture is important to the economy of this subbasin; approximately 79 percent of the farms are classified as irrigated farms. About 733,000 acres of land are believed to have some potential for irrigation development. Most of these lands occur in large blocks in the southern portion of this subbasin. Scattered smaller blocks are found in the central and northern portions, primarily in the river valleys next to the presently irrigated lands.

Storage of surface flows would be required to meet additional irrigation requirements. In certain areas, ground water supplies are abundant. Extensive ground water reservoirs are located in the Grande Ronde Valley, Baker Valley, and southern Malheur County.

The Snake River Basin is primarily beef country with forage and specialty crops being produced on the irrigated land. As additional land is brought under irrigation, it is presumed that cropping practices will change generally from a wheat-summer fallow program to a continuous cropping program in the northern portion and from noncropped pasture land to a forage and/or cash row crop program in the south.

Subbasin No. 4—Columbia

This subbasin has the largest acreage of potential arable land in the state. Nearly 2,461,000 acres have been identified as having physical potential for irrigation development. The majority of this land is in large blocks adjacent to the Columbia River in Umatilla, Morrow, Gilliam, Sherman and Wasco Counties. Other large potential areas are located along the east side of the Cascade Range in Deschutes and Jefferson Counties. The remaining potential arable lands are scattered in the major river valleys of the subbasin.

A wealth of storage sites is available throughout the subbasin. As the

demand for water increases, many of these sites will be developed. Some areas in Deschutes, Gilliam, and Sherman Counties have a potential for ground water development. Pumping from the reservoir pools on the Columbia River also offers excellent opportunities for extensive irrigation development.

A wide variety of crops are presently being grown in this subbasin through irrigation. As new lands are developed, it is expected that they will have the same general cropping pattern as the presently irrigated lands. Additional orchards could be developed in Hood River, Wasco, and Umatilla Counties. The beef cattle industry, one that offers great oportunities for expansion in Oregon's long-range agricultural picture, can be expanded through the development of irrigated pasture and forage crops.

Subbasin No. 5—Willamette

Approximately 1,835,000 acres of land in this subbasin can be classified as having some degree of potential for irrigation. Most of these lands are located in the valley; however, some are located on the foothills of the Coast and Cascade Mountains. Each county has some potential arable land; the majority is located in the middle Willamette counties.

Additional storage is necessary to fully develop the irrigation potential of this subbasin. Streamflows are generally inadequate in nearly all of the lower elevation tributaries, particularly those originating in the Coast Range. Expansion of irrigation in these areas is dependent upon development of new water supplies. Certain portions of this subbasin are underlain by aquifers which appear to have some potential for ground water development. The aquifer under French Prairie in Marion County is an example of this potential.

Additional problems affecting future irrigation development in this subbasin include flooding and lack of drainage. Some of the most productive lands in this subbasin are adjacent to streams that flood frequently. Poor drainage characteristics of certain soil groups found in this subbasin must also be alleviated.

A wide variety of crops could be produced under irrigation. An expansion in the types of cropping patterns, particularly in areas away from rapid urban development, will make the Willamette subbasin farmer more competitive economically.

Subbasin No. 6—Coastal

Of the 180,000 potential arable acres in this subbasin, the majority are located in three areas: (1) the river valleys in Tillamook, Clatsop, and Columbia Counties, (2) on the flood plains and surrounding hills of the Coos and Coquille Rivers in Coos County; and (3) on the flood plains and surrounding hills of the coastal streams in Lincoln County.

In the areas where irrigation could be developed, the cropping pattern would continue to be one of pasture, hay, and grass silage. Irrigation would result in higher yields and a better crop. In some

areas, with irrigation development, specialty crop production would likely increase.

Storage would have to be developed to permit any substantial irrigation in this subbasin. Around Coos Bay and near Tillamook are areas of signficant ground water potential.

Subbasin No. 7—Umpqua

This subbasin contains 120,000 acres of land having physical potential for irrigation. These lands are widely scattered throughout the western half of the subbasin. For the most part, they consist of narrow stringers located adjacent to the main streams and their tributaries.

Development of storage is the logical answer for creating an irrigation water supply. Many storage sites are available in this subbasin. The development of large supplies of ground water for irrigation is not likely in this subbasin.

It is expected that future irrigated lands will be devoted to pasture, hay, orchards, and miscellaneous specialty crops such as nursery products and vegetable seeds.

Subbasin No. 8—Rogue

This subbasin contains approximately 190,000 acres of land which have some potential for irrigation development. Most of these lands are located in the valleys of the Ro ue, Applegate, and Illinois Rivers. Additional lands are located along Evans, Graves, and Jumpoff Joe Creek.

Storage is necessary to serve additional irrigation in this subbasin. Many sites have been and are presently under study. There appears to be no substantial potential ground water supplies in this subbasin.

Orchards, commercially important now, would increase in importance as irrigation is expanded. Specialty crop production would also increase as would forage and pasture crops with additional irrigation development.

INVESTIGATIONS

The Bureau of Reclamation has a continuing investigation program to study projects throughout the state of Oregon. One study now underway is the *Columbia-North Pacific Region Study*. This study is a cooperative effort among all state and Federal agencies engaged in water conservation and related activities. All of Oregon except for the Klamath River subbasin is included. The basic objective is the formulation of a framework plan to provide a broad uide for the best use, or combination of uses of water, land, and related resources to meet foreseeable short- and long-term needs.

Studies completed, currently underway, or scheduled to start in the very near future are briefly described by subbasins in the following paragraphs. Figure 99 shows the location of the more recent and current investigations.

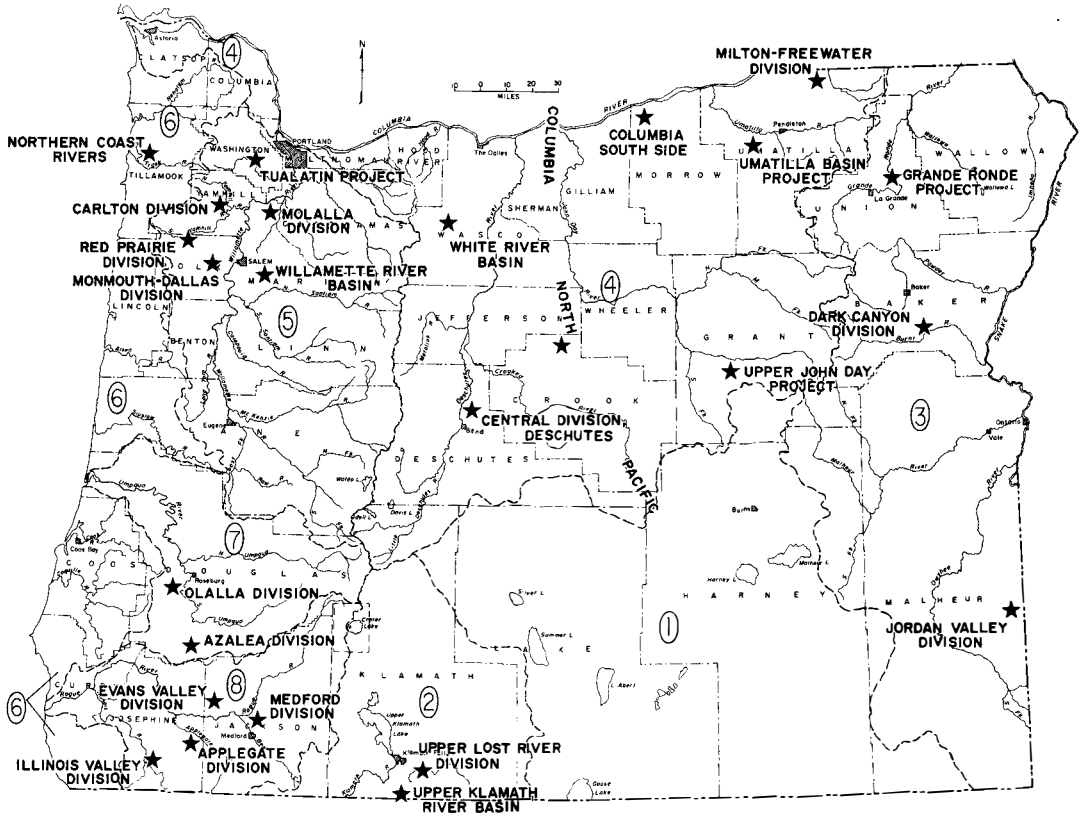

FIGURE 99.—Bureau of Reclamation investigations.

Subbasin No. 1—Closed Lakes

No project studies are underway or scheduled for the near future in this subbasin. However, the *Columbia-North Pacific* study does include this subbasin.

In 1951, the Bureau of Reclamation completed a study and report on the *Goose Lake* area of this subbasin. Considered during this study was rehabilitation of existing privately constructed facilities and construction of new facilities.

Subbasin No. 2—Klamath

This subbasin falls within the boundaries of the Bureau of Reclamation's Region 2 with headquarters in Sacramento. A reconnaissance survey of this subbasin was made during the early 1950's. Since that report has been prepared, several significant events have occurred including approval of the Upper Klamath River Compact and the occurrence of the two largest floods of record. There also is need in the subbasin to develop water resources for irrigation, flood control, fish and wildlife enhancement, recreation and possibly power and water quality control. A study is underway to identify areas of greatest need where further, more detailed investigations would be justified. An inventory report on the needs and interests of the entire Upper Klamath River basin will be completed in the near future.

A reconnaissance report on the development potential of the *Upper Lost River Division* of the Klamath project has been completed. A feasibility study is now underway. Constructing new storage and distribution facilities and enlarging existing facilities is being considered.

Subbasin No. 3—Snake

A number of Bureau of Reclamation investigations are underway in this subbasin. A recent reconnaissance report on the *Upper Owyhee Project* showed that further investigations of the *Jordan Valley* development in Malheur County were warranted. Being studied is a plan for a dam and reservoir on Jordan Creek having a total storage capacity of 60,000 acre-feet. Supplemental water would be provided to approximately 9,000 acres of land now inadequately irrigated. Recreation facilities would be provided and the Jordan Creek fishery would be improved.

The *Dark Canyon Division* of the Burnt River Project in Baker County would provide storage in two reservoirs and a distribution system to serve 10,500 acres of land. Other functions to be served include flood control, fish enhancement, and recreation.

To the north in Union County is the area being studied as part of the *Grande Ronde Project.* About 95,000 acres of land would be provided with either a full or a supplemental water supply. Storage would be provided by the Corps of Engineers and a distribution system constructed by the Bureau of Reclamation.

Subbasin No. 4—Columbia

Projects being investigated in this subbasin include the *Milton-Freewater Division* of the Walla Walla Project. The plan under consideration includes the construction of a dam and reservoir on the Walla Walla River in Umatilla County. Irrigation, fish and wildlife, recreation, flood control, water quality control, and municipal and industrial water are being evaluated.

Storage dams and reservoirs, pumping plants, and distribution facilities are the principal features of a plan currently being studied for the *Umatilla River Basin.* Functions being considered include irrigation for 110,000 acres, fish and wildlife, flood control, recreation, water quality control, and municipal and industrial water supply.

A reconnaissance investigation to determine the potential for multipurpose land and water resource development in northern Morrow and Gilliam Counties is scheduled to get underway. This study, known as the *Columbia South Side Project,* will evaluate the potential for irrigation, fish and wildlife, flood control, water quality control, and recreation.

An investigation of the *White River* watershed in Wasco and Hood River Counties will be made to determine the potential for multipurpose development. About 40,000 to 50,000 acres have a potential for irrigation. About 2,100 acres are presently irrigated but need a supplemental water supply.

The *Central Division* of the Deschutes Project is located in Deschutes, Jefferson, and Crook Counties. Being considered are the functions of irrigation, fish and wildlife, recreation, and municipal and industrial water.

A reconnaissance investigation is being made of the drainage area of the *John Day* River from above the North Fork in Grant, Wheeler, Crook, Umatilla, and Morrow Counties. This investigation includes an appraisal of all water and related land resources, including an inventory of storage sites.

Subbasin No. 5—Willamette

One Bureau of Reclamation project, the *Tualatin Project,* has been authorized for construction. Approximately 17,000 acres in Washington County will be irrigated from storage on Scoggins Creek, a tributary of the Tualatin River. A system of pumping plants, canals and laterals will also be constructed. Municipal and industrial water, recreation, and fish and wildlife will also be served by this project.

The *Red Prairie Division* of the Willamette River Project is located in Polk and Yamhill Counties. Storage at Gorge Dam and Reservoir on Mill Creek would provide a water supply for irrigation of 15,500 acres. Other functions to be served include fish and wildlife, recreation, and flood control.

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Also in Polk County is the proposed *Monmouth-Dallas Division.* Irrigation water for 17,200 acres initially and 28,000 acres ultimately would be provided by pumping from the Willamette River.

The plan for the *Carlton Division*, in Yamhill County, includes storage on the North Yamhill River and a distribution and drainage system. An irrigable area of 50,000 acres is being considered. Flood control, fish and wildlife conservation, recreation, quality control and pollution abatement, and municipal and industrial water are also being fully evaluated.

A potential of 160,000 acres in Marion and Clackamas Counties is being examined as a part of the plan for the *Molalla Division.* Flood control, fish and wildlife, recreation, water quality control, municipal and industrial water and power are also being evaluated.

The Bureau of Reclamation, in cooperation with other state and Federal agencies, is presently compiling data for the *Willamette River Basin.* Purpose of this study is to formulate plans to meet foreseeable short- and long-term needs with regard to the most effective use of the basin's water and related land resources.

Subbasin No. 6—Coastal

The watersheds of the streams in Tillamook, Clatsop and Columbia Counties flowing directly into the Pacific Ocean are being studied as a part of the *Northern Coast Rivers Project.* This study is a cooperative effort with other Federal, state and local agencies. The Bureau of Reclamation is investigating irrigation and other water-use programs. Although this area has heavy annual rainfall, during the summer months less than one inch per month is recorded over most of the area. In the winter flooding is a serious problem. Storage of the excess winter flows could be released during the summer months to both ease the flooding problem and provide more water for use during the summer.

Subbasin No. 7—Umpqua

The *Olalla Division* of the Umpqua River Project is located in this subbasin. About 14,400 acres of land in Douglas County 15 miles southwest of Roseburg would be served from storage behind a dam on Olalla Creek. Other functions which could be served include fish and wildlife, municipal and industrial water supply, recreation, flood control and water quality control.

The *Azalea Division* of the Umpqua River Project is located in the southern part of Douglas County. The Bureau of Reclamation will investigate various plans to deliver water to about 6,000 acres of land from storage possibilities being investigated by the Corps of Engineers. Other multipurpose functions will be studied.

Subbasin No. 8—Rogue

Four divisions of the Rogue River Basin Project are currently under study. The plan for the *Evans Valley Division* in Jackson County includes a storage dam and reservoir on Evans Creek, a diversion dam and two canals. More than 3,100 acres would be served.

The *Illinois Valley Division* in Josephine County would serve more than 12,000 acres. Storage would be developed on Sucker Creek to serve, in addition to irrigation, recreation and fish and wildlife.

TABLE 54.--POTENTIAL DAMS & RESERVOIRS

Subbasin and Map No.	Name	Stream	Subbasin and Map No.	Name	Stream
Closed Lakes			101	Monument	N. Fk. John Day R.
			102	Rail Creek	John Day R.
1	"P" Ranch	Donner and Blitzen	103	Hall Hill	John Day R.
2	Young	Silvies R.	104	Canyon Creek	Canyon Cr.
3	Lower Silvies Canyon	Silvies R.	105	Four Mile	S. Fk. John Day R.
4	Upper Silvies Canyon	Silvies R	106	Dayville	John Day R.
5	Suntex	Silver Cr.	107	Upper Bear Creek	Bear Cr.
6	Coffee Pot	Chewaucan R.	108	Lower Bear Creek	Bear Cr.
7	Upper Chewaucan	Chewaucan R.	109	Clarno	John Day R.
8	Dry Creek	Dry Cr.	110	Butte Creek	John Day R.
			111	Thirtymile Creek	Thirtymile Cr.
Klamath			112	Upper Rock Creek	Rock Creek
			113	Lower Rock Creek	Rock Creek
9	Sprague River	Sprague R.	114	Eightmile Reservoir	Eightmile Canyon Cr.
10	Sycan River	Sycan R.	115	Big Marsh	Big Marsh Cr.
			116	Black Rock	Crescent Cr.
Snake			117	Crescent Creek	Crescent Cr.
			118	Odell Lake	Odell Cr.
11	Three Forks	Owyhee R.	119	Davis Lake	Davis Lk.
12	Skinner Ranch	Jordan Cr.	120	Big Cultus Lake	Cultus Cr.
13	Duncan Ferry	Owyhee R.	121	Benham Falls	Deschutes R.
14	Upper Sucker Creek	Sucker Cr.	122	Indian Ford	Indian Ford Cr.
15	Lower Sucker Creek	Sucker Cr.	123	Powell	N. Fk. Beaver Cr.
16	Criffield	Sucker Cr.	124	Beaver Creek #1	N. Fk. Beaver Cr.
17	Gesie	Sucker Cr.	125	Beaver Creek #2	Beaver Cr.
18	Issac Ranch	Sucker Cr.	126	Wolf Mountain	Powell Cr.
19	Riverside	S. Fk. Malheur R.	127	Paulina	Beaver Cr.
20	Pine Creek	Pine Cr.	128	Crooked R.	S. Fk. Crooked R.
21	Otis	Otis Cr.	129	Howard Creek	Howard Cr.
22	Juntura	Malheur R.	130	Hudspeth Lake	N. Fk. Crooked R.
23	Little Valley	Malheur R.	131	Big Prairie	N. Fk. Crooked R.
24	Harper	Malheur R.	132	Post	Crooked R.
25	Cottonwood	Cottonwood Cr.	133	Bear Creek	Bear Cr.
26	Lamberson	Bully Cr.	134	Hoffman	Crooked R.
27	Warm Springs	Bully Cr.	135	Suttle Lake	Suttle Cr.
28	McPherson	Willow Cr.	136	Schoolie	Warm Springs R.
29	Golden Eagle	Willow Cr.	137	Wapinitia	Wapinitia Cr.
30	Birch Creek	Birch Cr.	138	Wamic	Wamic Cr.
31	Hardman	S. Fk. Burnt R.	139	Fifteenmile Creek #2	Fifteenmile Cr.
32	Antlers	N. Fk. Burnt R.	140	Larch Creek	Larch Cr.
33	Petticoat	N. Fk. Burnt R.	141	Pine Creek	Pine Cr.
34	Hereford	Burnt R.	142	Dry Creek #2	Dry Cr.
35	Dark Canyon	Burnt R.	143	Mays Canyon	Mays Canyon Cr.
36	Lawrence Creek	Lawrence Cr.	144	Dry Creek #1	Dry Cr.
37	Blue Canyon	Powder R.	145	Fifteenmile Creek #1	Fifteenmile Cr.
38	Bowen	Powder R.	146	Eightmile Creek	Eightmile Cr.
39	North Powder	N. Powder R.	147	Jap Hollow	Jap Hollow Cr.
40	Pilcher Creek	Pilcher Cr.	148	Mosier Creek	Mosier Cr.
41	Lower Wolf Creek	Wolf Cr.	149	East Fork Hood River	E. Fk. Hood R.
42	Park	Beagle Cr.	150	Lake Branch #2	W. Fk. Hood R.
43	Upper Site	Goose Cr.	151	Lake Branch #1	W. Fk. Hood R.
44	Sawmill	Sawmill Cr.	152	Neal Creek	Neal Cr.
45	Mehlhorn Mills	East Pine Cr.	153	Mud Creek	Mud Cr.
46	Sheep Ranch	Grande Ronde R.	154	Meadows	Salmon R.
47	Fly Valley	Fly Cr.	155	Linney	Salmon R.
48	Meadow Creek	Meadow Cr.	156	Little Sandy	Little Sandy R.
49	Upper Grande Ronde	Grande Ronde R.	157	Blazed Alder Creek	Blazed Alder Cr.
50	Lower Grande Ronde	Grande Ronde R.	158	South Fork	Cedar Cr.
51	Catherine Creek	Catherine Cr.	159	Unnamed	N. Scappoose Cr.
52	Little Indian	Little Indian Cr.	160	Upper Youngs River	Youngs R.
53	Indian Creek	Indian Cr.	161	Lower Youngs River	Youngs R.
54	Minam Creek	Minam Cr.			
55	Bear Creek	Bear Cr.	**Willamette**		
56	Lostine River	Lostine R.			
57	Hurricane Creek	Hurricane Cr.	162	Mosby Creek	Mosby Cr.
58	Rondowa	Grande Ronde R.	163	Abrams	Mosby Cr.
59	Elbow Creek	Grande Ronde R.	164	Disston	Row R.
60	Wenaha	Grande Ronde R.	165	Silk Creek	Silk Cr.
61	Troy	Grande Ronde R.	166	Natron #1	M. Fk. Willamette R.
62	Chico	Joseph Cr.	167	Three Sisters	Separation Cr.
63	Coverdale	Imnaha R.	168	Horse Creek	Horse Cr.
64	Saddle Creek	Imnaha R.	169	Foley Ridge	McKenzie R.
65	Pleasant Valley	Snake R.	170	Paradise	McKenzie R.
66	Appaloosa	Snake R.	171	Nimrod	McKenzie R.
67	Low Mountain Sheep	Snake R.	172	Rennie	McKenzie R.
68	High Mountain Sheep	Snake R.	173	Eugene Power Site #3	McKenzie R.
69	Nez Perce	Snake R.	174	Gate Creek	Gate Cr.
			175	Thurston	McKenzie R.
Columbia			176	Mohawk #1	Mohawk R.
			177	Mohawk	Mohawk R.
70	Cottonwood Creek	Cottonwood Cr.	178	Bunker Hill	Coyote Cr.
71	Harris Alternate	S. Fk. Walla Walla R.	179	Simonsen Road	Coyote Cr.
72	Harris	S. Fk. Walla Walla R.	180	Coyote Creek	Coyote Cr.
73	Couse Creek	Couse Cr.	181	Teng's	Spencer Cr.
74	Joe West	Walla Walla R.	182	Hanson's	Spencer Cr.
75	Pine Creek #3	Pine Cr.	183	Log Pond	Elk Cr.
76	Ryan Creek	Umatilla R.	184	Poodle Creek	Poodle Cr.
77	Gibbon	Umatilla R.	185	Smith	Long Tom R.
78	Thornhollow	Umatilla R.	186	Holley	Calapooia R.
79	Misson	Umatilla R.	187	Tum Tum	Tum Tum R.
80	Wildhorse Creek	Wildhorse Cr.	188	Wren	Marys R.
81	Greasewood Creek	Greasewood Cr.	189	Unnamed	Luckiamute R.
82	Tutuilla Creek	Tutuilla Cr.	190	Vincent Creek	Vincent Cr.
83	McKay Creek	McKay Cr.	191	Hoskins	Luckiamute R.
84	East Birch Creek	E. Birch Cr.	192	Unnamed	Ritner Cr.
85	West Birch Creek	W. Birch Cr.	193	Pedee	Luckiamute R.
86	Stage Gulch #1	Stage Gulch	194	Lewisville	Little Luckiamute R.
87	Butter Creek #3	N. Fk. Butter Cr.	195	Unnamed	Teal Cr.
88	Butter Creek #1	N. Fk. Butter Cr.	196	Patterson	South Santiam R.
89	Sanford Canyon	Juniper Canyon Cr.	197	Cascadia #1	South Santiam R.
90	Sixmile Canyon #2	Sixmile Canyon Cr.	198	Wiley Creek	Wiley Cr.
91	Carty West	Sixmile Canyon Cr.	199	Waterloo #1	South Santiam R.
92	Carty East	Sixmile Canyon Cr.	200	Waterloo #3	South Santiam R.
93	Rhea Creek #3	Rhea Cr.	201	Onehorse Slough	Onehorse Cr.
94	Rhea Creek #2	Rhea Cr.	202	Sawmill Site	Crabtree Cr.
95	Heppner	Willow Cr.	203	Thomas Creek	Thomas Cr.
96	Eightmile	Rock Creek	204	Jordan	Thomas Cr.
97	Nelson Meadows	Camas Cr.	205	Mowich and Duffey Lakes	N. Santiam R.
98	Camas Creek	Camas Cr.	206	Marion Lake	Marion Cr.
99	Snipe Creek	Snipe Cr.	207	Tunnel	N. Santiam R.
100	Fox	Fox Creek	208	Byars Creek	Breitenbush R.

RULE

RESERVOIRS

Subbasin Map No.	Name	Stream	Subbasin and Map No.	Name	Stream
209	Elkhorn	Little N. Santiam R.	317	Fall Creek	Fall Cr.
210	Unnamed	Little N. Santiam R.	318	Tioga	S. Fk. Coos R.
211	Miller	Mill Cr.	319	Tioga Fork	S. Fk. Coos R.
212	Unnamed	Beaver Cr.	320	Lower Sitkum	E. Fk. Coquille R.
213	Unnamed	Battle Cr.	321	Fairview Valley	N. Fk. Coquille R.
214	Dallas	Rickreall Cr.	322	Middle Fk. Coquille R.	M. Fk. Coquille R.
215	Unnamed	Rogue R.	323	Camas Valley	M. Fk. Coquille R.
216	Cedar Creek	South Yamhill R.	324	Rock Creek	Rock Cr.
217	Agency	South Yamhill R.	325	Myrtle Point	Coquille R.
218	Lower Fort Yamhill	South Yamhill R.	326	Fourmile Creek	Fourmile Cr.
219	Unnamed	Cosper Cr.	327	Eden Ridge	S. Fk. Coquille R.
220	Unnamed	Gold Cr.	328	Lookhart	S. Fk. Coquille R.
221	Wallace Bridge	South Yamhill R.	329	Avery Ranch	Sixes River
222	Gorge	Mill Cr.	330	Crew Canyon	Euchre Cr.
223	Unnamed	E. Fk. Willamina Cr.	331	Lower Chetco River	Chetco R.
224	Buck Hollow	Willamina Cr.	332	Winchuck River	Winchuck R.
225	Lower Willamina Creek	Willamina Cr.			
226	Upper Muddy Creek	Muddy Cr.	Umpqua		
227	Unnamed	Salt Cr.			
228	Unnamed	Ash Swale	333	Jackson Creek	Jackson Cr.
229	Unnamed	Trib. of N. Yamhill R.	334	Tiller	S. Umpqua R.
230	Lower Pike	N. Yamhill R.	335	Deer Butte	Elk Cr.
231	Moores Valley	Haskins Cr.	336	Galesville	Cow Cr.
232	Palmer Creek	Palmer Cr.	337	Days Creek	S. Umpqua R.
233	Coleman	Pudding R.	338	Unnamed	S. Myrtle Cr.
234	Victor Point	Drift Cr.	339	Unnamed	N. Myrtle Cr.
235	Silvercrest	Silver Cr.	340	Olalla	Olalla Cr.
236	Grange	Silver Cr.	341	Lookingglass	Lookingglass Cr.
237	Lower Meridian	Silver Cr.	342	Deer Creek	Deer Cr.
238	Unnamed	Abiqua Cr.	343	Cavitt Creek	Cavitt Cr.
239	Scotts Mills	Butte Cr.	344	Unnamed	Little R.
240	Rock Creek	Rock Cr.	345	Copeland	N. Umpqua R.
241	Bee Ranch	Molalla R.	346	Steamboat	N. Umpqua R.
242	Pelkey	Molalla R.	347	Unnamed	Steamboat Cr.
243	North Fork	Molalla R.	348	Boundary	N. Umpqua R.
244	Unnamed	Tualatin R.	349	Clark Ranch	N. Umpqua R.
245	Gastin	Tualatin R.	350	Rock Creek	N. Umpqua R.
246	Scoggins	Scoggins Cr.	351	Unnamed	Rock Cr.
247	Unnamed	Gales Cr.	352	Horseshoe Bend	N. Umpqua R.
248	Glenwood	Gales Cr.	353	Oak Creek	N. Umpqua R.
249	Gales Creek	Gales Cr.	354	Hinkle	Sutherlin Cr.
250	Unnamed	E. Fk. Dairy Cr.	355	Coon Creek	Coon Cr.
251	McKay Creek	McKay Cr.	356	Cassy Creek	Cassy Cr.
252	Shady Brook	McKay Cr.	357	Unnamed	Oldham Cr.
253	Big Bottom	Clackamas R.	358	Unnamed	Calapooya Cr.
254	Upper Austin Point	Collawash R.	359	Williams Creek	Willaims Cr.
255	Lower Austin Point	Clackamas R.	360	Unnamed	Elk Cr.
256	South Fork	Clackamas R.	361	Elk Creek	Elk Cr.
257	Unnamed	Eagle Cr.	362	Bully Creek	Bully Cr.
			363	Camp Creek	Camp Cr.
tal			364	Loon Lake	Lake Cr.
			365	Lower Lake Creek	Lake Cr.
258	Rock Creek #2	Rock Cr.	366	Unnamed	Smith R.
259	Clear Creek	Nehalem R.			
260	Pebble Creek	Pebble Cr.	Rogue		
261	Rock Creek #1	Rock Cr.			
262	Crooked River	Crooked R.	367	Lewis Creek	Rogue R.
263	Deer Creek	Deer Cr.	368	McNeil	Big Butte Cr.
264	Deep Creek	Deep Cr.	369	Elk Creek	Elk Cr.
265	Fishhawk Creek #1	Fishhawk Cr.	370	Trail Creek	Trail Cr.
266	Fishhawk Creek #2	Fishhawk Cr.	371	Debenger Gap	Rogue R.
267	Squaw Creek	Nehalem R.	372	Reese Creek	Reese Cr.
268	Tideport	Nehalem R.	373	Lake Creek	L. Butte Cr.
269	Buster Creek	Buster Cr.	374	Brownsboro	L. Butte Cr.
270	Elsie	Nehalem R.	375	Antelope Creek	Antelope Cr.
271	N - Z	Nehalem R.	376	Clawson	Emigrant Cr.
272	Spruce Run	Nehalem R.	377	Hull Mountain	Evans Cr.
273	Salmonberry	Nehalem R.	378	Upper Evans	Evans Cr.
274	Lost Creek	Lost Cr.	379	Evans Valley	Evans Cr.
275	Nehalem Falls	Nehalem R.	380	Carberry Creek	Carberry Cr.
276	Gods Valley	N. Fk. Nehalem R.	381	McKee Bridge	Applegate R.
277	North Fork Nehalem River	N. Fk. Nehalem R.	382	Yale	Little Applegate R.
278	Miami River	Miami R.	383	Little Applegate	Little Applegate R.
279	Kilchis River	Kilchis R.	384	Ruch	Applegate R.
280	Cedar Creek	Wilson R.	385	Applegate	Applegate R.
281	City of Hillsboro	M. Fk.-N. Fk. Trask R.	386	Williams Creek	Williams Cr.
282	Elkhorn Creek	Elkhorn Cr.	387	Slate Creek	Slate Cr.
283	Clear Creek	N. Fk. Trask R.	388	Sexton	Jump off Joe Cr.
284	Keyhole	N. Fk. Trask R.	389	Pease Bridge	Grave Cr.
285	Bark Shanty	N. Fk. Trask R.	390	Indian Hill	Wood Cr.
286	T - 2	N. Fk. Trask R.	391	Althouse Creek	Althouse Cr.
287	East Fork Trask River	E. Fk. Trask R.	392	Sucker Creek	Sucker Cr.
288	Hollywood	S. Fk. Trask R.	393	Deer Creek	Deer Cr.
289	Ginger Peak	Trask R.	394	Eight Dollar	Illinois R.
290	City of McMinnville	Nestucca R.	395	Copper Canyon	Rogue R.
291	Nestucca R.	Nestucca R.			
292	Blaine	Nestucca R.			
293	Beaver Creek	Beaver Cr.			
294	Three Rivers	Three R.			
295	Little Nestucca River	Little Nestucca R.			
296	Unnamed	Salmon R.			
297	Unnamed	Drift Cr.			
298	Falls #1	Siletz R.			
299	Valsetz	S. Fk. Siletz R.			
300	Sunshine Cr.	Siletz R.			
301	Unnamed	Sams Cr.			
302	Unnamed	N. Fk. Beaver Cr.			
303	Trout Creek	Drift Cr.			
304	Unnamed	N. Fk. Alsea R.			
305	Unnamed	Peak Cr.			
306	South Fork	S. Fk. Alsea R.			
307	Scott Mountain	Alsea R.			
308	Unnamed	N. Fk. Indian Cr.			
309	Triangle Lake	Lake Cr.			
310	Unnamed	S. Fk. Siuslaw R.			
311	Unnamed	Wolf Cr.			
312	Austa	Siuslaw R.			
313	Unnamed	Maple Cr.			
314	Lower Gould	W. Fk. Millicoma R.			
315	Golden Falls	Glen Cr.			
316	Falls	Mateon Cr.			

Studies are also underway for the *Medford Division* in Jackson County. About 30,000 acres would receive a full or supplemental water supply from the Corps of Engineers' authorized storage on Rogue River and on Elk Creek. Other possible water use functions are being considered.

The Corps of Engineers is considering a dam and reservoir in the upper reaches of the Applegate River. The Bureau of Reclamation's plan for the *Applegate Division* would use this stored water for irrigation by pumping reservoir releases to the irrigable lands.

SOURCE OF WATER

Many potential dam and reservoir sites are located in Oregon. Figure 100 shows the location of the known major sites. Table 54 presents data on each site.

NAVIGATION AND FLOOD CONTROL

Oregon has a continuing need of and potential for additional flood control and navigation projects. Even with construction of major flood control projects, flood damages are continuing to increase.

Floods which start on small tributary streams frequently develop into devastating proportions in the larger rivers. Often towns, cities, industrial areas, and thousands of acres of fertile farmland are inundated and the loss of property is tremendous.

There is a need to provide basic information to counties and cities for their consideration in examining land use regulations as a possible means to mitigate flood damages.

The 53rd Oregon Legislative Assembly authorized and appropriated funds to the State Water Resources Board to initiate flood plan identification studies. These reports are to provide a factual basis for local governments in planning the use or regulation of flood plains.

However, on occasion, adequate flood control and flood fighting may be beyond the reach of the affected property owners or even the local governmental agencies. In addition to its other activities, the Corps of Engineers is charged with the responsibility for certain flood emergencies.

When a need or condition of improvement is required in connection with flood control or river and harbor facilities, and local interests are unable to remedy the situation themselves, it is appropriate for those involved to request, through their Congressional delegation, the Corps of Engineers to investigate the feasibility and economics of correcting the situation.

Oregon has at present 25 port agencies. Along its coast and on its inland navigable waters, inspection, improvement and maintenance is continuing to provide safe and efficient access to coastal and inland ports.

There are a number of potential navigation and flood control projects underway or authorized in Oregon. Figure 101 and table 55 locate and present data for these projects.

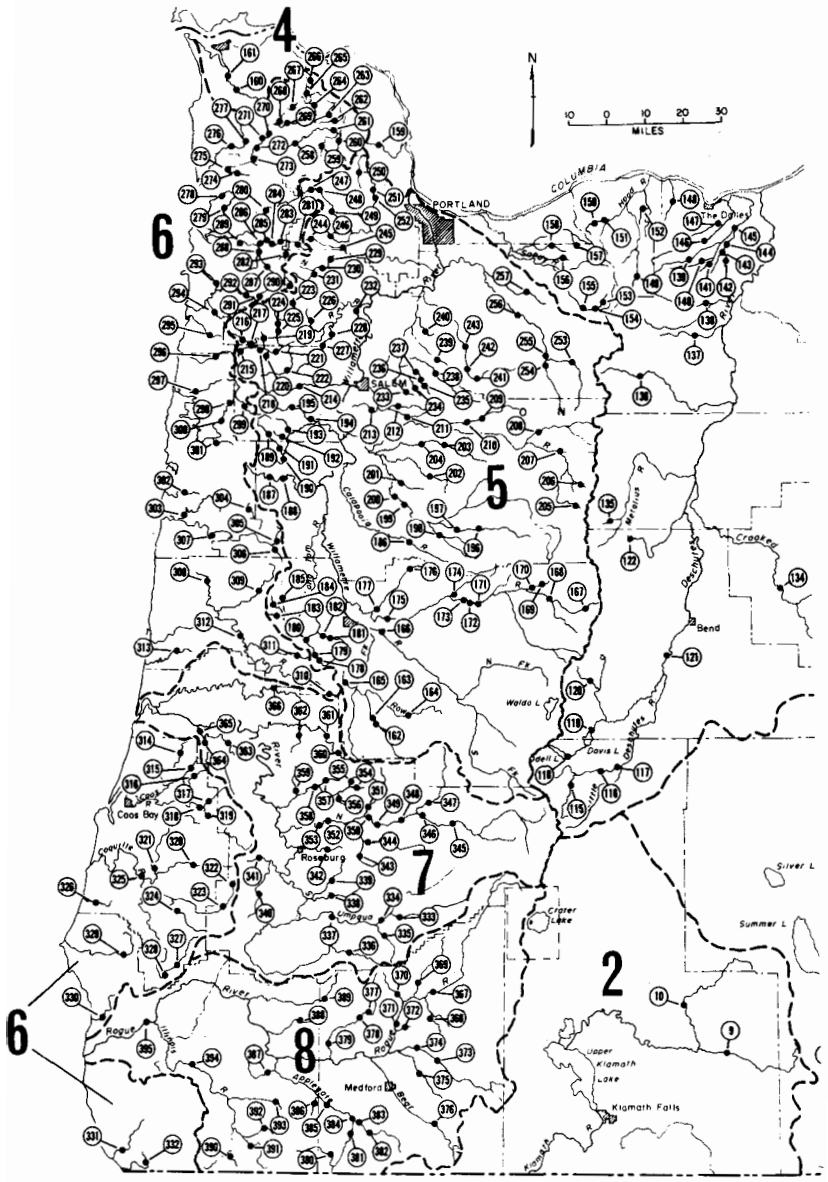

FIGURE 100.—Potential dams and reservoirs.

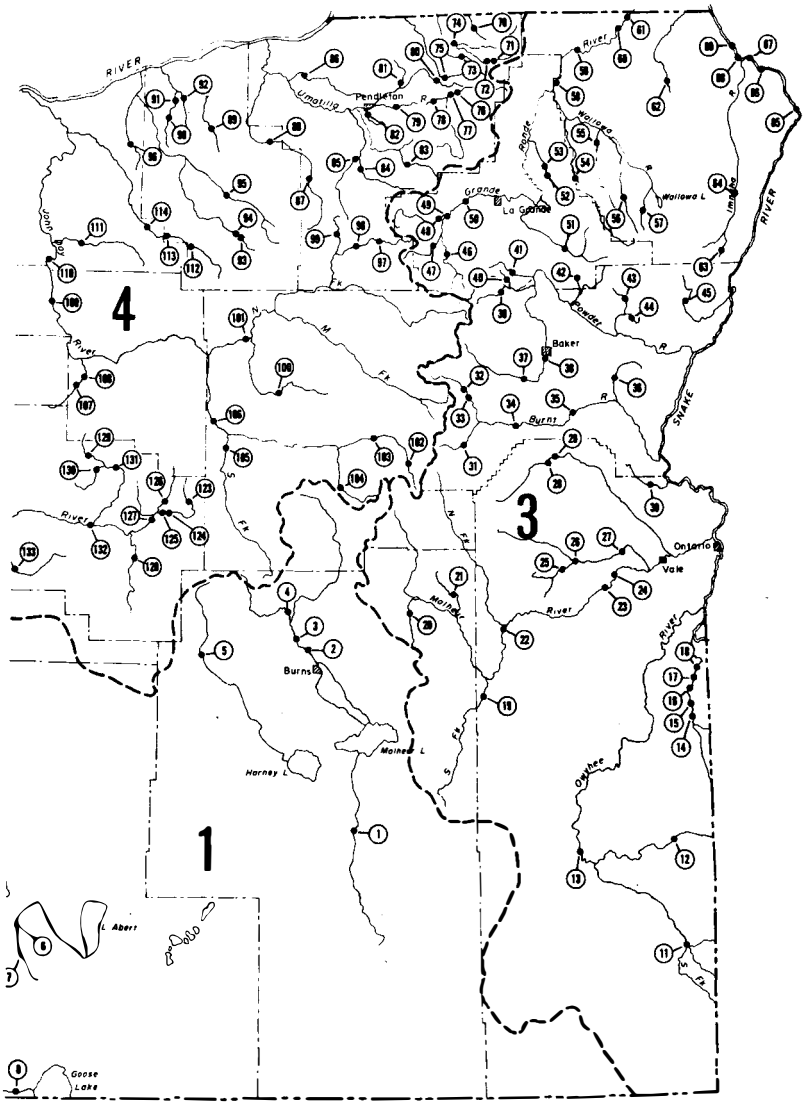

FIGURE 100—Continued

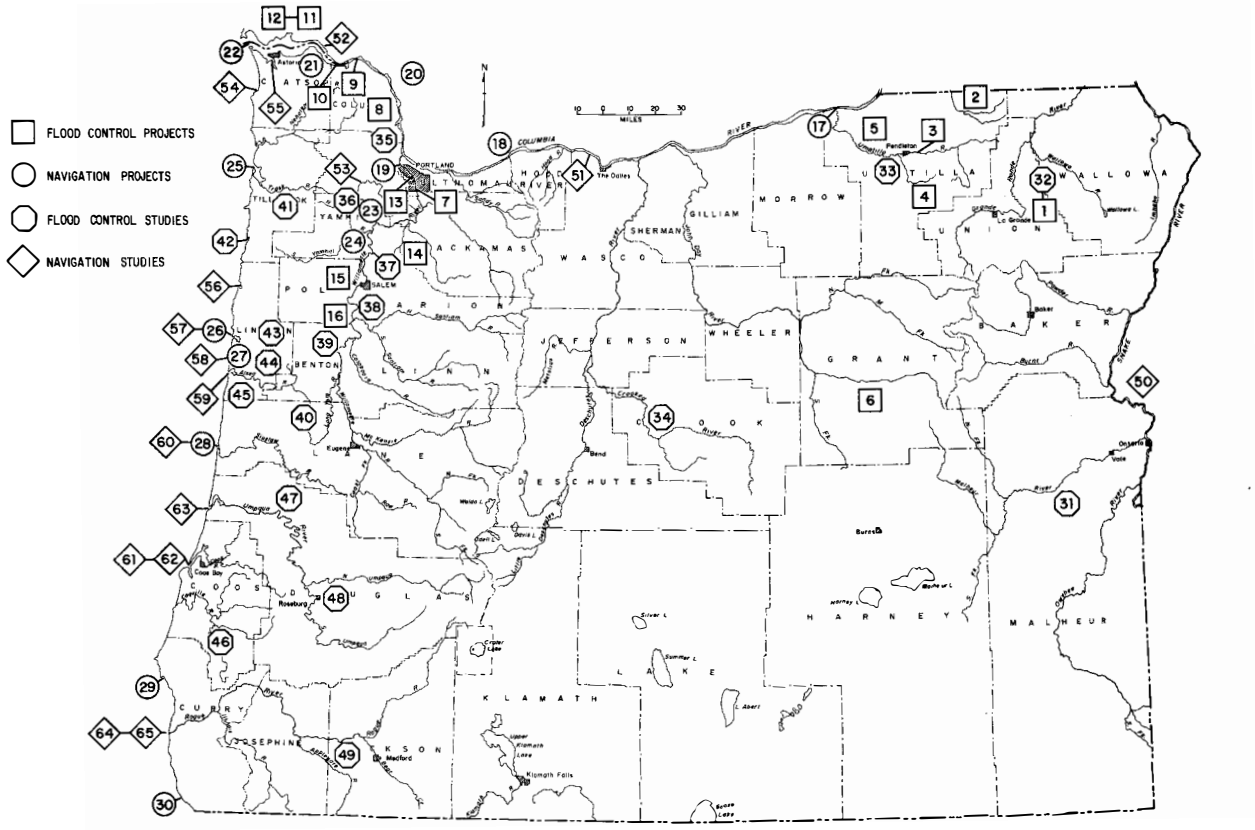

FIGURE 101.—Potential navigation and flood control development.

TABLE 55.—FLOOD CONTROL AND NAVIGATION PROJECTS UNDERWAY OR AUTHORIZED (OTHER THAN STORAGE)

FLOOD CONTROL PROJECTS

Map No.	Subbasin	Name	Principal features	Remarks
1	Snake	Grande Ronde Valley	Levees, channel clearing and straightening	Reclassified from active to restudy.
2	Columbia	Milton-Freewater	Levees and channel improvements to existing project	Plans and specifications have been completed.
3	do	Pendleton-Riverside Area	Extension of existing channel and levee project	Deferred; lack of local interest.
4	do	Pilot Rock, Birch Creek	Channel improvements, levees and revetments	Inactive.
5	do	Umatilla River-Echo Area	Channel rectification, levees, bank protection	Inactive; lack of local interest.
6	do	John Day River	Channel improvement, revetments, retaining walls, levees.	Project inactive because of lack of local interest.
7	do	Johnson Creek	Channel clearing, bank protection and bypass channel	Funds appropriated; need for a local sponsor.
8	do	Lower Columbia River at Hayden Island and Clatskanie River.	Levees, floodwalls, tide boxes and pumping plants	Inactive.
9	do	Beaver Drainage District	Improvements to the existing flood protection works	Preconstruction planning underway.
10	do	Midland Drainage District	do	Do.
11	do	Lower Columbia River	Improvements of existing works, new levees, strengthening of existing levees, additiional pumping plant capacity, tide boxes for drains ditches.	Project authorized, portions have been reclassified or deferred.
12	do	Lower Columbia River Bank Protection Works	Bank protection works, flood control	Work is underway.
13	Willamette	Floodwalls and Levees at Portland	Raising streets, building levees, flood walls, tide boxes and pumping plants.	Project is inactive.
14	do	Pudding River	Flood control and drainage facilities	Inactive.
15	do	Willamette River Basin Bank Project	Bank protection and channel clearing	Project authorized.
16	do	Channel Improvements for Flood Control and Major Drainage.	Tile drains, 16 streams tributary to the Willamette River.	The projects are inactive or have been deferred for further study.

TABLE 55.—FLOOD CONTROL AND NAVIGATION PROJECTS UNDERWAY OR AUTHORIZED (OTHER THAN STORAGE)—Continued

NAVIGATION PROJECTS

Map No.	Subbasin	Name	Principal features	Remarks
17	Columbia	Umatilla Harbor	Improvement of an existing harbor by removal of rocks	Project inactive because of increase in John Day Reservoir pool resolving problem.
18	do	Indian Fishing Grounds, Restoration	Campsites, land acquisition	To replace fishing areas destroyed by construction of Bonneville Dam.
19	do	Columbia Slough	7.7-mile channel from mouth of Willamette to Union Avenue.	Project authorized.
20	Columbia-Willamette	Columbia River and Lower Willamette	Channel rehabilitation and enlargement	Project 32 percent complete at end of fiscal year 1966.
21	Columbia	Westport Slough	Ship channel (alternate route)	Project inactive.
22	do	Columbia River at mouth	Channel across the bar, jetties, dikes	Traffic was 14,779,200 tons in 1964.
23	Willamette	Willamette Falls	Lock and lift system enlarged	Project authorized, construction not underway.
24	do	Willamette River above Portland and Yamhill River.	Channel deepening and construction	Project is 37 percent complete.
25	Coastal	Tillamook Bay and Bar	Extending existing jetty	Work is underway.
26	do	Yaquina Bay and Harbor	Jetty extension, deepening and widening of channel and turning basin.	Do.
27	do	Yaquina River Channel Improvement	Navigation channel and turning	Awaiting construction funds.
28	do	Siuslaw River and Bar	Extending jetty, dredging and deepening channel	Preconstruction planning in progress.
29	do	Port Orford	Extension of existing breakwater	Do.
30	do	Chetco River	Harbor entrance, jetty extension, turning basin, dike, small boat channel.	Preconstruction planning is underway.

The Corps of Engineers is also studying or has been authorized to study a number of navigation and flood control and water conservation projects. Figure 101 also shows the location of these studies. Information about them is contained in table 56.

The potential flood control projects under Public Law 566 are shown in figure 95 and table 52.

RECREATION

Even with its excellent existing recreation areas and facilities, Oregon has a continuing need for additional recreational development. The State has a uniquely beautiful and rugged coastline; additional stretches should be preserved as parks and beaches. Additional recreation areas are needed in the majestic Cascade Range. A shortage of easily accessible day- and weekend-use parks and recreation areas exists near the Portland urban area and in eastern Oregon. Consideration should be given to the establishment of a free-flowing condition in stretches of certain rivers. In addition, canoe trails, parkways and scenic routes should be established. Increased protection is needed for the State's archeological sites.

More than 113,000 acres are listed as potential state recreation areas; much of this is in eastern Oregon not readily accessible to large urban areas. Additional state and local recreation areas will be needed to serve the lar er urban areas.

The following recommendations for recreation opportunities in Oregon were made by the U.S. Department of the Interior's National Park Service in a 1964 report:

National.—Establishment of the proposed Oregon Dunes National Seashore and study of the desirability of establishing a Rogue National River.

State.—Enlargement of the state park system by adding 1,670 acres to three existing parks and the addition of two new parks, four recreation areas, and eight beaches; also further study of five other potential parks, eight recreation areas, five scientific monuments, five historic monuments, two nature preserves, and four scenic roads. Designation and protection of a state parkway, five free-flowing streams, and one canoe trail on the Rogue River. Further study of 11 canoe trails and the Pacific Coast Foot Trail.

Local.—Establishment of additional county and municipal parks, recreation areas, and beaches. Recommended are one park, three recreation areas, and one beach. Further study is needed on 11 recreation areas.

Supporting recommendations include:

1. Broadening the present policy which tends to limit establishment of new state parks to along highways. This would permit expansion of the system to include all areas of statewide significance regardless of location. Those small state parks which are not logical units of the stat park system might be transferred to other appropriate jurisdiction.

2. A study to determine the possibility of developing a hiking trail along the Oregon coast. This could be one of the outstanding trails in the country.

3. Provision of additional recreation facilities at nine important reservoirs.

TABLE 56.—FLOOD CONTROL AND NAVIGATION STUDIES UNDERWAY OR AUTHORIZED (OTHER THAN STORAGE)

FLOOD CONTROL STUDIES

Map No.	Subbasin	Name	Principal features	Remarks
31	Snake	Malheur River and Tributaries	Levees, channel improvements, storage	Report due fiscal year 1968.
32	do	Grande Ronde River	Flood control works including storage	Awaiting further appropriations.
33	Columbia	McKey Creek	Levees, channel improvements, storage	Study presently deferred.
34	do	Crooked River	Channel clearing, bank protection	Deferred for restudy.
35	do	Lower Columbia River and Tributaries	Improvements to existing works and new works	Report due in 1970 or 1971.
36	Willamette	Washington County	Flood plain information study	Report due in fiscal year 1969.
37	do	Interim flood plain reports	Information gathered at request of State Water Resources Board.	Need for this type of data because of 1964 Christmas flood.
38	do	Willamette Basin Review	Report to coordinate data from all water resource agencies.	State and Federal effort.
39	do	Mid-Willamette	A flood plain information study	Report due fiscal year 1968.
40	do	Lane County	Flood plain information study	Reports finished fiscal year 1967.
41	Coastal	Nehalem, Miami, Kilchis, Wilson, Trask and Tillamook Rivers.	Flood protective and control works	Studies to be completed fiscal year 1968.
42	do	Nestucca River	Flood protective works	Study completed 1967.
43	do	Yaquina River	Drainage and flood control	Study to be completed 1968.
44	do	Beaver Creek	do	Study completed 1967.
45	do	Alsea River	Flood control works	Report under consideration.

46	____do	Coquille River	____do	Study completed 1967.
47	Umpqua	Umpqua River	Water resource needs of the basin	Do.
48	____do	Interim flood plain report	Information gathered at request of State Water Resources Board.	Need for this type of data because of 1964 Christmas flood.
49	____do	____do	____do	Do.

NAVIGATION STUDIES

50	Snake	Snake River downstream from Weiser	Removal of shoals, enlarging channel	Awaiting construction funds.
51	Columbia	Mayer State Park	Small boat access channel	Awaiting study funds.
52	____do	Beaver Slough	Channel improvement dredging	Report work discontinued.
53	Willamette-Columbia	Willamette and Columbia River, Fisher Island to Barlow Point.	Navigation channel	Awaiting study funds.
54	Coastal	Seaside Harbor	Small boat basin	Report due fiscal year 1970.
55	____do	Youngs Bay and River	Lewis and Clark connecting channel	Project under consideration.
56	____do	Siletz River	Jett construction, small boat basin	Awaiting action by local interest.
57	____do	Yaquina Bay and Harbor	Small boat basin	Reconnaissance report underway.
58	____do	Yaquina River	Navigation channel	Report under consideration.
59	____do	Alsea Bay and River	Small boat basin	Requested by local interests.
60	____do	Siuslaw River	Navigation channel	Investigation underway.
61	____do	Coos Bay, South Slough	Channel extension, small boat basin enlargement	Presently under study.
62	____do	Coos Bay	Bar and bay channel improvement	Report due fiscal year 1968.
63	Umpqua	Umpqua River	Enlarging channel entrance	Study held in abeyance at request of local interest.
64	Rogue	Rogue River	North jetty extension	Report due fiscal year 1969.
65	____do	____do	Small boat basin at Gold Beach	Report under study.

The Bureau of Land Management has an active recreation program on lands under its jurisdiction in Oregon. The Oregon and California lands and the areas in eastern Oregon offer additional opportunities for recreation development. A survey of all BLM lands has been completed and several sites have been identified for future recreation development.

Figure 102 and table 57 locate and present pertinent data for potential recreation areas in Oregon.

Summary

Oregon, the "Beaver State," is a land of infinite variety. From sea level to the top of Mt. Hood, from the wind- and rain-swept coast to the driest desert, Oregon is tremendously endowed with scenic beauty and recreational opportunities. It is rich in the natural resources of land, water, timber, minerals, flora and fauna.

These abundant resources in conjunction with the continually expanding demand for goods and services make possible a diversity of conscientious resource development and use that is outstanding among states of the United States.

The development of the water and related land resources of the Pacific Northwest, with the Columbia River System as its core, is one of the world's greater undertakings of its kind. The attention of planners, economists, engineers, politicians, and the general public of this and many other countries has been attracted for many years to this development.

A great amount of planning and study remains to be accomplished. There is a need for overall land use planning according to character, quality and location, and to the needs of people in their expanding urban and rural uses. The material needs are fundamental and real; regional land use planning should include: new cropland for the increase in population and for replacement of withdrawn lands; new areas for fish and wildlife; additional land for community, urban, and industrial uses; new areas for recreation and related purposes; land for mineral resources development; land for forest and range; and areas for open space. Uses and demands for outdoor recreation, for example, under the cumulative effects of added population, disposable income, leisure time, and mobility, are expanding at rates far above those of population alone.

Approximately 1,608,000 or 20 percent, of the 8,040,000 acres of land in Oregon having some degree of irrigation potential were irrigated in 1964. Most of these irrigated lands are located east of the Cascades; this area also has the greatest degree of irrigation potential.

An area of great irrigation potential west of the Cascades is the Willamette Valley. Most of the present development in the Willamette is in scattered small blocks developed largely through the efforts of private enterprise. In the near future, large-scale, multiple-purpose projects with storage and distribution facilities to serve thousands of acres will be a reality in the Willamette Valley.

Resource planners for the present and future are particularly concerned with the ramifications of more rational and efficient uses of available water in relation to arable land. Prospective means include:

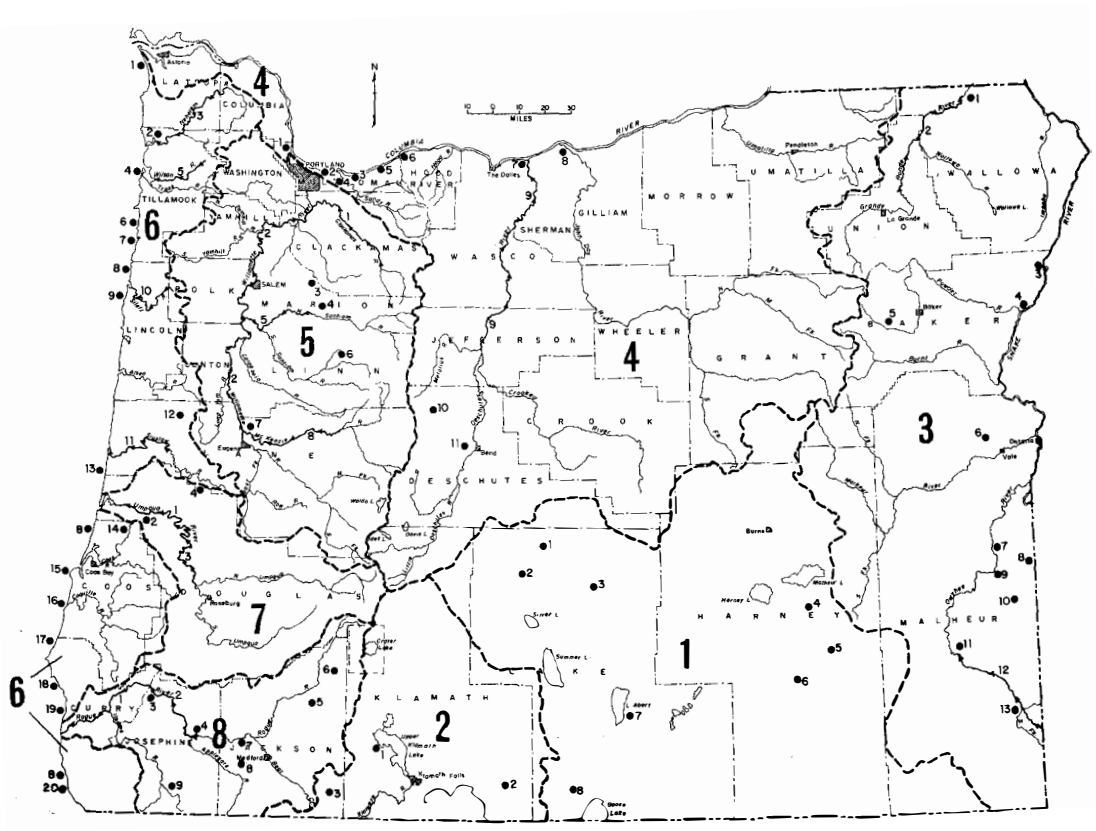

FIGURE 102.—Potential recreation areas.

TABLE 57.—RECREATION AREAS, OREGON—POTENTIAL

Subbasin	Acreage		Type of use				Activities									
	Total land area	Water surface	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness
CLOSED LAKES																
1. Devils Garden Monument	1,000		X				X	X						X		
2. Fort Rock Cave Historic	10		X													
3. Lost Forest State Park	5,000		X	X			X	X	X					X		
4. Diamond Craters Monument	15,000		X				X	X	X					X		
5. Steens Mountains Park	10,000	S	X	X			X	X	X							X
6. Steens Mountain Road	[1] 70		X													
7. Abert Rim Monument	5,000		X					X	X							
8. Drews Reservoir Recreation Area	160	4,600	X	X			X		X	X	X	X				
KLAMATH																
1. Upper Klamath Reservoir	120	68,200	X	X			X		X	X	X	X				
2. Gerber Reservoir	44	2,250	X				X		X	X	X	X				
3. Hyatt Prairie Recreation Area	200	900	X	X			X		X	X	X	X				
SNAKE																
1. Wenaha Reservoir Recreation Area	80	M	X	X			X		X	X	X	X				
2. Grande Ronde River Canoe Trail	[1] 97		X	X	X				X	X		X				
3. Oxbow Reservoir Park	40	L	X	X			X		X	X	X	X				
4. Powder River Recreation Area	10	15,000	X				X		X	X	X	X				
5. Mason Reservoir Park	250	2,450	X				X		X	X	X	X				
6. Bully Creek Reservoir Park	120	980	X				X		X	X	X	X				
7. Honeycombs State Park	2,000	12,742	X	X			X	X	X	X	X	X				
8. Sucker Creek State Park	1,000		X				X	X	X							
9. Leslie Gulch State Park	2,000	12,742	X	X			X	X	X	X	X	X				
10. Mahogany Mountain Preserve	5,000		X				X	X	X					X		
11. Jordan Craters Monument	39,910	560	X	X				X	X					X		X
12. Owyhee River (free flowing)	[1] 60	S	X							X		X				
13. Three Forks of Owyhee Monument	10,000	S	X	X				X	X	X						X

COLUMBIA																
1. Sauvie Island Recreation Area	100	M	X				X		X	X		X				
2. New Market Theater Historic	1		X													
3. Government Island Beach	1,850		X				X		X	X	X	X				
4. Sandy Oxbow Recreation Area	600		X				X	X	X	X	X	X				
5. Columbia Gorge Recreation Area	500		X	X	X		X	X	X	X	X	X				
6. U.S. 30 Parkway	[1] 80		X			X										
7. Deschutes (free flowing)	80	9,400	X			X	X		X	X	X	X				
8. John Day River (free flowing)	40		X			X		X			X					
9. Deschutes River Canoe Trail		[1] 85	X							X		X				
10. U.S. 126	[1] 80		X			X										
11. Century Drive	[1] 40		X													
WILLAMETTE																
1. Clackamas River Canoe Trail	[1] 50		X	X					X	X		X				
2. Willamette River Canoe Trail	[1] 165		X						X	X		X				
3. Butte Creek Falls Nature Area	280		X				X	X	X			X		X		
4. Little North Santiam Recreation Area	40		X	X			X		X	X	X	X				
5. Santiam River Canoe Trail	[1] 45		X	X					X	X		X				
6. Green Peter Reservoir Park	120	3,610	X				X		X	X	X	X				
7. McKenzie River (free flowing)		[1] 52	X							X		X				
8. McKenzie River Canoe Trail		[1] 52	X	X	X				X	X		X				
COASTAL																
1. Clatsop Plains Recreation Area	1,400		X	X	X		X	X	X		X	X				
2. U.S. Highway 101	[1] 390		X			X										
3. Nehalem Canoe Trail		[1] 53	X	X					X	X		X				
4. Tillamook Sandspit Beach	500		X	X			X	X	X		X	X				
5. Wilson River Canoe Trail		[1] 40	X						X	X		X				
6. Sand Lake Recreation Area	1,650	S	X	X			X	X	X		X	X				
7. Nestucca Sandspit Beach	900		X	X			X	X	X		X	X				
8. Pacific Coast Foot Trail	[1] 312		X	X	X			X	X							
9. Siletz Sandspit Beach	375		X	X			X	X	X		X	X				
10. Siletz River Canoe Trail	[1] 45		X						X	X		X				
11. Siuslaw River Canoe Trail	[1] 27		X						X	X		X				
12. Triangle Lake State Recreation Area	37	S	X				X		X	X	X	X				
13. Oregon Dunes Seashore	44,600	4,992	X	X	X	X	X	X	X	X	X	X	X	X		
14. Eel Lake State Recreation Area	40	S	X			X	X		X	X	X	X				
15. Coos Bay Sandspit	2,500		X	X	X		X	X	X	X	X	X				
16. Coquille Beach	1,620		X	X	X		X	X	X		X	X				
17. Langlois Beach	5,760		X	X	X		X	X	X		X	X				
18. Sisters Rock State Park	600		X	X			X	X	X		X	X				
19. Hubbard Mound-Otter Point Beach	400		X	X			X	X	X		X	X				
20. Crooks Point Beach	800		X	X			X	X	X		X	X				

See footnote at end of table.

TABLE 57.—RECREATION AREAS, OREGON—POTENTIAL—Continued

Subbasin	Acreage		Type of use				Activities									
	Total land area	Water surface	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness
UMPQUA																
1. Umpqua River Canoe Trail	[1]125		X	X	X				X	X		X				
2. Smith's Massacre Historic Site	20		X													
3. Umpqua and North Fork (free flowing)		[1]165	X							X		X				
4. Smith River Recreation Area	120		X				X		X		X	X				
ROGUE																
1. Rogue River Canoe Trail	[1]135		X	X	X				X	X		X				
2. Rogue River (free flowing)		[1]65	X							X		X				
3. Rogue River (wild river)	13,000		X	X	X	X	X	X	X	X	X	X				
4. Rogue-Rand Park	100		X				X		X	X	X	X				
5. Upper Rogue State Park	120		X	X			X		X	X	X	X				
6. Mill and Barr Creek Falls Recreation Area	80		X				X	X				X				
7. Raygold Recreation Area	60		X				X		X	X	X	X				
8. Jacksonville Historic Site	S		X													
9. Illinois River Recreation Area	100		X	X			X	X	X	X	X	X				

[1] Miles.

advancing technology in surface and underground water storage, transmission, and application; more efficient use of water; water transfers within and without local drainge basins and irrigation systems; and exchanges of water supplies to permit more efficient development and use of water and land resources.

Oregon has what many consider is the finest State Park system in the United States. This system is continually being expanded to meet the growing demands for outdoor recreation. Recreation developments are also continually being expanded, in the National Forests, on the O & C lands and around the Federal reservoirs. Private recreation developments have and will play an important role in the recreation picture for Oregon.

The harbor of the Pacific coast and the Columbia River provide for substantial water commerce to and from Oregon. Several industries have located at or near these ports. The easy water grade offered by the dam on the Columbia River and Oregon's plentiful water supplies and low-cost industrial power will continue to draw industries to these port districts. Navigation in the coastal harbors and the Columbia River will continually be improved.

The battle against flood damage is a never ending one. In addition to the existing flood control projects, studies are underway to construct new or rehabilitate and expand existing projects throughout the state.

Water resource development in the state will continue to progress. The people of Oregon have learned the value of wise conservation, intelligent development, sustained management, and controlled use of the natural resources. Excellent cooperation among the various development and management agencies from all levels of state, Federal and private enterprise has helped to make the state a mecca for its citizens and for the thousands of tourists who visit each year.

Multiple-purpose planning is of primary importance for the most efficient use and preservation of the resources. The foremost determinant in the development and preservation of the natural resources is the well-being of all the people. The abundance of clean water, fertile land and timbered areas, plus technological advances, will help to meet the future demands for more diversified agricultural production, recreational activities, and employment opportunities in the state of Oregon.

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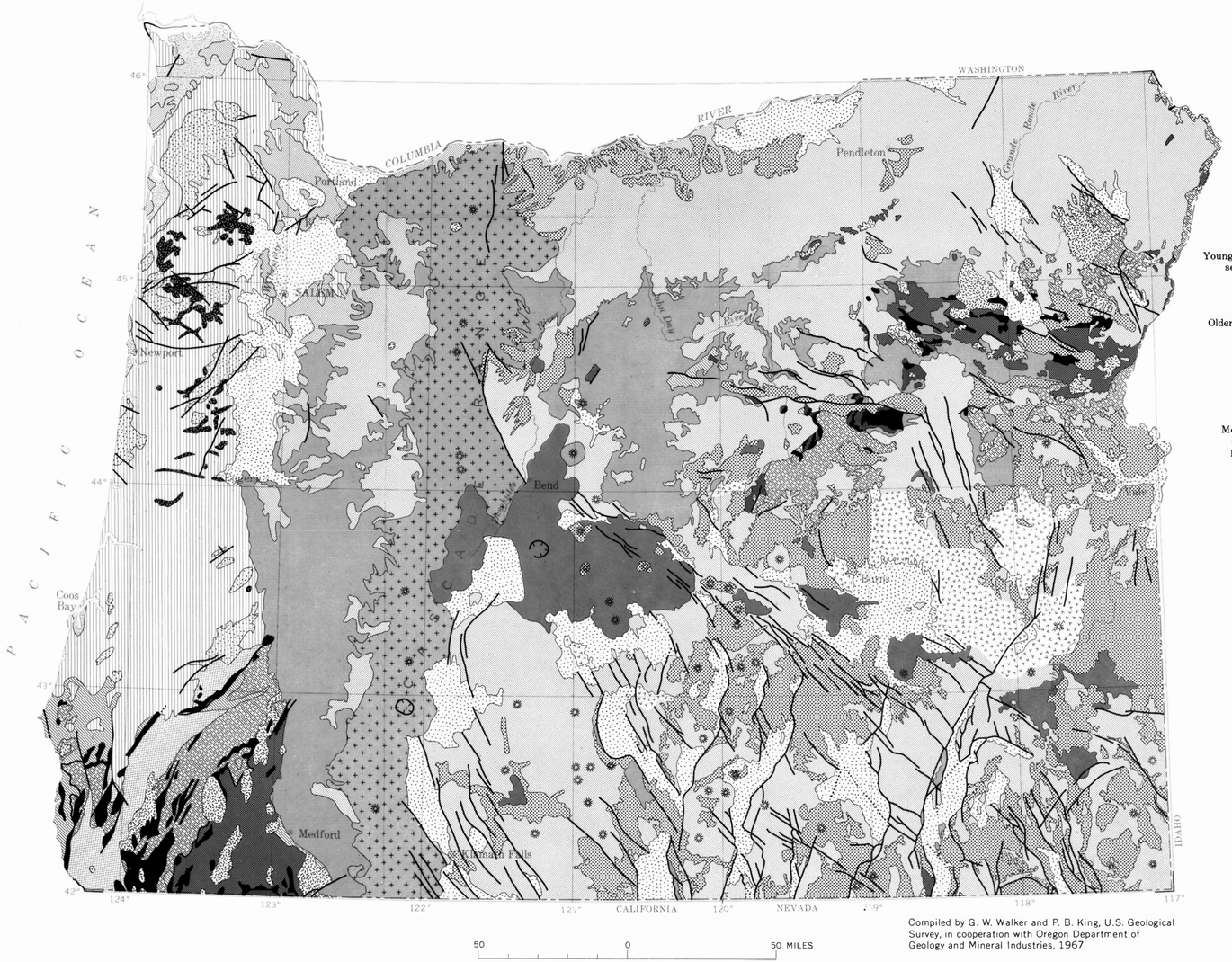

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Compiled by G. W. Walker and P. B. King, U.S. Geological Survey, in cooperation with Oregon Department of Geology and Mineral Industries, 1967

EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

Quaternary alluvium, lake sediments, fluvio-glacial deposits, and pumice

Late Cenozoic basalt and andesite

Andesite and basalt of High Cascade Range

Younger Cenozoic (post-early Miocene) marine sedimentary and minor volcanic rocks

Younger Cenozoic (Miocene and Pliocene) nonmarine (continental) sedimentary rocks, ash-flow tuffs, some interbedded rhyolite flows and domes

Younger Cenozoic (Miocene and Pliocene) basalt and andesite flows and minor continental sedimentary rocks

Younger Cenozoic (Miocene and Pliocene) sedimentary and volcanic rocks, undivided

Older Cenozoic marine and estuarine sedimentary rocks and minor volcanic rocks

Older Cenozoic marine and nonmarine basaltic and andesitic flows and tuffs; includes related intrusive rocks

Older Cenozoic (Eocene, Oligocene, and early Miocene) volcanic and continental sedimentary rocks

Late Mesozoic sedimentary rocks

Mesozoic sedimentary and minor volcanic rocks in southwest Oregon (Dothan Formation). Pre- or post-Nevadan; in places metamorphosed

Mesozoic sedimentary and volcanic rocks older than Kimmeridgian (pre-Nevadan orogeny); in places strongly metamorphosed

Permian and Triassic sedimentary and volcanic rocks; in places strongly metamorphosed

Paleozoic sedimentary rocks; in places strongly metamorphosed

INTRUSIVE IGNEOUS ROCKS

Cenozoic gabbro and diabase

Granitic rocks, chiefly of Mesozoic age

Ultramafic and gabbroic rocks, chiefly of Mesozoic age

Major volcanic vents and domes of Cenozoic age

Large volcanic craters

Contact

Fault, dotted where concealed

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