The Reconnaissance Geology and Mineral Resources of Eastern Klamath County and Western Lake County, Oregon

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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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Department of Geology and Mineral Industries
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By
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FOREWORD

Throughout history minerals have been important to mankind. Our present highly developed civilization could not exist if we were not able to utilize the many mineral products, both metallic and nonmetallic, that are available to us. All forecasts for the future indicate that the need for minerals will continue to increase, if we are to maintain our present standard of living. In the past century our population grew more than 400 percent, but our minerals consumption increased by more than 4000 percent. Today, per-capita demand for minerals in the United States amounts to about $150 per year. By the year 2000, the U.S. Bureau of Mines believes that our per-capita mineral demand will be approximately $420.

There is a large area in south-central Oregon between Klamath Falls and Lakeview where widespread metallic mineralization is known to occur. It is in this region that Oregon's only uranium mine operated during the late 1950's, and there has also been sporadic production of mercury, copper, lead, and zinc. The nonmetallic resources in Klamath and Lake Counties have never been adequately explored, but it is known that there are large deposits of diatomite, pumice, perlite, and peat.

The State of Oregon Department of Geology and Mineral Industries has now completed a geologic study of this area as part of its continuing program of investigating and reporting on the mineral resources of Oregon. The Great Northern Railway and the Pacific Power & Light Co. participated in this project by contributing funds to assist in the field work and to publish this bulletin. Mr. Hollis M. Dole, former State Geologist, initiated the study and coordinated the activities that led to the successful completion of the survey. It is hoped that the information presented in the report will result in the development of new industries for this part of the state as well as provide needed additional mineral resources for the nation's ultimate benefit.

R. E. Corcoran
State Geologist

February 1970

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ABSTRACT

The 6000-square-mile project area in eastern Klamath and western Lake Counties in south-central Oregon is underlain entirely by a thick assemblage of volcanic rocks and of sedimentary deposits derived from them. The rocks range in age from Oligocene to Holocene. In general the oldest rocks, which are predominently andesitic to rhyolitic pyroclastics, occur in the eastern third of the area. The younger rocks are mainly basaltic and cover the western and northern parts of the area.

The most conspicuous structural features are north to northwesterly trending normal faults of large and small displacement that are reflected in the present physiography, which is dominated by northerly trending parallel mountain ranges and valleys. Sometime after this prominent regional fault pattern was initiated, the whole area was folded into broad, low-amplitude anticlines and synclines with northerly axial trends. Quaternary events that have affected the area include explosive volcanic eruptions that resulted in the Big Hole and Hole-in-the-Ground maars and the eruption of the vast blanket of pumice from Mount Mazama.

Mineral resources typical of a region dominated by Cenozoic volcanism are abundant and widespread. The presence of hot springs, hot-water wells, and large areas of anomalously high heat flow are indications that geothermal energy has a promising future for economic development.

Most of the metallic mineral commodities are typical of a shallow, low-temperature origin. Exceptions are copper, lead, zinc, and silver occurring locally in the older rocks in the northeast part of the area where they are associated with a small granitic pluton.

A uranium occurrence north of Lakeview has had the most production in the past and perhaps has the most promise for future use. Mercury mineralization is widespread and occurs with a variety of rock types mainly in the eastern part of the area.

Nonmetallic resources occurring in large quantities and, in most cases, of unknown quality include diatomite, lump pumice and pumicite, perlite, and peat. Of these, diatomite, which occurs extensively in the Klamath Basin, probably has the best future for industrial use.

The building and construction materials such as cinders, scoria, sand, gravel, and stone all occur in sufficient quantities for local use.

The Reconnaissance Geology and Mineral Resources of Eastern Klamath County and Western Lake County, Oregon

By Norman V. Peterson* and James R. McIntyre**

INTRODUCTION

The specific purpose of this study is to assess the economic potential of the mineral resources in a region of approximately 6000 square miles in Klamath and Lake Counties of south-central Oregon. Because of the large size of the area and the limited time available for the project work, the results are of a reconnaissance nature. It is hoped, however, that this report will serve to introduce the area and its resource potential to those who will find it advantageous to proceed further with the evaluation of the more important mineral commodities discussed here. Following this introductory section, the main body of the report is organized under two large headings: 1) Descriptive Geology, and 2) Mineral Resources. Results of the reconnaissance geochemical program conducted by the State of Oregon Department of Geology and Mineral Industries in Klamath and Lake Counties are given in the addendum.

Location, Accessibility, and Culture

The index map (figure 1) delineates the location and limits of the study area. The region is bounded on the south by the California-Oregon state line; on the west by longitude 122°00'; on the north by township 25 S.; and on the east by an angled line to the eastern edge of range 20 E. and thence southward to the California border. A number of large-scale maps are available that provide adequate coverage for the project area. These include U.S. Geological Survey topographic quadrangle maps and U.S. Forest Service planimetric maps.

The area is readily accessible on the west by U.S. Highway 97 and on the east by Oregon State Highway 31 and U.S. Highway 395. It is crossed by State Highway 140, which connects Klamath Falls and Lakeview. In addition, other state highways, county roads, and a very extensive network of U.S. Forest Service and private logging roads serve the interior.

Two railroads, the Great Northern and the Southern Pacific, traverse the west side of the area. A branch line, the Oregon, California & Eastern Railroad, essentially a logging railroad, extends from Klamath Falls eastward to Bly. In addition, a branch of the Southern Pacific Railroad extends northward from California to its termination at Lakeview.

The area is served by electric power from transmission circuits within the Northwest Power Pool. Local power distribution is provided mainly by the Pacific Power & Light Co. Natural gas is available in the west side of the area from a pipeline which parallels U.S. Highway 97.

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The population density of the region as a whole is only about four persons per square mile. Klamath County (1960 census) has a population of about 50,000. Most of its residents live in or adjacent to Klamath Falls, which has a population of about 18,000 and is the county seat. Lake County has a population of about 6500, and approximately 3200 of its residents live in Lakeview, the county seat.

Diversified farming, logging and lumber processing, stock raising, and recreation are the chief industries of the area as a whole.

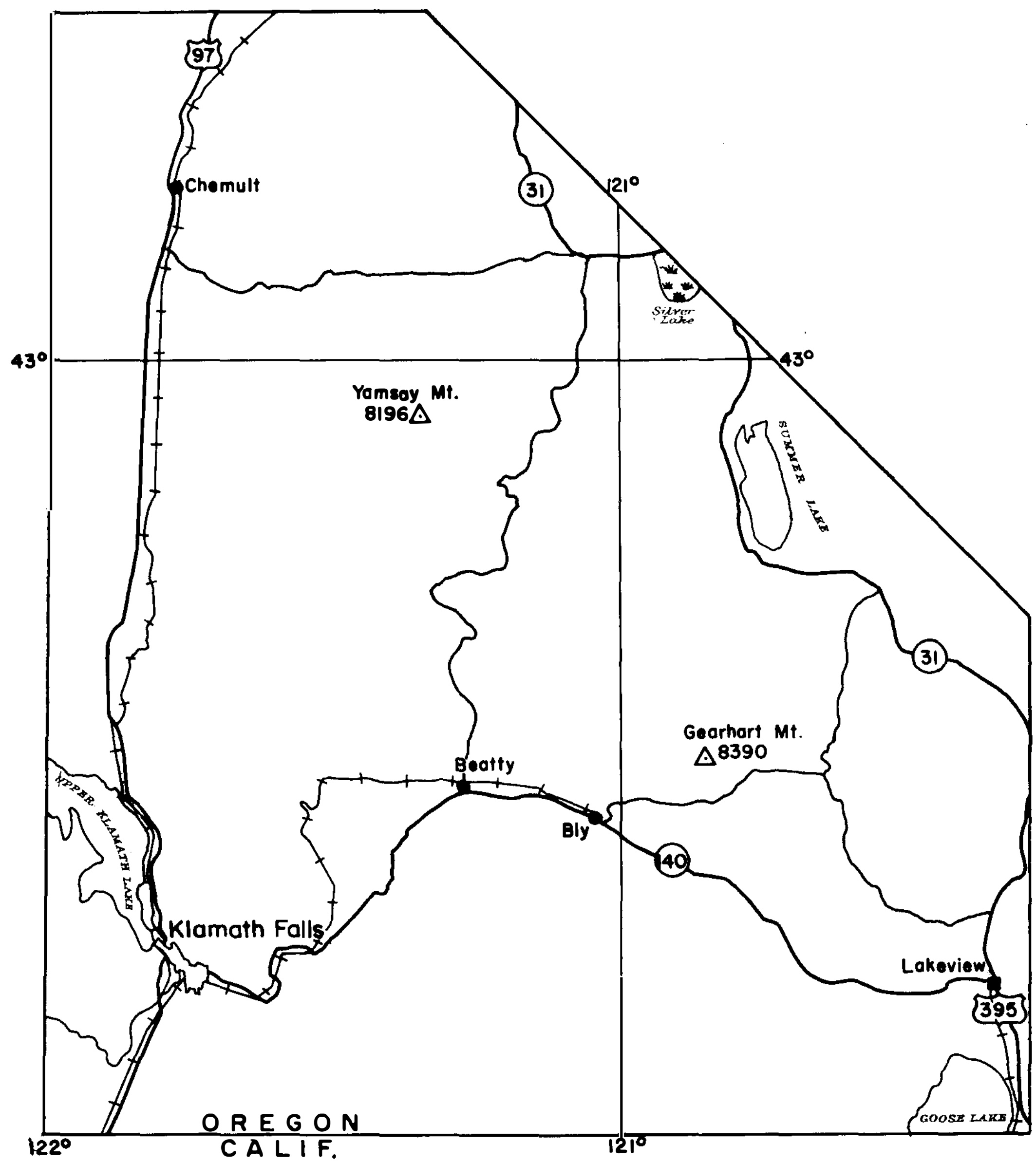

Figure 1. Index map of the study area.

Physiography, Climate, and Vegetation

The physiography of the project area is dominated by northerly trending, parallel mountain ranges and valleys. The valleys with the lowest elevation are on the east and west sides of the area. These are Summer Lake (4130 feet), Goose Lake (4680 feet), and Lower Klamath Basin (4050 feet). Valleys in the interior generally range from 4500 to 4800 feet in elevation. The highest elevations occur at Yamsay Mountain (8196 feet) and Gearhart Mountain (8390 feet) in the central part of the project area and in the Warner Mountains immediately east of Lakeview. The ridge elevations elsewhere generally range from 6000 to 7000 feet.

The climate is characterized by wide diurnal and seasonal temperature variations and low to moderate precipitation. The annual average precipitation at Klamath Falls over a long period of time is 12.89 inches, and 14.01 inches at Lakeview. A considerable amount of this precipitation occurs as snow, especially at the higher elevations. The humidity is low.

The normal annual temperature is 48.3° F. at Klamath Falls, 46.2° F. at Lakeview, and ranges from 42° to 54° F. elsewhere.

Under these conditions the vegetation consists of sagebrush and bunch grasses in the dry lower valleys, passing upward into extensive forests of Ponderosa Pine and Lodgepole Pine with less abundant stands of Douglas Fir, various true firs, White Pine, and cedar.

Methods of Study

Field work was begun in August of 1967 and completed in August of 1968. An initial field reconnaissance included examination of rock units in published and unpublished reports covering areas within and adjoining the project boundaries. The geology was then plotted on $7\frac{1}{2}$- and 15-minute quadrangles following a complete air-photo geologic interpretation. During the 1968 field season, traverses were made to check the photo-geologic interpretation in the field and to work out the stratigraphy and structure in selected areas. From the numerous rock samples studied, 12 were selected for chemical analyses, and 2 for age dating by the potassium-argon method.

Mining records were checked and all known mineral-commodity occurrences were visited and, where significant, were sampled for assay.

A separate geochemical sampling program was carried out during the summer of 1968, and 375 stream-sediment samples were collected from drainages where there is known mineralization or where silicic intrusive-extrusive rock types occur. In addition to work done for this project, data from 76 additional samples were contributed by Weyerhaeuser Company.

All known previously published maps and reports were studied. Where applicable they have been utilized in this report. The areas covered by these reports are shown on figure 2. Water-well logs and oil-exploration-well logs were examined to aid in interpreting stratigraphy and geothermal gradients. Gravity surveys were examined and plotted to aid in structural interpretations.

Acknowledgments

The joint sponsorship of this report by the Great Northern Railroad and the Pacific Power & Light Co. is gratefully acknowledged. H. E. Reed of Great Northern and Garth Duell and Winston Sahinen of Pacific Power & Light were helpful in discussing the scope and early planning of the project. The Weyerhaeuser Company supplied geochemical data; the Atlantic-Richfield Co. kindly provided the potassium-argon dates; the United States National Bank of Oregon as Trustee for the Klamath Indian Tribe and the U.S. Forest Service gave entry permits and other courtesies. J. Arnold Shotwell of the University of Oregon and George W. Walker of the U.S. Geological Survey contributed valuable paleontological information. Alfred Collier, John Glubrecht, and Mr. and Mrs. Randall Pope of Klamath Falls; Don Tracy, Zane Gray, and Leslie Shaw of Lakeview are some of the local persons who were helpful with information. The entire staff of the State of Oregon Department of Geology and Mineral Industries as always provided the skillful services required.

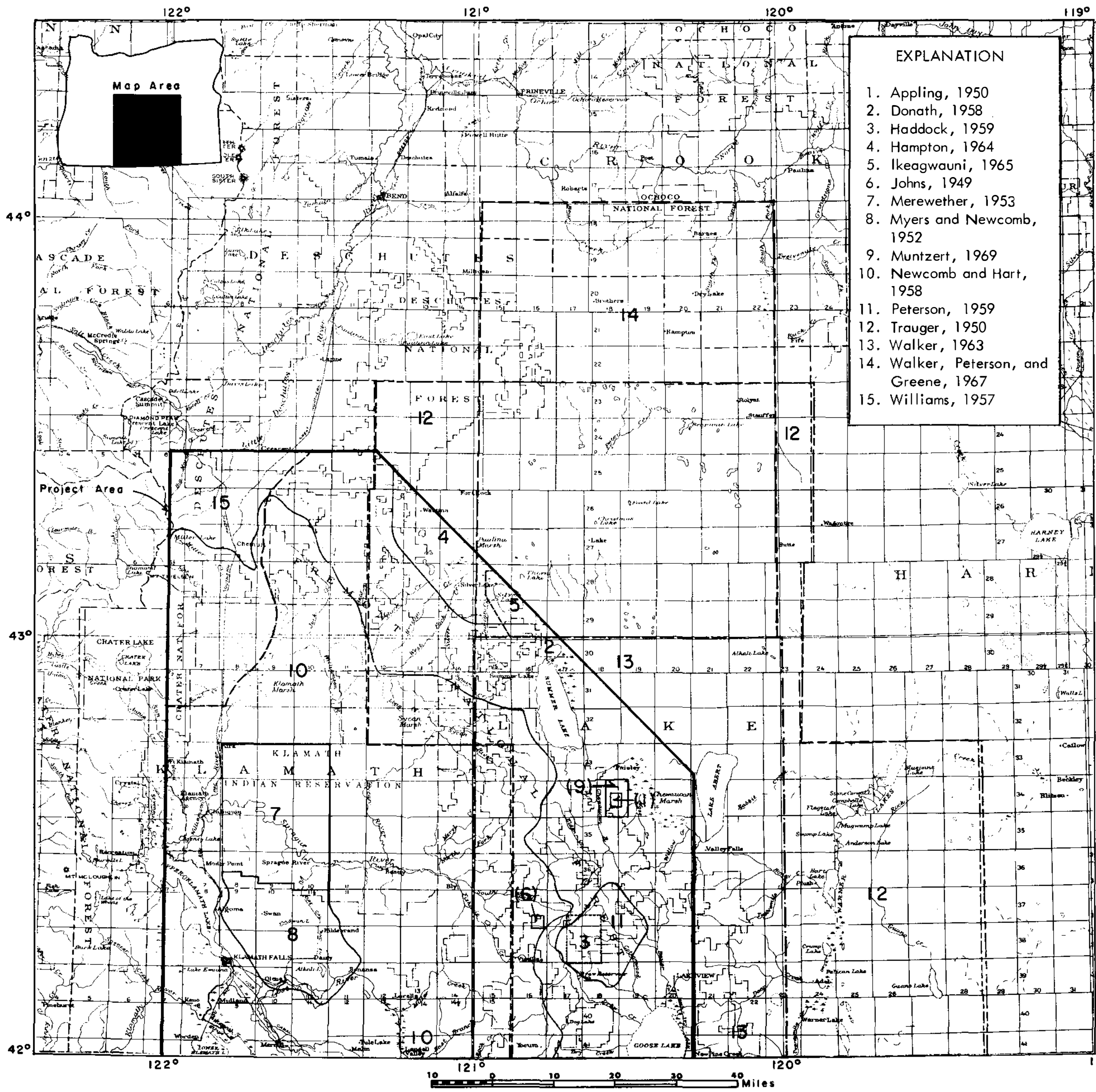

Figure 2. Index map of geologic mapping.

Suggestions for Future Work

Geologic studies

The project area has been covered only by reconnaissance geologic mapping, with the exception of a few small areas described in university theses. Many interesting problems in local and regional stratigraphy, volcanic petrogenesis, and regional structure remain to be studied in detail. As a basis for such work, new topographic maps now being issued will make mapping the region easier than it has been in the past. The need for further work can be inferred from some discussions in the geological section of this report.

There are a few subjects which can be cited as worthy of particular attention. The regional stratigraphy of the Pliocene lake beds is one which merits further study. Another stratigraphic problem exists in the need for a better understanding of the unwieldy (Ttf) map unit in the eastern part of the project area, particularly south of State Highway 140 between Fishhole Creek and Goose Lake. Studies in petrogenesis of volcanic rocks might be made on the major eruptive centers such as Yamsay Mountain and the Gearhart Mountain-Deadhorse Rim area. A detailed description of the occurrence of high-alumina diktytaxitic basalt also would be worthwhile.

Mineral resource studies

From the evaluation of the mineral resources, several commodities are considered to be worthy of further study:

1. Diatomite deposits of both Pliocene and Holocene age are present in large quantities and some have the physical properties necessary for industrial use. A thorough sampling program plus a study of the depositional basins will be needed for a meaningful evaluation of the diatomite.

2. Geothermal energy appears to have a much greater potential than present utilization; geophysical studies or a drilling program for evaluating this potential would be highly desirable.

3. Follow-up sampling and expansibility tests of perlite where the occurrences are close to rail and highway transportation are also recommended.

4. A more detailed study will be necessary to show the distribution and control of the copper, zinc, lead, and silver mineralization in the Paisley Hills and its association with the granite-type intrusive rocks.

5. The results of the stream-sediment sampling indicate that a follow-up should be made to determine the source of the anomalous uranium, at least in the Upper Drews Creek area and at the head of Swamp Creek.

6. Detailed geochemical work should be conducted in the vicinity of silicified dikes and plugs where cinnabar is known to occur to see if any large, low-grade deposits of mercury are present.

For a summary analysis of the mineral potential and a more detailed discussion of recommendations for future investigations in the project area, see Section 2 on Mineral Resources, beginning on page 31.

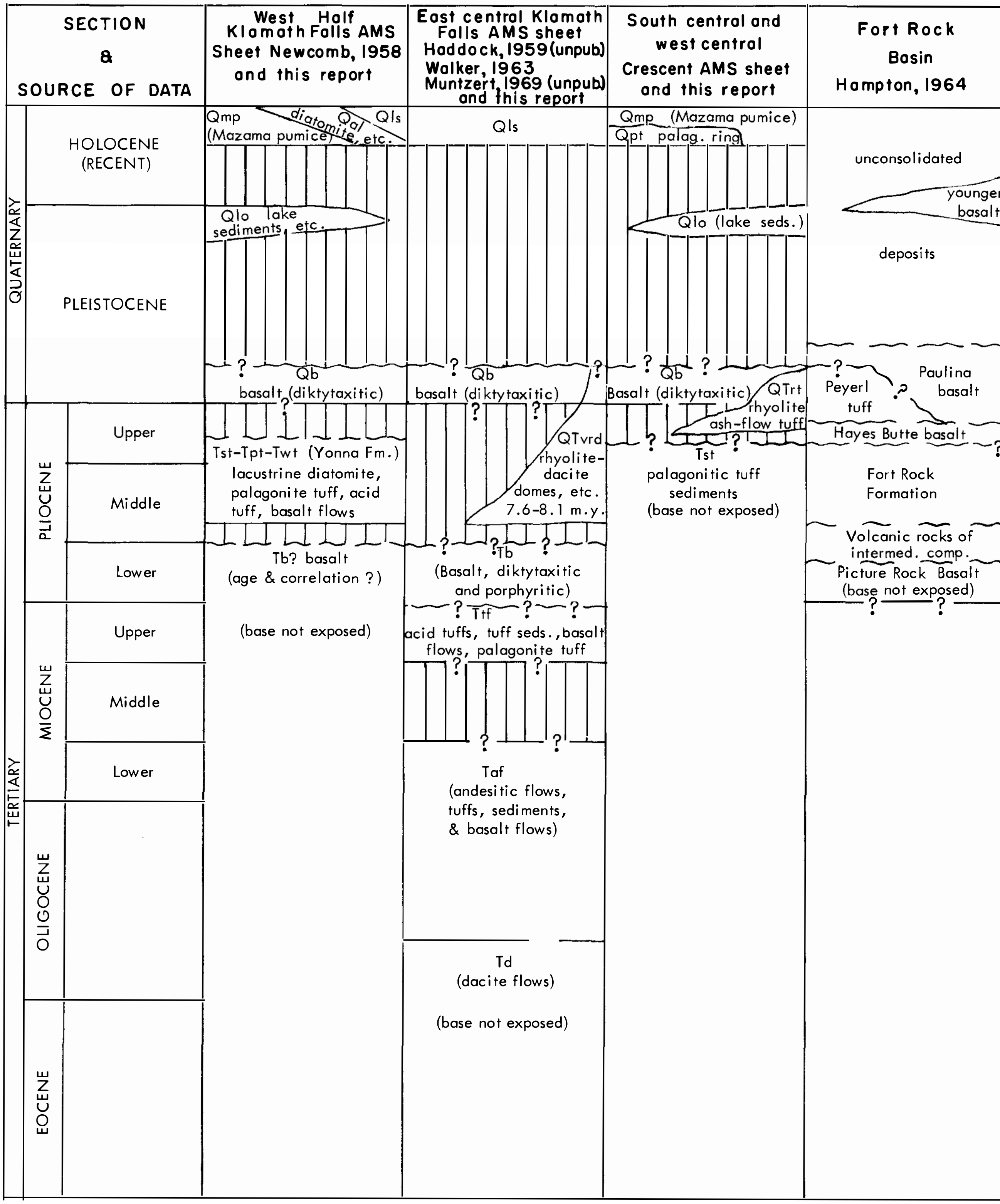

Figure 3. Correlation chart showing regional stratigraphic relationships.

SECTION 1. DESCRIPTIVE GEOLOGY

The oldest rocks within the project area are Oligocene or pre-Oligocene dacite flows occurring in a small part of the Paisley Hills* (plate 1). A thick section of andesite and basalt flows, pyroclastics, and related sedimentary rocks overlies these dacites. The outcrop area of andesitic rocks extends from the Paisley Hills intermittently to Coglan Buttes on the east and to Thomas Creek on the southwest. They are exposed again in the Warner Range near Lakeview. In the Paisley Hills both the dacite flows and the lower part of the andesite sequence are intruded by plutonic rocks with a radiometric age of 33.1 $\pm$ 1 m.y. A vertebrate fossil found near the top of the andesitic section in Thomas Creek was dated as of early Miocene age.

Following deposition of the predominantly andesitic rocks, a variable but generally thick section composed of rhyolitic and dacitic pyroclastics, minor basalt, palagonite tuff, and related tuffaceous sediments was deposited. Exposures of these rocks cover much of the eastern third of the mapped area. Vertebrate fossil remains from this unit indicate that it is of late Miocene or early Pliocene age near its top. The total thickness of pre-Pliocene Tertiary sediments and volcanic rocks appears, from well and surface data, to exceed 13,000 feet.

Widespread extrusions of basalt flows followed the episode of predominantly acidic tuff deposition. These flows appear to be overlain by a complex suite of rocks including diatomaceous and tuffaceous lacustrine sediments, palagonite tuffs, basalt flows and accumulations of cinders and other materials probably contemporaneous with the early phases of the building of large composite volcanic centers. Most of this material occurs in the western and northern part of the mapped area. Paleontological data indicate that the lacustrine phase of deposition was approximately of middle Pliocene to late Pliocene age. The eruptions at most volcanic centers appear to have ceased by the beginning of Pleistocene glaciation. Local intrusions and extrusions of rhyolite, dacite, and andesite occurred in the eastern part of the mapped area from the early Pliocene to Pleistocene or Holocene. Radiometric ages of two acidic plug domes of this assemblage are 7.6 and 8.1 million years.

The pre-Pliocene deformational history of the area is difficult to decipher. A northwesterly alignment of a few small volcanic eruptive centers and dikes indicates that the prominent regional normal fault pattern was initiated during the Pliocene. After the deposition of the Pliocene lacustrine materials and the building of most of the eruptive centers, the entire area was apparently folded into broad, low-amplitude anticlines and synclines with a northwesterly or northeasterly axial trend. One anticlinal axis seems to project through Silver Lake, Summer Lake, and Goose Lake grabens. A broad, poorly defined structural depression is indicated in the Sycan Marsh and Sprague River-Bly-Beatty area. This depression may have been flanked by an uplift on the west, in the Klamath Lake area, now obscured by faulting.

Most of the project area has been subjected to post-Pliocene normal faulting. The fault frequency and magnitude of displacement appear to be at a maximum along the areas of probable anticlinal uplift and to diminish inward toward the central structural depression. The predominant fault trend is northwesterly, with a subordinate trend in a northeasterly direction. In the northern part of the mapped area, the northeasterly trending faults become dominant in length and amount of displacement. The present terrain consists of parallel ridges and valleys resulting from normal faulting, with interspersed conical or irregularly shaped eruptive piles.

Late Pleistocene events in the area include glaciation of the highest peaks such as Gearhart Mountain, Yamsay Mountain, and Deadhorse Rim. Lacustrine deposition has taken place in the Klamath Lake-Agency Lake-Klamath Marsh depressions; in the Goose Lake-Summer Lake-Silver Lake graben trend, and in the Sycan Marsh. The intervening areas have been subjected to erosion during

* The mountainous region south of Paisley is known as the "Paisley Hills" by residents of the area, and for sake of convenience it is referred to by that name in this report.

this period. Late volcanic events affecting the area resulted in the formation of the Big Hole and Hole-in-the-Ground maars and the eruption of Mazama pumice, which covers the northern part of the mapped area.

This general sequence of events, both structural and stratigraphic, is shared by a much larger area of south-central Oregon. A correlation chart indicating these regional relationships is shown in figure 3. The exact synchroneity of some of the similar events in the adjacent regions with those in the area of this report has not been determined. Detailed discussions of the large-scale causative factors related to the geologic history would depend on the evaluation of data from a much larger area than that of this report and such a synthesis has not been attempted.

STRATIGRAPHY

The following discussion includes a definition of the lithologic units used in mapping the project area. In keeping with the large scale and reconnaissance nature of the mapping, the designated units were selected to be representative of major changes in depositional character. No formational names have been proposed. The complex facies relationships and poor rock exposures in critical areas will require a much more detailed study than has been made here before the proposal of formal stratigraphic units can be meaningful.

Tertiary Rocks

Oligocene or older

Dacite flows (Td): Dacite flows reported along the east side of the Paisley Hills between Jones Canyon and Johnson Canyon (T. 34 S., R. 18 E.) are the oldest rocks known to be present in the project area. These flows are generally poorly exposed in slopes of moderate to high relief. Platy flow jointing and brecciation are well developed. The rock weathers into yellowish or reddish-brown fragments that form talus slopes supporting only a sparse vegetative cover (Muntzert, 1969, p. 7-8). Unweathered samples are aphanitic and light gray, with a few scattered feldspar phenocrysts.

The base of the sequence is not exposed. Appling (1950, p. 31) estimated that more than 3000 feet of dacite flows are present. The basal part of the overlying (Taf) unit, made up of sediments containing dacitic debris, rests unconformably on these flows.

These dacite flows have been intruded by small bodies of diorite, granodiorite, and quartz monzonite (Ti), which have been dated radiometrically as of early Oligocene age (33.1 m. y.) (Muntzert, 1969, p. 52).

Oligocene-early Miocene

Andesite and basalt flows, pyroclastic rocks, and sediments of andesitic provenance (Taf): This rock assemblage was used as a regional mapping unit by Walker (1963). It is described as being an assemblage of tuff, tuff breccia, and tuffaceous sedimentary rocks of andesitic composition. Hornblende andesite and altered basalt flows are present in amounts which vary locally. Within the project area the lower part of the section is seen only south of Paisley in a northwesterly trending outcrop belt extending from T. 33 S., R. 18 E. into T. 35 S., R. 19 E. Muntzert (1969, p. 11-13) reports the presence of an unconformable basal breccia containing fragments of the underlying dacite unit (Td). This breccia is overlain by tuffaceous graywacke sandstone, mudstone, and thin conglomerate beds containing clay and clasts derived from an andesitic terrain. The rocks are thin to medium bedded. Graded bedding is sometimes visible. In the Paisley Hills, the middle and upper parts of this section contain abundant flows of andesite and basalt. Individual flows are generally less than 20 feet thick. The andesites are both porphyritic and nonporphyritic. Basalts in this part of the section are dark

Figure 4 - Taf unit.
Thin, dark greenish-brown tuffaceous sandstone beds overlain by an andesite flow (in shadow). Deadman Canyon, Warner Mountains, near Lakeview. (SE¼ sec. 15, T. 39 S., R. 20 E.)

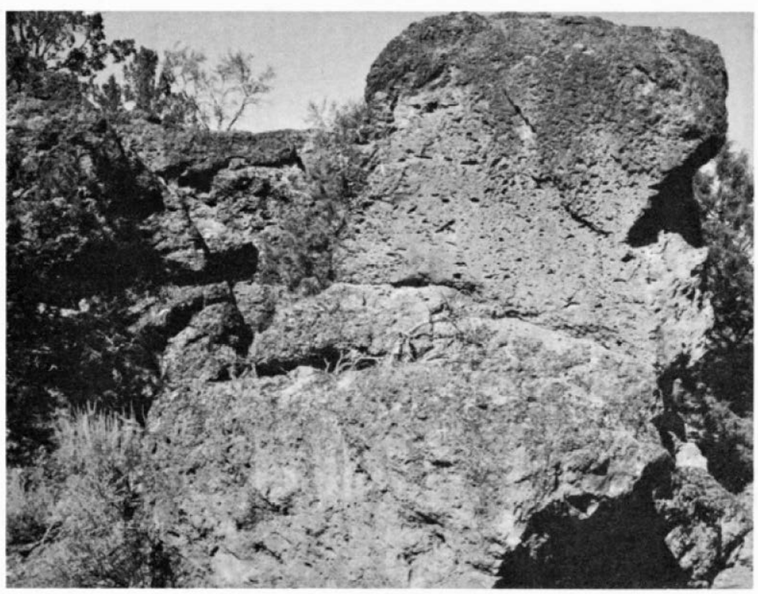

Figure 5 - Ttf unit.
Massive beds of dark brown weathering light green to tan ash-flow tuff in the lower part of the unit. Note how the less resistant rock and pumice fragments weather out, leaving cavities in the surface. Near Oregon State Highway 140, approximately 10 miles west of Lakeview. (SE¼ sec. 15, T. 39 S., R. 18 E.)

brownish-gray microcrystalline, vesicular, and sometimes porphyritic. Both the basalts and the andesites are often greenish brown in color due to alteration.

The upper part of this map unit is exposed extensively along the west front of the Warner Mountains east of Lakeview (figure 4). The contact with the overlying acidic tuffs of the (Ttf) unit appears to be gradational and conformable. In a small area of exposure in Thomas Creek (too small to show on the geologic map), dark gray and green, thinly bedded siltstones and graywacke sandstones of andesitic provenance, occurring immediately below light-colored acidic tuffs of the (Ttf) unit, contain plant and vertebrate remains noted below.

No complete section of the (Taf) unit is known, but it is estimated that at least 2500 feet of it is exposed in the Paisley area where the upper part of the section is apparently not preserved. Incomplete sections encountered elsewhere also contain thicknesses of this magnitude.

The age of the lower part of the unit is at least early Oligocene in the Paisley Hills where it is intruded by plutonic rocks with a radiometric age of 33.1 m.y. A tooth of a rhinoceros, Diceratherium, found near the top of a section of similar rocks in Thomas Creek (NW$\frac{1}{4}$ sec. 28, T. 37 S., R. 18 E.) has been dated as early Miocene in age (J. Arnold Shotwell, written communication, July 28, 1958). Fossil plants obtained from the same locality indicate no more than a probable Miocene age for the flora (Jack Wolfe, written communication, December 1, 1958). The early Oligocene, or older, to early Miocene time span of this section of rocks, as well as its lithologic character, suggests its tentative correlation, in part, with the Cedarville Formation of northeastern California (Gay and Aune, 1958).

Middle(?) Miocene - early Pliocene

Rhyolitic and dacitic tuff, tuffaceous sedimentary rocks, subordinate basalt and andesite flows, and palagonitic tuffs (Ttf): This map unit is thick and variable in composition within the project area. It is characterized by massive beds of light-colored rhyolitic and dacitic ash-flow tuffs (figure 5). The assemblage of lithologies taken as a whole is exposed throughout the mapped area from Winter Ridge to the California state line and westward nearly to 121°00' west longitude. Complex faulting, rapidly changing facies, and poor exposures make it difficult to obtain a comprehensive view of the total section.

The lower part of the sequence is exposed in the west face of the Warner Mountains near Warner Canyon. In this area there is some interbedding of dark-colored andesitic tuffs and sediments of the (Taf) unit and the overlying characteristic light-colored pumice-bearing tuffs of the (Ttf) unit.

At Dog Mountain and in the Willow Creek Hills massive ash-flow tuffs containing abundant pumice and exotic rock fragments are overlain by a thick section of thin-bedded, brown-weathering vesicular porphyritic basalt and interbedded palagonitic and pumice-bearing tuffs and tuffaceous sediments (figures 6 and 7). This section is best exposed in the Hay Creek drainage along the eastern base of Dog Mountain and also along Drews Creek below the dam at Drews Reservoir. From the Dog Mountain-Barnes Rim area westward to Barnes Valley and the Fishhole Creek drainage, additional section appears to occur above the basalt. This section contains massive beds of light-colored pumice-bearing ash-flow tuff and minor tuffaceous sediments similar in character to those beneath the basalt unit.

A palagonite tuff and tuffaceous sediment unit occurs in the upper Cottonwood Creek-upper Howard Creek area (secs. 14 and 15, T. 38 S., R. 17 E.) and northwestward as far as Drum Hill (figure 8) and Elder Creek, along strike beneath the younger basalt capping Coleman Rim. This lithology was not seen elsewhere. It resembles the palagonitic tuffs and tuffaceous sediments occurring in the middle Pliocene to Pleistocene section farther west. Haddock (1959, p. 13) reports a thickness of 1500 to 2000 feet of this palagonitic unit in the Howard Creek-Cottonwood Creek drainage.

The complete thickness of the (Ttf) unit in the project area is not known. The Humble Oil & Gas Co.'s Thomas Creek Unit No. 1 well, drilled as a test for oil in the NE$\frac{1}{4}$ sec. 2, T. 40 S., R. 20 E., penetrated 12,093 feet of tuffs, flows, and volcanic-derived sediments, reportedly without reaching the base of the Tertiary volcanic section. The surface rocks at the drill site appear to be about 1000 feet below the top of the (Ttf) unit. Although, with the information available, it was not possible to relate the subsurface section in this well to the surface map units, the well section appears

Figure 6 – Ttf unit.
Basalt dike feeding a flow in the middle part of the unit. Dog Lake Road (NW$\frac{1}{4}$ sec. 14, T. 40 S., R. 17 E.)

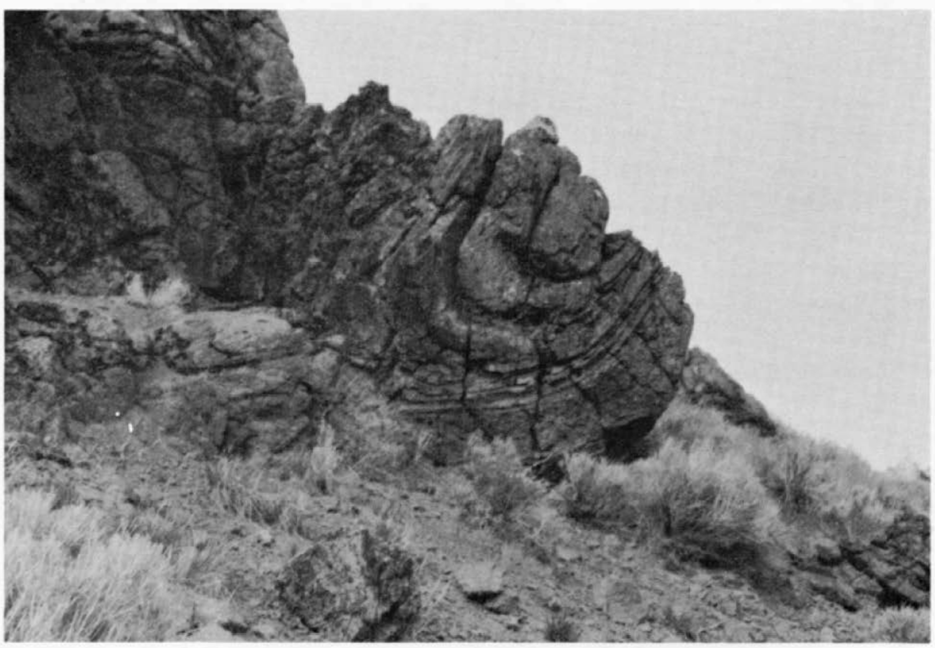

Figure 7 – Ttf unit.
Flow fold in basalt in the middle part of the unit. On Hay Creek (NW$\frac{1}{4}$ sec. 30, T. 39 S., R. 17 E.)

to suggest a combined (Ttf) - (Taf) section which may locally exceed 13,000 feet in thickness.

Late Miocene or early Pliocene vertebrate fossils have been reported from SE$\frac{1}{4}$ sec. 18, T. 40 S., R. 17 E., west of Dog Mountain (Walker, written communication, September 12, 1968). At Coglan Buttes on the eastern boundary of the map area, additional fossil collections, of late Miocene age, were obtained (Walker, 1963). No fossils have been found, however, from the lower part of the formation in the project area. Since the base of the (Ttf) unit immediately overlies fossiliferous (Taf) rocks dated as early Miocene, it appears that a Miocene to early Pliocene age is probable for the entire (Ttf) assemblage of rocks.

The (Ttf) unit is overlain by basalt flows of the (Tb) unit and the two formations are separated by an erosional unconformity. An angular discordance between them is mentioned by Haddock (1959, p. 15), but no specific localities showing this type of relationship were seen in the present study.

Pliocene

Basalt flows (Tb): Throughout the eastern part of the project area the Miocene-early Pliocene tuffs (Ttf) are overlain by basalt flows (Tb). These flows in the Grizzly Peak-Coleman Rim area (Tps. 37 and 38 S., R. 17 E.) have been described in some detail by Haddock (1959, p. 21-22). Two basalt units have been recognized. The older of the two includes olivine basalt porphyry with large labradorite phenocrysts and nonporphyritic olivine basalt. The thickness observed is from 10 to 150 feet. This flow sequence is overlain by a much more widespread light- to medium-gray vesicular basalt, highly feldspathic, containing pyroxene, magnetite, and olivine. The characteristic texture is diktytaxitic but intergranular textures are also present. This unit is composed of individual flows ranging from a few feet to as much as 30 feet in thickness. The total thickness is variable, ranging from about 20 feet to as much as 600 feet at Grizzly Peak where 20 individual flows were identified (Haddock, 1959, p. 30).

The flows with diktytaxitic texture appear to have been erupted from local vents. Several large diabase dikes mapped as (Tdb), which are likely to be the source of these flows, have been observed in the Grizzly Peak area (figure 9). Gradational dike-flow relationships are reported to occur in upper Drews Creek (SW$\frac{1}{4}$ sec. 35, T. 37 S., R. 17 E.) (Haddock, 1959, p. 25-30).

Regionally, the (Tb) unit dips gently westward throughout the east-central part of the map area and seems to project beneath later Pliocene tuff and lacustrine sediments in the Sprague River valley. Diktytaxitic basalts of this interval are lithologically distinct from all older basalts in the mapped area, but they are very similar to younger basalts described below, from which they are difficult to distinguish except on the basis of the stratigraphic position.

Tuffaceous and diatomaceous sediments and basaltic tuffs, breccias and flows (Tst); maars and tuff rings (Tpt); and welded tuffs (Twt): This group of units is composed of the interfingering deposits of rivers and lakes in a terrain dominated by contemporaneous basaltic eruptions of Pliocene age. Representatives of the assemblage are continuous over most of the project area west of 121°00' west long. and south of 42°45' north lat. North of this approximate boundary these rocks are covered by younger basalts; to the east they either have been removed by erosion or never were present. East of Coglan Buttes, however, these rocks are preserved in down-faulted blocks of the Abert basin. In general, exposures of this assemblage are poor and the terrain is one of low, rolling hills, except where centers of volcanic eruption are present.

The most extensive deposits in this assemblage of Pliocene rocks are those in the (Tst) unit, consisting of thin-bedded lacustrine diatomites and basaltic tuff sandstones and siltstones, generally altered to palagonite. The diatomaceous sediments are locally present in large amounts. They may occur throughout the section but seem to be most abundant in the upper part. Good exposures can be seen in bluffs about half a mile north of the town of Sprague River, in the hills in and adjacent to Klamath Falls, in irrigation canals at Olene Gap (figure 10), and at many other localities in Poe, Yonna, and Sprague River valleys and in the Klamath Lake basin. The volcanic ash content of the diatomites varies greatly, as discussed in the Mineral Resources section of this report.

The dominant sedimentary lithologic types in the (Tst) unit, however, are the basaltic sandstone and mudstone. These generally palagonitic materials range from thin beds of water-laid

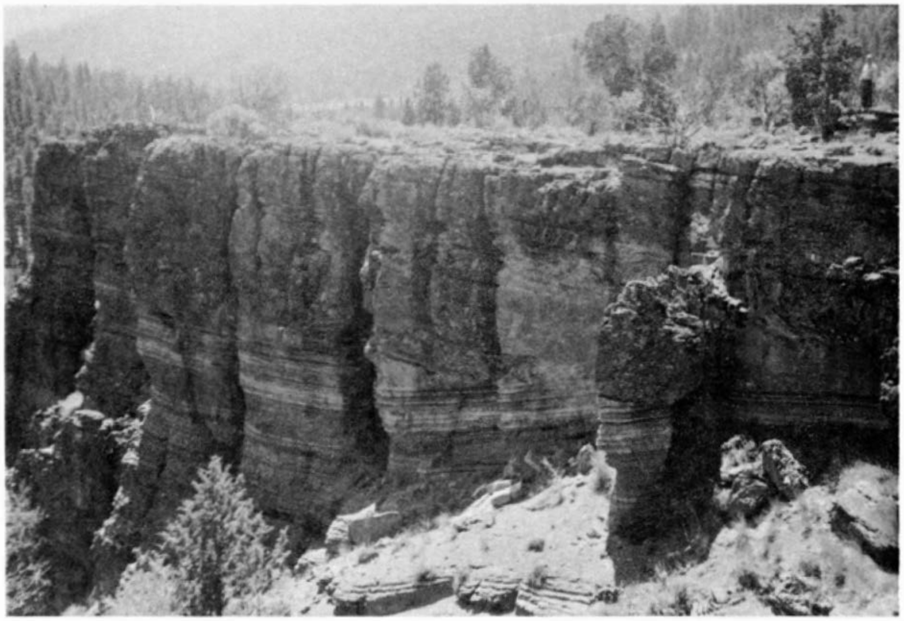

Figure 8 - Ttf unit.
Palagonitic tuff in the upper part of the unit. On the south flank of Drum Hill, about 20 miles northwest of Lakeview. (Sec. 12, T. 36 S., R. 17 E.)

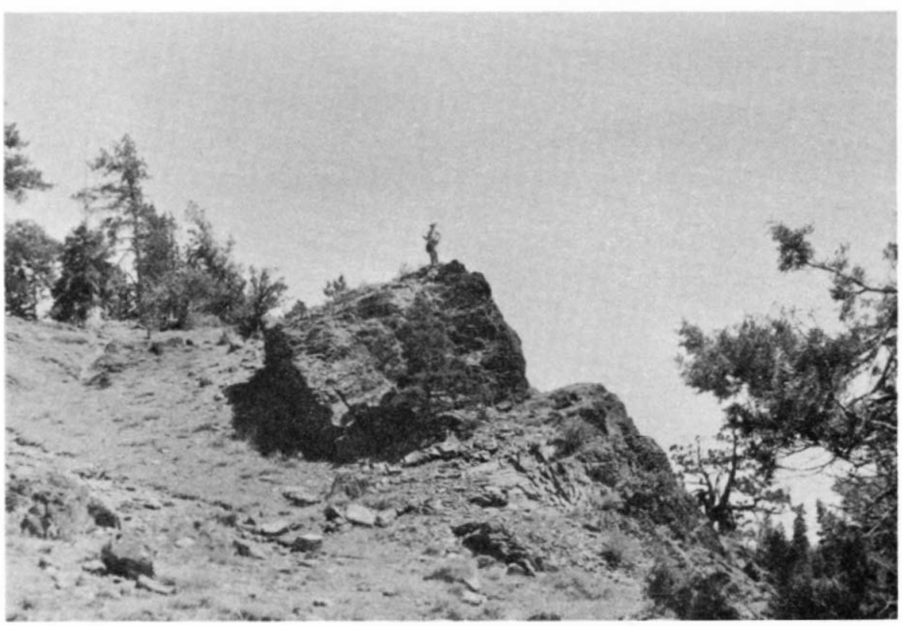

Figure 9 - Tdb unit.
Diabase dike believed to be a source of flows in the Tb unit. Near Fish Lake (sec. 29, T. 38 S., R. 18 E.)

tuffaceous sedimentary rock to piles of coarse tuff and breccia that accumulated in ring-like mounds around eruptive centers on the floor of an ancient lake. Tuff and breccia accumulations near vents, mapped as (Tpt), typically exhibit high initial dips of variable magnitude and strike (figure 11). Several well-preserved mound and ring eruptive structures (maars) have been exhumed from the surrounding softer lake sediments and are now exposed in relief on the floors of valleys. Especially notable examples are the Devils Garden (secs. 21 and 32, T. 36 S., R. 10 E.), Bad Lands (secs. 3, 4, 9, and 10, T. 36 S., R. 9 E.), and the Buttes of the Gods (secs. 20, 28, 29, and 33, T. 35 S., R. 10 E.). Good examples of well-bedded palagonitic lacustrine mudstone and sandstone occur along the Bonanza-Merrill highway between Harpold Dam and Buck Butte, and along State Highway 140 for a distance of about 5 miles northeast of Dairy (figure 12).

There are also thick, massively bedded, coarse-grained palagonitic sediments and pyroclastic rocks included in the (Tst) unit, that are not clearly related to specific eruptive centers. These make up the main part of such mountain masses as Hogback Mountain and western Stukel Mountain, the ridges trending through the northeast corner of T. 38 S., R. 9 E., and the southwest part of T. 38 S., R. 10 E., and through much of T. 40 S., Rs. 9 and 10 E. Cave Mountain east of Chiloquin appears to be another such accumulation of coarse-grained basaltic pyroclastic material.

Contemporaneous basaltic lava flows entered the lacustrine basin and are interbedded with sediments. These flows are dense, black, glassy, and vesicular. Some are brecciated and altered owing to their extrusion into water or wet diatomaceous ooze. Flows of this type can be seen in several places (SW$\frac{1}{4}$ sec. 19, T. 37 S., R. 11 E.; NW$\frac{1}{4}$ sec. 11, T. 39 S., R. 8 E.). In addition to the flows, at least one cinder cone was built in the lake (southwest corner sec. 6, T. 40 S., R. 12 E.).

The abundance of basaltic detritus in the sedimentary section suggests that a Pliocene-to-Holocene basaltic eruptive episode was well under way and that the large and small volcanic piles that figure prominently in the present landscape were already in the process of accumulation at this time. It seems likely that such masses and their contemporaneous wide-spread lava flows may have been a major factor in the topographic configuration of the Pliocene sedimentary basin.

Although basaltic materials dominate the section, a moderately extensive ash-flow tuff (Twt) of rhyolitic or dacitic composition occurs in the eastern edge of the depositional area at Whitemore Reservoir near Bly (secs. 8, 17, and 33, T. 36 S., R. 14 E.). The relationship of this tuff to other parts of the section is not clear. All that is known is that it occupies a similar stratigraphic position beneath later basalt flows (Qb).

The rock assemblage making up the (Tst-Tpt-Twt) map units is believed to overlie the basalt unit (Tb). A sediment-basalt contact can be seen at Harpold Dam (SE$\frac{1}{4}$ sec. 19, T. 39 S., R. 11$\frac{1}{2}$ E.) and in highway cuts in the center of the E$\frac{1}{2}$ sec. 14, T. 41 S., R. 10 E. In addition, water wells frequently encounter a thick basalt section after passing through the sediments and tuffs. It is not possible, however, to determine from available data whether or not these basalts are equivalent to the (Tb) unit of the eastern third of the project area. The (Tst) sequence is overlain on a surface of erosional unconformity by thin but extensive basalt flows (Qb) (figure 13). This relationship can be seen in the Sycan River canyon where a local thickening of basalt appears to indicate that it filled an old stream channel (NE$\frac{1}{4}$ sec. 6, T. 34 S., R. 12 E.)

The thickest sections of (Tst - Tpt) sedimentary and pyroclastic rocks appear to occur in the Sprague River valley, Klamath Falls-Lower Klamath Lake-Klamath Hills area, Swan Valley, Yonna Valley, Poe Valley, and some of the intervening ridges. Near the town of Sprague River a combination of surface outcrop and water-well data indicates as much as 800 feet of lacustrine sediments are present between the younger and older basalts. More than 1000 feet of similar sediments are reported from water wells in the Spring Valley-Lower Klamath Lake and Klamath Falls areas.

Age dating of the section is based on a few fossils from isolated fault-block exposures. Middle Pliocene vertebrate remains have been reported from the Stateline road, E$\frac{1}{2}$ sec. 14, T. 41 S., R. 10 E. Parts of a camel skeleton were found in an irrigation canal near Merrill (center of N$\frac{1}{2}$ sec. 36, T. 40 S., R. 10 E.). This material was dated as late Pliocene. Additional late Pliocene fossils have been reported from Wilson quarry at the north end of Stukel Mountain (NW$\frac{1}{4}$ sec. 32, T. 39 S., R. 10 E.) (Shotwell, written communication, September 12, 1968). Fossil fish remains are locally abundant in several localities noted on the map, but they have not been studied sufficiently to be of value in establishing the age of the formation. Mollusca occur occasionally and diatoms are abundant in

Figure 10 – Tst unit.
Massive diatomite exposed in irrigation canal at Olene Gap. (NE¼ sec. 14, T. 39 S., R. 10 E.)

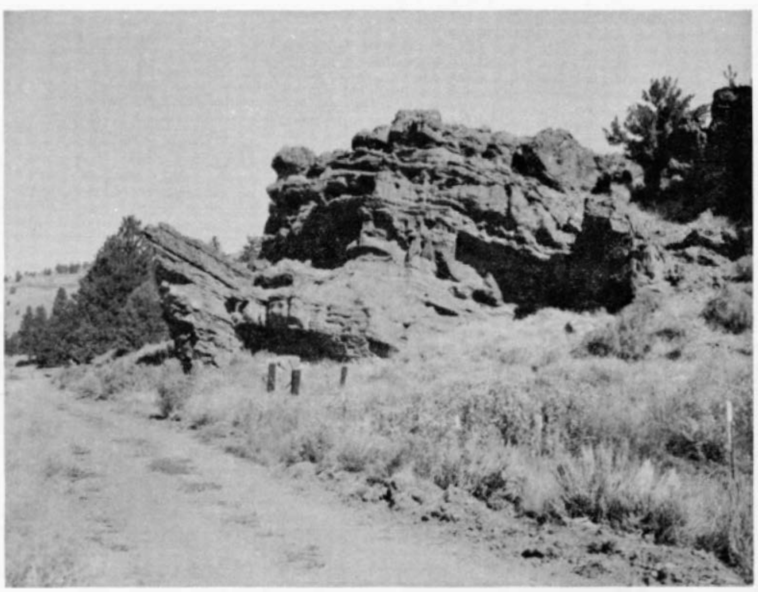

Figure 11 – Tst unit.
Polagonitic tuff near an eruptive center. Note the prominent initial dip. (NW¼ sec. 22, T. 35 S., R. 12 E.)

most parts of the formation, but these also have not been studied. In view of the uncertainty of the position of the fossil localities in the stratigraphic section, the age range of this unit is not known.

Newcomb (1958) assigned the name Yonna Formation to most of the assemblage included in the (Tst) map unit. As the application of formational names has not been attempted in this reconnaissance project, the term Yonna Formation has been recognized but not used. It was not possible to establish in the present study any widespread consistent subdivision of the (Tst) unit into a lower sedimentary (lacustrine) section and an upper basaltic lapilli tuff as suggested by Newcomb (1958, p. 42) in his type area. It appears more likely that the facies relationships between diatomaceous and tuffaceous sediments, tuffs, and flows is a complex one, with all of these being deposited simultaneously in some part of the basin.

Similar rocks are found to extend southward into Siskiyou and Modoc Counties in California where the name Alturas Formation has been applied (Gay and Aune, 1958). Northeastward in the Fort Rock Valley, diatomaceous lacustrine rocks and palagonitic tuffs of middle Pliocene age have been called the Fort Rock Formation (Hampton, 1964, p. B7-B11).

Late Pliocene or early Pleistocene

Andesite flows (QTa): At Walker Rim and Walker Mountain near Chemult, dark brown to black platy andesite flows that weather pink to tan are present. These rocks are occasionally exposed in the faces of fault-block ridges as far south as Wocus Bay and Skellock Draw on the east side of Klamath Marsh. The base of this andesite flow sequence has not been seen. Thicknesses of 500 or more feet are exposed in Walker Rim. Walker Mountain and Little Walker Mountain appear to be parts of a faulted andesitic eruptive center (QTvca) which may be related to these flows.

To the east of Walker Rim these andesites are overlain by extensive thin flows of diktytaxitic basalt (Qb) of probable Pleistocene age. The age of the andesite is not known precisely.

Rhyolitic ash-flow tuff, welded and nonwelded (QTrt): This distinctive acidic ash-flow tuff is exposed in small areas in the northeastern part of the mapped area east of the town of Silver Lake, in Dry Creek, and along the northwestern side of Thompson Reservoir. Typical outcrops of this unit can be seen in road cuts in the NW$\frac{1}{4}$ sec. 19, T. 30 S., R. 14 E. and in the canyon of Dry Creek (center of the N$\frac{1}{2}$ sec. 32, T. 25 S., R. 12 E.). The tuff is about 50 feet thick, massive and sometimes welded. It is dark brown to black on weathered surfaces and dark, reddish brown on fresh exposures. From a distance the outcrops resemble those of basalt flows. The rock is characterized in hand specimen by large, drawn-out blebs of black glass. Many accidental rock fragments are present and flow banding is common.

The (QTrt) unit overlies palagonitic tuffaceous sedimentary rocks exposed in a road cut extending from the center of section 6 into the N$\frac{1}{2}$ sec. 5, T. 26 S., R. 12 E. In this same area a thin capping basalt, correlated with the (Qb) unit, overlies this ash-flow tuff. A similar contact of basalt with ash-flow tuff can be seen in the west wall of Hole-in-the-Ground explosion crater.

The origin of this ash-flow tuff is unknown. If all of the isolated outcrops are part of a connected sheet, the source may have been along the east flank of Yamsay Mountain in the Partin Butte area, where a tuff of this type is found at its highest topographic elevation.

An early Pleistocene age of the (QTrt) unit is inferred from its stratigraphic position above palagonite tuffs (Tst) believed to be part of the Fort Rock Formation and beneath the (Qb) basalt. It has been subjected to normal faulting to the same extent as formations underlying it. The unit seems to be correlative with the Peyerl Tuff of Hampton (1964), which occurs in the adjacent Fort Rock basin.

Quaternary Rocks

Pleistocene (?)

Basalt flows (Qb): Widespread and generally thin basalt flows overlie the Pliocene sedimentary and tuffaceous section (Tst). Typical examples of this map unit occur in the Knot Tableland and

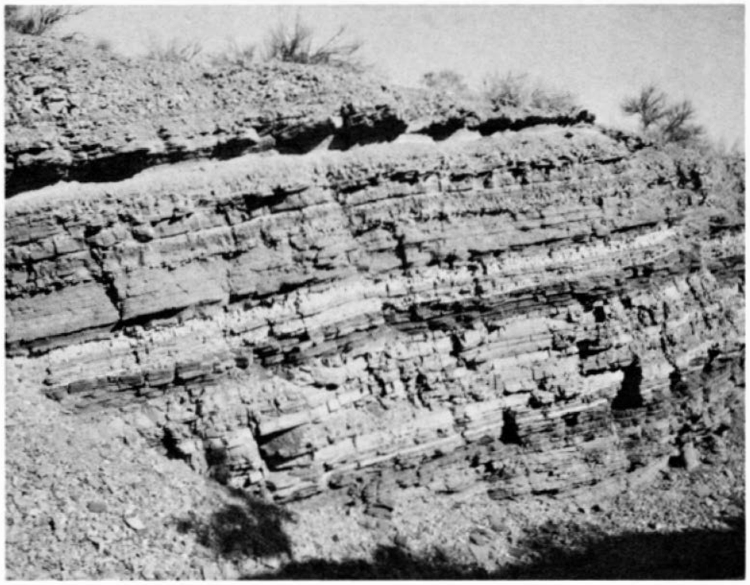

Figure 12 - Tst unit.
Typical interbedded lacustrine diatomite (white) and basaltic tuff sandstone (gray). Yonna Valley, northeast of Dairy (NE$\frac{1}{4}$ sec. 27, T. 38 S., R. 11$\frac{1}{2}$ E.)

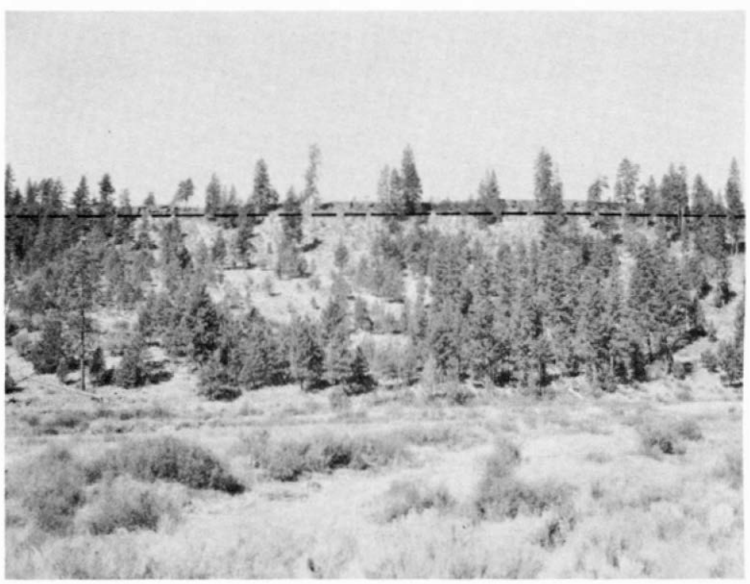

Figure 13 - Qb unit.
Knot Tableland basalt flow overlying Pliocene palagonitic tuffs (Tst). Contact indicated by dashed line. Canyon of the Sycan River (sec. 20, T. 35 S., R. 12 E.)

High Tableland areas north of the Sprague River (figure 13). The flows of this unit are approximately 20 to 30 feet thick in this area, but the number of individual flows and their thickness appear to increase to the north in the Sycan River canyon. Similar flows can be seen overlying lacustrine sediments in some of the low fault-block ridges around Klamath Falls. Additional good exposures are present at Spring Hill grade on Highway 93 north of Chiloquin and in the adjacent Williamson River canyon.

This basalt is usually moderately vesicular, medium to dark gray in color, and exhibits diktytaxitic and intergranular textures. It is often lithologically indistinguishable from the early Pliocene basalt unit (Tb).

The increase in flow unit thickness and in the number of flows northward and eastward from the Beatty-Bly area along the Sprague and Sycan Rivers suggests a source for at least some of the flows in the general area of the west slope of Winter Ridge, Shake Butte, and Green Mountain. The flows there seem to merge with low, fan-shaped terraces on these mountains, which may have been eruptive centers for lavas of low viscosity. Basalts of this composition and texture have been collected from the summits of several eruptive centers, for example Yainax Butte, Skookum Butte, Calimus Butte, and Solomon Butte. Dikes with glassy chilled borders and centers with diktytaxitic texture occur in the Williamson River canyon (center of N$\frac{1}{2}$ sec. 25, T. 33 S., R. 7 E.) and appear to be related to post-lacustrine diktytaxitic flows (Qb) in that area.

Flows of this unit were extruded onto an erosional surface developed on the Pliocene sedimentary beds. This can be seen on the Riverbed Butte quadrangle along the boundary between T. 35 S., R. 13 E. and R. 14 E., where isolated sinuous basalt ridges a few hundred feet wide seem to be the exhumed basalt fillings of old stream channels cut into the underlying rocks. The relationship between the Knot Tableland flow sequence and the flanking High Tableland basalt seems to imply that the High Tableland flows were extruded and then cut through over a large area by a river. The river bed then formed the channel in which the Knot Tableland basalt flowed and came to rest (Tps. 35 and 36 S., Rs. 11 and 12 E.).

The original pahoehoe surfaces of these flows are usually covered only by a thin veneer of soil and Mazama pumice, with the exception of the Klamath Lake-Agency Lake-Klamath Marsh area, in which lacustrine sediments of the present topographic basins overlie them.

The age of these flows appears to be early Pleistocene. They overlie probable middle to late Pliocene lake beds on an erosional unconformity, as has been indicated. Basalts assigned to this unit appear to have been subjected to the same amount of normal faulting as the underlying rocks, particularly to the west of the town of Sprague River and in the Klamath Falls area. The latest flows known, such as at Knot Tableland, have been considerably dissected by the Sycan River. Thus the tentative age assignment to early Pleistocene appears to be justified.

A major unsolved problem exists where these basalts rest directly on flows of similar appearance but of earlier age, such as the (Tb) unit and the basalts associated with the Miocene-Pliocene sedimentary section. This condition occurs over a large area along the west slope of Winter Ridge, in the canyons of the north and south forks of the Sprague River, and in the general area west of Barnes Valley. A more detailed study will be required to make an accurate distinction between the basalt sequences of several ages.

Pleistocene - Holocene

Of the many small deposits representing sedimentation in the present topographic basins, five have been distinguished at the reconnaissance level of the present mapping project. These are: fluvial, terrace, and lacustrine deposits of higher lake levels (Qlo), landslide deposits (Qls), basaltic tuff eruptive centers and associated maars (Qpt), Mazama pumice (Qmp), and alluvial deposits (Qal).

Fluvial, terrace, and lacustrine deposits (Qlo): The parts of the project area which appear to have received significant quantities of sediments during this interval are the Klamath Marsh-Agency Lake depressions on the west, the Silver Lake-Summer Lake-Chewaucan Marsh-Goose Lake depressions on the east, and the Sycan Marsh depression in the central area. Elsewhere active erosion was going on. Typical examples of (Qlo) sediments occur in the north end of Summer Lake in the Ana River canyon. Conrad (1953, p. 34-52) studied in detail approximately 50 feet of section exposed there. Apart from lacustrine sediments many pumice layers were noted, indicating contemporaneous volcanism. Thin caliche zones recorded periods of dessication. Beds of coquina, made up of gastropods, pelecypods, and fine-grained calcareous and dolomitic sediments, occur along the east side of Summer Lake (sec. 34, T. 31 S., R. 18 E.). Chemical analyses of these sediments show an unusually high MgO content of from 5 to 20 percent. The total thickness of lacustrine strata in this basin appears from water-well data locally to exceed 1286 feet, the depth of the deepest well (Allison, 1945, p. 793). Other prominent outcrop areas occur at the north end of the Goose Lake basin, along lower Thomas Creek, and in cuts along State Highway 140, 6 to 8 miles west of Lakeview. The northernmost deposits contain many conglomerate beds probably representing stream and delta deposits at the margin of an earlier, expanded Goose Lake. Elsewhere, thinly bedded, fine-grained tuffaceous sediments suggest lacustrine deposition.

In the Klamath basin, deposits assigned to this unit contain conglomerate, such as that exposed in the NE$\frac{1}{4}$ sec. 22, T. 38 S., R. 8 E., and unconsolidated tuffaceous sand seen in a pit in the SE$\frac{1}{4}$ sec. 36, T. 38 S., R. 9 E. (figure 14). Water-well logs in the Agency Lake-Fort Klamath area* report more than 300 feet of unconsolidated sand, gravel, cinders, and clay with abundant carbonized plant fragments.

The Sycan Marsh depression is presently a site of accumulation for peat and small amounts of sediment from the surrounding hills. The thickness and history of accumulation in this small area is not known, but it may include deposits in the subsurface assignable to (Qlo).

No diagnostic fossils are known to occur in (Qlo) sediments. These deposits were formed after the establishment of the present-day basins, resulting from post-Pliocene normal faulting. They are, however, related to depositional conditions no longer prevailing in their area, particularly to the high lake levels of the Pleistocene. In some cases, slight deformation of these beds by faulting is indicated. In summary, the general conditions of deposition suggest that a middle to late Pleistocene age is probable for most of the deposits assigned to this map unit.

<u>Landslide deposits (Qls)</u>: Landslide deposits large enough to be recorded at the mapping scale of this project have been formed along the eastern face of Winter Ridge. The local geological conditions under which they have developed consist of a steep fault scarp with parallel joint zones in the uplifted ridge and a stratigraphic sequence consisting of massive basalt flows overlying softer acid tuffs and tuffaceous sediments. The resulting slides have left a typically scalloped edge along the rim of Winter Ridge and a hummocky terrain at the foot of the ridge. Sag ponds and large, erratic blocks are abundant.

The straight front of the toe of many of these deposits suggests that they also may have been faulted, with displacements as large as 300 feet. High lake shoreline cuts are also visible at the base of these slides, indicating that some of them were in place before the establishment of the high Pleistocene lake levels.

A second prominent landslide area occurs on both flanks of the Barnes Rim-Fishhole Mountain ridge (T. 38 S., R. 16 E.), where the general geological conditions resemble those at Winter Ridge.

<u>Basaltic tuff eruptive centers and associated maars (Qpt)</u>: Local accumulations of palagonitic basalt tuffs were built up around vents during the Pliocene, Pleistocene, and Holocene. Large sublacustrine Pliocene tuff rings and mounds are indicated on the geologic map in the (Tpt) unit. Younger tuff mounds and open maars with bordering tuff rings are present in the northeast part of the mapped area.

Hole-in-the-Ground, in sec. 13, T. 25 S., R. 13 E., a short distance beyond the northeastern corner of the project area, is a volcanic explosion crater of this type. It is nearly circular, with steep walls sloping to a flat floor that is about 425 feet below a raised rim. The rims of the crater are built up of thin to thick layers of basaltic explosion tuffs and breccias.

The age of the short-lived Hole-in-the-Ground event is uncertain. The outward-sloping rims are overlain by pahoehoe lava flows originating on the flanks of Newberry Volcano to the north.

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* U.S. Forest Service, Fort Klamath Ranger Station well (H), sec. 21, T. 33 S., R. 7$\frac{1}{2}$ E.

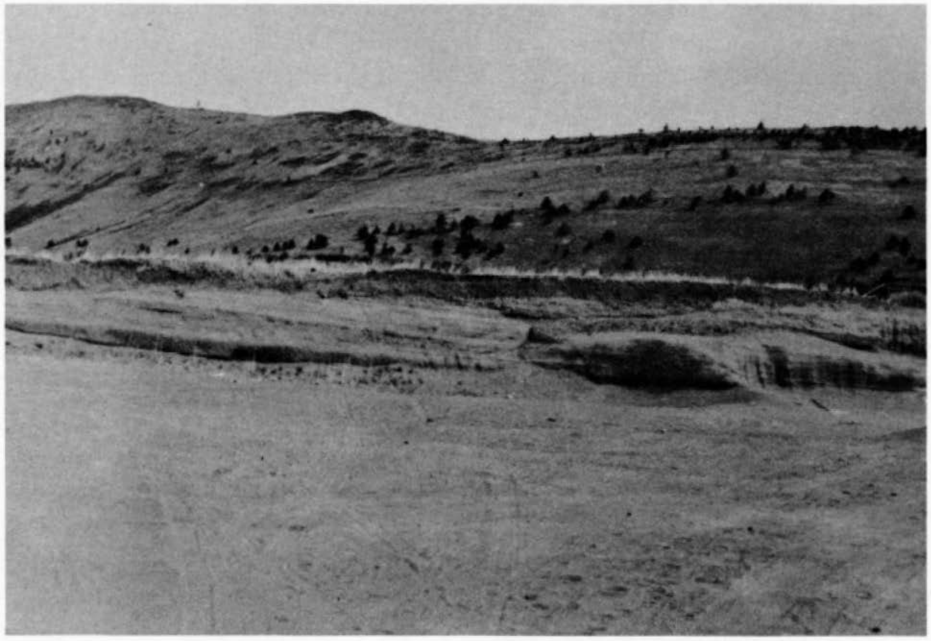


Figure 14 - Qlo unit.

Lacustrine(?) sediments deposited in the present lake basin at a higher lake level. Three miles east of the center of Klamath Falls. (SW¼ sec. 36, T. 38 S., R. 9 E.)

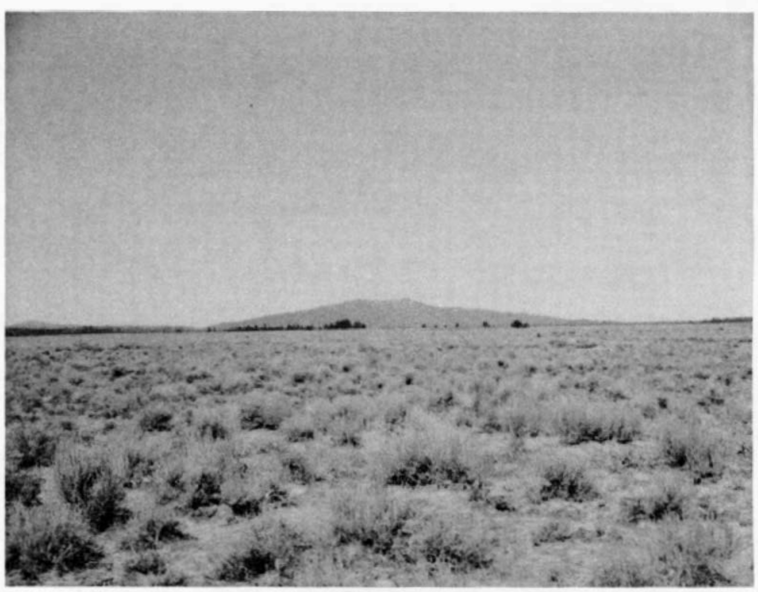


Figure 15 - QTvcb unit.

Fuego Mountain, a basalt and basaltic andesite eruptive center, seen from a distance of about 10 miles. Knot Tableland, the plain in the foreground, is floored by basalt (Qb). (NW¼ T. 34 S., R. 11 E.)

These flows show uneroded surface features and are probably of Holocene age. The crater is also older than the Mazama pumice which mantles it. In view of this and of the very slight erosional modification of the crater and its rims, it appears to be, at the most, late Pleistocene and more probably Holocene in age (Peterson and Groh, 1965, p. 19-28).

Big Hole crater a few miles northwest of Hole-in-the-Ground is larger ($1\frac{1}{2}$ miles in diameter) and shallower (200 feet deep) with greater volumes of dark-gray to brown lapilli explosion tuffs and breccias in the walls and rim. Big Hole is very similar to Hole-in-the-Ground but has probably had a longer and more complex eruptive history.

All of these features of Pleistocene(?) to Holocene age have been included in a single map unit (Qpt), even though they may not be exactly contemporaneous.

Unlike the Pliocene tuff rings, these features are not known to be associated with lake deposits and probably originated from the intrusion of basaltic magma into ground-water-bearing rocks.

Mazama pumice (Qmp): Almost all of the project area north of the Sprague River and Upper Klamath Lake and east to the Klamath County-Lake County line is mantled by an appreciable thickness of dacite pumice and pumicite erupted from Mount Mazama, the name given to the volcanic peak ancestral to the present-day Crater Lake in the Cascade Range. Immediately to the west of the study area Williams (1942, p. 69-87) distinguishes two main types of material resulting from the climactic eruptive phase of Mount Mazama. The earlier is very wide-spread pumice and pumicite distributed by air fall and designated as (Qmp) on the project map. Later, glowing avalanche deposits containing coarse lump pumice were laid down. These extend only a short distance into the area of this report and have not been differentiated from the earlier fall. An isopach map of the (Qmp) unit has been included (Mineral Resources Map, plate 2).

In general, the size of the pumice fragments becomes finer toward the margin of the depositional area. Some of the coarsest lump pumice observed in this study occurs in the area from Diamond Lake south to Lenz, along the Southern Pacific and Great Northern Railroads.

The color of the (Qmp) pumice is white or pale gray on fresh surfaces and buff to yellowish-brown on weathered surfaces. Pumice framents are equidimensional, and there are abundant drawn-out ovoid and tabular vesicles. The volume percentage of crystals is reported to range from 1 to 40 percent, but it is believed to average 10 to 15 percent in the region southeast of Klamath Marsh (Williams, 1942, p. 77). The crystals consist of plagioclase, hypersthene, augite, hornblende, magnetite, and ilmenite. The amount of exotic lithic fragments is small in the project area.

Carbonized wood fragments engulfed in the pumice have been collected in several areas. Radiometric age determinations by the carbon14 method have indicated the deposition of the unit to have been 6450 $\pm$ 200 years b.p. (Cressman, 1951). Very little soil has been developed on the pumice surface. Owing to its porous nature, water rapidly penetrates it and there is very little surface runoff. Consequently, there has been little redistribution of pumice by streams, except in the major drainages.

The Mazama pumice has been mapped as a unit only where it is thick enough to mask completely the character of the underlying rocks.

Alluvial deposits (Qal): No attempt has been made to map deposits of the present climatic cycle in detail. The most notable sediments now forming are diatomite and peat accumulating in Klamath Marsh and Upper Klamath Lake. The peat is being deposited in marshes peripheral to the bodies of open water. Diatomite is being deposited throughout the lake and pond environment. A shallow auger hole drilled in NE$\frac{1}{4}$ sec. 17, T. 31 S., R. 9 E. indicated that in this locality, from the surface downward, 4 feet of peat overlies about 3 feet of diatomite, which overlies an undetermined thickness of water-deposited pumice fragments believed to be Mazama pumice. The over-all distribution and thickness of recent diatomite in the Klamath Marsh-Klamath Lake depressions is not known, but the deposit may be extensive. Sand, silt, mud, and in some cases peat are also being deposited in Silver Lake, Summer Lake, Chewaucan Marsh, Goose Lake, and Sycan Marsh.

A minimum amount of alluvium has been shown on the maps. An interpretation of the underlying geology has been attempted wherever possible.

Late Tertiary and Quaternary Rocks of Uncertain Age or Relationships

Extrusive and shallow intrusive rocks at eruptive centers (QTvcb, QTvca, QTvcc, QTvrd:

There are numerous eruptive centers in the project area, ranging in size from small cinder cones covering a few acres to large volcanic piles such as Yamsay Mountain, which covers an area of nearly six townships and rises 3000 feet above its base. The larger volcanic centers such as Gearhart Mountain and Yamsay Mountain contain rock types ranging from rhyolite through basalt and record a complex eruptive history. The smaller volcanic centers usually contain only a single rock type (figure 15).

Basaltic eruptive centers (QTvcb) occur over the entire area. Their distribution seems to be random except in the Applegate Butte-Crawford Butte trend which is aligned parallel to the regional northwesterly fault strike. More questionable alignments with regional fault lineaments occur in the Gearhart Mountain-Shake Butte area, and the Edgewood Mountain-Chiloquin Ridge area.

Large basalt eruptive centers of low relief are believed to be present on the west slope of Winter Ridge. These are expressed as fan-shaped terraces on large-scale topographic maps of the area. They may be sources for the extensive basalt flows in Sycan Flat and the basalt tablelands of the lower Sycan River drainage.

Predominantly andesitic lavas (QTvca) appear to make up Yamsay Mountain, Gearhart Mountain, and Walker Mountain. They may be found elsewhere by more detailed studies.

Basaltic cinder cones (QTvcc) occur as isolated mounds or in satellite groups around the large eruptive centers, as in the area north of Yamsay Mountain in T. 29 S., R. 11 E.

There are numerous extrusive and shallow intrusive bodies of light-colored igneous rocks (QTvrd) occurring mainly east of 121°30' west long. and south of 43°00' north lat. These rocks range in composition from rhyolite through dacite to andesite vitrophyre. The acidic varieties are light gray to nearly white. The more basic are medium purplish or brownish gray. All of these rocks, with the exception of a few porphyritic dikes, have an aphanitic or glassy groundmass with scattered phenocrysts of feldspar. A few small magnetite crystals are also usually present. Obsidian and perlite masses are associated with several of these bodies. Contorted flow banding is commonplace.

The usual occurrence of the (QTvrd) unit is as intrusive-extrusive domes. An example of one of the many such features is that in Thomas Creek (sec. 27, T. 37 S., R. 18 E.). Clusters of domes occur in the Owen Butte-Quartz Butte area (T. 37 S., R. 16 E.). Silicification of these bodies is extensive. Rocks of these compositions also are present as dikes (QTrd), most of which are too small to map at a regional scale but which may be locally important to mineralization. Irregularly shaped piles of rhyolitic and dacitic rocks, which appear to be distinctly extrusive eruptive centers, occur at Partin Butte, Cougar Peak, Ferguson Mountain, Spodue Mountain, Bug Butte (figure 16), and others.

A wide range of ages is probable for this compositionally varied assemblage of eruptive centers. Almost all of the basaltic eruptive centers discussed here were essentially in place before the latest and most prominent stage of normal faulting, since they are cut by faults approximately to the same degree as the surrounding lowlands. Glaciation has modified the peaks that were of sufficient elevation to support summit snowfields. Yamsay Mountain, Gearhart Mountain, and Deadhorse Rim exhibit the most prominent glacial cirques and U-shaped canyons. Furthermore, all of the eruptive centers have been subjected to considerable erosion, as is evident from the exhumed dikes and the absence of any sign of vent area depressions. No very young eruptives, such as the flows and cone in sec. 19, T. 24 S., R. 8 E. to the northwest of the project area, were found within the map limits. The circumstantial evidence cited above suggests that upward building of these volcanic centers ceased in the early Pleistocene, and the oldest age that can be assigned is probably late Miocene or early Pliocene, contemporaneous with the regional occurrence of basaltic flows included in the (Tb) map unit.

The rhyolite, dacite, and andesite eruptive centers also appear to be of several ages. A radiometric age of 8.1 ± 0.5 m.y. has been determined for an intrusive rhyolite dome located on Thomas Creek (sec. 27, T. 37 S., R. 18 E.). Several field relationships in the upper Drews Creek area (Tps. 37 and 38 S., R. 17 E.) indicate that rhyolite domes and andesite vitrophyre piles are younger

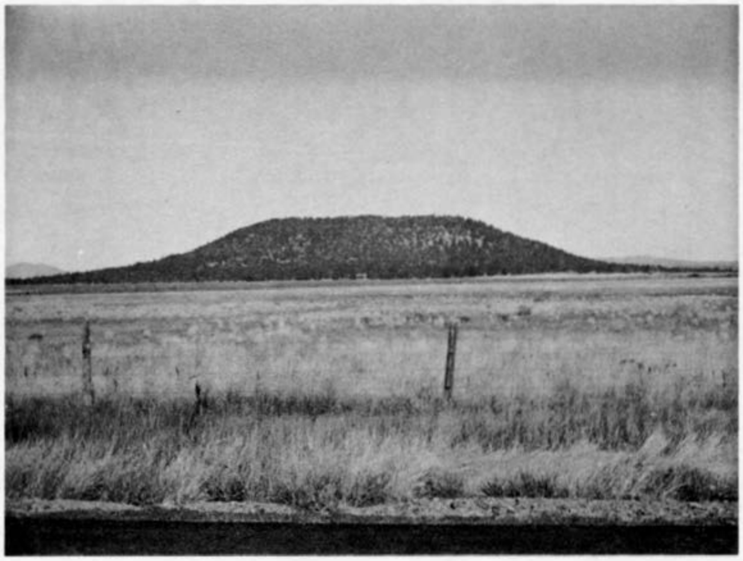


Figure 16 - QTvca.
Bug Butte, a small porphyritic andesite dome seen from a distance of about 3 miles. (secs. 24 and 25, T. 36 S., R. 11 E.)

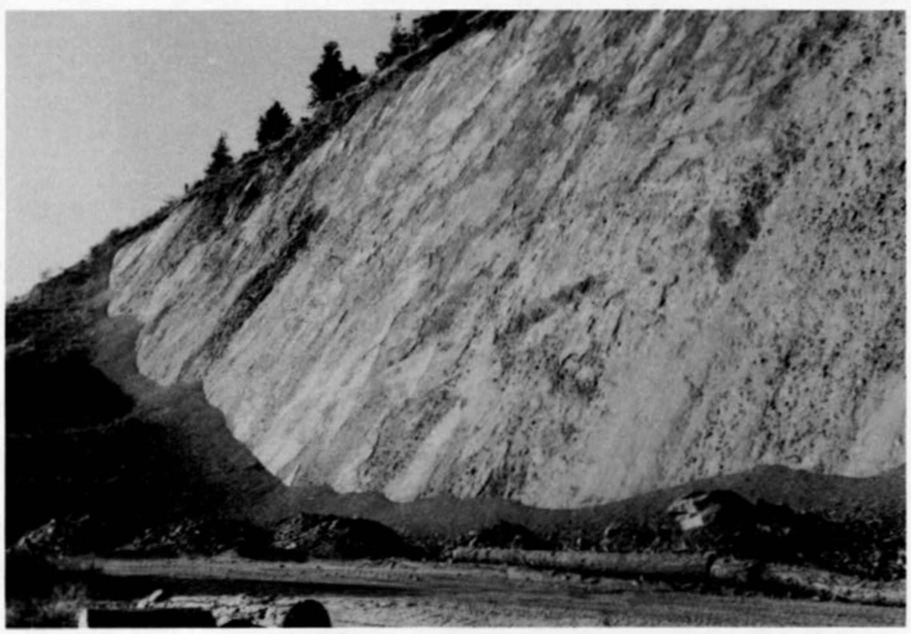


Figure 17 - Fault plane exposed by the removal of talus in a quarry south of Rattlesnake Point, east side of Klamath Lake. (NE$\frac{1}{4}$ sec. 25, T. 37 S., R. 8 E.)

Table 1. Chemical analyses of representative extrusive and intrusive rocks in Klamath and Lake Counties.

Locality and unit	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Loss on ignition	P_2O_5	Total
Dacite pumice (Qmp) sec. 8, T. 27 S., R. 8 E. (Moore, 1937, p. 159)	68.56	0.58	14.22	1.42	1.49	0.03	0.83	2.35	5.18	2.47	3.32	0.10	100.55
Dacite pumice (Qmp) (Moore, 1957, p. 157)	69.50	0.41	15.18	1.24	1.42	0.03	0.83	2.08	4.78	2.18	2.51	0.21	100.37
* Pleistocene dacite pumice (Pre-QTb - not mapped separately) NE¼ sec. 29, T. 35 S., R. 12 E. (P. 33116)	65.64	0.16	19.24	**1.52		0.09	1.21	3.51	4.13	1.45	2.74	N.R.	99.69
* Pliocene-Pleistocene basalt (QTb) center sec. 28, T. 39 S., R. 12 E. (P. 33112)	48.48	0.83	21.26	**9.38		0.21	6.86	9.22	0.52	0.30	0	N.R.	97.06
* Pleistocene basalt (Qb) Basalt of Knot Tableland sec. 20, T. 35 S., R. 12 E. (P. 33468)	47.74	N.R.	21.88	**8.82		N.R.	7.92	11.03	0.61	0.18	0	N.R.	98.18
* Pleistocene basalt (Qb) Basalt capping Goodlow Rim sec. 20, T. 39 S., R. 13 E. (P. 33467)	50.44	N.R.	21.88	**8.66		N.R.	5.77	9.32	0.45	0.20	0	N.R.	96.72
* Pliocene-Pleistocene basalt (QTb or Tb) Basalt capping Barnes Rim sec. 21, T. 39 S., R. 15 E. (P. 33469)	47.92	N.R.	21.44	**8.74		N.R.	7.98	11.13	0.58	0.24	0	N.R.	98.03
* Pliocene-Pleistocene basalt (QTvcb) Calimus Butte eruptive center SW¼ sec. 8, T. 34 S., R. 10 E. (P. 33507)	53.94	N.R.	22.71	**6.49		N.R.	1.90	7.72	4.65	1.62	0.26	N.R.	99.29

* Samples analyzed by State of Oregon Department of Geology and Mineral Industries.

** All iron calculated as Fe_2O_3.

Locality and unit	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Loss on ignition	P_2O_5	Total
* Platy andesite (QTa) of Walker Rim E½ sec. 15, T. 27 S., R. 8 E. (P. 33113)	58.00	0.94	22.61	**4.89		0.32	2.41	5.89	2.35	0.38	0	N.R.	97.79
* Pliocene palagonite tuff (Tpt) E½ sec. 29, T. 35 S., R. 10 E. (P. 33505)	49.00	N.R.	17.99	**11.23		N.R.	4.59	7.37	2.78	0.61	4.80	N.R.	98.37
* Pliocene basalt interbedded in lake sediments (Tst) sec. 24, T. 37 S., R. 8 E. (P. 33506)	50.48	N.R.	21.44	**8.58		N.R.	4.24	8.77	4.36	0.97	0	N.R.	98.84
* Pliocene basalt (Tb) capping Coleman Rim W½ sec. 20, T. 37 S., R. 17 E. (P. 33111)	48.16	0.43	20.93	**8.45		0.16	9.43	11.43	1.47	0.28	0	N.R.	100.74
* Pliocene basalt (Tb) ? at the base of the (Tst) sec. 36, T. 39 S., R. 7 E. (P. 33508)	47.10	N.R.	23.26	**8.34		N.R.	4.50	10.53	3.66	0.26	2.40	N.R.	100.05
* Rhyolite vitrophyre dome (QTvrd) W. edge sec. 27, T. 37 S., R. 18 E. (P. 33114)	76.20	0.07	13.34	**0.80		0.13	0.30	0.75	3.77	3.40	1.24	N.R.	100.00
* Rhyolite vitrophyre dome (QTvrd) center sec. 23, T. 37 S., R. 16 E. (P. 33115)	70.18	0.08	14.43	**1.31		0.11	0.91	1.90	3.15	3.25	3.16	N.R.	98.48
Quartz monzonite (Ti) of the Paisley Hills (From Muntzert, 1969, p. 49) (JM-291)	60.40	0.79	17.19	2.88	2.38	0.15	2.48	4.29	4.20	3.08	1.70	0.20	99.74
Quartz diorite (Ti) of the Paisley Hills (From Muntzert, 1969, p. 49) (JM-63E)	57.12	1.00	17.99	3.61	3.49	0.16	3.02	5.23	3.94	1.97	1.88	0.32	99.73

* Samples analyzed by State of Oregon Department of Geology and Mineral Industries.
** All iron calculated as Fe_2O_3.

than basalt flows (Tb) which cap Coleman Rim and Grizzly Peak. Cougar Peak also appears to have been built above the (Tb) basalt unit (Haddock, 1959, p. 32-36). Quartz Butte, a rhyolite vitrophyre dome, has been radiometrically dated as 7.6 ± 0.4 m.y. In the Bly Mountain Pass area (center of N$\frac{1}{2}$ sec. 15, T. 37 S., R. 15 E.), Pliocene lacustrine sediments seem to overlap andesite vitrophyre. North of Beatty (NW$\frac{1}{4}$ sec. 35, T. 35 S., R. 12 E.) a roadside quarry exposes rhyolite on the upthrown side of a normal fault, in contact with Pliocene lake beds. Elsewhere, however, rhyolite dikes are intrusive into tuffaceous sedimentary beds which are probably part of the Pliocene assemblage (NE$\frac{1}{4}$ sec. 24, T. 36 S., R. 12 E.).

The great thickness of rhyolite-dacite tuff and tuffaceous sediments in the (Ttf) map unit suggests that local vent areas for this unit might be found. Thus far, however, none of the rhyolite-dacite intrusive-extrusive masses have been determined to be the source for (Ttf) rocks. Rhyolite-dacite dikes (QTrd) intrusive into the (Ttf) unit were observed in Dry Creek (sec. 36, T. 40 S., R. 17 E.) and at the White King mine (center of sec. 30, T. 37 S., R. 18 E.), as discussed elsewhere.

There is a small amount of evidence concerning the relationships between the time of emplacement of the various basalt flows and eruptive centers and that of the more acidic rocks. Young basalts, such as those included in the (Qb) unit, appear to flow around and lap onto rhyodacite and andesite vitrophyre at Bly Mountain Pass, in the south fork of the Sprague River-Quartz Mountain area, and around Ferguson Mountain, between Beatty and Bly. In addition, the basalt flow covering Knot Tableland overlies a bed of pumicite containing large clasts of white rhyolite vitrophyre like that of the (QTvrd) eruptive centers (NE$\frac{1}{4}$ sec. 29, T. 35 S., R. 12 E.). This pumicite may represent eruptive material from one of the local rhyolite centers erupted previously to the youngest basalt flows in the mapped area (Qb).

Basalt flows, breccias, agglomerates, and pyroclastic rocks of uncertain stratigraphic position (QTb):

In addition to basaltic lavas which appear to be specifically associated with local eruptive centers, there are thick sequences of basalt flows, breccias, agglomerates, and pyroclastic rocks which cannot be assigned to local vents and which are in doubtful relationship to other stratigraphic units. Typical outcrop areas assigned to this map unit (QTb) occur at Naylox Mountain, immediately northeast of Klamath Falls; Stukel Mountain; Bryant Mountain, northeast of Malin; and adjacent parts of the western project area. This assemblage (QTb) is associated with several unsolved mapping problems which appear to involve complex interfingering between lacustrine sediments (Tst) and volcanic rocks. In addition, basalts of both the (Tb) and (Qb) intervals may be included in this unit in a few areas of the map.

Tertiary and Quaternary Intrusive Rocks

Diorite, granodiorite, and quartz monzonite stocks and dikes (Ti):

Small plutonic bodies of dioritic composition, with subordinate granodiorite and quartz monzonite, have been described in detail by Muntzert (1969, p. 36-52). They occur in isolated outcrop areas between Brattain Canyon (NW$\frac{1}{4}$ sec. 7, T. 34 S., R. 19 E.) and Ennis Creek on the east side of the Paisley Hills. Chemical analyses of two of these rocks have been included in table 1.

Field relations indicate that these plutonic rocks intrude both the dacite (Td) unit and the andesite, basalt flow, pyroclastic, and sedimentary members of the (Taf) unit. Potassium-argon ages determined from quartz monzonite samples range from 33.6 ± 1.5 m.y. to 32.6 ± m.y. (Muntzert, 1969, p. 51).

The lack of widespread metamorphism or deformation of the country rocks, lack of foliation in the intrusives and country rocks, and the presence of sharp, chilled borders on the intrusives indicate they are epizonal in character.

Radial vein systems and hydrothermal alteration of the associated country rocks have been mapped by Appling (1950) and Muntzert (1969). Chalcopyrite, sphalerite, and galena occur sporadically in the narrow vein systems adjacent to or associated with the plutonic rocks.

Basalt and diabase dikes and sills (Tdb):

It has been noted elsewhere that early Pliocene basalt flows mapped in (Tb) appear to be associated with dikes or sills which may have been their source. Intrusive bodies of this type which are large enough to appear at the present mapping scale occur in the southwestern part of T. 40 S., R. 17 E. and in the Cougar Peak-Grizzly Peak area (see figure 9). These dikes range in texture from fine-grained diktytaxitic basalt to very coarsely crystalline diabase with gabbroic pegmatite inclusions (Haddock, 1959, p. 23). In these pegmatites, crystals of plagioclase feldspar and augite reach 1 to 2 inches in length. One such coarse-grained body, on Thomas Creek (sec. 25, T. 37 S., R. 17 E.), contains zeolite minerals. In this area, the intruded volcanic siltstone has been locally converted to hornfels.

The largest body of diabase is reported by Haddock (1959, p. 23) to be about 4 miles long. This dike and sill complex occurs in upper Drews Creek (SE$\frac{1}{4}$ T. 37 S., R. 17 E.). The largest dikes and sills are between 100 and 200 feet thick. The northwesterly trend of most of these elongate bodies provides evidence for tensional fault activity along one of the major fault directions of the area as early as the Pliocene. A few feeder dikes for basalts of other ages were observed but not mapped because of their small size.

Rhyolite, dacite, and andesite dikes (QTrd):

Most of the rhyolite, dacite, and andesite vitrophyre intrusive bodies are domal and have been included in the (QTvca) and (QTvrd) map units. A few large dikes of this compositional range have been observed and mapped separately with the designation (QTrd). The most notable of the andesite dikes are on the west slope of Gearhart Mountain. A prominent rhyolite dike occurs in Dry Creek (sec. 5, T. 41 S., R. 18 E.). These bodies appear to be of the same age as the domal intrusions of similar composition. In the Dry Creek area, silicification and mercury mineralization occur adjacent to the dikes.

An interesting flow-banded dike-like mass of rhyolite has intruded the late Miocene sedimentary section at the White King uranium mine. Uranium and other epithermal metallic minerals accompany silicification and alteration that is associated with this intrusive.

GEOLOGIC STRUCTURE

The dominant structural features of the area are normal faults. These faults can be grouped into two systems based on relative age, general strike trend, and to some extent on the amount of displacement.

The first major group of faults, and probably the earlier one, is characterized by relatively small displacement, close spacing, and consistency in the strike pattern. In preparing the map for this project, all evident zones of rupture have been included along which any evidence of displacement could be seen. Fractures along which no movement could be distinguished appear to conform to the fault pattern but were not mapped. Most faults of this group show dip-slip movement of less than 500 feet. A few, however, such as those bounding Bryant Mountain northwest of Malin and those along the east side of Swan Lake Valley and Upper Klamath Lake, are in excess of 1000 feet.

In the southern four-fifths of the map the predominant fault-strike direction is northwesterly, associated with a few faults with northeasterly strike. In the northwestern part of the map, however, the northeasterly trend is predominant and the northwesterly subordinate. These two fault directions have been described in adjacent regions (Donath, 1962, and Larson, 1965). The change in strike direction of the majority of the faults in the trend is not abrupt but appears to come about by means of a gradual shift in strike through faults west of Klamath Marsh which trend nearly due north.

Exposures of fault planes in this set of faults occur at several localities on the west side of the project area (SE corner sec. 12, T. 34 S., R. 7½ E.; SW¼ sec. 6, T. 37 S., R. 9 E.; NW¼ sec. 6, T. 38 S., R. 8 E.; NE¼ sec. 32, T. 39 S., R. 10 E.; NE¼ sec. 25, T. 37 S., R. 8 E.; and elsewhere). In all of them the dip of the fault plane exceeds 60°. As far as could be determined from the fault planes and from geomorphic evidence, all of the movement on these faults has been in the dip-slip direction (figure 17).

The direction of dip and amount of displacement in the fault blocks also exhibit a pattern sufficiently consistent to be worth noting. In general, most fault blocks west of Klamath Lake are tilted to the southwest and down dropped to the northeast. East of Klamath basin and into the broad, central flat area of the Sprague River-Sycan Marsh most of the fault blocks have been tilted to the northeast. From Bly eastward to Goose Lake, the tilt in fault blocks is again generally to the southwest. East of Goose Lake the dip reverses to an easterly direction. The cross section on plate 1 illustrates this pattern. The frequency of faults and the amount of their displacement decrease markedly from both the Klamath Lake and Goose Lake sides of the map toward the relatively undisturbed central area.

The earliest age of movement on this set of faults is unknown, but Pliocene activity concurrent with lacustrine sedimentation is suggested by the northwesterly trending alignment of a row of tuff rings near Sprague River (SE¼ T. 35 S., R. 10 E.), the alignment of the Applegate Butte-Crawford Butte volcanic group, and the strike of dikes in the Cougar Peak area. The climax of activity in this group of faults appears to have occurred after the deposition of Pliocene lacustrine sediments and the emplacement of the early Pleistocene basalt flows (Qb). Diminishing fault activity is indicated in later periods by small offsets in Pleistocene lacustrine sediments (Qlo) at the north end of Goose Lake Valley. In the western part of the mapped area, high-angle fault scarps such as those along the east side of Upper Klamath Lake show relatively little modification by erosion. Although the faulting here is post-Pliocene in age, its precise position in the sequence of Quaternary events is not known. This group of faults appears to be offset by the "range" faults discussed below, and to be slightly older than these "range" faults.

The second group of faults includes those which trend in a northerly direction and appear to displace faults of the first group. The faults of the east face of Winter Ridge and the west face of the Warner Mountains and along the Abert Rim are typical of this category (figure 18). Smaller faults along the east side of the Summer Lake depression and on the west side of Goose Lake may also belong to this group. The name "range" faults has been applied by Larson (1965, p. 71-77), who considers them to be an expression of the large-scale Basin and Range system developed in southeastern Oregon, eastern California, Nevada, and western Utah.

Actual fault planes have been observed at the base of Winter Ridge (center of sec. 23, T. 30 S., R. 16 E.) and the Warner Mountains near Lakeview (center of NW¼ sec. 10, T. 39 S., R. 20 E.). In both places the dip of the fault plane is nearly vertical. All of the observed displacement indicates dip-slip movement. The amount of displacement along the west side of Summer Lake appears, by comparison of the surface section with deep water wells, to be in excess of 5000 feet. A comparable amount of movement appears to have taken place along the west side of the Warner Mountains.

The earliest movement along the "range" faults appears to have been early in the Pleistocene, at which time the present major topographic basins and intervening fault-block uplifts were formed. Most of the range elevation appears to have been achieved prior to the onset of glaciation, which has affected the highest parts of the Warner Mountains. Several stages of uplift are indicated in the northern Warner Mountains by well-developed terraces and faceted spurs (figure 18). At the base of Winter Ridge, landslide debris (Qls) seems to have been offset by faulting in several areas and to cross the fault zone undisturbed in others.

The fairly consistent regional pattern of dips in fault blocks suggests that faulting may have been superimposed on pre-existing broad, gentle folds. Scattered dips measured in tilted fault blocks may indicate the presence of a long and sinuous anticlinal axis trending through the Silver Lake and Summer Lake grabens, to Cox Flat and into and perhaps through the Goose Lake depression. This feature, which has been plotted generally on the geologic map, is most clearly indicated immediately south of Silver Lake (T. 29 S., R. 16 E.) on the cross sections accompanying Walker and others, 1967, and in the Shoestring Butte area (center of N½ T. 37 S., R. 18 E.).

Regional dip inward toward the Yamsay Mountain-Sycan Marsh-Sprague River area suggests the presence of a broad, irregularly shaped synclinal basin. This same line of reasoning indicates the possibility that one long northwesterly trending anticlinal uplift may have passed through Klamath Lake and another, trending northeasterly, may be present in the Chemult area. The inferred presence of these structures is supported by the increase in faulting in the vicinity of the anticlines and its decrease in the central syncline. The age of the folding is unknown, but it appears to have precededor to have been contemporaneous with the older of the two main groups of faults and to have occurred after deposition of the Pliocene lacustrine sediments, which show some evidence of having been folded.

Large-scale causes for the structures observed in southeastern Oregon have been discussed recently by Donath (1962), Larson (1965), and Pease (1969). It does not appear that a synthesis of the structure and geologic history of the region as a whole is sufficiently detailed as yet to warrant definite conclusions regarding the origin of the over-all structural pattern.

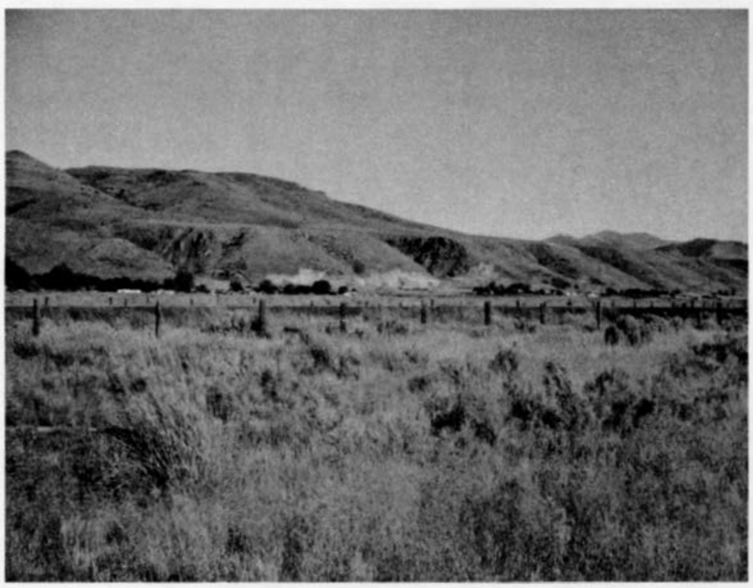


Figure 18 - Fault scarp along the east side of the Warner Mountains at Lakeview. Note the elevated terraces, indicating rejuvenation of faulting. (SW¼ T. 39 S., R. 20 E.)

SECTION 2. MINERAL RESOURCES

SUMMARY AND RECOMMENDATIONS

The actual and potential mineral resources of the project area are characteristic of a geologic province dominated by Cenozoic volcanism and the associated sedimentary deposits of nonmarine basins (see Mineral Resources Map, plate 2). The resources described in this report can be grouped into three broad classifications: (1) earth energy, (2) metallic minerals, and (3) nonmetallic minerals.

Earth-Energy Resources

The energy resources of the area are geothermal power, which is associated geologically with the Tertiary volcanism, and oil and gas. The generally favorable geologic environment and the evidence of large areas of anomalously high heat flow, as indicated from hot springs and wells, suggest areas in which prospecting for steam is warranted. The potential for development of energy in the form of oil and gas deposits appears inconclusive, for only 12 test wells have been drilled within the project boundary. Small amounts of combustible gas have been obtained from water wells and oil tests in the Lakeview area.

Metallic Mineral Resources

The metallic mineral resources investigated in this study are typical associates of shallow, low-temperature igneous activity. With the exception of indications of quicksilver in hot-spring areas near Klamath Falls, all of the known metallic mineralization occurs in the eastern part of the study area where acid igneous rocks are exposed. Of the mineral occurrences, uranium at the White King and Lucky Lass mines has accounted for almost all of the dollar value of metallic minerals produced from the project area in the past and appears to have the greatest potential for future economic development.

The most widespread metallic mineralization noted is the occurrence of the quicksilver ore mineral, cinnabar. Cinnabar occurs in association with basaltic, andesitic, and rhyolitic extrusive and intrusive rocks, but the most notable prospects are of the opalite type, including silcified plugs and dikes. Geologic exploration was not sufficiently detailed to preclude the possibility of the occurrence of a quicksilver deposit of economically significant size.

Some silver, lead, zinc, and copper deposits of varying size and quality are found in the Paisley Hills, in narrow veins associated with plutonic masses of granitic-type rocks. The known presence of metallic minerals, both in the veins and disseminated in the adjacent granitic plutonic rocks, warrants further geophysical and geochemical exploration. Gold has been recovered from early Tertiary rhyolite in the High Grade district, which straddles the Oregon-California line south and east of Lakeview. The district has a record of production but has long been dormant.

Geochemical sampling for metallic elements in the upper Drews-Whitworth Creek area, which is underlain by acid intrusive rocks, showed an anomalous occurrence of copper. Surface samples of large exposures of iron-stained brecciated rhyolite at Lee Thomas Crossing and in the Fitzwater Peak-McCoin Creek area were assayed, and even though these samples showed no precious metals they represent large areas of hydrothermal alteration and should be checked systematically.

Black sands, consisting of alluvial magnetite and ilmenite concentrations, have been collected from streams and lake-shore sediments in the Upper Klamath Lake-Agency Lake area. A shallow drilling program would be required to evaluate the reports of "black sand" from well-drillers' logs.

Nonmetallic Mineral Resources

Very large tonnages of the potentially valuable nonmetallic mineral commodities, diatomite, pumice, pumicite, and perlite, exist in the project area.

Diatomite occurs in thick and extensive beds associated with other sediments in Pliocene and Pleistocene-Holocene lake beds, either exposed at the surface or buried at shallow depths, in the western part of the project area. At least two deposits were found to contain filter-grade material, but detailed exploration by surface sampling and core drilling would be required to determine whether or not adequate volumes of material of marketable grade are available.

Deposits of dacitic lump pumice and pumicite are also volumetrically important in the western part of the project area. These deposits are at the surface and readily accessible to railroad and highway transportation. A small deposit near Klamath Falls produced some pumice during and after World War II. Detailed studies will be required to determine the location and amount of material qualitatively suitable for any of the particular markets for pumice and pumicite.

Perlite deposits of very large size have been outlined at several locations in the central and eastern parts of the project area, associated with shallow acidic intrusive bodies. Some have been sampled and are expansible. Additional qualitative evaluation of these occurrences will be required to determine their economic value.

Reed-sedge peat is present in extensive deposits of unknown thickness in the Klamath Lake basin, Klamath Marsh, and Sycan Marsh. Shallow drilling would be required to determine the volume of the deposits.

Agates and fossil wood can be found in the eastern part of the project area. The semiprecious gem stones in Oregon are of ever-increasing interest to "rockhounds," and some fine specimens have been discovered in Klamath and Lake Counties.

Materials such as cinders, scoria, sand, gravel, and stone suitable for building purposes and crushing all occur within the area in sufficient quantities for local use. Clay suitable for use in brick manufacture has been quarried in Klamath Falls from a deposit which is no longer accessible.

RECOMMENDATIONS FOR FUTURE MINERAL INVESTIGATIONS

Earth Energy

Geothermal steam

During the past few years there has been a considerable amount of geophysical study in areas having geothermal potential. As has already been noted, there are large areas in Klamath and Lake Counties having anomalously high heat flow. Drilling based on detailed geological, geophysical, and hydrological studies will be required to determine the real significance of this apparent potential for the large-scale production of geothermal steam. In addition to the favorable geological conditions, the presence of some private landholdings in the areas of interest is a further inducement to pursuing exploration while awaiting clarification of federal geothermal land-leasing policies. Concurrent studies of the economic aspects of geothermal steam-power generation and the production of large volumes of hot water should also be undertaken.

Metallic Minerals

Uranium

The demand for uranium to fuel nuclear electric-power generating plants will certainly increase in the coming years. Geochemical sampling has indicated possible unexplored anomalous concentrations of uranium in Swamp Creek and upper Drews Creek. These areas warrant further sampling, geologic mapping, and/or a radiometric survey. Vein deposits such as those at the White King mine should be present in other areas, and there is also the possibility of finding blanket-type bedded deposits in the early Tertiary nonmarine tuffaceous sediments.

Cinnabar

There are probably more than 50 square miles underlain by rhyolitic or rhyodacitic igneous rocks within the project area. Cinnabar mineralization appears to be primarily associated with these types of acid shallow intrusive and extrusive bodies, as well as silicified dikes and plugs. The possibility exists, therefore, that there are potentially large areas of disseminated quicksilver mineralization. It is suggested that more detailed geochemical sampling be done throughout the area known to be underlain by rhyolitic or andesitic rocks, coupled with exploratory drilling to determine the possible extent of mercury mineralization in this region.

Lead, zinc, copper

As has been noted above, there has been some production of lead, zinc, and copper, particularly in the Paisley Hills north of Lakeview. Geochemical anomalies have been discovered in other places within the project area. It is suggested that particular attention be given to the zone of hydrothermally altered rocks in the vicinity of Lee Thomas Crossing and the Fitzwater Peak-McCoin Creek area.

Nonmetallic Minerals

Diatomite

Diatomite appears to be the most promising nonmetallic mineral resource in south-central Oregon. Of 10 samples collected during the course of the field study, at least 2 were found to be of filter-aid quality. Many of the deposits are located within easy access to the Great Northern and Southern Pacific Railroads which serve California, Oregon, and Washington.

A study should be made to determine the environmental conditions that promoted the growth of certain types of diatoms that produce the best quality of filter cake. This should be followed by a broad geologic reconnaissance and sampling program preparatory to drilling in those areas showing the greatest potential. It should also be pointed out that diatoms are growing today in Klamath Lake, and efforts should be made to determine whether these deposits could be harvested economically. One company is presently carrying on a "mining" operation of this type in Iceland - a good example of the wise use of a renewable resource.

EARTH-ENERGY RESOURCES

GEOTHERMAL ENERGY

Geothermal energy is being harnessed in a small way in many parts of the world, not only in the form of steam for power production but also through the use of hot water from shallow wells for space heating of residential and industrial buildings. The first geothermal steam electrical power station was built in Larderello, Italy in 1904. Since then, power plants have been established in New Zealand, California, and Japan. Similar plants are planned in other areas. All together, only about one million kilowatts of electrical power are currently being generated around the world by this means, but as the technology for locating and developing geothermal steam resources improves, the utilization of this energy source will increase significantly. The use of hot water for space heating has reached large scale economic proportions in Iceland and may find valuable industrial applications elsewhere. Hot water is presently used on a small scale for domestic and industrial purposes in the project area.

The working out of the basic geologic characteristics of geothermal steam fields is in the beginning stages, but from the geologic studies thus far performed, the following generalizations can be made: 1) Promising geothermal areas are almost always found in geologically young orogenic belts or regions with recent volcanic activity; 2) Calderas, grabens, or tilted fault blocks are the most common geologic structures in steam-producing areas; 3) The presence of hot water wells, hot springs, geysers, or fumaroles are favorable indications of the presence of a thermal anomaly.

Geologic factors necessary for the presence of a producible steam field include four other criteria: 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 2000 to 5000 feet; 3) a cap rock or confining layer with low permeability that inhibits loss of fluids and heat; and 4) adequate fluid recharge. As far as can be determined at this time, there is a reasonable probability that all of these requirements can be satisfied in the project area.

Apart from technological problems, exploration for geothermal resources has been deterred by the lack of a federal law allowing its exploitation on public land. Legislation has been introduced, however, and it is to be hoped that suitable areas of federal land will be available for leasing whenever this law is established. There appears to be no impediment to the production of steam on non-federal land at the present time.

Geothermal Potential in the Project Area

The geologic environment of much of the area appears to be favorable for the occurrence of some geothermal potential. The basalts contain porous and permeable zones of fractured and scoriaceous rock that are suitable for steam reservoirs. The lacustrine beds can function as cap rocks to confine the steam in underlying basalt reservoirs. The extensive normal faulting can provide additional zones of porosity and structures in which steam could be localized. Some parts of the area have anomalously high heat flows. These are indicated by hot springs and hot-water wells. The presence of volcanic eruptive centers of Pliocene and Pleistocene age makes it likely that intrusive bodies are present at depth and are the source of the indicated heat.

A study of hot springs and available water well logs has made it possible to outline large, near-surface thermal anomalies (plate 2). In general, the anomalies are located in valleys, perhaps because this is where the wells are concentrated. The conditions considered anomalous were based on the departure of the temperature of the well from an assumed normal temperature of 48°F. plus 1°F.

for each 50 feet of depth below 100 feet.

The discussion of the thermal anomalies in the project area falls into three large divisions, as follows: the Klamath graben complex, the central project area, and the Goose Lake-Summer Lake graben complex.

Klamath graben complex

The succession of geologic events in this part of the project area, as known from surface outcrops and shallow wells, began with the extrusion of probable early Pliocene basalt. This was followed by deposition of Pliocene diatomaceous and tuffaceous lacustrine sediments and basalt flows. Extensive faulting, occurring after emplacement of the sediments and basalts, resulted in the horst ridges and graben valleys of the present terrain. Deposition of fluvial and lacustrine sediments has continued to the present, buryingsomeof the fault blocks that are present in the bottom of the valleys.

The Klamath graben complex includes two anomalous thermal areas that are of particular interest. These are centered around Klamath Falls and the Klamath Hills. In addition there are some scattered anomalous occurrences of warm water elsewhere.

Klamath Falls anomaly: This anomaly extends through much of the city of Klamath Falls along the east edge of the Klamath Lake basin (area no. 1 on plate 2). Peterson and Groh (1967) made a preliminary study of the geothermal potential in the Klamath Falls area, from which part of the following discussion is derived.

The geothermal area is near the east edge of the large Klamath graben complex in slightly tilted northwesterly trending blocks that are elevated a few hundred feet above the valley floor. Well logs indicate that diatomaceous tuffs and layered sediments (Tst) are at least several hundred feet thick. These are usually impervious to the flow of water and act as a cap at the surface. Broken lava flows and zones of scoria and cinders are encountered at various depths. In most cases in the thermal area these horizons yield large quantities of live hot water. At least one strong northwest-trending fault is present on the east side of the geothermal area. The brecciated rocks associated with this fault may provide the conduit for the rise of hot water from a deeper reservoir.

Figure 19. Shallow dry-steam well in the Klamath Falls geothermal zone.

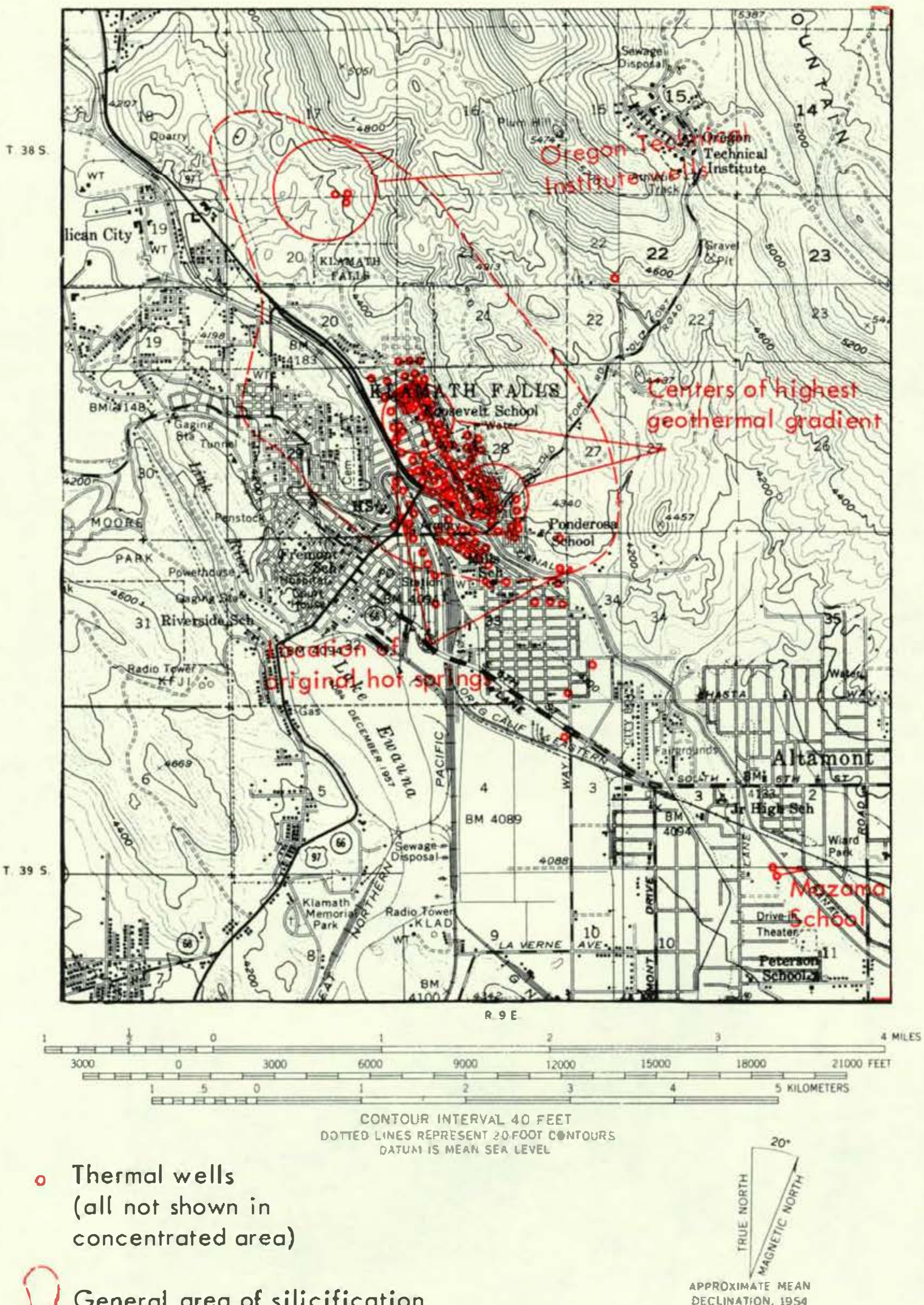


Figure 20 - Klamath Falls geothermal zone.

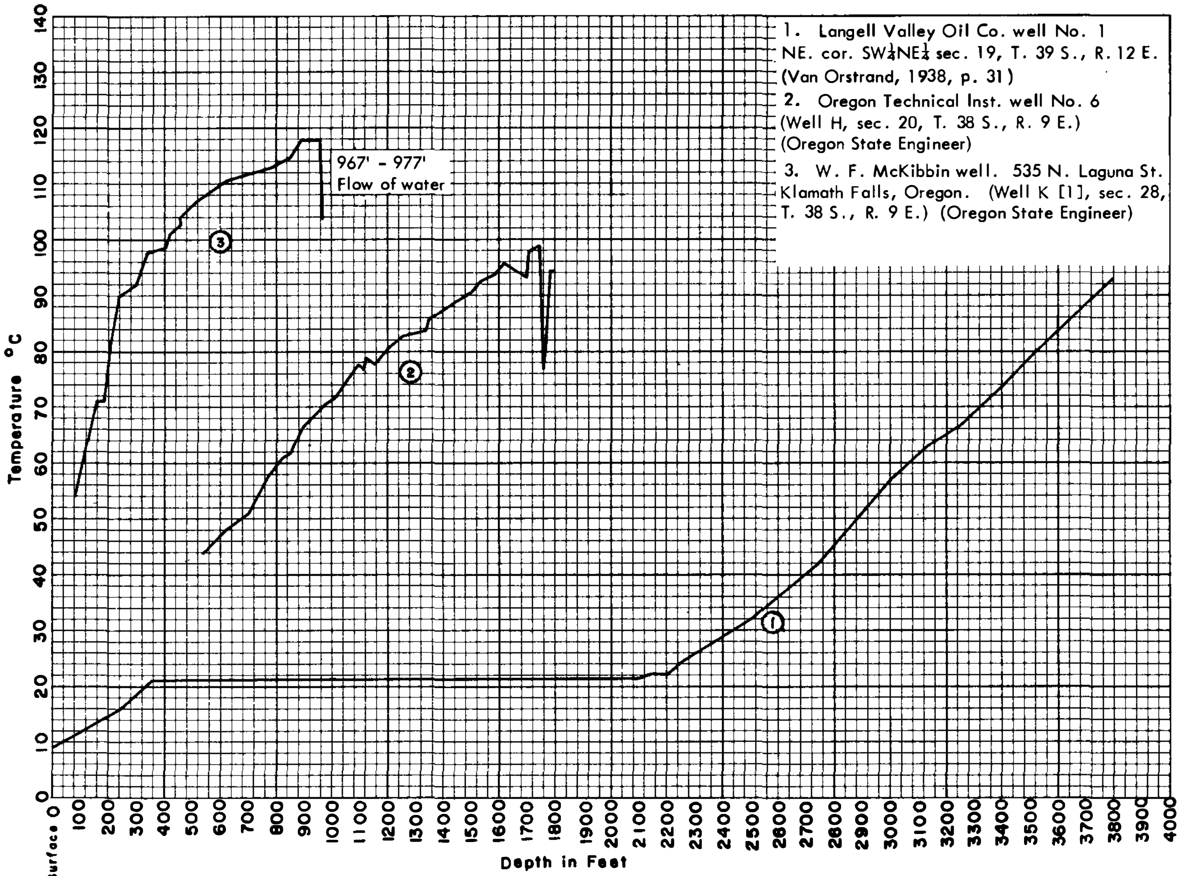


Figure 21. Temperature data from selected wells.

Although the heat source is not known, Pliocene-Pleistocene dikes and sill-like masses intercalated in lacustrine deposits in adjacent areas suggest the presence of a cooling igneous mass at depth. The existence of bleached and silicified rocks, deposits of calcite and gypsum, and a minor halo of mercury mineralization surrounding the geothermal area corroborates this supposition. A more important indication is the large amount of heat flow that is being tapped for local use (figure 19). Approximately 350 wells have been drilled to date, mostly for space-heating requirements of more than 450 residences, a number of apartments, seven schools, several business and commercial firms, and the new Oregon Technical Institute plant. According to present knowledge of the geothermal zone, the water hotter than 140°F. extends from the OTI campus in the northwest part of this zone to the Mazama School in the southeast, a distance of about 4.5 miles. A broad area of warm water extends beyond the hot wells.

The depth of the wells ranges from 100 feet to a maximum of 1800 feet. The water table generally seems to coincide with the elevation of Upper Klamath Lake (4136 feet), and static water level depths vary with the topography. Wells south of the irrigation canal generally are artesian, since the water table is near the surface in this area (figure 20).

Temperatures of the thermal wells in the geothermal zone range from 140°F. to 235°F. The highest temperature gradients seem to cluster about two centers in the zone. One of the centers, in figure 20, is located on Hillside Avenue. There, several wells in the range of 100 to 200 feet in depth emit dry steam with a pressure of several pounds per square inch (figure 19). It is probable that the steam is flashing into the well bore from a very limited water flow in impervious rocks at a temperature of about 230° to 235°F.

Because of the imperviousness of the rocks, temperatures and depths at which water flows are encountered vary to some degree from well to well. Drillers report measuring well-bore temperatures as high as 250°F. in some wells while still in dry rock. Upon striking a flow of water, well-bore temperatures drop to the 220°-230°F. range. Apparently the rock in some places is reaching a higher temperature by conducted heat and is cooled slightly when water enters the well bore (figure 21).

Chemical analyses of the thermal waters in the area seem to show that the thermal fluid from depth is not adding significant minerals to the cool ground water with which it is presumably mixing (see table 2, in pocket). On this basis, it is probable that the thermal fluid flowing upward into the geothermal zones is steam. The temperatures and quantities of heat involved seem to require a fluid having the enthalpy of steam to heat the ground water. The steam may be coming from a deep, dry steam reservoir (Grindly, 1964), or perhaps may be boiling off from superheated fluids contained at depth (Facca and Tonani, 1964). In either case, the presence of a higher temperature geothermal source seems to be indicated, and hence economic possibilities may exist for the generation of power in addition to the present space-heating uses.

Klamath Hills anomaly: The Klamath Hills is a large, isolated fault block within the Klamath graben, about 10 miles south of Klamath Falls (area No. 2 on plate 2). The geologic environment of this thermal zone is similar to that of the Klamath Falls area. Basalt flows and associated breccias, scoria, and cinders predominate in the exposed rocks of the Klamath Hills fault block. A halo of silicified lake sediments and tufa is present in an area about 4 miles long (figure 22). Large volumes of hot water (200°F.) are encountered at shallow depths in a narrow zone along the southwest side of the fault block.

A well located on the John Liskey ranch in sec. 34, T. 40 S., R. 9 E. uses hot water for irrigation after storage in a reservoir for a few days to allow cooling (figure 22). This well pumps 1000 gals./min. of 200°F. water from a depth of 285 feet. At one time this well was test pumped at a rate of 7000 gals./min. Analysis of the water is given in table 2.

Another hot-water well at the Osborn ranch, about half a mile to the north, pumps 186°F. water from a depth of 418 feet at a rate of 450 gal./min., also for irrigation purposes. Two wells in sec. 28, T. 40 S., R. 9 E., and three wells in sec. 1, T. 41 S., R. 9 E. have temperatures around 80°F.

The Liskey well would seem to be nearest the point at which the thermal fluid from depth is reaching the ground-water zone. The channel is probably along a fault bounding the Klamath Hills horst. It is likely that the thermal zone extends for some distance southward beneath the alluvium of Lower Klamath Lake basin, but the zone appears to be somewhat smaller in areal extent than the Klamath Falls geothermal zone.

Other anomalies in the Klamath graben complex: Many of the wells drilled in the Klamath graben complex are reported to produce water which is warmer than "normal" for its depth. Areas of particular note appear to be located at the south end of the Klamath Hills, immediately to the north and west of Stukel Mountain, and in Miller Hill.

Aside from the original hot springs in Klamath Falls that have disappeared through the lowering of the water table and through culture changes, two natural thermal displays still exist within the Klamath graben complex. One of these is a spring on the north bank of the Lost River at Olene Gap. It has a temperature of 165° F., with a flow estimated to be at least 100 gallons per minute. An analysis of this spring water is given in table 2. Another spring is located at Eagle Point, on the shore of Upper Klamath Lake. Here a temperature of 94°F. was measured at the bottom of an old cistern. The high level of the lake at the time of measurement was causing considerable dilution of the spring water. Some gas, which was not tested but is probably carbon dioxide, bubbles through the water along the shore. A faint odor of hydrogen sulfide is also present.

Central project area

The geology of the central part of the project area is similar to that of the Klamath graben, with the exception that Pleistocene to Holocene valley fill is thin or absent. The structure is dominated by normal faulting and the stratigraphy by early Pliocene basalt (Tb) overlain by impermeable lake beds of later Pliocene age (Tst).

Natural warm water occurs in several wells and springs in the Poe, Yonna, and Langell Valleys east of the Klamath basin. In Langell Valley a hot spring (142°F.) is located in the center of the south line of the NW$\frac{1}{4}$ sec. 10, T. 40 S., R. 13 E. Another warm (72°F.) spring occurs in the center of the NE$\frac{1}{4}$ sec. 6, T. 40 S., R. 14 E.

Hot water was reported in two oil-test wells drilled along the southern edge of Yonna Valley (Van Orstrand, 1938). The Langell Valley Oil & Gas Co. "Bonanza" well in the NE$\frac{1}{4}$ sec. 19, T. 39 S., R. 12 E. recorded a water temperature of 200° F. at a depth of 3850 feet. The significance of this test lies in the fact that a constant temperature of 70°F. was maintained from near the surface to 2000 feet, where it rose very rapidly to 200°F. in the next 1800 feet. From the shape of the temperature curve it appears there is a possibility of a high-temperature source at depth overlain by an insulating formation that does not allow much of the heat to escape. A graph of the well temperature is shown on figure 21. The other oil test, the Yonna Valley No. 1 drilled in sec. 13, T. 39 S., R. 11$\frac{1}{2}$E., also shows a near isothermal curve to a depth of a little more than 2000 feet, below which it records rapidly increasing temperatures. The well bottomed at 2250 feet with a temperature of about 93° F.

The Sprague River valley has two areas in which wells contain water which appears to be a few degrees above normal. One of these areas is along the valley floor between the towns of Sprague River and Beatty. The other is northwest of Bly.

These scattered reports suggest that important geothermal anomalies may occur in the central project area. They are too inadequately known, however, to be included on plate 2.

Goose Lake-Summer Lake graben complex

A zone of hot springs and wells occurs in the valleys extending along the east side of the project area from the north end of Summer Lake intermittently to the northern part of Goose Lake Valley. This elongate zone is shown on plate 2.

The structural setting of these occurrences is much the same as it is elsewhere in the project area. The valleys are complex grabens formed by downdropped blocks of Miocene volcanic rocks and tuffaceous sediments covered by lower Pliocene basalt. Middle or upper Pliocene sediments have not yet been reported from these basins, but Pleistocene to Holocene lake beds have buried the intrabasinal fault-block terrain. No evidence of recent intrusion or volcanism has been seen. The hot springs issue from alluvium near the fault zones along the sides of the grabens and many of the warm water wells are also located here. The water from all of these springs and wells seems to be generally similar to the water from the Klamath Falls area (table 2).

The more notable anomalies are briefly discussed below.

Lakeview anomalies: Two groups of hot springs are present along the eastern margin of the Goose Lake graben in a narrow zone that extends about 3 miles north and 3 miles south of Lakeview. In this area early Tertiary volcanic rocks are exposed in the fault escarpment along the east side of the graben, but the valley floor where the hot springs occur is underlain by several hundred feet of alluvium and Pleistocene lake beds.

The largest group of springs is the one known as Hunter's Hot Springs located 2$\frac{1}{2}$ miles northwest of Lakeview (area No. 4 on plate 2). These springs have been developed as a spa since the early 1900's, with a motel and swimming pool at present. The thermal area can be seen from U.S. Highway 395, especially in winter when a shallow drilled well called "Old Perpetual" erupts like a geyser about every 30 seconds (figure 23). In addition to the springs that heat the motel resort, several shallow wells have been developed for residential heating and for operating an experimental greenhouse in the immediate locality. Surface temperature at the spring orifices is near boiling (205°F. to 210°F.) at this altitude.

The Nevada Thermal Power Co. drilled a test well about a quarter of a mile southeast of Hunter's Hot Springs in 1960 but abandoned the hole at about 650 feet because of drilling problems. The steam potential here is as yet untested. It is estimated from the surface heat flow that there is enough heat available to provide much of the space heating required for the city of Lakeview.

The other group of hot springs in the Lakeview anomaly area occurs at Rocky Point about 2

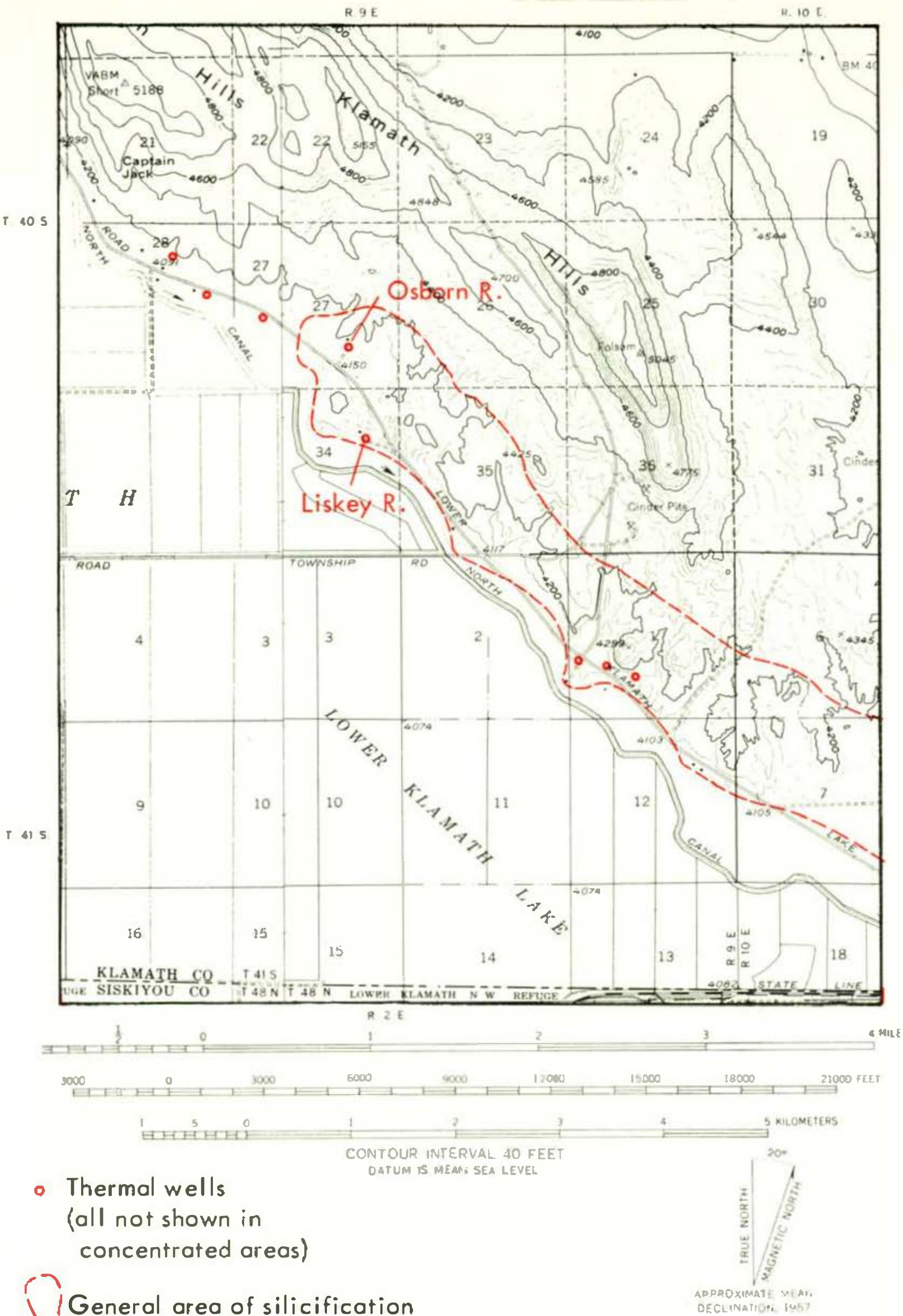


Figure 22 - Klamath Hills geothermal zone.

Figure 23.

Man-made geyser at Hunter's Hot Springs, about 3 miles north of Lakeview.

miles south of Lakeview (area No. 3 on plate 2). The location is on the Barry ranch in sec. 27, T. 39 S., R. 20 E. Here, three hot springs have temperatures near boiling, but they are not used because the water has a strong odor of hydrogen sulfide.

Other anomalies in the Goose Lake-Summer Lake graben: Several slightly warmer than normal wells occur along Crooked Creek to the north of Goose Lake. Distinctly warm wells are reported from drillers' records in the town of Paisley. Here a temperature of 104°F. was recorded from a depth of 315 feet, in section 23, T. 33 S., R. 18 E. Farther to the north, Summer Lake Hot Spring, NE¼ sec. 12, T. 33 S., R. 17 E., produces water at a rate of 21 gallons per minute at 116°F. (area No. 5, plate 2) (Trauger, 1950, p. 224). Wells in this area are also warm, as are others along the base of the fault scarp in sections 10 and 23, T. 31 S., R. 16 E. Ana Spring, sec. 6, T. 30 S., R. 17 E., one of the largest springs in the United States, flows 45,000 gallons per minute at a temperature of 66°F. (Trauger, 1950, p. 220). While the temperature of this spring is too low to be of commercial significance, it is further evidence of the large amount of heat being transported to the surface in this area.

Summary of Geothermal Energy in the Project Area

There is impressive evidence of abnormal geothermal gradients in a large part of the project area. A significant, if undetermined, value has already accrued to the residents of Klamath Falls from the relatively unsystematic exploitation of hot water produced from wells there. The same is true for the Lakeview area to a much lesser degree. Sophisticated exploration for steam for power generation appears to be warranted but has not yet taken place. Furthermore, the development and utilization of large volumes of hot water for industrial use in processing such potential local resources as diatomite and wood pulp should be studied.

OIL AND GAS

The occurrence of oil and gas deposits in sufficient size to be of economic significance is determined by several factors. Among them are the presence of organic-rich, fine-grained sedimentary source rocks in which hydrocarbons could be generated, associated with porous and permeable reservoir rocks in which hydrocarbon fluids could be concentrated and from which they could flow into a well bore. Common source rock types are dark-colored shales, siltstones, and fine-grained limestones

Table 3. Oil and gas exploratory wells and two water wells with small shows of gas.

Company	Well name	Locality	Year	Depth	References
		Oil and gas exploratory wells			
Klamath Oil Co.	Manning No. 1	Approx. 7 miles south of Klamath Falls. SE¼ sec. 1, 40S, 9E, 100' S. of N. line & 400'W. of E. line. Elev. 4100'.	1919-1930	1965'	(Buwalda, 1921)
Langell Valley Oil Co.	"Bonanza Well"	NE¼ sec. 19, 39S., 12E. Elev. 4150'.	1926-1941	4365'	Cable tools. Hit hot water (200°F.) at 3850'. (Van Orstrand, 1938)
Oakland interests	Oakland No. 1	Dairy. SW¼ sec. 19, 38S., 11E. Elev. 4160'.	1931	500'	Cable tools. (Van Orstrand, 1938)
The Crater Oil&Gas Co.	Well No. 1	Merrill. 41S., 10E. Elev. 4060'.	1930's	685'	Cable tools. (Van Orstrand, 1938)
Yonna Valley Oil & Gas Co.	Dairy No. 1	Bonanza area. Sec. 14, 39S., 11½E. Elev. 4120'.	?	2000'+	Cable tools. Flowed warm water at 550', 935', and 1300' (85°F.) (Van Orstrand, 1938)
Lakeview Oil Co.	Well No. 1	West of Lakeview. SE¼ sec. 16, 39S., 19E. Elev. 4800'.	1940	2870'	Rotary. Small amount of gas reported. (Dept. file)
Lakeview Oil Co.	Well No. 2	West of Lakeview. Sec. 22, 39S., 19E. Elev. 4800'.	1940-1941	1680'	Rotary. (Dept. file)
Humble Oil &Refg. Co.	Leavitt No. 1	Lakeview. NE¼ sec. 2, 40S., 20E. 412'S. of N. line & 991'W. of E. line. Elev. 4784'.	1960-1961	9579'	Rotary. Gas shows in carbonaceous sediments at 7500'. (Dept. file)

Table 3. Oil and gas exploratory wells and two water wells with small shows of gas (continued).

Company	Well name	Locality	Year	Depth	References
		Oil and gas exploratory wells, continued			
Humble Oil & Refg. Co.	Thomas Ck. Unit. Block III Well No. 1	NE¼ sec. 18, 36S., 18E., 400'N. of S. line & 925'W. of E. line. Elev. 5260'.	1960	12,093'	Rotary. No shows. Drilled entirely in Tertiary volcanics and cont. seds. (Dept. file)
Stark, Ralph W. (Tri-State Petr.)	Fisher No. 1	West of Lakeview. SW¼ sec. 22, 40S., 19E. Elev. 4750' Gr.	1950-1951	2900±	Rotary. Strong flow of gassy water. See analysis in Table 4. (Dept. file)
Stark, Lyell W.	Stockburger No. 1	West of Lakeview. NW¼ sec. 15, 40S., 19E. Elev. 4700' Gr.	1953	1730'	Rotary. Hit flow of warm, gassy water (80°F.). (Dept. file)
Stone, Chas. A.	Anderson No. 3	West of Lakeview. SW¼ sec. 20, 39S., 19E. 2290' N. of S. line & 20' E. of E. line. Elev. 4800'.	1955	730'	Rotary. No shows reported. (Dept. file)
		Water wells			
Carter ranch	Water well	Approx. 9 miles south of Lakeview. 40S., 19E.	1915±	370'	Small flow of flammable gas with water. See analysis in table 4. (Buwalda, 1921)
City of Lakeview	water well	Lakeview. NE¼ sec. 15, 39S., 20E. Elev. 5000'.	Before 1938	2380'	Hot water found in lower portion of the hole (150°F.) (Van Orstrand, 1938)

of marine or lacustrine origin. Any porous rock may serve as a reservoir for fluids, under the appropriate conditions. Common reservoir rock types are sandstones and porous carbonate rocks. Fractured igneous rocks sometimes produce oil when in association with suitable sedimentary source rocks. A trap also must be present in the reservoir rock in a producing area. A trap constitutes a barrier to further migration of hydrocarbon fluids in the rock, against which these fluids may accumulate.

Within the project area, 12 exploratory wells for oil or gas have been drilled, 5 of them in Klamath County and 7 in Lake County. A brief summary of these wells from Newton (1965, p. 22, 23) is given in table 3 and their location shown on plate 2. In addition to the wells drilled specifically for oil or gas, two water wells in Lake County encountered small shows of gas. These are also listed in table 3. No indications of hydrocarbons have been reported except the traces of gas noted in table 3. Gas analyses for two wells are given in table 4.

The rocks exposed at the surface in the project area and those encountered in the subsurface by wells are not of the type generally associated with commercial accumulations of oil or gas. The section is dominated by lava flows, volcanic ash, and lacustrine and fluvial deposits derived from volcanic materials. All of these rocks are of Tertiary or Quaternary age. Fine-grained diatomaceous sediments are common in the Pliocene and the Pleistocene to Holocene lake beds of Klamath County, but none appear to be rich in organic material. Carbonaceous shales associated with a small gas show were reported on the mud log of the Humble Leavitt No. 1 well in Lake County in the interval from 7300 to 7500 feet. There is no evidence available concerning the areal extent of these carbonaceous shales in the subsurface.

The most extensive and intensive evaluation of the commercial hydrocarbon potential within the project area was that undertaken by Humble Oil & Refining Co. in the period from 1958 to 1961. This company reportedly had hoped to test pre-Tertiary marine rocks in its two Lake County holes. Description of cores and cuttings indicates that the drilling terminated in Tertiary volcanic formations and never reached the marine objective. Pre-Tertiary marine formations may underlie the region and possibly contain deposits of oil or gas. It is also conceivable that, if such hydrocarbons exist, they could have migrated upward into porous layers of the overlying Tertiary volcanic rocks.

Structurally, the project area is dominated by normal faulting. No simple anticlinal folds were seen which could be considered as traps for fluid hydrocarbons. Other types of traps, both stratigraphic and structural, could exist, but none were apparent from the limited amount of data available to this study.

There is no evidence available from the results of the present geological studies or from past drilling to indicate that the possibilities for discovery of commercial quantities of oil and gas within the project area are good. As far as is known, there is no exploration activity going on at the time of publication of this report.

Table 4. Gas analyses for two wells in Klamath and Lake Counties.

Locality	BTU	Methane %	Ethane %	Nitrogen %	Carbon dioxide %	Hydrogen sulfide -%
Fisher well No. 1 SW$\frac{1}{4}$ sec. 22, T. 40 S., R. 19 E. Lake County 1/	914	90.33	0.96	8.41	0.30	Nil
Carter ranch water well, approx. 9 mi. sw. of Lakeview, Lake County, T. 40 S., R. 19 E. 2/	783	73.5	----	26.0	0.5	----

1/ Analysis, El Paso Natural Gas Co., 11/18/53. 2/ Analysis, U.S. Bur. Mines, in Buwalda, 1921.

METALLIC MINERAL RESOURCES

URANIUM

So far, the only uranium of economic significance in Oregon has been found northwest of Lakeview at the White King and Lucky Lass mines. From the time of the discovery in 1955, nearly 400,000 pounds of U_3O_8 has been produced from 125,000tons of ore, most of it from the White King mine. A 210 t.p.d. mill was built in 1958 to process ore from the two mines, as well as other amenable custom ores.

In the Klamath-Lake Counties project area, the known uranium occurrences are confined to a rather small area northwest of Lakeview in the Fremont Mountains. The uranium mineralization appears to result from low-temperature, near-surface processes and is found mainly in ashy tuffs at their contact with scoriaceous basalt flows or where they have been intruded by dacite or rhyolite plugs and dikes similar to rocks dated as 7.6 and 8.1 million years old in nearby areas.

The forecast of a scarcity of uranium for planned nuclear electrical generating plants through 1980 has already encouraged mining companies to re-evaluate the potential of the Lakeview area. Although the vein-type hydrothermal deposits northwest of Lakeview are likely to have only moderate reserves, additional deposits in the area could provide appreciable amounts of ore as Oregon's contribution to the future uranium market.

Short descriptions of the White King and Lucky Lass mines, the two uranium mines with productive records, are given below. The other prospects and occurrences are summarized in table 5. Map numbers indicate locations on plate 2.

White King Mine

The White King mine is located near the center of sec. 30, T. 37 S., R. 19 E., about 15 miles northwest of Lakeview, Oregon. The mine is in the southern Fremont Mountains at about 6300 feet elevation, near the west edge of an upland meadow through which Augur Creek meanders. Heavy soil cover and abundant timber are typical of the area. The discovery in 1955 of secondary green uranium minerals in siliceous rhyolite and tuff outcrops at the surface began a short-lived but interesting history

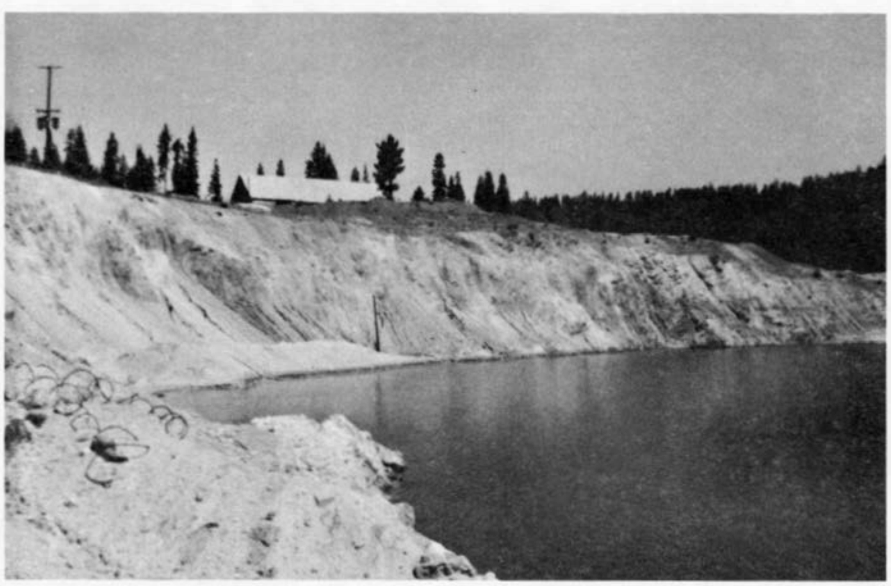


Figure 24.

View of the White King mine open pit, looking north toward the 150-foot-wide mineralized fault zone that trends nearly due north.

Table 5. Summary of uranium mines and prospects in Klamath and Lake Counties.

Map No.	Name	Location	Geologic occurrence	Remarks	References
		Lake County			
1	White King mine	sec. 30, T. 37 S., R. 19 E.	Low-temperature hydrothermal deposit. Primary uranium minerals in veins and disseminated in clayey tuffs. Rhyolite intrusive into tuffs.	Production 115,000 tons of ore. Associated minerals include realgar, orpiment, stibnite, cinnabar, pyrite, and ilsemannite.	Schafer, 1955; Peterson, 1958, 1959
2	Lucky Lass mine	sec. 25, T. 37 S., R. 18 E.	Primary black uranium minerals and minor secondary autunite in lenses and masses in and near fault zones in clayey tuffs.	Production of about 5000 tons of ore from large open pit.	Schafer, 1955; Peterson, 1958
3	Lucky Day OO prospect	sec. 26, T. 37 S., R. 18 E.	Secondary uranium minerals in and above thin, vesicular basalt flows interbedded with layered tuffs and breccias.	No production. Extensive exploration by open pits.	Dept. of Geology and Mineral Ind. mine-file report
4	Marty K prospect	sec. 13, T. 37 S., R. 18 E.	High radioactivity in sooty coatings in highly fractured pumice tuff breccia.	No production. Several open cuts and pits.	Matthews, 1955
5	Big Enough prospect	secs. 32, 33, T. 37 S., R. 18 E.	Apple-green secondary uranium minerals disseminated in and coating fractures in iron-stained ash-flow tuff.	No production.	Matthews, 1955
6	Myers and Hammersley prospect	sec. 35, T. 37 S., R. 18 E.	Mineralization at tops and bottoms of vesicular basalt interbeds in tuff. Similar to Lucky Day OO.	No production.	Dept. of Geology and Mineral Ind. mine-file report

of production for the mine. The property was leased to the Lakeview Mining Co. after limited exploration by trenching and drilling indicated the possibility of a commercial ore body extending out into the Augur Creek meadow. Only small quantities of ore were mined and shipped from 1955 to 1957 while underground exploration and development were carried on.

In 1958 a government contract prompted the building of a 210 t.p.d. processing mill at Lakeview which went on stream late in 1958. Early in 1959, a production shaft at the mine had to be abandoned because of excess water and heavy ground. Soon after, stripping began to allow mining from an open pit (see figure 24). The near-surface ore was mined out by the end of 1959 and it was not deemed feasible to go deeper with the open pit. The sketch map in figure 25 shows the present outline of the open pit with the old underground workings superimposed. By the end of 1960 no easily minable ore or custom ore was available and the mill closed. In 1962, 1963, and 1965 small tonnages of high-grade ore were mined at the base of the west wall of the open pit and shipped by individual lessors. Total production from 1956 to 1965 has been about 350,000 pounds of U_3O_8 from 115,000 tons of ore.

The uranium mineralization at the White King is in an area of complex stratigraphy and structure. It appears to be associated with a flow-banded dike-like mass of rhyolite that has intruded clayey tuffs, tuff breccias, agglomerates, and basaltic lava flows of Miocene-Pliocene age. Black uranium oxides and a variety of associated minerals including 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 ore bodies. Near the surface, concentrations of a rare, bright yellow-green, secondary uranium mineral, metaheinrichite (hydrous 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. The ore bodies tend to be somewhat tabular and are displaced by numerous northwest-trending faults.

During 1967, 1968, and 1969 at least two major companies conducted airborne radiometric exploration, and at the White King a detailed drilling program has been carried out by one company to determine ore reserves. Also, in 1968, the Atlantic Richfield Co. announced the purchase of the uranium processing mill at Lakeview.

Lucky Lass Mine

The Lucky Lass mine is in sec. 25, T. 39 S., R. 19 E., a mile northwest of the White King mine. It was also found in 1955, shortly after the White King discovery was made public. The Lakeview Mining Co. mined about 450 tons of ore (3200 lbs. of U_3O_8) from a narrow open pit in 1955 and 1956. Then, following a period of inactivity, the owners enlarged the open pit during intermittent operations, and from 1961 to 1965 produced another 5000 tons of ore that contained about 33,000 pounds of U_3O_8. At the present time the mine is not being operated and the large open pit is filled with water.

Mineralization at the Lucky Lass mine was apparently controlled by several fault and shear zones in bedded clayey tuffs and tuff breccias that are similar to the rocks at the White King mine. The most important mineralized zone is about 10 feet wide, strikes N. 75° W., and dips 80° N. The layered tuffaceous rocks strike generally northwest and dip 15° to 40° to the southwest. They are overlain by vesicular basalt flows. Blocks of altered basalt are commonly found in the shear zones. Near the surface, secondary yellow fluorescent uranium minerals similar to those at the White King were present as coatings and disseminated in the tuffs and vesicular basalt. At depth discrete uranium minerals are not recognizable but probably are present as minute disseminations of black uraninite or sooty pitchblende. Geiger counters were necessary to separate ore from waste.

The owners report that longhole drilling in the pit has indicated more radioactive mineralization at depth, but the amount and the grade are not known.

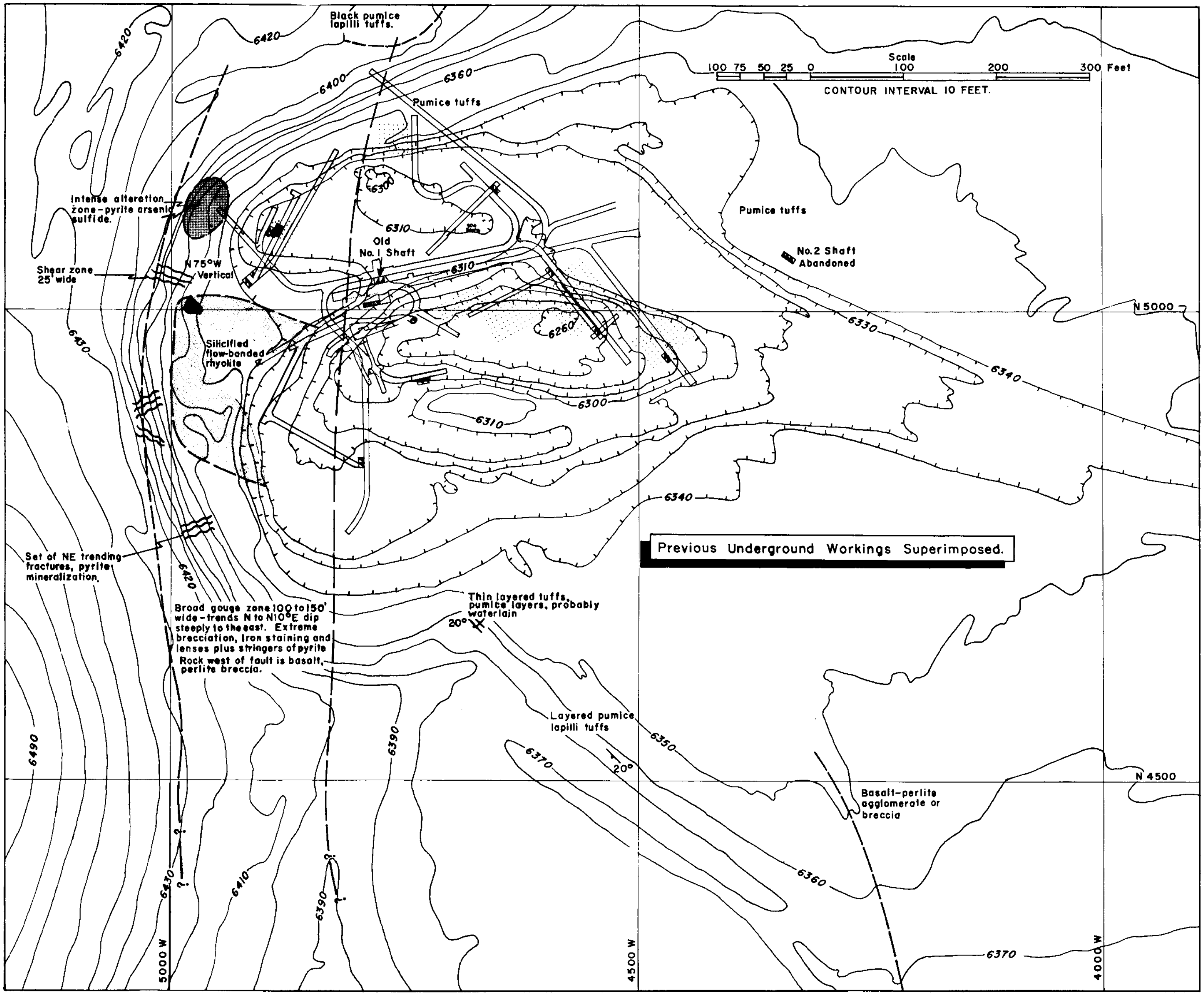


Figure 25 - Map of the White King mine showing development and geology.

QUICKSILVER

Even though the production has been small, mercury follows uranium in importance as a metallic mineral in the project area. Brooks (1963), in a study of quicksilver in Oregon, shows the recorded production from the project area to be 34 flasks all from one property, the Angel Peak mine near Quartz Mountain. An additional unrecorded 2½ flasks has been credited to the Currier prospect at the south end of Summer Lake.

The map of mineral deposits (plate 2) shows the scattered nature of the quicksilver occurrences. Mercury occurs in all of them as the mineral cinnabar, associated with intermediate-to-acid intrusive-extrusive rocks (QTvrd). Wherever it occurs, silicification and/or opalization is also abundant. Near Quartz Mountain there is a small concentration of prospects. The quicksilver mineralization occurs with opalized rhyolite, rhyolite tuffs, and silicified rhyolite breccia in a narrow, irregular northwest-trending zone several miles long. Potassium-argon dating of the surrounding glassy rhyolite shows that the mineralization here must be less than about 8 million years old.

The following descriptions of individual quicksilver mines and prospects and the information in table 6 is mainly from Brooks' (1963) study. Map numbers indicate locations on plate 2.

Angel Peak Mine

The Angel Peak mine was developed and operated from time to time between 1956 and 1959. Total production has been 34 flasks of quicksilver. A 30-inch rotary furnace formerly located at the property has been removed and the mine is now idle. The deposit is at the top of a hill locally known as Angel Peak (see figure 26).

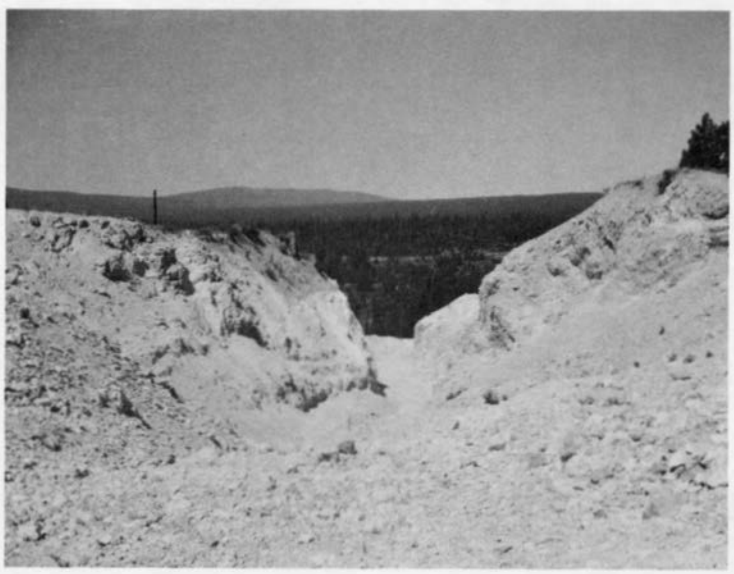


Figure 26.

Large north-trending open cut at the Angel Peak quicksilver mine. Vertically flow-banded rhyolite vitrophyre has been altered to opal and clay.

Brooks (1963, p. 175) described the occurrence as follows:

> On the crest of Angel Peak an area about 100 yards in diameter has been stripped of overburden. Much of the rock exposed has been opalized, though some parts of it have been altered to a soft powdery mixture of silica and alunite. Identifiable rocks in the opalized area and along its edges include rhyolite, tuffs, tuff breccias, and glassy andesite. Along the west edge of the opalized area the glassy rocks are interlayered with the opalized material.

Table 6. Quicksilver occurrences in Lake and Klamath Counties.

Map No.	Name	Location	Geologic occurrence	Remarks	Reference
1	Oregon Technical Institute	N. edge sec. 20, T. 38 S., R. 9 E.	Minor disseminated cinnabar in layered opal and agate of hot-spring origin. Pleistocene (?) age.		
2	Klamath Hills	S. edge sec. 35, T. 40 S., R. 9 E.	Minor disseminated cinnabar in siliceous sinter of Pleistocene (?) age.		Department assay rept.
3	Givan ranch prospect	NE¼ sec. 25, T. 36 S., R. 12 E.	Cinnabar assays as high as 16 lbs./ton reported from zones of opalization in layered rhyolite breccias.	No production.	Brooks, 1963
4	School Creek	NE¼ sec. 10, T. 34 S., R. 16 E.	Cinnabar on fractures, in opalized, bleached rhyolite. Grab sample assayed 3.7 lbs./ton.	Discovered in 1968 (?).	No report.
5	Currier mine	Sec. 36, T. 32 S., R. 16 E.	Cinnabar occurs as fracture filling and splotchy aggregates in a sheared brecciated zone 50 ft. wide in andesite.	Production of 2½ flasks.	Brooks, 1963; Ross, 1941.
6	O'Leary prospect	Sec. 5, T. 35 S., R. 18 E.	Cinnabar occurs in thin veinlets and coatings on fractures of andesite breccia and massive rhyolite.	No production.	Brooks, 1963
7	Chewaucan River	Secs. 9, 16; T. 34 S., R. 18 E.	Not known.	On banks of Chewaucan River, short adit. No production.	Brooks, 1963
8	Crone prospect	NE¼ sec. 34, T. 37 S., R. 16 E.	Cinnabar occurs sparingly in isolated boulders of silicified rhyolite breccia.	No record of production.	Brooks, 1963; Johns, 1949.
9	Manzanita group	SW¼ sec. 26, NW¼ sec. 35, T. 37 S., R. 16 E.	(See Text)	9 claims. No production.	
10	Angel Peak mine	NW¼ sec. 32, T. 37 S., R. 17 E.	(See Text)	Recorded production of 34 flasks.	Brooks, 1963
11	Rosalite prospect	SE¼ sec. 5, T. 38 S., R. 17 E.	Mineralization similar to the Angel Peak - intense opalization and bleaching of rhyolite.	No production.	Brooks, 1963
12	Digmore or Salt Creek	NE¼ sec. 12, T. 38 S., R. 20 E.	Cinnabar disseminated in clayey altered tuffs and fracture coatings in opalite breccia.	Several bulldozer cuts and prospect pits. No production.	Department open-file report.
13	Pinto group	Sec. 6, T. 41 S., R. 18 E.	Cinnabar occurs disseminated and as fracture fillings in chalcedony and opal in altered pumice tuffs.	No production.	Brooks, 1963
14	Batman prospect	Sec. 4, T. 41 S., R. 18 E.	Bleached and iron-stained pumice tuffs - no cinnabar seen in several open cuts.	No production.	Brooks, 1963.

Controls for the localization of cinnabar are obscure. No persistent fracture trends were noted. Cinnabar is concentrated along poorly defined fractures and coats fragments in brecciated zones within silicified parts of the rock. Small amounts also occur as a fine dispersion in the silica. Most of the ore mined was recovered from a mineralized zone about 40 feet long, 20 feet wide, and 10 to 15 feet deep. Small pods of ore that assay from one to two percent quicksilver were included, but the over-all grade of ore probably would not exceed 0.15 to 0.2 percent quicksilver. Outside this mineralized zone only scattered bunches of cinnabar were found.

Manzanita Group

The Manzanita group prospect is on the west flank of North Butte and Quartz Butte about $2\frac{1}{2}$ miles due west of the Angel Peak mine in the Quartz Mountain area. Mineralization is similar to that at Angel Peak. Cinnabar occurs randomly in intensely altered, opalized flow-banded rhyolite, and associated tuffs as thin coatings and minute disseminations. Several deep bulldozer cuts have explored a wide mineralized zone.

The exploration work done so far has not found the small podlike deposits and stringers to be numerous enough or close enough together to constitute a commercial ore body.

GOLD, SILVER, LEAD, ZINC, AND COPPER

Gold, silver, and associated base metals have been reported from two widely separated locations, the High Grade district and the Brattain district.

High Grade District

Free gold was mined from silicified breccia zones and quartz veins in early Tertiary rhyolite in the extreme southeast corner of the project area. This locality is a part of a larger area in Modoc County of northern California known as the High Grade district. In Oregon it includes several prospects in the hills a few miles east of New Pine Creek, a small community on U.S. Highway 395 about 15 miles south of Lakeview. Gay (1966, p. 100) reports production from the district as a whole of about $85,000 from the period 1909 to 1934.

Brattain District

In this area along the east side of the Paisley Hills, about 5 miles south of Paisley, gold is reported to have been discovered in 1875. About 1900, a man named Gaylord dug a tunnel and several shafts that exposed lead, zinc, and copper minerals with some associated gold and silver. Gaylord is reported to have hired a crew and supported his family from the proceeds of his mining. Since that time only assessment work and location work have been done (Appling, 1950, p. 45). The Gaylord tunnel is in the NE$\frac{1}{4}$ sec. 11, T. 34 S., R. 18 E., at the head of Brattain Canyon (plate 2). The tunnel exposes one of a number of narrow siliceous veins that trend N. 30° to N. 45° W. in the immediate area. Galena and sphalerite are the most prominent metallic minerals. Silver accompanies the galena. The metallic minerals are found in discontinuous lenses and minor disseminations in the veins.

In 1965 copper, lead, and zinc minerals were discovered on the east flank of Ennis Butte in secs. 18 and 19, T. 34 S., R. 19 E., associated with a small stock and dikelike masses of diorite and quartz monzonite. The mineralization appears to be confined to narrow fault zones that trend mainly about N. 60° W. with minor N. 20° E. shears. Mineralization at the surface is spotty and comprises the sulfides, pyrite, sphalerite, galena, and minor chalcopyrite. Several mining companies have made cursory surface examinations, including surface mapping (Muntzert, 1969) and shallow trenching, but so far no extensive exploration or development has been done. Although silicified rhyolite breccias have been sampled for assay in several other areas, none of these metals was detected.

BLACK SAND

Surface concentrations of black sand containing iron and titanium are present in a broad area about 20 square miles in extent between Scott and Sand Creeks, in T. 31 S., Rs. 7 and 8 E. Thin, lens-shaped concentrations of olivine, augite, hornblende, magnetite, and ilmenite result from the normal fluviatile processes as Sand Creek and Scott Creek meander across the flat area of the Antelope Desert. Small amounts of ilmenite-magnetite sand were also observed on a beach along the east side of Klamath Lake (NW¼ sec. 17, T. 36 S., R. 7 E.). The heavy minerals appear to be derived from the breakdown of pumice and scoria of the glowing avalanche deposits of Mount Mazama described by Williams (1942). The magnetite-ilmenite fraction is low and the present surface concentrations do not appear to have economic significance.

Considerable black-sand thicknesses have been reported by drillers in water wells along the west side of Klamath Marsh and adjacent to Agency Lake and north Klamath Lake. From drillers' logs it is not possible to distinguish between ilmenite-magnetite concentrations and sand composed of fine black cinders. Careful sampling of these reported black sands in future drilling will be required before it will be possible to assess their significance.

Table 7. Diatomite analyses, Klamath and Lake Counties.

Location	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl	CO_2	H_2O*	Total
North of the town of Sprague River (1) (Sample 227)	65.52	0.86	3.34	14.44	1.56	0.87	0.91	0.42	0.03	0.10	0.04	11.91	100.00
Northeast of Ferguson Mtn., sec. 5, T. 36 S., R. 14 E. (1) (Sample 222)	76.00	0.13	2.03	5.96	0.38	0.23	0.33	0.15	0.17	0.06	0.20	14.36	100.00
Northeast of Merrill NE¼ sec. 25, T. 40 S., R. 11 E. (1) (Sample 232)	75.30	0.45	2.89	8.42	1.90	0.63	0.71	0.32	0.03	0.34	N.R.	9.01	100.00
4½ miles southwest of Klamath Falls (1) (Sample 187)	75.56	0.64	2.66	8.64	1.20	0.37	1.08	0.26	0.06	-	0.11	9.42	100.00
Range of composition of commercial grades of diatomite (2)	85-92%	N.R.	0.8-2.0%	4-10%	0.1-2.0%	0.1-2.0%	0.2 - 1.5%		N.R.	N.R.	0-3% organic material	5-8% L.O.I.	

* by difference.

(1) From Moore, B. N. (1937).

(2) From Leppla, P. W., 1953, p. 2.

NONMETALLIC MINERAL RESOURCES

DIATOMITE

Characteristics of Diatomite

Diatomite, or diatomaceous earth, is a friable, light-colored sediment or sedimentary rock of low density, composed of the microscopic siliceous shell-like frustules secreted by aquatic plants called diatoms. These plants abound in shallow marine or lacustrine waters in which favorable temperature conditions, light, nutrients, and a dissolved silica supply are available. Many thousands of living and fossil diatom species are known. Each species has a characteristic frustule shape, size, and associated ornamentation of spines and shell perforations (figure 27, a and b).

Dry diatomite is normally white. Other colors are due to included sediment or organic impurities. The opaline silica particles have a hardness of 4.5 to 6.5 but the aggregate is incoherent, with a hardness of about 1. Because of the large amount of pore space in and around the frustules, the apparent density of the dry blocky diatomite is about 25 to 37 pounds per cubic foot, and of the dry powder, 5 to 16 pounds per cubic foot. The shape, size, and sorting of frustules as well as the proportion of frustule fragments vary greatly in different deposits and affect the properties of the diatomite. Diatom frustules are insoluble in most acids, but will dissolve in strong alkalies.

There is a commonplace association of diatomite deposits and volcanic activity in many sedimentary basins. The silica and mineral nutrients needed by these plants are provided in abundance in volcanic areas, either directly from volcanic emanations or indirectly from the weathering of volcanic rocks. As a consequence, however, volcanic ash and other volcanic-derived sediments often accompany diatomite and contaminate it. The presence of these contaminants is indicated in the chemical analyses by the constituents other than silica and water, particularly by the presence of alumina. The range of composition of commercial grades of diatomite is given in table 7. For many industrial uses, chemical purity is less important than size, shape, and sorting of the diatoms. Volcanic ash, which is difficult to remove, or iron in sufficient quantities to discolor the calcined diatomite are generally undesirable ingredients.

The industrial uses of diatomite include a wide variety of filters, fillers, insulating materials, absorbents and fluid carriers, lightweight cement aggregates and pozzolan, abrasives, and ceramic products. Each particular use demands diatomite with specific characteristics of purity, particle size, shape, and sorting. Diatomite is a bulk product which, to be produced economically, must be available in large deposits that can be mined, processed, and transported to market at a low unit cost.

Diatomite in the Project Area

There are two diatomite-containing formations in the project area. The most extensive of these is the diatomite facies of the Pliocene lacustrine map unit (Tst) in the southwestern quarter of the area. A second diatomite unit occurs in the Pleistocene-Holocene deposits in Klamath Lake, Agency Lake, and Klamath Marsh. Impressive amounts of diatomite are being deposited in these basins at the present time.

<u>Pliocene deposits:</u> Diatomaceous sedimentary rocks of Pliocene age occur in the faulted ranges and valleys superimposed on a formerly continuous or semi-continuous Pliocene lake basin. The basin in which this material accumulated also received large amounts of volcanic-derived sediments. There are, therefore, complex facies relationships between relatively thick and pure diatomite beds and impure tuffaceous and diatomaceous siltstones and shales. Diatomite is a prominent component of several sections exposed in ridges around Klamath Falls, at Olene Gap, in Poe Valley, at Wolff ranch

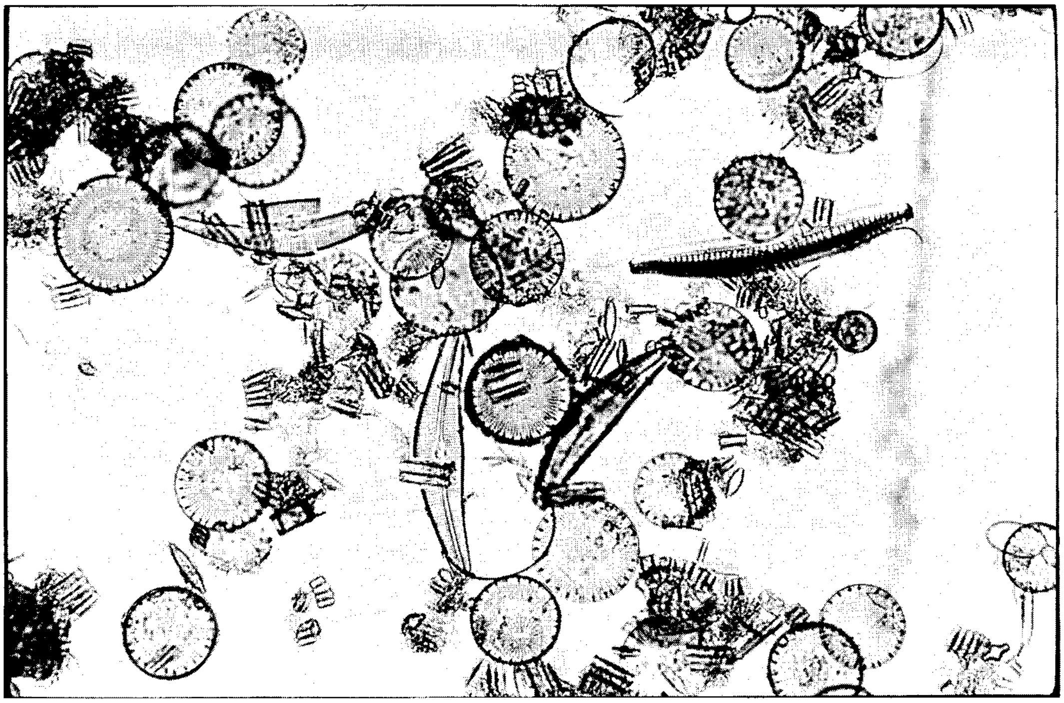


Figure 27-a. Photomicrograph of diatom assemblage now thriving in the Klamath Lake waters (X 320).

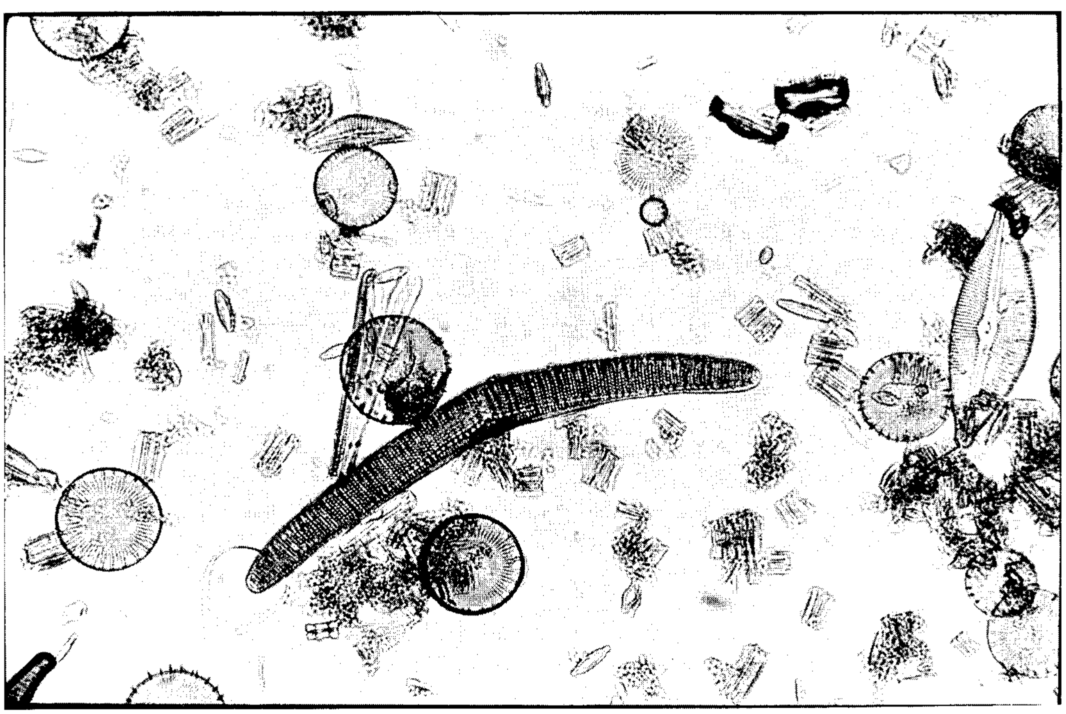


Figure 27-b. Photomicrograph of diatom species from recent diatomite in the Klamath Marsh (X320).

(center sec. 31, T. 34 S., R. 9 E.) and at the town of Sprague River in Sprague River valley. All these locations are indicated on plate 2. Moore (1937, p. 42) describes an aggregate thickness of impure diatomite at Klamath Falls making up 240 feet of a 400-foot exposure of lacustrine sediments. Massive beds of diatomite separated by tuffaceous siltstone partings a few inches thick make up the 250-foot-thick sequence seen at the town of Sprague River. Many other surface outcrops contain poorly exposed and unmeasured thicknesses of diatomite. Water-well logs show thick sections of diatomaceous material on the floors of Sprague River, Langell, Poe, Yonna, Swan, and Lower Klamath Lake valleys. The quality and quantity of diatomite in these wells cannot be determined from driller's logs. There is not sufficient data available to trace diatomite beds of industrial quality or to estimate their volume. A high volcanic-ash content is a detrimental aspect of many samples collected from the most prominent surface outcrops, as noted in the chemical analyses in table 7.

A limited number of evaluations of diatomite samples have been made by major producing companies which have conducted reconnaissance studies in the project area. The results of these analyses were not available for this report. Only the deposit at Wolff ranch is known to have been studied intensively by a producing company. A short distance south of the project area, near the Little Tableland, Siskiyou County, Cal. (T. 46 N., R. 2 E.) an extensive investigation of Pliocene diatomite was carried out from 1951 to 1955. The material found was reportedly not of the type or purity to lend itself to commercial use in filters or fillers. It seems probable that an adequate evaluation of the diatomite potential in the Pliocene rocks of the project area would require a thorough sampling based on extensive core drilling associated with a reconstruction of depositional conditions in the Pliocene lake basin.

Pleistocene-Holocene deposits: It has been noted in the discussion of the geologic history that diatomaceous sediments are being deposited in lakes in the Klamath Lake-Agency Lake-Klamath Marsh depressions. A limited amount of information can be obtained from irrigation ditches in the center of S½ sec. 6, T. 38 S., R. 8 E. and near the center of sec. 8, T. 36 S., R. 7 E.; from dredge material along the east end of Lamm crossing of Klamath Marsh and from Agency Lake (SW corner sec. 19, T. 34 S., R. 7 E.). A test hole dug in the center of the NE¼ sec. 17, T. 31 S., R. 9 E. exposed a section consisting of 3 feet of peat overlying 5 feet of diatomite. The hole was terminated in water-deposited Mazama pumice. The thickness of diatom oozes presently accumulating beneath the open waters of the lakes has not been ascertained.

The areal extent of these Pleistocene-Holocene deposits may be very great. Furthermore, the runoff from the terrain surrounding the lakes may have been sufficiently limited to reduce the contamination of diatomite by volcanic material, as compared to the Pliocene deposits. As in the case of the Pliocene diatomites, detailed coring and studies of sedimentary environment would probably assist in outlining the areas of thickest and purest diatomite in these young basins.

There is no record of any production of diatomite from the project area. A few carloads of Pliocene material from a deposit located in sec. 33, T. 39 S., R. 7 E., a short distance to the west of the project boundary, were used as a cement additive in dam construction on the Klamath River.

PUMICE AND PUMICITE

Definition of Pumice and Pumicite

Pumice and pumicite are produced during a volcanic eruption by the natural expansion of dissolved gases, mainly water vapor, in a viscous silicic lava such as rhyolite or dacite. Pumice is a frothy rock made up of glass-walled gas bubble casts. This material may include crystals derived from crystallization of the melt and exotic fragments picked up from surrounding rocks through or over which the cooling melt moved. Pumice may remain as a coherent mass, essentially a highly vesicular, glassy lava flow or vent filling, or it may be more or less fragmented by violent eruption from a vent. Pumicite is a name applied to uncemented or poorly cemented individual ash particles or aggregates of particles less than 4 mm in diameter (Chesterman, 1956, p. 6). These pumicite ash particles are too small to contain the open frothy texture of pumice, although they do contain microscopic gas bubbles. Pumice is found relatively close to the vent from which it was erupted, while pumicite may be carried by winds for great distances before settling as an accumulation of fine-grained ash or tuffaceous sediment.

Economic Factors

The physical properties which make pumice and pumicite useful in industrial applications include: low bulk density, good thermal insulating properties, and excellent abrasive capability. Pumice ranges in size from blocks several feet in diameter down to fine granular material which grades insensibly into the still finer pumicite. Large pumice lumps having the proper texture are sold for landscaping and architectural enhancement. By far the greatest amount of pumice is sold as an aggregate for lightweight concrete building blocks. Various mixtures of pumice and volcanic cinders are commonly used in blocks to produce units having different weights, crushing strength, and color. Minor amounts of ground pumice and pumicite are used in making pozzolan for cement and as a soil conditioner, nursery bedding material, insecticide carrier, filler, and abrasive.

The economic factors involved in mining and marketing pumice and pumicite include not only the wide range of sizes and textures of the materials found at the various deposits and the rather widely varying prices which each commands, but the cost of mining, beneficiating, and marketing which may also have a considerable range. As is the case with nearly all industrial minerals, a potential producer must develop his own markets and sell his product for what he can get, since, unlike the metals, no established market exists and each sale must be considered on its own merits. Neither pumice nor pumicite enjoys a monopoly in the market place. Substitutes for all of the various applications for which these commodities are suited are readily available and a market exists only when a combination of price, ease of handling and processing, and quality of the finished product makes it attractive to the purchaser.

Pumice and Pumicite in the Project Area

Two separate deposits of pumice and pumicite occur in the project area. The largest of these is that resulting from the climactic eruptions of Mount Mazama. A second and somewhat older deposit of a lesser extent and thickness occurs in the Sprague River valley area.

Mazama pumice

This deposit is an essentially continuous layer of pumice and pumicite extending over the north half of the project area. It is one of the most recent formations in the area and mantles the surface, except for an occasional thin covering of soil or stream or lake deposits in a few low-lying locations (figure 28). As noted elsewhere, the pumice eruption began with a widespread air fall of fine-grained material, followed by pumice flows or glowing avalanche deposits restricted to areas near the vent, west of Klamath Marsh.

A generalized isopach map is outlined on plate 2. The thickness of the deposit decreases regionally from about 90 feet in the Antelope Desert-Chemult area southward and eastward to depths of a few inches. Many local variations occur where pumiceous materials thicken in topographically low areas or thin out on steep slopes and topographically high areas. The coarseness of pumice fragments and the grain size of pumicite generally decrease with increased distance from the source, in trends paralleling those of thickness. Lumps of pumice 2 to 3 feet in diameter are common near Beaver Marsh in the area reached by the glowing avalanche deposits. Immediately to the east the fragment size decreases rapidly to granule and coarse sand sizes. Where the pumice fragments are largest, however, fine fragments are intermixed with the coarse. Additional details concerning the distribution and grain size variation of this deposit can be found in Moore (1937, p. 157), Williams (1942, p. 69-71), and Walker (1951, p. 2-4). The total volume of the deposit is to be measured in cubic miles. The data available are not sufficient, however, to permit the estimation of thickness and tonnage of material in specific fragment sizes.

Figure 28 - A blanket of Mazama pumice at least 3 feet thick covers a basalt flow near Chemult. Basalt quarried from the flow beneath the pumice has furnished large quantities of crushed rock for ballast for the Great Northern Roilwoy.

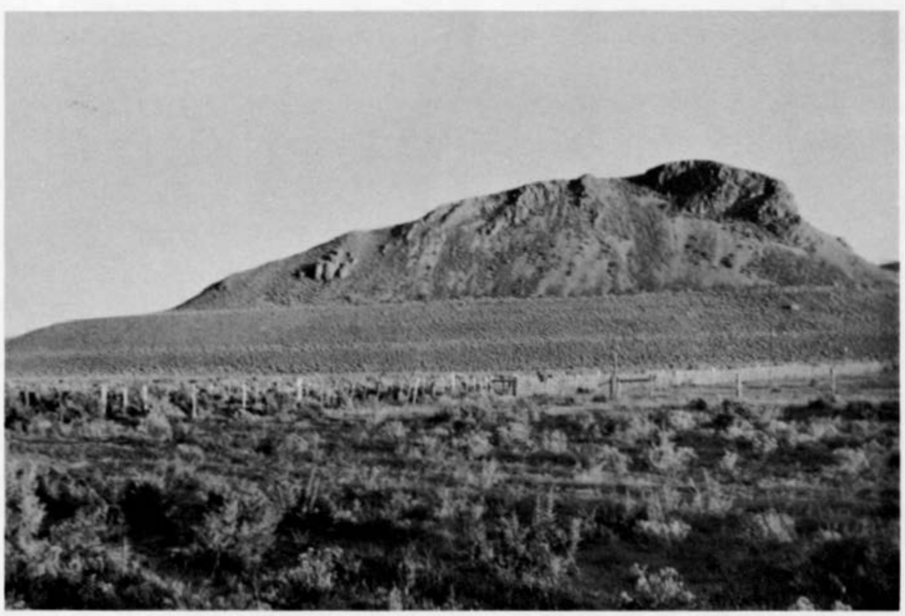


Figure 29 - Looking south at Tucker Hill, a domelike moss of perlite about 10 miles southeast of Paisley. Note the wove-cut benches that mark shorelines of ancient pluvial lakes.

The usefulness of pumice and pumicite, particularly for abrasives, is dependent on its freedom from crystal and exotic rock inclusions and on the uniformity of the vesiculate texture. Within the project area accidental rock fragments do not appear to be present in significant quantities. Crystals of plagioclase, hypersthene, augite, hornblende, and magnetite are reported to average between 10 and 15 percent of the rock by volume. The crystal content is reported to increase away from the vent, as the deposit thickness and pumice clast size decrease (Williams, 1942, p. 77). The distribution of vesicles is uneven, as is vesicle size.

The chemical composition of pumiceous materials is important to the major bulk use of this type of material as a cement additive. Analyses of three pumice and pumicite samples are shown in table 1. In addition, a large number of chemical and physical tests on pumice and pumicite samples from the Lenz-Chemult area have been made relative to their use in pozzolan (King, D.P., 1965).

From the limited amount of sample data available, the Mazama pumice appears to be a large resource of readily accessible dacite pumice and pumicite of a wide variety of lump and granule sizes. The quality of the deposit appears to be acceptable by present standards for most of the uses to which such materials are put. The chief limitations are the widespread occurrence of crystals in the pumice which restrict its use as an abrasive.

In addition to considerations of quality, volume, and minability, the proximity of the deposit to transportation and ultimately to the market is of vital importance to its development. The coarse lump pumice areas of the deposit are immediately adjacent to U.S. Highway 97 and the Great Northern and Southern Pacific Railroad lines. The finer grained pumicite deposits farther east are accessible over large areas by unpaved graded forest roads.

The local market for pumice is restricted to use in production of a small volume of construction materials in Klamath Falls and this market is supplied from the large deposits at Glass Mountain, Siskiyou County, Cal. Production of Mazama pumice and pumicite of significant volume would require the development of new markets outside the central Oregon area.

Moore (1937, p. 175) records a small amount of pumicite production from sec. 8, T. 27 S., R. 8 E. for use in stucco as early as 1929, and several quarries were reported by him to have been opened in the Chemult area prior to 1937. No sustained production has been recorded from the period prior to or during World War II. During 1945, small mining operations were again set up in the Chemult area. The product was shipped to points as far away as Bellingham, Wash. and King City, Cal. (Wagner, 1947, p. 32). Most of the product found its use in cement block manufacture. Production figures from that part of the deposit within the project area are not known. By 1956, all production in the project area had ceased.

Upper Sprague River pumice and pumicite

Isolated patches of pumice and pumicite, probably erosional remnants of a formerly more extensive layer, occur in the upper Sprague River area north of Beatty and north and east of Bly. This pumicite overlies the (Tst) map unit and is overlain by the youngest basalt (Qb). It is approximately 10 feet thick where the road crosses over the edge of Knot Tableland (NE¼ sec. 29, T. 35 S., R. 12 E.). Other outcrops of similar material occur in the SE¼ sec. 19, T. 36 S., R. 15 E. and the SE¼ sec. 15, T. 37 S., R. 15 E. Due to soil cover at these localities the thickness was not determined, although it probably exceeds 10 feet. The areal extent of the horizon is not known because of poor exposures.

These deposits consist mainly of unconsolidated sand-size white granules, most of which are less than 2 mm in diameter. Crystal fragments of pyroxene, plagioclase feldspar, and magnetite make up approximately 10 percent of the volume of the material. Occasional cobble-sized clasts of light-colored rhyolite or dacite vitrophyre occur scattered through the deposit. No detailed mechanical or petrographic analyses of this material are known to have been made. A chemical analysis of it is included in table 1, under the name Pleistocene dacite pumicite.

The deposits referred to this group are all close to good graded unpaved roads and to Oregon Highway 140 between Klamath Falls and Lakeview. A branch rail line extending from Klamath Falls to Bly comes within a few miles of them.

There has been a small amount of production from the two pumicite localities located in sections 15 and 19, as noted above. The latter of these is reported to have produced approximately 4000 cubic yards between 1946 and 1950. No other production records were available, but both pits have long been idle. The pumicite obtained was shipped to Klamath Falls for plaster and mortar aggregate and to Los Angeles, Cal. for use as a soil conditioner and a construction material.

PERLITE

Perlite is a variety of obsidian in which 2 to 5 percent by weight of the material is chemically combined water. It is a glassy volcanic rock of rhyolitic or dacitic composition, is red, gray, or black in color, and has a waxy or pearly luster. The rock characteristically exhibits perlitic structure, which is a tendency to break into spherical fragments along concentric fractures produced during cooling.

On rapid heating at temperatures in the range of 800° to 2200° F., the chemically combined water in perlite is liberated as steam which expands the thermally softened glass into a frothy mass resembling pumice. To be of economic value, perlite should be capable of undergoing expansion to a minimum of four times its original volume. Like pumice, the expanded perlite is chemically inert, possesses good thermal insulating and accoustical properties, and has a low density. With respect to their common uses, however, perlite often has the advantage over pumice, because the frothy structure of perlite can be varied according to specification by adjusting the duration and temperature of calcination. Furthermore, the unprocessed perlitic glass can be shipped to plants near the point of use before being expanded, thus avoiding the transport of a bulky product.

Not all perlite expands adequately, has suitable chemical properties, or is sufficiently free of crystal or other nonexpandable inclusions to meet industrial specifications. Thus, careful laboratory testing of perlite deposits is required to determine their value. Since this material is a commodity of low unit value, it must be available for production on a large scale, at low cost, and in favorable locations for the market. In the project area it would probably compete with either diatomite or pumice for their common uses in lightweight aggregates, loose fill insulation, filter aids, foundry sand, fillers, and abrasives.

Perlite is known to be associated with many of the rhyolite and dacite intrusive and extrusive bodies occurring in the eastern two-thirds of the project area (figure 29). Not all of the prospective rhyolite-dacite terrains have been examined, but several areas with potentially large tonnages are noted in table 8 and located on plate 2. No systematic sampling has been carried out, as far as is known, on any of these deposits. The expansion tests reproduced in table 8 are based on reconnaissance sampling, and the degree to which they are representative of these deposits is unknown.

CINDERS AND SCORIA

Cinders and scoria, the red, brown, or black clinkery products of explosive volcanoes of basaltic composition, are abundant and widespread in the project area. The cinder cones and mounds are made up of layered fragments of vesicular lava a fraction of an inch to several inches in diameter. The cones range in size from a few hundred feet to a thousand feet in diameter and are as much as 500 feet high. Many cinder cones have been identified and located on the geologic map (plate 1).

In the project area, pit run cinders and scoria are used for road construction and maintenance. Innumerable pits have been opened at convenient locations by both private logging companies and federal agencies (figure 30). There appears to be an adequate supply of this type of construction material for all foreseeable local uses.

Table 8. Perlite prospects - Klamath and Lake Counties.

Map No.	Locality	Sample number	Expanded volume*	Temperature (30 seconds)	Locality description (Peterson, 1961)
1	Tucker Hill area. secs. 25 and 36, T. 34 S., R. 19 E.	P-26137 P-26137 P-26138	200% 650% 700%	1600° F. 1850° F. 1850° F.	Large amount of light gray perlite along east flank of an elongated dome-shaped mass of glassy flow-banded rhyolite. Deposit includes perlite, perlitic glass, obsidian, and glassy rhyolite (see figure 28).
2	Adjacent to the Marty K. uranium prospect sec. 14, T. 37 S., R. 18 E.	P-25602 P-25603	350% 200%	1900° F. 1900° F.	Perlite at contact of large rhyolite dome and massive pumice tuffs.
3	Drews Valley Ranch secs. 16 and 17 T. 38 S., R. 17 E.	P-25488 P-25490 P-25491	125% 550% 550%	1850° F. 1850° F. 1850° F.	Area appears to contain a large deposit of perlitic glass associated with dacite and zones of obsidian. Samples are from widely separated parts of the deposit.
4	Roselite quicksilver claims sec. 5, T. 38 S., R. 17 E.	No data	No data	No data	Light gray glassy rhyolite exposed in quicksilver prospects also reported from drill holes. Where opalization and clay alteration are not present, rocks have a perlitic structure.
5	Owen Butte NW¼ sec. 30, T. 37 S., R. 16 E. sec. 24, T. 37 S., R. 15 E.	P-25653 P-25654	500% 700%	1850° F. 1850° F.	Perlitic material in pink-gray glassy dacite dome. Abundant feldspar and biotite.
6	Bly Mountain sec. 17, T. 37 S., R. 11 E.	P-33117	180%	1850° F.	Large area of perlitic glassy dacite north of Bly Mountain Pass.
7	Near Blaisdell NW¼ sec. 8, T. 37 S., R. 16 E.	P-33118	220%	1850° F.	Rhyolite dome with extensive perlitic border zone.

* Laboratory expansion tests made by grinding and screening to obtain a -20 +28 mesh sample. Measured sample is heated in electric muffle furnace and preheated to 1850° F. for 30 seconds. Expanded volume is percentage increase over original sample.

SAND, GRAVEL, AND CRUSHED STONE

Sand and Gravel

Sand, gravel, and crushed stone are the vital raw materials for the construction industry. In both Klamath and Lake Counties, as in the state as a whole, these commodities rank first in dollar value of mineral production. Population centers and highway and dam construction provide the main markets for sand and gravel.

The physical properties of the sand grains and rock fragments in gravel deposits vary widely and the quality of the material determines the quality of the finished concrete product. The State Highway Department has set up specifications for the cleanness, hardness, durability, impurities, and amount of chemically reactive materials for particular uses. Also, since the product has a low value per ton, economically workable deposits must be located close to the markets to eliminate excessive haulage costs. Local deposits of sand and gravel of good quality are scarce near Klamath Falls, and the current utilization of sand and gravel is from two deposits that occur as alluvial fans where streams entered an ancient lake. Recent movement on the bounding faults of the Klamath graben have elevated these deposits about 300 feet above the valley floor.

The largest deposit is in the NE$\frac{1}{4}$ of sec. 32, T. 39 S., R. 10 E. at the north end of Stukel Mountain about 10 miles southeast of Klamath Falls. The deposit covers about 20 acres on a sloping terrace at about 4300 feet elevation. The gravels are poorly sorted, crudely stratified, and as much as 50 feet thick. The high percentage of volcanic rocks, clay, and ash limit the uses for the sand and gravel from this deposit. There are large tonnages available.

A similar deposit is located in the NE$\frac{1}{4}$ sec. 22, T. 38 S., R. 8 E., just 3 miles northeast of Klamath Falls on the Old Fort Road. This deposit has gravel, sand, and silty layers as much as 20 feet thick, and an area of about 5 acres has been mined. The visible reserves of this deposit are limited.

When the local deposits are exhausted it may become necessary to haul from greater distances, and the east flank of the Cascades could furnish adequate quantities of usable gravel. About 20 miles northwest of Klamath Falls, Oregon Highway 140 crosses a broad gravel fan of glacial outwash. The deposit covers parts of secs. 5, 31, and 32, T. 36 S., R. 7 E. and extends to the south shore of Klamath Lake at Ball Bay. The gravels are reported to be at least 24 feet thick in test pits dug on 300-foot centers, over a large area. A well report shows gravel 90 feet thick. The volcanic nature of all the rock fragments will probably limit the use of the aggregate from this source. Preliminary information indicates an almost inexhaustible quantity of sand and gravel here.

In the Lakeview area there are considerable quantities of sand and gravel on the periphery of Goose Lake in the (Qlo) map unit. An especially large delta-like deposit extends into the north end of the Goose Lake basin to within about 3$\frac{1}{2}$ miles of Lakeview. This deposit covers several square miles and in some places may be as much as 200 feet thick. The quality of the sand and gravel is not known.

Crushed Stone

Where sufficient quantities of gravel aggregate of good quality and size are not available, the residual gravel and boulders themselves are crushed or massive rock deposits are quarried and crushed as a substitute. Crushed rock must also meet standard specifications for hardness, durability, and chemical stability. Again the distance of the haul to the market is a very important economic factor.

Suitable crushing rock close to Klamath Falls is rather scarce, although some of the Pliocene basalt flows intercalated within the diatomaceous tuffs (Tst) have been opened as quarries for crushed rock. At a quarry in the NW$\frac{1}{4}$ sec. 11, T. 39 S., R. 8 E. about 6 miles southwest of Klamath Falls a jointed black glassy basalt is crushed and screened to furnish large quantities of concrete and asphalt aggregate.

A large crushing and screening operation utilizes talus debris that has been built up along the conspicuous fault plane on the east side of Klamath Lake near Rattlesnake Point (figure 17). Removal of debris has exposed the slickensided fault plane for more than half a mile. The available material of this type at this location is rapidly being exhausted. Similar deposits have also been removed at the north end of Stukel Mountain.

In the Lakeview area, available rock for crushing is limited to fractured basalt and andesite flows and to talus derived from them along the bounding fault of the Goose Lake basin.

For highway construction there are adequate quarry sites in jointed basalt and basaltic andesite flows throughout most of the project area. Large quantities of rock for railroad ballast are taken from a quarry in fractured andesite near Chemult (figure 27).

BUILDING STONE

Many of the light-to-varicolored volcanic rock types, mainly in the eastern part of the project area, have suitable physical properties for use as building stone. Besides local use by individuals, there has been considerable production of a reddish scoria agglutinate and light gray rhyolite for decorative walls in home construction and landscaping. Large blocks of the red scoria were quarried from a deposit on lower Howard Creek in NE$\frac{1}{4}$ sec. 15, T. 37 S., R. 17 E., and have been marketed in the Portland area. Light-gray rhyolite and dacite with intricate flow banding have been quarried from at least two locations on Thomas Creek and from one area just south of Oregon Highway 140 near Quartz Mountain. This rubble stone was marketed under the trade name "Palomino rhyolite" in the Portland area in the early 1960's.

If marketing and transportation problems can be overcome, there are probably many places where appreciable tonnages of volcanic building stone could be developed.

CLAY

Clays suitable for products other than common brick and tile do not appear to be present in other than small occurrences. The only brick and tile manufacturer in the project area has dug large quantities of a local clay-rock mixture which, when blended with other clays, produced a good marketable brick. The source has been taken over by a freeway right-of-way and so far another quarry of similar quality material has not been found.

Impure bentonitic clays have been reported from the upper part of McCoin Creek (sec. 30, T. 40 S., R. 10 E.) and Gold Creek (approximately the N$\frac{1}{2}$ sec. 27, T. 34 S., R. 16 E.) associated with rhyolite intrusive bodies and tuffs of the (Ttf) unit. Many additional localities for this type of material probably occur in the eastern half of the mapped area. The occurrences observed in the course of the study were too small and impure to be of commercial interest.

PEAT

Peat is produced by the partial decomposition of plant material under water or in a water-saturated environment. Three types of peat are recognized. These are moss peat, composed of various moss groups; reed-sedge peat made up predominantly of reeds and other higher plants; and peat humus, which is decomposed plant material of indeterminate composition in a relatively advanced stage of decay.

The commercial production of this material is mainly for consumption as a soil conditioner. Large amounts have been and are at present being used for fuel in various parts of the world.

Peat occurs extensively in the parts of the project area that are covered by shallow lakes and swamps at the present time or which have been covered during periods of more extensive rainfall in the Pleistocene. Peat is now accumulating in the shallow arms of Upper Klamath Lake, Agency Lake, Klamath Marsh, Sycan Marsh, and probably in many smaller lakes and ponds. This material appears to be of the reed-sedge type. Slightly older peat is encountered in excavations in the present lake basins in areas which were under water at higher lake levels. It can be seen in shallow excavations in Wocus Marsh, Caledonia Marsh, and other farmland areas that lie west of Klamath Lake but were formerly part of it. A pit dug in the NE¼ sec. 17, T. 31 S., R. 9 E. encountered 3 feet of peat at the surface.

In general, the commercial peat deposits would appear to be confined to parts of the lake basins still under water or else under cultivation. It is possible, however, that if commercial production of diatomite from these lake basins is ever attempted peat could be obtained as a by-product.

AGATE AND FOSSIL WOOD

Fossil wood is found in the upper Miocene tuffs (Ttf), especially in the upper Fishhole Creek area near the Hunt ranch and in Barnes Valley. The wood ranges from black and white opaline varieties to gray to brown chalcedony. An unpublished report describes at least 10 species of conifers, oak, and other hardwoods from fossil woods of possible Miocene age collected by Alfred D. Collier of Klamath Falls (George F. Beck, written communication, 1968).

Brightly colored agate and jasper of polishing quality are found sparsely but widely distributed in the southeast part of the project area, mainly southwest of Drews Reservoir.

Figure 30. Layered cinders in Merrill cinder pit 1 mile west of Merrill, Klamath Hills. This pit has provided large quantities of road-building material for southern Klamath County.

ADDENDUM

GEOCHEMICAL SAMPLING

As rocks and mineral deposits weather, the elements contained in them are released to soils and streams as constituents of insoluble detrital minerals and as soluble ions. The ions may be reprecipitated in the soils and stream sediments and the detrital minerals may be concentrated by a variety of physical and chemical processes. Systematic sampling and analysis of these sediments may provide indications of the presence of unusual concentrations of valuable elements in the stream drainage area.

A reconnaissance geochemical sampling project was carried out as a part of the present study. The sample collecting and analysis was done by Richard G. Bowen of the State of Oregon Department of Geology and Mineral Industries. A total of 375 stream-sediment samples was collected and analyzed for copper, zinc, molybdenum, mercury, and uranium. In addition, 76 sample analyses were made available to the project by the Weyerhaeuser Co.

The four general areas sampled are listed below. They lie in the southeastern quarter of the project area and all contain acid intrusive or extrusive rocks, hydrothermally altered rocks, or actual occurrences of metallic mineralization. Within selected parts of these areas, all streams which had a drainage area of at least one square mile were sampled.

SAMPLED AREAS

1. Drainage northwest of Lakeview. This area includes the uranium mines and most of the known uranium occurrences.
2. Quartz Mountain, Quartz Butte, Razorback Ridge. There are quicksilver prospects and large exposures of opalized, bleached, and altered rocks in this region.
3. Lee Thomas Crossing, Slide Mountain east to the Chewaucan River, including the east and west slopes of the Paisley Hills. There is a large body of iron-stained silicified rhyolite and tuff in the Lee Thomas Crossing area and copper-lead-zinc mineralization in the Paisley Hills.
4. Fitzwater Point-Dry Creek. Quicksilver prospects and silicified rocks occur in this area.

The analytical results for all sample locations are available in an open file at the Department of Geology and Mineral Industries office in Portland.

The location of samples which appear to have anomalously high concentrations of one or more of the elements investigated have been plotted on the accompanying mineral resources map (plate 2). In interpreting these anomalies it should be noted that the elements detected in more than normal quantities may not necessarily be present in commercial amounts. They may, however, indicate the presence of some mineralization in the drainage system. As would be expected, the sediments downstream from the known mineral occurrences do contain anomalous concentrations of metallic elements (Paisley Hills, Augur Creek-White King mine area, Quartz Mountain, and Dry Creek).

SUMMARY OF SAMPLING RESULTS

Molybdenum Anomalies

Molybdenum was detected in only one sample, on Augur Creek below the White King mine. The source can be easily traced to the mine, where the soluble vivid blue hydrous oxide of molybdenum, ilsemannite, is a common mineral.

Uranium Anomalies

All concentrations of uranium equal to 1 ppm or more were considered to be anomalous and were plotted on the mineral resources map (plate 2). Concentrations of this magnitude or greater are scattered widely over the sampled area, occasionally in association with unusual concentrations of other elements in the same general area but not in the same sample. Anomalous concentrations of uranium occur in sediments derived from all four of the areas known to contain mineralized rocks, even though commercial uranium mineralization has been found thus far in only one of these (Augur Creek-White King mine area).

East slope of the Paisley Hills

The short streams draining the east slope of the southern Paisley Hills from Schoolhouse Creek to upper Moss Creek contain anomalous concentrations of uranium, based on single samples. The highest concentration, 2 ppm, was recorded on Moss Creek (center of south line of SE$\frac{1}{4}$ sec. 28, T. 35 S., R. 19 E.). The streams in this area cross rhyolitic intrusives and both the (Taf) and (Ttf) pyroclastic and sedimentary units. No uranium-bearing rocks are known to have been found in place in this area.

West slope of the Paisley Hills and tributaries of the Chewaucan River

Several short tributaries intersecting the Chewaucan River from both the east and west sides contain concentrations of 1 ppm uranium. Some of these may reflect the same terrain in the southern Paisley Hills as do the samples from the east slope. The highest uranium concentration, 3 ppm, occurs in a somewhat isolated drainage at the head of Swamp Creek (NW corner sec. 25, T. 36 S., R. 18 E.).

Augur Creek, below the White King uranium mine

Seepages from the dumps and mine wastes have been carried into Augur Creek from the White King mine for 10 years. Sampling of the stream sediments at distances of 2 and 4 miles below the mine yielded the highest concentrations of uranium obtained in the sample program, 10 ppm and 5 ppm, respectively.

Upper Thomas Creek-Cottonwood Creek drainage

A scattered group of samples containing concentrations of uranium of 1 ppm occurs in upper Thomas Creek, and in Tom Young and Helphenstein Creeks (N$\frac{1}{2}$ T. 38 S., R. 18 E.). The largest concentration, 2 ppm, occurs at the headwaters of Mesman Creek (center of SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 3, T. 38 S., R. 18 E.). In general, this is an area of rocks already known to contain small amounts of uranium mineralization.

South Fork of the Sprague River-Drews Creek

Two isolated samples are grouped together here on the assumption that they may be related to the elongate trend of rhyolite intrusive masses extending from Quartz Butte to Owen Butte.

(a) South Fork of the Sprague River: A uranium concentration of 2 ppm was detected in a sample collected on a tributary entering the south side of the Sprague River in approximately the center of the SW$\frac{1}{4}$ sec. 10, T. 37 S., R. 16 E. This drainage heads into the Quartz Mountain rhyolite dome.

(b) Upper Drews Creek: A concentration of 5 ppm of uranium occurs in a stream sample from a gulch entering Drews Creek from the north, approximately in the center of the north line of the NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 32, T. 37 S., R. 17 E. This is the highest concentration encountered in the study, with the exception of sediment from Augur Creek contaminated by mine waste. The area sampled is one in which large silicified rhyolite dikes and domes occur, containing minor amounts of cinnabar. No uranium mineralization is known to have been detected here in earlier work.

A few additional scattered anomalous concentrations of 1 ppm are shown on the map. Their significance is not known.

Copper Anomalies

Concentrations of copper in excess of 80 ppm are considered to be anomalous in the area studied. Copper mineralization has been seen in the project area only in the rocks of the Brattain mining district in the Paisley Hills, but none of the stream-sediment samples obtained several miles downstream from the mineralized outcrop contained anomalous copper concentrations. The only two areas that contain above-normal concentrations are as follows:

Upper Whitworth Creek-Quartz Butte area

No copper mineralization has been detected in the rock outcrops of this area, but the unusual concentration of copper in the stream sediments was obtained independently in both the Weyerhaeuser sampling project and the present study. The anomalous copper concentration may represent concealed copper mineralization or be derived from a trace element halo of copper associated with a mineralized zone. Two types of rock occur in this anomaly area, either of which may have contributed the copper. One is the rhyolite intrusive complex around Quartz Butte, and the other is a group of diabase dikes associated with basalt extrusion in upper Drews and Whitworth Creeks (see text describing Tertiary and Quaternary intrusive rocks).

Lower Drews Creek-Fitzwater Point area

Two samples containing anomalous concentrations of copper were obtained in short, eastward-flowing drainages along the west side of Goose Lake valley. As far as can be determined, these head into a terrain in which basalt and tuff are exposed. There is no apparent reason why a copper anomaly should exist here.

Zinc Anomalies

All samples containing concentrations of zinc in excess of 140 ppm in the project area are considered to be worthy of note. Unusual zinc concentrations occur rather widely, most of them adjacent to anomalous concentrations of other elements. Zinc minerals have been described from the rocks of the Brattain mining district in the Paisley Hills (Appling, 1950). Zinc was found in unusual concentrations in stream sediments along the east side of the Paisley Hills, probably reflecting that area of mineralization. Relatively high zinc values accompany uranium anomalies in Swamp, Tom Young, and Helphenstein Creeks, and in the mine-waste-contaminated uranium anomaly in Augur Creek. Both the Quartz Butte and Fitzwater Point areas have zinc in anomalous amounts, with other elements. The possibility of sample contamination from galvanized road culverts is always present and perhaps less emphasis should be placed on anomalous zinc concentrations than on other evidence.

Mercury Anomalies

Samples containing more than 0.2 ppm mercury in the project area are considered to be anomalous. Those that showed a stronger than average concentration were resampled.

The strongest anomaly of 0.8 ppm, near Angel Spring in sec. 31, T. 37 S., R. 17 E., was verified by repeat sampling. This anomaly occurs in the area of known mercury mineralization around Quartz Mountain. The anomaly of 4 ppm on Dry Creek in the E$\frac{1}{2}$ sec. 36, T. 40 S., R. 17 E. could not be reproduced by repeat sampling. The 0.7 ppm anomaly on Schoolhouse Creek in the N$\frac{1}{2}$ sec. 4, T. 35 S., R. 19 E. also failed to be reproduced on resampling. The other anomalies shown on plate 2 generally held up under repeat analysis, but they were not resampled in the field.

SELECTED BIBLIOGRAPHY

Allison, I. S., 1945, Pumice beds at Summer Lake, Oregon: Geol. Soc. America Bull., v. 56, no. 8, p. 789-807.

_________, 1949, Fault pattern of south-central Oregon [abst.]: Geol. Soc. America Bull., v. 60, no. 12, pt. 2, p. 1935.

_________, 1966, Pumice at Summer Lake, Oregon - a correction: Geol. Soc. America Bull., v. 77, no. 3, p. 329-330.

Anderson, C. A., 1941, Volcanoes of the Medicine Lake Highland, California: Univ. Calif. Dept. Geol. Sci. Bull., v. 25, no. 7, p. 347-422.

Appling, R. N., 1950, Economic geology of the Brattain mining area, Paisley, Oregon: Univ. Oregon master's thesis, unpub., 74 p.

Averill, C. V., 1935, Mines and mineral resources of Siskiyou County, California: in Thirty-first Rept. of the State Mineralogist, Calif., p. 255-338.

Berg, J. W., Jr., and Thiruvathukal, J. W., 1967, Complete Bouguer gravity anomaly map of Oregon: Oregon Dept. Geology and Mineral Industries map GMS 4-b.

Baldwin, E. M., 1946, Diatomite: Oregon Dept. Geology and Mineral Industries The ORE BIN, v. 8, no. 1, p. 1-7.

Blank, R. H., Jr., 1966, General features of the Bouguer gravity field in southwestern Oregon: U. S. Geol. Survey Prof. Paper 550-C, p. C113.

Bodvarsson, G., 1964, Physical characteristics of natural heat resources in Iceland: United Nations Conf. on New Sources of Energy, Proceedings, v. 2, Geothermal Energy: 1, p. 82-90.

_________, 1966, Energy and power of geothermal resources: The ORE BIN, v. 20, no. 7, p. 117-124.

Bodvarsson, G., and Palmason, G., 1964, Exploration of subsurface temperature in Iceland: U.N. Conf. Proceedings, v. 2, Geothermal Energy: 1, p. 91-98.

Bowen, R. G., 1968, Geochemical sampling data, Klamath and Lake Counties, Oregon: Oregon Dept. Geology and Mineral Industries open-file rept., unpub.

Brooks, H. C., 1963, Quicksilver in Oregon: Oregon Dept. Geology and Mineral Industries Bull. 55.

Buwalda, John P., 1921, Report on oil and gas possibilities of eastern Oregon: Oregon Bur. Mines and Geology Mineral Res. of Oregon, v. 3, no. 2, 47 p.

California Division of Mines, 1959, Geology of northeastern California: Calif. Div. Mines Mineral Inf. Service, v. 12, no. 6, p. 1-7.

Chesterman, C. W., 1956, Pumice, pumicite, and volcanic cinders in California (with Schmidt, F.S., Technology of pumice, pumicite, and volcanic cinders): Calif. Div. Mines Bull. 174, 119 p.

Conrad, C. F., 1953, Geology of the Ana River section, Summer Lake, Oregon: Oregon State Univ. master's thesis, unpub., 92 p.

Cotton, C. A., 1952, Volcanoes as Landscape Forms: New York, John Wiley & Sons, 416 p.

Cressman, L. S., 1951, Western prehistory in the light of carbon-14 dating: Southwestern Jour. Anthropology, v. 7, no. 3, p. 289-313.

Donath, F. A., 1958, Basin-Range structure of south-central Oregon: Stanford Univ. doctoral diss., unpub., 144 p.

_________, 1962, Analysis of Basin-Range structure, south-central Oregon: Geol. Soc. America Bull., v. 73, no. 1, p. 1-16.

Donath, F. A., and Kuo, J. T., 1962, Seismic-refraction study of block faulting, south-central Oregon: Geol. Soc. America Bull., v. 73, no. 4, p. 429-434.

Ellis, A. J., 1964, Geothermal drillholes: geochemical investigations: U.N. Conf. Proceedings, v. 2, Geothermal Energy: 1, p. 208-218.

Facca, G., and Tonani, F., 1964, Natural steam geology and geochemistry: U. N. Conf. Proceedings,

v. 2, Geothermal Energy: 1, p. 219-229.

Ford, R. S., and others, 1963, Northeastern counties' ground-water investigation: Calif. Dept. Water Res. Bull. 98, v. 1 text, 246 p., v. 2, plates.

Fuller, R. E., 1931, The geomorphology and volcanic sequence of Steens Mountain in southeastern Oregon: Univ. Washington Pub. in Geol., v. 3, no. 1.

Fuller, R. E., and Waters, A. C., 1929, The nature and origin of the horst and graben structure of southern Oregon: Jour. Geol., v. 37, no. 3, p. 204-238.

Gardner, M. C., 1964, Cenozoic volcanism in the High Cascade and Modoc Plateau provinces of northeast California: Univ. Arizona doctoral dissertation, unpub.

Gay, T. E., Jr., 1966, Economic mineral deposits of the Cascade Range, Modoc Plateau, and Great Basin region of northeastern California: in Calif. Div. Mines and Geol. Bull. 190, p. 97-105.

Gay, T. E., Jr., and Aune, Q. A., 1958, Geologic map of California, Alturas sheet: Calif. Div. Mines and Geol., scale 1:250,000.

Gillson, J. L., ed., 1960, Industrial Minerals and Rocks: A.I.M.E., 3rd ed.

Grindley, G. W., 1964, Geology of New Zealand geothermal steam fields: U.N. Conf. Proceedings, v. 2, Geothermal Energy: 1, p. 237-245.

Haddock, G. H., 1959, Geology of the Cougar Peak volcanic area, Lake County, Oregon: Washington State Univ. master's thesis, unpub., 72 p.

Hampton, E. R., 1964, Geologic factors that control the occurrence and availability of ground water in the Fort Rock basin, Lake County, Oregon: U.S. Geol. Survey Prof. Paper 383-B, 29 p.

Hanna, G.D., and Gester, G. C., 1963, Pliocene lake beds near Dorris, California: Calif. Acad. Sci. Occasional Papers 42, 17 p.

Healy, J., 1964, Geology and geothermal energy in the Taupo volcanic zone, New Zealand: U.N. Conf. Proceedings, v. 2, Geothermal Energy: 1, p. 250-258.

Heath, C. O., Jr., and Brandenburg, N. R., 1953, Pozzolanic properties of several Oregon pumicites: Oregon State Univ. Eng. Exp. Sta. Bull., no. 34, 35 p.

Hill, J. M., 1915, High Grade district, Modoc County, California, in Some mining districts in northeastern California and northwestern Nevada: U.S. Geol. Survey Bull. 594, p. 38-48.

Ikeagwauni, F.D., 1965, Photogeology of the Picture Rock Pass area, Lake County, Oregon: Univ. Oregon master's thesis, unpub., 75 p.

Johns, W. R., 1949, The geology and quicksilver occurrences at Quartz Mountain, Oregon: Univ. Oregon master's thesis, unpub., 76 p.

Johnson, D. W., 1918, Block faulting in the Klamath Lakes region [Oreg.]: Jour. Geology, v. 26, p. 229-236.

Kaufman, Alvin, 1964, Geothermal power, an economic evaluation: U.S. Bur. Mines Inf. Circ. 8230, 24 p.

King, C. R., 1948, Pumice and perlite as industrial materials in California: Calif. Jour. Mines and Geology, v. 44, no. 3, p. 293-319.

King, D. P., 1965, U.S. Bureau of Mines Pozzolanic Materials Project: U.S. Bur. Mines unpub. data.

Kuno, Hisashi, 1960, High alumina basalt: Jour. Petrology, v. 1, p. 121.

Larson, E. E., 1965, The structure, stratigraphy, and paleomagnetics of the Plush area, southeastern Lake County, Oregon: Univ. Colorado doctoral diss., unpub., 166 p.

Leppla, P. W., 1953, Diatomite: Calif. Div. Mines Mineral Inf. Service, v. 6, no. 11, p. 1-5.

Lessing, Lawrence, 1969, Power from the earth's own heat: Fortune, v. 79, no. 7, p. 138-141, 192, 196, 198.

MacDonald, G. A., 1966, Geology of the Cascade Range and Modoc Plateau, in Calif. Div. Mines and Geology Bull. 190, p. 65-96.

Marliave, Chester, 1944, Geological reconnaissance report on feasibility of dam construction on Sprague River situated in Lake and Klamath Counties, Oregon: U.S. Army Corps of Engineers, San Francisco District.

Matthews, T. C., 1955, Oregon radioactive discoveries in 1954 and 1955: The ORE BIN, v. 17, no. 12, p. 87-92.

McNitt, J. R., 1963, Exploration and development of geothermal power in California: Calif. Div. Mines and Geology Spec. Rept. 75, 45 p.

Merewether, E. A., 1953, Geology of the lower Sprague River area, Klamath County, Oregon: Univ. Oregon master's thesis, unpub., 62 p.

Meyers, J. D., and Newcomb, R. C., 1952, Geology and ground-water resources of the Swan Lake-Yonna Valleys area, Klamath County, Oregon: U.S. Geol. Survey open-file rept., 151 p.

Moore, B. N., 1934, Deposits of possible nuee ardente origin in the Crater Lake region, Oregon: Jour. Geol., v. 42, no. 4, p. 358-375.

__________, 1937, Nonmetallic mineral resources of eastern Oregon: U.S. Geol. Survey Bull. 875, 180 p.

Muntzert, J. K., 1969, Geology and mineral deposits of the Brattain district, Lake County, Oregon: Oregon State Univ. master's thesis, unpub., 70 p.

Newcomb, R. C., 1958, Yonna Formation of the Klamath River basin, Oregon: Northwest Sci., v. 32, no. 2, p. 41-48.

Newcomb, R. C., and Hart, D. H., 1958, Preliminary report on the ground-water resources of the Klamath River basin, Oregon: U.S. Geol. Survey open-file rept., 248 p.

Newton, V. C., Jr., 1965, Oil and gas exploration in Oregon: Oregon Dept. Geology and Mineral Industries Misc. Paper 6, rev.

Noble, D.C., Drake, J.C., and Whallon, M.K., 1969, Some preliminary observations on compositional variations within the pumice- and scoria-flow deposits of Mount Mazama: in Proceedings of the Andesite Conference: Oregon Dept. Geology and Mineral Industries Bull. 65, p. 157-164.

Nockolds, S.R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007-1032.

North, O. S., 1955, Perlite: in Mineral Facts and Problems: U.S. Bur. Mines Bull. 556, p. 595-600.

Pakiser, L. C., 1964, Gravity, volcanism, and crustal structure in southern Cascade Range, California: Geol. Soc. America Bull., v. 75, no. 7, p. 611-620.

Peacock, M. A., 1931, Modoc lava field, northern California: Geographical Rev., v. 21, p. 259-275.

Pease, R. W., 1969, Normal faulting and lateral shear in northeastern California: Geol. Soc. America Bull., v. 80, no. 4, p. 715-720.

Peck, D. L., and others, 1964, Geology of the central and northern parts of the Western Cascade Range in Oregon: U.S. Geol. Survey Prof. Paper 449, 56 p.

Peterson, N. V., 1958, Oregon's uranium picture: The ORE BIN, v. 20, no. 12, p. 111-118.

__________, 1959, Preliminary geology of the Lakeview uranium area, Oregon: The ORE BIN, v. 21, no. 2, p. 11-16.

__________, 1961, Perlite occurrences in southeastern Klamath and southwestern Lake Counties, Oregon: The ORE BIN, v. 23, no. 7, p. 65-70.

Peterson, N. V., and Groh, E. A., Editors, 1965, Lunar geologic field conference guide book: Oregon Dept. Geology and Mineral Industries Bull. 57, 51 p.

____________________, 1967, Geothermal potential of the Klamath Falls area, Oregon, a preliminary study: The ORE BIN, v. 29, no. 11, p. 209-231.

Powers, H. A., 1932, The lavas of the Modoc Lava Bed quadrangle, California: Am. Mineralogist, v. 17, no. 7, p. 253-294.

Russell, I. C., 1884, A geological reconnaissance in southern Oregon: U.S. Geol. Survey 4th Ann. Rept., p. 435-464.

__________, 1905, Preliminary report on the geology and water resources of central Oregon: U. S. Geol. Survey Bull. 252, 138 p.

Russell, R. J., 1928, Basin and Range structure and the stratigraphy of the Warner Range, northeastern California: Univ. Calif. Dept. Geol. Sci. Bull., v. 17, no. 11, p. 387-496.

Schafer, Max, 1955, Preliminary report on the Lakeview uranium occurrences, Lake County, Oregon: The ORE BIN, v.17, no. 12, p. 93-94.

__________, 1956, Uranium prospecting in Oregon, 1956: The ORE BIN, v. 18, no. 12, p. 101-107.

Skinner, K. G., and others, 1944, Diatomites of the Pacific Northwest as filter aids: U.S. Bur. Mines Bull. 460, 87 p.
Stein, H. A., and Murdock, J. B., 1955, The processing of perlite: Calif. Jour. Mines and Geol., v. 51, no. 2, p. 105-116.
Studt, F. E., 1964, Geophysical prospecting in New Zealand's hydrothermal fields: U. N. Conf. Proceedings, v. 2: Geothermal Energy: 1, p. 380-385.
Trauger, F. D., 1950, Basic ground-water data in Lake County, Oregon: U.S. Geol. Survey in coop. with Oregon State Engineer, unpub. rept., 287 p.
Van Orstrand, C.E., 1938, Temperatures in the lava beds of east-central and south-central Oregon: Am. Jour. Sci., v. 35, no. 205, p. 22-46.
Wagner, N. S., 1947, The lightweight aggregate, pumice: The ORE BIN, v. 9, no. 4, p. 29-34.
__________, 1949, Oregon's pumice industry: The ORE BIN, v. 11, no. 12, p. 79-82.
Walker, G. W., 1951, Pumice deposits of the Klamath Indian Reservation, Klamath County, Oregon: U.S. Geol. Survey Circ. 128, p. 1-6.
__________, 1963, Reconnaissance geologic map of the eastern half of the Klamath Falls (AMS) quadrangle, Lake and Klamath Counties, Oregon: U.S. Geol. Survey Mineral Inv. Field Studies Map, MF-260.
Walker, G. W., Peterson, N. V., and Greene, R. C., 1967, Reconnaissance geologic map of the east half of the Crescent quadrangle, Lake, Deschutes, and Crook Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-493.
Waring, G. A., 1908, Geology and water resources of a portion of south-central Oregon: U.S. Geol. Survey Water-supply Paper 220, 86 p.
__________, 1965, Thermal springs of the United States and other countries of the world -- A summary; rev. by R. R. Blankenship and Ray Bentall: U.S. Geol. Survey Prof. Paper 492, 383 p.
Weissenborn, A. E., ed., 1969, Mineral and water resources of Oregon: Oregon Dept. Geology and Mineral Industries Bull. 64, 462 p.
Wentworth, C. K., and Williams, Howel, 1932, The classification and terminology of the pyroclastic rocks: Natl. Research Council Bull. 89, p. 19-53.
White, D. E., 1955, Geothermal energy: U.S. Geol. Survey Circ. 519, 17 p.
__________, 1957, Thermal waters of volcanic origin: Geol. Soc. America Bull., v. 68, no. 12, pt. 1, p. 1637-1658.
__________, 1957, Magmatic, connate, and metamorphic waters: Geol. Soc. America Bull., v. 68, no. 12, pt. 1, p. 1659-1682.
__________, 1964, Preliminary evaluation of geothermal areas by geochemistry, geology, and shallow drilling: U.N. Conf. Proceedings, v. 2, Geothermal Energy: 1, p. 402-409.
White, D. E., Hem, J. D., and Waring, G. A., 1963, Data of geochemistry: Chemical composition of subsurface waters: U.S. Geol. Survey Prof. Paper 440-F, p. F1-F67.
Williams, Howel, 1935, Newberry Volcano, central Oregon: Geol. Soc. America Bull., v. 46, no. 2, p. 253-304.
__________, 1942, The geology of Crater Lake National Park, Oregon: Carnegie Inst. Wash. Pub. 540, 162 p.
__________, 1949, Geology of the MacDoel quadrangle, California: Calif. Div. Mines Bull. 151, p. 7-60.
__________, 1953, The ancient volcanoes of Oregon: Oregon State Sys. Higher Ed., Condon Lectures, Eugene, Oregon, 64 p.
__________, 1957, A geologic map of the Bend quadrangle, Oregon and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Dept. Geology and Mineral Industries geol. map.
Wilson, S. H., 1964, Chemical prospecting of hot-spring areas for utilization of geothermal steam: U.N. Conf. Proceedings, v. 2, Geothermal Energy: 1, p. 410-420.

INFORMATION ABOUT FOSSIL LOCALITIES AND AGE DATING
TO ACCOMPANY GEOLOGIC MAP, PLATE I.

Map No.	Location	Fossil type	Age	Identified by and/or reference
1	Wilson quarry - Stukel Mt. Sec. 32, T. 39 S., R. 10 E.	Vertebrate mammalian	Middle Pliocene	Meyers and Newcomb, 1952
2	Bodnar ranch Sec. 34, T. 37 S., R. 11½ E.	Fresh-water molluscs, fish	Pliocene	Myers and Newcomb, 1952
3	Sec. 36, T. 40 S., R. 10 E.	Vertebrate, camel	Late Pliocene	J.A. Shotwell, personal communication
4	Sec. 14, T. 41 S., R. 10 E.	Vertebrate, mammalian	Late Pliocene	J. A. Shotwell, personal communication
5*	Hunt ranch - Fishhole Creek	Fossil wood 10 species	Early Miocene	Geo. F. Beck, personal communication
6	Dog Mountain Sec. 18, T. 40 S., R. 17 E.	Vertebrate, mammalian	Lower Pliocene? Upper Miocene	G. W. Walker, personal communication
7	Sec. 20, T. 39 S., R. 18 E.	Fossil tracks	No older than late Miocene	J. A. Shotwell, personal communication
8	Thomas Creek Sec. 27, T. 37 S., R. 18 E.	Vertebrate, rhinoceras	Lower Miocene	Peterson, 1959
9	Sec. 27, T. 37 S., R. 18 E.	Leaves	Middle Miocene	Peterson, 1959
10	Sec. 34, T. 37 S., R. 18 E.	Leaves	Early Pliocene Late Miocene	Peterson, 1959
11	Sec. 13, T. 34 S., R. 18 E.	K/A date quartz monzonite	32.6 ± .7 m.y. Late early Oligocene	Muntzert, J. K. 1969
12	Coglan Buttes T. 34 S., R. 20 E.	Vertebrate, mammalian	Early Miocene	Walker, G. W. 1963
13	Coglan Buttes T. 34 S., R. 20 E.	Vertebrates?		
14	Ten Mile Butte Secs. 25 & 36, T. 31 S., R. 18 E.	Vertebrates	Middle Pliocene	J. A. Shotwell, personal communication
16	Moss Creek Sec. 13, T. 35 S., R. 19 E.	Vertebrates	Early Miocene	J. A. Shotwell, personal communication
17	Harvey Creek Sec. 6, T. 33 S., R. 17 E.	Vertebrates	Late Miocene	J. A. Shotwell, personal communication
18	Malin Sec. 10, T. 41 S., R. 12 E.	Vertebrates	Late Miocene	J. A. Shotwell, personal communication
19	Hildebrand Sec. 35, T. 37 S., R. 11½ E.	Fish		
20	Parker place Sec. 32, T. 37 S., R. 11½ E.	Fish	Plio-Pleistocene	Miller, R. R. personal communication
21	Worden Sec. 4, T. 41 S., R. 8 E.	Fish	Plio-Pleistocene	Miller, R. R. personal communication
22	Secs. 7 and 8, T. 40 S., R. 11 E.	Fish	Plio-Pleistocene	Miller, R. R. personal communication
23*	Thomas Creek Sec. 27, T. 37 S., R. 18 E.	K/A date on Rhyolite vitrophyre	8.1 ± 0.5 m.y.	Geochron Lab., this report
24*	Quartz Valley Mt. Sec. 23, T. 37 S., R. 16 E.	K/A date on Rhyodacite vitrophyre	7.6 ± 0.4 m.y.	Geochron Lab., this report
25*	Switchback Hill SE¼ sec. 29, T. 36 S., R. 10 E.	Fish	Plio-Pleistocene	R. R. Miller personal communication

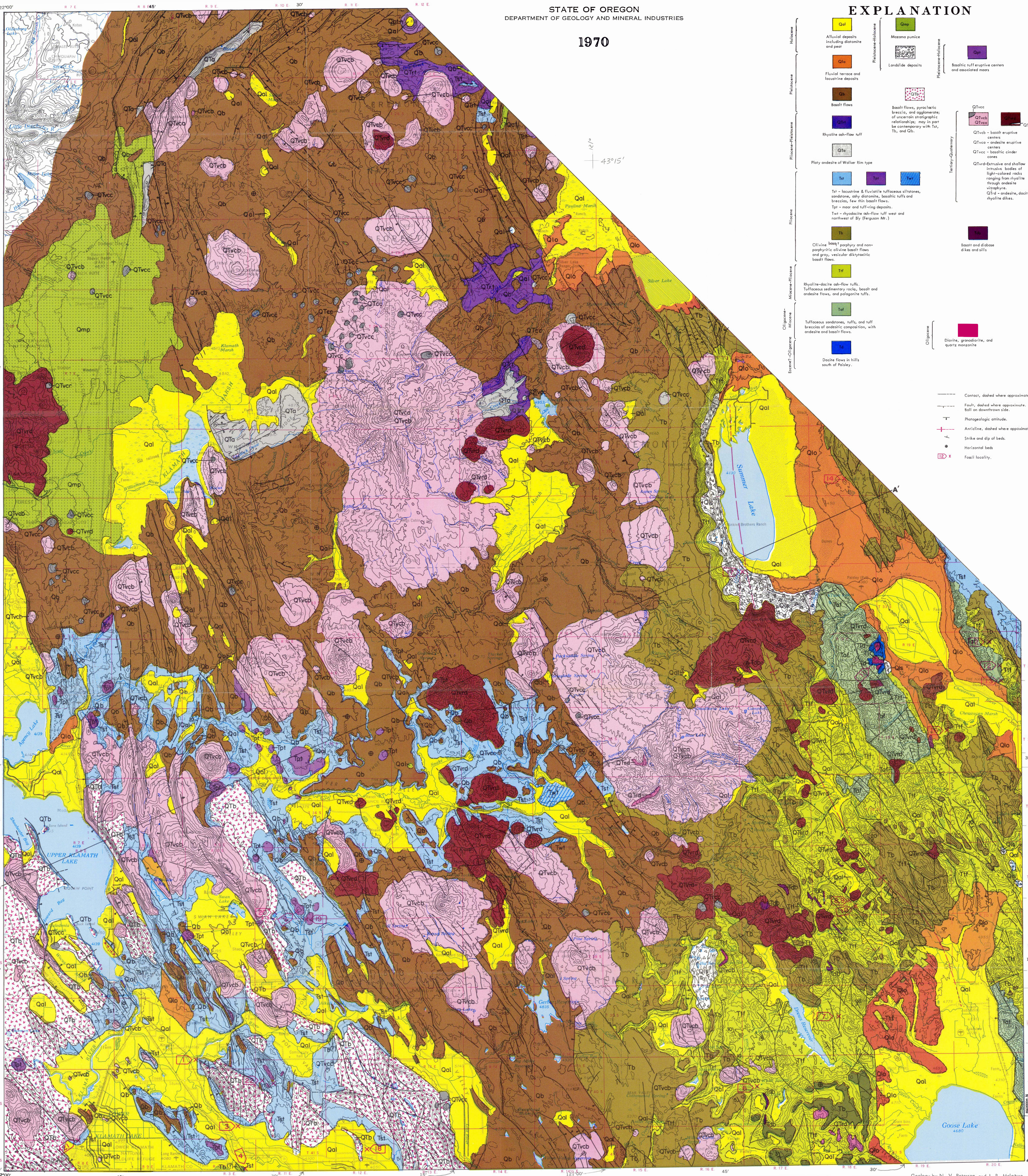
* Not located on map (Plate 1).

MAP CORRECTION NOTICE: Cross section line A - A' is slightly misplaced on the geologic map (Plate 1). A' should be half an inch north of its present position, so that a line drawn between A and A' corresponds to the Generalized Geologic Cross Section.

GEOLOGIC MAP of the KLAMATH-LAKE COUNTIES REGION, OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

1970



EXPLANATION

Holocene

Qal — Alluvial deposits including diatomite and peat

Pleistocene-Holocene

Qmp — Mazama pumice

Qls — Landslide deposits

Pleistocene-Holocene

Qpt — Basaltic tuff eruptive centers and associated maars

Pleistocene

Qlo — Fluvial terrace and lacustrine deposits

Qb — Basalt flows

QTb — Basalt flows, pyroclastic breccia, and agglomerate; of uncertain stratigraphic relationships; may in part be contemporary with Tst, Tb, and Qb.

Pliocene-Pleistocene

QTrt — Rhyolite ash-flow tuff

QTa — Platy andesite of Walker Rim type

Tertiary-Quaternary

QTvcc, QTvcb, QTvca, QTvrd, QTrd

QTvcb - basalt eruptive centers

QTvca - andesite eruptive centers

QTvcc - basaltic cinder cones

QTvrd - Extrusive and shallow intrusive bodies of light-colored rocks ranging from rhyolite through andesite vitraphyre.

QTrd - andesite, dacite, rhyolite dikes.

Pliocene

Tst, Tpt, Twt

Tst - lacustrine & fluviatile tuffaceaus siltstones, sandstone, ashy diatomite, basaltic tuffs and breccias, few thin basalt flows.

Tpt - maar and tuff-ring deposits.

Twt - rhyodacite ash-flow tuff west and northwest of Bly (Ferguson Mt.)

Tb — Olivine basalt porphyry and non-porphyritic olivine basalt flows and gray, vesicular diktytaxitic basalt flows.

Tdb — Basalt and diabase dikes and sills

Miocene-Pliocene

Ttf — Rhyolite-dacite ash-flow tuffs. Tuffaceous sedimentary rocks, basalt and andesite flows, and palagonite tuffs.

Oligocene-Miocene

Taf — Tuffaceous sandstones, tuffs, and tuff breccias of andesitic composition, with andesite and basalt flows.

Oligocene

Diorite, granodiorite, and quartz monzonite

Eocene?-Oligocene

Td — Dacite flows in hills south of Paisley.

Contact, dashed where approximate.

Fault, dashed where approximate. Ball on downthrown side.

Photogeologic attitude.

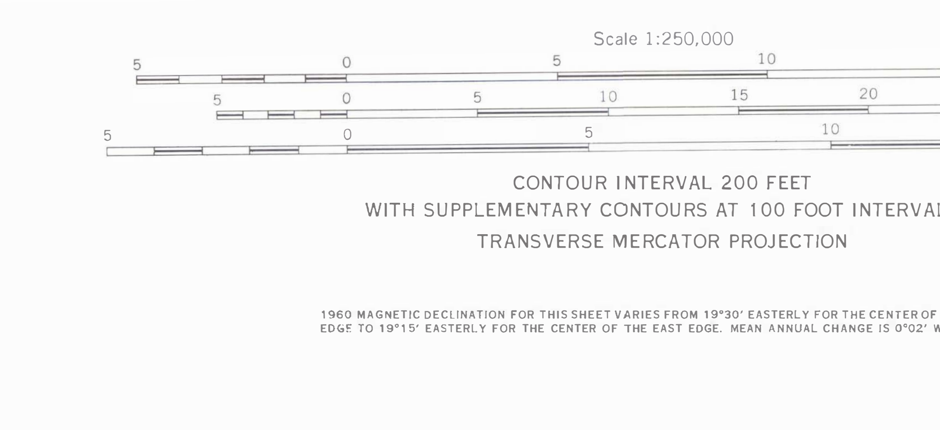
Anticline, dashed where appoximate.

Strike and dip of beds.

Horizontal beds

Fossil locality.

Base map from Army Map Service 1:250,000 Topographical Map Sheets, Crescent NK10-3, and Klamath Falls NK10-6.



Scale 1:250,000

20 Statute Miles

30 Kilometers

15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

1960 MAGNETIC DECLINATION FOR THIS SHEET VARIES FROM 19°30' EASTERLY FOR THE CENTER OF THE WEST EDGE TO 19°15' EASTERLY FOR THE CENTER OF THE EAST EDGE. MEAN ANNUAL CHANGE IS 0°02' WESTERLY.

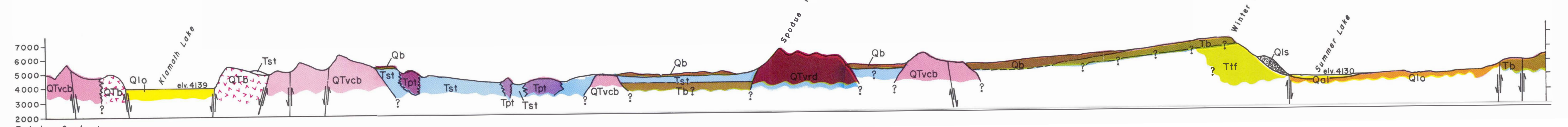
SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by N. V. Peterson and J. R. McIntyre

Cartography by C. J. Newhouse & S. R. Renoud

GENERALIZED GEOLOGIC CROSS SECTION



MINERAL RESOURCE MAP of the KLAMATH-LAKE COUNTIES REGION, OREGON