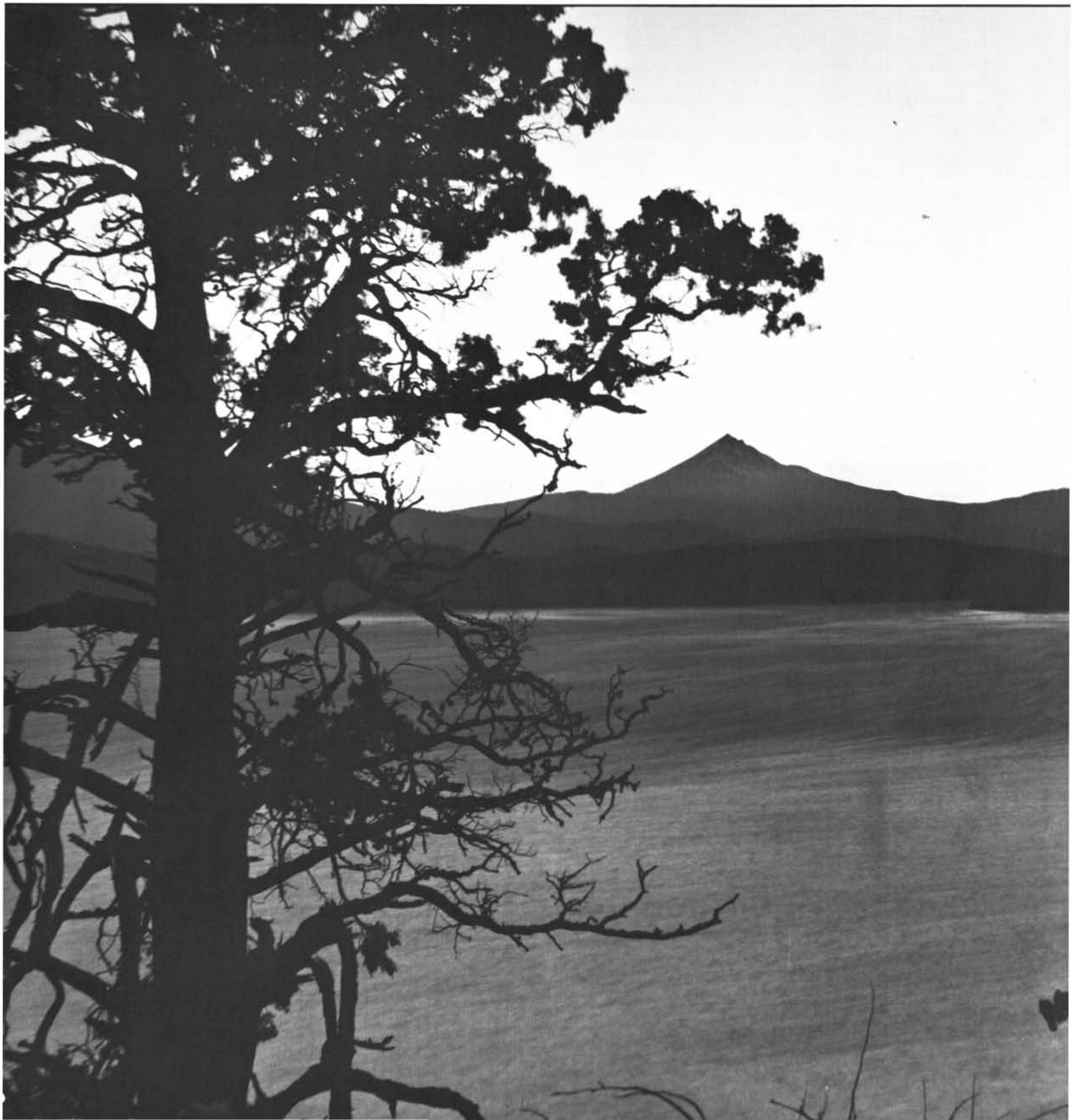
OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 42, NUMBER 11 NOVEMBER 1980



OREGON GEOLOGY
(ISSN 0164-3304)

VOLUME 42, NUMBER 11 NOVEMBER 1980

Published monthly by the State of Oregon Department of Geology and Mineral Industries (Volumes 1 through 40 were entitled *The Ore Bin*).

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Subscription rates: 1 year, $4.00; 3 years, $10.00. Single issues, $.40 at counter, $.50 mailed.
Available back issues of *The Ore Bin:* $.25 at counter, $.50 mailed.

Address subscription orders, renewals, and changes of address to *Oregon Geology,* 1069 State Office Building, Portland, OR 97201.

Send news, notices, meeting announcements, articles for publication, and editorial correspondence to the editor, Portland office. The Department encourages author-initiated peer review for technical articles prior to submission. Any review should be noted in the acknowledgments.

Second class postage paid at Portland, Oregon.
Postmaster: Send address changes to *Oregon Geology,* 1069 State Office Building, Portland, OR 97201.

COVER PHOTO

Mt. McLoughlin, seen from Upper Klamath Lake, the shrunken remnant of pluvial Lake Modoc discussed in article beginning on next page. (Oregon Department of Transportation photo)

Mineral resource data now accessible through Department computer terminal

The Oregon Department of Geology and Mineral Industries is offering a new service starting December 1, 1980. The Department, through a computer terminal in the Portland office, now has access to the U.S. Geological Survey's Computerized Resource Information Bank (CRIB) and the Geothermal Sample Data/ Chemical Analysis systems. Information on Oregon's metallic deposits, mines, and prospects and geothermal springs and wells can now be retrieved in the form of a computer printout.

At the present time, the CRIB system has 2,800 entries for Oregon. As the Department, under contract to the USGS, updates the system, the total for Oregon may rise to 4,000 or more entries. The northeast portion of the State has been updated, and the southeast section is in the process of being completed. Data from CRIB can be retrieved by county, mining district, deposit name, topographic map, commodity, size, or conceivably by any other of 200 parameters that can be listed for a deposit under CRIB.

Data on 189 of Oregon's thermal springs and wells can also be obtained through the terminal. The Geothermal Sample file contains information concerning the physical characteristics, geology, geochemistry, and hydrology of national and some international geothermal resources. It also includes chemical analyses of water, condensate, and gas.

The Department is offering to extract data from either of the two systems for the cost of the terminal plus staff time. The cost of staff time will probably equal that of the terminal cost. The work must be scheduled in view of other project demands and will therefore require reasonable lead time. For more information, contact Jerry Gray, Albany Field Office, phone (503) 967-2039. □

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Pluvial Lake Modoc, Klamath County, Oregon, and Modoc and Siskiyou Counties, California

by Samuel N. Dicken, Emeritus Professor of Geography, University of Oregon, Eugene, Oreg. 97403

INTRODUCTION

The Klamath Lakes, Upper and Lower, together with Tule Lake are the shrunken remnants of pluvial Lake Modoc (named in this article by the author). The old pluvial lake, which existed in Pleistocene time, consisted of several connected arms with an overall length of nearly 75 mi (120 km). The southern end was in California, south of Tule Lake; the northern end was near Fort Klamath in west-central Klamath County. At maximum extent, the 400 mi (663 km) of shoreline was at the nearly uniform elevation of 4,240 ft (1,292 m) above sea level. The lake basins were formed by block faulting and igneous activity and partially filled by sediment—cinders, ash, and pumice carried by meltwater from the Cascade Range to the lake. Eight major basins are included in the bed of the old lake. The largest are Upper Klamath, Lower Klamath, and Tule Lakes; the smaller basins, called valleys, are Spring Lake, Poe, Swan Lake, Yonna, and Langell Valleys. At the present time, only Upper Klamath Lake has a large body of water, the largest in Oregon.

PLUVIAL LAKES OF EASTERN OREGON

The pluvial lakes of western North America attracted the attention of geologists and geographers a century ago. The classic studies of Lakes Bonneville in Utah (Gilbert, 1890) and Lahontan in Nevada (Russell, 1885) are well known. Several brief general references have included Oregon's pluvial lakes (Meinzer, 1922; Feth, 1961), some accompanied by small-scale maps showing the general location but no details of shoreline. A map of Pleistocene pluvial lakes in the Great Basin compiled by Snyder and others (1964) from field studies, topographic maps, and aerial photographs indicates areas, names (if any), and outlets. Pluvial Lake Modoc was not included since it is not in the Great Basin. Two Oregon pluvial lakes have been studied and mapped in detail, Fort Rock (Forbes, 1972; Allison, 1979) and Chewaucan (Allison, 1945). Table 1 gives information about the pluvial lakes of eastern Oregon.

In addition to the lakes listed in Table 1, many smaller basins held water in Pleistocene times, when large parts of Klamath, Lake, Harney, and Malheur Counties were covered with water. Many of these lakes are yet unnamed, because the practice of naming the pluvial lakes has been slow to develop. Furthermore, because it would seem desirable that the names should be distinct from those of the present-day lakes, the pluvial lakes now called Malheur and Goose should have new names.

PLUVIAL LAKE MODOC

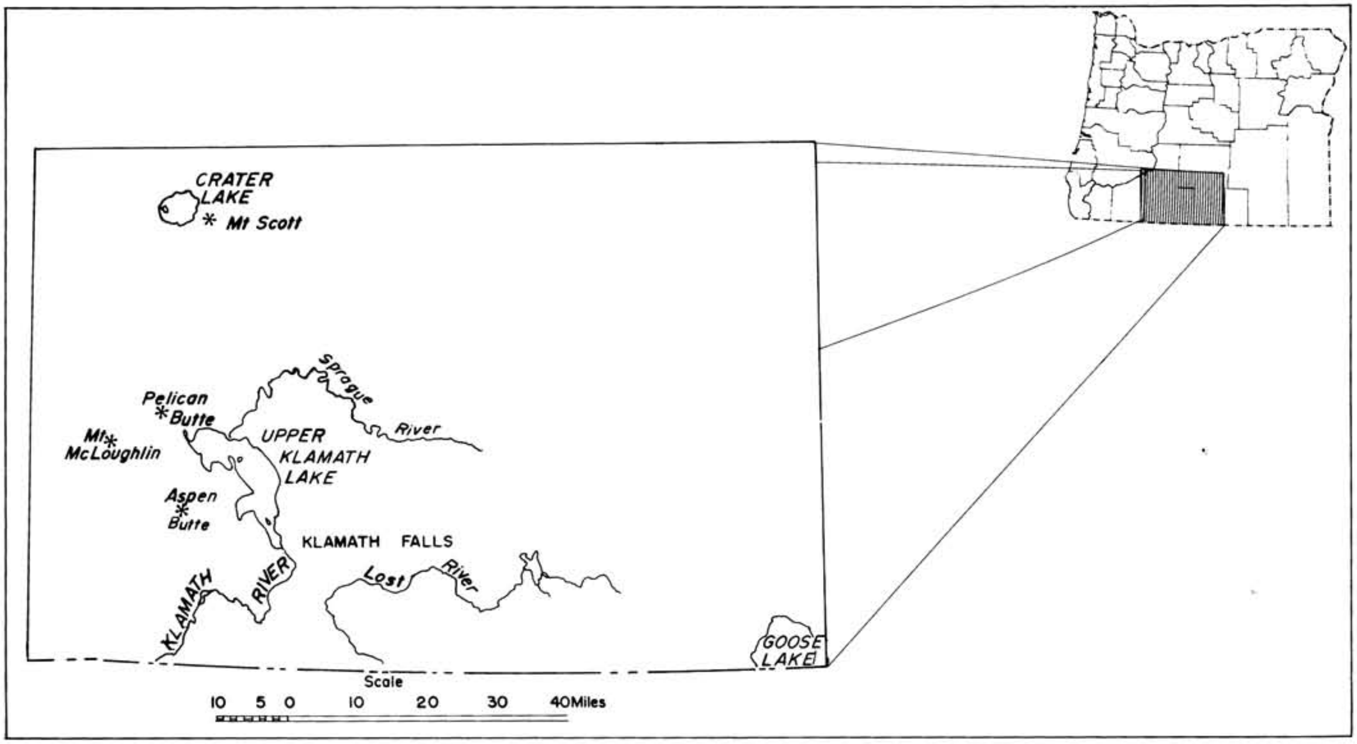
Lake Modoc, which covered an area of 1,096 sq mi (2,839 km^2), differed in some respects from the other pluvial lakes described above. It lay in the Basin and Range Province, not in the Great Basin. The location near the Cascade Range assured a large supply of water down to and including historic time, so that the lake has had a continuous surface outlet. The lake plain, as it is exposed, is nearly level from one end to the other, showing very little evidence of warping. In the pages to follow, the features of the old lake are described with some notes on its evolution and the modifications made by man in the present century.

Lake Modoc was developed on the northwest margin of the Basin and Range Province where block faulting and igneous activity formed numerous closed depressions, intervening ridges, and uplands. This Basin and Range type of structure can be traced through California, Nevada, Arizona, and far into Mexico. In the Lake Modoc area, the fault patterns are unusually complex and closely spaced; the geologic map of western Oregon (Wells and Peck, 1961) shows more than 100 faults in the vicinity of the lake, the major ones trending northwest-southeast. A complex line of faults separates the lake from the east slope of the Cascade Range. On the east side of Upper Klamath Lake, a fresh fault scarp rises abruptly from the lake. The major arms of the lake as well as the ridges are bordered by faults.

Numerous fault blocks in the form of hogback ridges,

Table 1. Other pluvial lakes of eastern Oregon

Pluvial lake name and location	Area	Comments
Fort Rock, Northern Lake Co., Oreg.	585 sq mi (1,510 km^2)	Two lobes, one in Fort Rock Valley, one in Christmas Valley. East-west length, 50 mi (80 km); north-south width, 30 mi (48 km). May not always have had surface outlet.
Chewaucan, Central Lake Co., Oreg.	461 sq mi (1,190 km^2)	Covered area of present-day Summer and Abert Lakes and surrounding marshy lowland. Irregular shape, with length of nearly 50 mi (80 km).
Goose, Southern Lake Co., Oreg.; Modoc Co., Calif.	368 sq mi (953 km^2)	Length, 50 mi (80 km); width, 17 mi (27 km). Dry more than once in historic time; located on southern immigrant trail. Highest of Oregon's pluvial lakes, with highest shoreline near 5,000 ft (1,524 m). Drainage south to Pitt River.
Malheur, Harney Co., Oreg.	920 sq mi (2,380 km^2)	Included present-day Harney and Malheur Lakes and surrounding plains, called Harney Basin. Tributaries from Blue Mountains on the north and Steens Mountains on the south; outlet eastward to Malheur and Snake Rivers.
Coleman, Southwestern Lake Co., Oreg.	483 sq mi (1,250 km^2)	Remnant lakes, known collectively as Warner Lakes, include Bluejoint, Flagstaff, Hart, and Crump Lakes. Long and narrow shape.
Catlow, Harney Co., Oreg.	351 sq mi (909 km^2)	Drained into pluvial Lake Malheur.
Alkali, Eastern Lake Co., Oreg.	212 sq mi	– (549 km^2)
Alvord, Harney Co., Oreg.	491 sq mi (1,270 km^2)	Length greater than 100 mi (161 km); width only 10 mi (16 km).



Map showing locations of some features discussed in this article.

hills, and mountains rise above the plain. Some of the smaller ones, like Miller Hill southeast of Klamath Falls and Turkey Hill near Malin, which were islands in the old lake, provide the best preserved examples of the old shoreline. The larger and higher fault block uplands are called rims, scarps, hills, or mountains according to their size, shape, profile, and the whim of the people who named them. Some of them like Stukel Mountain, Hogback Mountain, and Moyina Hill rise 2,000 ft (610 m) above the lake plain.

Plum Hills, named from the wild plums which grew there once, is a fault splinter, 8 mi (13 km) long, rising to nearly 6,000 ft (1,829 m). Farther east is Hogback Mountain, broader and slightly higher. Stukel Mountain is part of a hilly upland, 10 mi (16 km) long and 7 mi (11 km) wide, between Poe Valley and the lower valley of Lost River. Bryant Mountain is 15 mi (24 km) long and 5 mi (8 km) wide, separating Langell Valley from the basin of Tule Lake. The highest point is just under 6,000 ft (1,829 m). The broader and higher mountains are broken up into ridges and narrow valleys by interior faults. In Modoc and Siskiyou Counties, California, some of the elevations are in the form of conical hills, including cinder cones and dome mountains. A few elevated lava-capped mesas occur, such as Big Tableland southwest of Lower Klamath Lake. The Modoc Lava Beds extend into the lake, covering a part of the old shoreline (Pease, 1965).

Basalt, andesite, and dacite flows and extrusions of cinders, ash, and pumice from numerous vents and fissures contributed to the filling of the depressions between the fault blocks—in some cases to depths of hundreds of meters. Some of the pumice came from the eruption of Mount Mazama only 6,000 years ago, during the formation of Crater Lake. Some pumice eruptions took the form of surface flows, nuées ardentes, which went down stream beds to the lake basins. Nearby mountains such as Mount McLoughlin and Pelican and Aspen Buttes also contributed sediment. Additional material was supplied, almost to historic time, by weathering of the lava flows. Sediment was transported by wind and water, and some large rock fragments found in the soils of the lake plain may have been rafted by ice on the lake. Accumulations of diatoms and peat helped to fill the lake.

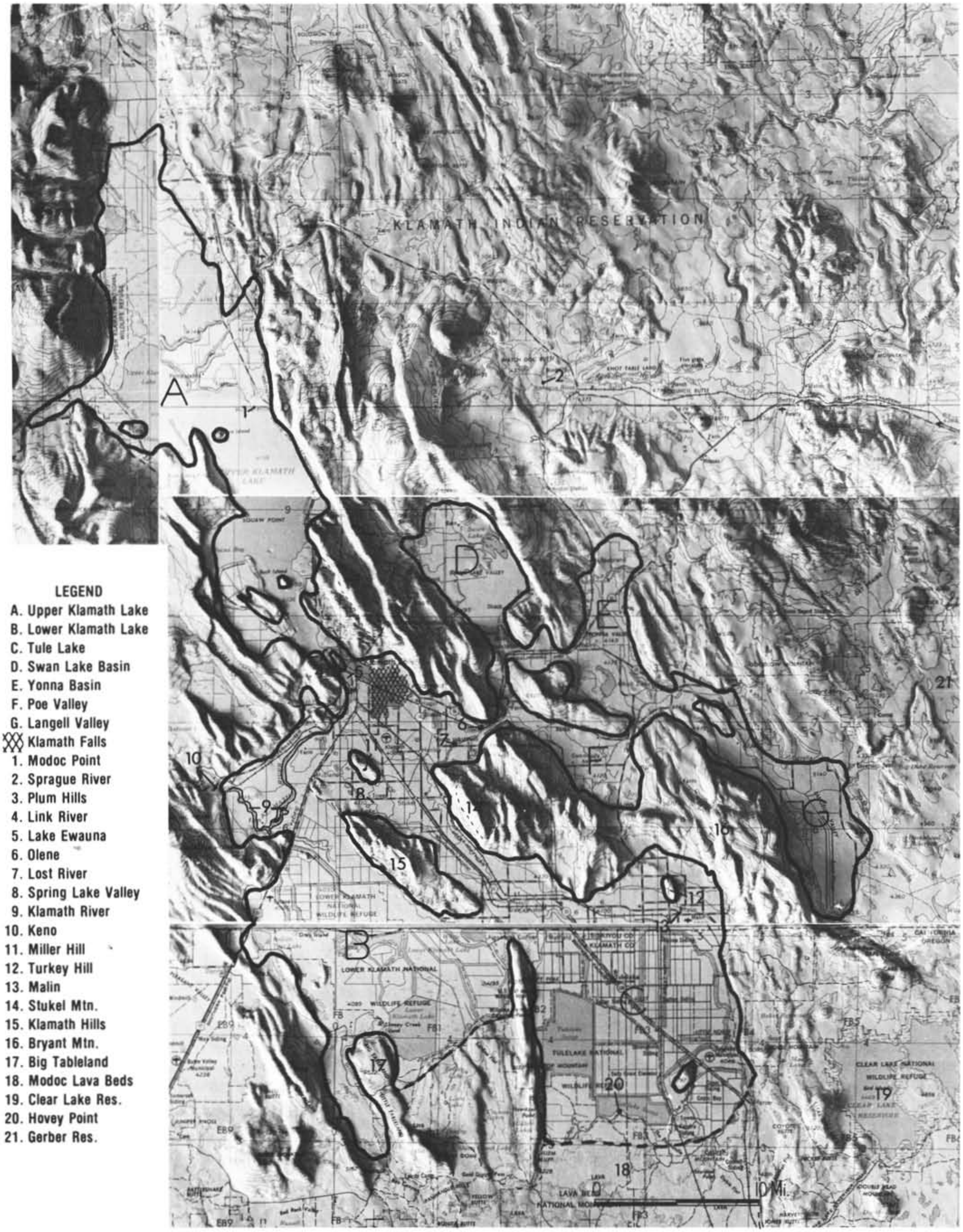
The lake bottom soils have a high water-holding capacity. They are of such a low density that when steamboats ran aground on Lower Klamath Lake at the turn of the century, the disturbed sediment sometimes floated to the surface of the lake.

THE WATERSHED

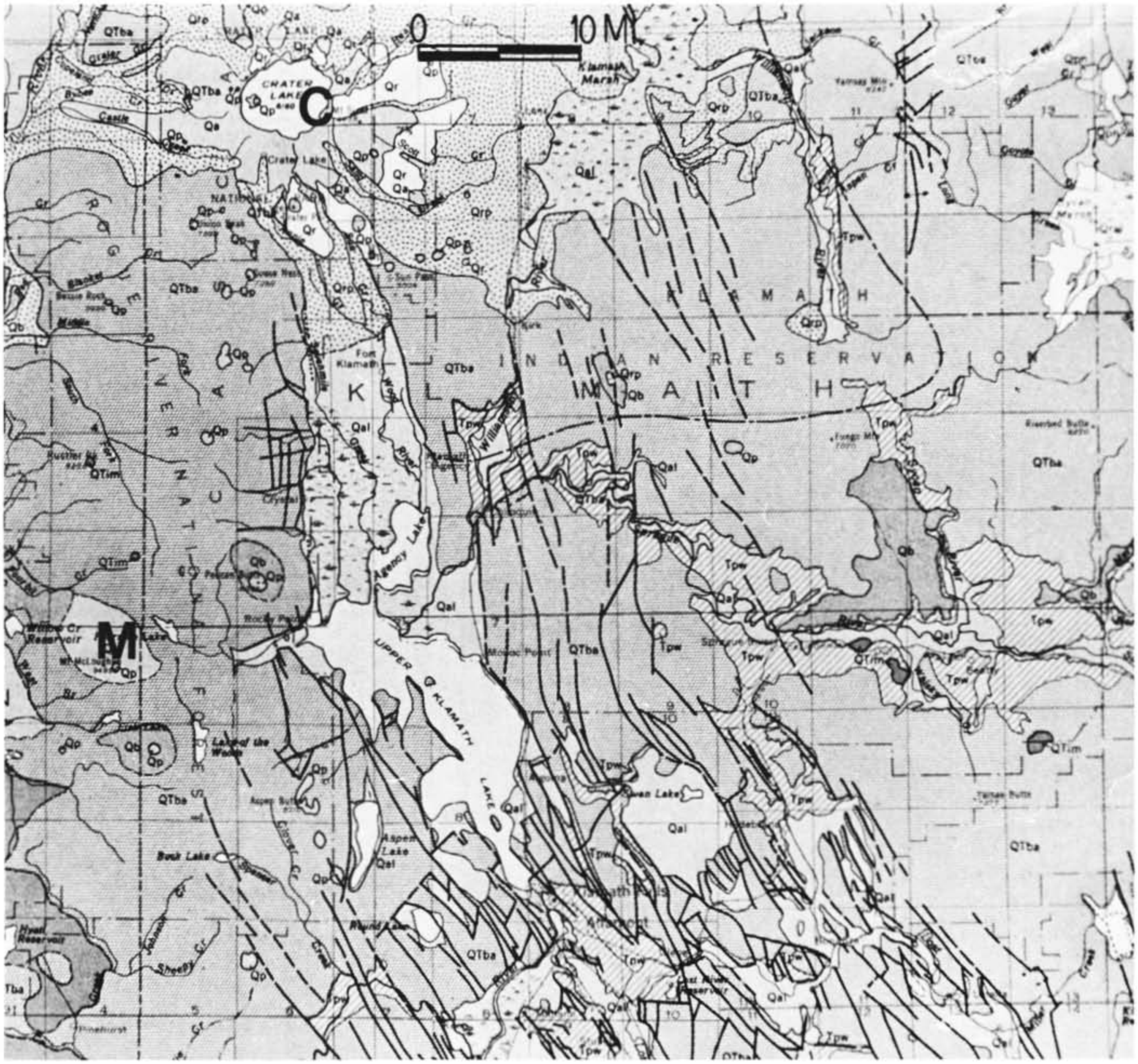
A broad network of surface streams from an extensive watershed brought the sediment to the lake. The watershed includes most of southern Klamath County and smaller parts of Jackson and Lake Counties in Oregon, and the northern parts of Modoc and Siskiyou Counties in California. The drainage area extended from the crest of the Cascades on the west and Crater Lake on the north to as far east as western Lake County.

On the north, Williamson River is the principal stream with tributaries on the east slope of Mount Scott. Streams on its slopes are probably fed by Crater Lake, the level of which scarcely changes, and tend toward a uniform flow. Numerous creeks drain the east front of the Cascades into the basins of Upper and Lower Klamath Lakes. On the east, Sprague River and Lost River have large drainage areas including some of the higher basin ranges.

During the short summers of Pleistocene time, the lake must have been the recipient of almost constant sediment-laden floods, since the climate was wetter as well as colder. Snows were heavy on the higher elevations. The Cascade Range was covered with accumulations of ice, and some peaks had active glaciers. The lake basin was filled to overflowing, and one outlet probably was to the south, from the Tule Lake Basin. This outlet, if it existed, was blocked later by a lava



Preliminary map of area covered by Pluvial Lake Modoc. Highest shoreline (solid line) is near 4,240-ft contour except in the south, where lava flows have encroached on lake bed (dashed line).



Part of geologic map (Wells and Peck, 1961) of Upper Klamath Lake area, showing closely spaced fault pattern. Crater Lake (C) is at upper left. Crest of Cascade Range passes over Mount McLoughlin (M).

flow; however, large quantities of water, but not sediment, were able to escape by seepage—which explains why the water of Tule Lake at the time of discovery was only slightly brackish. The outlet in historic time is to the Klamath River. When Lower Klamath Lake was high, the Klamath River began at Keno; when it was low, the river began at the outlet of Link River, at Klamath Falls. Lake Ewauna is, in effect, merely a wide place in the Klamath River.

THE CHANGING CLIMATE

Tree ring records are perhaps the best measure of climate fluctuations that occurred before precipitation records were available. In a semiarid region, it is assumed that tree growth is limited mostly by moisture. However, other factors such as temperature and tree diseases may affect the thickness of the annual rings. The only rings that could be compared with precipitation records were those that formed after 1884, when records of precipitation were first kept. A study of the annual rings of ponderosa pine (Keen, 1937) included five sites marginal to Lake Modoc. Some of the readings were made from the stumps of harvested trees that were as much as 700 years old. The rings show peak growth in 1673, 1702, 1752, 1775, 1791, 1814, 1861, and 1893. The last two dates are known to have been years of heavy floods.

The tree ring record shows alternating wet and dry periods of varying lengths. The wettest period was from 1670 to 1680. The weather between 1805 and 1840 was wet also; Meriwether Lewis testified to the heavy rains on the Clatsop Plains near Astoria during the winter of 1805-1806. Drought was severe from 1840 to 1854, the period of large-scale migration to Oregon, partly by the southern routes passing through the

Lake Modoc area. At that time, people and livestock suffered severely from lack of water and forage. Precipitation was generally above average from 1860 to 1900, but the period from 1918 to 1936 was a time of severe drought, with dust storms in the latter part of the period. Keen (1937) estimated that the variation of precipitation was up to 60 percent above and below the mean.

Weather Bureau precipitation records begun in 1884 agree partially with the tree ring records. The first three years of record, 1884 to 1886, were above the average precipitation of 13 in. (330 mm) for the entire weather record. From 1904 to 1910, precipitation again was above normal. As noted below, this was a time of low lake levels for Lower Klamath and Tule Lakes. The years 1910 to 1926 were dry, followed by two wet years. Then came the severe drought of 1928 to 1936, when the average rainfall was only 9.1 in. (231 mm). Since that time, the amounts of precipitation have been quite variable. The rainiest year on record with 20 in. (500 mm) of precipitation was in 1948, the year of the great Columbia River flood. The following year, 1949, was the driest: 8.31 in. (211 mm) of precipitation.

It is obvious that a deficiency of water exists in the Lake Modoc area. Evaporation is greater than precipitation in most years, which results in an average deficit of 10 in. (256 mm) (Loy, 1976). Then any part of the Lake Modoc Plain not supplied by tributaries or irrigation tends to become increasingly dry.

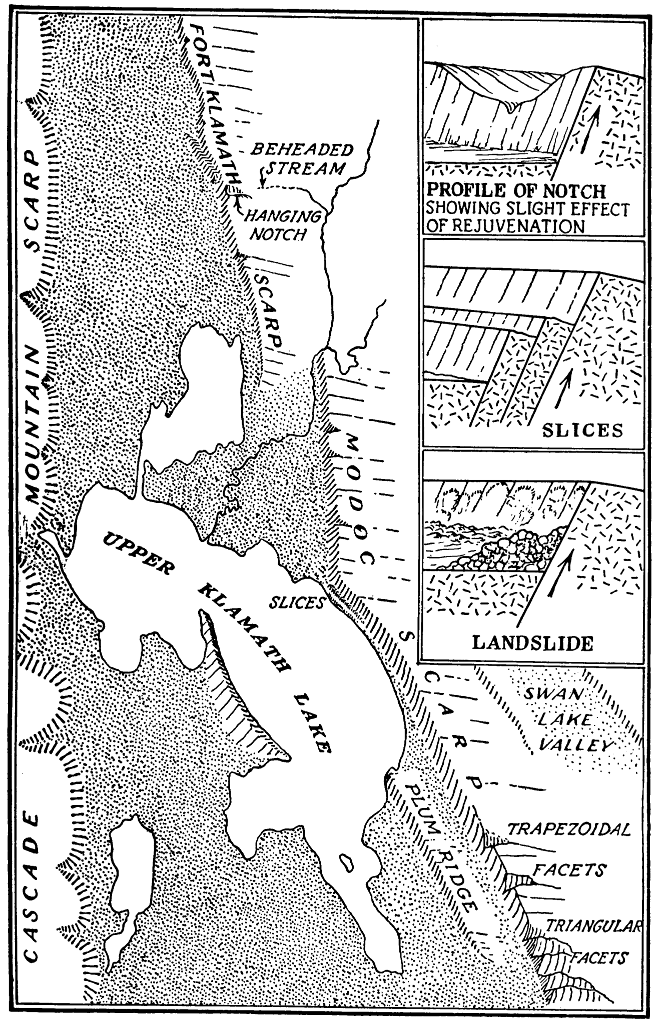
LOWERING OF LAKE MODOC

At the end of the Pleistocene, perhaps 10,000 years ago (Crandell, 1960), the climate gradually settled into its present semiarid, fluctuating, and unpredictable state, and Lake Modoc began to shrink. At first, the lowering of Lake Modoc was uniform for all basins, since all were interconnected. After the climate became drier, the water level was reduced from the maximum of 4,240 ft (1,292 m) to 4,142 ft (1,262 m); the flow from Upper Klamath Lake to the southern basins was diminished; and the lake level dropped further. By 1906, when an accurate survey of lake levels was made, Upper Klamath Lake was at 4,142 ft (1,262 m), Lower Klamath Lake at 4,084 ft (1,245 m), and Tule Lake at 4,056 ft (1,236 m). The bottom of Lower Klamath Lake was at 4,069 ft (1,240 m) and that of Tule Lake at 4,031 ft (1,229 m). The other six basins were completely dry except for a few small pocket lakes or marshy areas. Lake levels fluctuated with the variations of precipitation, and although the lakes rose slightly above the 1906 levels in succeeding years and steamboats served several landings on Lower Klamath Lake as late as 1909 (Drew, 1974), it was evident that Lower Klamath and Tule Lakes were on the way to extinction.

EARLY DESCRIPTIONS OF THE KLAMATH LAKES AREA

Peter Skene Ogden was the first to describe the Klamath Lakes area (Davies, 1961). He arrived from Fort Vancouver with a party of trappers and traders in wet and cold weather in late November 1826, looking for beaver and also seeking a river to the ocean which might be used to transport furs to the ocean. The party visited an Indian village in the middle of Klamath Marsh, where the water was too deep to approach on horseback or on foot. This was near the end of a long, wet cycle, according to tree rings. When J.C. Frémont visited the same marsh in 1843, thinking it was Klamath Lake, he found no difficulty in riding to the village (Frémont, 1856). Frémont surmised that in summer the marsh was a dry savannah.

Ogden reached Upper Klamath Lake near the mouth of



Generalized diagram of Upper Klamath Lake graben. Pluvial Lake Modoc covered entire shaded area. Pictures on right show features found where Basin and Range faulting occurs. (From Lobeck, 1939)

the Williamson River and followed the shoreline southward. At Modoc Point, it was necessary to ascend to the upland, since during severe weather, passage near the lake, with horses, was apparently not feasible. From the Link River, the party traveled in a southeasterly direction through Spring Lake Valley, also known as the main valley, and along Lost River, which was forded with difficulty, the banks being steep and soft and the water deep. Ogden noted a rock barrier or dam in Lost River, "made by the natives for taking small fish." Later travelers called this "a natural bridge" (Williamson and Abbot, 1856; Landrum, 1971).

Ogden missed Lower Klamath Lake but went along the east side of Tule Lake along the route that was later to become a part of the southern immigrant trail. The party then turned westward, reaching and crossing the Klamath River at the hot springs near the present-day Beswick, California.

On the advice of Indians, Ogden rejected Klamath River as a water route to transport furs. There were few small streams with willow and cottonwood and, therefore, few beaver. Because game was very scarce, Ogden's party was forced to purchase dogs from the Indians for food and to eat some of their horses.

John C. Frémont visited Upper Klamath Lake in May 1846, arriving from California via Tule Lake, which he named

Rhett Lake (Frémont, 1856). He found the Link River "unfordable" but crossed it anyway and traveled along the west side of Upper Klamath Lake, not realizing, apparently, that the trail on the east side of the lake was much easier. Frémont described the variety of timber trees on the west side of the lake and determined the latitude and longitude of several points around the lake. He, too, looked in vain for a navigable river leading to the coast, apparently unaware that Ogden and others had made negative reports.

Frémont found the Indians less friendly than on his previous visit to Klamath Marsh, and when the party slept one night with their camp unguarded, three of his men were killed. Frémont's visit was cut short by a summons from California, since he was an army officer on active duty.

Following close on the heels of Frémont was a party from the Willamette Valley, led by Lindsay Applegate, marking out the southern immigrant road. This route crossed the Cascade Range from Jacksonville via Green Springs Pass, crossed the Klamath River at Keno, ran southward along the west side of Lower Klamath Lake, thence eastward, to the north of Tule Lake. The route was much used by the immigrants in spite of Indian hostility.

In August 1855, Lieutenants R.S. Williamson and H.L. Abbot, topographic engineers, arrived in the Klamath Lakes area, charged with surveying two possible routes for a railroad connecting San Francisco Bay with the Columbia River (Williamson and Abbot, 1856). The party, which included several assistants, packers, mules, 100 mounted soldiers, a botanist-geologist, and an artist for sketching landscapes, carried instruments for the determination of latitude and longitude and an odometer, mounted on a cart, for measuring distances traveled. Their lengthy report included the first good maps of the Klamath Lakes. Williamson noted that Lower Klamath Lake had very little water and that the shoreline was

Vertical air photo of lower end of Upper Klamath Lake and Link River. Outlet of river is at lower right. Part of city of Klamath Falls is on right. One irrigation canal takes out from lake near bridge, upper center, and enters tunnel near freeway crossing. Canals also parallel Link River below dam. (U.S. Geological Survey photo)

so miry that it was difficult to water the horses. He reported cattails and bulrushes on the margins of the lake and tules and water lilies in the middle. He mapped the shore vegetation rather than the waterline.

In the summer of 1860, Lieutenant Alexander Piper arrived in the Klamath Lake area with 66 soldiers to establish a military post designed to protect the immigrants from the Indians (Piper, 1968). His first camp was near Keno and Lower Klamath Lake, which he described as "an immense bed of tules with no water visible except for Klamath River." So Piper mapped the shoreline as if the lake were full. His carefully drawn maps included vegetation, streams, lakes, and trails. His chief interest was in wood and water for his camps, grass for his animals, and Indians. A few ranchers were beginning to move cattle into the area, which tended to incite the Indians.

MAN-MADE CHANGES

White settlement in the Klamath Lakes area, delayed by Indian hostilities and the lack of roads, began to pick up in the late 1860's (Sisemore, 1941). The first permanent settler came in 1866, Linkville was settled in 1867, and the name was changed to Klamath Falls in 1893. Klamath County was formed from Jackson County in 1882, and the first census showed 2,444 residents, not including approximately 1,000 Indians.

The establishment of the Klamath Indian Reservation (1870) was intended to solve the Indian problem (Stern, 1970). Both Klamaths and Modocs were included, but the Modocs soon became discontented and left the reservation. They lived by themselves on Lost River or on the shores of Tule Lake, hunting, fishing, and occasionally begging from the settlers. The settlers were unhappy with the situation, and an army unit was sent to arrest Captain Jack, the leader of the Indians. A fight resulted, and the Indians fled southward to the lava beds, which provided strong defense positions. Additional army units were brought in with artillery, and the bloody battles of the Modoc War followed in which the army suffered heavy losses. But the Indians were defeated, their leaders captured, and white settlement began to spread over the area at an accelerated pace.

The settlers found some conditions favorable and some unfavorable. The broad lake plain covered mostly with sagebrush and greasewood (Sweet, 1910) was not too difficult to clear. On the ridges, juniper, wild plum, and ponderosa pine furnished firewood and timber for building; streams and lakes supplied water. Good grazing was available on the lake margins and on the ridges. The unfavorable conditions were the dry climate, later compensated by irrigation, and the cool summers with a constant frost hazard—a condition unsuitable for many crops. Nevertheless, grazing, agriculture, and logging were successful, and slowly the landscape was transformed. Fires, used for clearing the land or set by lightning, burned over some of the timbered land, but forest fires were less damaging here than in western Oregon. A map of forest land shows burned-over areas on ridges in several localities (Leiberg, 1900).

In the early days of settlement, ranchers depended on natural forage, but they were soon sowing rye and harvesting it as hay. In most years, grazing was available all year round, but in times of heavy snows, feeding with hay was necessary. Potatoes were introduced and planted on the lower part of the hill slopes, immediately above the plain where frost hazard was less. The first crops were grown without irrigation.

The first irrigation was by waterwheel on Lost River. The current turned huge wheels to which buckets were attached to lift the water to nearby fields. Large-scale irrigation was introduced in 1884 with the construction of the Klamath Canal (later called the Main Canal), which led southeastward from the upper Link River. One branch paralleled Lost River almost to Tule Lake; another continued eastward through the gap at Olene and into Poe Valley. The waters of the upper Lost River also were diverted into canals.

After 1900, plans were made for more extensive irrigation (Strantz, 1953). In 1905, the three major lakes—Upper Klamath, Lower Klamath, and Tule—were ceded to the United States Government and placed in charge of the Bureau of Reclamation, so that the construction of large irrigation ditches became possible. Construction of the Keno Canal began in 1906 and was completed in 1908 (Gustafson, 1971). It led from Link River down the west side of Lower Klamath Lake, crossing the Klamath River at Keno by means of an inverted siphon. In 1907, Canals A and B led water from Upper Klamath Lake to Spring Lake Valley and to the vicinity of Olene.

In 1908, the first public notice of homesteading brought thousands of potential farmers to the plain. In 1909, additional canals were completed, and the northwestern part of Lower Klamath Lake was cut off by the Southern Pacific Railroad embankment. In 1910, the Clear Lake dam was completed, controlling the flow of Lost River which had been diverted to irrigate Langell Valley. The population of Klamath County had grown to 8,554. Lower Klamath Lake, denied most of its water, became dry in the northern part and available for cultivation. The southern part of this lake was set aside for a wildlife refuge. Tule Lake is now mostly under cultivation; the remaining two sumps are controlled by pumping.

All area shown in this vertical air photo, 3 mi south of Lower Klamath Lake, was part of Lower Klamath Lake until railroad embankment (black line) blocked off Klamath River in 1909. Canal diverts surplus water from Lost River to Klamath River. (Production Marketing Administration photo)

← *Vertical air photo shows lava flow covering old shoreline of pluvial Lake Modoc at Hovey Point on south shore of Tule Lake in Siskiyou County, California. White lines in fields are irrigation ditches. Captain Jack's stronghold was immediately south of bay. (U.S. Geological Survey photo)*

WATER CONTROL

The presence of a large water supply at a higher level than the plain in Upper Klamath Lake, Clear Lake, and Gerber Reservoir makes gravity irrigation possible. Many improvements in the control of water, especially dam construction, made the system more productive and efficient (Strantz, 1953). The dam on the upper part of Link River controls the level of Upper Klamath Lake and is of first importance. Dams at the lower end of Clear Lake and one at Gerber Reservoir help in the control of Lost River. The problem of run-off water from the irrigated lands is solved by drainage and pumping. A channel diverted from Lost River to the Lower Klamath Lake plain reduces the amount of water reaching Tule Lake. Water is pumped from the sumps in the southern part of Tule Lake through a tunnel to Lower Klamath Lake, from which it is pumped into the Klamath River. The controls make it possible to supply water to almost all the plain. Only a few large areas are not irrigated, such as Swan Lake Basin and the northern part of Yonna Basin.

Low dam in upper Link River controls level of Upper Klamath Lake and regulates flow into irrigation canals. ↓

LAND USE

Most of the cropland in Klamath County is in the Klamath Lakes area; the 1974 total was 207,000 acres (84,000 ha). The land in farms and ranches, including the uplands, was 754,000 acres (305,000 ha). Most of the farms in the irrigated areas average less than 160 acres (65 ha), but the average holding is 986 acres (399 ha). Eighty-five percent of the cropland is irrigated, of which 23 percent is pasture. The chief crops are hay, 34 percent; barley, 15 percent; wheat, 6 percent; and potatoes, 5 percent. Livestock in Klamath County includes 39,000 beef cattle, 2,300 dairy cows, and 15,000 sheep. Woodland on farms and ranches runs to 178,000 acres (72,000 ha).

As soon as railroad and highway transportation was available, the lumber industry expanded, with the largest mills located in Klamath Falls. The timber harvest averages nearly 400 million board feet annually, most of it coming from National Forest land.

SUMMARY

Pluvial Lake Modoc, which once covered 1,096 sq mi (2,838 km^2), is now mostly dry land. The drier climate and the lowering of the outlet to the Klamath River are the main causes of the shrinkage. Only Upper Klamath Lake, with an area of less than 100 sq mi (259 km^2), remains. It also is at some risk of shrinkage as it slowly fills with sediment and vegetation, thus reducing the storage capacity.

The plain of Lake Modoc, in effect the exposed bed of the old lake, is the dominant natural resource in a large part of Klamath County and parts of Siskiyou and Modoc Counties in California. Here is most of the cropland, and here most of the people live. The plain is extensive, remarkably level, and at an elevation allowing for easy irrigation. The soils, though not all of the highest quality, are easy to till and irrigate. The location of the plain near the Cascade Range assures a good water supply, as well as a timber resource for the wood industries.

Less favorable factors are the light regional precipitation —significant for grazing areas—and the cool summers, unfavorable for some crops and with risk of frost in every month. The Bureau of Reclamation has established numerous water controls in the form of dams, reservoirs, ditches, canals, and other structures, providing for efficient distribution and use of the water. In the future it may be necessary to construct additional storage facilities on the tributaries to supplement the capacity of Upper Klamath Lake.

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Brownfield joins DOGAMI staff

On August 27, 1980, Michael E. Brownfield became a member of the Portland staff of the Oregon Department of Geology and Mineral Industries (DOGAMI). He was hired as a geologic mapper to manage and lead the Department's mapping subprogram in northwest Oregon, which includes the Coast Range, Willamette Valley, and northern part of the Oregon Cascades. In terms of geologic mapping, this has been an area of neglect for several years. Recent discoveries of gas in the Mist Gas Field and evolving concepts of plate tectonics now make northwest Oregon an area of priority.

Brownfield will be coordinating efforts with federal and university counterparts, with the long-term goal of the revision of the geologic map of western Oregon.

Michael E. Brownfield

A native Oregonian, Brownfield received his bachelor's and master's degrees from the University of Oregon. Since June 1973, he was a geologist with the U.S. Geological Survey (USGS), doing geologic mapping in the Rocky Mountain coal regions. Before that time, he was an engineering geologist for the Willamette National Forest and was employed in mineral exploration and mapping programs for Humble Oil, Bear Creek Mining Company, and the USGS. He has authored and coauthored several geologic maps and other publications for the Survey.

He is married to Isabelle K. Brownfield, a geologist and archeologist, who is currently working for the Uranium-Thorium Branch of the USGS. The Brownfields are the parents of a daughter, Kathleen Marie, born September 29, 1980. □

Exploration for mineral fuels intensifies in Oregon

Exploration for mineral fuels in Oregon increased dramatically during the past year, and the emphasis is on natural gas. As compared to 1978, expenditures for oil and gas exploration more than doubled in 1979, according to the Oregon Department of Geology and Mineral Industry summary of exploration expenditures in the various segments of the private industry, as shown in the following table:

EXPLORATION EXPENDITURES

	Oil and gas	Geothermal	Metals
1979........	$10,695,000	$1,928,000	$4,037,000
1978........	4,608,000	1,298,000	4,435,000
1977........	2,000,000	600,000	3,600,000
1976........	2,000,000	1,400,000	2,300,000

OIL AND GAS

Industry interest in Oregon's oil and gas potential has been steadily increasing during the past few years. The great upsurge in well drilling followed the discovery of natural gas at Mist in May of 1979.

GEOTHERMAL ENERGY

Geothermal resource exploration by private groups increased modestly in 1979, with the activity divided almost equally between the Western Cascade Range and southeastern Oregon. The less than $2 million of private geothermal exploration expenditures were overshadowed, however, by Federal funding for resource assessment of more than $3.3 million in Oregon during 1979. During the past four years, the ratio of public funding to private investment has increased continually, with the Federal government, principally the U.S. Department of Energy, providing most of the public monies.

METALS

Twenty-eight companies expended significant sums in prospecting for metallic minerals during 1979. Precious metals, uranium, nickel, and copper were the commodities of greatest interest. Exploration projects for metals were concentrated in the Klamath Mountains of southwestern Oregon, the southern portion of Harney and Malheur Counties in the southeastern corner of the State, and various gold mining districts in the Blue Mountains. □

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time we will print abstracts of new acquisitions that we feel are of general interest to our readers.

INTERPRETATION OF GRAVITY MEASUREMENTS MADE IN THE CASCADE MOUNTAINS AND ADJOINING BASIN AND RANGE PROVINCE IN CENTRAL OREGON, by Gerald Stephen Pitts (M.S., Oregon State University, 1979)

Gravity measurements made during the summers of 1975 and 1976 and previously acquired measurements in the Cascade Mountains and adjoining Basin and Range Province in central Oregon provide data for analysis of the crustal structures pertinent to geothermal resources in the area. An average uncertainty of 1.5 mgal in the complete Bouguer gravity anomalies is primarily due to uncertainties in elevation.

A rapid increase of the free-air gravity anomalies, from an average of less than zero over the Miocene Western Cascades to greater than +30 mgal over the Quaternary High Cascade volcanics, is explainable in part as the "Randsenken" or edge effect associated with a relatively abrupt change in the depth of the mantle. Free-air gravity anomalies greater than +90 mgal associated with the Three Sisters volcanic complex and Newberry Caldera are too great to be accounted for by topography alone.

The complete Bouguer gravity anomaly field is dominated by an eastward decreasing regional gradient that is attributable to the eastward thickening of the continental crust. Determination of Bouguer anomalies with different reduction densities suggests that the shield volcanoes of the High Cascades have an average density of at least 2.6 g/cm^3. Lookout Mountain, a 500-m-high basaltic cinder cone, has an average density of 2.30 g/cm^3 which suggests a composition of approximately 40 percent flows and 60 percent cinders.

A residual gravity anomaly field which results from the removal of a regional field from the Bouguer anomalies is dominated by intersecting linear trends of closed positive and negative anomalies that parallel Basin and Range structures in the eastern portion of the map and north-south structures of the Cascade Range in the western portion of the map. These trends of closed anomalies are flanked by continuous linear anomalies with 4 to 10 mgal of relief and typical gradients of 1 to 2 mgal/km. The amplitudes and gradients of the anomalies suggest upper crustal sources.

The analysis of the gravity data presented in this study indicates that structural trends of the Basin and Range Province continue into the Cascades physiographic province and suggests that the location of the major vents of the southern High Cascades Province are strongly influenced by the Basin and Range structures.

The continuous nature of the positive anomaly trends and coincidence of the closed positive residual anomalies with volcanic centers suggest structural control and contemporaneous development. The linear trends of the positive anomalies are interpreted as an indication of lithospheric fractures or lineations of structural weakness in the lower crust which have acted as conduits for the rise of magmas.

The contiguous nature of the negative anomalies west of the High Cascades, which trend north-south, and the anomalies east of the High Cascades, which trend northwest-southeast, are interpreted as an indication of graben-like structures. The north-south trending negative anomalies west of the High Cascades are bounded on the west by a linear anomaly with gradients as high as 4 mgal/km. This anomaly, which is coincident with the valleys of five major rivers, is interpreted as indicating a major normal fault, with the eastern block downdropped to the east. The density contrast of 0.5 g/cm^3 between lower Eocene oceanic basalts and overlying marine sediments that produces the observed anomaly is thought to exist at a depth of 3 to 4 km below sea level and have a vertical extent of 1.2 to 1.5 km.

GEOLOGY AND GEOCHEMISTRY OF A MASSIVE SULFIDE DEPOSIT AND ASSOCIATED VOLCANIC ROCKS, BLUE CREEK DISTRICT, SOUTHWESTERN OREGON, by Cynthia Taylor Cunningham (M.S., Oregon State University, 1979)

The Turner-Albright copper-zinc-gold deposit in the Blue Creek mining district of southwestern Oregon may be classed as an ophiolitic massive sulfide deposit. Mineralization occurs within a series of spilitized tholeiitic basalts and shallow gabbroic intrusions. Replacement of permeable flow breccias and sedimentary sulfide deposition appear to have been the dominant mechanisms of sulfide mineralization. Brecciation and permeability of the rocks may have been increased by explosive hydrothermal activity. A pipe-like zone of hydrothermal silicification, chloritization, and disseminated sulfide mineralization stratigraphically below the deposit indicates proximity to a hydrothermal vent.

Stratigraphic relations suggest that the volcanic rocks hosting the mineralization are of Middle Jurassic age. It is suggested that the basalts formed in a marginal basin to the east of the Jurassic Rogue-Galice island arc.

Sulfur isotope studies of hydrothermal minerals suggest a mixture of magmatic and seawater sulfur in the deposit. Rare-earth element patterns of hydrothermal minerals appear to reflect the chemistry of hydrothermal solutions. Light rare-earth enrichment and positive europium anomalies are consistent with a direct magmatic origin of the metals. However, leaching of metals by reaction of ascending hydrothermal solutions with volcanic rocks cannot be unequivocally discounted on the basis of present experimental data. □

USGS film on natural hazards available

A color-sound motion picture providing information about various natural hazards and methods to mitigate their impacts on lives and property has been produced for the U.S. Geological Survey, Department of the Interior, and is available for public viewing.

The 26½-minute film, titled "When the Earth Moves," focuses on volcanic eruptions, earthquakes, subsidence, landslides, swelling soils, flooding, and glacial outbursts.

Although the film explains the basic causes, nature, and occurrence of the hazards, the major emphasis of the film is on choices people and governments have to mitigate or avoid hazards.

The film includes case histories of various hazards. As planners, scientists, and residents in several communities in different parts of the country are interviewed, the following themes are developed:

1. These hazards are part of natural processes that occur throughout the country, and their damages can affect practically anyone at almost any time.
2. Government and other groups can choose among several alternative methods (land-use planning, structural solutions, and prediction) to reduce damage. For the long term, land-use planning to avoid or minimize exposure to risk may offer the greatest savings, while the "do-nothing" policy, on the other hand, usually has the greatest cost.
3. Federal, state, and local government agencies and the general public need to have earth-science information available for planning and decision making.

"When the Earth Moves" was produced for the USGS by Amram-Nowak Associates, Inc., New York City. Copies of the film are available for viewing on a short-term basis or may be purchased. Information about the availability of the film may be obtained from the U.S. Geological Survey's Branch of Visual Services, 303 National Center, Reston, Va. 22092; phone (703) 860-6171. □

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Please note that your subscription expiration date is marked on the front cover of this month's *Oregon Geology*. Because we are unable to notify you by letter when your subscription is about to expire, it will have to be your responsibility to remember to renew at the appropriate time—or sooner if you want to be sure not to miss even one issue of *Oregon Geology*. □

Post-eruption map of Mount St. Helens published by Geo-graphics

Geo-graphics, a private cartographic firm in Portland, has recently published a two-color map of Mount St. Helens showing the effects of the May 18, 1980, eruption. The new crater; areas affected by pyroclastic and debris flows, explosive eruption of hot gas, and mud and ash flows; and the new boundaries of Spirit Lake are plotted on a U.S. Geological Survey topographic map at a scale of 1:62,500 (1 in. = approximately 1 mi). The 23 by 27 in. map covers parts of Cowlitz, Skamania, and Lewis Counties, Washington.

On the reverse side of the map are photographs taken during and following the eruption; sketches showing Mount St. Helens before, during, and after the eruption; a chronology of events leading up to the eruption, and a brief text by Paul Hammond, Patricia Knolls, and Al Cardwell.

The map may be purchased by mail for $5.00 from Geo-graphics, 519 S.W. 3rd, Suite 418, Portland, Oregon 97204; phone (503) 241-9287. Rates for larger orders are available on request. □

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2. DATE OF FILING: October 1, 1980
3. FREQUENCY OF ISSUE: monthly
A. NO. OF ISSUES PUBLISHED ANNUALLY: 12
B. ANNUAL SUBSCRIPTION PRICE: $4.00
4. LOCATION OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP Code) (Not printers)*: 1069 State Office Building, Portland, OR 97201
5. LOCATION OF THE HEADQUARTERS OR GENERAL BUSINESS OFFICES OF THE PUBLISHERS *(Not printers)*: 1069 State Office Building, Portland, OR 97201
6. NAMES AND COMPLETE ADDRESSES OF PUBLISHER, EDITOR, AND MANAGING EDITOR

PUBLISHER *(Name and Address)*: Oregon Department of Geology and Mineral Industries, address see 4/5

EDITOR *(Name and Address)*: Beverly Vogt, Oregon Department of Geology and Mineral Industries

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