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Geothermal Potential of the Klamath Falls Area, Oregon
A Preliminary Study

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The use of the earth's natural heat in the form of steam and hot water for the generation of electrical power, for residence heating, and for other industrial uses is becoming more and more important.

The successful exploitation of natural steam for generating power in Italy, New Zealand, and California is encouraging the search for other potential producing areas.

Oregon's extensive Pliocene, Pleistocene, and Recent volcanism and the faulted structures associated with this volcanic activity indicate an excellent potential for large local concentrations of heat near the surface.

The part played by the Oregon Department of Geology and Mineral Industries in the search for this new energy source is of a preliminary nature. So far, the general areas where favorable geologic provinces occur have been designated (Groh, 1966). As time permits, these areas will be studied to learn the general geologic setting, data on hot springs and water wells will be tabulated, and geothermal gradients will be determined. It is hoped that this preliminary information will encourage private companies to continue with detailed geologic studies and geophysical surveys in areas that show promise and will eventually lead to production of energy from Oregon's geothermal resources.

The first area chosen for study is the Klamath Falls area in southern Klamath County (plate 1), where surface indications appear favorable and where natural hot water has been used for space heating since the early 1900's.

Another slightly smaller geothermal zone on the southwest side of the Klamath Hills 10 miles south of Klamath Falls occurs in a similar geologic environment and is included in this report.

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Geography and History

Klamath Falls, a city of 17,000 population, is near the center of an elongate, northwest-trending structural valley called the Klamath graben. It is a complex structural valley about 50 miles long and 10 miles wide. Upthrown fault blocks, or horsts, bound the valley on both east and west sides. Upper Klamath Lake, Oregon's largest lake, and numerous other smaller lakes, ponds, and swamps occupy the lowest parts of the valley. Unlike the other large graben valleys of the Basin and Range geomorphic province of the western United States, which have internal drainage, Upper Klamath Lake is drained by the Klamath River that flows south and then west through the High Cascades to the Pacific Ocean.

In the early days of Klamath Falls several groups of hot springs and boiling mud pots were present in the flats and low, rolling hills where the city is now built. The Indians were the earliest users of the hot springs and they cooked fish and game and also, because they had great faith in the healing power of the water, bathed and soaked themselves in the overflow pools.

The early settlers used them infrequently for various things, including the scalding of hogs, and by 1915 there was a greenhouse built over one of the hot springs. By 1928 Klamath Falls boasted a modern Hot Springs Natatorium in which the pool water was completely changed daily. At the present time there are more than 350 relatively shallow wells that tap the natural hot water to heat schools, industrial buildings, apartments, and houses.

Geology

The stratigraphy of the Klamath Falls area is not easily deciphered. The abundant and widespread Pliocene and Pleistocene volcanic activity in the High Cascades just to the west and also within the basin, complex faulting, and sedimentation all happening concurrently have resulted in a heterogeneous sequence of volcanic and sedimentary rocks (figure 1). The thickness and composition of rock types varies greatly from place to place, making it very difficult to describe a complete stratigraphic section.

Previous work by Newcomb and Hart (1958, p. 21-22) in a ground-water study of the Klamath River basin describes a sequence of Pliocene and Pleistocene rocks that includes a lower unit composed of basaltic lava flows (0-800') that they called "lower lava rocks," which are overlain by a volcanic-sedimentary unit called the "Yonna Formation" (200' to 1000'), in turn overlain by a thinner unit of basaltic lavas (50' to 200'). Newcomb and Hart further divided the "Yonna Formation" into a lower phase predominantly of diatomite and lake-deposited sediments, and an upper phase of volcanic-sedimentary rocks, mainly brown lapilli tuffs of great lithologic variation. From meager fossil information, the Yonna Formation has been dated as middle Pliocene and the overlying "upper lava rocks"

Figure 1. Volcanic-sedimentary rocks exposed in road cut on U. S. Highway 97 along east shore of Upper Klamath Lake. Layers of cinders and scoria alternate with thin basalt flow units.

Figure 2. Fault-plane slickenside exposed at Rattlesnake Point on the east side of Upper Klamath Lake.

were believed to be Pliocene-Pleistocene.

For the purpose of this paper the rocks are considered to be an almost continuous interfingering depositional sequence, and on the reconnaissance geologic map (plate 1) they are shown as Pliocene-Pleistocene volcanic-sedimentary rocks. Where one rock type predominates in the sequence in a relatively large area, it is so indicated on the geologic map. The basement rocks are unknown but are probably Miocene andesitic and basaltic flows, volcanic breccias, and minor tuffs similar to the volcanic rocks of the Western Cascades described by Callaghan and Buddington (1938) and Peck and others (1964).

Complex faulting, most of which occurred in late Pleistocene time, has broken the whole area into a characteristic pattern of northwest-trending fault-block ridges and intervening down-dropped graben valleys. Tilted fault blocks are numerous within the Klamath graben.

Perhaps nowhere else in the United States is the geologic evidence for recent faulting so well displayed. At no less than nine separate locations the shiny, polished fault surfaces are starkly exposed. All are high-angle normal faults and dip from 55° to 70° into the valleys. One of the most spectacular faults has been exposed along the east side of Upper Klamath Lake (figure 2), where removal of talus has uncovered the fault plane for nearly a third of a mile in length and as much as 250 feet in height. Grooves in the slickensided surfaces indicate that the last and perhaps all of the displacement has been vertical (figure 3). At least 1600 feet of vertical displacement is indicated in the vicinity of Modoc Point, and movements of this order of magnitude can be estimated at other places where the steep fault escarpments are elevated about this much above the valley floors.

The northwest trend of the Klamath graben and its alignment with the Crater Lake caldera to the north and the Medicine Lake volcanic highland in California to the south cannot be ignored; there is almost certainly some association of the Recent climactic eruptions of Mount Mazama (Crater Lake) and the Medicine Lake highlands with the last faulting and adjustment of the crustal rocks of the Klamath graben.

Klamath Falls area

The Klamath Falls geothermal area is near the center of the graben in slightly tilted fault blocks that are elevated a few hundred feet above the valley floor. These tilted blocks are made up of impure diatomite, thin beds of tuffaceous sandstone, clayey tuff, and minor intercalated basalt flows. The tilted blocks have, in turn, been complexly faulted into elongate ridges that generally trend northwest. Because they are so easily eroded, they are now seen as low, rolling hills.

Well logs indicate that the diatomaceous tuffs and layered sediments are at least several hundred feet thick and in most places are impervious to the flow of water and act as a cap at the surface (figure 4). Broken lava

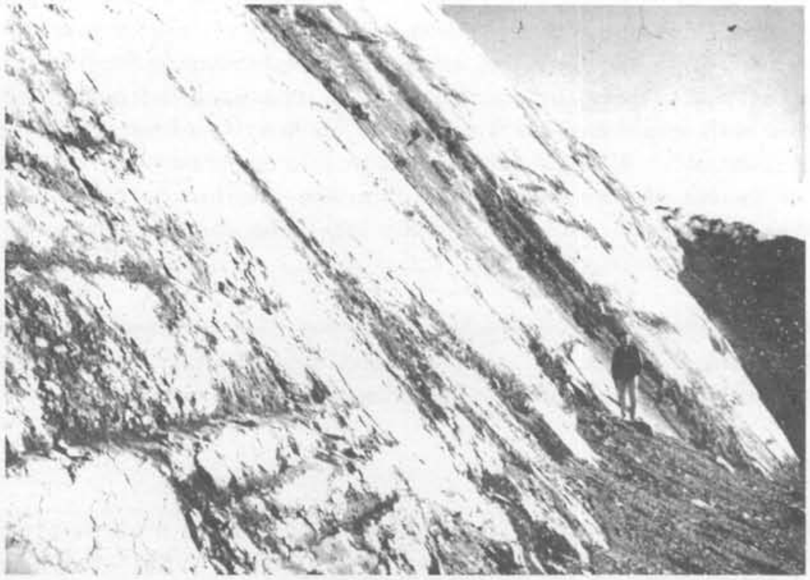


Figure 3. Closer view of slickensided fault plane shown in Figure 2. Striations show vertical movement.

Figure 4. Clayey tuff and impure diatomite are intricately faulted with minor displacement of beds.

flows and zones of scoria and cinders are encountered at various depths and 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, and the brecciated rocks associated with this fault could provide the conduit for the rise of hot water from a deeper reservoir. Although the heat source is not known and no surface rocks of Recent age are present, the Pliocene-Pleistocene dikes and sill-like masses that are intercalated in the lacustrine deposits (figure 5) may indicate the presence of a larger intrusive rock mass cooling at not too great a depth.

A long history of hot-spring activity is shown by the presence of bleached silicified rocks (figure 6), deposits of calcite and gypsum, and minor mercury mineralization in a broad halo surrounding the geothermal zone.

Klamath Hills area

Klamath Hills is a large, isolated fault block within the Klamath graben about 10 miles south of Klamath Falls. Large volumes of hot water (200° F.) are found at shallow depths in a narrow zone along the southwest side (figure 7). The geologic environment of this thermal zone is similar to that of the Klamath Falls area and a halo or border of silicified lake sediments and tufa is present. High-angle normal faults with a general northwest trend are common, and again the recency of faulting is shown by slickensided fault surfaces. Basalt flows and associated breccias, scoria, and cinders predominate in the Klamath Hills fault block. Drillers' logs from a few water wells indicate several hundred feet of lake sediments and layered tuffs in the Lower Klamath Lake basin south of Klamath Hills. A large area in the southeastern part of the Klamath Hills is underlain by cinders, scoria, and palagonitic tuff breccias, indicating that here a basaltic magma encountered water or saturated sediments near the surface and violent explosive eruptions resulted.

Present Natural Thermal Displays

The original hot springs in Klamath Falls have disappeared through lowering of the water table and culture changes. Temperature and flow data are not accurately known, but Stearns and others (1935) give a temperature of 185° F. and a flow of about 150 gallons per minute.

Two natural thermal displays still exist within the confines of the map area shown in plate 1. A spring on the north bank east of the irrigation flume crossing the Lost River at Olene Gap has a temperature of 165° F. The flow is estimated to be at least 100 gallons per minute, all of which passes into the Lost River. A slight trace of hydrogen sulfide was detectable. An analysis of this spring water is given in table 2. Another spring is located

Figure 5. Contact of highly fractured, sill-like mass of basalt and diatomite.

Figure 6. Low, rolling hills just south of the Oregon Technical Institute campus, where layered tuffs and diatomite have been silicified by former hot-spring activity.

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 that time 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 and a faint odor of hydrogen sulfide is present.

Klamath Falls Geothermal Zone

Extent of the zone

Some 350 wells have been drilled to date, mostly for the space-heating requirements of more than 450 residences, a number of apartments, six schools, several business and commercial firms, and the new Oregon Technical Institute plant (figure 8). Many of the installations provide for the heating of the domestic water also. Most of the wells are concentrated in a zone extending northwesterly from the canal for about 1.5 miles and more than half a mile wide (plate 2a), and in this area practically all are for residential use. As new building progresses northward, more wells are being added to this concentration. Three wells at Oregon Technical Institute, the deepest of which is 1805 feet, constitute the northernmost extension of the known boundaries of this geothermal zone.

South of the canal into the business district and southeasterly for about a mile wells are more scattered and temperatures fall below 200° F. Two wells drilled recently at the new Mazama School are in the most southeasterly extension of the hot-water zone and lie about 4.5 miles from the Oregon Technical Institute wells.

Depth and temperature of wells

Depth of wells drilled ranges from as little as 100 feet to a maximum of 1805 feet. Most are in the 200- to 350-foot range. The water table generally seems to coincide with the elevation of Upper Klamath Lake, and static water level depths vary with the topography. Much of the rock penetrated in the geothermal zone is quite "tight" or impermeable, and perched water influences the height of the local water table in many cases. Drillers report drops of water levels amounting to as much as 50 feet from levels initially encountered as drilling proceeds to greater depths. Wells south of the canal generally are artesian or flowing wells, since the water table is near the surface in this area.

Temperatures of the wells in the geothermal zone range from 140° F. to 235° F. Wells below 140° F. are usually not considered by drillers to be satisfactory for a heating system. However, wells of lower temperature probably could be utilized under some conditions. The highest temperature gradients seem to cluster about two centers in the zone. One of the centers,

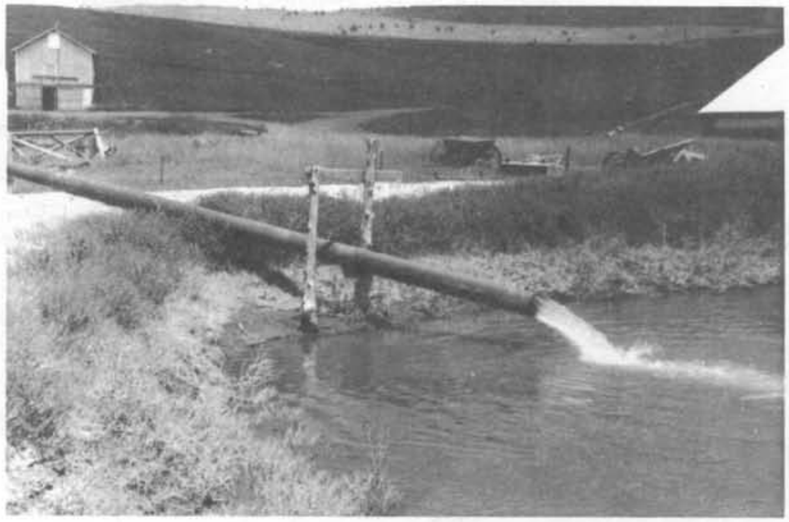


Figure 7. Hot well at the Liskey ranch in the Klamath Hills. This well, 285 feet deep, reportedly has a capacity of 1000 gallons per minute of 200° F. water.

Figure 8. Buildings and campus of the Oregon Technical Institute; Upper Klamath Lake and Cascade Range in the background.

Table 1. Well temperature logs, Klamath Falls, Oregon.

Depth in feet	Well location-L.H.Strid, Old Fort Rd. Elev. about 4190 feet. Static Level 73 feet. Temp. °F.	Well location, 155 N. Wendling Ave. Elev. about 4230 feet. Static Level 60 feet. Temp. °F.
50	130	136
75	164	180
100	166	206
200	199	218
300	211	218 T.D.
400	219	
500	225	
600	229	
700	233	
795	234 T.D.	

designated "A" in plate 2a, is located on Hillside Avenue between Dixon and Waring Streets, where high temperatures are reached at shallow depth. A well 100 feet deep at 341 Hillside Avenue emits dry steam with a pressure of several pounds per square inch (figure 9). 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. Three similar wells are in the immediate vicinity but are drilled to depths of nearly 150 feet. The very high geothermal gradient in this area indicates heat flow approaching a hundred times that of normal and constitues an area of "warm ground."

The other center of high heat flow, labeled "B" in plate 2a, lies in the vicinity of Roosevelt School. The geothermal gradient in this area is slightly less than in the center "A"; temperatures of 200° F. and greater are reached at depths of 200 to 300 feet.

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 then drop to the 220°-230° 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.

Temperature-depth logs of two wells are given in table 1. The wells were accessible and had been undisturbed for several years. Temperatures were taken with maximum-reading thermometers and may be considered as typical of wells in and near the high thermal gradient centers of the Klamath

Falls geothermal zone. Thermal gradients diminish with increasing depth and indicate a probable maximum or base temperature of 230° to 250° F. for the hot-water reservoir developed in the upper ground-water zone.

Use in heating

A heat-exchange system within the well is the predominant method of utilizing the thermal water for space and other heating. It also minimizes corrosion, waste, and discharge problems arising from its direct use. Klamath Falls has a city ordinance permitting hot-water discharge to the storm-sewer system, ditches, and the canal in only limited quantities.

After a well is drilled to a satisfactory depth for the desired temperature and flow conditions, it is cased to the bottom and perforated. A long, single return bend pipe coil is then lowered into the casing, extending to near the bottom of the well. The wellhead is then covered and welded or bolted shut. Hook-ups are made between the coil and the radiators which do the space heating. Clean domestic water is placed in the coil and radiator system which then circulates by the thermo-syphon method, receiving heat from the well water and passing this heat out at the radiators. Such a system has proven over the years to be simple and effective. Temperature control can be obtained through the use of a motorized or solenoid valve operated by a thermostat. Where two or more residences or a large installation are on a single well, a pump is used to provide a more rapid circulation than a thermo-syphon system alone can produce. Figure 10 shows a typical wellhead installation.

A rough estimate of the heat withdrawn from wells in the Klamath Falls geothermal zone, at this time, amounts to about 3000-4000 Btu/sec. averaged over the year. Conductive heat flow to the surface and heat lost through underground drainage are difficult to estimate, but they must be at least equal to and perhaps several times that presently withdrawn from wells.

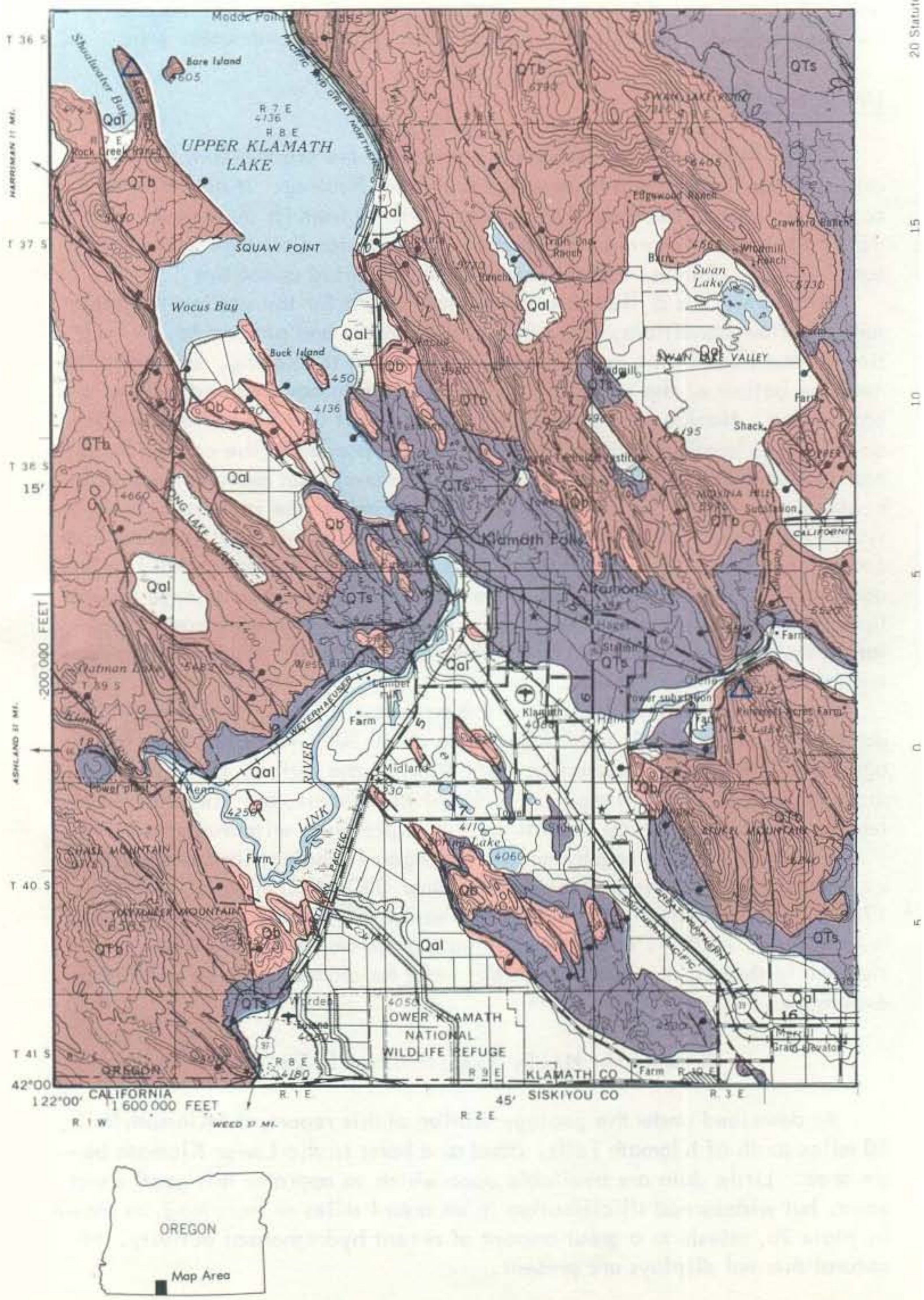
The large heating requirements at Oregon Technical Institute are met by a well 1716 feet deep equipped to pump 350 gals./min. of water at 193° F. Static water level is 358 feet below the surface. A temperature drop of about 100° F. occurs in the heating system before the water is discharged to the drain. Two other wells exist for standby service and future expansion.

Klamath Hills Geothermal Zone

As described under the geology section of this report, the Klamath Hills, 10 miles south of Klamath Falls, stand as a horst in the Lower Klamath basin area. Little data are available upon which to appraise this geothermal zone, but widespread silicification in an area 4 miles or more long, as shown in plate 2b, attests to a great amount of recent hydrothermal activity. No natural thermal displays are present.

PLATE 1

GEOLOGIC MAP OF THE KLAMATH FALLS AREA



EXPLANATION

Recent

Qal

Alluvium and other unconsolidated surficial deposits. Includes terrace gravels, talus, landslide debris, and possibly some areas of late Pleistocene lakebeds.

Pliocene and Pleistocene

Qb

Upper Basalt

Dark gray to black capping basalts. Mainly within the grabens. Includes black, dense intrusive masses, cinder and scoria mounds. Correlates in part with "upper lavas" of Newcomb and Hart (1958).

QTs

Layered sedimentary and pyroclastic rocks

Correlated with "Yonna Formation" of Newcomb and Hart (1958). Includes massive layers of impure diatomite, thin beds of tuffaceous sandstone, clayey tuffs, and, near eruptive centers, thick deposits of palagonitized basaltic tuff and tuff breccia. Also includes minor intercalated and/or interfingering basalt flows.

QTb

Undifferentiated basalt and pyroclastic rocks

Mainly dark gray diktytaxitic basalt flows with associated pyroclastic rocks (scoria, cinders, and agglomerate) that form broad, thick piles near eruptive centers. Includes tilted black, dense basalt flows that correlate with the "lower lavas" of Newcomb and Hart (1958). Probably includes some Qb in and adjacent to fault escarpments.

Contact, dashed where inferred.

Fault, dashed where approximately located, bar and ball on down side.

Hot spring.

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. This well (figure 7) pumps 1000 gals./min. of 200°F. water from a depth of 285 feet. Analysis of the water is given in table 2. A trace of hydrogen sulfide is present. At one time the well was test pumped at a rate of 7000 gals./min.

Another hot-water well at the Osborn ranch, about half a mile to the north, pumps 186° water from a depth of 418 feet at a rate of 450 gals./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., shown on plate 2b, have temperatures around 80° F. The Liskey well would seem to be nearer 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.

Geochemical Data on the Klamath Falls Area

Ground-water analyses

Table 2 lists chemical analyses of eight thermal-water samples from a number of well locations within the geothermal zones and one from the hot spring at Olene Gap. Two representative samples, one a nonthermal water, Sample No. 10, and a slightly thermal water, Sample No. 11, were added for comparison purposes.

The most obvious impression gained at first glance is the uniformity of constituents among the samples of thermal water. This holds even for Sample No. 8 from the Liskey ranch, which is 12 miles south of Klamath Falls, and also for Sample No. 9 from Olene Gap Spring 8 miles to the southeast. Only one, Sample No. 7, shows some deviation, which is probably due to the lower temperature and its location on the margin of the Klamath Falls geothermal zone.

Among the most notable characteristics of the thermal waters is the high sulfate content and the fact that its ratio to chloride averages about 8. In relation to Sample Nos. 10 and 11, the thermal waters show a very great increase in sodium and sulfate and to a less extent chloride. Silica and calcium increase by 50 to 100 percent and bicarbonate drops by a factor of three or so.

The increase in sodium sulfate coupled with the small addition of sodium chloride in the Klamath Falls thermal waters is at variance with the generally accepted theories concerning hot springs and waters assumed to have a volcanic origin (White, 1957a,b; Ellis, 1964; White, 1964; and

Table 2. Chemical analyses of thermal and non-thermal groundwater of the Klamath Falls area (in parts per million).

Sample No.	1	2	3	4	5	6	7	8	9	10	11
Temperature (°F.)	178	164	160	193	205	196	143	200	165	45	69
Silica (SiO_2)	81	87	83	73	68	78	92	75	79	51	38
Iron (Fe) total	.04	.0	.0	.03	.04	.03	.09	.09	.03	.03	.12
Calcium (Ca)	23	25	22	25.1	27.3	27.3	5.4	27	34.9	15	11
Magnesium (Mg)	.0	.0	.0	1.04	< .2	< .2	1.04	1.89	1.09	11	4.3
Sodium (Na)	213	221	207	331	360	370	246	388	294	} 13	44
Potassium (K)	4.2	4.4	3.8	3.5	3.5	3.0	6.0	3.5	4.5		3.8
Bicarbonate (HCO_3)	32	32	*47	22	23	24	40	51	40	128	114
Carbonate (CO_3)	8	8	-	16	16	12	60	16	0	n.a.	n.a.
Sulfate (SO_4)	403	431	393	384	442	462	256	364	346	1.4	21
Chloride (Cl)	54	56	50	48	54	54	35	61	58	1.4	27
Fluoride (F)	1.2	1.6	1.4	1.12	1.18	1.18	1.0	1.3	1.12	.2	.1
Ammonia (NH_4)	n.a.	n.a.	n.a.	.54	.79	0.90	5.8	0.81	0.55	n.a.	n.a.
Nitrate (NO_3)	.0	.0	.2	< .01	.03	.09	.09	1.32	.91	1.9	.0
Boron (B)	.96	.91	.74	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	.0	.01
Aluminum (Al)	n.a.	n.a.	n.a.	.03	.03	< .02	< .02	.02	.03	n.a.	n.a.
Manganese (Mu)	n.a.	n.a.	n.a.	< .02	.06	.03	< .02	< .02	.06	n.a.	n.a.
Arsenic (As)	n.a.	n.a.	n.a.	.018	.037	.072	.005	.04	.027	n.a.	n.a.
Solids, total	833	881	812	816	821	902	631	833	812	158	214
Hardness as $CaCO_3$	58	62	55	67	66	67	18	75	92	83	45
Specific conductance	1160	1230	1100	1000	1100	1120	795	1080	1000	200	316
pH	8.8	8.7	8.5	8.6	8.5	8.4	8.7	8.4	7.3	7.7	8.3

*Contains equivalent of 4 ppm CO_3. n.a. = Not available.

1. Medo-Land Creamery, Klamath Falls, well (Newcomb and Hart, 1958, table 4).
2. J. E. Friesen, Klamath Falls, well (Newcomb and Hart, 1958, table 4).
3. Lois Merruys, Klamath Falls, well (Newcomb and Hart, 1958, table 4).
4. Oregon Technical Institute, Klamath Falls, well No. 5, analysis by Oregon State Board of Health laboratory.
5. Dr. Soule residence, 1945 Main St., Klamath Falls, well, analysis by Oregon State Board of Health laboratory.
6. Mills School, Klamath Falls, well, analysis by Oregon State Board of Health laboratory.
7. Mazama School, Klamath Falls, well, analysis by Oregon State Board of Health laboratory.
8. John Liskey ranch, Lower Klamath Lake Road, T. 40 S., R. 9 E., sec. 34, well, analysis by Oregon State Board of Health laboratory.
9. Olene Gap Spring, T. 39 S., R. 10 E., sec. 14, analysis by Oregon State Board of Health laboratory.
10. Fred Coleman ranch, T. 37 S., R. 10 E., sec. 30, well (Newcomb and Hart, 1958, table 4).
11. C. W. Lewis, T. 40 S., R. 10 E., sec. 28, well (Newcomb and Hart, 1958, table 4).

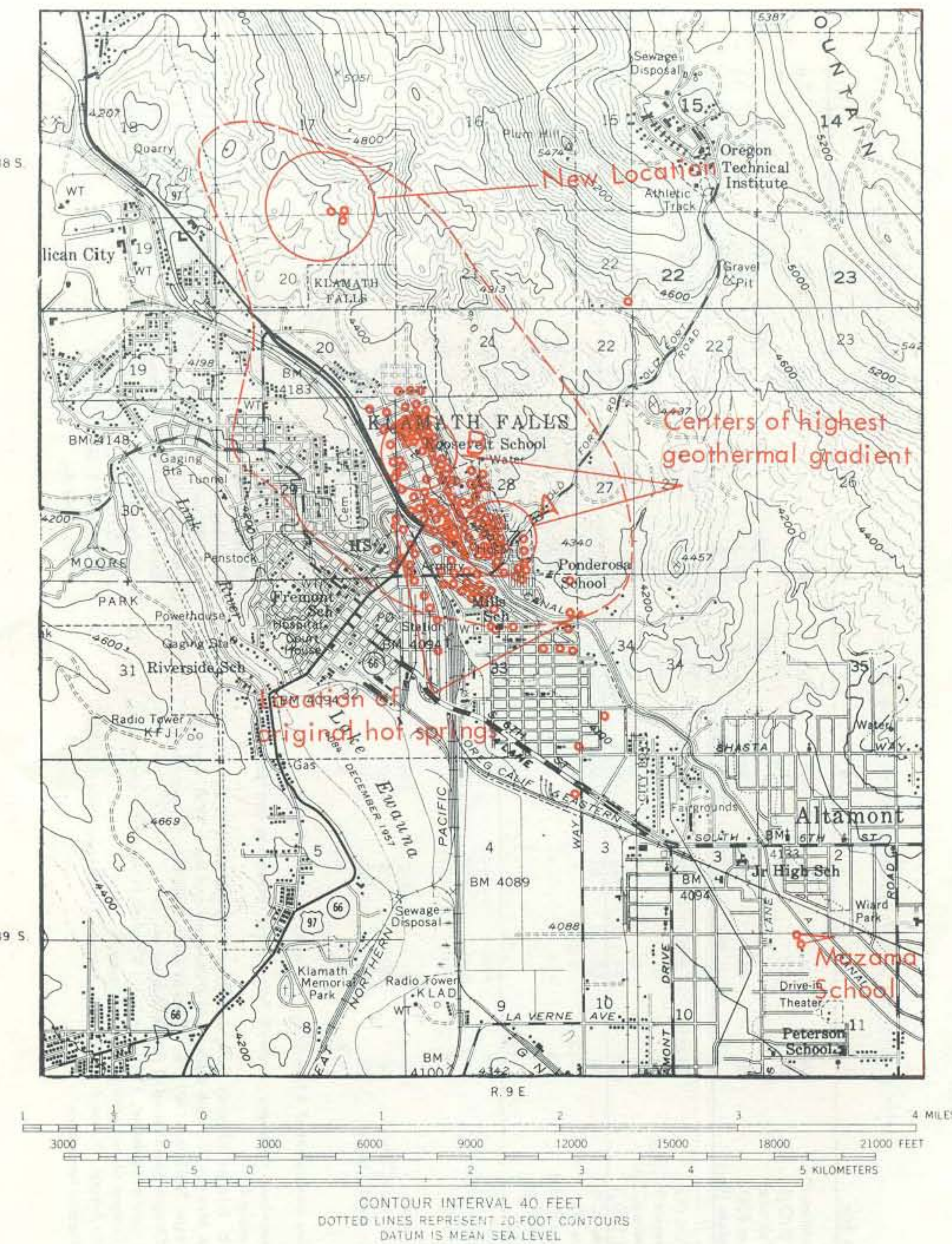
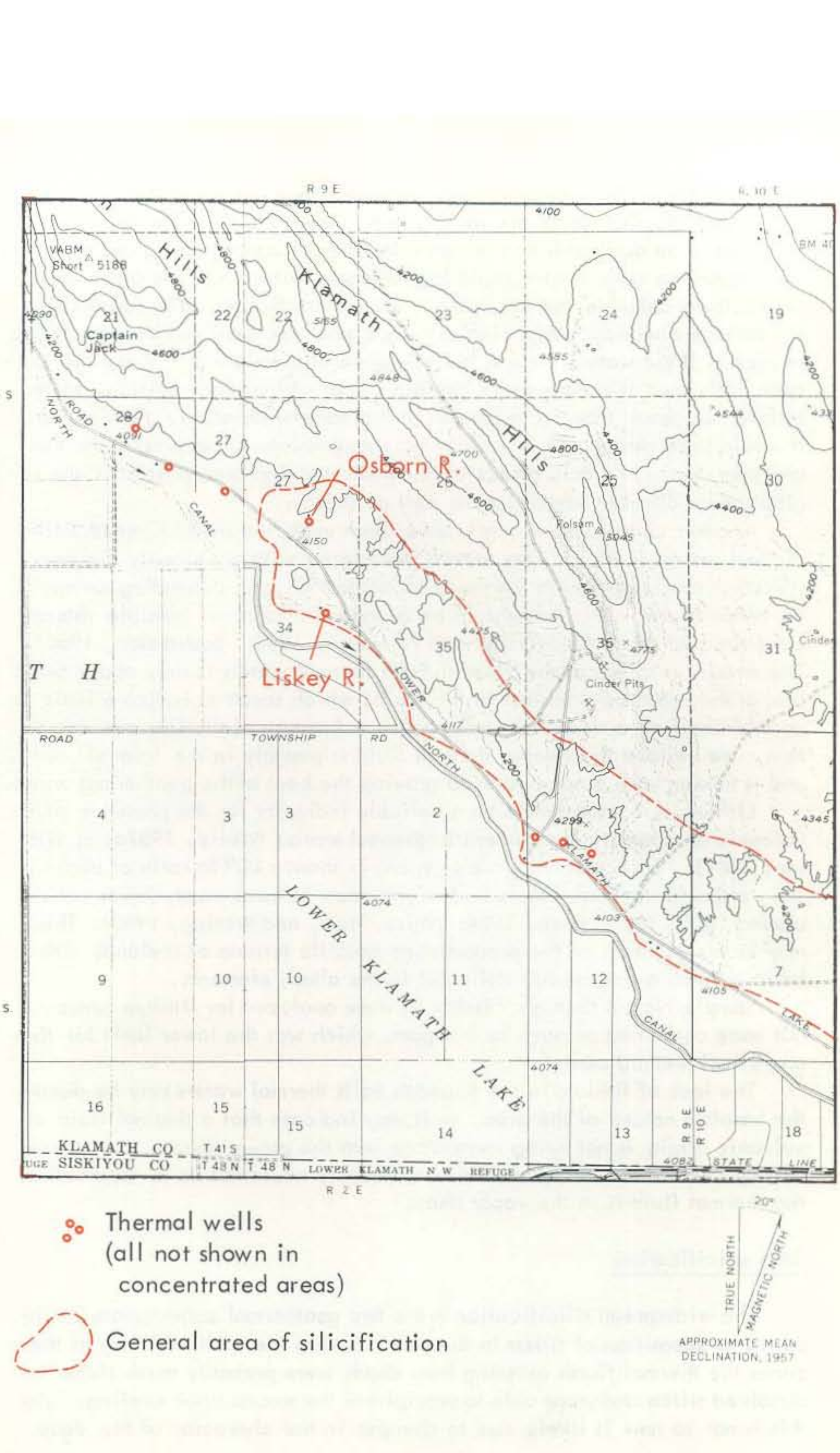


Plate 2. a) Klamath Falls geothermal zone (shown above);
b) Klamath Hills geothermal zone (on right).


R 9 E
R. 10 E
VABM Short 5188
Hills
Klamath
Hills
Captain Jack
40 S
41 S
NORTH ROAD
CANAL
Osborn R.
Liskey R.
Folsom 5045
Cinder Pits
T H
ROAD
TOWNSHIP RD
NORTH
LOWER
KLAMATH
LOWER KLAMATH LAKE
CANAL
LAKE
KLAMATH CO
SISKIYOU CO
T 41 S
T 48 N
LOWER KLAMATH N W REFUGE
STATE LINE
R 2 E
R 9 E
R 10 E
Thermal wells
(all not shown in
concentrated areas)
General area of silicification
20°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN
DECLINATION, 1957

Wilson, 1964). According to these theories, chloride is the dominant addition and SO_4/Cl ratios are usually low, around .05. The chloride is believed to be derived from a dense supercritical vapor passing out from magma and mixing with deep-circulating meteoric water. On the other hand, acid sulfate-chloride and acid sulfate waters are thought to be formed near the surface where accompanying sulfurous gases are oxidized by atmospheric oxygen. These waters have a low pH, generally below 3. Since the Klamath Falls area thermal waters contain traces of hydrogen sulfide, some sulfate may result from its oxidation in the zone of aeration. If this is so, it would seem reasonable to expect more magnesium to be present in the analyses, since any acid attack of the basic rocks characteristic of the region should dissolve magnesium as well as sodium.

Another constituent which is lower than expected in the Klamath Falls thermal waters is silica. For waters associated with a volcanic terrane, silica is usually present in the range of 200 to 600 ppm, depending somewhat on temperature. It is thought to be a good indicator of possible thermal conditions at depth (Bodvarsson and Palmason, 1964; Bodvarsson, 1966). The amount in silica of the Klamath Falls thermal waters is only about twice that of the nonthermal waters in the basin, which seems to indicate little or no addition from a deeper thermal source. Because of the low concentration, we believe the deeper thermal fluid is possibly in the form of steam and is mixing with groundwater to provide the heat of the geothermal zones.

Lithium is considered to be a reliable indicator for the presence of a volcanic or magmatic component in thermal waters (White, 1957a, b; Wilson, 1964). Such thermal waters generally show a Li/Na ratio of about .01, although thermal waters in Iceland seem to have much lower ratios, around .0005 (Bodvarsson, 1964; White, Hem, and Waring, 1963). This may be a reflection of the predominant basaltic terrane of Iceland, since basic magmas are somewhat deficient in the alkali elements.

Sample Nos. 4 through 9 (table 1) were analyzed for lithium content, but none contained as much as 0.1 ppm, which was the lower limit for the analytical method used.

The lack of lithium in the Klamath Falls thermal waters may be due to the basaltic nature of the area, or it may indicate that a thermal fluid of volcanic origin is not being introduced into the ground waters as a source of heat. On the other hand, lithium probably could not be transported if the thermal fluid is in the vapor phase.

Rock silicification

The widespread silicification in the two geothermal zones (plate 2 a, b) points to deposition of silica in the past. During the earlier history of these zones the thermal fluids entering from depth were probably much richer in dissolved silica and were able to precipitate the excess upon cooling. Why this is not so now is likely due to changes in the character of the deep

Figure 9. Dry steam well located at 341 Hillside Ave. in Klamath Falls.

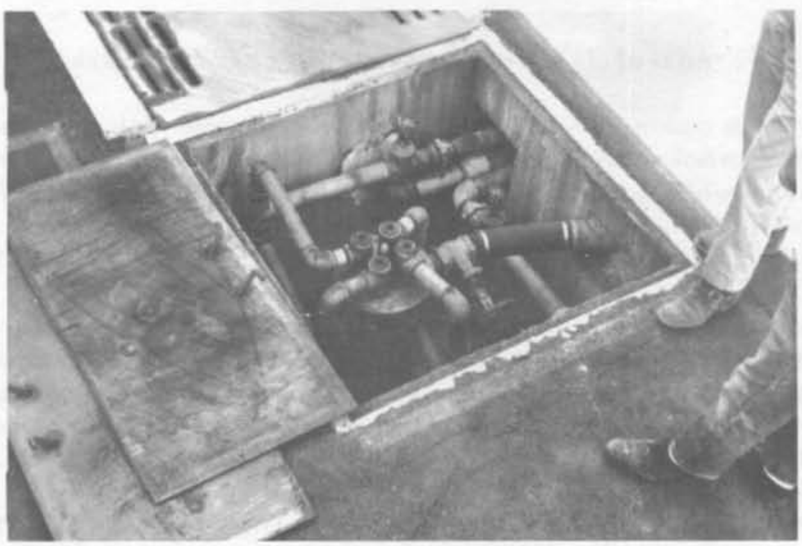


Figure 10. Typical hot-water wellhead installation at the Mills School. This particular well has two coils extending down the casing.

geothermal system, which for lack of data cannot be satisfactorily explained at this time.

A group of samples was taken from each of the two silicified zones and analyzed for mercury. All samples showed trace amounts of mercury ranging from 1 to about 10 ppm. One grab sample contained visible cinnabar and another ran 0.4 lbs./ton mercury. The presence of mercury is typical of low-temperature or epithermal mineralization and characteristic of hot-spring systems in volcanic areas.

Gravimetric Data on the Klamath Falls Area

Recently the State of Oregon Department of Geology and Mineral Industries published a series of three gravity maps entitled "Gravity Maps of Oregon (Onshore and Offshore)." One of this set, Map GMS 4-b, "Complete Bouguer Gravity Anomaly Map of Oregon" (Berg and Thiruvathukal, 1967), is constructed with contours at 10 mgal intervals and shows several anomalies are present in the Klamath Falls area. Most notable is a 20-mgal negative anomaly over the Lower Klamath Lake basin. The probable interpretation of this anomaly, as indicated by the structure and stratigraphy of the area, is that of a down-faulted block overlain by a fill of light tuffaceous and diatomaceous sediments. A 10-mgal negative anomaly south of Klamath Falls and another centered at the western edge of Swan Lake Valley may be similarly interpreted.

Potential Geothermal Resources at Depth

A large amount of heat is available in the Klamath Falls and Klamath Hills geothermal zones at depths ranging to 1000 feet or more. It is in the form of hot water with temperatures that vary from warm to above the boiling point. Such a thermal fluid is satisfactory for water heating and space heating, but it does not have the temperature and enthalpy needed for power generation.

As previously described in the geologic section of this report, Pliocene-Pleistocene volcanic-sedimentary rocks underlie the region. Subsidence, perhaps due to the late volcanism to the north, south, and west, has caused faulting and production of horst and graben structures. Such structures are considered to be favorable for the development of geothermal resources (McNitt, 1965).

The generally impervious properties of the Pliocene-Pleistocene rocks and their broad extent should provide a cover or "cap" to any existing deeper geothermal reservoir. Such a cap prevents the flow of geothermal fluids to the surface and consequent rapid dissipation of the reservoir heat (Facca and Tonani, 1964; Grindley, 1964). We believe the layered sedimentary-pyroclastic unit (plate 1) is performing this function in the Klamath Falls area. The present surface displays and the hot-water zones are only a manifestation of leakage along faults through these rocks from a hotter, deeper reservoir.

The rocks which compose this reservoir may be older basalt flows underlying the layered sedimentary and pyroclastic rocks which are correlative with the "lower lavas" of Newcomb and Hart (1958). Such a reservoir would have good permeability and would allow the circulation of thermal fluid in a convection system. If these basalt flows are thin or missing, the reservoir may exist in rocks equivalent to the Tertiary volcanic series of the Western Cascades. This assemblage of flows, breccias, and tuffs may have low permeability from alteration, although considerable fracture permeability may be developed from the great amount of faulting which has occurred in the Klamath area.

Chemical analyses of the thermal waters in the Klamath Falls 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. On this basis, we are inclined to believe the thermal fluid flowing upward into the geothermal zones is probably 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 (Grindley, 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.

Exploration of a possible deeper geothermal reservoir in the Klamath Falls area can best be accomplished in and about the two major geothermal zones. Here the escape of steam from depth into the upper ground-water zone is apparently taking place and would, therefore, be the best location to probe the reservoir. Additional geophysical and geochemical studies may prove valuable in helping to define the nature of this reservoir, although a deep test well probably would provide the most information at this stage of exploration.

Acknowledgments

We wish to thank Mr. Alfred Collier and Mr. John Glubrecht of Klamath Falls for their cooperation in securing information about the early development of hot wells in Klamath Falls and for data of the hot springs and wells. Mr. James W. Pinninger of Oregon Technical Institute furnished well logs and other information, and many other people living in the Klamath Falls area were most helpful.

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Locating a promising geothermal system is a difficult problem. A system is apparent only when it is defective - when it is "leaking" hot water or steam to the surface. These obvious areas of hot springs and geysers are currently being explored, but it is entirely possible that the best areas are as yet undetected. Experts have said that the state of our knowledge regarding geothermal resources is comparable to that regarding petroleum resources at the turn of the century. (From U.S. Geological Survey news release.)

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In the United States, serious interest in geothermal resources began about 1955, when The Geysers area, located about 75 miles north of San Francisco, was redrilled, and four strong wells began producing at a depth of less than 1000 feet. In 1958, the owners of the wells and the Pacific Gas & Electric Co. signed a contract arranging for the wells to supply steam to a plant erected for generation of electricity. Production was started in 1960 at a rate of 12,500 kilowatts, and the capacity has enlarged since to more than 56,000 kilowatts. The entire steam field at The Geysers is estimated to be capable of producing more than 1 million kilowatts. The Geysers operations has stimulated exploration through the western United States. (From U.S. Geological Survey news release.)

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The electrical energy requirements of the United States are steadily climbing, and will probably continue to do so in the foreseeable future. Most of our requirements at the present time are met by energy produced from the burning of coal, oil, and gas, and other fuels. Although geothermal heat is now only of minor importance as an energy source, the quantities available in geothermal systems are large, and, with additional research and development, recovery is likely to increase greatly. (From U.S. Geological Survey news release.)

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CRESCENT AREA MAPPED

"Reconnaissance geologic map of the east half of the Crescent quadrangle, Lake, Deschutes, and Crook Counties, Oregon" by G. W. Walker, N. V. Peterson, and R. C. Greene has been published as Misc. Geol. Invest. Map I-493 by the U.S. Geological Survey. This is the fifth in a series of Oregon geologic maps to be issued at this scale (1 inch equals approximately 4 miles) on AMS sheets, preparatory to publication of the eastern half of the State Geologic Map. The report covers a large region of the High Lava Plains of south-central Oregon, from the east flank of Newberry Volcano to within a few miles of the western edge of the Harney Basin. Rocks range in age from Eocene-Oligocene (Clarno Formation) to Recent, and comprise 26 geologic units shown on the map by color and pattern. One structural cross section also accompanies this report. Each unit in the explanation column is described in some detail and suggested correlations with other geologic formations in the state are given.

Copies may be obtained from the U.S. Geological Survey, Federal Center, Denver, Colo., 80225. The price is $1.00.

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REGIONAL GEOLOGIC MAP OF OWYHEE UPLAND ISSUED

"Geologic map of the Owyhee region, Malheur County, Oregon" has been published as Bulletin 8 by the Museum of Natural History at the University of Oregon. The report includes much of the Owyhee Upland physiographic province of southeastern Oregon from the Malheur River canyon on the north to the Jordan (Morcom) Craters on the south.

A map of the northeast portion of this area, covering the Mitchell Butte quadrangle, was published by the Oregon Department of Geology and Mineral Industries in 1962.

Copies of Bulletin 8 may be obtained from the Museum of Natural History, University of Oregon, Eugene, Oregon 97403. The price is $2.00.

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LEASE MINING NOT HARMFUL TO RESERVOIR SITES

The U.S. Bureau of Reclamation has applied for the withdrawal of a total of 110 acres in the Whitman National Forest from location under the mining laws to protect the Hardman and Dark Canyon reservoir sites in southern Baker County. The withdrawal contains no restriction on the mining of leasable minerals. The sites are located in section 28, T. 13 S., R. 36 E. and sections 20 and 21, T. 12 S., R. 41 E.

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