An estimate of the geothermal potential of Newberry Volcano, Oregon

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INTRODUCTION

Newberry Volcano is a large Quaternary volcano located in central Oregon about 32 km (20 mi) southeast of Bend (Figure 1). It covers an area of nearly 1,300 km^2 (500 mi^2) and, according to MacLeod and others (1981), consists of "basalt and basaltic andesite flows, andesitic to rhyolitic ash-flow and air-fall tuffs and other types of pyroclastic deposits, dacite to rhyolite domes and flows, and alluvial sediments produced during periods of erosion." More than 400 cinder cones dot the flanks of the volcano. The most recent activity occurred approximately 1,400 years ago in the summit caldera and resulted in the formation of the Big Obsidian Flow. The volcano is considered dormant but capable of future eruptions (MacLeod and others, 1981).

During the summer of 1981, the Geothermal Research Program of the U.S. Geological Survey (USGS) completed drilling a 930-m (3,051-ft) test hole (Newberry 2) in the summit caldera of Newberry Volcano. Fluids at a temperature of 265° C (509° F) were encountered in permeable rocks in the bottom 1.8 m (6 ft) of the hole (Sammel, 1981).

The intent of this paper is to provide a general update of the estimated geothermal electrical generation potential of the volcano, based on refinements in the estimates of reservoir temperature and volume. The temperature refinements are based on considerations of the relative validity of various methods of geothermometry and on data obtained from the USGS drill hole. The volume refinements are based on USGS drill-hole data and on gravity modeling recently completed in the area by the USGS (Williams and Finn, 1981).

PREVIOUS RESERVOIR ESTIMATES

In USGS Circular 790, Brook and others (1979) estimate the mean reservoir thermal energy of Newberry to be $27 \pm 10 \times 10^{18}$ J (joules), resulting in a theoretical electrical generation potential of 740 MWe (megawatts electric). These estimates are based upon a mean reservoir temperature of 230° ± 20° C and a mean reservoir volume of 47 ± 16 km^3.

GEOTHERMOMETRY

Normally, chemical geothermometers are used to estimate the reservoir temperatures of geothermal systems. These temperature-dependent water-rock reactions, however, are valid only for hot-water systems, as the chemical constituents used in the calculations (Na, K, Ca, Mg, SiO_2, Cl) are not soluble in steam (White, 1973). Although there are two hot springs in the summit caldera of Newberry Volcano (East Lake and Paulina Hot Springs), their chemistry is not considered a reliable indicator of reservoir temperature. Both springs issue from lapilli tuffs along the shores of lakes occupying the caldera floor and are characterized by low flow rates and high silica concentrations. Mariner and others (1980) believe that (1) the springs are probably drowned volcanic gas vents, and (2) the solution of glass from the lapilli tuffs could account for observed high silica and magnesium concentrations which, in turn, would be a function of the length of time that heated lake waters were in contact with the tuffs. A warm well located in Little Crater Campground (between East and Paulina Lakes) probably suffers from the same limitations.

Because of the uncertainty surrounding the geothermometers derived from the chemistry of East Lake and Paulina Hot Springs, Brook and others (1979) infer a reservoir temperature of 230° ± 20° C, based on temperatures estimated for other Quaternary volcanoes. Since results of the Newberry 2 test hole (Figure 2) indicate a minimum temperature of 265° C at the top of the reservoir, the problem becomes one of estimating maximum and mean reservoir temperatures. One possible solution is to use the chemical geothermometers while keeping in mind their limitations. Unfortunately, the Na-K, Na-K-Ca, and SiO_2 geothermometers all indicate minimum reservoir

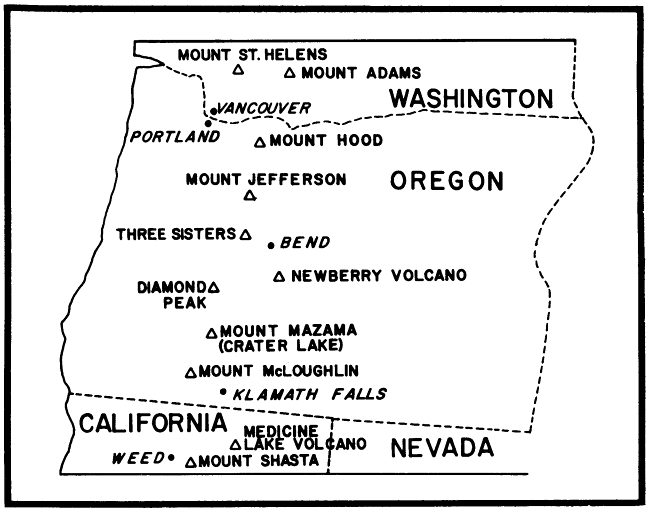

Figure 1. Map showing locations of some major volcanoes in the High Cascades Range of Washington, Oregon, and California. Taken from Sammel (1981).

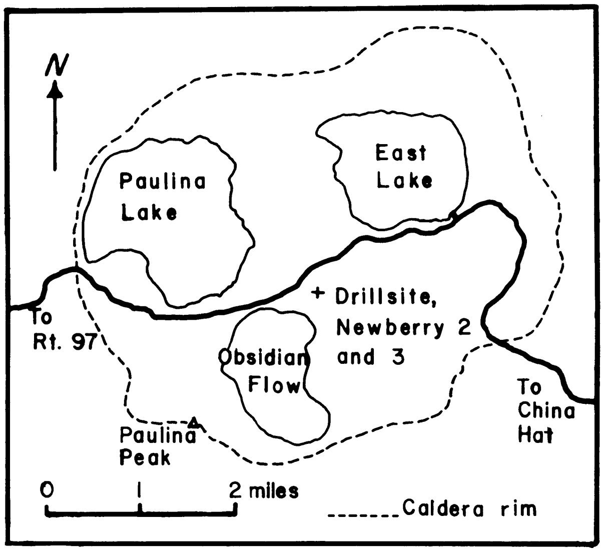

Figure 2. Map of Newberry Caldera, showing the Newberry 2 test site. Taken from Sammel (1981).

temperatures of less than 200° C (Mariner and others, 1980). A new method based on the Na/Li ratio (Fouillac and Michard, 1981) gives reservoir temperatures of 335° C, 375° C, and 370° C for East Lake Hot Springs, Paulina Hot Springs, and the Little Crater Campground warm well, respectively (based on analyses from Mariner and others, 1980).

The reliability of the Na/Li geothermometer is difficult to assess. In general, higher temperatures correspond to lower Na/Li ratios. If, however, the concentration of sodium in the thermal water is a function not only of temperature but also of the length of time that the water has been in contact with lapilli tuffs (Mariner and others, 1980), then the result is a higher Na/Li ratio and a lower estimated reservoir temperature. This implies that the calculated temperatures are minimums, assuming, of course, that the concentration of lithium in the thermal water is a function of subsurface temperature and is not affected by the length of time the water is in contact with the tuffs. This may indeed be the case. According to Fouillac and Michard (1981), the concentration of lithium in thermal waters increases with increasing temperature, varying over about four orders of magnitude between 0° and 300° C. They feel that it is unlikely that the concentration of lithium in thermal waters is due to chemical equilibrium between water and a lithium mineral, and they believe that water-rock ratios and rock type do not affect lithium concentrations. Given these findings, it is possible that the temperatures resulting from Na/Li ratios give useful indications of minimum reservoir temperatures beneath the caldera at Newberry Volcano. Even if Paulina and East Lake Hot Springs are drowned fumaroles, the Na/Li ratios should be characteristic of the temperature of the thermal fluid at the point of mixing. Since the temperature of the mixture is presumably less than the temperature at depth, the resulting Na/Li geothermometer should give useful minimum reservoir temperatures.

Based on the above considerations, a maximum reservoir temperature of 360° C and a mean reservoir temperature of 312.5° C have been selected for use in the calculations of geothermal potential. The maximum is simply the mean of the three Na/Li geothermometers (335° C, 375° C, and 370° C) discussed above, while the mean reservoir temperature is the arithmetic average of the maximum (360° C) and the temperature encountered at the bottom of the Newberry 2 test hole (265° C). These temperatures are higher than those encountered in many producing geothermal fields around the world, but they are not unheard of. The Cerro Prieto field in the Mexicali district of Mexico, for example, produces fluids at temperatures of 310° to 350° C from depths of 1,700-2,000 m (Espinosa, 1982).

RESERVOIR VOLUME

Brook and others (1979) assume a reservoir volume of 47 ± 16 km^3 in their estimation of the geothermal potential of Newberry Volcano. This estimate is based upon a caldera area of 32 km^2 and a minimum, maximum, and most likely depth to the top of the reservoir of 0.5, 2.0, and 1.5 km, respectively. They chose these numbers because the depths to the tops of the reservoirs in most drilled geothermal systems fall within that range and because at the time of their study there were no drill hole data available from Newberry indicating the true top of the reservoir. Assuming a maximum drillable depth of 3 km for the reservoir bottom, Brook and others (1979) calculate a maximum reservoir thickness of 2.5 km, a minimum of 1.0 km, and a most likely thickness of 1.5 km. The results from Newberry 2 indicate a depth to the top of the reservoir of 0.93 km (Sammel, 1981) and thus a calculated reservoir thickness of 2.07 km, the value that is used in this paper in calculating reservoir thermal energy. An important assumption used in the calculation of reservoir volumes is that all portions of the reservoir are considered to be equally porous and permeable; no attempt is made to separate those portions of the reservoir which are porous and permeable from those which are not (Brook and others, 1979).

Williams and Finn (1981), in a reexamination of gravity data from Newberry, delineate a large positive residual gravity anomaly associated with the volcano. The anomaly extends well outside the margins of the volcano, covers an area of approximately 275 km^2 (D.L. Williams, 1982, personal communication), and is interpreted by Williams and Finn (1981) to be a subvolcanic intrusive. The top of the intrusive lies at a depth of less than 2 km (D.L. Williams, 1982, personal communication) and is probably composed of a complex of many separate intrusions in different states of cooling (Williams and Finn, 1981). While it is highly unlikely that temperatures similar to those encountered in the Newberry 2 test hole underlie the entire area of the positive gravity anomaly, calculations will be made using that assumption in order to arrive at an upper limit for the electrical generation potential of the volcano.

ELECTRICAL POWER CALCULATIONS

The techniques developed by Brook and others (1979) for estimating the electrical generation potential of a geothermal area are relatively straightforward, once reasonable estimates of reservoir temperatures and volumes have been made. As a first step, the accessible resource base (the stored heat of the system above 15° C and shallower than 3 km) is calculated, using the formula:

$$q_R = pc \cdot a \cdot d \cdot (t - t_{ref}),$$

where q_R is the reservoir thermal energy in joules (J), pc is the volumetric specific heat of rock plus water (2.7 J/cm^3/° C), a is the reservoir area in km^2, d is the reservoir thickness in km, t is the reservoir temperature, and t_{ref} is the reference temperature (15° C). The value for pc assumes a reservoir porosity of 15 percent and t_{ref} is the mean annual surface temperature, which for simplicity is assumed to be constant throughout the United States.

Once the reservoir thermal energy (q_R) has been calculated, the problem becomes one of determining how much of that energy can be turned into electricity. To generate electricity, the thermal energy of the reservoir is converted into mechanical energy (work), which in turn is converted to electrical energy. The mechanical work available (W_A) at the wellhead can be determined from a graph conveniently provided in USGS Circular 790 (Brook and others, 1979). For a reservoir temperature of 312.5° C and a depth to the center of the reservoir of 2 km, the ratio W_A/q_R is equal to 0.082 ($W_A/q_R = 0.082$). Hidden within this simple computation are the following important assumptions which are discussed in more detail by Brook and others (1979): (1) In an ideal reservoir, 50 percent of the reservoir thermal energy can be recovered at the wellhead; (2) nonideal reservoir conditions, mostly related to the fact that much of the reservoir volume is not porous and permeable, limit wellhead recoverability to 25 percent of the reservoir thermal energy; and (3) the condenser rejection temperature is 15° C. This last assumption tends to maximize the available work (W_A) term, as the true condenser rejection temperature will usually be higher, around 40° C.

The electrical energy obtainable from a geothermal system is calculated from the equation:

$$E = W_A \cdot \eta_u,$$

where η_u is a utilization factor that accounts for losses that occur in the power cycle (Brook and others, 1979). The value of η_u is simply the ratio of actual work to available work (W_A) for a given system. A value of 0.4 was chosen by Brook and others (1979) as typical of hot water systems and is used in this paper. It should be noted that the calculation of actual work (used in determining η_u) assumes a condenser rejection temperature of 40° C.

Table 1 lists the results of the various calculations made for Newberry Volcano. The values for electrical energy are given in electrical megawatts based on a 30-year life span.

Table 1. *Estimates of volume, temperature, and energies of Newberry Volcano*

Source of calculation	Reservoir volume (km^3)	Reservoir temperature (° C)	Reservoir thermal energy (10^{18} J)	Electrical (MWe for 30 years)
USGS Circ. 790[1]	47 ± 16	230 ± 20	27 ± 10	740
DOGAMI[2]	47	312.5	38	1,316
DOGAMI[3]	66	312.5	53	1,843
DOGAMI[4]	569	312.5	457	15,837

[1] Brook and others, 1979, p. 54.

[2] Oregon Department of Geology and Mineral Industries (DOGAMI) calculation, using reservoir volume estimate of Brook and others (1979) and new temperature data from Newberry 2 test well.

[3] DOGAMI calculation using increases in both reservoir temperature and volume from Newberry 2 hole (Sammel, 1981).

[4] DOGAMI calculation using volume estimate based on gravity work of Williams and Finn (1981).

Two things are immediately obvious from the information contained in Table 1. First, the new data from the Newberry 2 test well more than double the theoretical electrical generation potential of the caldera portion of the Newberry Volcano; and second, there may be enormous potential outside the caldera proper. The 15,837-MWe estimate for the entire gravity anomaly associated with the volcano is, of course, an absolute maximum. It is based on the assumptions that (1) the intrusive causing the gravity anomaly is everywhere providing heat at the rate found in the Newberry 2 test hole, and (2) the reservoir is everywhere 2.07 km thick (i.e., the top of the reservoir lies everywhere at a depth of approximately 1 km). While these assumptions are certainly not completely valid, they provide a useful upper limit on the potential of the volcano. The extent to which they are in error and the true geothermal potential of the volcano can be determined only by exploratory drilling.

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MEETING ANNOUNCEMENTS

GSOC luncheon meetings

The Geological Society of the Oregon Country (GSOC) holds noon meetings in the Standard Plaza Building, 1100 SW Sixth Avenue, Portland, in Room A adjacent to the third floor cafeteria. Topics of upcoming meetings and speakers include:

April 16—*Bella Coola by Freighter and Beyond*: by Phyllis and John Bonebrake, members and president of GSOC, 1975.

May 7—*The Columbia River Gorge: Who Is Watching?* by Nancy Russell, lecturer on Oregon native plants and chairwoman of Friends of the Columbia Gorge.

May 21—*Forty Floods*: by John Eliot Allen, Emeritus Professor of Geology, Portland State University.

For additional information, contact Viola L. Oberson, Luncheon Chairwoman, phone (503) 282-3685.

AIME dinner meeting

The monthly dinner meeting of the Oregon section of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) will be held Friday evening, April 16, at the Flamingo Best Western Motel and Restaurant, 9727 NE Sandy Boulevard in Portland. The speaker will be Herbert H. Kellogg, 1982 Henry Krumb Lecturer and Professor of Metallurgy at the Henry Krumb School of Mines at Columbia University, who will speak on *Energy Use in Metal Production.*

Cocktail hour is at 6 p.m., dinner at 7 p.m., and program at 8 p.m. Reservations should be made by Wednesday, April 14, with either Mike York in Corvallis (phone 757-0349) or the Oregon Department of Geology and Mineral Industries receptionist in Portland (phone 229-5580). ☐

DOGAMI publishes new geologic map of Bourne quadrangle, eastern Oregon

A new geologic map for a part of eastern Oregon, published by the Oregon Department of Geology and Mineral Industries (DOGAMI), shows gold and silver mines and prospects as well as the geology of a historic mining area.

The multicolored map, *Geology and Gold Deposits Map of the Bourne Quadrangle, Baker and Grant Counties, Oregon*, was prepared by H.C. Brooks, M.L. Ferns, R.I. Coward, E.K. Paul, and M. Nunlist and appears in DOGAMI's Geological Map Series as Map GMS-19. At a scale of 1:24,000, it delineates 11 different bedrock and surficial geologic units, identifies 61 gold and silver lode and placer mines and prospects, and indicates known quartz veins. In three cross sections, it interprets basic geologic structure. Also printed on the map, partly in tabular form, is a summary of geologic and historical data for the deposits.

The Bourne 7½-minute quadrangle covers a part of the northwest corner of Baker County and about one square mile of Grant County. The region's mining areas, especially the North Pole-Columbia lode and the Cracker Creek, Cable Cove, and Rock Creek mining districts, are well known from their active periods between 1895 and 1940, when their total production value was an estimated $11 million.

DOGAMI Map GMS-19 is available now at the Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. The purchase price is $5.00. Orders under $20.00 require prepayment. ☐

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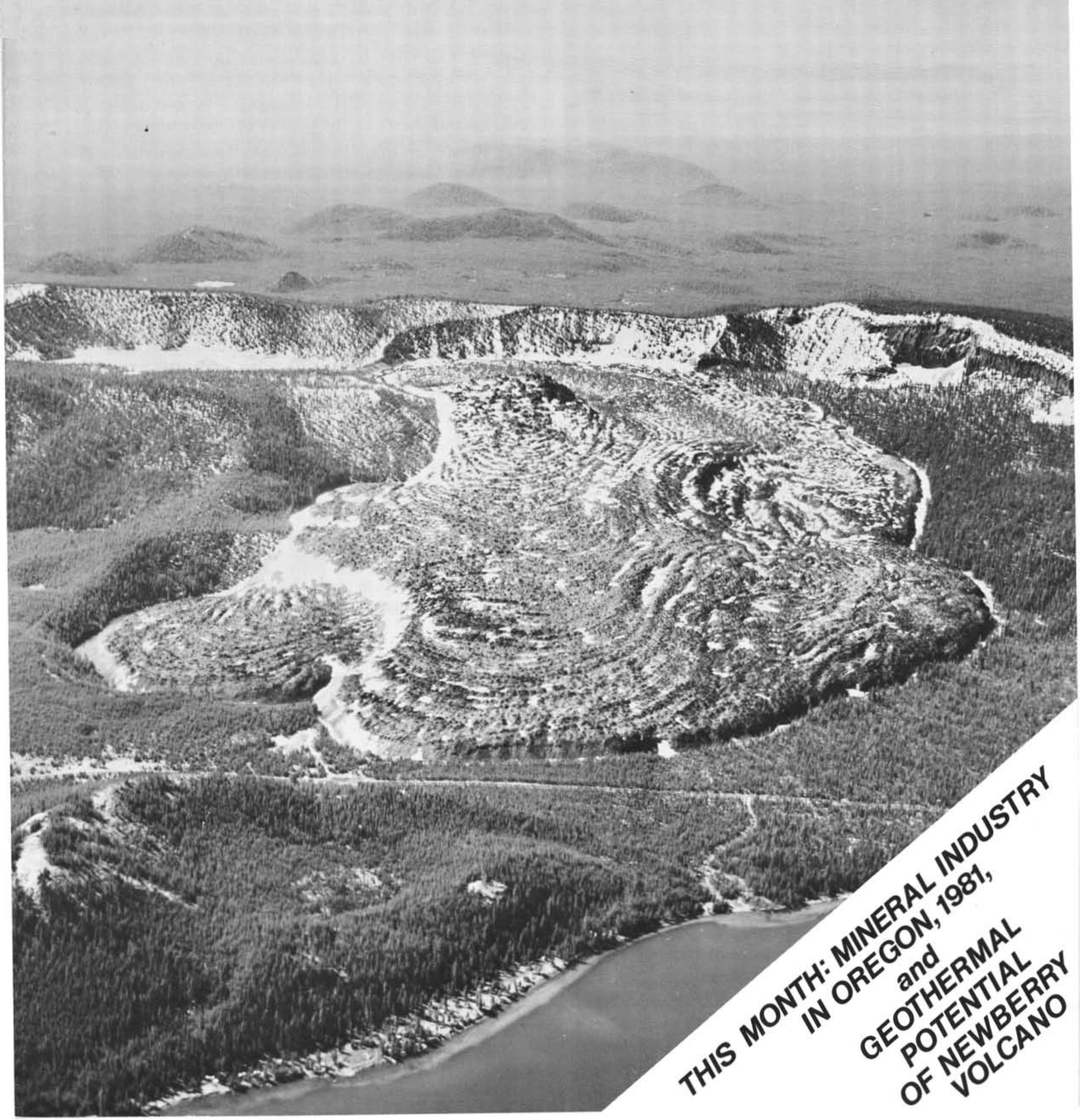

THIS MONTH: MINERAL INDUSTRY IN OREGON, 1981, and GEOTHERMAL POTENTIAL OF NEWBERRY VOLCANO

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COVER PHOTO

Looking to south at 1,400-year-old Big Obsidian Flow in caldera of Newberry Volcano. Article beginning on page 44 discusses geothermal potential of this large Quaternary volcano located southeast of Bend in central Oregon. Some data used in article came from U.S. Geological Survey drilling site to left (east) of Big Obsidian Flow. Several of more than 400 cinder cones that occur on flanks of volcano can be seen in background.

OIL AND GAS NEWS

Mist Gas Field:

Reichhold Energy Corporation continues to be the only active operator in the Mist Gas Field at present. The company recently finished the redrill of Columbia County 41-2 in sec. 2, T. 6 N., R. 5 W. The redrill, which reached a depth of 3,040 ft, was abandoned as a dry hole. Reichhold then moved the Taylor Drilling Company rig to Columbia County 12-9, a well drilled in 1980, and redrilled it to a depth of 2,917 ft. This redrill, too, was dry.

Columbia County:

About 10 mi southeast of production at Mist, Reichhold is rigging up to drill Columbia County 32-26. Located near the town of Pittsburg, this well is planned for 6,500 ft of depth. Depending on the results, the well may be followed by one or two others in the area.

State Lands lease sale:

On February 24 and 25, the Oregon Division of State Lands held an oil and gas lease auction in Portland. Over 75 people were present for bidding on 115,533 acres of state property in 15 counties. Bonus bids brought in over $590,000 on 212 of the 311 parcels offered; parcels without bids were awarded to the applicant for the annual rental fee of $1 per acre.

The highest bid was $215 per acre offered by Marathon for a 280-acre tract in Columbia County. Other acreage in Oregon's only gas-producing county went to Nahama and Weagant for $200 per acre.

Elsewhere in the state, bids were far lower. In Washington County, adjacent to Columbia County, several companies competed for acreage, with most of it going to Universal Resources for as high as $62 per acre. Other bidders included Conoco, Marathon, and Nahama and Weagant.

Central Oregon acreage was sought after by several bidders, including Anderson Oil Properties, Depco, EMEFCO, Shell Oil, Texaco, Tyrex, and Universal. Anderson was successful in leasing over 7,000 acres in Gilliam and Morrow Counties at offers averaging about $14 an acre. Depco leased all 13 parcels of submerged and submersible land under the Columbia River, Gilliam County.

Remaining acreage, mainly in Harney, Malheur, and Lake Counties, was awarded to the applicant or went for bids of only a few dollars an acre. Garth Tallman, Jerry Ryan, Inca Oil and Gas, and Anschutz Corporation took most of the acreage in these counties for no bid.

Lease sale results may be obtained from the Division of State Lands, 1445 State Street, Salem, Oregon 97310, phone (503) 378-3805.

Northwest Association of Petroleum Landmen organize:

After the lease sale discussed above, about 25 landmen, consultants, and attorneys gathered to form a Northwest Association of Petroleum Landmen for Oregon, Washington, and Idaho. They will try to affiliate with the nationwide American Association of Petroleum Landmen. A temporary committee was formed to organize the group. ☐

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