REPORT ON THE
NEWBERRY CRATER, OREGON
GEOTHERMAL PROSPECT

by

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INTRODUCTION

The Newberry Crater Geothermal Prospect is located about 25 miles south-southeast of Bend in Central Oregon (Fig. 1). Paulina and East Lakes are located at the center of Newberry Crater which is a heavily forested and very scenic area managed by the Forest Service. Newberry Crater is one of the few calderas in the western United States which is probably underlain by magma at a relatively shallow depth. It is probably the best geothermal prospect in Oregon, although some people may argue the South Sister area of the Cascades is as promising.

Phillips began exploration work in this area in 1975. The initial work was done by Ken Kazmerski. In 1976, the Reno office assumed responsibility for geothermal exploration in the area and performed additional work during the summer and fall. The work done to date includes general geology, gradient-hole drilling, a seismic groundnoise survey, a telluric-magnetotelluric survey, a gravity survey, a ground-magnetic survey, and water, gas, and isotope geochemistry.

The results of much of the work done so far is ambiguous and sometimes meaningless, due to hydrological and geological conditions in the area. In addition to these difficulties, recent political decisions by the State of Oregon and the Forest Service make it difficult, if not impossible, to explore for, or produce, geothermal power in the most promising area.

This report is written at this time to promote discussion as to the best exploration techniques and political strategy for this prospect. Developing the proper exploration tools for this geological environment is needed because there are other promising geothermal prospects in the west which are similar to the Newberry area in many ways.

FIGURE 1

MAP OF OREGON SHOWING THE LOCATION OF THE AREA OF INTEREST.

ALSO INCLUDED ARE MAJOR STRUCTURAL FEATURES AND RHYOLITIC DOMES IN THE SOUTHEASTERN PART OF THE STATE. (BLACK AREAS) HACHURES ARE SHOWN ON THE DOWNTOWN SIDE OF THE LARGER FAULTS OF THE BASIN AND RANGE PROVINCE.

(FROM MACLEOD ET. AL. 1975)

REGIONAL GEOLOGY

No colored published geologic map showing the regional geology of the Newberry area is readily available for inclusion in this report. A useful map is presented in Peterson et. al 1976. In this report the regional geology is best shown on Figure 1.

The Newberry Volcano is located between the Cascade Range on the west and the Brothers fault zone on the northeast. Consequently both features, along with the Walker Rim control most of the structural aspects of the volcano. The Newberry Volcano is also located at the western end of a 175 mile (250 Km) long belt of siliceous domes and flows (MacLeod et. al 1975). These domes and flows become progressively younger toward the west. Near the Newberry Volcano all the dated domes and flows are less than one million years old.

The rocks surrounding the Newberry Volcano are all volcanic, or volcanic-derived sediments, and range in age from Eocene to Holocene. The nearest pre-tertiary rocks are found in the Blue Mountains, more than 60 miles (96 Km) to the northeast. It is not known what rocks underlie the volcano. Higgins (1967) states "Thus a variant of Tertiary and Quaternary rocks probably are represented in the basement beneath the Newberry shield". Possibilities include the Columbia basalts, the tuffaceous Clarno and John Day Formations, and other local units.

LOCAL GEOLOGY

The Newberry Volcano is a Pliocene to Holocene basaltic shield volcano covering about 600 square miles (Plate 1). It is located at the intersection of large concentrations of faults belonging to three major regional trends (Higgins 1967). These trends show up clearly on the flanks of the volcano as alignments of cinder cones, normal faults and other linear features. On the north side of the volcano northwest-trending lineaments of the Brothers trend are predominant. On the south side northeast-trending lineaments of the Walker Rim trend are predominant. A lesser north-south trend, the Cascade trend, is present in the general area of the elongate north-south axis of the volcano.

It was first pointed out by Williams (1935) that the flanks of the shield may be separated into a very gently sloping lower portion and a steeper upper portion (Fig. 2).

Fig. 2. View of the Newberry Volcano from Bend, Oregon. The upper flanks are noticeably steeper than the lower flanks. Note the many forest covered cinder cones.

The lower flanks are comprised mostly of basalts and merge imperceptibly with the surrounding Quaternary basalts. There are two large areas outside the caldera where the basalts are overlain by ash-flow tuffs which presumably originated from the Newberry caldera. Plagioclase from pumice lumps in the ash flow northwest of the caldera gives a K-Ar age of $.7 \pm .7$ my (MacLeod et. al, 1975). The upper flanks outside the caldera have been assumed to be mostly basalt but recent mapping by MacLeod in this poorly exposed area suggests that a fair amount of siliceous rock underlies the upper flanks (Norman MacLeod personal communications). The approximate contact between the upper and lower flanks is shown on Plate 1 and is based primarily on the change in slope.

The caldera is located at the center of the shield and occupies 18 or 19 square miles. Within the Newberry caldera lie some of the most recent, and most interesting, volcanic features in the United States (Fig. 3).

Fig. 3. View of the Newberry caldera from Paulina Peak. Paulina Lake is on the left. The large cone between the lakes is the Pumice Cone with the Little Crater Tuff Ring in front of it. The Interlake obsidian flow is behind the Pumice Cone. The Big Obsidian flow is clearly shown.

Newberry Crater was first recognized as a collapsed caldera by Howell Williams (1935) and mapped in detail by Higgins (1967). Details of the complex geology within the caldera and exposed on the inward facing walls are not included in this report. These aspects are covered by Williams (1935) and in greater detail by Higgins (1967). Pleistocene basalts and rhyolites make up the inward facing walls of the caldera. Very little intermediate composition rock is present at the Newberry Volcano. Many other papers on the area are available but will not be cited here.

The location of the caldera margins appears to be controlled by the three regional fault trends and has been interpreted as being formed by a slow tectono-volcanic process unlike nearby Mount Mazama which contains the famous Crater Lake. Inside the caldera there are mafic tuff rings, cinder cones, basalt flows, rhyolitic domes, flows, and pumice cones, all less than 10,000 years old. (Fig. 3). Hydration-rind dates on obsidians within the caldera range from 1350 to 5000 years (Table 1). The youngest date is 1270 years from the most recent pumice eruption.

Outside the caldera there are several features which may be geothermally significant. The most spectacular is the northwest rift zone (Peterson and Groh, 1965, 1969). This rift zone extends from the northeast shore of East Lake (Fig. 4) to Lava Butte, a distance of fourteen miles. At least eight separate Holocene basalt flows occur along the rift (Plate 1). Four of the flows have been dated at close to 6000 years old by radiocarbon methods (Table 1). An unfavorable feature for geothermal exploration in this rift zone is the fact that no siliceous rocks have been noted along it on the lower flanks of the volcano.

On the east and west sides of the volcano rhyolitic domes up to two miles in diameter are present. Three of these domes have been dated at $.58 \pm 0.1$ my, 0.78 ± 0.2 my, and 0.87 ± 0.05 my (Table 1). No dates from the

Fig. 4. View of the East Lake fissure. This crack is the most southeasterly expression of the Northwest rift zone and may be the youngest geological feature in the caldera.

unnamed dome southwest of the caldera have been published. The dates from these domes are young enough to be geothermally significant. Detailed mapping on the upper flanks of the volcano suggests other poorly exposed rhyolitic domes may be present (Norman MacLeod personal communications).

In summary there are four geothermally interesting areas on Newberry Volcano: (1) the caldera; (2) the upper flanks of the volcano by virtue of its Holocene rhyolites and proximity to the caldera; (3) the areas near the rhyolitic domes outside the caldera; and (4) the basaltic northwest rift zone. Of these the caldera is the most promising area and the northwest rift zone the least promising.

TABLE 1

TABLE OF AGE DETERMINATIONS
IN THE NEWBERRY VOLCANO AREA

Dates Outside the CalderaName of Flow

Lava Cascade Flow	5800 $\pm$ 100 years	Radiocarbon	Peterson and Groh (1969)
Gas Line Flow	5800 $\pm$ 150 years	Radiocarbon	Peterson and Groh (1969)
Forest Road Flow	5960 $\pm$ 100 years	Radiocarbon	Peterson and Groh (1969)
Surveyor Flow	6080 $\pm$ 100 years	Radiocarbon	Peterson and Groh (1969)
Lava Cast Forest Flow	6150 $\pm$ 210 years 6380 $\pm$ 130 years	Radiocarbon	Peterson and Groh (1969)
East McKay Butte	.58 my $\pm$.1 my	Potassium-Argon	MacLeod et. al (1975)
China Hat	.78 my $\pm$.2 my	Potassium-Argon	MacLeod et. al (1975)
East Butte	.85 my $\pm$.05 my	Potassium-Argon	MacLeod et. al (1975)
Ash Flow Tuff north- west of Newberry Crater	.7 my $\pm$.7 my	Potassium-Argon	MacLeod et. al (1975)

Dates Inside the Caldera

Pumice Bed	1270 $\pm$ 60 years	Radiocarbon	Peterson and Groh (1969)
Big Obsidian Flow	1350 years	Hydration Rind	Peterson and Groh (1969)
Interlake Obsidian Flow	1700 years	Hydration Rind	Peterson and Groh (1969)
East Lake Obsidian Flow Western	1900 years	Hydration Rind	Peterson and Groh (1969)
East Lake Obsidian Flow Eastern	2600 years	Hydration Rind	Peterson and Groh (1969)
Pumice Cone Crater Obsidian Dome	5000 years	Hydration Rind	Peterson and Groh (1969)

HYDROLOGY

The hydrology of the Newberry Volcano has not yet been studied in detail because there is essentially no water on, or near, the surface. The basalts and cinders, which must comprise about 90% of the volume of Newberry Volcano, are very permeable. This is born out by almost constant lost circulation problems during the gradient-hole drilling. The volcano is forest covered and the upper portions must receive over 50 inches of precipitation a year, most of it as snow, with snowpacks six to ten feet being common. Even though there is a large amount of precipitation, Paulina Creek is the only stream present on the entire 600 square mile volcano. During the gradient-hole drilling water was encountered in only one of seven holes. Clearly a large volume of cold water flows downward at considerable depth through the volcano. This, coupled with the possibility that the regional water table beneath the flanks of the volcano may be over 1000 feet below the surface, (personal communication with Larry Chitwood USFS geologist), means that useful gradient information may not be obtainable within 1000 feet of the surface. There are no artesian wells or springs on the volcano and only in widely separated places on the lower flanks has it been possible to obtain water samples from nonflowing wells and springs. The locations of the analyzed water samples are shown on Plate 1.

Inside the caldera there is a shallow water table near the lakes as evidenced by the lakes and shallow campground wells. There are no springs or streams above the level of the lakes in the caldera so the lakes must be fed by groundwater. East Lake is about 40 feet higher than Paulina Lake so drainage between the lakes is underground.

As may be expected from this discussion the near-surface thermal gradients and geochemical sampling points are more or less controlled by the hydrology.

THERMAL FEATURES

Within the crater there are two groups of hot springs. Both groups are found near the shores of the lakes and are therefore hard to sample. The locations of these springs are shown on Plate 1. The temperature measurements are difficult to obtain due to mixing of thermal and lake waters, and should be regarded as minimum values.

The highest measured temperatures are found in the group of springs at the southeast corner of East Lake (Plate 1). All of these springs discharge directly into the lake bottom or into the gravels of the shore at the level of the lake. Therefore, the water samples collected from these springs are probably not pure thermal water. The maximum temperature measured was 58.8°C (138°F). Mariner et. al (1976) report a temperature of 62°C (144°F) and Peterson et. al (1976) report a maximum temperature of 65.6°C (150°F). It is not possible to estimate the discharge of these springs. Sulfur is the only mineral being deposited by these springs which are rich in hydrogen sulfide. In the vicinity of the hot springs the tuffs show a moderate degree of alteration with some powdery masses of opal and iron staining. Much gas is being discharged from these springs. It has been sampled and the results will be discussed later.

The second group of thermal springs is found along the northeast shore of Paulina Lake (Plate 1). These springs and some associated gas leaks occur over a distance of about one mile and generally discharge directly into the lake. There is no hydrogen sulfide odor. A few springs occur above the level of the lake and are visibly flowing so the sampling is easier than at East Lake. The maximum reported temperature is 57.3°C (135°F) (Peterson et. al 1976). There is a well near the north end of the Little Crater Campground which produces water at a temperature of 35.9°C (96.6°F) when pumped.

There is a considerable amount of travertine-cemented breccia along the east side of the lake. No silica, sulfur, or mercury is associated with these springs and there is no hydrothermal alteration of nearby rocks.

The two groups of springs and the warm well are the only known active thermal features of the entire volcano. The surficial appearance of these springs is quite unimpressive, however the fact that these thermal springs are present at an elevation of 6300 feet (the area surrounding the volcano is about 4300 feet) and are located within the caldera in close association with holocene rhyolites makes them very interesting.

GEOCHEMISTRY

Water Geochemistry

As previously stated, there are few places on the Newberry Volcano where water samples can be collected at the surface and many of these appear stagnant. The deep water table effectively prohibits drilling for water samples. Therefore, only a limited geochemical survey is possible. Nearly every available source of water from the area of interest was sampled during this survey so it will not be possible to improve the results by increasing the number of sample points. The locations of the water samples are shown on Plate 1.

All the water analyses are presented in Table 2 and shown on Fig. 5, a normal piper plot. The data have been broken into four groups, based on temperature and geologic considerations. They are:

- 1) waters from the basaltic terrain outside the caldera
- 2) waters from the alluvial terrain outside the caldera
- 3) nonthermal waters within the caldera
- 4) thermal waters

The waters from the basaltic terrain outside the caldera are all very dilute mixed-cation bicarbonate waters (Figs. 5 and 6) which show no indications of geothermal potential. Two of these samples were collected from wells in alluvium but appear to have originated in the surrounding basalt.

The waters collected from the alluvial terrain to the west of the volcano are similar to the basaltic terrain waters except the sample from the Wickieup Jct. Store which is enriched in sulfate and chloride. These samples are also more saline and greatly enriched in ammonia and nitrates relative to the basaltic terrain waters. The high nitrate and ammonia are a reflection of the wet, swampy nature of this area and have nothing to do with geothermal processes.

The only unique water collected from outside the caldera is the sample from

TABLE 2

TABLE OF WATER ANALYSES

Sample	Location	Date	Temp °C	Cond.	ph Lab	ph Field	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	B	NH ₃	SiO ₂	NO ₃
<u>THERMAL WATERS</u>																	
East Lake Hot Springs#	T21SR13E Sec29		62	396		6.49	38	16	32	3.8	.4	58	184	.93		36	
East Lake Hot Springs	T21SR13E Sec29	10-76	59	953	6.12		86	43	55.0	8.1	3.5	445.	76.5	.80	.750		.44
East Lake Hot Springs	T21SR13E Sec29	11-74	51	810	8.56		45.5	40.0	56.0	10.0	1.00	23.0	452.	0.41	.663	242.	1.96
East Lake Hot Springs	T21SR13E Sec29	10-76	49	871	6.97		79	42	58	8.1	4.2	113	474	.85	.060?		.44
East Lake Hot Springs	T21SR13E Sec29	7-75	41.	609.	8.24	6.6	49.1	23.4	43.5	6.60	0.50	42.0	326.	0.85	.245		0.60
Paulina Hot Springs	T21SR12E Sec26	11-74	52	1170	8.30		23.8	77.5	140.	19.0	7.50	0.82	811.	0.37	.046	219.	1.12
Paulina Hot Springs	T21SR12E Sec26	10-76	49	967*			53				13.	8.23		.50	.126		
Paulina Hot Springs	T21SR12E Sec26	10-76	48	1095*			52				17.	8.23		.25	.100		
Paulina Hot Springs	T21SR12E Sec26	10-76	44	1170			58				6.0	<.41		.50	.500		
Paulina Hot Springs	T21SR12E Sec26	11-74	40	1029	8.30		40.9	55.0	118.	1.35	7.60	4.12	704.	0.52	.146	118.	1.31
Paulina Hot Springs	T21SR12E Sec26	10-76	24	568	7.50		31	32	51	7.5	3.9	10.3	399	.45	.028		.44
Paulina Hot Springs	T21SR12E Sec26	10-76	24				31				3.0	4.12		.25			
Little Crater	T21SR12E Sec36	10-76	36	807*			56				10.0	<.41		.75			
Little Crater	T21SR12E Sec36	7-75	34.	1050.	8.30	6.2	56.5	50.0	95.0	11.0	4.00	0.41	698.	1.49	.265		0.14

USGS Analysis

* diluted 10:1 and corrected

<u>Sample</u>	<u>Location</u>	<u>Date</u>	<u>Temp</u> °C	<u>Cond.</u>	<u>ph</u> <u>Lab</u>	<u>ph</u> <u>Field</u>	<u>Ca</u>	<u>Mg</u>	<u>Na</u>	<u>K</u>	<u>Cl</u>	<u>SO₄</u>	<u>HCO₃</u>	<u>B</u>	<u>NH₃</u>	<u>SiO₃</u>	<u>NO₃</u>
<u>NON THERMAL WATERS</u> <u>WITHIN THE CALDERA</u>																	
Little Crater Well	T21SR12E Sec36	7-75	11.	144.	7.85	7.6	11.9	6.50	8.10	1.20	0.40	1.65	93.2	0.06	.006		0.25
Little Crater Well	T21SR12E Sec36	10-76	7.	448*			32.				4.0	.41		.70	.012		
Little Crater Well	T21SR12E Sec36	10-76	9	301*			20.				3.0	.41		.03			
Cinder Hill Well	T21SR13E Sec29	7-75	11.	82.4	7.60	8.6	5.20	1.70	8.20	0.30	0.20	0.41	51.6	0.03	.004		<0.05
Hot Springs Well	T21SR13E Sec32	7-75	16.	300.	7.89	7.3	23.2	10.7	20.0	3.35	0.30	42.0	121.	0.57	.004		<0.05
East Lake Well	T21SR13E Sec31	7-75	16.	300.	7.88	7.4	22.7	10.0	20.0	3.30	0.30	42.4	119.	0.53	.004		<0.05
Lost Lake	T21SR12E Sec36	7-75	22.	85.0	5.85	7.1	4.00	3.90	4.40	1.30	0.15	29.6	2.23	0.03	.004		0.35
Paulina Lake Well	T21SR12E Sec34	7-75	12.	70.0	7.34	7.5	2.4	2.65	5.50	1.70	0.40	<0.41	41.8	0.03	.005		<0.05
Paulina Lake	T21SR12E Sec26			562*			29.		48.		3.5	.41		.62	.013		
East Lake	T21SR13E Sec29			351*			27		22.		3.0	48.6		.80	.016		
<u>WATERS FROM THE</u> <u>BASALTIC TERRAIN</u> <u>OUTSIDE THE CALDERA</u>																	
Lava Lands Visitor Center Well	T19SR11E Sec24	7-75	11.	94.6	7.60	7.4	3.30	4.20	9.00	1.48	0.90	<0.41	58.7	0.04	.005		0.53
Swamp Well	T20SR13E Sec 7	7-75	23.	22.4	6.25	6.9	1.00	1.75	<0.50	1.70	0.25	2.47	10.8	0.02	.0195		0.78

Sample	Location	Date	Temp °C	Cond.	ph Lab	ph Field	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	B	NH ₃	SiO ₃	NO ₃
Evans Well	T20SR14E Sec10	7-75	15.	212.	7.39	8.3	9.30	7.10	22.0	3.28	5.00	1.23	110.	0.11	.005		1.16
Prairie Well	T21SR11E Sec28	7-75	16.	96.5	7.45	7.9	3.30	4.40	8.20	1.60	0.75	<0.41	59.8	0.04	.004		<0.05
China Hat Project Camp	T22SR14E Sec22	7-75	15.	71.0	7.55	7.6	4.45	2.35	5.60	1.48	0.25	1.23	42.4	0.02	.004		0.07
Spring Butte Well	T23SR11E Sec25	7-75	13.	88.6	7.20	6.9	6.50	2.90	6.00	2.98	0.65	<0.41	53.6	0.02	.005		0.67
Jones Well	T23SR12E Sec17	7-75	13.	91.0	7.40	7.0	7.87	2.10	5.00	2.42	0.70	<0.41	54.2	0.03	.005		0.53
Indian Springs Camp	T23SR13E Sec28	7-75	10.	138.0	7.45	6.7	14.0	3.70	9.00	3.75	1.90	1.23	78.5	0.05	.055		0.53
Unnamed Well	T24SR11E Sec 4	7-75	16.	150.	7.30	6.8	77.40	6.50	11.2	5.37	5.00	2.06	80.0	0.08	.027		4.24
Drill Hole #6	T21SR13E Sec15			1417	8.10		150	35.0	150	14.0	11.5	637	148	.52	.020	120	1.49
Paulina Cr	T21SR11E Sec28	7-75	16.	622.	8.55	8.7	27.8	38.2	50.5	5.32	1.80	<0.41	393.	0.80	.005		0.28
Paulina Cr	T21SR11E Sec35	7-75	16.	631.	8.50	8.8	27.8	37.0	47.5	5.35	1.80	2.47	388	0.79	.005		<0.05
Paulina Cr	T21SR11E Sec34	7-75	16.	626.	8.33	8.5	28.2	36.0	47.8	5.40	1.80	0.82	399.	0.83	.005		0.21
<u>ALLUVIAL WATERS</u>																	
Land of Lakes Well	T21SR11E Sec18	7-75	19.	517.	7.95	7.6	24.5	22.0	45.5	3.35	2.00	<0.41	303.	0.56	2.200		8.68
Wickieup Jct. Store Well	T21SR10E Sec36	7-75	19.	336.	7.50	6.7	17.2	13.4	20.0	5.55	20.0	15.2	69.3	0.11	.007		45.4
Lapine Texaco Sta. Well	T22SR10E Sec14	7-75	17.	582.	8.00	7.4	24.8	21.2	58.0	4.45	1.30	<0.41	339.	0.08	18.50		14.6

FIGURE 5. Piper plot.

drill hole NC-6. This sample will be discussed later.

Within the caldera the geochemistry becomes much more interesting and the interpretation much more ambiguous. Both the thermal and nonthermal waters show large chemical variations (Fig. 5). The previously discussed sampling difficulties of the thermal springs (page 10) are partly responsible for this variation.

For example, the Paulina Hot Springs have variable temperatures and compositions. A graph of several elements verses temperature (Fig. 7) shows a clear trend which proves near surface or even surface mixing between the thermal and lake waters. Other elements do not show this trend and may reflect other complexities such as precipitation, loss of volatiles, or chemical changes between the time of sampling and analysis.

It may not be possible to collect an undiluted sample of thermal water from the Paulina Hot Springs. For this reason only an estimate of the composition can be made. Extrapolation from Figs. 5 and 6, makes it seem likely that the thermal water before dilution at 100°C would have a salinity of about 40 meq/l and have a Na + K reaction value of around 18 or 20. The anion ratios show no significant variation with temperature. Also it could have up to 1 or 1.5 ppm ammonia. Ammonia values this high in a totally igneous environment would be definitely anomalous. There is then a question as to whether this ammonia reflects steam leakage at depth or whether the thermal water contains this amount of ammonia without being enriched by steam leakage. As of now there is no answer to this question.

The analyses of thermal waters from the East Lake Hot Springs show a very large variation in anion ratios and salinity while the cation ratios remain quite constant. The chloride contents are always less than 5 ppm so the variation is due to large changes in the sulfate and bicarbonate contents. The chemical variation shows no simple relationship with temperature as would be

FIGURE 7. Graph of temperature versus several elements for Pauline Lake thermal waters.

expected if near surface mixing of thermal and lake water was a large factor in controlling the composition as at the Paulina Hot Springs (Fig. 5). All of the samples collected from the East Lake Hot Springs were collected in a very small area at the lakeshore so the chemical variation is not due to sampling widely separated springs.

Possibly the great variation between the 59°C sample and the others is due to the fact this sample was very murky when collected while the others were clear. The spring needs to be resampled to see if this analysis is reproducible.

It is interesting to note that the 59°C sample appears very similar to the cold sample collected from drillhole #6 located high on the lower east flank of the shield. This sample is the most saline water which has been found and which doesn't crop out at the surface. Whether it originates within or outside the caldera is not known. It appears to be low in ammonia. However, the ammonia analysis was not carried out in the field.

Based on these two analyses it is possible to propose a model whereby the saline cold sulfate water is present beneath the eastern part of the caldera and is heated and diluted by steam so that the 59°C sample from the East Lake Hot Spring is located very close to a line between the drillhole #6 water and pure water, i.e. steam condensate (Fig. 6). This model is based on extremely limited and possibly questionable data.

The water sample from Lost Lake is also a high-sulfate water but this is partly due the very dilute nature of the water. This lake also discharges some gas which is mostly CO₂ (Table 3). The origin of the sulfate in this sample is not known.

The other samples (62°C, 49°C, 41°C, and 51°C) from the East Lake Hot Springs, especially the 62°C USGS sample, are basically similar to the groundwater under nearby campgrounds (Fig. 5). The thermal waters are clearly

enriched in ammonia and gases and have a lower pH. These analyses probably represent a mixing of thermal and cold groundwaters in the eastern part of the caldera.

In summary the chemical results are ambiguous and can probably be interpreted in different ways. However, in a general way a background water low in volatiles has been defined. Superimposed on this background there are thermal waters clearly enriched in volatiles such as ammonia and gases. The chloride contents of the thermal waters are also very low. These features are indicative of, but do not prove, the existence of steam leakage in the area.

Isotope Geochemistry

It is well known that the isotopic composition of meteoric waters is controlled by such factors as distance from the ocean, latitude, elevation, and a host of less important factors (White 1973). It is also well documented that nearly all thermal waters have isotopic compositions which can be related to nearby meteoric waters. As a rule deuterium contents of thermal waters are similar to those of local surface waters. The thermal waters are normally enriched in O^{18} relative to local meteoric waters because of subsurface exchange reactions with rocks at elevated temperatures.

Mariner et. al (1975) have published isotope analyses of many of Oregon's thermal springs. The data suggests that distance from the ocean is the dominant control of the isotopic composition of Oregon thermal waters (Figure 8). This suggests that most Oregon thermal waters are predominantly meteoric in origin.

The isotopic composition of the East Lake hot springs clearly does not fit the distance trend. For its distance from the ocean it is highly enriched in deuterium and moderately enriched in O^{18} . Unfortunately, no isotopic background from meteoric waters in the area has been published. Without the background data it is impossible to prove or disprove possible origins for this thermal water. As a point of interest, White (1973) has shown that Wilbur Hot Springs in California contains nonmeteoric water. Wilbur Springs is also highly enriched in deuterium and O^{18} when compared to its distance from the ocean.

In summary the very limited isotope data may be suggesting that a non-meteoritic component is present in thermal water from the East Lake hot springs. More isotopic work is needed to prove or disprove this hypothesis but with the current land status situation additional study will probably be academic in value.

FIGURE 8. Isotopic compositions of Oregon thermal waters. The numbers are the distance from the ocean in miles for each thermal spring.

Gas Geochemistry

Gases have been collected from several areas in the caldera but due to laboratory problems some analyses have not been completed. All the available gas data is shown on Table 3. For comparative purposes gas analyses from two producing geothermal fields are shown as well as an analysis from an area in Nevada with low potential.

All the analyses show carbon dioxide to be the most abundant component. Gas analyses from the Geysers and Wairakei have hydrogen-to-methane ratios near one while the ratios for Hyder and Newberry are much less than one. More gas work needs to be done at the Newberry caldera as there is very poor agreement between Phillips R & D lab and the USGS lab. Gases from East Lake Hot Springs and the Paulina Hot Springs need to be resampled at a convenient time.

At the present time it is not possible to interpret these gas compositions with any certainty.

TABLE 3
GAS ANALYSES

Location	Lost Lake Newberry Caldera	East Lake Newberry Caldera	East Lake Newberry Caldera	The Geysers California	Wairakei New Zealand	Hyder Nevada
Lab	Phillips R&D	Phillips R&D	U.S.G.S.	Literature	Literature	Phillips R&D
Geothermal Potential	?	?	?	high	high	low
CO ₂	97.15	90.42	56	62.45	91.34	96.82
N ₂	1.19	5.76	30	3.45	3.76	2.55
O ₂	n.d.	n.d.	6	0	—	0.36
Ar	.04	.15		—	—	.12
CH ₄	1.61	3.64	9	15.9	1.08	.41
H ₂	.006	.009	n.d.	16.65	1.25	.0001
He	.001	.004	n.d.	—	—	.0333
C ₂ H ₆	.006	.004				
H ₂ S				1.60	1.73	
NH ₃					.83	

GEOPHYSICS

Gradient Hole Results

During August, September, and October 1975, Hines Drilling Company drilled six gradient holes for Phillips. The holes ranged from 40 feet to 218 feet in depth. Due to the high cost of drilling (about \$17.00 per foot) and the poor results obtained from the holes only about 1/3 of the planned holes were drilled, with most of these being much shallower than intended. Several other holes in the area were drilled by the Oregon Department of Geology and Mineral Industries (DOGAMI) in 1976. These holes have been probed and are included in the results (Table 4 and Plate 1). Due to the shortage of usable data no temperature-gradient map or isothermal maps are included in this report. No other available holes deep enough to provide useful information are known to be present in the area. All of the Phillips holes showed either reverse gradients or were isothermal. These holes were dry with the exception of NC#6 and were drilled in basalts and basaltic cinders. It was these basalts and interbedded cinders which made the drilling very difficult and expensive. Caving and lost circulation were the two major drilling problems. The 118-foot-deep DOGAMI hole at McKay Butte is the only hole in the area that appears to show a positive gradient. This hole shows a gradient of 3 to 5°F/100' between 80 and 118 feet.

A further problem with shallow gradient holes is the presence of ice caves on the lower flanks of the volcano. In addition to cold water flowing through the permeable basalt cold air also appears to be flowing downward and outward through the volcano.

Perhaps gradient holes located in the caldera could provide useful information within a few hundred feet of the surface but drilling within the crater is currently prohibited and would also be difficult and expensive.

In short, for hydrological reasons, shallow gradient hole drilling on the flanks of the Newberry Volcano does not provide useful information.

TABLE 4
TEMPERATURE GRADIENT HOLE RESULTS

Hole #	Location	Depth	Temp at 100'		Temp at 200'	
			°F	°C	°F	°C
1	T19S R12E C30	218'	43.9	6.6	42.5	5.85
2	T19S R12E C25	190'	43.2	6.2	43.2*	6.2 *
3	T20S R13E C17	60'	—	—	—	—
4	—	—	—	—	—	—
5	T21S R13E C6	105'	38.5	3.6	—	—
6	T21S R13E SESE 15	200'	38.5	3.6	38.5	3.6
7	T21S R14E CNW 32	137'	41.5	5.3	—	—
DOGAMI 1	T21S R11E NWNW 25	118'	45.7	7.6	—	—
DOGAMI 2	T22S R14E C3	250'	41.4	5.2	41.5	5.25

* projected

Telluric-Magnetotelluric Survey

Between September 23th and October 12, 1975, a 47-station magnetotelluric survey was run for Phillips by Senturion Sciences (Senturion 1976). The survey was conducted as a telluric-magnetotelluric survey with only one magnetometer at a base station. The details of data acquisition and handling are in the Senturion report. The results of this survey, as interpreted by Senturion, are:

- 1) There is a major structural depression, the North Paulina low, which is centered about three miles north-northeast of East Lake. The electrical basement at the center of this anomaly lies about 3.5 kilometers below the surface.
- 2) The topographic caldera and the North Paulina low are surrounded by a ring-shaped system of high-resistivity material that is interpreted to be a series of intrusives. These intrusives may come within 500 to 1000 meters of the surface.
- 3) There are two main areas of high conductivity, the Pumice Butte Anomaly and the Southwest Paulina Lake Anomaly. These are 1500 to 4500 foot thick (.5 to 1.5 km) zones of 1-10 ohm-meter material and overlie the "electrically mapped" intrusives.

Senturion suggests that where these highly conductive areas overlie the "intrusives" a geothermal system may be present.

This interpretation makes for interesting reading but it is based on misleading data and bears no resemblance to the geology in the area.

The North Paulina low has been drawn on the total conductance map (Plate 2). No explanation was given as to what constitutes electrical basement in this area. Senturion states "The basement complex, where a reliable estimate could be made of its resistivity appears to have resistivities on the order of 2000-5000 ohm-meters". With these very high resistivities the basement must be solid dry rock. It appears that the Senturion survey has not detected any magma below the volcano. The North Paulina low does not correlate well with the surface ex-

pression of the caldera. Senturion suggests that the center of the collapsed zone shifts with depth. If this were true the center of the collapsed zone would shift about 6000 meters NNE while dropping about 3500 meters. This means the collapsed zone would be inclined at an angle of about 30° . This is not possible. The collapsed zone should be near vertical. Until the factors defining the electrical basement are known it is not possible to further interpret this data.

By computer contouring a vector gradient map of the contoured depth to electrical basement Senturion manages to produce a large ring-shaped structure of what are interpreted to be a series of intrusives. These intrusives are interpreted to be at depths from 1500 to 3000 feet (500 to 1000 meters) below the surface. Senturion's vector gradient map is highly misleading. Much of the structure shown is based on highly questionable and unsubstantiated contouring between data points. When the map is redrawn to fit the data much of the ring structure disappears. The "structures" on the corrected vector gradient map show little or no relationship to the known geology. It is likely that the entire vector gradient map is meaningless and therefore it is not included in this report.

Senturion did find several areas of high total conductance. With the exception of one site (station 2) these are all outside the caldera. These areas are interpreted to be generally shallow and vary from about 1500 to 4500 feet (500 to 1500 meters) thick.

Two of the anomalies have been closed. These are the Southwest Paulina Anomaly and the Pumice Butte Anomaly (Plate 2). To the north of the caldera there are three sites with very high conductivity. These appear to be representing three different anomalies. It seems that highly conductive areas are quite common on the lower flanks of the volcano. The cause of the three northern anomalies is not known but there is no other corroborating evidence to

suggest they are geothermally related.

Three of the data points defining the Southwest Paulina Anomaly are located on welded tuff. This welded tuff could be in large part responsible for the high conductivities. If this is true, the Southwest Paulina Anomaly becomes much smaller with most of its area effectively withdrawn from exploration (Plate 5).

The Pumice Butte Anomaly is located between China Hat and the upper flanks of the volcano. The geology in this gently sloping area is covered by several feet of very recent air-fall ash and pumice lapilli deposits which were ejected from within the Newberry Caldera (Higgins, 1969). Therefore the geology in this area is poorly known. The cause of the high conductivity is also unknown. It may be the result of a buried rhyolitic dome or a relatively high, moderately saline water table (see the water analysis from NG#6 Table 2). It is unlikely that this anomaly, or any of the others, is due to a viable geothermal heat source. Both gradient holes in this anomaly (Plate 1, Table 4) are cold and show no gradient to depths of 137 feet and 250 feet. Also there are no surface indications of near surface heat such as fumaroles, hot springs, alteration, or mineralization, in the vicinity of any of the conductive anomalies.

Seismic Groundnoise Survey

Between July 17th and August 4, 1975, Senturion Sciences ran a 43-station seismic groundnoise survey for Phillips (Senturion, 1975). The details of data acquisition and handling are included in Senturion's report and will not be repeated here. The data quality is considered good by Senturion with no major continuous cultural influences. Predominant power peaking was notably absent.

Four single-station groundnoise anomalies were detected (Plate 1). All the anomalies are found outside the caldera. Three are found near the contact between the upper more siliceous flanks and the lower basaltic flanks. The fourth anomaly is found along the northwest rift.

Alternatively, three of the anomalies can be viewed as lying along the northwest rift and a possible southeastly extension. In this case it is possible that two of the anomalies occur at the intersection of this rift with the contact between the upper and lower flanks of the volcano. No microearthquake events were detected during this survey.

Only one of the groundnoise anomalies occurs in the same area as the telluric-magnetotelluric conductive anomalies.

These results seem to indicate that the upper flanks of the volcano and the northwest rift zone offer the most potential from a groundnoise point of view.

Gravity Survey

A simple Bouguer gravity map has been prepared by Phillips personnel and is shown on Plate 3. Without additional corrections this map is meaningless. It shows a near perfect correlation with elevation which must mask other features. The lack of complete corrections is in part due to incomplete topographic coverage.

A more complete map covering a much larger area should be available in 1977 from Dr. Richard Couch of Oregon State University.

Magnetic Survey

A ground magnetic survey has been carried out by Phillips personnel and the computer contoured results are shown on Plate 4. The dominant features on the map are the abundant one-point anomalies of moderate-to-high relief. In volcanic terrains where basalts are abundant this is a normal pattern and such patterns are difficult to interpret or extrapolate to depth.

On a larger scale the magnetic map correlates fairly well with the geologic map. Many surface lineaments have magnetic expression. In general the magnetic trends correspond to the three main structural directions.

The ground magnetics in this area are of no help in deciphering subsurface targets. This is due to the complex geology and the wide spacing between data points.

LAND STATUS

Phillips has no land position in the Newberry area. In the area of interest there are only $1\frac{3}{4}$ sections of private land, which is all owned by Leonard Lundgren of Bend, Oregon. All of the rest of the area is managed by the Forest Service (Plate 5). All of the land within the caldera, and much of the upper flanks of the volcano, have been classified as a KGRA by the U.S.G.S. Outside of the KGRA only a few scattered sections which probably have little potential remain open. No date has yet been set for a sale of the KGRA lands and it will be years before a sale is held, if ever.

The Oregon Energy Facility Siting Council, on orders from the state legislature, has ruled that all the land within the caldera and most of the upper flanks are unsuitable for thermal power plant siting. The boundaries of this area are shown on Plate 5. This action by itself does not rule out exploration within the area, however, the Forest Service is not allowing gradient hole drilling or other ground disturbing work in the area. The Lava Cast Forest, located along part of the northwest rift zone is under similar restrictions. Information from the Energy Facility Siting Coordinator, W. Kelly Woods, is that the Newberry Crater area and the Lava Cast Forest designation are rather unassailable. The area outside the crater is currently withdrawn, however, it may be possibly changed. Making this land available for exploration and production would require much work, including public hearings before the Energy Facility Siting Council and the Forest Service. This would be a long and costly process.

There are only two areas where it is now possible to disturb the ground on the upper flanks of the volcano near the caldera margins. This is where the road enters the caldera at Paulina Lake and where the road leaves the caldera southeast of East Lake. Both areas are part of the KGRA.

CONCLUSIONS

The available information for this area suggests that the geothermal potential is highest within the caldera, with the eastern two thirds of the caldera containing the highest potential. This is based on the caldera geology, geochemistry, and location of hot springs. The presence of Holocene rhyolites in the caldera suggests there is an excellent possibility of a high level siliceous magma chamber(s) existing beneath the floor or margins of the caldera.

For similar reasons the upper flanks of the volcano may be promising. The Big Obsidian flow and Interlake Obsidian flows originate very near the margins of the caldera. Due to the shortage of roads in this area only very limited geophysical information has been accumulated on this part of the volcano. Due to the hydrology no geochemical information is available. Proximity to the caldera margins would be desirable if a test were located here.

The other siliceous domes in the area, McKay Butte, China Hat and East Butte, are young enough to be geothermally interesting. The problem with these areas is that there are no indications of present day heat associated with these domes. The shallow gradient holes are cold and no hot springs or recent alteration has been noted. Two conductive anomalies of questionable origin may be associated with these domes. In fairness to these areas, however, it needs to be pointed out that the focus of exploration to date has been near the caldera.

The last interesting area on the volcano is the northwest rift zone. There was much basaltic volcanism along this zone about 6000 years ago. It offers a clearly defined target but the lack of any rhyolitic material and indications of heat are major problems. Also much of this zone has been removed from exploration by the State of Oregon.

Based on the information available, most of it being geologic in nature, it is felt that the Newberry Caldera has the highest geothermal potential in Oregon. However, political decisions by the Oregon Energy Facility Siting Council and Forest Service and U.S.G.S. have effectively made it impossible to drill in the most promising areas. Any of these political obstacles can be removed but it will be many years before they are removed and deep drilling permitted within or near the caldera.

RECOMMENDATIONS

In the Newberry area geologic and hydrologic conditions combine to make many of the current exploration tools impossible to use. Shallow gradient-hole drilling and water geochemistry are particularly limited. Electrical methods will provide ambiguous results which will have to be tested by deep drilling. Groundnoise and microearthquake studies do not appear to be promising. Magnetic data will be impossible to interpret so as to provide new information. Detailed gravity data should be available in 1977.

It is felt that the best way to adequately evaluate the Newberry area is to drill deep tests within the caldera. This is a risky strategy and should be recognized as such. However, it is probably the only strategy that will prove effective and will need to be done irrespective of geophysical and geochemical results. It is expected that drilling in this area will be difficult and expensive.

At the present time political problems are much greater than geological problems. It seems best to keep expenditures in this area to a minimum until the political climate improves. If additional data from outside sources becomes available it should be assimilated.

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Table 2.—Major element composition of thermal springs and wells sampled in Nevada and Oregon after May, 1974
[Concentrations in milligrams per litre]

Spring name and identification number	Temperature (°C)	pH	Specific conductance	Silica (SiO ₂)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Alkalinity (as HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Boron (B)
Churchill County, Nevada														
4 Shallow research well (Soda Lake)	100	7.84	5,110	150	82	2.1	1,000	48	1.4	144	360	1,500	0.6	5.7
5 Shallow research well (Soda Lake)	22	9.20	978	6.8	25	4.5	180	8.2	0.05	134	210	110	.2	0.35
Elko County, Nevada														
6a Unnamed hot spring near Wells ^{1/}	50	7.0	1,760	84	49	13	390	41	.7	1,120	18	40	7.2	.77
4b Unnamed hot spring near Wells	34	6.30	1,740	76	51	13	340	36	.63	1,150	29	34	7.0	.80
6c Unnamed hot spring near Wells	60	6.58	1,730	110	78	34	300	30	.73	1,210	24	26	6.1	.77
7b Unnamed hot spring near Wells	55	6.60	1,820	86	48	13	370	44	.72	1,230	12	37	7.4	.73
10 Hot Sulphur Springs ^{1/}	90	7.3	733	143	12	.3	160	36	.8	343	61	22	10	1.2
Eron County, Nevada														
1b Vahaska Hot Springs	94	8.04	1,610	110	39	0.1	300	14	.25	74	620	35	6.2	10
3 Unnamed hot spring near Fernley	84	7.05	3,350	130	70	1.5	620	38	1.6	100	400	820	4.2	5.6
Humboldt County, Nevada														
5 Beaver's Hot Spring	46	9.34	243	47	2.9	0.2	50	0.6	.09	76	38	6.3	2.8	.20
White Pine County, Nevada														
1 Unnamed hot spring (Cherry Creek)	61	7.77	692	105	12	.3	150	4.8	.45	380	1	14	1.2	.35
2 Monte Neva	79	6.33	322	32	63	21	16	5.6	.07	303	26	5.0	1.0	.04
Deschutes County, Oregon														
1 East Lake Hot Springs	62	6.49	396	36	38	16	32	3.8	.01	184	58	0.4	0.2	.93
	62	6.49	396	36	38	16	32	3.8	.01	184	58	.4	.2	.93
Lane County, Oregon														
3 McGredie Springs	73	7.29	6,730	79	440	.9	1,000	22	1.4	21	240	2,200	2.7	14
Malheur County, Oregon														
8 Vale Hot Spring	73	7.47	1,530	130	.19	.8	110	14	.28	143	100	360	6.1	9.4

^{1/} Chemical analyses and temperature reversed in original report (Mariner and others, 1974a).

R 11 E

R 12 E

R 13 E

R 14 E

PLATE 2

TELLURIC SURVEY

PHILLIPS PETROLEUM COMPANY

AREA: NEWBERRY CRATER

COUNTY: DESCHUTES
STATE: OREGON

TOTAL CONDUCTANCE (Mhos)

DATES OF ACQUISITION: SEPT. 23 - OCT. 12, 1975

CONTOUR INTERVAL: 20

SENTURION SCIENCES, INC.

TULSA, U.S.A.

PLATE 2

NOTE: DASHED CONTOURS DESIGNATE ESTIMATED
DEPTH TO ELECTRICAL BASEMENT FOR THE NORTH
PAULINA LOW.

R10E

R16E

R12E

T18N

R13E

T18N

R14E

T18N

T19N

T19N

T20N

T20N

T21N

T21N

T22N

T22N

T23N

T23N

T24N

T24N

T25N

T25N

DESCHUTES CO. OR
KLAMATH CO. ORDESCHUTES CO. OR
KLAMATH CO. ORDESCHUTES CO. OR
KLAMATH CO. OR

T26N

T26N

T27N

T27N

R10E

R16E

T18N

R12E

T18N

R13E

T18N

R14E

T18N

PLATE 4

PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA
NATURAL RESOURCES GROUP
ENERGY MINERALS DIVISION

GROUND MAGNETICS

NEWBERRY CRATER GEOTHERMAL PROSPECT
Deschutes, Klamath, and Lake Counties, Oregon
NOV. 1975

SCALE 1:62,500

CONTOUR INTERVAL = 100 GAMMAS

CONTOUR INTERVAL = 100 GAMMAS