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Portland Oregon 97201

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THE COW HOLLOW GEOTHERMAL ANOMALY, MALHEUR COUNTY, OREGON

R. G. Bowen* and D. D. Blackwell**

During the past four years, the Oregon Department of Geology and Mineral Industries has been conducting a regional study, sponsored by the U.S. Bureau of Mines with grant No. S0122129, on the geothermal potential of eastern Oregon. In the course of the study, an area of anomalously high heat flow was discovered a few miles southeast of Vale, Malheur County, in an area known locally as Cow Hollow (see Figure 1, p. 116-117). The anomaly, which covers an area at least 6 miles by 3 miles, gives heat-flow values ranging from slightly greater to more than three times greater than normal for this region.

In 1973, Bowen and Blackwell (Ore Bin, 1973) reported geothermal gradient and heat-flow values for the Cow Hollow area (at that time referred to as the Chalk Butte area). In 1974, when Federal lands in Oregon were opened for geothermal leasing and multiple filings were made in Cow Hollow, the area, which is entirely under Federal ownership, was established as a Known Geothermal Resource Area (KGRA). A sale of geothermal leases in Cow Hollow has been scheduled by the U.S. Bureau of Land Management for September 25, 1975.

Since publication of the early geothermal information on Cow Hollow, The Oregon Department of Geology and Mineral Industries has gathered additional geological and geophysical data for the area, has drilled 24 shallow (3 to 4 meter) temperature holes, and has published results (Hull, 1975) on a deeper drilling in the area. This summary of the geologic interpretations and geophysical data is published as a preliminary report in order to make the information available for those working to develop the geothermal resources of the area. A future report (Blackwell and Bowen, in prep.) will describe in more detail the heat flow and shallow temperature data together with the geological and geophysical information.

Although the authors accept responsibility for the geologic concepts outlined in this paper, they wish to acknowledge the help given them by Department staff, including V. C. Newton, R. E. Corcoran, Alan Preissler, Deborah Fisher, and Donald Hull.

* Consulting Geologist, Portland, Oregon
**Associate Professor of Geology, Southern Methodist Univ., Dallas, Texas

Previous Geologic and Geophysical Studies

A geologic map and report on the Mitchell Butte quadrangle, which includes the Cow Hollow area, was prepared by Corcoran and others (1962). A report by Newton and Corcoran (1963) on the western Snake River Basin details the subsurface conditions in the region. A geologic map by Kittleman and others (1967) covers the Owyhee Region south and west of the Cow Hollow area. A reconnaissance surface magnetic map of the area has been prepared by Brott and Blackwell (SMU, unpublished data), and gravity and magnetic maps have been prepared by K. H. Koenen, consulting geophysicist, Portland.

Geology

Stratigraphy

The Cow Hollow area (see Figure 1) lies in the northeastern part of the Mitchell Butte 30' quadrangle and southern parts of the Jamieson and Moores Hollow quadrangles. The area is underlain by a thick sequence of late Tertiary continental sedimentary and volcanic rocks. Quaternary alluvium and terrace gravels mask the Tertiary units in the valleys of the Snake River, Malheur River, and Willow Creek. The youngest Tertiary rocks belong to the Idaho Group of Pliocene age. Originally described as one unit by Cope (1883), the Idaho Group has been divided by Corcoran and others (1962) into three formations: two lacustrine units, the Chalk Butte and the Kern Basin Formations, separated by the Grassy Mountain Basalt.

The Chalk Butte Formation, the uppermost member of the Idaho Group, is composed of tuffaceous claystone and siltstone with lesser amounts of tuff, conglomerate, ash beds, and fresh-water limestone. Thickness of the formation, estimated from well data to the east and west, ranges from 2,500 to 3,500 feet. The Grassy Mountain Basalt, which underlies the Chalk Butte Formation, is reported by Corcoran and others (1962) to be 500 to 1,000 feet thick. Beneath the Grassy Mountain Basalt is the Kern Basin Formation composed of tuffaceous claystone, siltstone, sandstone, and, less commonly conglomerate. The Kern Basin Formation is not exposed in the area, but at its type locality, about 20 miles to the south, it is 750 feet thick.

Underlying the Kern Basin Formation, with apparent unconformity, is the Deer Butte Formation of late Miocene age. The Deer Butte is composed chiefly of lacustrine and fluviatile tuffaceous siltstone and shale but also includes prominent beds of well-cemented conglomerate and sandstone. Measured sections of the Deer Butte Formation elsewhere in the Mitchell Butte quadrangle have a maximum thickness of 1,248 feet.

The Owyhee Basalt, which underlies the Deer Butte sediments, is a very widespread and prominent section consisting of basalt flows and interbedded tuff. It is middle Miocene in age and can be traced southwestward to the Steens Basalt and northwestward to the Columbia River Basalt.

Under the Owyhee Basalt is the Sucker Creek Formation, named by Corcoran and others, 1962. It crops out extensively in the southern part of the Mitchell Butte quadrangle, where it consists mostly of tuffaceous sediments with interbedded rhyolitic and felsitic volcanics in the upper part and basalt flows in the lower part.

Intrusions and associated flows of Tertiary-Quaternary age occupy small areas in the southwestern part of the map area.

Structural geology

Regionally, the structural position of the area is on the west limb of the western Snake River Basin, which is a part of the Snake River downwarp, a large structural trough extending from Yellowstone Park across southern Idaho and into eastern Oregon. The Idaho part of the western Snake River Basin appears to be a large graben, as high-angle faults parallel the general trend of the basin along its northeastern and southwestern edges (Hill, 1963). The bounding faults mapped in Idaho have not been identified in Oregon, however. Corcoran and others (1962) show no faults or structures except the regional northeasterly dip in the Cow Hollow area.

From the data gathered as a part of this study, the authors interpret a major northwest-trending fault zone transecting the Cow Hollow area and believe the geothermal manifestation and high heat-flow anomaly reflect leakage along this fault. The magnetic and gravity mapping appear to corroborate this thesis. The authors have named this the Willow Creek fault after the Willow Creek valley northwest of Vale. Evidence for the Willow Creek fault is mainly from physiographic expression and geophysical measurements. Displacement of lithologic units has not been found and amount of throw has not been determined. The strongest physiographic expression of the fault is the lineament formed by Willow Creek valley extending for 30 miles in a nearly straight line to the northwest of Vale. Southeast of Vale the trend continues but is less conspicuous. The presence of Vale Hot Spring on the fault, several reported warm-water wells in the Willow Creek area, and the high heat flow to the southeast along the zone are additional evidence for the fault.

Lawrence (in press) describes a series of right lateral tear fault zones, one of which he calls the Vale Zone. This zone, consisting of several linear segments, includes Willow Creek and portions of the Snake River in Idaho. The Vale Zone includes what we have called the Willow Creek fault in this paper.

A parallel fault zone, named the Bully Creek fault, lies about 6 miles to the west. Physiographic evidence is similar to the Willow Creek fault but the trends are not as prominent. To the north, Owyhee Basalt has been uplifted on the west side of the Bully Creek fault trend, indicating that the area between the Willow Creek and Bully Creek faults is a graben. Electric logs from the Sta-Tex "Russell well" east of the Bully Creek fault and from the El Paso "Federal well" west of the fault indicate the western block is uplifted, corroborating the interpretation of a graben between the two faults.

A third fault, appproximately perpendicular to the Willow Creek fault, here called the Malheur River fault, is believed to parallel the course of the Malheur River northeast of Vale. Its existence is interpreted largely from geophysical mapping by Koenen, but there is also a strong physiographic expression of a fault at this location. Vale Hot Spring appears to be located on the intersection of the Willow Creek and the Malheur River faults. Rinehart Butte and Vale Butte, situated just east of Vale, are believed by the authors to represent silicified remnants of hot springs that have maintained their topographic expression through resistance to erosion. Corcoran and others (1962) believe the two buttes represent topographic highs in the pre-Idaho terrain and that sediments of the Idaho Group were deposited around these ancient highs.

Geophysical evidence for the Willow Creek fault comes from a ground magnetic profile made in 1973 (Brott and Blackwell, SMU, unpublished data). This information shows a magnetic high along the eastern side of the fault zone to the southeast of Vale. Gravity and magnetic data of the Vale KGRA by Koenen are included on Figure 1. These patterns show strong northwest trends with gravity and magnetic highs on the east side of the zone, consistent with the northwest fault trends as proposed here for the Bully Creek and Willow Creek fault zones. The accompanying cross section (Figure 2) shows this relationship. Koenen (oral communication, 1975) believes the gravity and magnetic maps indicate a series of intrusives along a northwest-trending fault zone.

Geothermal Systems

Heat-flow information

Measuring variations in the rate of heat escaping from within the earth and flowing toward the surface is one of the best methods of prospecting for geothermal resources, and it was the method used for this study. Other geophysical methods, such as electrical and seismic, provide indirect evidence of conditions related to geothermal energy accumulation and help to support the heat-flow data. Detailed information on the mechanics of heat-flow acquisition and reduction is given by Roy and others (1968).

High heat flow always indicates the presence of a geothermal accumulation, but temperature, depth, or size of the accumulation must be obtained by other exploration tools. A high-level anomaly may prove to be only warm geothermal waters at a relatively shallow depth, whereas a lower-level anomaly may represent fluids of very high temperature at greater depths. Although other geophysical and geochemical methods in conjunction with geologic investigations can be used for depth estimates along with the heat-flow data, it is necessary to sample formation fluids by drilling in order to determine reservoir characteristics.

Basically, heat flow is the product of the geothermal gradient (rate of increase of temperature with depth) and the conductivity of the rocks (rate of passage of heat through the rocks). Units used in heat-flow measurements are microcalories per Cm^2 per second and are commonly referred to as HFU's (Heat Flow Units). Worldwide average heat flow of continental areas is about 1.4 HFU. In areas of Tertiary volcanic rocks, such as eastern Oregon and Idaho, average heat flow is closer to 2 HFU (Blackwell, 1969).

The map, Figure 1, shows some of the heat-flow values in the western Snake River Basin gathered as a part of this study as well as data previously published (Bowen, 1972; Bowen and Blackwell, in Ore Bin, 1973), including five recently drilled holes (Hull, 1975), with additional unpublished geothermal data. The Cow Hollow anomaly is represented by the concentration of data along the Willow Creek fault where gradients range from 76° to 214°C/km and heat-flow values from 2.3 to 6.4 HFU. All of the bore holes, which range in depth from 65 to 395 meters, are in the Chalk Butte Formation. One of the new drill holes, about 1 mile east of the highest heat-flow value, has a heat flow of only 2.3 HFU. Thus the geothermal anomaly appears to be elongated in a northwest direction and is asymmetric, with the sharpest drop in heat flow to the east. The anomaly also appears to be related to leakage along the Willow Creek fault, and suggests that the fault dips to the west, consistent with a down-to-the-west normal fault.

The heat-flow values on the remainder of the map range from 1.9 to 4.6 but the data are too sparse for any conclusions about the presence or absence of other anomalies. The average gradient for 20 wells in the western Snake River Basin, excluding the ones in the geothermal anomaly, is 81°C/km (4.4°F/100 ft.) with a range of 44° to 112°C/km. Table 1 lists all geothermal data used as a part of this paper.

Geothermal possibilities

For a geothermal deposit to be economically viable, three reservoir conditions must exist. 1) There must be sufficient heat, since the amount of heat in the fluids determines the use and the value of the deposit. For example, temperatures of 200°C (392°F) or greater are suitable for electric power production; temperatures of 150°C (302°F) to 250°C have potential value for heating and process uses; and temperatures below 150°C can be applied to space heating or lower-grade process uses. 2) There must be a sufficient volume of geothermal fluid in the reservoir to produce the necessary quantities of heat energy for 30 to 50 years. Either this volume of fluid must be present in storage or suitable hydrologic conditions must exist to allow recharge. To meet such requirements, reservoir rocks must be sufficiently porous to hold fluids and sufficiently permeable to allow the fluids to migrate from the reservoir rocks to the bore holes. 3) The system must

Table 1. Geothermal data used for Cow Hollow–western Snake River Basin study

Location	Hole No.	N. Lat.	W. Long.	Elev. meters	Depth interval meters	Gradient °C/km	Topo Cor.* Grad. °C/km	K 10^{-3}cal/cm sec. °C	Q (10^{-6}cal/cm^2 sec.)	Cor.* Q (10^{-6}cal/cm^2 sec.)	Qual.**	Lithology
Willow Creek	17-44S11	44°06'	117°17'	719	-370	94.4		2.8	2.6		B	Siltstone
	17-44S31	43°59'	117°20'	829	15-70	85.7		2.8	2.4		B	Siltstone
South Fork Jacobsen Gulch	VN-75-2	44°07'	117°14'	721	30-60	110		3.0***	3.3		B	Basalt
	VN-75-3	44°07'	117°10'	814	50-150	76		2.54	1.9		A	Siltstone
	VN-75-4	44°05'	117°06'	762	30-150	120		2.53	3.0		A	Siltstone
	VN-75-5	44°06'	117°02'	732	60-150	76		2.53	1.9		A	Siltstone
Bully Creek	18-44S21	43°59'	117°20'	760	25-85	66.8		2.8	1.9		B	
Sand Hollow	19-44S19			777	31-395	87.3****		3.0***	2.6		B	
Cow Hollow	19-45S11	43°55'	117°10'	835	30-65	185.7	176.1	3.0	5.6	5.3	A	Siltstone
	19-45S14	43°54'	117°10'	910	20-145	175.2	158.3	3.0	5.3	4.7	A	Siltstone
	19-45S22	43°53'	117°11'	843	30-115	110.4		3.05		2.9	A	Siltstone
	19-45S25	43°53'	117°09'	813	30-70	232.6	213.6	3.0	6.9	6.4	A	Siltstone
	19-45S26	43°52'	117°10'	822	30-175	119.3	114.0	3.0	3.6	3.4	A	Siltstone
	19-45S28	43°53'	117°13'	872	10-90	70.8	76.5	3.0	2.1	2.3	A	Siltstone
	20-45S6	43°51'	117°15'	823	20-135	73.6	69.8	3.0	2.2	2.1	A	Siltstone
	20-45S10	43°50'	117°12'	780	30-135	114.8	104.0	3.0	3.4	3.1	A	Siltstone
	20-45S18	43°50'	117°16'	849	10-40	71.9	63.2	3.0	2.1	1.9	B	Siltstone
	VN-75-1	43°54'	117°08'	879	25-150	91.4		2.53	2.3		A	Siltstone

*Topographic correction

** Quality: A = ± 10%; B = ± 25%

*** Estimated K

****Van Ostrand, 1938

be confined in some way by a relatively impermeable barrier to the migration of the fluids so that a trap is formed, thereby allowing the fluids to accumulate.

High heat flow, defined by bore-hole data, signifies a concentration of heat at depth in the Cow Hollow area. In addition, temperatures of hot springs surrounding Cow Hollow indicate a regional accumulation of heat at depth. Thermal springs at Vale to the north have a temperature of 98°C (208°F), and several springs along the Owyhee River to the south have temperatures up to 77°C (171°F). The chemical constituents in the thermal springs at Mitchell Butte have been analyzed by Mariner and others (1974), who estimate minimal reservoir temperatures of 72°C (162°F).

The authors believe the subsurface geologic conditions in the Cow Hollow area are favorable for the presence of a reservoir and trap. Using data from deep oil and gas exploration wells drilled in the western Snake River Basin (Newton and Corcoran, 1963), a cross section has been constructed for the Cow Hollow area to show the geologic sequence and the potential reservoirs (Figure 2). The two basalt flows of this area, the Grassy Mountain Basalt and the Owyhee Basalt, should make excellent geothermal reservoirs as they have sufficient inter-flow permeability to allow the storage and movement of major quantities of fluids. The few thin sands in the sedimentary units (Newton and Corcoran, 1963) may form minor reservoirs.

Another potential reservoir is the silicic rocks of the Sucker Creek Formation. These rocks, called the Idavada Volcanics farther to the east along the southern margin of the Snake River Basin, are a major warm artesian aquifer sequence (Ralston and Chapman, 1968).

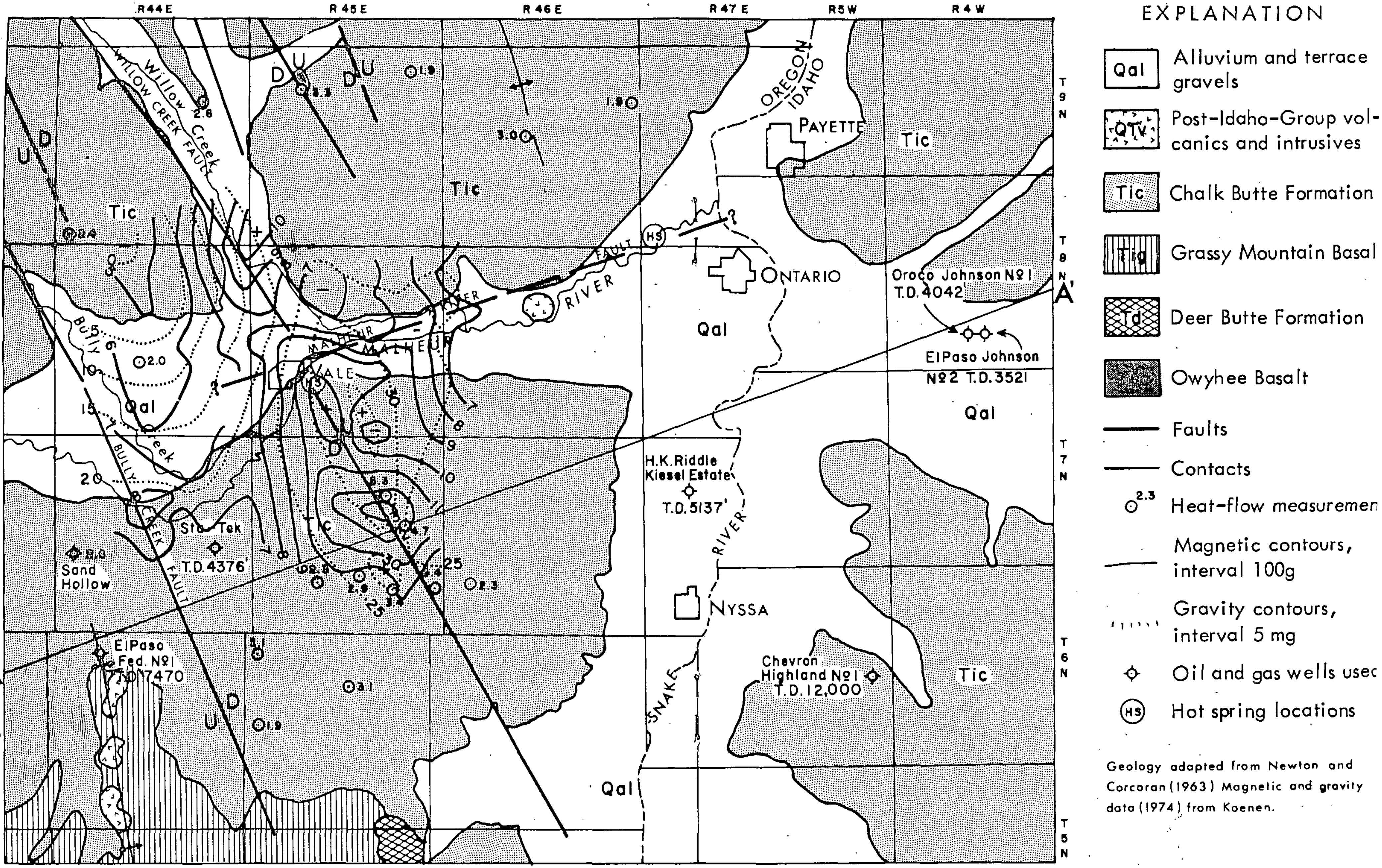
Because of its great extent and thickness, making more water available for storage and recharge, the Owyhee Basalt is probably the best potential reservoir. This thick, multiple-flow sequence of fine-grained to porphyritic basalt has been down-warped and buried to depths of several thousand feet in the Snake River Basin and has undoubtedly been subjected to a great deal of heating through the period of late Tertiary and early Quaternary volcanic activity. This heat energy would be transferred to the accumulated ground water in storage in the basalt. Because of the greater mobility and lower density of hot water and steam, the geothermal fluids would tend to migrate updip to the nearest barrier, where they would accumulate. The steam, if present, would tend to concentrate in the upper part of the permeable zones and the hot water in the lower, similar to the layering of steam and water in a man-made boiler or to the layering of oil and gas in a petroleum reservoir.

In the region of this study, the most common type of barrier would be a fault zone where the impermeable tuffaceous sediments are faulted against the truncated edges of the basalt flows. Another type of trap might occur where lava flows and tuffaceous sediments interfinger. In the Cow Hollow area, a trap may have been formed where the west side of the Willow Creek fault has moved down, bringing the Idaho Group sediments into juxtaposition

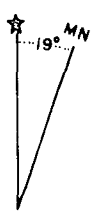
20-45S10	43°50'	117°12'	780	30-135	114.8	104.0	3.0	3.4	3.1	A	Siltstone
20-45S18	43°50'	117°16'	849	10-40	71.9	63.2	3.0	2.1	1.9	B	Siltstone
VN-75-1	43°54'	117°08'	879	25-150	91.4		2.53	2.3		A	Siltstone

*Topographic correction
** Quality: A = ± 10%; B = ± 25%
*** Estimated K
****Van Ostrand, 1938

FIGURE 1



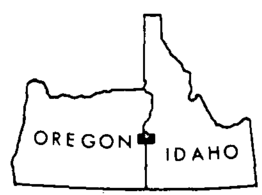
Geology adapted from Newton and Corcoran (1963) Magnetic and gravity data (1974) from Koenen.

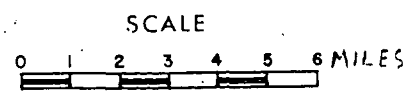


Generalized Geologic Map *of the* WESTERN SNAKE RIVER BASIN

Showing

Hot Spring and Heat Flow Measurement Locations





against the truncated edge of the Grassy Mountain and Owyhee Basalts (Figure 2).

Estimate of depths and temperatures

Information on the depths and thicknesses of the shallower rock units in the western Snake River Basin were compiled by Newton and Corcoran (1963). Until recently, there has been little information on the deeper subsurface stratigraphy, but in 1973 a deep oil and gas test well was drilled by Standard Oil Company of California, "Highland," about 14 miles east of Cow Hollow, near Parma, Idaho. This well, drilled to a total depth of nearly 12,000 feet, passed through the Owyhee Basalt and into underlying siliceous volcanics, lacustrine sediments, and interbedded basalts, a sequence that may correlate with the Sucker Creek Formation in the Mitchell Butte quadrangle. It is reported that the Standard "Highland" well encountered high temperatures in the Owyhee Basalt and underlying rocks. In this well, the top of the Grassy Mountain Basalt was at a depth of 3,800 feet (-1,153 msl) and the Owyhee Basalt at 6,720 feet (-4,073 msl). Newton and Corcoran (1963,Plate 3) show a depth to basalt of 3,820 feet (-1,643 msl) in the Oroco Oil and Gas Kiesel No. 1 well, which is about 8 miles east of Cow Hollow and is believed to be in a deeper part of the Basin.

From the general structural pattern for the area as outlined by Corcoran and others (1962), the authors infer that the Chalk Butte Formation is about 1,500 feet thinner in the Cow Hollow area than in the Oroco-Kiesel well to the east. If this is true, then the Grassy Mountain Basalt is at a depth of about 2,500 feet (+100 to -200 msl), and the Owyhee Basalt is at about 5,500 to 6,000 feet (-2,800 to -3,300 msl). These relationships are shown schematically in Figure 2.

Under some conditions it appears to be possible to predict subsurface temperatures using the near-surface gradients. In the western Snake River Basin, the average geothermal gradient is 81°C/km (4.4°F/100 ft.) with most of the observed gradients between 65° and 100°C/km. The lithologies, and therefore also thermal conductivities, in which the measurements were made are relatively uniform so that gradients are directly comparable. Assuming that heat flow is by conduction and remains constant with depth, the temperature in the various stratigraphic units can be predicted if the depth is known. If the depth to the Grassy Mountain Basalt is in the range of 1 to 1.5 km (3,300 to 4,500 ft.), the temperature would be on the order of 120°C ± 30° (248°F±50°). If the top of the Owyhee Basalt is on the order of 2 km (6,600 feet), the temperatures would be on the order of 170°C ± 40°. The lower units of the Owyhee Basalt and the underlying silicic rocks could have temperatures correspondingly higher. It is emphasized that these are minimum temperatures based on the projected temperature gradients corresponding to a heat-flow value near the regional average. Since temperatures almost certainly exceeding 200°C occur at depth in porous and

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References

Blackwell, D. D., 1969, Heat flow determinations in the northwestern United States: Jour. Geophys. Res., v. 74, p. 992-1007.

_____, 1974, Heat-flow studies in geothermal areas [abs.]: Geol. Soc. America Abstracts with Programs, v. 6, no. 7, p. 657.

Bowen, R. G., 1972, Geothermal gradient studies in Oregon: Ore Bin, v. 34, no. 4, p. 68-71, 5 figs.

Cope, E. D., 1883, On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin, and of the Idaho Pliocene lake: Acad. Nat. Sci. Phila. Proc., p. 134-166.

Corcoran, R. E., Doak, R. A., Porter, P. W., Pritchett, F. I., and Privrasky, N. C., 1962, Geology of the Mitchell Butte quadrangle, Oregon: Oregon Dept. of Geol. and Mineral Indus. Geol. Map Ser. GMS 2.

Hill, D. P., 1963, Gravity and crustal structure of the western Snake River Plain, Idaho: Jour. Geophys. Res., v. 68, no. 20, p. 5807-5819.

Hull, Don, 1975, Geothermal studies in the Vale area, Malheur County, Oregon: Ore Bin, v. 37, no. 6, p. 104-106.

Kittleman, L. R., Green, A. R., Haddock, G. H., and others, 1967, Geologic map of the Owyhee Region, Malheur County, Oregon: Mus. Nat. Hist., Univ. of Oregon Bull. 8.

Lawrence, R. D., (in press), Strike slip faults terminate Basin and Range Province, Oregon: Geol. Soc. America Bull. (1975?).

Mariner, R. H., Rapp, J. B., Willey, L. M., and Presser, T. S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon: U.S. Geol. Survey open-file report, 27 p.

Newton, V. C., Jr., and Corcoran, R. E., 1963, Petroleum geology of the western Snake River basin: Oregon Dept. Geol. and Mineral Indus. Oil and Gas Invest. 1.

Ore Bin, 1973, Progress report on geothermal measurements in Oregon: Ore Bin, v. 35, no. 1, p. 6-7.

Ralston, D. R., and Chapman, S. L., 1968, Ground water resource of the Mountain Home area, Elmore County, Idaho: Idaho Dept. of Reclam. Water Inform. Bull. 4.

Roy, R. F., Decker, E. R., Blackwell, D. D., and Birch, F., 1968, Heat flow in the United States: Jour. Geophys. Res., v. 73, p. 5207-5222.

Van Ostrand, C. E., 1938, Temperatures in the lava beds of east-central and south-central Oregon: Am. Jour. Sci., v. 35, no. 205.

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