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# INTERPRETATION OF GEOPHYSICAL DATA FOR THE VALE, OREGON GEOTHERMAL SYSTEM

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## ABSTRACT

The Vale, Oregon geothermal system is located on the western edge of the Snake River Plain. The Vale hot springs discharge 164°F (73°C) water at about 20 gpm into the Malheur River. The surface heat flow anomaly is about 8.5 miles (13.5 km) long by 2 miles (3 km) wide, as defined by the 7°F/100feet (127°C/km) temperature gradient contour, and has a conductive heat output greater than 10 MW. Maximum observed subsurface temperatures are approximately 290°F (143°C), close to the estimated geochemical reservoir temperature of about 320°F (160°C). Data from 54 shallow temperature gradient holes, several existing deep wells, one new deep well, and geophysical surveys, were used to construct a conceptual model of the geothermal system. The temperature gradient anomaly correlates very well with a gravity high and a small topography high, suggesting a buried horst block, volcanic center or other elevated structure. The upflow is in a buried igneous structure, or along faults, with perhaps some shallow lateral flow driven by local topography. Exploration wells appear to have come close to the main flow system, but have not hit permeability.

## INTRODUCTION

The Vale geothermal system is located at the western edge of the Snake River Plain and north of the Basin and Range in the Owyhee uplands province. The system was first identified from hot springs that discharge into the Malheur river. Discharge temperatures in the range of 164°F (73°C) to 198°F (93°C) have been reported (Gannett, 1988). Most of the discharge appears to be into the river bottom with only 0 to 20 gpm discharging above river level. Wells have been pumping thermal water for industrial use in the town of Vale since the early 1900's (Gannett, 1988).

In the early 1970's a large surface heat flow anomaly was discovered extending southeast from the hot springs for about 8 miles along a previously unknown structure (Bowen and Blackwell, 1975). The structure, which Bowen and Blackwell (1975) named the Willow Creek fault was defined mainly by gravity data. Lillie and Couch (1979), also using gravity placed the fault in a more east-west orientation. Brown (1982) mapped a surface fault zone which agreed with the proposed trend of Bowen and Blackwell. More recently, Fern et al. (1993) referred to the surface faulting in the region of the heat flow anomaly as the Vale fault zone.

The stratigraphy of the Vale 1/2°x1° sheet has recently been summarized by Fern et al. (1993). An extensive volcanic episode occurred at about 15 Ma. Four major calderas formed within 30 to 50 miles (18 to 36 km) to the south and west of Vale. Each of these was the source of voluminous ash flows that in part covered the Vale area. At essentially the same time, basalts from the Columbia River group/Owyhee basalts were covering the area from the north and west. Since 12 Ma, volcanic activity has been more sparse, ending by about 5 Ma. Draping over all these volcanic rocks are the siltstones of the Idaho Group. These locally derived sediments are relatively impermeable, and vary in thickness from 4,600 feet (1.4 km) ten miles east of Vale to less than 1,000 feet (0.3 km) in the Vale area. Evidence from landslide deposits at the base of buttes near Vale hot springs and from well cores, show that hydrothermal deposits almost completely seal the rocks, indicating a long history of flow systems at this site. (Gannett, 1988)

## GEOPHYSICAL AND GEOCHEMICAL DATA

The availability of 54 shallow gradient well logs allowed a detailed temperature gradient map to be made for the 300-600 foot depth range as shown in Figure 1 below. All the gradients are conductive and, terrain corrections where needed, followed the technique of Blackwell et al. (1980).

Gravity data from the area was used to construct a residual Bouguer anomaly map, which is shown in Figure 2 with an overlay of the temperature gradient map from Figure 1. The gravity contours show a clear correlation with the temperature gradients. There is also a slight topographic high (not shown) that correlates well with the gravity and thermal gradients. The total field magnetic anomaly map shows a high centered very close to the peak of the thermal anomaly, but a more variable pattern in detail than the other geophysical signals.

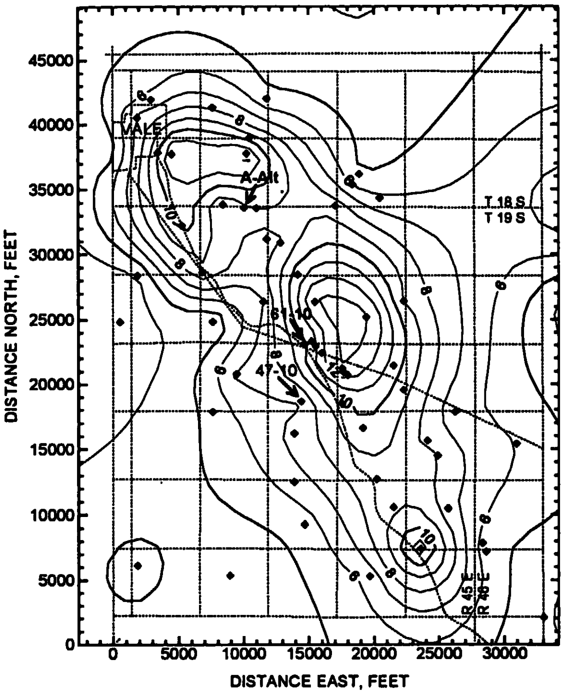

Figure 1. Surface temperature gradient map of the Vale system. Gradients are in °F/100 feet (multiply by 18.2 to get °C/km). Data locations are indicated by diamonds.

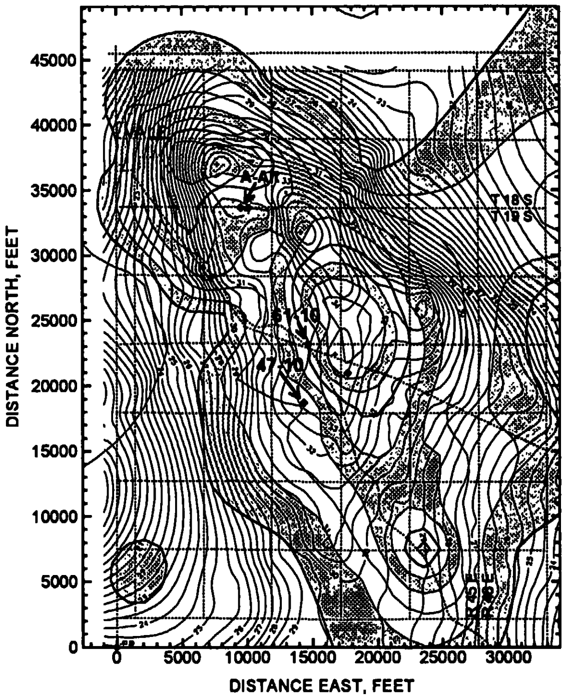

Figure 2. Residual Bouguer gravity anomaly map of the Vale area overlaid with the temperature gradient map. Contours are in milligals. Note the good correlation between the gravity and temperature gradient anomalies.

There are three deep holes with temperature logs available in the Vale area, Trans-Pacific A-Alt, Union 47-10, and the recently completed Trans-Pacific 61-10. In addition the DOE Ore-Ida #1 well, located ten miles to the east, in Ontario, Oregon, has been logged to 8000 feet (2.4 km). The temperature-depth curves from these wells are shown in Figure 3. The Ore-Ida well is the only one that was logged at thermal equilibrium, the others are at various non-equilibrium states. The A-Alt well was logged very shortly after drilling, is far from equilibrium, and is therefore difficult to interpret. A-Alt is probably warmer in the lower section than the log indicates. The 47-10 log appears conductive in the basalt section, about 750-2,700 feet (0.23-0.8 km ), but then turns downward and is isothermal for the final few hundred feet. The bottom hole temperature is 280°F (138°C) at 3800 feet (1.2 km)

Well 61-10 was drilled in 1995. It is sited closer to the center of the thermal gradient high than 47-10 and A-Alt, but is still roughly 1/2 mile from the peaks of the gravity and thermal anomalies (Figures 1 & 2). Below 978 feet (0.3 km), the lithology is mostly basalt with some interbedded silts and tuffs to 5328 feet (1.6 km). Below the basalt is rhyolite to the total depth of 5825 feet (1.8 km). Continuous core was obtained from 3100 feet (0.95 km) to total depth. The core shows abundant hydrothermal vein filling, with some larger fractures retaining open apertures of several millimeters.

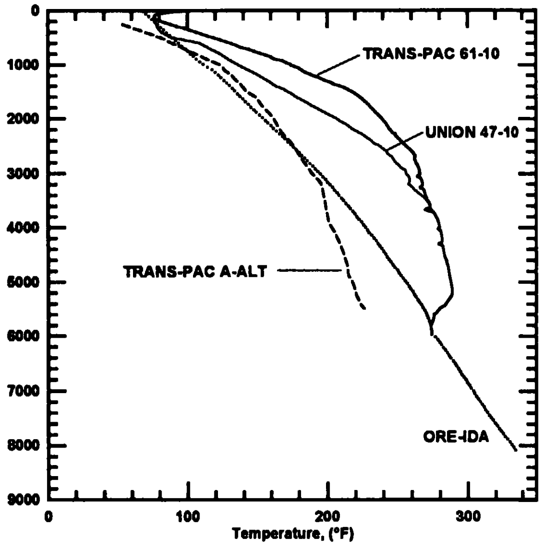

Figure 3. Temperature depth curves for deep wells in the Vale area. The A-Alt well is not at equilibrium, and may be hotter in the lower section than shown. Ore-Ida is 10 miles east of Vale. 47-10 and 61-10 are on the west flank of the central temperature gradient high.

The 61-10 log appears conductive in the upper 2,700 feet (0.8 km), but below this there are inflow/outflow zones and a clear rollover at 5,100 feet (1.5 km), just above the basalt-rhyolite contact. None of the lost circulation zones demonstrated good connected permeability. The 61-10 well was logged several times after drilling. The log shown in Figure 4, is from 48 days after circulation, and is reasonably close to equilibrium, except in zones of lost circulation.

Geochemical thermometers give estimates of the reservoir temperature for the Vale system ranging from about 250°F to 340°F (121°C-171°C), but the most reliable estimates are considered to be about 320°F (160°C) (Gannett, 1988). The Ore-Ida well had a higher BHT of 380°F at 10,000 feet (193°C at 3 km), but this was under conductive conditions and at greater depth. The 61-10 and 47-10 wells both experienced temperature rollovers in the 290°F-300°F (143°C-149°C) range, just below the predicted reservoir temperature. On a regional scale, Mariner et al. (1994) found that the Vale geothermal system waters were not part of a regional scale system, and that in particular they were not connected to the Owyhee Uplands springs 40 to 50 miles south of Vale.

## INTERPRETATION

The most striking feature of the data is the very good correlation between the shallow temperature gradients, high gravity and high topography. Over the top of the anomaly, the Idaho Group sediments are only 700-1000 feet thick, several thousand feet less than a few miles to the east. Taking typical densities of the sediment and volcanic sections to be 1584 and 1865 lbs/ft$^3$ (2,250 and 2,650 Kg/m$^3$) respectively, would yield a 3-4 mgal change in gravity for every 1000 feet (0.3 km) of change in Idaho Group thickness. The gravity anomaly over the Vale system averages about 12-16 mgal, implying about a 4,000 foot (1.2 km) structural or stratigraphic offset. The topography high mentioned earlier is far too small to account for the gravity anomaly. The gravity data, combined with the surface evidence of faulting suggests that there is a buried horst block, volcanic center, or some other structural high, under the sediments as first proposed by Blackwell and Bowen (1975).

The temperature gradient map shows three distinct peaks aligned north-west to south-east, along the trend of the anomaly, which could be caused by an elongated upflow zone along a fault, or a single upflow zone and shallow lateral flow along the axis of the anomaly. There is no pronounced asymmetry on either side of the gradient anomaly or in any of the other geophysical data. The symmetry in the data indicates, but does not prove, that if the structure is a horst block, it is not rotated much, or if upflow is along a fault, then the fault is near vertical. The only asymmetry in the gradient map is the hook shape of the northern high, but this area is also where the hot springs and the very shallow industrial wells are located, and it is likely that the shape of this lobe is due to shallow outflow.

The gradient map also has some bearing on the geometry of the upflow. The central high is the largest of the three, and the other two highs are topographically downhill from it, which is what would be expected if upflow were confined to the central high followed by topographically driven outflow, within the fault zone, in the shallow subsurface.

The surface temperature gradient map was also used as a starting point for downward continuation modeling (Brott, et al., 1981). Where fluid flow is confined to discrete paths, continuation can define the boundaries of the system much better than simple extrapolation. Figure 4 shows a calculated depth to the 300°F (149°C) isotherm based on continuation models. These model results show a reservoir aligned with the surface heat flow anomaly, with three 300°F (149°C) peaks at about 2,000-2500 feet (0.6-0.8 km) below the surface.

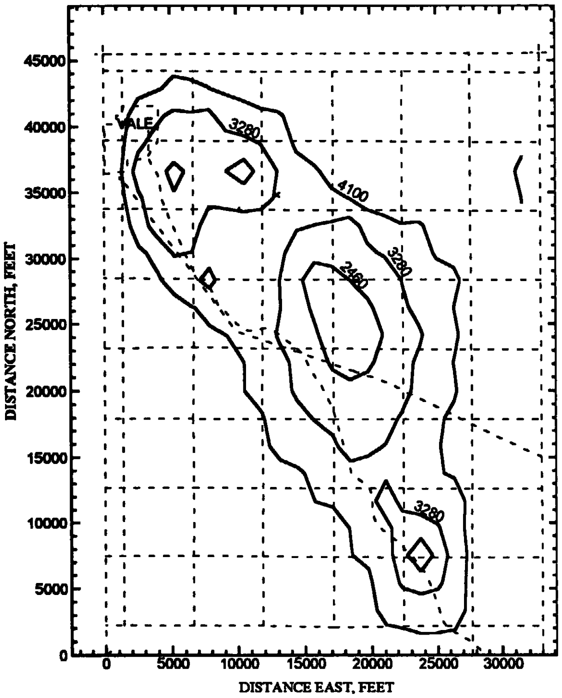

Figure 4. Depth to the 300°F (149°C) isotherm, in feet below surface, based on downward continuation. This map indicates that the 300°F isotherm peaks at about 2,000-2500 feet below the surface over the center of the three highs.

The drilling data shed some additional light on the system. The log for Ore-Ida appears to be conductive, with very little advective disturbance and is probably indicative of the regional background conditions. The A-Alt well is mainly useful in delineating the upflow zone. A-Alt is located near the saddle between the two northernmost highs, and since it did not intersect an upflow zone, it somewhat limits where the possible flow paths are. The 47-10 and 61-10 wells are similar, both are on the eastern flank of the central high, and both have similar shapes and maximum temperatures. 47-10 was not deep enough to confirm a temperature rollover, but it is likely that with depth it would show a rollover similar to 61-10. On the temperature gradient map, 61-10 is much closer to the center of the anomaly, but on the gravity map, both wells are on the same gravity level, thus if the gravity map does correspond to structure, both wells could be in the same position relative to the main flow system, which would account for the similar temperature profiles. The overturn in the temperature log for 61-10 does indicate that the flow system is nearby.

The conductive heat loss for the geothermal system is greater than 10MW. Total water flow through the system, based on a 10MW heat loss, a 320°F reservoir temperature, and a 165°F discharge temperature is on the order of 400 gpm.

Most geothermal system's shallow anomalies are located at topographic lows. The Vale geothermal system is rare in that it is centered on a slight, 500 foot (0.15 km) topographic high. This combination suggests that there is some mechanism forcing hot water up in a location other than it would normally rise in a homogeneous media. Gannett (1988) proposed that the thermal fluid moved laterally at depth until encountering a fault that juxtaposed impermeable and permeable units, some of the fluid then flowed up the fault to discharge at the surface or into shallow permeable strata. Another possibility is that fluid circulates mainly inside the horst block/volcanic center igneous section with some leakage into the bounding faults and/or shallow subsurface. The presence of a topographic high on top of a buried structural high, suggests that there is moderately recent movement on the structure. Recent fault movement could generate the permeable path for fluid upflow.

## CONCLUSIONS

The Vale geothermal system represents a significant resource. There is obviously a large volume of fluid flow at a temperature of about 300°F (149°C), even though the permeable zone associated with the flow has not been drilled yet. Water is circulating in igneous rocks at depth and the flowing up into the near-surface along one or more faults or fault intersections. The strong correlation of high temperature gradient, high gravity, high topography and high magnetic anomalies suggests that there is an elevated structure, possibly a horst block, or volcanic center, with a thick igneous section, buried beneath the sedimentary cover. At present there is insufficient information to differentiate between an elongated upflow zone along a fault, a single upflow zone with shallow lateral flow north-west and south-east.

## ACKNOWLEDGMENT

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