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THE ROOSEVELT FIELD: NEW MODEL AND GEOCHEMICAL EVALUATION

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ABSTRACT

A detailed model has been developed of the Roosevelt geothermal field and its surroundings. It involves a dissection of the three-dimentional geometry of tho rock masses, and of the mass and energy flow systems operating within them.

This model forms the "ground truth" for evaluating a new kind of geochemical reconnaissance, multi-element analysis of surface microlayer samples. A fresh viewpoint of geothermal potential in the Milford Valley evolves from the study.

The Roosevelt geothermal field lies near intersections of five geologic zones of major significance: 1) the Basin and Range/ Colorado Plateau Transition; 2) the Intermountain Seismic Belt; 3) the Pioche Mineral Belt; 4) a zone of late Tertiary and Quaternary volcanism; 5) the geothermal belt of Lund-Thermo-Roosevelt-Cove Fort. The crust is thin (around 25 km) and heat flow is high. A mantle upward is apparently present along this eastern margin of the Basin and Range province. Major subplate boundaries, seismically very active, lie nearby to the east and south. Quaternary volcanism in the immediate area involves a bimodal association of rhyolites and basalts, consistent with the crustal dynamics pictured here. Rhyolite domes and flows as young as 500,000 years confirm the presence of suitable shallow heat sources favorable for geothermal conditions.

The gross structure of the region is typical of Basin and Range block faulting. The Milford Valley is a graben with the crystalline basement buried under more than 10,000 feet of Cenozoic clastics and volcanics. The horst blocks to east and west consist of Precambrian metamorphic rocks covered by a miogeosynclineal sequence of carbonates and well-sorted sandstones ranging in age from Eocambrian through Jurassic.

This sequence was involved in the Cretaceous Sevier orogeny, with strong eastward overfolding and thrusting. Block faulting followed in the Cenozoic, accompanied by extensive volcanism ranging from the Eocene or Oligocene through the present.

East of the Milford graben lies the horst of the Mineral Range, with the Roosevelt field between them. The horst is a regional structural high in this area: Precambrian gneisses and schists are exposed or covered only by a few hundred feet of alluvium.

The Precambrian rocks are cut by a very large granitic pluton 20 to 30 m.y. old. The geothermal field lies within the roof and outer margins of this pluton, which is itself cut, a few miles east of the field, by ten rhyolite domes dated between 0.6 and 0.5 m.y.

Structurally, this part of the Milford graben and the Mineral Range is cut by four major fault systems. New air photo interpretation has shown that a set of WNW-trending faults typified by the Negro Mag Wash fault are vertical right-handed strike-slip faults of major structural importance, which slice the basement into a series of separate blocks. A second set of N-trending normal faults are currently active in the continuing deepening of the Milford graben: the fault scarps are well-developed, and some of the faults involve dip slip of as much as 1,500'. A major zone of NNE-trending faults extends over thirty miles through the Milford Valley west of the field and is interpreted as a major zone of strike-slip movement, with focal depths greater than 10 km. The fourth system of faults trends ENE parallel to a major lineament, obvious in satellite imagery, which can be traced into and across the Milford Valley from the Pavant Range. It cuts the northern Mineral Range near Pinnacle Pass and its effects on basin geometry are clearly displayed in the gravity and magnetic data. To the south, the basin has a simple form at depth. To the north, the range front fault system is displaced eastward, and the basin is shallower and much more complex in shape. Faults of the ENE system are less numerous than the others, but are important zones of right-handed strike slip.

These fault systems have been mapped in detail in the Milford Valley and the Mineral Range. The shallow alluvial cover is obviously incapable of sustaining and transmitting signif: cant stresses and the fault traces at surface simply express the response of the cover to displacements occuring at greater depths in more consolidated material. The surface traces there fore tend to be irregular and discontinuous, but provide excellent indications of zones of active faulting at depth, and potential pathways for geochemical transport.

The Opal Mound fault is enigmatic, as its strike lies between the N and NNE trends of the main fault systems. Over it, the ground surface is downdropped a few tens of feet to the east, and gravity data show the alluvium thickens abruptly to the east, almost 165'. Accordingly, it has usually been treated as a normal fault and assumed to dip east. However, geothermal wells east of it have not identified it at depth with any certainty and it may in fact be vertical or dip west: present movement on it may be different than earlier movement.

The alluvial cover between the Opal Mound fault and the Mineral Mountains ranges up to about 700', being 300' in wells 3-1, 14-2 and 13-10, nearly 500' in 72-16 and about 600' in 52-21. Over the narrow horst west of the Opal Mound fault it is less than a hundred feet. West of that it thickens progressively to about 3,000' in the center of the Milford Valley, where it overlies a thick wedge of Tertiary clastics and volcanics that thin laterally to zero at the edges of the valley and are evidenced only in seismic data and in the deep test in the valley, Acord 1-26.

The gross structure and the three-dimensional geometry of the rock masses in the Roosevelt area is thus relatively simple. The known geothermal reservoir lies between the Mineral Range and the Opal Mound fault. Twelve deep tests have been drilled, seven commercially successful (Phillips 3-1, 54-3, 13-10, 25-15, and 12-35; ATO's 14-2 and 72-16). The successful wells ranged in depth from 1254' (72-16) to around 7500'.

Key unsuccessful wells include 9-1, west of the Opal Mound fault, which showed BHT of 446^{o} F and extremely small flow: this led to the consensus that the Opal Mound fault seals the field and is its western boundary. To the south, 52-21 is considered to be beyond the southern boundary with its BHT of 402^{o} and no flow. The north and east boundaries are very indefinitely known, and are generally defined by the heat flow pattern measured in shallow wells.

Fifty-three holes with temperature gradients and thermal conductivity data are available for a heat flow map. The pattern of shallow gradients is profoundly influenced by upflow of hot brines along the Opal Mound and Negro Mag Wash faults and other parallel faults, and by a near-surface plume of laterally moving brine below the northwest part of the area: there are indications of upward leakage of hot brines along the Negro Mag Wash fault west of the Opal Mound fault, in the zone that trends toward the Acord well, 1-26. Another lobe in the heat flow pattern has been mapped east of the field.

Separating conductive and convective regions is very difficult, and the heat flow pattern so far mapped may be a poor guide to the real location and areal extent of reservoir conditions. Gradients fall west of the Opal Mound fault, but then rise again west of a major zone of N-trending faults. In combination with chemical data from wells in the center of the Milford Valley, this indicates reserVior conditions may well exist there. The Acord well achieved commercial reservoir temperatures but produced no flow.

Plumes of geothermal brine are carried WNW-ward by the shallow groundwater flow within the alluvium. Alluvial aquifers vary in transmissivity from about 1000 to more than 40,000 ft^2/day; the higher values are for well-sorted, coarse clastics in the valley center. Hydraulic conductivity has been estimated at 0.1 to 10 ft./day in the alluvium, and 10^{-6} to 10^{-3} ft./day in the Tertiary sequence below it. Depths to water table are a few tens of feet in much of the valley but increase to two or three hundred feet in the area of the geothermal field, near the edge of the Range.

Analyses of groundwater in wells and springs averages slightly less than 600 mg/l TDS. The geothermal brines, in contrast, show 6,000 to 7,000 mg/l TDS. There is an extreme chemical contrast between the typical basin fill aquifers of the valley, which are calcium sulphates and bicarbonates and the almost pure sodium chloride brines of the field. Groundwater wells northwest of the field show mixtures of brine and groundwater, as expected from the known plume of brine in that area but wells west of the southern part of the field show the same mixing, implying either that the Opal Mound fault is not sealed or that there is another zone of leakage west of it in the Milford Valley.

The difficulties of defining the boundaries of this field have been stressed above. Hot, dry wells have discouraged further exploration to the south and west and boundaries have been drawn there along fault zones. To the north, high temperature gradients continue for almost a mile beyond the northernmost successful well.

To the east the gradients fall, but the boundary seems likely to be economically determined rather than a geologic break.

The well control is inadequate to truly define the field at this early stage of development. Within the main area of drilling one can, however, deduce the general geometry of the rock masses. The self-sealed cap has narrow projections up to surface along the Opal Mound and Negro Mag Wash faults; it is generally up to 1,000' deep near the Opal Mound fault and is deeper both west and east of it. The base of the cap and the top of the reservoir is slightly less than 2,000' deep where the Opal Mound and Negro Mag Wash faults intersect. At 72-16 it is nearer 1,200', but becomes progressively deeper to the east and west, and rapidly deepens below 7,500' to the south. North of Negro Mag Wash available data are very scanty. The top of the reservoir is between 1,800' and 4,500'.

Once the top of the reservoir has been penetrated, the wells become isothermal. None of the wells have reached the bottom of the reservoir.

The reservoir is hot-water dominated. Subsurface temperatures reach well over 500° F and successful wells produce over 1 million lb/hr of fluids. Pressure is around 2250 psi.

Geothermometers give estimated temperatures up to 563° F that agree well with observed temperatures and suggest the fluids have reached equilibrium with the granitic reservoir rocks at reservoir temperature. Several chemical arguments show the reservoir volume is large compared to the discharge, and the fluids have a long residence time. Intersections with fracture zones provide all the production; there is essentially no intergranular porosity. Strong convective movement and mixing is probably occurring on major through-going fractures. There is little chemical variation in fluids from different producing wells.

Roosevelt Hot Springs water was essentially identical to reservoir fluids and the Roosevelt seep shows only a small component of cold groundwater. Detailed chemical evaluations show that waters in 9-1 and 52-21 show compositions compatible with a mixture of hot brine plus about 10% cold groundwater, perhaps refuting the idea they are not in communication with the main part of the reservoir. In support of that idea, Na-K-Ca geothermetry for well 9-1 does indicate 504° F (BHT is 446° F).

The reservoir fluid is derived from local rainfall and snowmelt, based on oxygen and hydrogen isotope data. Tritium content (less than 1 TU) confirms the relatively long residence time.

Flow patterns within the reservoir are hard to infer, but probably involve upward convective movement in the zones of the Opal Mound and Negro Mag Wash fault, rising to the shallowest parts of the reservoir, with downward movement further east and at the southern boundary. Leakage from the top of the reservoir has mainly been up the major faults which have probably had a history of episodes of sealing alternating with re-opening by renewed faulting.

At surface, opaline sinter deposits variously estimated as dating back from 35,000 to 350,000 years) occur along the Opal Mound and Negro Mag Wash faults, and their branches. Deposits west of the Opal Mound fault confirm that geothermal fluids once leaked there, whether or not the zone is now hot but dry. Hor ground exists around areas of sinter and cemented alluvium.

Steam and other gases (including helium, radon, COS and CS2) leak in several areas. The Negro Mag Wash fault is a major zone of de-gassing, with steam, CO_2, H_2S and other bases being detected, and with deposits of sulphur, mercury and arsenic. Sulphur, and sometimes realgar, are constituents of the sinter. Radon flux is related to faults, including a branch west of the Opal Mound fault.

Present day liquid discharge is confined to the Roosevelt seep, but signs of leakage in historic times are evident in Negro Mag Wash, west of the Opal Mound fault. Surface alteration of the alluvium by acid sulphate waters, formed where geothermal fluids reach surface, produces extensive alunite along with the precipitation of opal (the silica content of reservoir fluid is up to 380 ppm).

In the soils, arsenic and mercury anomalies have been mapped around the interesction of the Opal Mound and Negro Mag Wash faults, and in a second area around the Opal Mound itself. The arsenic pattern is similar on the two sides of the Opal Mound fault but mercury is concentrated west of it north of Negro Mag Wash, and east of it in the main area of the field south of the Wash. Other elements are concentrated at and near the Opal Mound fault: tungsten at the fault and antimony 1500' west. Tin, thorium and broad lithium anomalies have also been recorded.

In a new survey, about three hundred samples of the surface microlayer were collected and analyzed by Barringer Resources, Inc. from an area ten miles square, centered one mile west of well 9-1. Inductively coupled plasma spectrometry, and other techniques were used for determination of a wide variety of elements and ions: Al, Fe, Ca, Mg, Ti, Mn, Na, K, P, Be, Cd, Cr, Cu, Ni, Sr, Th, V, Mo, Ag, Si, Ba, Hg, Sb, As, Se, Rb, Li, Cs, F, Cl, PO_4, NO_3, SO_4, B, Rn.

Conventional soil samples were taken at the same sites as 89 of the microlayer samples. Somparisions indicated the latter generally provided sharper anomalies with greater contrast to background.

The results show that the As, Sb and Cs anomalies are the most clearly related to the geothermal features, wtih highs located near the Opal Mound and at the intersection of the Opal Mound and Negro May Wash faults. Other anomalies in these elements are strung along the WNW-trending fault zone of the Negro Mag Wash and Salt Cove faults, and a conspicuous anomaly was mapped where this zone intersects major NNE- and N-trending faults, about a mile north of the Acord well. Mercury highs coincide with some of these highs but not with others.

Many other elements display anomalous highs or lows in the same areas as the As-Sb-Cs anomalies.

A pattern found in most of the plots of lateral variation for individual elements involves subdued variation in the area south of the Negro Mag Wash fault and west of the Opal Mound fault, contrasting with markedly greater variation north of Negro Mag Wash and the area of the field.

In the most ideal circumstances, the geothermal explorationist would like geochemical tools that involve strictly vertical, uniform upward movement of some pathfinder element, or group of elements, that move to the surface above the geothermal reservoir and become fixed in abnormal concentrations in the soil or surface microlayer, conveniently ready to delineate the shape and size of the reservoir below. Mapping such an anomalous area would be equivalent to mapping the areal extent of the geothermal field itself.

Such a dream is unlikely to be fulfilled, of course. Instead one has, in reality, fault and fracture zones which carry fluids and pathfinders preferentially, so that the surface expression of the area of the reservoir is distorted by "spikes" related to these conduits. Even worse, the conduits will probably be oblique rather than vertical, and the anomalies at surface may thus be displaced relative to the area of origin.

This is the same problem one has in temperature gradient work, where one would like to be dealing with simple conductive heat flow, abnormally high immediately over and around the reservoir.

However, the results of the surface microlayer work, interpreted in detail, demonstrate the value of the technique, which is a low cost method of geochemical reconnaissance (Atkinson and Meyer, 1980). The data suggest geothermal signatures are present along the Negro Mag Wash-Salt Cove fault zone for as much as five miles west of the known field. Whether these are related to lateral movement or hot near-surface brines, or to upward leakage of brine from geothermal zones to the west is not clear, but several lines of evidence favor the latter interpretation and encourage the possibility of additional geothermal discoveries in the Milford Valley.

REFERENCES

Atkinson, D. J. and T. W. Meyer, 1980. Low Cost Airborne Geochemical Detection and Evaluation. Geothermal Resources Council, TRANSACTIONS Vol. 4, September 1980.

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