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STRUCTURAL CONTROL OF THE BALTAZOR HOT SPRINGS GEOTHERMAL SYSTEM, HUMBOLDT COUNTY, NEVADA

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ABSTRACT

The Baltazor Hot Springs KGRA is centered on a low-yield, (4-28 lpm), sodium-sulfate, 76-98°C/167-208°F hot spring, surrounded by small opaline sinter mounds and believed to be presently precipitating silica, thus suggesting a deep reservoir temperature of at least 180°C/356°F. The position of the springs, associated calcite-silica stockworks, and presumably a deep thermal reservoir at Baltazor, is clearly controlled by the intersection of a northeasterly-trending Basin and Range fault trough with an older, northwest-trending normal fault system. Of numerous exploration techniques applied at Baltazor, thermal gradient drilling, mapping of geology and alteration, geothermometry, detailed gravity and dipole-dipole resistivity have been most useful in appraising the geothermal resource potential. Baltazor is indicated by these techniques, -- and by probable active silica precipitation -- to remain an encouraging prospect: At least one additional deep drill hole is warranted. The target for this hole is a fracture-controlled reservoir in Miocene volcanics and pre-Tertiary metamorphic rocks at depths greater than 2000 ft (610 m) beneath Baltazor Hot Springs.

INTRODUCTION

The Baltazor Hot Springs KGRA, near Denio, Humboldt County, Nevada (Fig. 1), has been intensively explored since 1977 by Earth Power Production Company (EPPC), under the terms of the Department of Energy's Industry Coupled Program. These exploration efforts have clearly demonstrated Baltazor to be a structurally-controlled system heated by deep circulation along permeable fault zones. This paper will discuss the nature of these structural controls, as revealed by various exploration techniques and deep drilling, and will assess the prospect's remaining resource potential.

PREVIOUS WORK

Diverse exploration methods have been applied with varying success in appraisal of the geothermal potential of the Baltazor Hot Springs KGRA and vicinity. Photogeologic mapping by Gardner and Koenig (1978) delineated previously mapped faults and major new photo-linears. Groundwater sampling and (in particular) geothermometry (Klein and Koenig, 1977) targeted the immediate Baltazor Hot springs area as the region's most promising geothermal prospect. Shallow- and intermediate-depth thermal gradient drilling (Langenkamp, 1978; EPPC well log data) delineated strong heat flow anomalies at Baltazor and the Painted Hills prospect (Hulen, 1979), about 11 miles/17.7 km to the southwest. A regional aeromagnetic survey (Scintrex, 1972) had shown only broad regional basement configurations, of little use in characterizing geothermal features. Senturion Sciences (1977) demonstrated contemporary microearthquake activity along, among other structures, the range front fault system passing west of Baltazor Hot Springs, thus enhancing chances for discovery there of adequate subsurface permeability. Edquist (1981) completed detailed gravity profiling, extremely useful in structural interpretation of the surprisingly deep graben beneath Baltazor Hot Springs. Dipole-dipole resistivity and self-potential data gathered by Mining Geophysical Surveys, Inc. (1981) for EPPC were also interpreted by Edquist (1981). He correlated shallow, near-surface resistivity lows and rapidly changing self-potential values at Baltazor with mapped and gravity-inferred fault zones believed to be the prime conduits for deep thermal fluid convection. A mercury-arsenic soil survey (Truex, 1980) of the Baltazor area revealed no diagnostic anomalies exclusively related to the active thermal system. Hulen (1979) produced preliminary geology and hydrothermal alteration maps of Baltazor and the Painted Hills. The Baltazor map, together with results from EPPC's recently completed deep well near Baltazor, form the basis for the detailed surface and subsurface geologic interpretations presented in this report.

GEOLOGIC SETTING

At the northwestern margin of the Basin and Range province, the Baltazor Hot Springs KGRA and vicinity exemplify the regional geology of northwestern Nevada. The Pueblo Mountains, west of Baltazor (Fig. 1), are a typical, northerly-trending, tilted fault block range. East of the Pueblos, Continental Valley, which hosts Baltazor Hot Springs, is an equally typical, deeply alluviated graben valley, in this case surficially blanketed with lacustrine sediments. The Pueblo

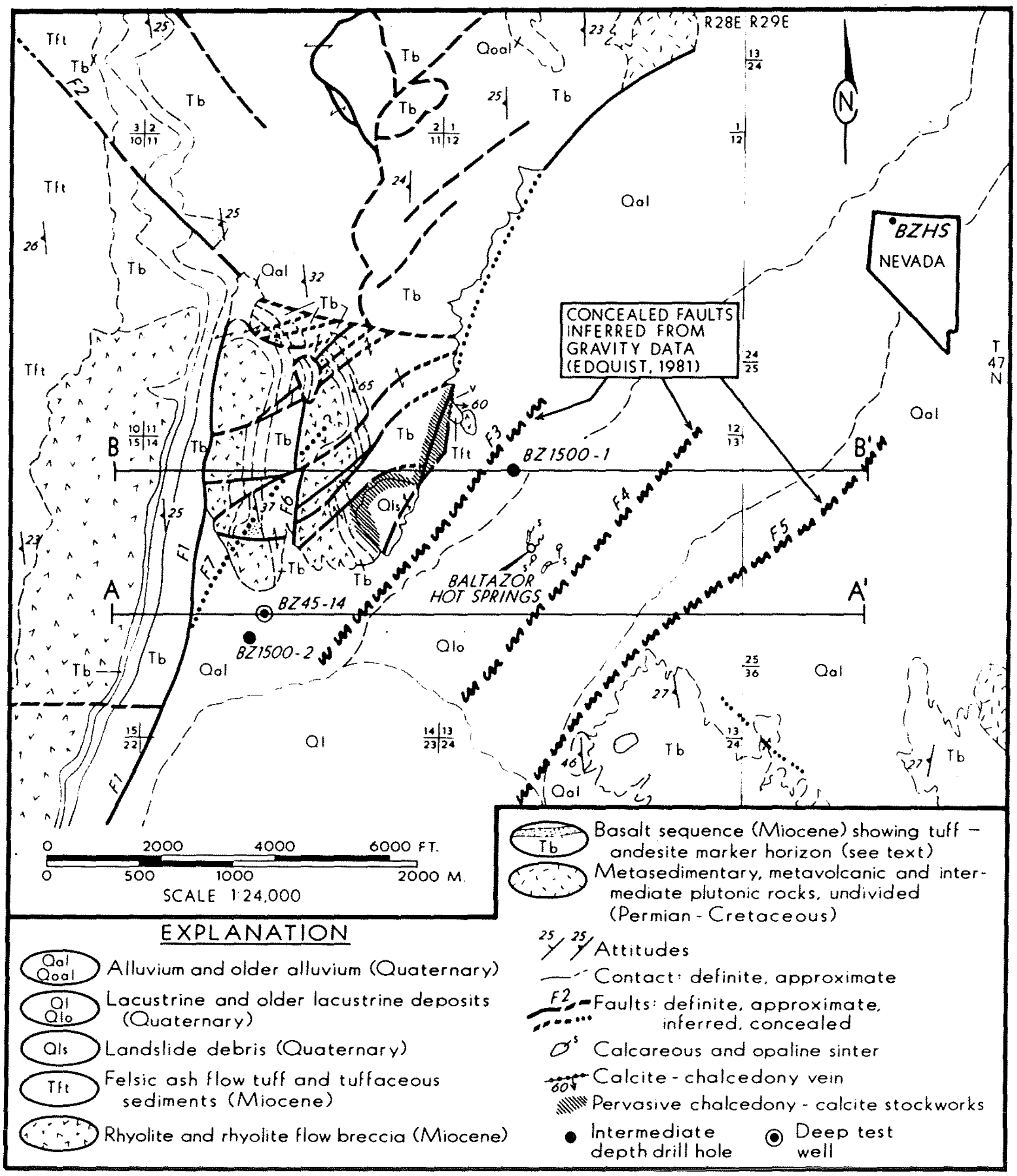

Figure 1. Geologic map of the Baltazor Hot Springs KGRA and vicinity, Humboldt County, Nevada.

Mountains are formed of a deeply dissected, highly variable Miocene-Pliocene volcanic and volcaniclastic sequence resting with profound unconformity on Permian-Triassic (?) metavolcanic and metasedimentary rocks intruded by intermediate composition plutons of Jurassic-Cretaceous age (Fig. 1; Willden, 1964; Rowe, 1970; Burnham, 1971). Immediately above this eroded basement near Baltazor is a thick sequence of Miocene porphyritic basalt flows, flow-breccia, and tephra beds locally interrupted by volcaniclastic sediments, air-fall tuffs and ash-flow tuffs. In the upper portion of this sequence, a thin dacite (?) ash-flow tuff and a dense hornblende andesite flow, along with an intervening basaltic andesite flow, form an easily mappable marker interval (Figs. 1-3). The basalt sequence is disconformably overlain by a cliff-forming rhyolite, also Miocene, which in turn is overlain by Miocene felsic ash-flow tuffs and volcaniclastic sediments.

The Pueblo Mountains are tilted gently westward and bounded on the east by a major normal range-front fault system. Maximum displacement in this system is interpreted by Edquist (1981) to have occurred along a fault (F3) concealed by alluvium and trending northeast just west of Baltazor Hot Springs (Figs. 1, 3). Alluvial depth east of fault F3 is modeled on the basis of gravity data by Edquist to be as much as 2000 ft (610 m). Low- to moderate-angle faults F1 and F6 in the range west of fault F3 probably were caused by range-front oversteepening resulting from F1 faulting. The complexity of F1 and F6 immediately north of well 45-14 (Fig. 1) is almost certainly due to interaction of these faults with fault F2, a northwest-southeast-trending structure of minor normal displacement which, projected southeastward, passes directly beneath Baltazor Hot Springs.

THERMAL PHENOMENA AND HYDROTHERMAL ALTERATION

Baltazor Hot Springs, with measured temperatures varying between 76°C/167°F and 98°C/208°F, produces, essentially from a single orifice, sodium sulfate waters at rates fluctuating between 4 and 128 lpm (Klein and Koenig, 1977). Silica and Na-K-Ca geothermometers indicate present subsurface temperatures of at least 160°C/320°F (Klein and Koenig, ibid.). Ooze collected from the edge of the Baltazor Hot Springs pool is revealed by X-ray diffraction (XRD) analysis to consist largely of opal with minor cristobalite and quartz, suggesting reservoir temperatures of at least 180°C (White et al., 1971). Frothy-appearing opaline sinter mounds scattered in the immediate vicinity of the springs (Fig. 1) attest to past reservoir temperatures at least this high.

Range-front normal faults and the sole of a recent landslide west of Baltazor (Fig. 1) are pervasively altered by silica-bearing (chalcedony, cristobalite and minor tridymite as shown by XRD) calcite veins and veinlets, locally accompanied by bleaching of their host rocks. The veins, from less than 4 in/10 cm to at least 10 ft/3 m in thickness (mapped vein in Fig. 1), range in texture from massive to vuggy and delicately banded. Cross-cutting relationships and brecciation in the veins suggest several alternating episodes of carbonate deposition and silicification. A few small (<6 ft/1.8 m) surface mats and mounds of mixed siliceous and calcareous sinter are scattered across the surface of the landslide, probably indicating the associated calcite - silica veins to have been former feeder channels for thermal springs.

Other alteration in the Baltazor area cannot be attributed to the active geothermal system. Base metal sulfide mineralization and associated alteration in Permian - Cretaceous basement rocks is clearly Pre-Tertiary. Faults F1 and F6, particularly near the hot springs, commonly contain, as identified by XRD, calcitic and hematitic jasperoid (chalcedony), locally bearing small (<2 in/5 cm) pods of bright yellow-green pure smectite, almost certainly nontronite.

DEEP DRILLING RESULTS

Well 45-14, collared about one mile/1.7 km southwest of Baltazor Hot Springs (Figs. 1-3) penetrated alluvium to a depth of 160 ft/49 m, a thick Tertiary volcanic sequence to 2180 ft/664 m, then pre-Tertiary interstratified chlorite-sericite schist and intermediate metavolcanic rock to the base of the sampled interval at 3590 ft/1094 m; total depth is 3640 ft/1109 m. The rocks penetrated in the well, most with distinctive gamma-ray signatures (Fig. 2) can be readily correlated with surface rocks. A prominent fault between 1780 and 1790 ft. (543 and 546 m) separates massive basalt from underlying interbedded tuffs, sediments and thin basalt flows. This fault is interpreted to be F1. A major fault (F7; Fig. 3) pre-dating F1 (and F6) is inferred from the foreshortening of the basalt sequence in 45-14 (1700 ft/518 m) relative to its thickness just a mile (1.6 km) to the north and two miles (3.2 km) east (2700 ft/823 m).

Alteration of the rocks in well 45-14 is minimal. Trace to minor amounts of the yellow-green smectite described earlier are erratically scattered in the interval between 400 ft/122 m and 1000 ft/328 m, along with traces of calcite, goethite and chalcedony. The basalt sequence is essentially unaltered, except for local traces of celadonite, smectite, calcite, and various zeolites. Local quartz-pyrite chalcopyrite veinlets in the Permian-Triassic (?) metamorphic sequence are undoubtedly pre-Tertiary in age.

An equilibrium temperature profile for 45-14 (Fig. 3) shows three distinctive segments -- an isothermal interval at about 43°C/109°F between 100 ft/30.5 m and 640 ft/195 m; an interval with a temperature gradient of about 130°C/km to a depth of 2100 ft/640 m; and a conductive, low-gradient (38°C/km) interval from 2100 ft/640 m to the bottom of the well, at which the maximum temperature of 119.67°C/247.40°F was recorded. The deep, conductive, low gradient interval is confined almost entirely to pre-Tertiary metamorphic rocks, and

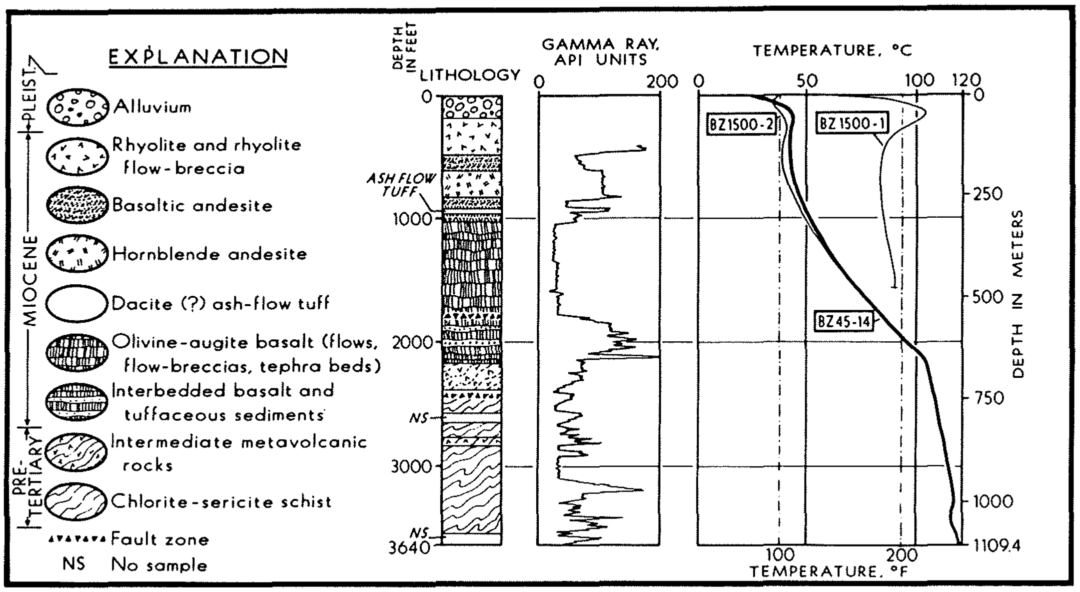

Figure 2. Lithology, gamma ray and temperature logs for deep test well BZ45-14, Baltazor Hot Springs KGRA, Humboldt County, Nevada. Temperature logs for BZ1500-1 and BZ1500-2 are shown for comparison. Gamma-ray log by Gearhart (1983). Temperature data from Southwest Drilling and Exploration Co. (1983).

probably indicates these rocks to be impermeable. The intermediate level higher gradient interval could reflect generally lower thermal conductivities of associated basalts. The isothermal portion of the profile indicates cool water influx in fractured high-level volcanic units.

DISCUSSION AND CONCLUSIONS

The location of the Baltazor Hot Springs thermal area is almost certainly controlled by the intersection of northeasterly-trending normal faults with an older, northwest-trending high-angle fault system. The main fault of this system (F2; Fig. 1), in fact, projects southeastward, beneath younger fault blocks and alluvium, to a position almost directly beneath the present hot spring location. The interaction of these two fault systems would create a zone of high fracture permeability, allowing deep circulation and resultant heating of fluids (facilitated by the abnormally high regional thermal gradients of the Battle Mountain heat-flow high; Sass et al., 1971), followed by rapid convection of these heated fluids to shallow depths. Additional reservoir permeability could be developed in rock rubble accumulated in the deep fault trough beneath Baltazor Hot Springs, from the breakage, into the trough, of high-level low-angle fault blocks exposed north of well 45-14 (Figs. 1,3).

As demonstrated by deep-drilling, these low angle fault blocks, the lower of which was penetrated by 45-14 (Fig. 3) apparently do not presently form part of the Baltazor geothermal reservoir. This may be due to high-level sealing along faults west of F3 along the western margin of the deep fault trough discussed above. Evidence of such sealing is the pervasive, recently-developed calcite-silica stockwork at the range front just northwest and west of the hot springs (Fig. 1).

The Baltazor Hot Springs area remains an encouraging moderate- to high-temperature geothermal exploration target. If, as indicated by XRD, Baltazor Hot Springs is presently precipitating silica, reservoir temperatures of at least 180°C/356°F can be reasonably anticipated. Adequate permeability can be expected in fractured volcanics and metavolcanics, and perhaps in overlying rock rubble, beneath about 2000 ft/610 m. Fault F3 (Figs. 1, 3), concealed by alluvium, is probably the principal conduit along which thermal fluids now ascend. The high-temperature "spike" in drill hole BZ1500-1 (Fig. 2) may represent eastward channeling of these fluids into a subsurface alluvial aquifer, or may indicate a concealed fault subsidiary to F3. The temperature decrease beneath the "spike", and associated low thermal gradient, probably indicates the trough-filling sediments below the "spike" to be relatively impermeable.

The depths at which commercially attractive higher temperatures might be encountered is conjectural. Simple downward projection of the apparently conductive gradients (35-38°C/km)

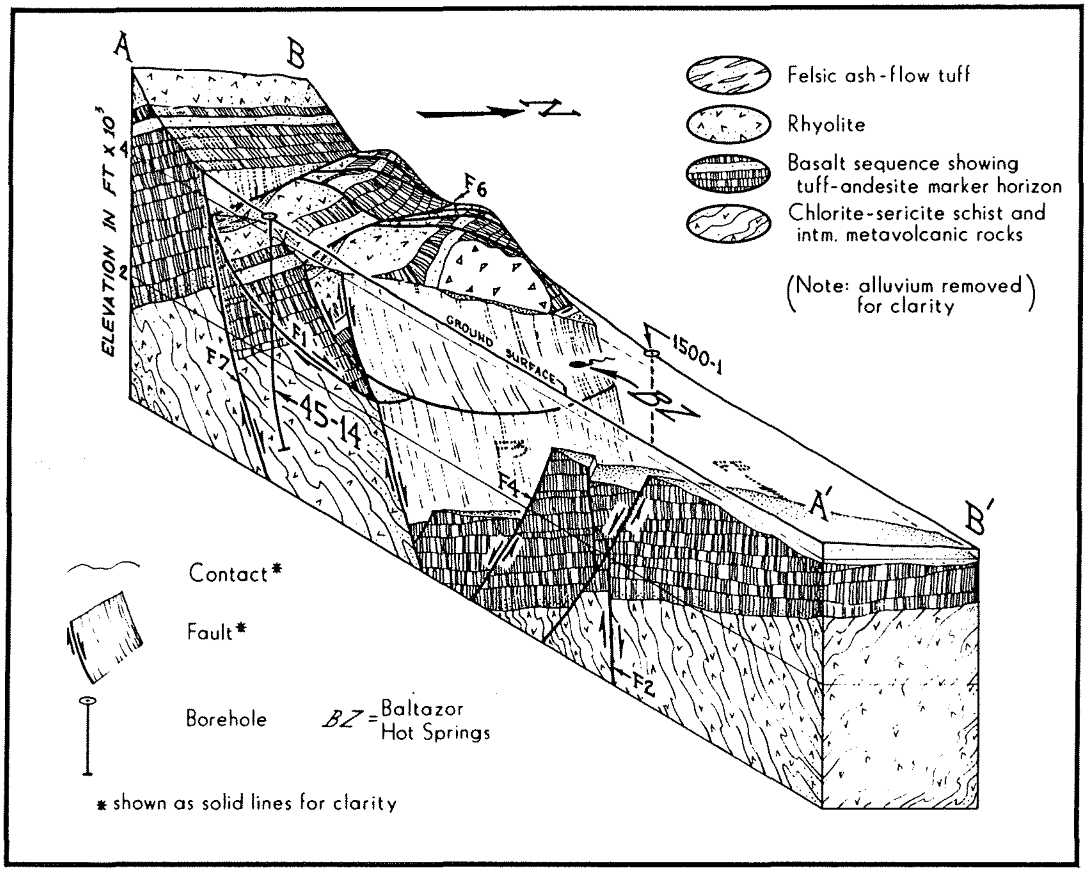

Figure 3. Interpretive 3-D geologic section AA'-BB' through Baltazor Hot Springs and deep well BZ45-14.

encountered in the lower portions of BZ45-14 and BZ1500-1, however, yields temperatures of 150°C/302°F at about 5800 ft/1768 m and 180°C/356°F at about 8500 ft/2991 m. Presumably, convection would result in these temperatures prevailing at shallower depths.

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