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STRUCTURAL INFERENCES FROM GEOLOGIC AND GEOPHYSICAL DATA AT THE BEOWAWE KGRA, NORTH-CENTRAL NEVADA

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ABSTRACT

Lithologic and structural patterns in the Beowawe KGRA as inferred from resistivity and shallow seismic reflection data are consistent with mapped geologic units and structures and with the logs of two deep geothermal test holes. The spectacular surface phenomena at The Geysers mark an area where several fault patterns intersect. East-northeast and northwest normal faults control hot spring distribution and structural blocks in a thick sequence of basaltic andesite flows overlying minor tuffs and the Ordovician Valmy Formation. A similar structural complexity occurs in Horse Heaven, 4 mi (6.4 km) southwest of The Geysers.

INTRODUCTION

The Beowawe geothermal system has been the subject of intermittent exploration activity since 1959. Explorationists have focused their efforts largely on the area within and immediately adjacent to the sinter apron and have drilled fifteen wells on the prospect (Garside and Schilling, 1979). Initial exploration encountered a reservoir of 200°C fluid at depths less than 100 feet (300 m) below the terrace (Oesterling, 1962). Chevron Resources Co., however, has recently drilled two deep wells 1.0 mi (1.6 km) southwest of The Geysers. Their wells and geophysical data have expanded the area of exploration interest at the Beowawe KGRA.

Electrical and seismic surface geophysical data from the Beowawe KGRA, Nevada effectively complement mapped structures and geologic units. Our numerical modeling of 78 line-miles (125 km) of dipole-dipole resistivity data permits extrapolation of known geologic features and strengthens models of unexposed structure. A shallow active seismic survey provides additional support. Chevron Resources Co. submitted the raw geophysical data as part of the Department of Energy, Division of Geothermal Energy's Industry Coupled Program. Our work, funded by contract no. DE-AC07-78ET-28392, will contribute to models being developed by Earth Science Laboratory (ESL) in a detailed case study of the Beowawe KGRA area.

The surface expression of the Beowawe geothermal system is a 0.75 sq. mi. (2 sq. km.) sinter apron with two clusters of hot springs, fumaroles, and weakly active geysers (Fig. 1). Recent hot spring activity along a mapped fault bounding the Malpais Rim has produced a narrow, 0.5 mi. (.8 km) long sinter terrace. Present natural geyser activity is weak due to the recent uncapping of wells on the terrace which eject water and steam to heights of 30 feet (10 m). Several hot springs boil at 95°C (Rinehart, 1968). Various chemical geothermometers indicate reservoir temperatures ranging from 200°C to 250°C (Muffler, 1978).

GEOLOGY

The Malpais Rim is one of several east-northeast striking cuestas in north central Nevada (Fig. 1). A steeply inclined scarp slope faces northwest towards Whirlwind Valley. The general inclination of the Malpais dip slope is 5° to 10° southeast.

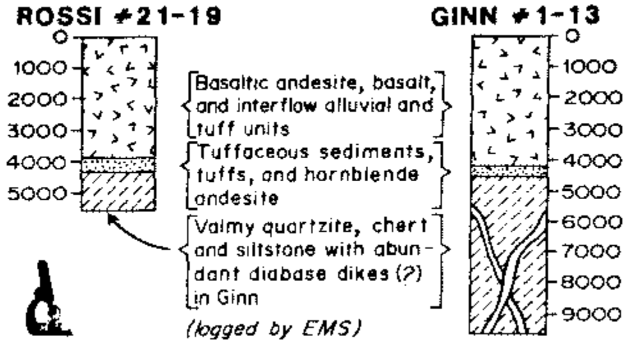
Normal faulting on a northwest trend predates the growth of the Malpais scarp. An early- to mid-Miocene trough (Zoback, 1979) developed to the southwest of the Whirlwind-Crescent boundary fault zone, Fig. 1. During this period, tuffaceous sediments, tuffs, and hornblende andesite flows filled and overflowed the trough, covering the quartzites, cherts, and siltstones of the Ordovician Valmy Formation. Cuttings from the Chevron test holes (Fig. 2), indicate that these Miocene rocks accumulated to a thickness of 500 feet (150 m) within the trough, whereas a maximum of 100 feet of the unit appears in poor exposures on the Malpais scarp slope to the northeast of the Whirlwind-Crescent boundary fault zone. Late Miocene to Pliocene basaltic andesite and basalt flows subsequently filled the developing trough and produced a 4000 foot- (1,200 m-) thick section of volcanics in the vicinity of The Geysers and the Chevron test holes. A drastically thinned 200 to 500 foot (60 to 150 m) section of volcanics extends east of the boundary fault zone. The volcanics gradually taper in thickness from The Geysers toward the southwest end of Horse Heaven.

The Malpais fault zone developed after the eruption of the basaltic andesites; the normal faults controlling the scarp vary in strike from east-northeast to north-south. The orientations of these faults accomodate two flexures in the overall east-northeast trend of the Malpais Rim. The Geysers occur at one of these flexures. A set of steeply dipping east-northeast trending faults controlling the Malpais Rim scarp slope apparently carry hot fluid to the surface. Northwest and west-northwest trending vertical faults may limit the northern and southern extent of modern surficial thermal activity. At the southwest end of the terrace, the Malpais scarp curves to the south-west; however, elements of the east-northeast fault set appear to continue westward into the valley, creating a subtle horst-like structure.

North-south trending faults at the east end of Horse Heaven also deflect the Malpais Rim from its general northeasterly trend. The structural complexity there offers potential for upward migration of thermal fluids, although no surficial thermal features exist.

Uplift along the Malpais scarp east of the Whirlwind-Crescent fault zone exposes the Valmy and a swarm of chalcedony-carbonate veins. Broad areas of silicification, argillization, and brecciation overlap the Valmy formation and the basaltic andesites. Apparently, the faults controlling the Malpais scarp also served as conduits for hydrothermal fluids earlier in the evolution of the scarp.

FIGURE 2
Lithology Summary of Chevron Test Holes



RESISTIVITY

Figure 3 is a map of the Whirlwind Valley area showing the interpreted intrinsic resistivities for the first 400 feet (120 m) below the surface. It also shows major faults inferred from our detailed two-dimensional numerical models of the ten dipole-dipole pseudosections provided by Chevron Resources Co. (Chevron, 1979).

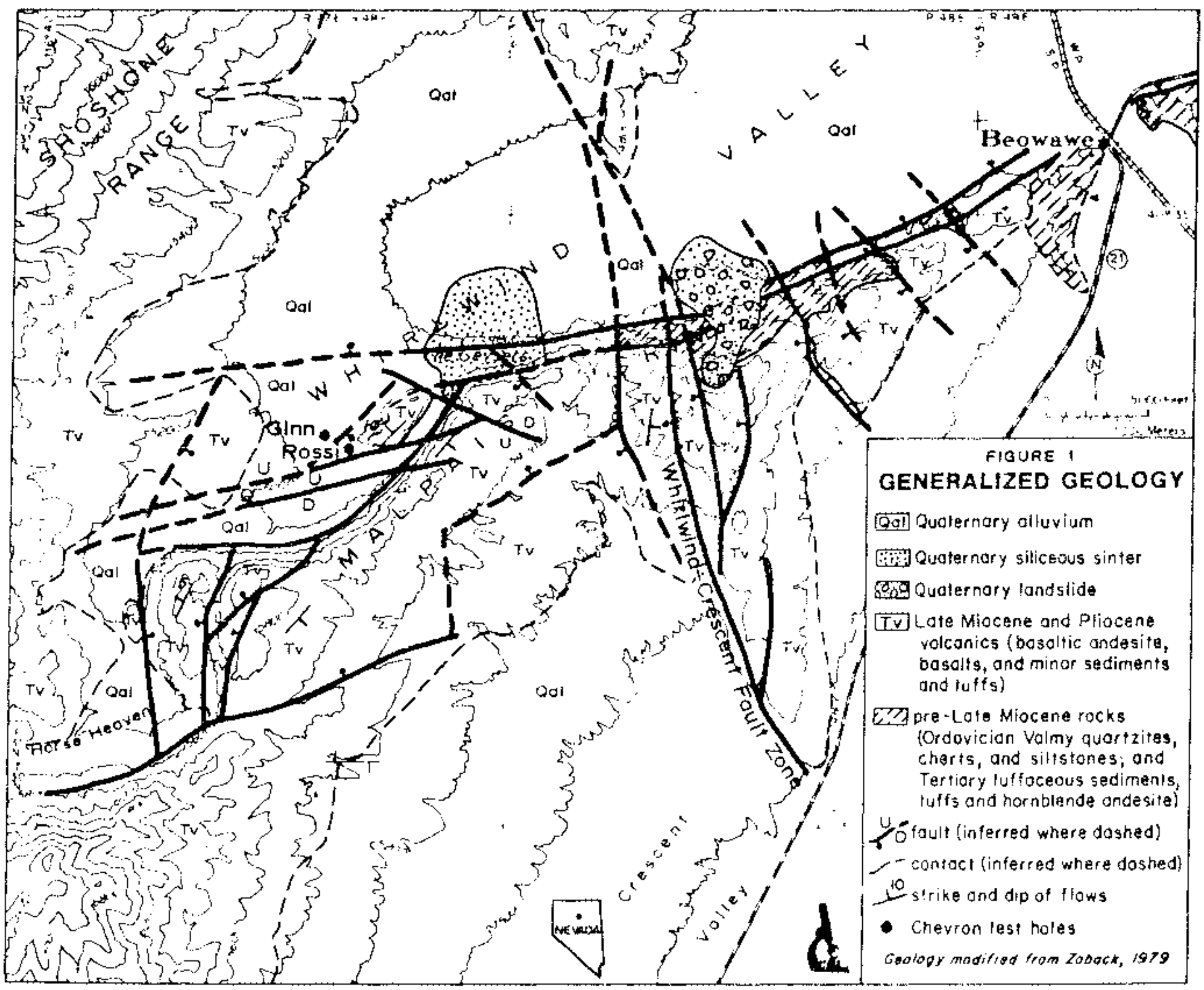


FIGURE 1
GENERALIZED GEOLOGY

Two anomalous conductive zones have been delineated: one is coincident with The Geysers, the other crosses Horse Heaven. Both zones are structurally complex. The inferred faults strike approximately east-west and define a horst. They have as much as 1000 feet (300 m) of throw but have been neither identified in the Shoshone Range nor traced across the conductive zone that crosses Horse Heaven.

The distribution of near-surface resistivities generally mimics the mapped pattern of outcrops. The weathered basaltic andesite of the Malpais Rim and the Shoshone Range has 50-65 ohm-m resistivities. Higher resistivities (75-150 ohm-m) occur within the Whirlwind Valley where a veneer of alluvium covers the volcanics. The conductive zone below the Malpais Rim is less than 400 feet (120 m) thick and spreads from The Geysers to the northeast, down the hydraulic gradient within the valley fill. The resistivity data suggest that upwelling hot water is restricted to a small area immediately adjacent to The Geysers. The anomaly that crosses Horse Heaven may indicate the location of a separate, buried hydrothermal resource or, alternatively, be the response to a carbonaceous or pyrite-bearing sequence of the Valmy Formation. East of The Geysers, a small area with very high (300 ohm-m) resistivity (Fig. 3) coincides with exposures of brecciated, highly silicified Valmy siltstones and quartzites (Fig. 1).

Figure 5 is our interpreted cross-section along WV-2, the dipole-dipole line that passes nearest the deep Chevron wells. Figure 2, the lithologic logs for these wells, provides control for the interpretation of the resistivity section. Five distinct electrical units appear in Figure 5; Table 1 summarizes these units and their lithologic correlations.

SEISMIC REFLECTION

Our interpretation of weight-drop seismic reflection data provided by Chevron delineates several faults in a nine square mile (15 sq. km.) area southwest of The Geysers (Fig. 4). The trend of inferred shallow faults in the Whirlwind Valley is predominantly east-west. Near the southwest end of the valley, the seismic data reveal a flexure in the fault pattern; some of the faults trend northeast-southwest and may connect with mapped faults in Horse Heaven (Fig. 1). Directly

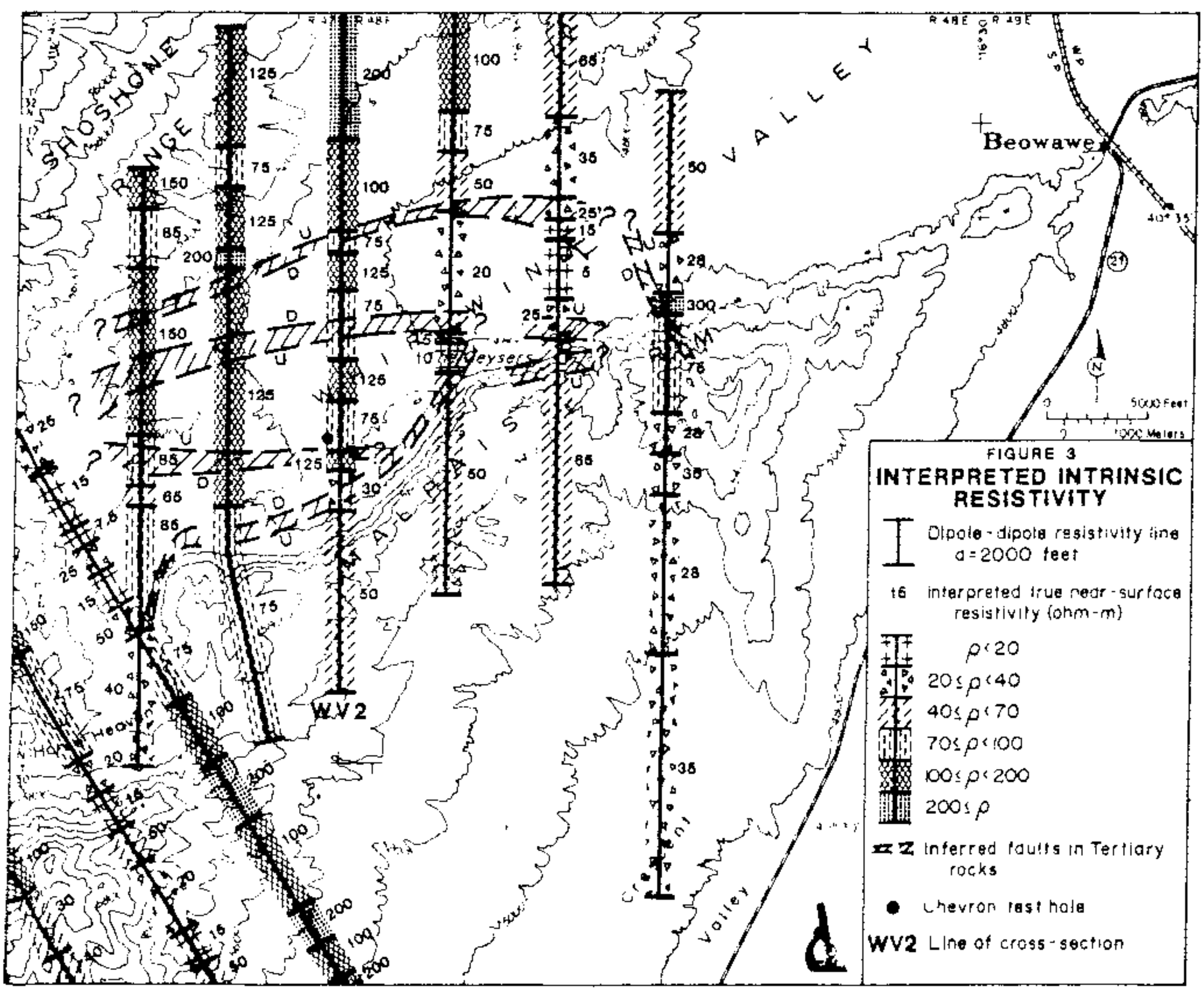


FIGURE 3
INTERPRETED INTRINSIC RESISTIVITY

west of a low hill in the valley below the Malpais Rim is an area that is remarkably free of faulting. This area is an east-west uplift relative to the Whirlwind Valley to the north and the base of the Malpais Rim scarp to the south.

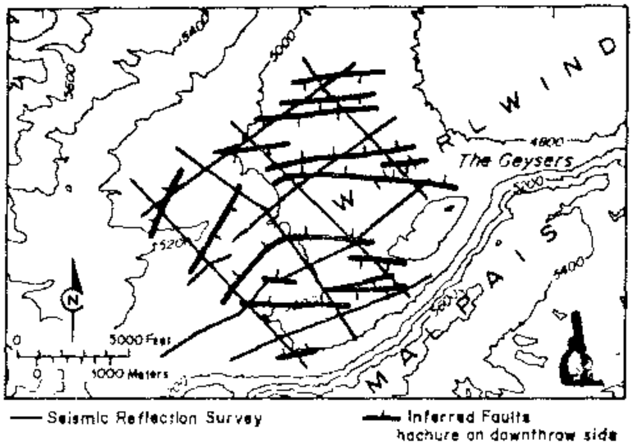


FIGURE 4 FAULTS INFERRED FROM SEISMIC REFLECTION SURVEY

CONCLUSIONS

The electrical units inferred from the resistivity data correspond in area and thickness to lithologies mapped on the surface and encountered in the deep test wells. A shallow conductive zone appears at The Geysers, an area where mapped fault zones intersect and the Malpais scarp flexes. Geologic evidence suggests that east-west trending faults extend west of The Geysers and form a subtle horst-like structure. This structure is apparent in both the resistivity and seismic data but has not been traced into the Shoshone Range. The seismic data suggest that the buried structure bends to the southwest near Horse Heaven and may connect with north-south trending structures apparent in geological and electrical data from Horse Heaven.

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TABLE 1 - ELECTRICAL UNITS AND CORRELATIVE LITHOLOGIES

Electrical Unit	Interpreted Intrinsic Resistivity (ohm-m) average	range	Location and Correlative Lithology
1	50	35-200	Weathered basaltic andesite of Malpais Rim and Shoshone Range (Tba).
2	100	50-250	Basalts and Tba within Whirlwind Valley and Horse Heaven.
3	30	20-40	Ordovician Valmy Fm (Ov); underlies units 1 and 2.
4	10	5-15	Hot water and hydrothermally altered Tba and Ov.
5	10	5-15	Possible hot water or carbonaceous or sulfide-rich sequence within (Ov).

FIGURE 5 ELECTRICAL CROSS-SECTION: LINE WV 2