FINAL REPORT

FIELD STUDIES OF GEOTHERMAL RESERVOIRS RIO GRANDE RIFT, NEW MEXICO

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KEY WORDS

New Mexico, Rio Grande rift, alteration, geologic mapping, Jemez Pueblo, Hillsboro, Rincon, San Diego Mountain, hydrothermal history, hydrogeologic models

1.0 PROJECT BACKGROUND

The Rio Grande rift provides an excellent field laboratory to study the nature of geothermal systems in an extensional environment (Figure 1). Much of the geologic complexity that is found in the Basin and Range is absent because the rift is located on cratonic crust with a thin and well-characterized Phanerozoic stratigraphy and tectonic history. On the other hand, the Neogene thermo-tectonic history of the rift has many parallels with the Basin and Range to the west (Chapin and Seager, 1975; Seager and others, 1984).

The geology of the southern Rio Grande rift is among the best characterized of any rift system in the world. Also, most geologic maps for the region are rather unique in that detailed analyses of Quaternary stratigraphic and surficial units are added in concert with the details of bedrock geology (Gile and others, 1981; Seager and others, 1982; Seager and others, 1987; Seager and Hawley, 1973; and Seager and others, 1971).

Pleistocene to Holocene entrenchment of the Rio Grande and tributaries unroofs the alteration signatures and permeability attributes of paleo outflow plumes and upflow zones, associated with present-day, but hidden or "blind," hydrothermal systems at Rincon and San Diego Mountain (Witcher, 1991a, and 1998).

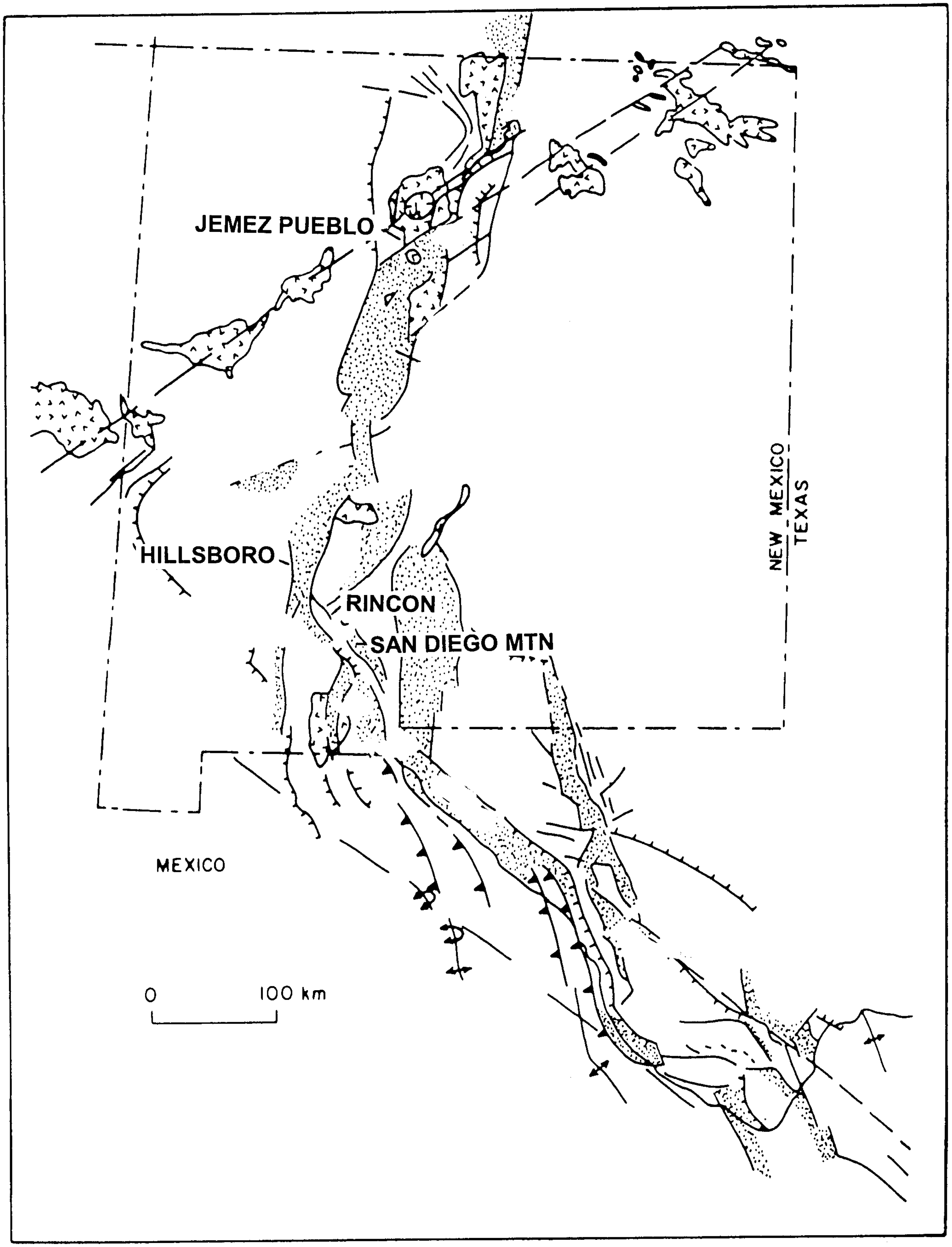

Figure 1 Location map of the Rio Grande rift and field study areas.

These areas are important because both the hanging wall and footwall expressions of major controlling structures are exposed. Alteration aureoles, intercalated paleo hot spring deposits, and domains of fault- and geothermal-related fracturing exposed in badlands topography allow a "four" dimensional view of these systems. A view of the fourth dimension, time, for these geothermal systems is possible because the stratigraphy, tephrochronology and paleomagnetic signature of host Pleistocene sediments is very well characterized (Mack and others, 1998; Mack and others, 1996; Mack and others, 1993; and Mack and James, 1986). In addition, hydrothermal alteration and paleo spring deposits provide additional datable material. In many cases, paleo hot spring deposits are draped across geomorphic surfaces (terraces and straths) associated with an entrenching ancestral Rio Grande (post 700 ka) (Jarvis and others, 1998).

This project also has a near-term economic development goal to spur geothermal use at Jemez Pueblo in order to provide much needed revenue and employment opportunities. Available resource data suggest that geothermal production for direct-use may have among the lowest capital and operating cost potential of the resources in New Mexico due to the shallow reservoir depth and artesian head of the fluids (Witcher, 1991b).

2.0 PROJECT OBJECTIVES

Recognition of geohydrologic windows through the use regional subcrop map compilations appears to provide a first-order geologic model to predict resource occurrence on regional and intermediate scales (Witcher, 1988). However, the actual nature of the flow paths, recharge sources, depth of circulation, relation to Neogene tectonism and magmatism, and behavior of the systems through time is unknown or very poorly defined for Rio Grande rift geothermal systems outside of the Valles Caldera area in Jemez Mountains of New Mexico. This research project is directed at defining the main geologic and hydrogeologic characteristics of higher temperature geothermal systems in the Rio Grande rift outside of the Valles Caldera.

2.1 Technical Objectives

- Identify and map primary and secondary structural and stratigraphic controls on system upflow and lateral outflow.
- Characterize the signatures associated with the upflow and lateral outflow alteration and fracture mineralization.
- Describe the paragenetic sequence of alteration minerals and events.
- Map the extent of petrologic signatures of hydrothermal processes and events.
- Determine paleo temperatures where suitable information may be obtained from alteration and fracture mineral phases.
- Define the lateral extent of the shallow geothermal resource at Jemez Pueblo.

2.2 Expected Objectives

- Document the temporal and spatial evolution and development of geohydrologic windows for rift hydrothermal systems with respect to architectural elements of the rift and complementary normal faults and stratigraphy.
- Document the nature and importance of older deeply-penetrating pre-rift structures for fracture permeability and reservoir hosts.
- Detail the hydrothermal history and relate this history to the Neogene timelines of regional geologic evolution and climate.
- A dipole-dipole resistivity survey will determine the extent of the shallow geothermal resource at Jemez Pueblo and lead to near-term utilization.

The results of the field case studies have much value to successfully explore and wisely develop "blind" Basin and Range or rift-related and fracture-dominated geothermal systems.

3.0 APPROACH

Detailed geologic mapping delineates the structural permeability of these systems and the alteration types and distribution. Major stratigraphic units include fluvial channel deposits of sand and gravel, opal beds (siliceous sinter), overbank silt and clay and other beds as necessary to describe the outflow plume alteration and hydrostratigraphy. Stratigraphically coherent sampling for alteration was performed in conjunction with the mapping. Alteration studies include petrographic study of thin-sections and X-ray diffraction. Petrographic analysis of core from the 371 m deep Rincon SLH#1 core hole was also being conducted.

Finally, a dipole-dipole electrical resistivity survey in conjunction with Dr. Howard Ross, Energy and Geoscience Institute (EGI), University of Utah and Claron Mackelprang was completed in the geothermal resource areas south of Jemez Pueblo.

4.0 RESEARCH RESULTS

The Rincon and San Diego Mountain geothermal systems are associated with Neogene inversion tectonics within the rift. Both areas represent basement terranes or horst blocks that are actively piercing upward from an older Miocene graben floor through Oligocene to Late Miocene volcanics and basin fill. The hanging walls on both uplifted terranes contain fracture and breccia zone barite and minor fluorite mineralization. Uplift of Precambrian granite to the surface at San Diego Mountain may exceed 2 km since 9.6 Ma, the age of the Seldon basalt flow (Seager and others, 1984) that was extruded on to the floor of the

Miocene Rincon basin near the end of basin deposition. An apatite fission track age on the San Diego Mountain granite in the footwall indicates uplift through the 120 ^{o}C isotherm at 6.5 +/- 2.2 Ma (Kelley and Chapin, 1997).

Footwall barite mineralization in these areas has several important implications. First, this mineralization may document reservoir conditions of present-day geothermal systems in the rift because the low salinity and moderate homogenization temperatures of fluid inclusions are compatible with salinity and maximum geothermometers of many higher temperature systems such as Rincon (Witcher, 1991a and McLemore and others, 1998). Pleistocene barite mineralization is also observed in fractures of core from the Rincon SLH1 borehole. Second, the life span of these systems may exceed 6.5 million years and be a hydrogeologic consequence or expression of the tectonism.

At Rincon, mapping shows that the north striking East Rincon Hills fault segments and jogs left lateral in the area of highest temperature gradients and most anomalous SP survey areas discussed in Ross and Witcher (1998). As fault tips are approached at the lateral offset, the fault zone damage increases in intensity and breadth and is characterized by a widening zone of erosion resistant silicified breccia. Hanging wall strata show a "half dome" upwarp geometry around the fault "dog leg." A set of high-angle fractures cuts the hanging wall region of fault tips or segment termination. These fractures are oblique to fault strike and are filled with banded opal. Core from the Rincon SLH1 borehole indicate that the fracture fills change systematically with depth (Witcher, 1998). Only opal is present above 122 m depth, opal is absent below 183 m depth. Drusy quartz is present below 143 m depth along with pyrite and some barite. While fractures are largely filled above 122 m depth, the fractures are partially to fully open at greater depth.

Rift accommodation or transfer zones are emerging from this research as extremely important generators of fracture permeability and for the evolution of hydrogeologic windows for shallow geothermal resources in fault footwalls and horst blocks in the rift. Also, the local architecture of faults such as small-scale transfer zones seems to enhance or create open fracture permeability along the fault plane and in the adjacent hanging walls.

5.0 INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

A. Industry	Three areas, Hillsboro, San Diego Mountain, and Rincon, studied in this project have had lease applications submitted since this project began for exploration and development of binary electrical power production or large-scale (>10 acre) geothermal greenhouse business.
B. Geoscience	Witcher led 110 members of New Mexico Geological Society on field trip to Rincon geothermal area to view surface features the present day geothermal system and the Pleistocene precursor and to discuss alteration and structural controls on the geothermal system.
C. Tribal	Jemez Pueblo is actively planning to develop geothermal as a vehicle for tribal economic development.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This project identified several concepts that are new to Rio Grande rift and southern Basin and Range geothermal systems. Higher temperature Rio Grande rift systems are bedrock-hosted and occur in structurally-high terrane in normal fault footwalls or horst blocks and are preferentially associated with regional rift and local normal fault accommodation or transfer zones. The systems also show a strong pre-rift basement structural setting that is especially well characterized by Laramide (Late Cretaceous -early Tertiary) zones of convergent compressional deformation.

Quaternary to late Miocene horst blocks formed by structural inversion and penetrative uplift of up to several km's through mid and early Miocene rift basin interiors show the strongest fracture permeability potential and alteration. These sites have erosionally- and tectonically-stripped aquitards that expose fractured bedrock to form "geohydrologic windows" at relatively low elevations for discharge of geothermal waters associated with deeply-penetrating regional bedrock and "thermally-sweeping" ground water flow systems.

But probably most important, older Laramide Orogeny northwest-trending convergent zones of compressional deformation where they underlie Neogene geohydrologic windows provide the best local sites for intermediate-to-high temperature geothermal systems in the rift and southern Basin and Range.

A dipole-dipole resistivity survey of about 4 km^2 at Jemez Pueblo is complete and analysis of the data with existing geologic data and other geophysical survey data shows the lateral and vertical extent of the resource along with several promising drill targets for production wells. It is believed that the Jemez Pueblo geothermal resource will be used for a geothermal direct-use by the Pueblo in the near future.

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