AN OVERVIEW OF THE GEOTHERMAL POTENTIAL OF THE SPRINGERVILLE AREA, ARIZONA

by

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I. INTRODUCTION

The "Springerville area," Apache County, Arizona (Fig. 1) initially was selected (Hahman, personal commun., 1977) as a site-specific target for geothermal exploration on the basis of: 1) moderate to high chemical geothermometers, 2) the proximity of young volcanics, and (3) the intersection of regional lineaments based on the alignment of young volcanics, in the White Mountain volcanic field. Based on prior work by Swanberg and others (1977), the initial program focused on the area between the towns of Springerville and St. Johns. Later work directed serious attention as far south as the town of Alpine.

The land status of the study area can be seen in Figure 2. North of Springerville land ownership is a checkerboard of private, state, and federal land, the latter managed by the Bureau of Land Management (BLM). The southeastern area is Apache National Forest. To the southwest are lands of the Sitgreaves and Apache National Forests and the White Mountain Apache Indian Reservation.

II. GEOLOGY

A brief description of the regional geology is presented below. For details, the reader is referred to the reports

LOCATION MAP - PHYSIOGRAPHIC PROVINCES

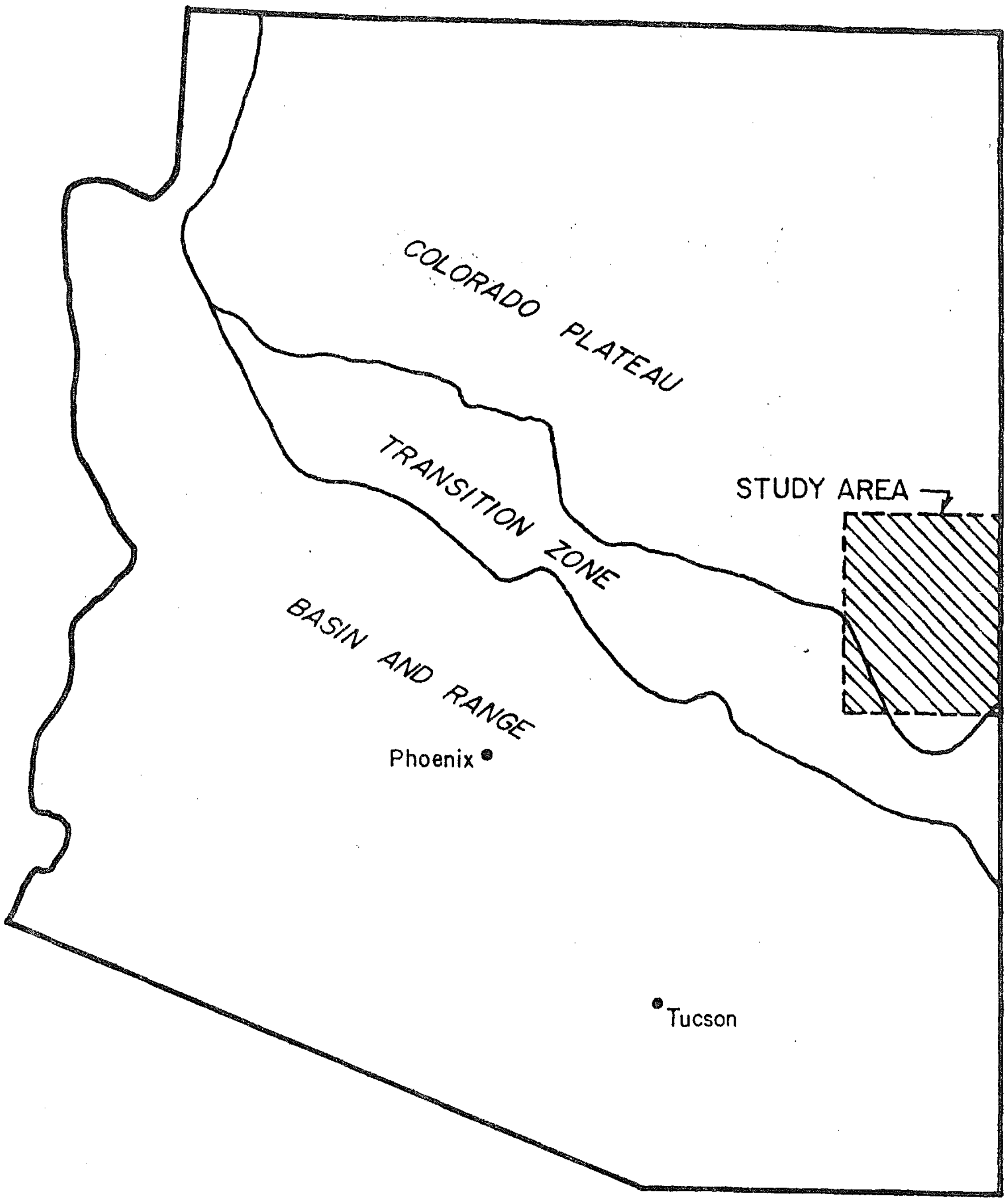


FIGURE 1

LAND STATUS MAP

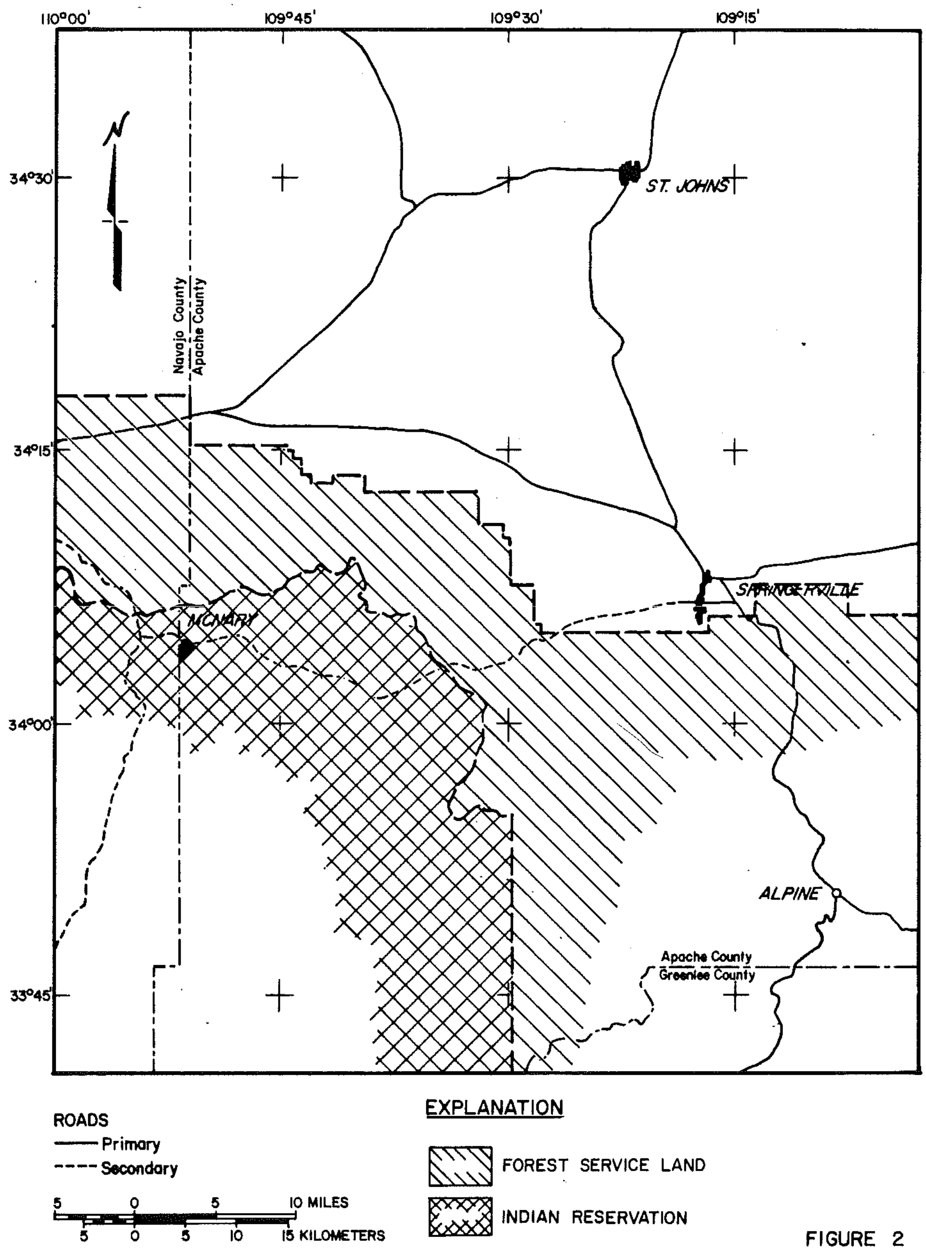


FIGURE 2

of Akers (1964), Merrill and Péwé (1977), Sirrine (1958), and Wrucke (1961). Reconnaissance mapping by Aubele and Crumpler (unpub. reports, 1978) completes the preliminary geologic survey of nearly all of the study area outside the boundaries of previously published reports.

The southern part of the study area comprises principally the Miocene-age Datil Formation which consists of a lower sedimentary member of mainly volcanic detritus and an upper member composed of porphyritic andesite. Overlying the Datil are sandstone, the "upper sedimentary formation" of Wrucke (1961), and basalts of Tertiary and Quarternary age. Two outcrops of the Pennsylvanian or Permain age Naco (?) Formation also were mapped in this area by Wrucke, but their outcrops occur hundreds of feet higher than their usual position in the region. Wrucke states they "may not represent bedrock on which younger formations were deposited," but may be xenoliths rafted in the Datil andesites. Structurally, this southern part of the study area is at the northern edge of the Transition Zone which separates the Colorado Plateau and Basin and Range physiographic provinces (Fig. 1). The Cenozoic formations, while nearly flat-lying, lap northward onto the Colorado Plateau and dip about 1° southward. Wrucke states that the area has few faults and that he can find no structural evidence of separation of the Transition Zone from the Colorado Plateau.

The northern portion of the study area, the Mogollon slope, is lithologically more varied both in outcrop and sub-surface rocks. The sedimentary rocks range in age from late Pennsylvanian to Quarternary. The pre-Cretaceous rocks of the Mogollon slope are characterized by a broad gentle dip to the northeast. During pre-Late Cretaceous time, erosion removed the entire Jurassic system and beveled the surface so that progressively older rocks crop out to the south. Drilling logs indicate the depth to Precambrian granitic basement ranges from about 700 to 1400m. A single deep borehole east of Springerville (Peirce and Scurlock, 1972) confirms the continuation beneath the White Mountains of the stratigraphic units exposed to the west of the volcanic field, specifically the Kaibab Limestone, the Coconino Sandstone and the Supai Formation, all of Permian age.

Volcanism began in the White Mountain volcanic field in middle Tertiary time with the eruption of volcanic and volcaniclastic rocks of basaltic to trachyandesitic composition, with minor rhyolite to the south and east of the Mount Baldy area. This initial phase was nearly continuous between about 38 and 12 m.y.B.P. (Merrill and Péwé, 1977). The second episode of volcanism, the Mount Baldy volcanics, began in late Miocene time. These rocks are composed principally of latite, quartz latite and alkali trachyte and have an aggregate thickness of less than

500m. Merrill and Péwé identified an upper and lower member and present chemical analyses showing that the upper member is more differentiated than the lower and that both units are more differentiated than the pre-Mount Baldy volcanics. The faulted character of the initial, middle Tertiary volcanics versus the relatively unfaulted Mount Baldy Formation led Merrill and Péwé to conclude that the Mount Baldy episode began about 12 million years B.P. An age of 8.6 $\pm$ 0.4 million years was obtained from a late-stage rhyolite flow from the top of Mount Baldy (Merrill, 1974) and provides a probable minimum age to the Mount Baldy episode. A second age determination by Merrill on a basalt from the base of the Mount Baldy area yielded an age of 8.9 $\pm$ 0.9 m.y. and suggests that the transition from intermediate to basaltic volcanism in the White Mountain volcanic field occurred about early Pliocene time.

Aubele and Crumpler (unpub. reports, 1978) identified three units of basaltic lavas, with some late-stage differentiation including silicic domes, that were erupted during the third and latest pulse of activity in the White Mountain volcanic field. New age dates on basalts from this region range from about 6.03 to 0.19 m.y. (Damon and Shafiqullah, personal commun., 1979) from which it can be inferred that basaltic volcanism has been nearly continuous to almost 10,000 years B.P. since its inception nearly 9 million years ago. Aubele and Crumpler through field examination place a lower age limit of greater than 10,000 years on all structures in their study area. Crumpler confirms the suspected WNW and NE orientation of fissures and the alignment of cinder cones along the fissures. He infers from the topography in general that the area is "chopped up with minor faults" but states that the faults predate the lavas of the intermediate unit. Aubele mapped very young travertine mounds and deposits covering an extensive area around Lyman Lake, immediately north of the volcanic field.

An AFM diagram depicting chemical trends of the three major episodes of volcanism (Merrill and Péwé, 1977) clearly shows that the lavas were not generated by continuous differentiation from a single source. It is likely that major tectonic events of the western United States periodically reactivate partial melting at depth along zones of inherent lithospheric weakness. Three such major zones of weakness expressed as regional lineaments, based on alignment of young volcanics, (Fig. 3) (Chapin and others, 1978; Lepley, 1977; Swanberg and others, 1977) intersect in the White Mountain volcanic field and undoubtedly have a dynamic influence on continuing magma generation and volcanism in the area.

III. HYDROLOGY

A summary of ground water conditions in the study area, condensed from Harper and Anderson (1976), follows:

> "...Ground water is present in several aquifers that are made up of one or more formations. The aquifers are stacked one on the other and are generally in poor hydrologic connection. ...in 1974 ground water withdrawal was estimated to be 7,400 acre-ft., which probably is typical of the quantity pumped in recent years."

The Coconino is the principal aquifer in the region; it comprises the Kaibab Limestone, the Coconino Sandstone, and the uppermost part of the underlying Supai Formation. The potentiometric surface in this aquifer shallows to the north. Harper and Anderson state:

> "...Groundwater generally moves from south to north. The depth to water ranges from several feet above the land surface to more than 650 feet below the land surface and depends, to some extent, on the topography. Well yields range from about 100 to 2,500 gal/min...The chemical quality of the groundwater in the Coconino aquifer varies greatly with location. In general, west of Concho the water is of excellent quality and contains less than 300 mg/l (milligrams per liter) of dissolved solids; east of Concho, the quality of water is poor, and the dissolved-solids concentrations are as much as 2,500 mg/l." (See Fig. 5).

Spring and well temperatures are shown in Figure 4. Temperatures greater than 20°C are considered anomalous as the mean temperature for the Colorado Plateau is 16.1°C (Swanberg and others, 1977). It can be seen that a large number of anomalous temperatures occur in the northeast portion of the study area.

LINEAMENT MAP BASED ON ALIGNMENT OF YOUNG VOLCANICS

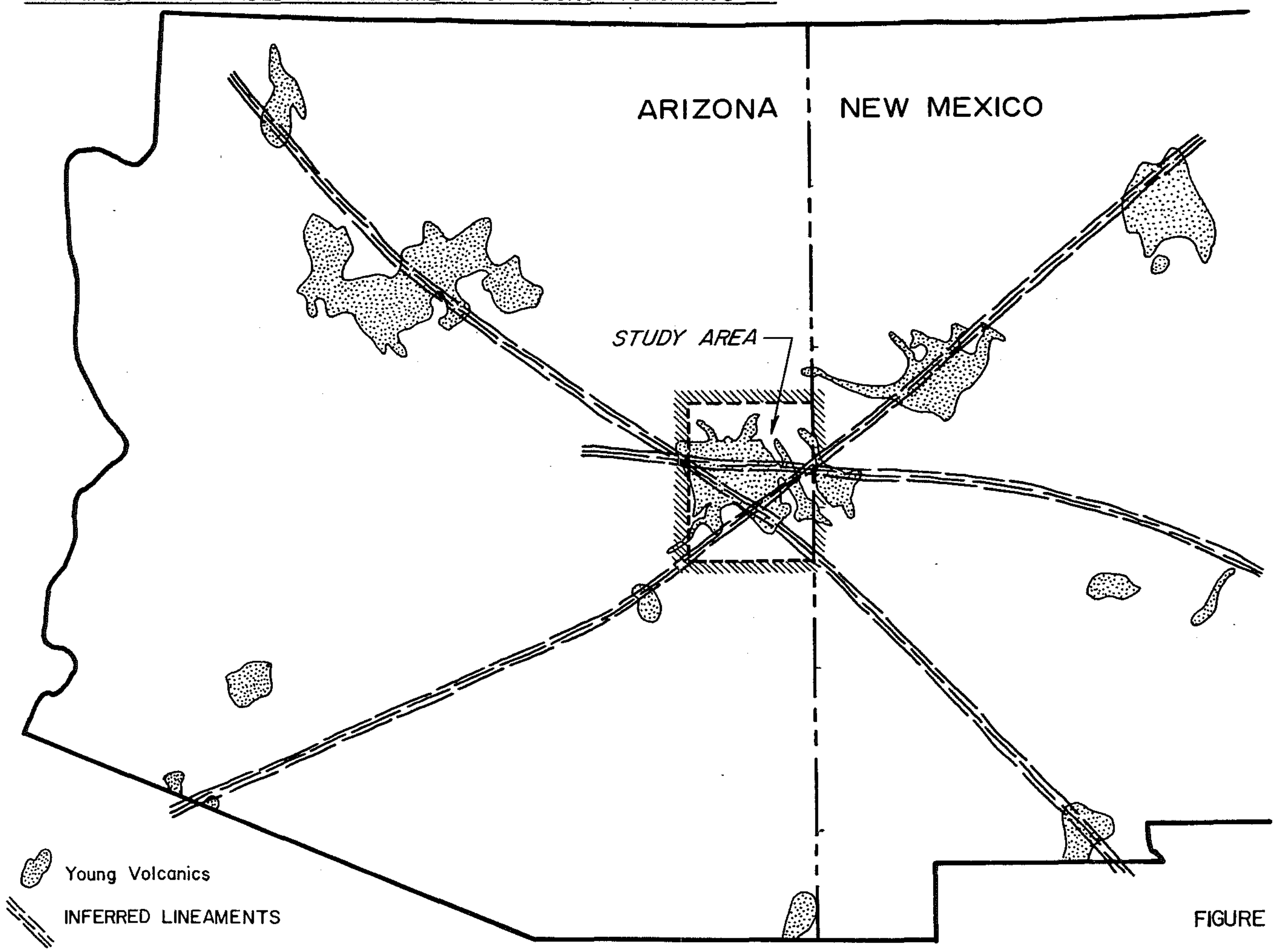


FIGURE 3

WELL LOCATIONS, MEASURED TEMPERATURES

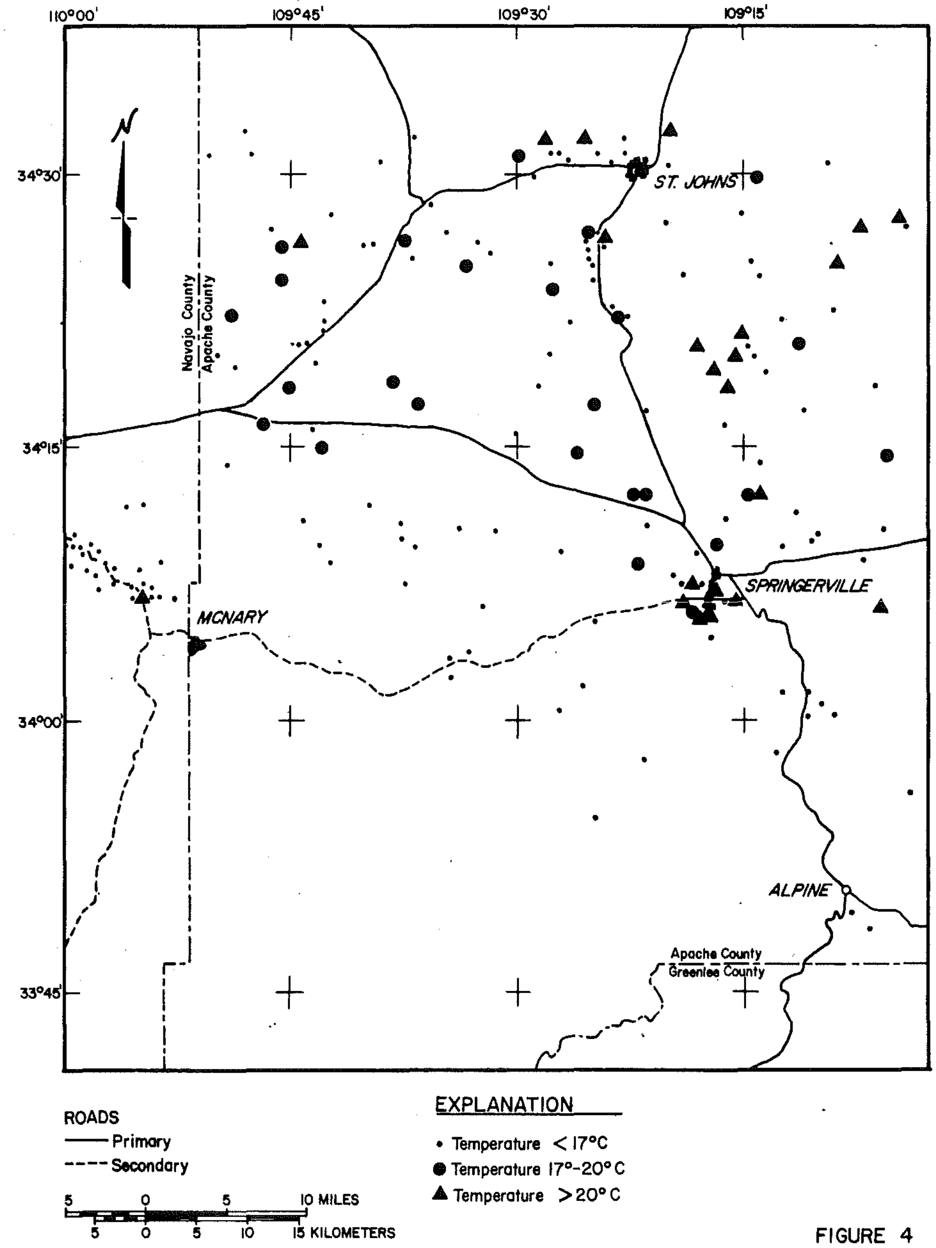


FIGURE 4

IV. GEOCHEMISTRY

Chemical analyses of well and spring waters sampled in the study area (James C. Witcher, personal commun., 1979) and analyses taken from published reports (Swanberg and others, 1977; Akers, 1964) show anomalous Na-K-Ca temperatures, in the range of 170-190°C, around and northeast of the Lyman Lake travertine deposits mapped by Aubele. The deposition of travertine in that area implies that the high Na-K-Ca geothermometers are more likely a result of calcium deposition than of an actual geothermal anomaly (Eckstein, 1975). A problem arises, however, in categorically accepting such a simplistic explanation for the anomalous geothermometers. First, an overlarge percentage of wells and springs with anomalous in situ temperatures of 20°C or greater fall within the general area of the high Na-K-Ca geothermometers (Fig. 4). Most anomalously high geothermal gradients discussed below (Fig. 6), and ground water with high total dissolved solids (Fig. 5) also occur in the same area. These indicators clearly suggest at least qualitatively the existence of a geothermal anomaly.

A second group of springs and wells between Springerville and Nutrioso locally have anomalous SiO_2 geochemical temperatures in the range of 80-90°C (Fig. 5). The average SiO_2 geothermometer for the Colorado Plateau is 49.8°C (Swanberg and others, 1977) so this range is not especially high. Nonetheless, the silica contents (mg/l) of these waters are more than twice the background value for the study area. Qualitatively, this local concentration may also signify a geothermal anomaly.

Geothermal gradients were measured by calibrated thermistor probe at 12 sites within the study area. Additional gradients were computed from tables of water temperatures and well depths (Harper and Anderson, 1976). The data were plotted on a Thermal Gradient versus Depth Plot and gradients that appear anomalous for a given depth were identified. Of the measured gradients two were anomalously high, 27.7°C/km over a 400m depth and 29.1°C/km over a 420m depth and two were anomalously low, 12.3°C/km over a 160m depth and 11.8°C/km over a 200m depth. The two wells with low gradients each exhibited two zones of convection that were not observed in other measured wells. It can be seen in Figure 6 that the wells with low gradients occur mainly in the western part of the study area while those with high geothermal gradients coincide with the occurrence of other geochemical anomalies to the east.

IV. GEOPHYSICS

A large negative Bouguer gravity anomaly, -250 milligals, occurs between Springerville and Alpine (Fig. 7) (West and Sumner, 1973) and is confirmed by Aiken (1975)

ANOMALOUS GEOTHERMOMETERS AND ZONE OF HIGH T.D.S.

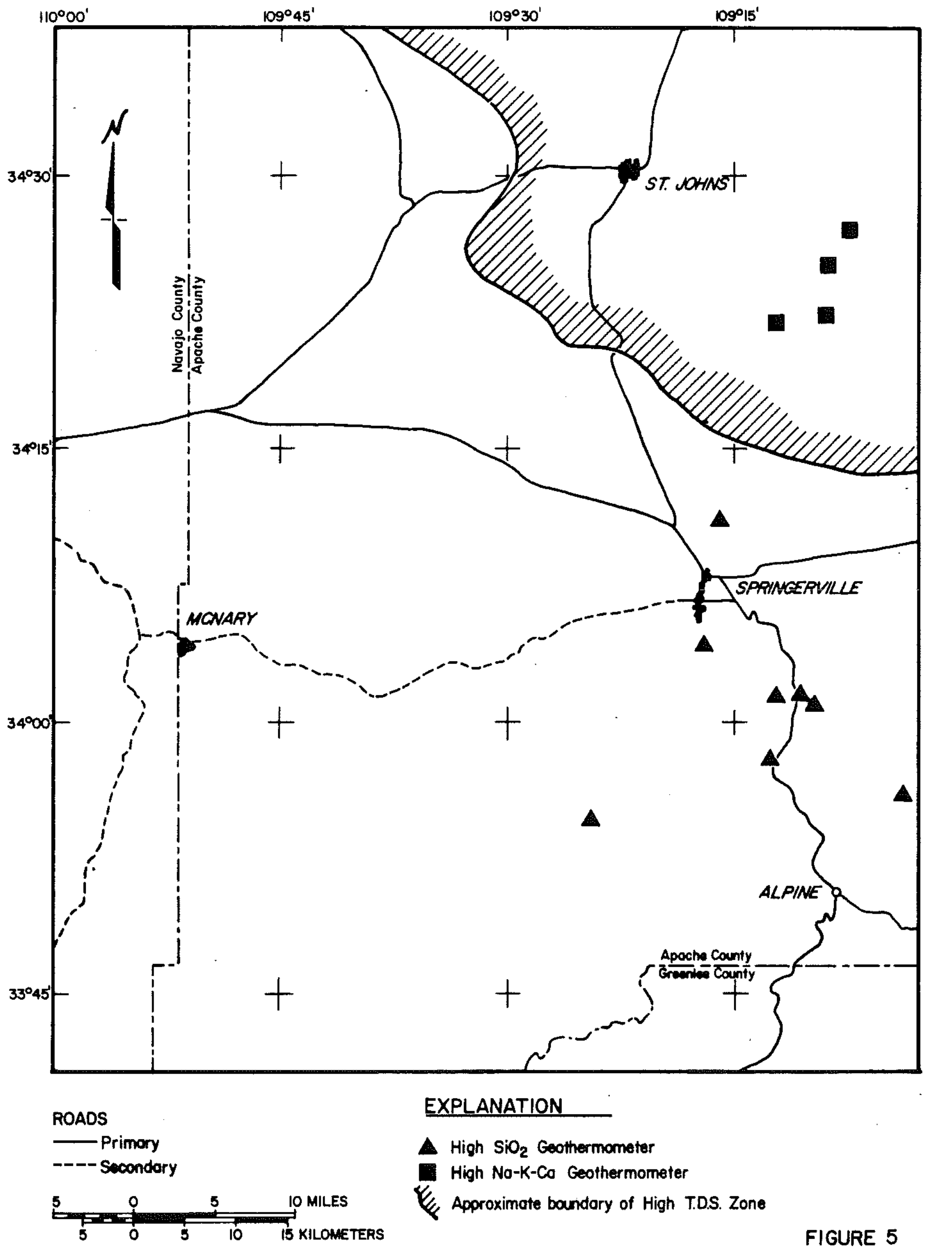


FIGURE 5

ANOMALOUS GEOTHERMAL GRADIENTS

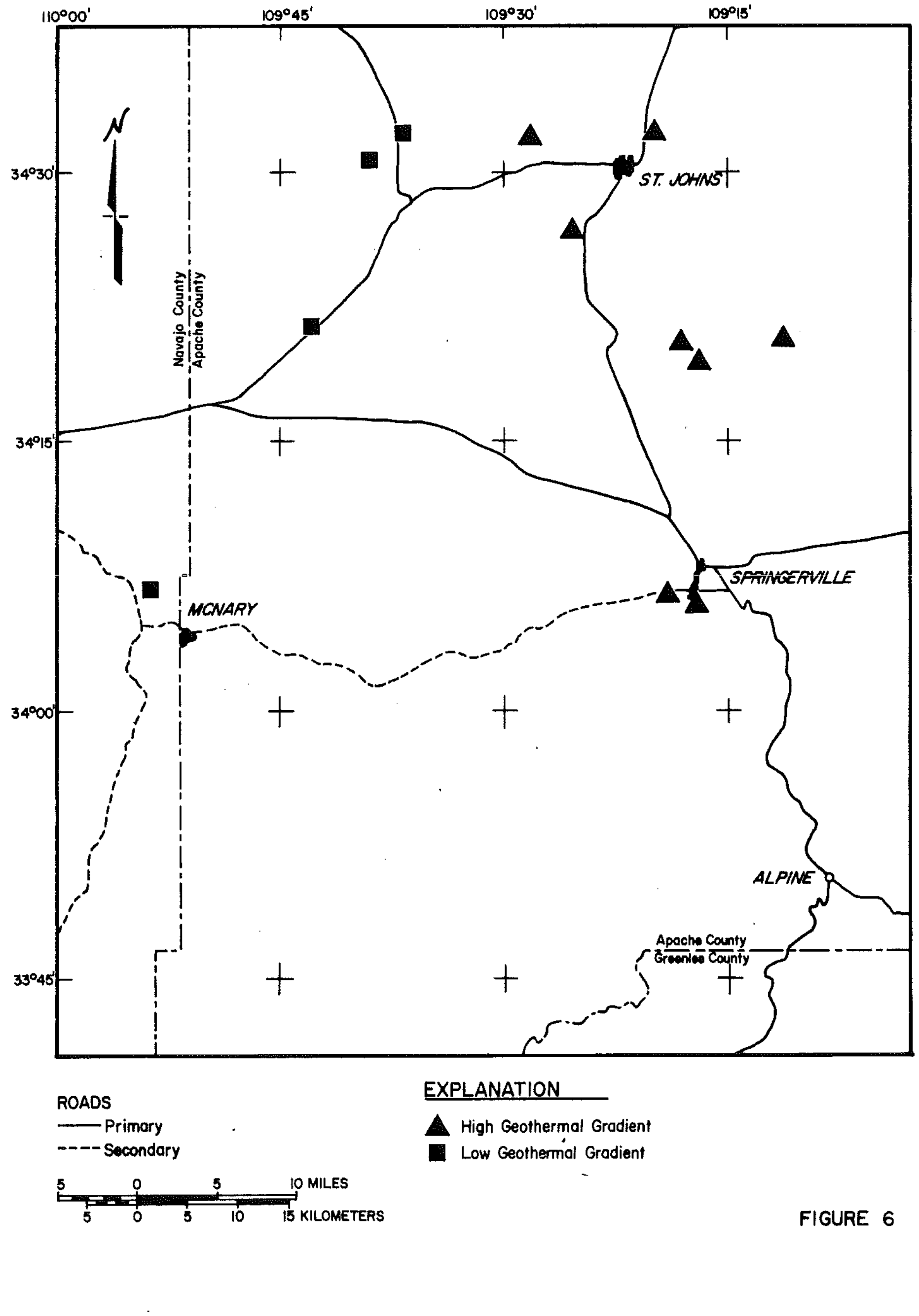


FIGURE 6

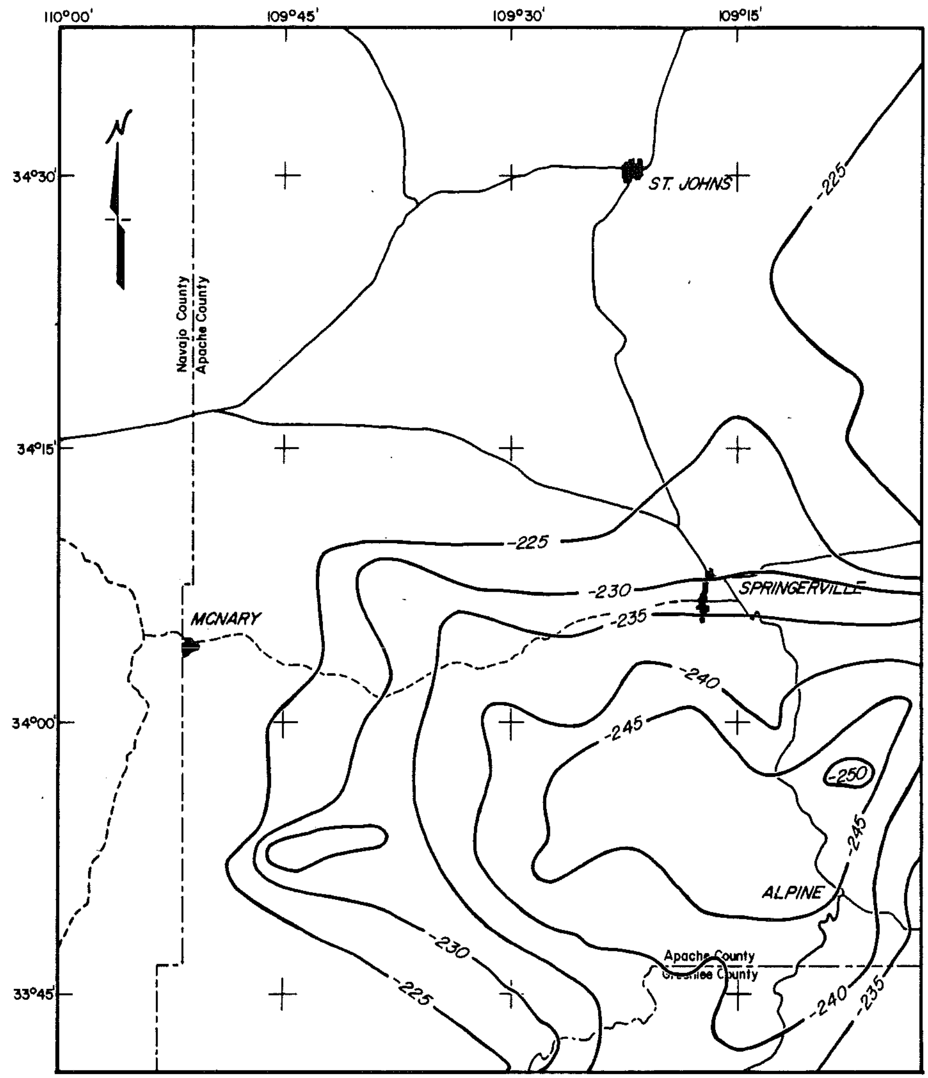
(Fig. 8). Such a local gravity low possibly represents: 1) less dense strata, 2) hydrothermal alteration 3) a magma reservoir, or 4) a buried pluton. Negative Bouguer gravity anomalies of similar magnitude occur in many geothermal areas of the Western U.S.

A single heat flow measurement of $80 mWm^{-2}$ was made from an observation water well north of Springerville. The heat flow was calculated by multiplying the temperature gradient over each linear section of the temperature profile by the appropriate thermal conductivity (Sass and others, 1978). The data are presented in Table 1. This heat flow value falls within the range of regional heat flow inferred for the area by Lachenbruch and Sass (1977) as well as within the upper limits of heat flow predicted for the area by the silica-content method of Swanberg and Morgan (1978).

TABLE 1. MEASURED VALUES USED TO CALCULATE HEAT FLOW FOR SPRINGERVILLE AREA

DEPTH RANGE meters	CONDUCTIVITY W/mK	THERMAL GRADIENT $^oC/k$	HEAT FLOW mWm^{-2}
160-226	2.48	32.3	80.1
226-338	3.80		
	3.04		
	3.08		
	2.98		
	3.00		
	3.16 AVE.	25.0	79.1
338-420	4.44		
	5.28		
	5.02		
	5.28		
	5.01 AVE.	16.1	80.6

BOUGUER GRAVITY ANOMALY MAP



ROADS
—— Primary
---- Secondary

5 0 5 10 MILES
5 0 5 10 15 KILOMETERS

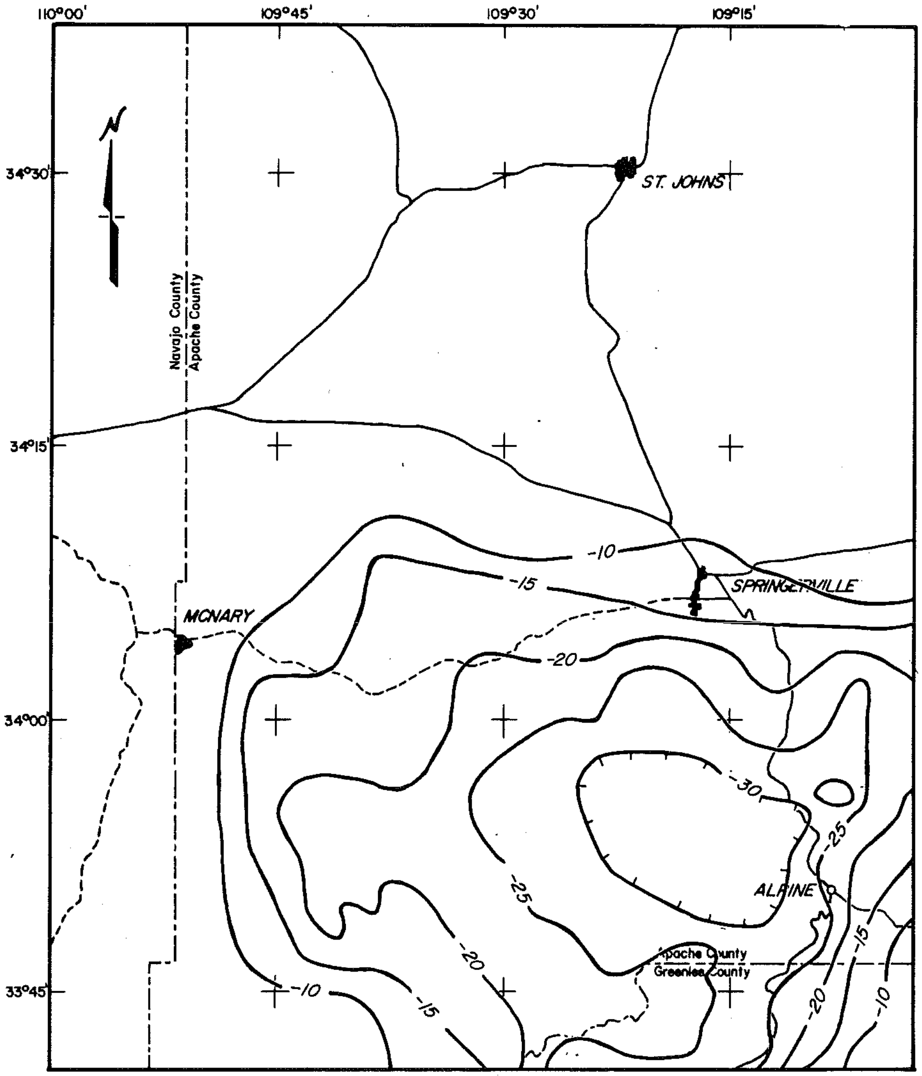
EXPLANATION

BOUGUER GRAVITY ANOMALY MAP
(After R. West and J. Sumner, 1973)

CONTOUR INTERVAL 5 MILLIGALS

FIGURE 7

RESIDUAL BOUGUER GRAVITY ANOMALY MAP



ROADS
—— Primary
---- Secondary

5 0 5 10 MILES
5 0 5 10 15 KILOMETERS

EXPLANATION

RESIDUAL BOUGUER ANOMALY MAP
(After C. Aiken, 1975)

CONTOUR INTERVAL 5 MILLIGALS

FIGURE 8

Preliminary interpretation of a telluric current survey over much of the study area (Young, unpub. report, 1979) shows a broad area of low resistivity, generally south of the highway between Springerville and McNary (Fig. 9). Specifically the survey indicates higher resistivity over the more-northerly sedimentary rocks and lower resistivity over the volcanic rocks to the south. Young interprets the low resistivity as anomalous and possibly indicative of a geothermal anomaly since the survey results are the opposite of those predicted from the geology.

Thompson and Burke (1974) show a pronounced upper mantle LVZ (low velocity zone) trending northeastward through the study area and interpret it as thicker LVZ or lower upper mantle velocity, indicative of a greater degree of partial melting. In another important study, cited by Thompson and Burke (1974), Porath and Gough (1971) estimate variations in depths to the surface of the electrical conductor, inferred to correspond approximately with the 1500°C isotherm. The depths are 190km under the Basin and Range and 350km under the Colorado Plateau, with a ridge beneath the boundary at a depth of 120km. A study by Byerly and Stolt (1977) supports the results of Porath and Gough (1971). Byerly and Stolt identified a narrow zone crossing central Arizona where

RESISTIVITY MAP

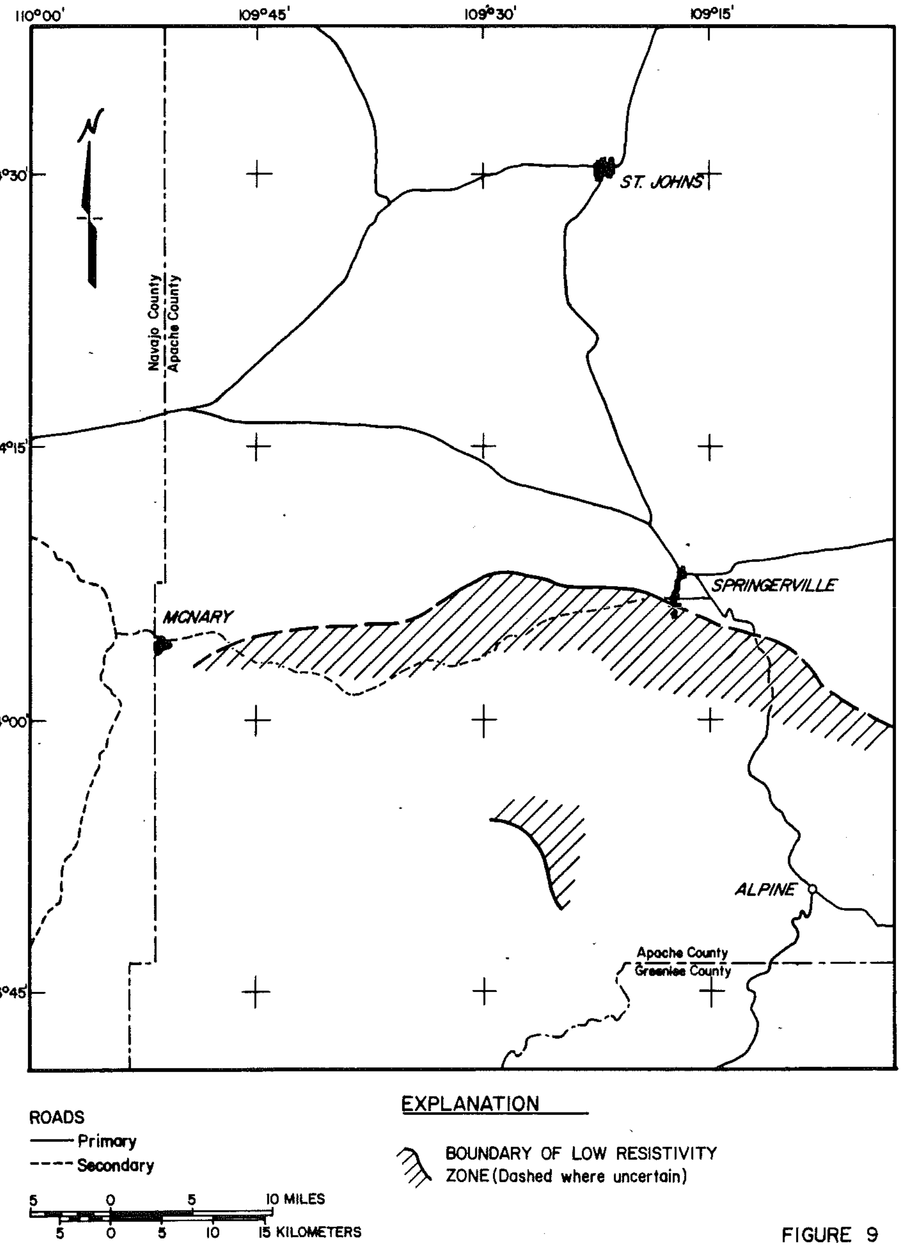


FIGURE 9

depth to the base of the magnetic crust shallows to about 10km or less. The base of the magnetic crust is interpreted by the authors as an isothermal surface at approximately the Curie temperature, taken as 500°C in their study.

V. SUMMARY

Various geological, geochemical and geophysical evidence has been presented describing the geothermal characteristics of the Springerville area. Reactivation of partial melting in the upper mantle (?) along regional zones of fundamental lithospheric weakness has resulted in recurrent volcanism since about 38 million years B.P. Anomalous Na-K-Ca geochemical thermometers occur near Lyman Lake, coincident with: 1) young travertine deposits, 2) anomalous in situ temperatures, and 3) anomalously high geothermal gradients. High silica concentrations are found further south, with slight overlap of both geochemical geothermometers at the town of Springerville. Geophysical data reveal a large negative residual Bouguer gravity anomaly and an electrical resistivity low stacked over the area between Springerville and Alpine. Additional studies from the literature present evidence for a pronounced LVZ, a mantle upwarp, and a rise in the Curie isotherm beneath the region.

VI. CONCLUSIONS

The paucity of geochemical data for the southern part of the study area and a lack of site-intensive geophysical investigations preclude a more definitive assessment at this time of the "Springerville" geothermal anomaly. Still, two inferences can be drawn from the apparent correlation among the known geological, geochemical, and geophysical parameters presented. First, a relatively shallow heat source of unknown character and dimensions exists, probably beneath the area between Alpine and Springerville. Because the single heat flow value north of Springerville is in the normal range the anomaly is most likely small in areal extent. The precise location of the heat source may coincide with the surface expression of the negative residual Bouguer gravity anomaly (Fig. 8). Second, ground water supplying the eastern half of the study area is positively affected by this heat source.

It appears that meteoric water from higher elevations in the White Mountains percolates to some depth where it is heated. This less dense "hot" water then rises along permeable fracture zones. Some of the hot water eventually mixes with cold water from the shallow aquifers and leaks out at the surface in the two areas suggested by the geochemical anomalies. The number of geothermal indicators is greater north of Springerville possibly because hot water more easily intersects the land surface there, where the surface is no longer veneered by insulating volcanic rocks. An alternative explanation is that the fracture permeability is greater in that area than elsewhere.

Several additional studies would enable a more precise evaluation to be made of the geothermal anomaly. First, additional water chemistry and temperature data are needed, along with an understanding of the hydrologic regime south of Springerville. These problems should be resolved in the near future by planned heat flow drilling. Second, geochemical mixing models should be calculated to estimate percent mixing and maximum reservoir temperatures. A detailed gravity survey south of Springerville is necessary to determine reservoir characteristics, and a detailed resistivity survey is essential to define the depth to and size of the geothermal anomaly outlined by the preliminary survey.

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