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GEOTHERMAL POTENTIAL IN THE ALBUQUERQUE AREA, NEW MEXICO

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INTRODUCTION

The Albuquerque area of central New Mexico is at the junction of four of the North American continent's major physiographic provinces. To the west is the broad tableland of the Colorado Plateau, an uplifted region of deeply incised streams, canyons, and major volcanic centers superimposed upon a relatively undeformed and stable platform. Southwest is the tectonically active and structurally deformed Basin and Range province which is characterized by severe crustal disturbances that formed numerous parallel, faulted, mountain ranges and valleys. Adjacent to the east, southeast, and northeast is the southernmost extension of the continent's major structural uplift, the Rocky Mountains. Immediately east of these is the flat-lying, gradually eastward sloping, generally stable mid-continent region of the Great Plains.

These regional relationships emphasize the unique geologic setting of Albuquerque in a tectonic depression known as the Rio Grande rift that is marginal to and separates these larger elements. New Mexico's largest water artery, from its headwaters in the western San Luis Valley of south-central Colorado to the vicinity of El Paso, Texas, flows through a series of en-echelon troughs or grabens that have subsided between mountain uplifts. The Rio Grande has occupied these troughs for millions of years, filling them with the clays, sands, and gravels eroded from adjacent uplifts and with much of the water the river used to transport this huge sediment load.

Access to the near-surface fresh water zone of this enormous unconfined ground-water aquifer is Albuquerque's greatest economic asset to accommodate growth. Utilizing the vast subsurface hot-water system underlying the normal temperature, near-surface regime has the potential to make much of New Mexico's largest community independent of natural gas for its space-heating requirements.

ALBUQUERQUE BASIN

The Albuquerque basin occupies a region in central New Mexico of about 6,530 km' (2,500 mi2) between the Sandia, Manzanita, Manzano, and Los Pinos mountains on the east and the Rio Puerco on the west. The Rio Grande bisects the basin from its northern limit, arbitrarily defined for purposes of this discussion to be near Cochiti dam, to bedrock constrictions near San Acacia, 23 km (14 mi) north of Socorro. Terrain within the basin is essentially flat, with elevations ranging from 1,512 m (4,960 ft) at the Rio Grande in Albuquerque to about 1,780 m (5,840 ft) on the mesas east and west of the river.

Although the surface geology of the region is relatively uncomplicated and exposures in and surrounding the basin have been described in numerous publications, subsurface relationships are not well understood. Well control is extremely sparse. Only eight wells have penetrated the Tertiary basin fill to test the resources of Cretaceous or older formations, and only two wells are drilled into Precambrian rocks (for details see Black, this guidebook).

Indicative of the basin's structural complexity, the Shell Oil Company No. 2 Isleta in sec. 16, T8N, R2E, was completed in 1980 at a depth of 6,482 m (21,266 ft) in what was reported to be basin fill. Ten kilometers (6 mi) east in sec. 8, T8N, R3E, the TransOcean No. 1 Isleta penetrated 1,600 m (5,250 ft) of basin fill before encountering Cretaceous rocks. Precambrian was identified at 3,147 m (10,324 ft) in the TransOcean well. Assuming the Shell well bottomed close to the top of the Cretaceous, adding 1,524 m (5,000 ft) of sedimentary rocks overlying the Precambrian to its 6,482 m (21,266 ft) depth would suggest that the Precambrian surface would be encountered at not less than 8,006 m (26,266 ft) or 6,442 m (21,135 ft) below sea level (surface elevation of 1,564 m 15,131 ft] less drilling depth to the Precambrian). The equivalent datum at the TransOcean well was 1,542 m (5,060 ft) below sea level, indicating a minimum of 4,900 m (16,075 ft) of displacement or structural relief between similar Mesozoic, Paleozoic, or Precambrian horizons in the two wells. The same relationships between these strata at the location of the Shell well and those found at the top of the 3,048 m (10,000 ft) Sandia Mountains nearby demonstrate stratigraphic displacement of at least 9,490 m (31,135 ft).

Cretaceous horizons exposed on or near the Rio Puerco west of Albuquerque are found 3,658 m (12,000 ft) to more than 6,401 m (21,000 ft) below the surface in the basin. This relationship suggests that one or more steeply dipping north-south faults are in the subsurface to form the basin's western boundary and are masked by recent, surface deposits. Similarly, the eastern boundary of the basin appears to be defined by large faults with displacements measured in the thousands of feet near the base of the Sandia Mountains (Sandia fault) and west of a bedrock bench extending 6.4 to 9.7 km (4 to 6 mi) west of the Manzano and Los Pinos mountains to the south (Hubbell Spring fault; see Kelley, this guidebook and Machette, this guidebook).

EASTERN SIDE OF RIO GRANDE RIFT

Physiographic Provinces

Virtually all of the principal tectonic events that formed the eastern side of the Rio Grande rift, the Albuquerque basin, and the adjoining mountain ranges occur on and have profoundly affected lands just south of Albuquerque on Kirtland Air Force Base (Kirtland AFB). At least two major faults, the Tijeras fault, with movement commencing in the Precambrian and continuing through the Quaternary, and the Hubbell Spring fault, believed to be the geologically recent fault that marks the eastern side of the rift, intersect here. Two other faults or fault systems which complete the regional tectonic picture are: (1) the Manzano fault along which the Manzanita, Manzano, and Los Pinos mountains were elevated 396 to 914 m (1,300 to 3,00 ft) above the Hubbell bench, and (2) the Sandia fault that appears to be a northward extension of the Hubbell Spring fault and is presumed to be the point where the massive, east-tilted Sandia Mountains broke away from rocks underlying the Rio Grande rift.

These faults are the geologic basis for subdividing the area into four distinct physiographic provinces. The wedge-shaped region formed by the southwestward projecting, Precambrian granite outcrops of the Four Hills uplift, which terminate at the low hills in the southern half of sec. 28 and northern half of sec. 33, T9N, R4E, is the southernmost extension of the Sandia Mountains. East of the Manzano fault are the Manzanita and Manzano mountains, together forming a relatively undeformed uplift that exposes Precambrian rocks capped by shallowly dipping Pennsylvanian limestones. South of the Tijeras fault, west of the Manzano fault, and east of the Hubbell Spring fault is the Hubbell bench, a zone of Triassic, Permian, Pennsylvanian, and Precambrian rocks mostly capped by a thin veneer of alluvium (see Kelley, this guidebook). West of the Hubbell Spring and Sandia faults is the Albuquerque basin, the only one of the four provinces with significant geothermal implications. These physiographic relationships are shown in Figures 1 and 2.

Tij eras Fault

The Tijeras fault and related tectonic system is one of the most extensive in New Mexico. From its intersection and probable point of truncation by the later Hubbell Spring fault on Kirtland AFB (fig. 2), it trends 93 km (58 mi) northeast to the Cationcito area of the Sangre de Cristo Mountains. It is probable that this fault extended southwest across the area presently occupied by the Albuquerque basin prior to rifting (Ander, 1980). If so, it was bisected by the Hubbell Spring fault and dropped or collapsed with its related segments into the rift, complicating the geometry of structural details in the basin south of Albuquerque.

Chapin and others (1978) have mapped several major crustal lineaments trending northeast across New Mexico and Colorado. These shear zones dominate the structural grain of Precambrian rocks in the southern Rocky Mountains, tend to be oriented along lines of Laramide volcanic plutons (as well as recent lava flows of predominantly basaltic composition), and generally coincide with well-known mineral belts. Where these lineaments cross the Rio Grande rift, they produce a characteristic suite of structural elements. High heat flow and geothermal activity are not uncommon in these areas. Although it is not included in the lineaments described by Chapin and others (1978), the Tijeras fault system would appear to have similar qualities in terms of age, trend, displacement, mineralization (Tijeras Canyon, San Pedro, Ortiz, and by extension, Pecos mining districts), volcanism (Cerro Verde, Lucero Mesa, Cat Hills, Wind Mesa, and Isleta volcanic centers just west of the Rio Grande), and apparent basement complexity.

Hubbell Spring Fault

The Hubbell Spring fault is a remarkable geologic feature. Its length is apparently unbroken for about 58 km (36 mi) from the southeast part of T3N, R4E in Socorro County, to its intersection with the Tijeras fault south of Albuquerque. If the presumed Sandia fault is an extension of the Hubbell Spring fault, its length becomes some 40 km (25 mi) longer. It has almost perfect straight-line symmetry from south to north and, in its northern 29 km (18 mi), it is aligned with a series of freshwater springs that are anomalies on the otherwise dry, desert tableland of the east mesa. Recent movement has raised a prominent 31-to-46 m (100-to-150 ft) scarp on its east side along its northern length. The sharply defined scarp supports a block of flat-lying strata of Triassic through Pennsylvanian age overlying Precambrian rocks that are exposed in the vicinity of Ojo Huelos in sec. 20, T6N, R4E (fig. 3); Hubbell Spring in sec. 9, T8N, R4E; and south of the Tijeras fault (fig. 2).

Titus (1963) has an excellent description of the fault and its relationship to the ground-water regime which is important to the geothermal model in the region:

> Ground water moves westward from the Manzano Mountains toward the Rio Grande in the Cenozoic sediments which rest on rocks of Permian and Triassic age in the upthrown block of the Ojuelos (Hubbell Spring) fault . . . East of the Ojuelos fault the water table in much of the area is less than 100 ft (31 m) below land surface; at the fault the several springs indicate that the water table is at the surface; west of the fault the water table is 400 to 500 ft (122 to 153 m) below the surface. As water moves across the fault into the more permeable rocks of the Santa Fe, it cascades abruptly to the lower level within a short distance.

Whether the Hubbell Spring fault is a master fault identifying the eastern side of the Rio Grande rift or one of several step faults that control basement topography is presently unknown. Gravity surveys conducted on Kirtland AFB revealed a sharp break in the gravity slope north of the Isleta Indian Reservation on the trace of the Hubbell Spring fault, south of its intersection with the Tijeras fault (Grant, 1981).

Sandia Fault

Kelley (1977), Kelley and Northrop (1975), and Woodward and others (1975) postulate a major rift fault separating the Sandia Mountain uplift from the Albuquerque basin, extending some 40 km (25 mi) north from the intersection of the Hubbell Spring fault and the Tijeras fault on Kirtland AFB to the vicinity of Placitas in Sandoval County. Although evidence for this fault is somewhat subjective, many geologists might agree that the concept of a large, extensive, basin-bounding fault or faults is a logical interpretation of tectonic events that would account for the great structural relief between the deepest parts of the basin and the top of the Sandia Mountains. The interpretation of gravity data by Birch (1980), Aiken and others (1978), and Cordell and others (1978) tends to support the premise of a major fault system in front of the Sandias on the eastern boundary of the Albuquerque basin.

A geophysical experiment using controlled-source audio-magnetotelluric (CSAMT) electromagnetic (EM) techniques was conducted at Kirtland AFB in and adjacent to sec. 10, T9N, R4E (Bartel and others, 1981). The experiment was designed to test procedures of locating the Sandia fault where it was presumed to be present beneath the alluvial cover. The results indicated a major change in the depth to granite beneath the alluvium at approximately the common corners of sections 3, 4, 9, and 10. Here, the depth to basement (granite) increases from about 800 m (2,625 ft) to more than 1,300 m (4,265 ft) in a horizontal distance of less than 100 m (325 ft) (fig. 4). The rapid change in depth to bedrock is in the approximate position of the inferred Sandia fault, but whether it is part of a major fault system or a minor step fault was not determined.

The "Travertine Hills"

Travertine is known to be abundant on the western side of the Albuquerque basin along the eastern flank of the Lucero uplift, some 27 to 32 km (17 to 20 mi) west of Belen and Los Lunas (Kelley, 1977). On the eastern side of the basin, travertine has previously been described only as minor deposits located just west of Placitas on the north end of the Sandia Mountains (Kelley, 1977) and at a small outcrop near the CO_2-emitting Coyote Spring located south of the Tijeras fault on Kirtland AFB in sec. 24, T9N, R4E (Reiche, 1949).

The low hills in sections 27, 28, and 33, T9N, R4E, described by Reiche (1949) as Tertiary gravels, are travertine mounds rising some 30 to 38 m (100 to 125 ft) above the east mesa floor, covering about 97 hectares (240 acres). The hills are aligned in a north-south direction, offset less than 0.8 km (0.5 mi) east from the prominent bench of the Hubbell Spring fault trace on the Isleta Indian Reservation, some 4 km (2.5 mi) south. Travertine is also abundant in the channel of Coyote arroyo on both sides of a bridge which crosses it in sec. 22, T9N, R4E.

All of the travertine deposits are conglomeratic. Those in the drainage of Coyote arroyo contain clasts that are predominantly Precambrian granite, quartzite, and schist, while those in the low hills have a preponderance of Paleozoic limestone, sandstone, and shale. Clasts range in size from sand-size material through boulders as large as 30 cm (12 in) in diameter. It would be difficult to assign any significance to the conglomeratic components in terms of an attempt to date travertine accumulations. Beds containing predominantly Precambrian clasts are adjacent to the Tijeras fault where older rocks were probably exposed prior to the beginning of travertine deposition, and the travertine hills are within 1.6 km (1 mi) of Paleozoic outcrops on the Hubbell bench. Boulders of Precambrian quartzite up to 2 m (6 ft) in diameter are found on the northern slope of the northernmost travertine hill. These deposits imply high values of stream competence during periodic floods from the Manzanita Mountains.

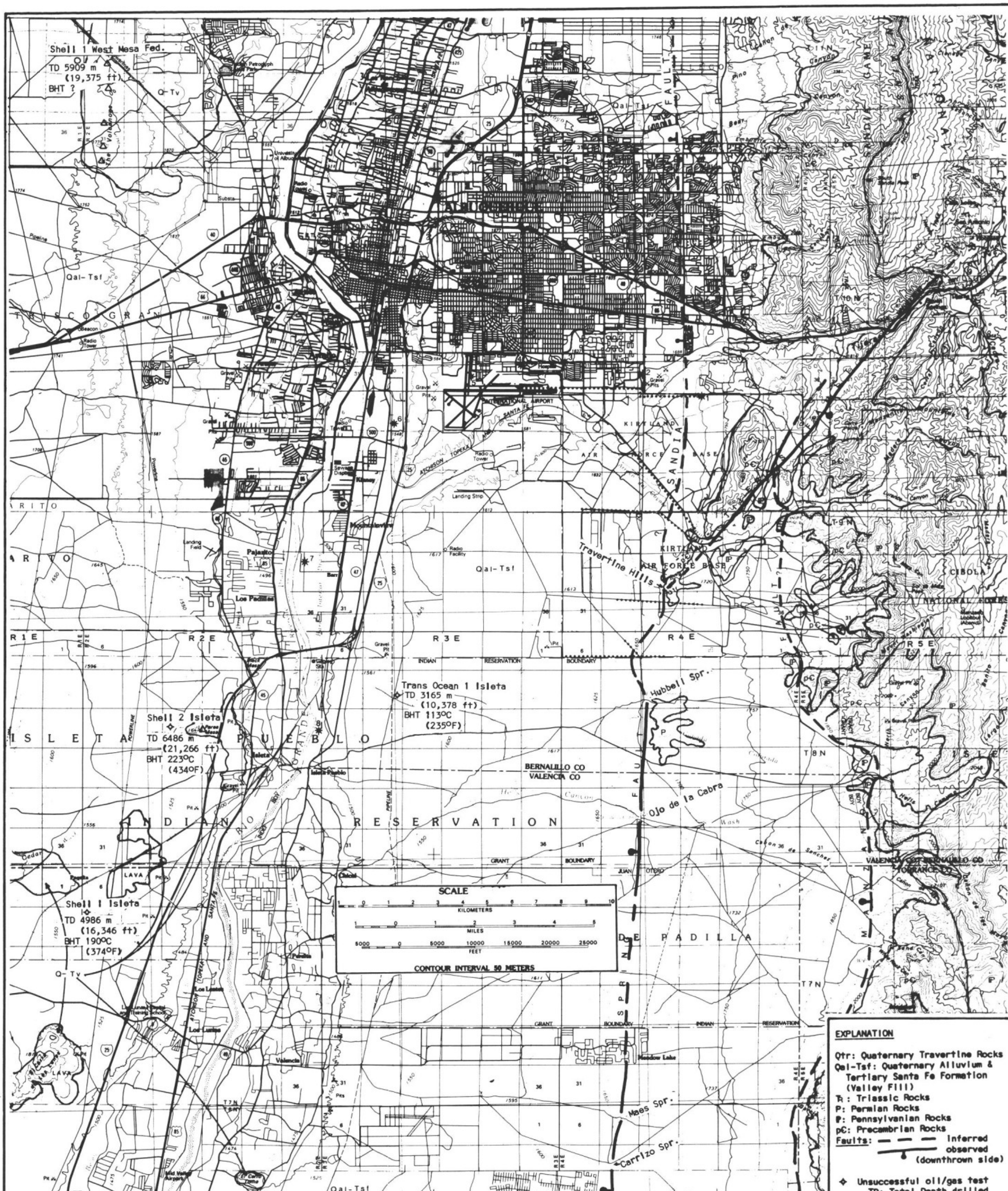

Figure 1. Reconnaissance geologic map of the Albuquerque area, New Mexico.

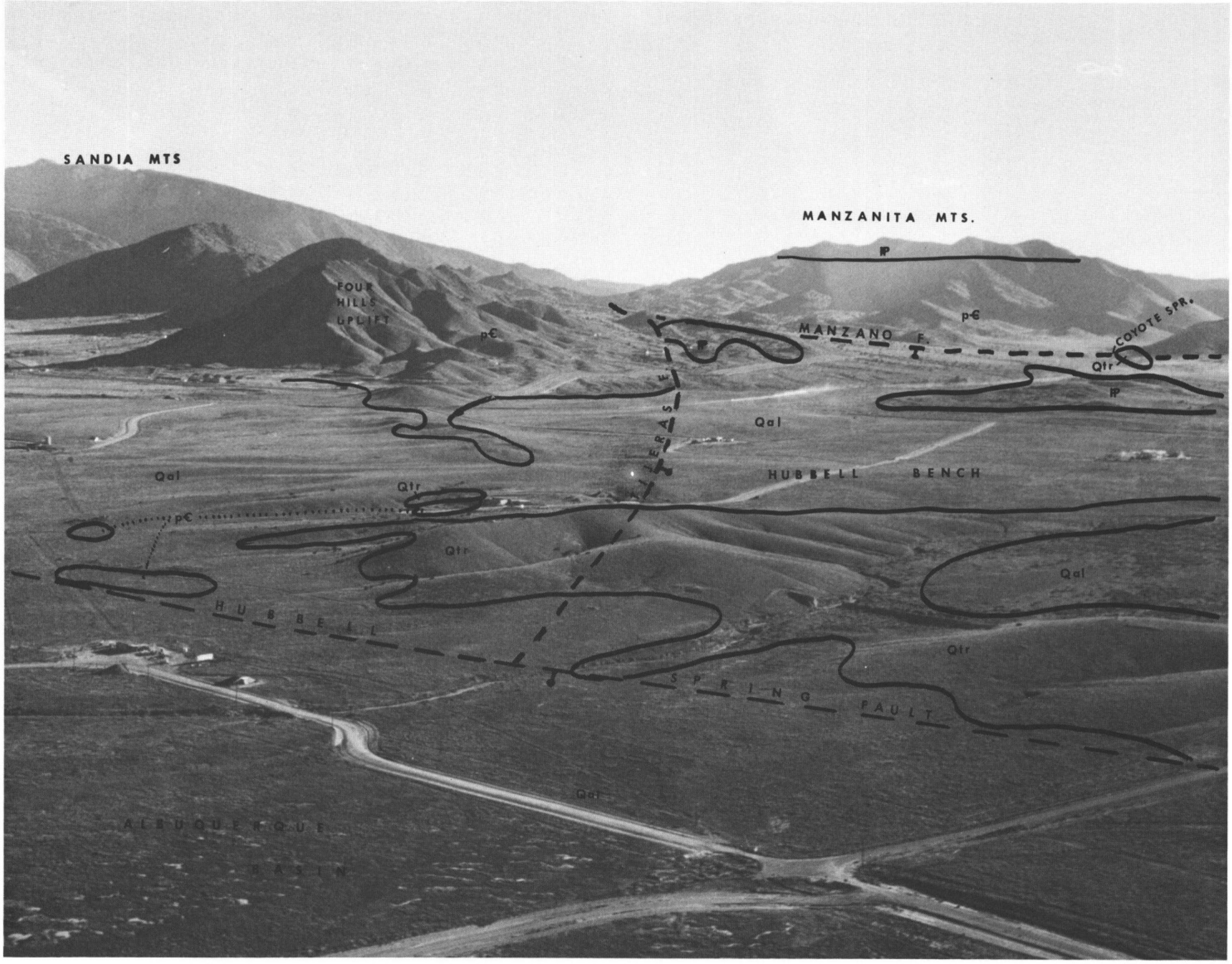

Figure 2. Structural and stratigraphic relationships along the Hubbell Spring fault, Kirtland Air Force Base. Air view from position about 11.2 km (7 mi) south of Eubank and Central intersection in Albuquerque. Qal: Quaternary surface alluvium; Qtr: Quaternary travertine deposits; IP: Pennsylvanian rocks; pЄ: Precambrian rocks.

Figure 3. Hubbell Spring fault scarp just south of Ojo Huelos in sec. 20, T6N, R3E. Triassic and Permian rocks are exposed on the upthrown side. Albuquerque basin in foreground.

The occurrence of travertine is not, by itself, evidence of a hydrothermal regime. In connection with other data, however, it lends support to a geological basis for predicting one. The travertine hills or mounds are at the intersection of the Hubbell Spring, Tijeras, and presumed Sandia faults. They are indicative of an underlying major fault system through and along which large volumes of water freely migrated.

HYDROLOGY

A model of the hydrology would suggest that a previous system circulated meteoric water through the Santa Fe deposits in the rift to a depth where it was subjected to substantially wanner temperatures and then rose to the surface by convection currents along the master faults (fig. 5). It would be logical to expect the focal point for this hydrologic activity to occur at the intersection of the tectonically active Tijeras and Hubbell Spring—Sandia faults. Later events, perhaps including plugging of the fault permeabilities by travertine deposition, a change in the regional hydrologic gradient, and masking of the thermal water by low-temperature meteoric water (cascading from the mountain front across the Hubbell bench into the basin as described by Titus in 1963), resulted in cessation of spring and possible thermal activity at this site. Morgan

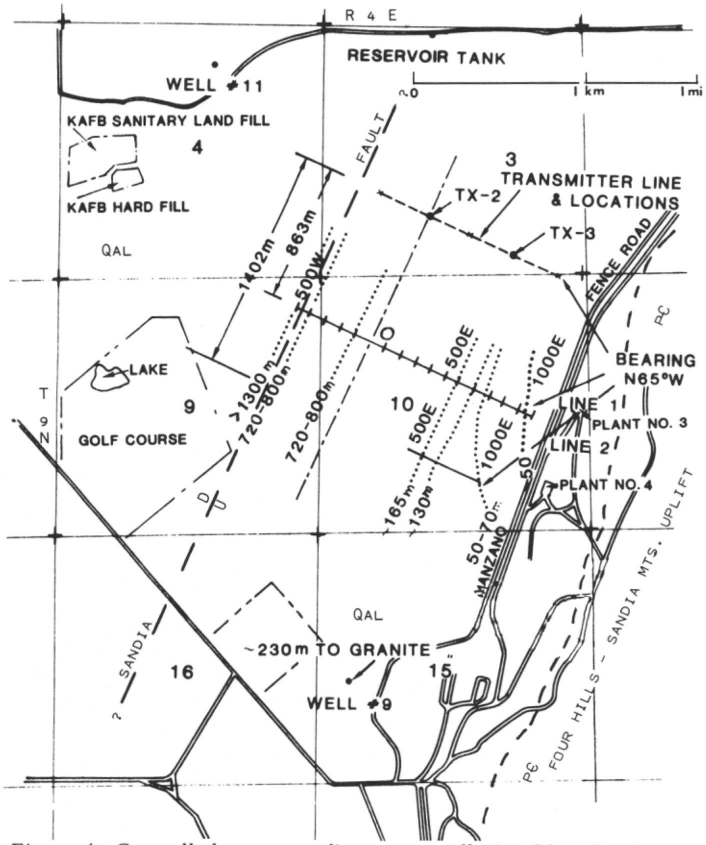

Figure 4. Controlled source audio-magnetotelluric (CSAMT) electromagnetic (EM) geophysical experiment east of Four Hills uplift. Sandia fault identified by long dashed line, downthrown to the northwest. Depth to basement (granite) in meters shown by dotted lines. Qal: Quaternary surface alluvium; p€: Precambrian rocks (Bartel and others, 1981).

and others (1981) describe a similar process to account for surtace and near-surface hydrothermal anomalies where ground-water heated in the deeper parts of the basins of the Rio Grande rift discharges across subsurface-bedrock constrictions at their downstream ends.

TEMPERATURE

Considerable geophysical evidence associated with seismicity and presumed shallow magma bodies suggests higher than normal temperatures should be encountered in the subsurface beneath Albuquerque. It is significant, however, that there is no requirement for anomalous hydrothermal regimes in this area. If appropriate conditions of structure and stratigraphy are present, basically a thick suite of porous and permeable valley-fill sediments, normal subsurface thermal gradients are more than adequate to supply sufficient thermal energy to meet large-scale space heating and cooling requirements.

Kelly (1974) indicated that I50°C (302°F) temperatures should be encountered in the Albuquerque basin at depths of 5,182 m (17,000 ft). He also estimated that wells completed to the 3,658 m (12,000 ft) level would yield about 32 liters per second (500 gallons per minute). Production of water from the lower part of the valley-fill aquifer would not involve pumping from great depths. The aquifer is essentially unconfined, and the water table is near the surface at the level of the Rio Grande and is only a few hundred feet below the surface at the higher parts of the mesas bordering the river. The hydrostatic head or column would bring the deeper thermal water to or near the surface in a cased well.

Deep wells drilled in the basin provide the only definitive data regarding subsurface conditions of sediment type and thickness and water temperature. Several Shell Oil Company oil and gas tests drilled in the vicinity of Albuquerque exhibit high, but not abnormal, subsurface temperatures and a geothermal gradient of about 35°C/km (2°F/100 ft + 60°F ambient temperature) (Table 1 and fig. 1).

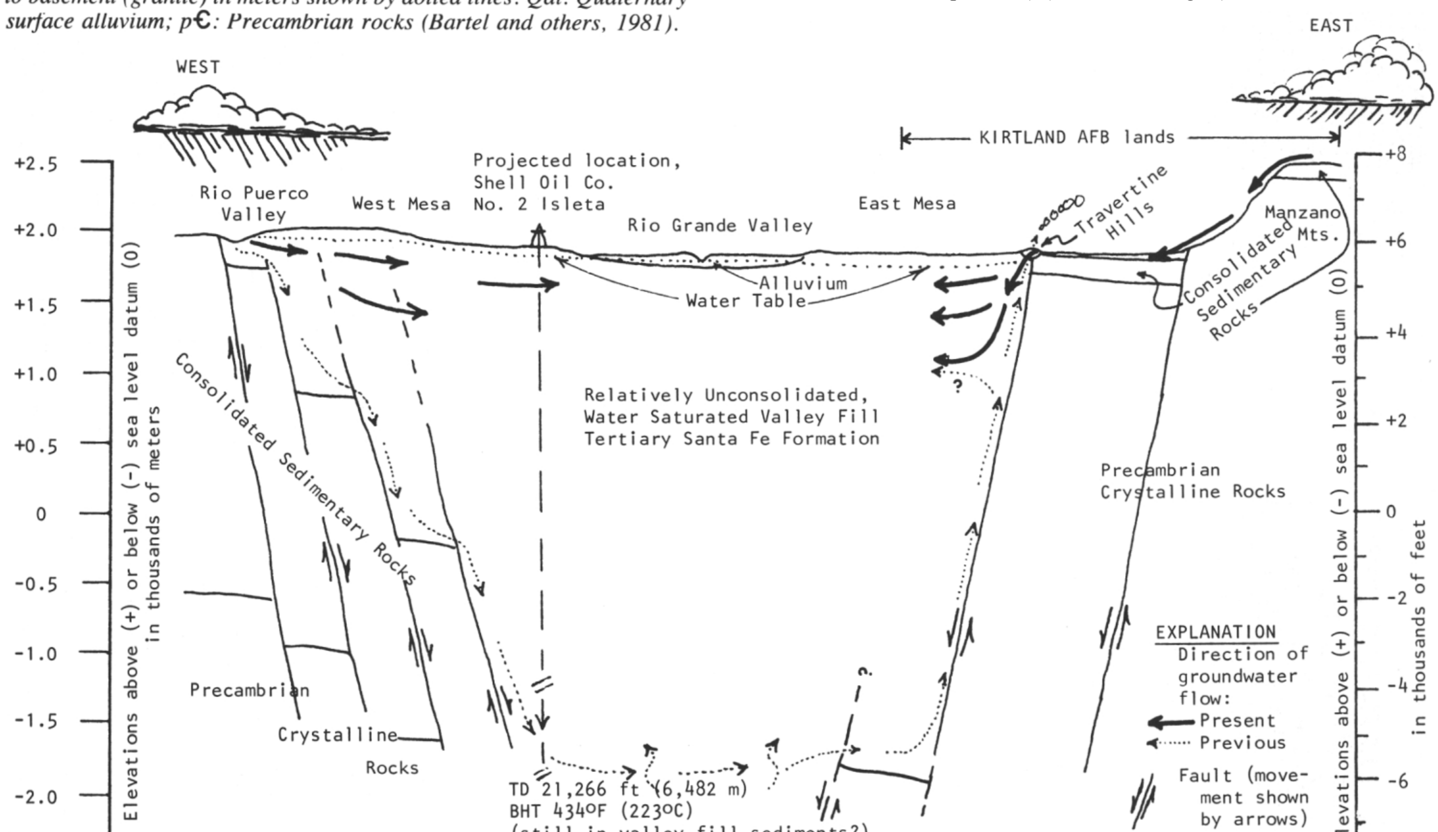

Figure 5. Schematic east-west cross section of the Albuquerque basin near the southern boundary of Kirtland AFB.

Table 1. Temperature gradients and thickness of valley fill in deep wells near Albuquerque. Adapted from Kauffman and Houghton (1980) and Kelley (1977).

Well and Location	Total Depth	Bottom Hole Temperature	Gradient (°C/km)	Base of Santa Fe	Subcrop
Shell No. 1 Santa Fe sec. 18, T13N-R3E	3,369 m (11,045 ft)	113.3°C (236°F)	29.21	906 m (2,970 ft)	Cretaceous
Shell No. 3 Santa Fe sec. 28, T13N-R1E	3,134 m (10,276 ft)			1,276 m (4,185 ft)	Cretaceous
Shell No. 1-24 West Mesa Federal sec. 24, T11N-R1E	5,906 m (19,375 ft)		No data released 8/9/82		
West Mesa No. 1 (City Water Well) sec. 20, T10N-R2E	360 m (1,180 ft)	32.2°C (90°F)	47.88	Spud in Santa Fe	
Shell No. 1 Laguna sec. 8, T9N-R1W	3,390 m (11,115 ft)	119.4°C (247°F)	30.83	Spud in Cretaceous	
TransOcean No. 1 Isleta sec. 8, T8N-R3E	3,165 m (10,378 ft)	112.8°C (235°F)	30.91	1,601 m (5,250 ft)	Cretaceous
Shell No. 2 Isleta sec. 16, T8N-R2E	6,486 m (21,266 ft)	223.3°C (434°F)	32.14	Tertiary to bottom of hole	
Shell No. 1 Isleta sec. 7, T7N-R2E	4,986 m (16,346 ft)	190.6°C (375°F)	35.24	3,694 m (12,110 ft)	Cretaceous

VALLEY-FILL THICKNESS

Although they may be a result of different periods of in-fill, all of the Tertiary rocks above pre-basin deposits are lithologically similar, probably hydrologically interconnected, and can be collectively designated valley fill. The Tertiary Santa Fe deposits of Miocene and Pliocene age and, where present, the Baca and Galisteo formations of Eocene age compose the valley-fill aquifer that contains water at depth. If deposits are thick enough this water should be heated by normal thermal gradients to usable temperatures. The pre—Santa Fe Tertiary sediments are difficult to recognize in the subsurface, and where they are differentiated in surface exposures, they are less than 914 m (3,000 ft) thick (Kelley, 1977). Knowledge of the thickness of the Tertiary valley fill is, therefore, crucial to an exploration program for geothermal resources in the Albuquerque basin.

In addition to subsurface temperature data, Table 1 incorporates valley-fill thickness data for the deep wells drilled in the vicinity of Albuquerque.

ECONOMICS

The economic limits of any energy resource including geothermal are basically those of Btu's. If there are enough of them and if they are recoverable in a socially and environmentally acceptable manner, to be applied at a cost the user can afford, it matters little what form they take.

Kauffman and Houghton (1979) determined that the heat load/Btu demand for Albuquerque's climate means that a geothermal well with water temperature of 88°C (190°F) would have to produce: (1) 25.2 Vs (400 gpm) to heat an apartment complex of 46,450 m= (500,000 ft=) or hospital with 34,373 m2 (370,000 ft2) or (2) 56.8 1/s (900 gpm) to meet the heat demands of an 89,902 m2 (967,730 ft2) shopping center. These investigators also developed and assessed various economic cases and models comparing continued use of natural gas and fuel oil to heat buildings on the campus of the University of New Mexico. They concluded that the overall economics of a hot-water geothermal system are favorable, and that the continued use of natural gas is more expensive than installing a geothermal system (Kauffman and Houghton, 1980).

Since May, 1982, New Mexico State University (NMSU) in Las Cruces has been using a nearby hydrothermal regime tied to the heating systems of 12 campus buildings and the school's swimming pool as a direct result of the State of New Mexico's energy research and development program. Water with a temperature of 61°C (142°F) is delivered at a rate of 15.8 Us (250 gpm) from a well 259 m (850 ft) deep located about 1.6 km (1 mi) east of the campus. The water takes the place of 79 billion Btu's per year of natural gas, costing about $300,000 annually, that had been burned to generate steam. The savings represent displacement of 44-46 percent of NMSU's central-plant natural-gas consumption or 32 to 35 percent of the school's total annual consumption. Project costs for research, development, demonstration, and application were $1.5 million. Payout will come in 4 to 6 years (Cuniff and others, 1981). Additional commercial applications are being investigated in the Las Cruces area.

CONCLUSIONS

Geological and geophysical data and its interpretation in the Albuquerque basin (though far more advanced, extensive, and balanced than just a few years ago) still lacks maturity. However, these data are sufficient to predict the existence of an extensive intermediate-to-high temperature (93°C to more than 149°C; 200°F to 300°F) hydrothermal system beneath much of the region in and surrounding Albuquerque. Of significance is the concept that the thick suite of valley-fill deposits underlying the region require no anomalous thermal conditions for economic temperatures. Normal subsurface thermal gradients are more than adequate to supply sufficient Btu's for large-scale space heating and cooling requirements, providing that rock characteristics at depth include reasonable parameters of porosity and permeability. The drilling and testing of deep gethermal wells will provide definitive answers.

ACKNOWLEDGMENTS

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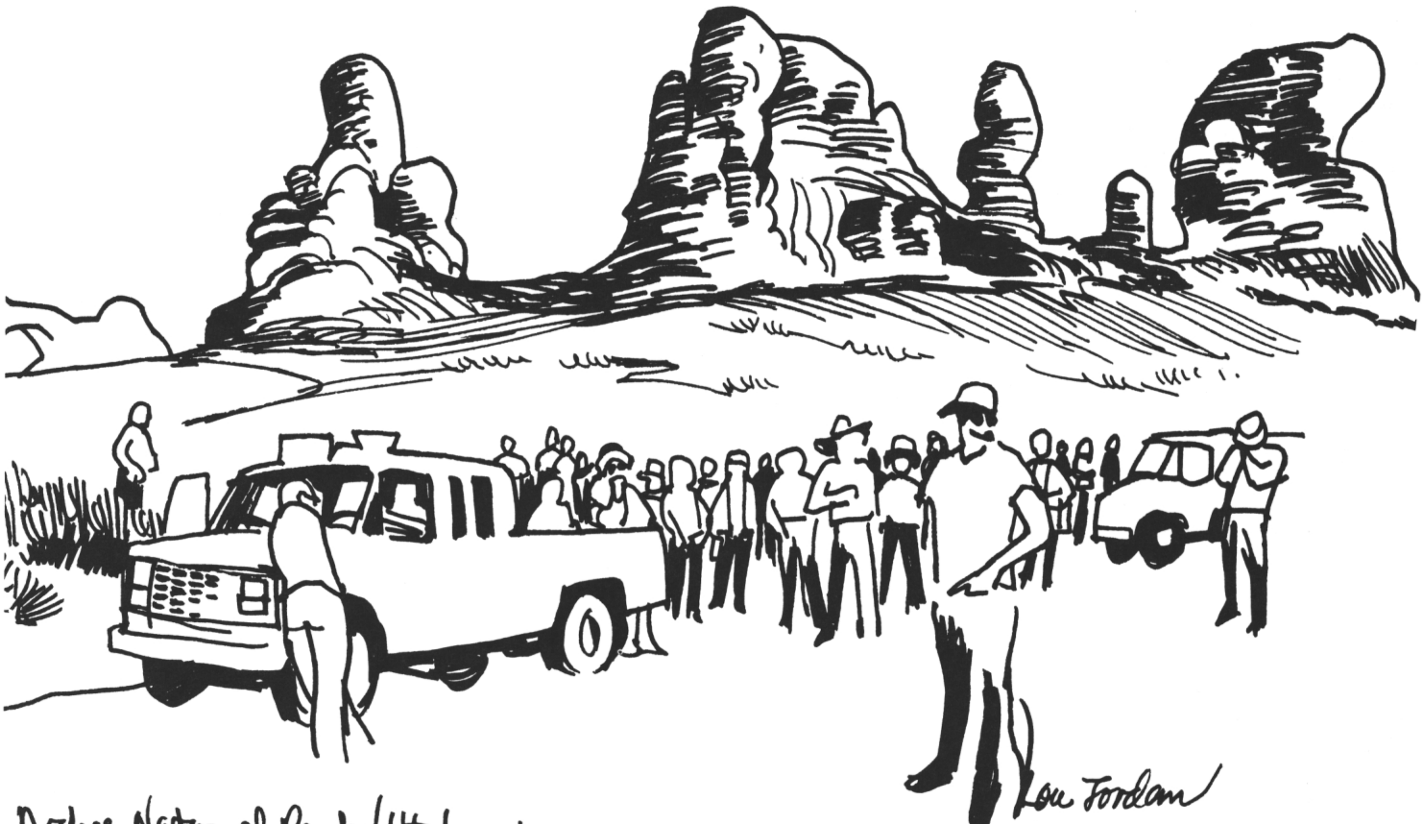

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