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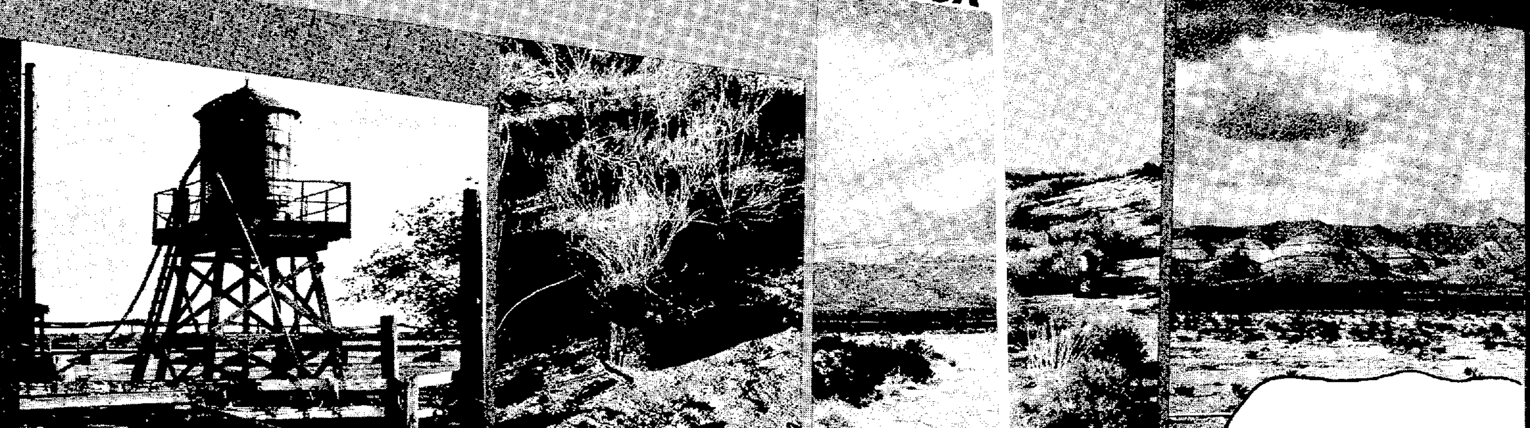
A Preliminary Assessment of the Geologic Setting, Hydrology, and Geochemistry of the Hueco Tanks Geothermal Area, Texas and New Mexico

CHRISTOPHER D. HENRY and JAMES K. GLUCK



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ABSTRACT

The Hueco Tanks geothermal area contains five known but now inactive hot wells (50° to $71^{\circ}C$). The area trends north-south along the east side of Tularosa-Hueco Bolson astride the Texas-New Mexico border approximately 40 km northeast of El Paso. Because of its proximity to El Paso, geothermal water in the Hueco Tanks area could be a significant resource.

Hueco Bolson is an asymmetric graben. Greatest displacement along boundary faults is on the west side adjacent to the Franklin Mountains. Faults, probably with less displacement, also form an irregular boundary on the east side of the bolson. Several probable faults may allow the rise of thermal waters from depth.

Ground water in the central part of Hueco Bolson flows southward to the Rio Grande. However, four of the five hot wells occur in a ground-water trough along the eastern margin of the bolson. The trough may be bounded by one of the postulated faults serving as a barrier to ground-water flow. Data on permeability of potential reservoir rocks, including basin fill and fractured bedrock, suggest that they may be sufficiently permeable for development of geothermal water.

The concentration of dissolved solids in the geothermal waters varies from 1,100 to at least 12,500 mg/L, but most waters show high concentrations. They are $Na-Cl-(SO_4)$ waters similar in composition to nonthermal waters in basin fill. The composition probably results from contact with evaporite deposits either in basin fill or in Paleozoic bedrock. Shallow reservoirs reach maximum temperatures of about 80° to $110^{\circ}C$.

Available data are too limited to evaluate adequately the resource potential of geothermal water in the Hueco Tanks area. A complete exploration program, including geological, hydrological, and geochemical investigation, is recommended.

INTRODUCTION

Interest in potential geothermal resources of the Hueco Tanks area has emerged for several reasons. (1) Most important, at least five wells, all of which have been destroyed or are now inactive, tapped hot water (50° to $71^{\circ}C$) at depths of about 112 to 152 m (366 to 497 ft). (2) A recent geophysical exploration program (Roy and Taylor, 1980) found thermal gradients above the water table as high as $300^{\circ}C/km$ near two of the hot wells. (3) The Hueco Tanks geothermal area lies along the edge of the Tularosa-Hueco Bolson, a Basin and Range or Rio Grande rift graben. Both geological provinces are favorable for geothermal energy development.

This report summarizes new and existing data on the geologic setting, geochemistry, and hydrology of both cold and hot ground water in the Hueco Tanks area. This information is intended to provide a preliminary assessment of the geothermal potential that will be helpful in planning future research and exploration programs.

REGIONAL GEOLOGIC SETTING

The Hueco Tanks geothermal prospect area lies on the east side of the Tularosa-Hueco Bolson in New Mexico and Texas (fig. 1). The Tularosa and Hueco Bolsons are part of the southeastern Basin and Range Province and may also be the southern end of the Rio Grande rift. As defined by Chapin (1971), the Rio Grande rift trends north-south from Colorado into New Mexico, includes Tularosa Bolson, but ends at the southern border of New Mexico. Henry (1979a) and Seager and Morgan (1979), on the basis of geological and geothermal data, suggested that the Rio Grande rift may turn to a southeast trend to follow the Rio Grande along the Texas-Chihuahua border. The Rio Grande rift is similar, in most respects, to the southern Basin and Range Province but is distinguished by geophysical data that indicate that the rift has deeper basins, a shallower mantle, and higher heat flow than the adjacent Basin and Range (Decker and Smithson, 1977). The distinction between the Basin and Range Province and the Rio Grande rift may be important for geothermal exploration because, although both are favorable areas, the greater heat flow of the Rio Grande rift may indicate that higher temperatures could be encountered there at shallower depths than in the Basin and Range.

Hueco Bolson is an asymmetric graben bordered on the west by the Franklin Mountains and on the east by the Hueco Mountains. The Franklin Mountains are composed of Precambrian and Paleozoic sedimentary and igneous rocks; the Hueco Mountains are mostly upper Paleozoic carbonate and clastic sedimentary rocks.

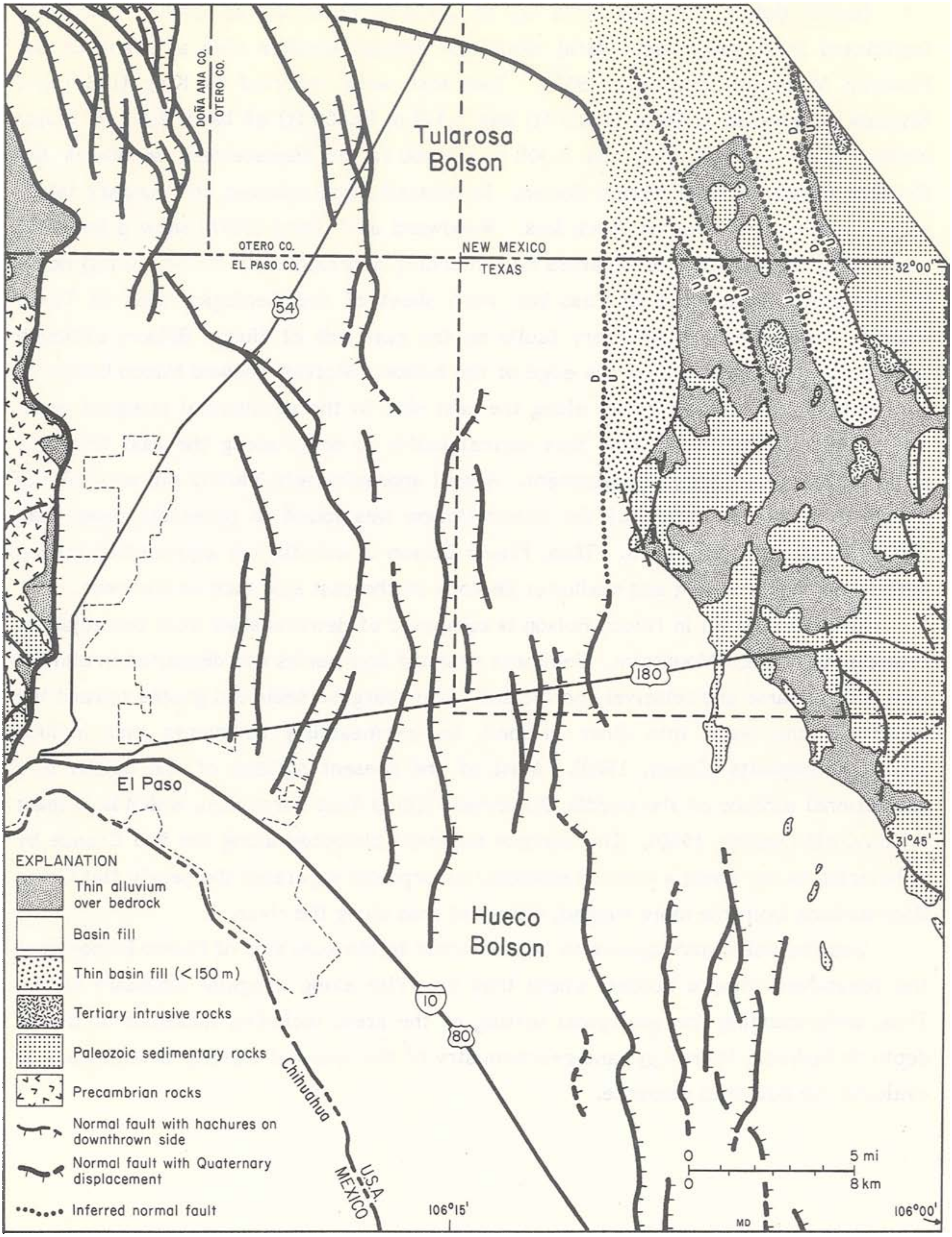

Figure 1. Tectonic map of Hueco Bolson near El Paso, Texas. Quaternary faults from Seager (1980) and this study. Outlined section is area of figures 2, 3, 4, 5, 6, and 8.

Hueco Bolson is filled with up to 2,750 m (9,000 ft) of clastic sediments (estimated from geophysical data) along the deeper, western side adjacent to the Franklin Mountains (Mattick, 1967). Two test wells reported by King (1935) and Mattick penetrated 1,500 m (4,900 ft) and 1,310 m (4,300 ft) of basin fill. A major normal fault with as much as 5,500 m (18,000 ft) of displacement separates the Franklin Mountains from Hueco Bolson. In contrast, displacement on boundary faults on the eastern side may be much less. Woodward and others (1978) show a bounding fault along the east side of Tularosa Bolson ending approximately 20 km (12 mi) north of this study area. The El Paso-Van Horn sheet of the Geologic Atlas of Texas (Barnes, 1968) shows no boundary faults on the east side of Hueco Bolson, although several faults cut bedrock at the edge of the bolson. Mattick showed Hueco Bolson to be a half graben with no faults along the east side in the geothermal prospect area. The results of this study show that normal faults do occur along the east side, and some exhibit Quaternary displacement. A well approximately 3 km (2 mi) west of the irregular eastern boundary of the Hueco Bolson was found to penetrate more than 700 m (2,380 ft) of basin fill. Thus, Hueco Bolson is actually an asymmetric graben with lesser displacement and shallower bedrock on the east side than on the west.

Sedimentary fill in Hueco Bolson is composed of detritus shed from the adjacent Franklin and Hueco Mountains. Sediment near the boundaries was deposited in alluvial fans and is coarse and relatively permeable. This marginal sediment grades toward the center of the basin into finer grained, low-permeability sediments that include lacustrine deposits (Cliett, 1969). Most of the present surface of the bolson is a depositional surface on the middle Quaternary Camp Rice Formation, which is at least 0.5 m.y. old (Seager, 1980). This surface has been dissected along the Rio Grande by tributaries to the river; a distinct erosional escarpment separates the nearly flat Camp Rice surface from the more rugged, dissected area along the river.

Geothermal waters appear to be restricted to the east side of Hueco Bolson near the Texas-New Mexico border, where they may rise along irregular boundary faults. Thus, understanding the geological setting of the area, including locations of faults, depth to bedrock, hydrology, and geochemistry of the thermal waters, is necessary to evaluate the potential resource.

ORIGIN AND LOCATION OF GEOTHERMAL WATERS

Hot Wells

Five wells (M-11, N-8, N-9, N-11, and 49-08-1A), all either destroyed or no longer in use, encountered hot water at depths of 112 to 152 m (366 to 497 ft). All available information on them and other wells in the area is reported in appendices A, B, and C. Three wells in the northern part of the area (M-11, N-9, and N-11) occur near Davis Dome in New Mexico (figs. 2 and 3). Reported temperatures range from 50° to 71°C (McLean, 1970); ambiguous records for the hottest well (N-9) indicate a temperature possibly as high as 80°C. Two wells occur near (N-8) or just south of (49-08-1A) the Texas-New Mexico state line. Hoffer (1978) reports a temperature of 58°C for well 49-08-1A. No temperature is available for N-8; it is reported as "hot and highly mineralized" by Knowles and Kennedy (1958). Steel casing remains in the ground for wells N-8, N-9, and 49-08-1A. However, N-9 is plugged with sand, and N-8 and 49-08-1A are blocked with metal debris. Wells M-11 and N-11 were both destroyed shortly after drilling.

Source of Heat and Ground-Water Flow Paths

Most geothermal water in hot springs or hot wells is simply meteoric water that has circulated to a sufficient depth to be heated and then returned to the surface. The hot water rises to the surface because of the hydraulic gradients between areas of recharge and discharge--a mechanism that controls all springs, whether hot or cold. Hydraulic gradients are affected by topography, aquifer geometry and hydraulic characteristics, and fluid density. The fluid density is particularly important for thermal waters because hot water is considerably less dense than cold water containing an equivalent concentration of dissolved solids. Thus the discharge point of low-density, hot water can be above its recharge point, where the water is colder and more dense. Thermal gradients alone are not important except when they affect density.

Two factors are required to generate a hot spring or shallow hot well: a source of heat and permeable flow paths to transmit the water to the heat and back to or near the surface. The two most common sources of heat for geothermal waters are (1) a hot magma chamber related to very young igneous activity and (2) the normal thermal gradient of the Earth. The first source is unlikely but not impossible for

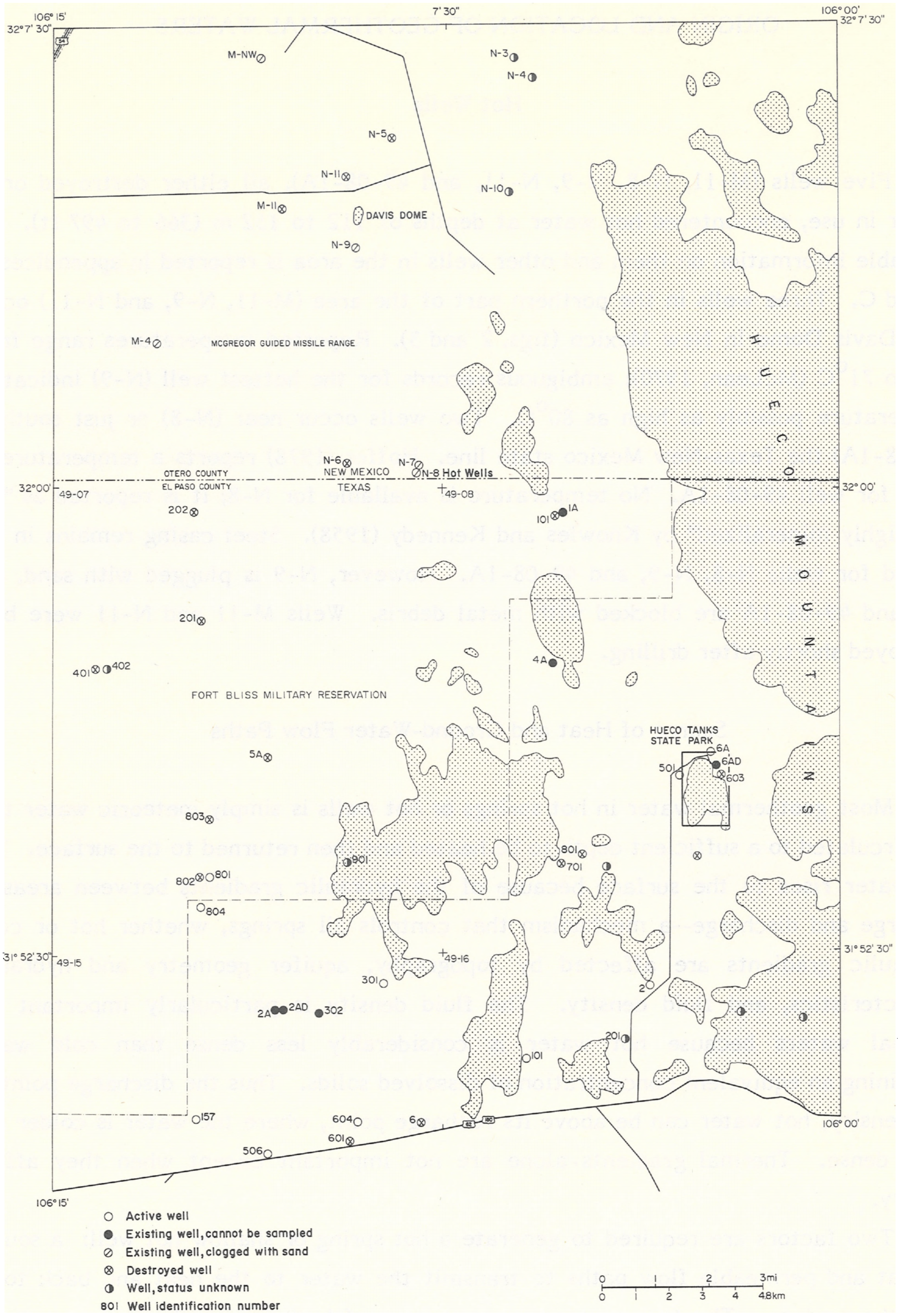

Figure 2. Wells in Hueco Tanks geothermal area. Well status symbols are also used on figures 3, 4, 5, 6, and 8. Wells in Texas are prefixed by a four-digit code that identifies the quadrangle in which the well occurs. This number is shown in the northwest corner of each quadrangle (for example, 49-07 at approximately lat 32° N. and long 106°15' W.).

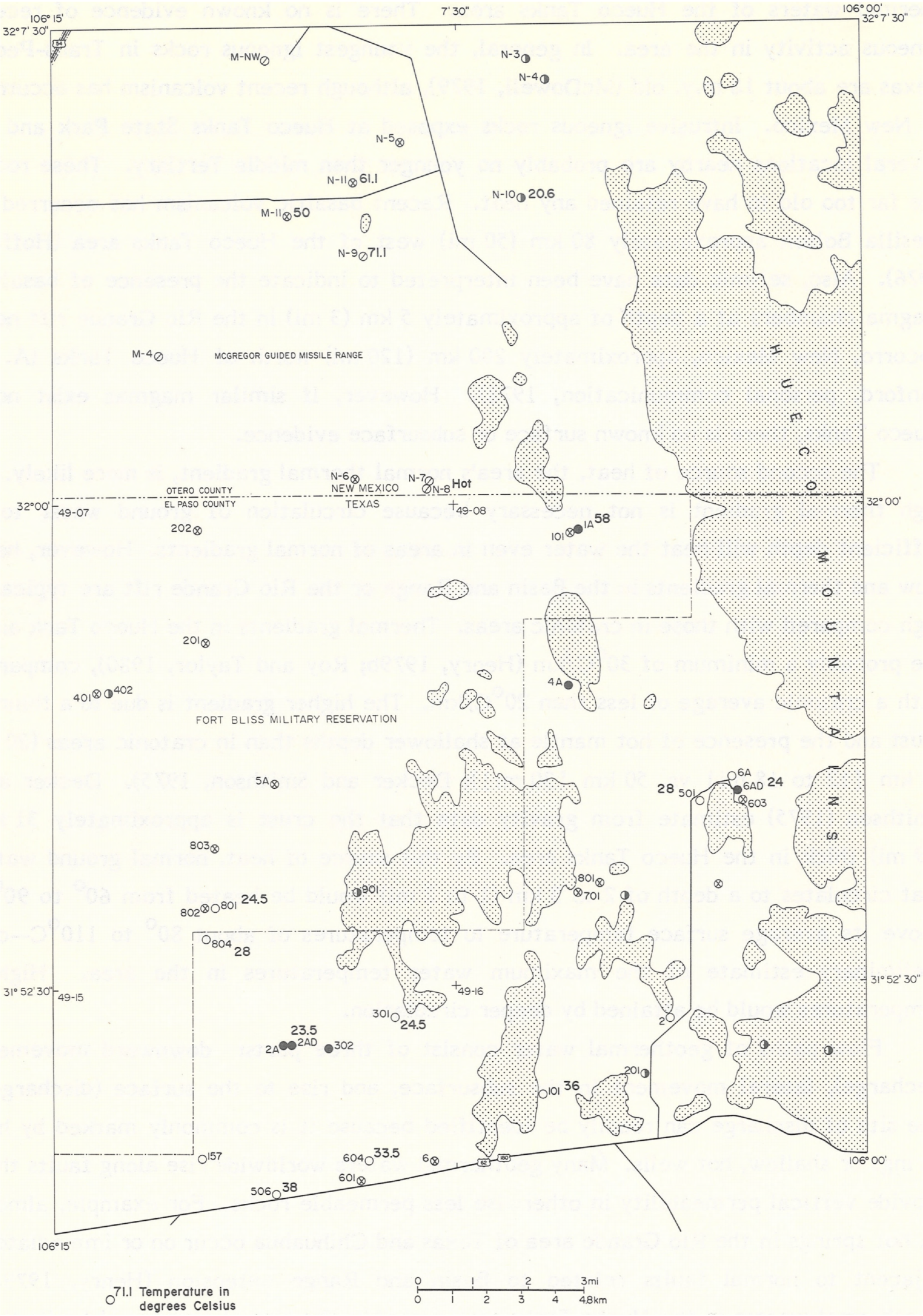

Figure 3. Measured and reported temperatures ($^{\circ}$C) of thermal and nonthermal wells.

thermal waters of the Hueco Tanks area. There is no known evidence of recent igneous activity in the area. In general, the youngest igneous rocks in Trans-Pecos Texas are about 18 m.y. old (McDowell, 1979), although recent volcanism has occurred in New Mexico. Intrusive igneous rocks exposed at Hueco Tanks State Park and at several locations nearby are probably no younger than middle Tertiary. These rocks are far too old to have retained any heat. Recent basaltic volcanism has occurred in Mesilla Bolson approximately 80 km (50 mi) west of the Hueco Tanks area (Hoffer, 1976). Also, seismic data have been interpreted to indicate the presence of basaltic magma chambers at a depth of approximately 5 km (3 mi) in the Rio Grande rift near Socorro, New Mexico, approximately 200 km (120 mi) north of Hueco Tanks (A. R. Sanford, personal communication, 1978). However, if similar magmas exist near Hueco Tanks, there is no known surface or subsurface evidence.

The second source of heat, the area's normal thermal gradient, is more likely. A high thermal gradient is not necessary because circulation of ground water to a sufficient depth will heat the water even in areas of normal gradients. However, heat flow and thermal gradients in the Basin and Range or the Rio Grande rift are typically high compared with those in cratonic areas. Thermal gradients in the Hueco Tank area are probably a minimum of 30°C/km (Henry, 1979b; Roy and Taylor, 1980), compared with a cratonic average of less than 20°C/km. The higher gradient is due to a thinner crust and the presence of hot mantle at shallower depths than in cratonic areas (20 to 30 km [12 to 18 mi] vs. 50 km [30 mi]); Decker and Smithson, 1975). Decker and Smithson (1975) estimate from gravity data that the crust is approximately 31 km (19 mi) thick in the Hueco Tanks area. By this source of heat, normal ground water that circulates to a depth of 2 to 3 km (1 to 2 mi) would be heated from 60° to 90°C above its average surface temperature to temperatures of about 80° to 110°C--our preliminary estimate of the maximum water temperatures in the area. Higher temperatures would be attained by deeper circulation.

Flow paths of geothermal water consist of three parts: downward movement (recharge), lateral movement in the subsurface, and rise to the surface (discharge). The site of discharge can readily be identified because it is commonly marked by hot springs or shallow, hot wells. Many geothermal waters worldwide rise along faults that provide vertical permeability in otherwise less permeable rocks. For example, almost all hot springs in the Rio Grande area of Texas and Chihuahua occur on or immediately adjacent to normal faults related to Basin and Range extension (Henry, 1979a). Geothermal waters in the Hueco Tanks area probably also rise along normal faults that form the eastern edge of Hueco Bolson. The five known hot wells follow a roughly linear north-northwest trend from near Hueco Tanks State Park to the Davis Dome area in New Mexico. These waters may be rising along a common fault zone, or in fractured bedrock adjacent to the fault zone that follows the same trend. The thermal waters do not reach the surface because the water table is generally about 120 m (400 ft) below the surface. Thus hot water rising along fault zones could reach the water table and discharge into permeable basin fill or pre-fill bedrock. It is important to know the location of the faults that may serve as conduits because the hottest water and the greatest quantity of water should occur in or near the conduits.

Recharge and lateral movement of water in the subsurface are commonly much more difficult to identify. Recharge to ground water is probably occurring over much of the Hueco Tanks area, and there is no way to determine if any particular site is contributing to the thermal waters. Recharge for the thermal waters could occur in the adjacent highlands of the Hueco Mountains, or from water circulating in deep basin fill of Hueco Bolson. Implications of the chemical composition of the thermal waters for possible sources and flow paths are discussed below.

Faults in Geothermal Area

Because the thermal waters may be rising along fault zones, it is important to know their locations within the geothermal area. We have identified the locations of several possible faults or fault zones (figs. 1, 4, and 5). No faults could be positively identified from aerial photographs or ground inspection in the area, but, for the following reasons, faults probably exist: (1) Faults occur in Paleozoic bedrock around the geothermal area and cut basin fill south and west of the area. (2) Several major linear topographic features appear to be controlled by faults. (3) Attitudes and outcrop patterns of Paleozoic bedrock require either faults or folds. (4) Depth to bedrock in basin-fill sediments near bedrock outcrops requires either faults or extensive erosional scarps. (5) The linear distribution of known hot wells and thermal anomalies suggests a fault trend. These five reasons are elaborated below:

1. Faults, probably of late Tertiary age, cut bedrock around the Hueco Tanks area. Also, abundant faults cut basin-fill sediments west and south of the area (Seager, 1980; this study). These faults cut a middle Quaternary geomorphic surface. Bedrock faults generally trend north or north-northwest and show minor normal displacement. King and others (1945) indicate maximum displacements of less than 100 m (330 ft).

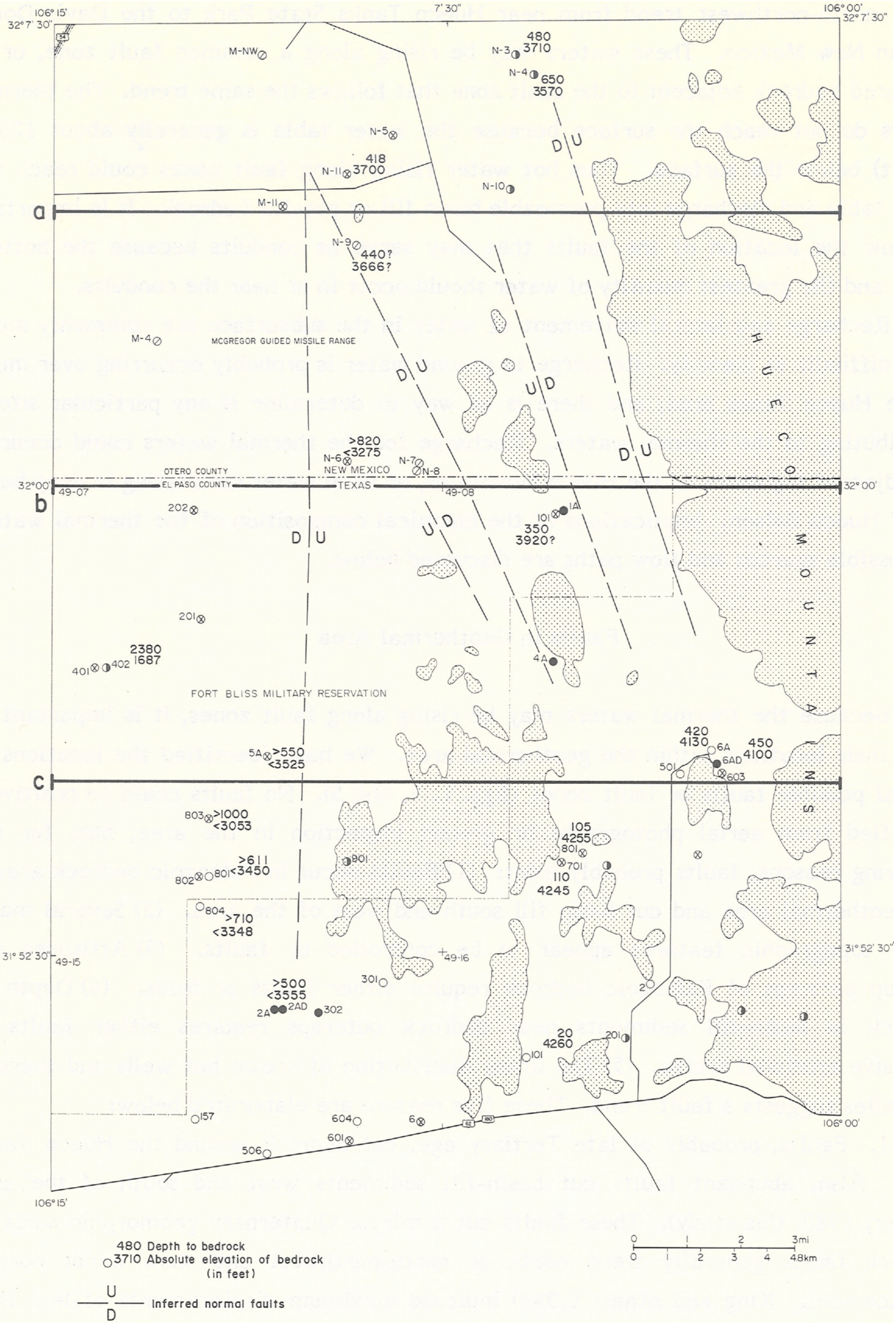

Figure 4. Depth to bedrock, absolute elevation of bedrock, inferred normal faults, and lines of section shown in figure 5.

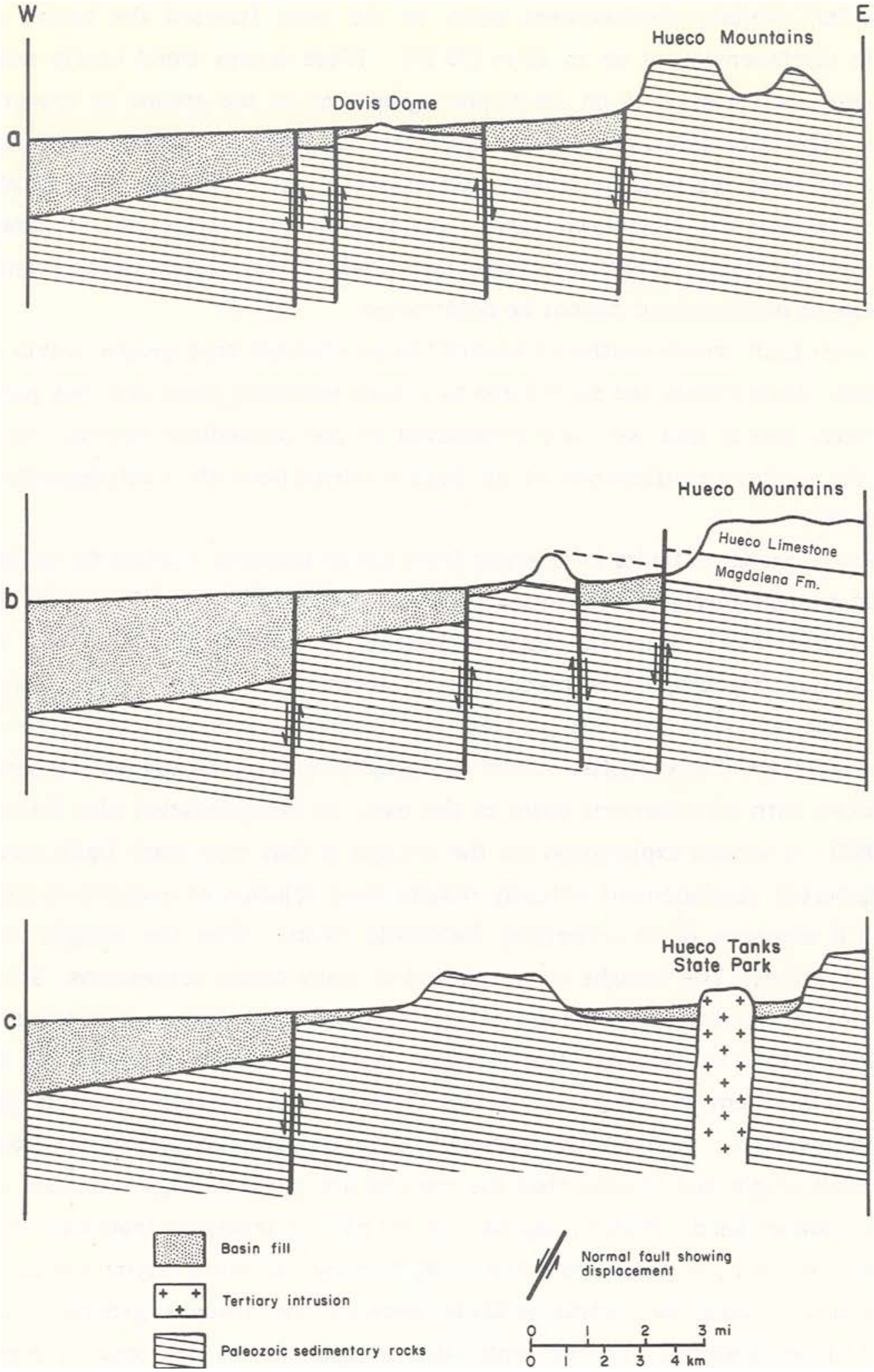

Figure 5. Generalized west-east cross sections in Hueco Tanks geothermal area showing normal faults and relative thicknesses of basin fill: (a) through Davis Dome, (b) along Texas-New Mexico border, and (c) through Hueco Tanks State Park. Locations are shown in figure 4. Cross section b also shows contact relationships between Hueco Limestone and Magdalena Formation discussed in text.

Two types of faults occur in basin fill. One group, consisting of five or six mapped faults, exhibits displacement down to the west (toward the basin) and a topographic displacement of up to 10 m (33 ft). These scarps trend nearly north to south and are easily identified on aerial photographs or on the ground by topographic expression, vegetation lines, and nearly linear trends. Morrison (1969) considered the surface cut by these faults to be middle Quaternary in age (0.5 m.y.). The faults are commonly veneered by windblown sand. Because at least some of the sand was deposited during historic times and would not retain evidence of displacement, the minimum age of displacement cannot be determined.

One such fault trends southeast toward the geothermal area around Davis Dome (fig. 1). Near Davis Dome, the fault turns to a more southerly trend and may join with one of several faults that we have postulated in the immediate geothermal area. However, the southern continuation of the fault is buried beneath eolian deposits south of Davis Dome.

A second group of faults is inferred from linear features marked by continuous asymmetric troughs throughout Tularosa and Hueco Bolsons (fig. 1). The steep side of the troughs faces away from the basin, suggesting that displacement is down to the east. Maximum topographic displacement is about 5 m (16 ft). The faults are generally more sinuous than, but parallel to, the first set of faults. These linear features may be antithetic faults. Their topographic expression suggests a series of rotated blocks with displacement down to the east, an interpretation also favored by Seager (1980). A second explanation for the troughs is that they mark fault zones but that the apparent displacement actually results from solution of evaporites either in the basin-fill sequence or in underlying Paleozoic rocks. Thus the troughs may be subsidence features. The troughs are composed of many closed depressions. Some are related to eolian activity, but some are clearly sinkholes where the rare surface water accumulates. This explanation still requires that the linear features be faults. However, displacement on them could be older than middle Quaternary and might not be down to the east. A third explanation for the topographic depressions does not require a fault origin and implies that the troughs are paleodrainage channels, partly filled by windblown sand. Present-day sand dunes exhibit transport from east to west; the channels would have filled from the east, thereby becoming asymmetric. However, this last explanation seems unlikely because the troughs generally do not resemble channel systems. For example, the troughs do not decrease in elevation consistently in one direction, nor do they bifurcate upstream.

The absence of surface fault scarps in the geothermal area may be explained by superposition of younger deposits, either windblown sand or alluvial fans. Windblown sand partly buries several scarps to the south and west of the geothermal area and may completely bury others. One fault scarp trends toward, and disappears into, an alluvial fan just north of U.S. Highway 180 and just west of bedrock outliers (fig. 1). This fault may join with the fault near Davis Dome mentioned above. The mapped fault scarps cut the Camp Rice Formation, which is approximately 0.5 m.y. old; time of youngest movement is unknown. Both eolian and alluvial deposition is active and has been for some time. The geothermal area is completely covered by eolian material or alluvial fan sediment that may have buried existing fault scarps in the basin. The effectiveness of eolian deposits in covering major topographic features is illustrated by the burial of a 15-m-high (50-ft) Paleozoic bedrock hill located 2 km (1.2 mi) south of Hot Wells; this feature is mapped by King (1935).

2. In the study area the front of the Hueco Mountains (excluding the numerous bedrock outliers) forms a distinct topographic escarpment as much as 300 m (1,000 ft) high that trends N. 15° W. (fig. 1). The escarpment is about 10 km (6 mi) long and remarkably linear. No outcrops exist between this escarpment and two northwest-trending rows of bedrock outliers approximately 3 to 7 km (2 to 4 mi) to the west. The intervening area consists of coalesced alluvial fans and a northwest-trending trough, which includes a playa lake. The trough resembles the second set of fault scarps recognized in basin-fill deposits, although on a much larger scale. The escarpment could be the eroded face of a major normal fault that dies out to the south. Woodward and others (1978) show a major normal fault along the east edge of Tularosa Bolson, which, if continued to the south, would coincide exactly with the proposed fault. Woodward and others terminate the Tularosa fault approximately 20 km (12 mi) to the north, but the proposed fault may be a continuation of their fault. The east face of the Franklin Mountains, which are known to be fault bounded, exhibits similar topographic expression.

3. The presence of faults between bedrock outliers and the Hueco Mountains escarpment discussed above can be evaluated by comparing the elevation of formation contacts in the two areas (fig. 5b). Outcrops of Paleozoic sedimentary rocks generally dip gently to the east in the geothermal area. The escarpment is supported by Hueco Limestone overlying the upper part of the Magdalena Formation. Both formations dip to the east at about 10°, and the contact between them is about 1,460 m (4,800 ft) in elevation along the escarpment (King, 1935; Wise, 1977). Outliers surrounded by bolson fill are composed of the upper part of the Magdalena Formation, which also dips

to the east at about 10°. King (1935) estimated a maximum thickness for the upper Magdalena of approximately 150 m (500 ft). To be conservative, we have assumed that the outliers consist of the lowermost part of the upper Magdalena. Using these dips, this thickness, and this assumption, it is possible to determine the elevation of the Magdalena-Hueco contact projected from the outliers to the escarpment. Projected from the nearest outliers approximately 3 km (2 mi) away, the contact should intersect the escarpment at an elevation of about 1,100 m (3,600 ft). If projected from the more distant outliers, approximately 7 km (4 mi) from the escarpment, the contact should occur at about a 275-m (900-ft) elevation.

The discrepancy between the actual and computed contact elevations requires either faulting or changes in dip between both the outliers and the escarpment and between separate outliers. Changes in dip are possible. Both King (1935) and Wise (1977) show gentle folds in Paleozoic rocks; so faults are not required. Nevertheless, the rocks dip consistently eastward in this area; no outcrops with opposing or gentler dips are exposed. One would expect more evidence of folding if it existed.

4. Depth to, or elevation of, bedrock has been determined wherever possible from driller's logs or other information (fig. 4). In general, bedrock in the basin adjacent to outcrops is more than 100 m (330 ft) deep. The sedimentary fill in this area is not simply a thin veneer over bedrock. The considerable thickness of fill also supports, but does not prove, the existence of faults adjacent to bedrock.

Two examples are significant: (1) Three wells west of the major escarpment discussed in reason 2 (N-3, N-4, and 49-08-101) encounter bedrock at depths of 110 to 210 m (360 to 690 ft). Thus the total change in bedrock elevation across the topographic scarp is as much as 500 m (1,650 ft). (2) Only one well west of the westernmost bedrock outlier (49-07-402) reaches bedrock at a depth of approximately 700 m (2,380 ft) (elevation of bedrock approximately 550 m [1,800 ft]). All other wells bottomed in basin fill, including several wells within 2 km (1.2 mi) of outcrop and as deep as 300 m (1,000 ft). On the basis of this information, major faults should exist along the topographic escarpment discussed above and along a roughly north-south line just west of the westernmost bedrock outliers (including Davis Dome) where much of the geothermal activity occurs. This latter fault is the same fault indicated by Quaternary fault scarps.

5. The five identified hot wells and the area of anomalously high thermal gradients delineated by Roy and Taylor (1980) form an approximately linear trend that may coincide with a fault zone. Included are three wells near Davis Dome (M-11, N-9, and N-11), one at Hot Wells (N-8), and one in Texas, 3 km (2 mi) southeast of Hot

Wells (49-08-1A). The area of anomalous gradients surrounds the latter two wells. This trend extends generally north-northwest in an area where we have suggested the possible existence of two faults. Thermal water may be rising along a fault zone, or in fractured bedrock adjacent to the fault zone, toward the water table. There the water may spread laterally within permeable basin-fill sediments. The paucity of wells in the known geothermal area does not allow association of thermal water with other suspected faults. However, two wells adjacent to faults south and west of the geothermal area (49-15-506 and 49-15-604) produce slightly anomalous water (38°C and 33.5°C, respectively), considering the shallow well depths.

Implications of Geophysical Data

Gravity and thermal gradient data (Roy and Taylor, 1980, and unpublished data) are significant in the interpretation of faults and thermal water in the area. A Bouguer gravity map displays an approximate northwest-trending anomaly through the area of hot wells both near Davis Dome and near the Texas-New Mexico border. This gravity anomaly may be in response to a fault approximately coincident with the one that we postulated from surface geology, or it may join with the fault indicated by the northwest-trending Quaternary scarp west of Davis Dome (fig. 1).

Thermal gradients, generally above the water table, measured by Roy and Taylor range up to 300°C/km. High gradients (greater than 50°C/km) occur in a 4-km-wide (2.5-mi) band across the postulated fault zones near hot wells N-8 and 49-08-1A (fig. 4). These gradients should not be extrapolated below the water table, but they can be used to identify the occurrence of hot water. The highest gradient of 306°C/km was measured in a 45-m (150-ft) hole adjacent to well 49-08-1A. Two high gradients (151° and 179°C/km) were measured 1 to 2 km (0.6 to 1.2 mi) south of the area, which suggests that thermal waters occur along the southern continuation of the faults. At this time, no gradients have been measured in New Mexico, but the presence of the three hot wells near Davis Dome suggests that thermal waters may occur in a continuous zone between the two areas of hot wells.

Gradients drop to background levels both east and west of the area. A low gradient of 56°C/km near the easternmost postulated fault, along the main Hueco Mountains scarp, suggests that thermal waters are not associated with this fault.

HYDROLOGY

Data Availability

Available well data were inventoried for that part of the Hueco and Tularosa Bolsons in West Texas and New Mexico bounded by the coordinates 106°00' W. to 106°16' W. (essentially U.S. Highway 54 in New Mexico) and 31°49' N. (U.S. Highway 62-180 in Texas) to 32°08' N. This includes all of the wells in the area covered by figure 2 and some additional wells to the west of that area. Also included are the wells at Newman on the Texas-New Mexico border. Approximately 60 water or exploration wells occur within this study area. Most wells are no longer operating, many having been abandoned or destroyed in the 1950's. Only nine wells are currently in operation, and all of these produce cold water.

Information of any kind is scarce for most wells. Wells can be grouped on the basis of the availability of data into three categories. First are wells drilled before World War II; two-thirds of all wells fall within this category. In general, very little information is available on these older wells, and very few are usable or even exist today. The second group of wells was drilled in the early 1950's as test wells by the U.S. Geological Survey. Considerable information is available for these wells; however, most were filled or plugged shortly after being completed and, consequently, are unavailable for current testing. The third group of wells was drilled since about 1960 for land development; these wells are generally in use or at least are available for re-examination. Permeability and yield data are available for so few wells that most estimates of permeabilities are extrapolated from other wells in Hueco Bolson.

The information on all wells in the Hueco Tanks area comes from five primary sources: (1) Sayre and Livingston (1945), U.S. Geological Survey Water-Supply Paper 919; (2) Knowles and Kennedy (1958), U.S. Geological Survey Water-Supply Paper 1426; (3) McLean (1970), U.S. Department of the Interior, Office of Saline Water Research and Development Progress Report 561; (4) files of the Texas Department of Water Resources; and (5) personal communications with drillers and property owners in the El Paso-Las Cruces region. The southeastern section of Hueco Bolson, which is outside this study area, is discussed by Gates and others (1978). All available well data are summarized in appendix A.

Water-Table Elevation

Sayre and Livingston (1945) extrapolated water-table elevations into the western part of the study area on the basis of data from six wells located along the western margin of the Hueco Tanks geothermal area (fig. 2). Because no wells were available in the geothermal area at the time, the extrapolated elevations are inaccurate. Knowles and Kennedy (1958) extended and refined the water-table contours, particularly in the U.S. Highway 62-180 area where several new wells had been drilled. In general, the water table appeared to drop by 1 to 1.5 m (3 to 5 ft) between 1945 and 1958. However, there were too few data in the geothermal area to map the water table. Nevertheless, both studies show that ground water generally flows from north to south in the central part of the bolson.

Recent data from old wells and water levels in new wells generally agree with the 1958 data for the central part of the bolson and indicate lowering of the water table in more populated areas by 1.5 to 3 m (5 to 10 ft) since 1958 (fig. 6). Slight differences in water-table elevation between neighboring wells probably result from drawdown in heavily pumped wells. In the eastern part of the study area, near the Hueco Mountains, there are still too few wells to provide a reliable view of the water-table configuration. However, a curious pattern is shown by the available data. Water levels in five wells from near Davis Dome south to the state border are approximately 21 m (70 ft) lower than wells to the west in the central part of the bolson. The water levels indicate a distinct water-table trough along the eastern edge of the bolson, where water levels might be expected to increase gradually toward the Hueco Mountains. Only one well (N-7) has a water-table elevation consistent with this view, and it appears to be perched above the hot water in an adjacent well (N-8). The water-table trough cannot be traced farther south because information is unavailable except near Hueco Tanks State Park. Water levels there are much shallower than in the trough area and appear to follow closely the surface topography.

At this time the only hypothesis we can offer to explain a water-table trough along the bounding fault is that one of the postulated faults in the area serves as a barrier to horizontal ground-water flow. Flow on both sides of the fault is to the south, but at lower elevations on the east side of the bolson. The lower elevations may indicate greater permeability and better drainage of ground water in either coarse basin fill adjacent to the mountains or in fractured bedrock within the horst block roughly coincident with the trough. A major problem with this interpretation is that, although most hot wells occur on the trough side of the postulated fault, one well

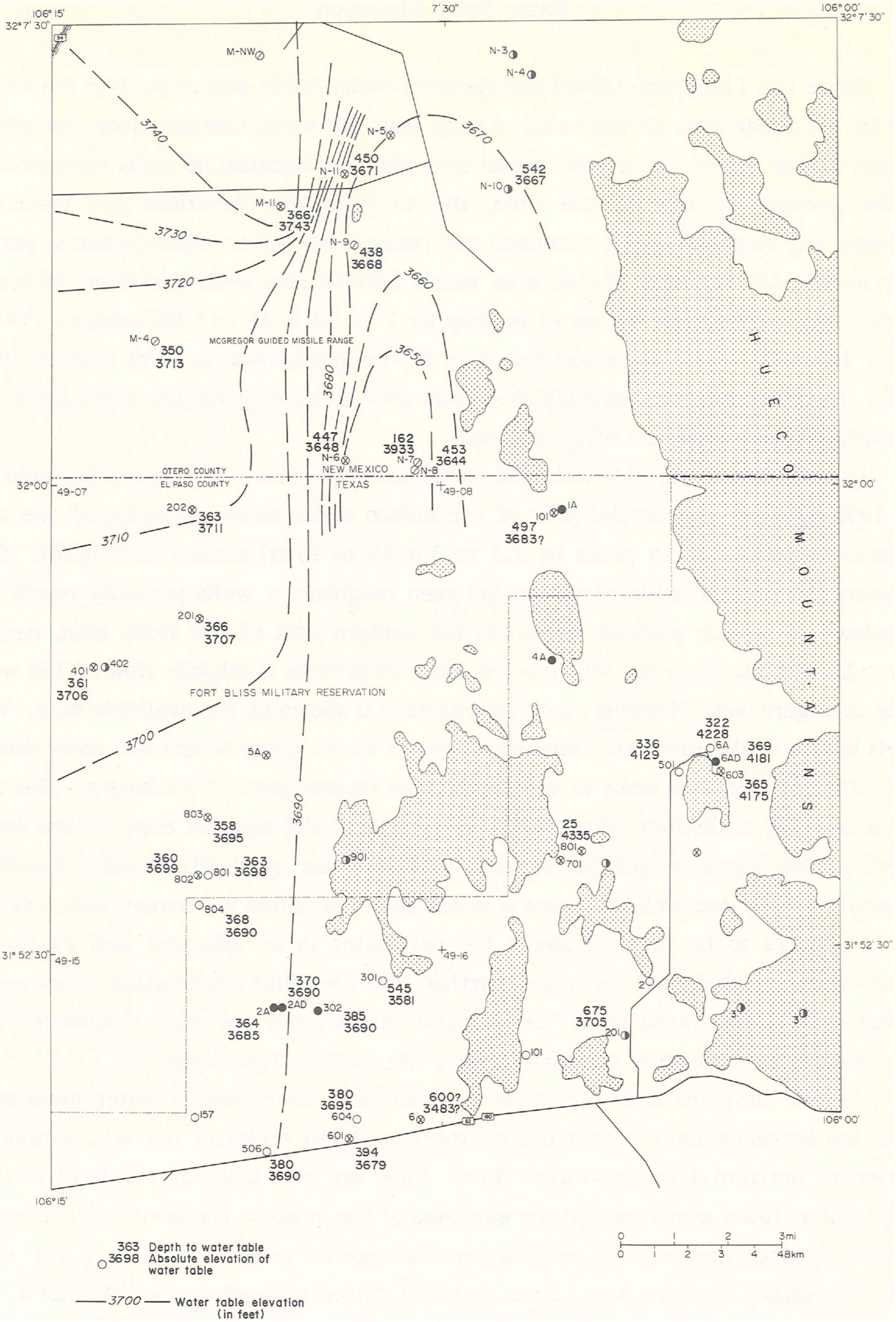

Figure 6. Depth to water table, absolute elevation of water table, and water-table elevation contours. Contours along western edge are extrapolated from data outside map area.

(M-11) occurs on the opposite side. If a fault were serving as a ground-water barrier, hot water would be expected to be restricted to one side. The lower water-table elevations are not simply a result of drawdown because these wells were never significantly pumped. In contrast, one well in the southern part of the study area (49-15-301) has been pumped heavily. Its low water table probably does result from heavy pumping. Nor are the low water-table elevations simply the result of measurement errors. The wells were drilled and water-table elevations measured by different people at different times (appendix A). Until more accurate and detailed information is available, no conclusions can be reached about the origin of the water-table trough.

Substrate Permeability

Although hot water is known to occur in the Hueco Tanks area, little is known about how much water could be produced and from what kind of rock. No permeability or production values have been reported for any of the hot wells. The only qualitative information available is for well N-11, where a "small supply of water" (McLean, 1970) was produced from fractures in felsite bedrock. Two other hot wells (N-9 and 49-08-1A) appear to produce from Paleozoic bedrock. No substrate information is available for wells M-11 and N-8, but they may produce from either bedrock or bolson fill. Permeability values and yields are also unavailable for most of the cold wells in the area, although McLean (1970) estimates that yields of moderately saline water from basin-fill aquifers should be less than 300 gal/min. Most studies of ground-water availability were in more populated areas of the bolson. For these reasons, we have used data from other areas to evaluate qualitatively the possible productivity of geothermal wells in the Hueco Tanks area. Potential geothermal reservoirs include sands and gravels in basin fill and bedrock below the fill, especially along fault zones where fracturing may have increased the permeability.

Knowles and Kennedy (1958) and Gates and others (1978) list transmissivity values in basin fill ranging from 5,000 to 33,000 ft^2/d (38,000 to 250,000 gal/d/ft). The wide range in values reflects considerable variation in composition and thickness of fill. The highest values are for coarse, thick fluvial deposits immediately adjacent to the Franklin Mountains. In contrast, lacustrine deposits in the central part of the basin have very low transmissivities, probably less than 5,000 ft^2/d. Productivity of wells in the geothermal area should depend on the type of basin-fill deposits and on the abundance of coarse clastic sediment in them.

We used driller's logs to determine the types of deposits and the percentages of sand, gravel, and clay (and depth to bedrock) in basin-fill sediments. There are complete driller's logs for only 12 wells, and the wells are irregularly distributed in the area. Incomplete logs exist for several of the wells; some of these logs could be used to determine the depth to bedrock.

Two methods were used to determine percentages of different lithic constituents in each well. The first method required designating an interval in a log on the basis of the major rock type in that interval. Thus, descriptions such as sand and clay; sand/clay; and sand, clay, and gravel were all designated "sand." This method resulted in four major categories: (1) gravel, including conglomerate, (2) sand, (3) clay, including shale, and (4) bedrock, including limestone and igneous rock. Caliche, normally a minor surficial component, was ignored.

The second method weighted rock types in each interval. Thus, a 30-ft interval of sandy clay and caliche arbitrarily became 21 ft clay, 3 ft sand, and 6 ft caliche. In general, the two methods agreed closely. Electric logs were available for six wells. A comparison of electric logs with driller's logs showed the driller's logs to be reasonably accurate.

Analysis of the driller's logs shows no definite lateral lithologic trends (fig. 7). The only obvious conclusion is that bedrock occurs at the shallowest depths in wells immediately adjacent to outcrops. Only one well within Hueco Bolson encountered bedrock. All other wells, even those wells within a few kilometers of outcrop, bottomed in basin fill. The great thickness of fill further substantiates the presence of faults in the area. The proportions of different lithic constituents within the bolson deposits vary considerably, even within a small area. For example, six wells in the southern part of the Nation's East Well Quadrangle (49-07) and the northern part of the Nation's South Well Quadrangle (49-15) show ranges in sand content from 28 to 69 percent and in clay content from 23 to 68 percent. Two wells approximately 1 km (0.6 mi) apart contain 28 and 68 percent sand, and 69 and 23 percent clay, respectively. All six of these wells are within approximately 3 km (2 mi) of a large bedrock outlier (approximately 8 km [5 mi] in diameter).

No discernible marker beds or correlative sequences were noted in the logs of the wells. The lack of correlative marker beds is probably a function of the style of deposition within the basin. The bolson fill was probably deposited by coalescing alluvial fans with sediments shed from the Hueco Mountains and various bedrock outliers. Correlation of beds even within individual fans would be difficult; correlation between fans would be nearly impossible.

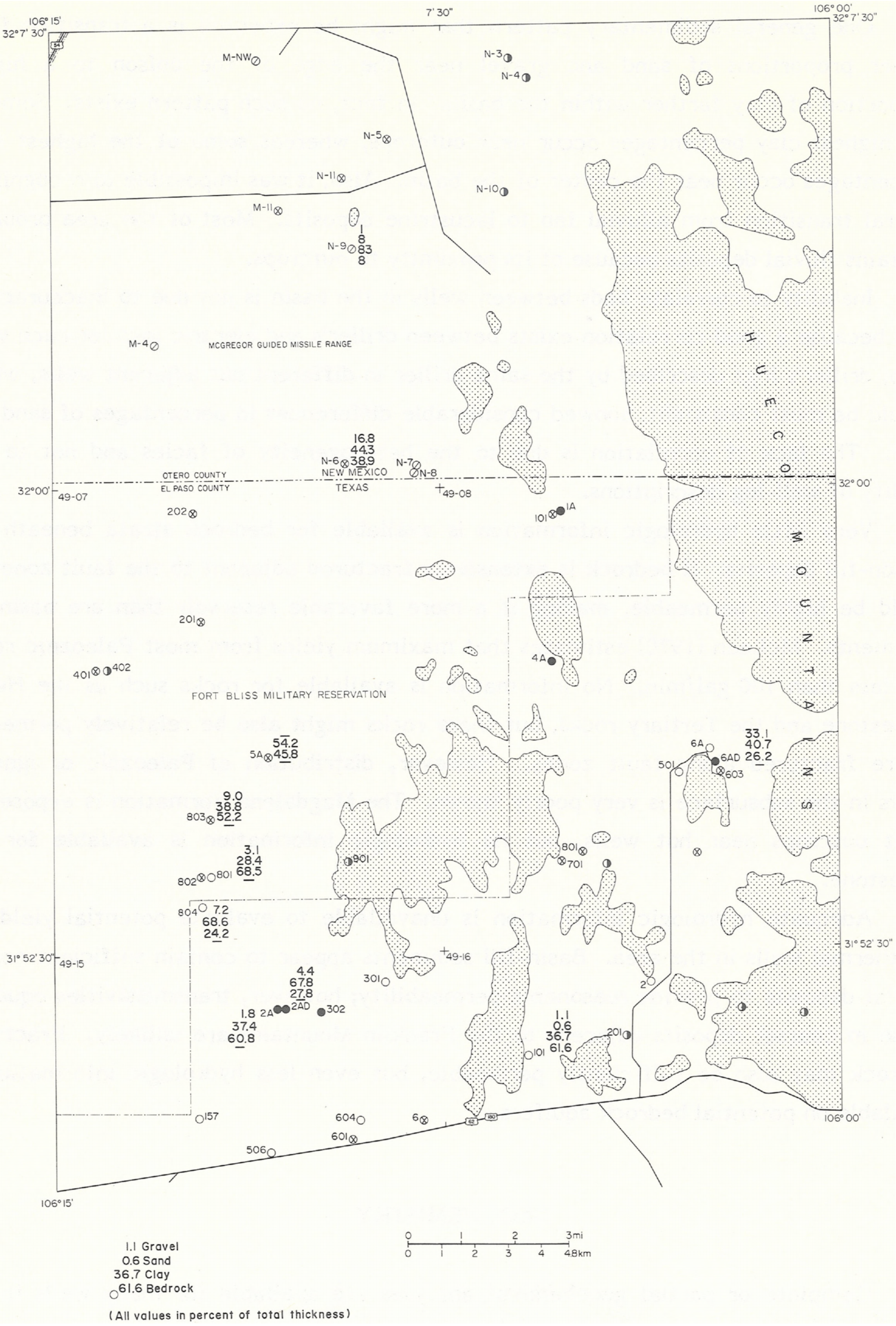

Figure 7. Percentages of gravel, sand, clay, and bedrock from driller's logs.

One general sedimentary pattern that might be expected is a transition from higher proportions of sand and gravel near the edge of the bolson to a higher proportion of clay farther within the basin. In fact, no such pattern exists. Some of the highest clay percentages occur near outcrops, whereas some of the highest sand percentages occur near the center of the basin. Also, it was impossible to recognize a lateral transition from alluvial fan to lacustrine deposits. Most of the area probably contains fluvial deposits because of its proximity to outcrops.

Inability to correlate beds between wells in the basin is not due to inaccuracy of logs because a good correlation exists between driller's and electric logs for each well. Also, driller's logs described by the same driller in different but adjacent wells, which should be most consistent, showed considerable differences in percentages of sand and clay. The lack of correlation is due to the heterogeneity of facies and not to the quality of well-log descriptions.

Very little hydrologic information is available for bedrock strata beneath the bolson-fill deposits. If bedrock is extensively fractured adjacent to the fault zones, it could be highly permeable, making it a more favorable reservoir than are basin-fill sediments. McLean (1970) estimates that maximum yields from most Paleozoic rocks are less than 100 gal/min. No information is available for rocks such as the Hueco Limestone and the Tertiary rocks, but these rocks might also be relatively permeable where fractured along fault zones. However, distribution of Paleozoic or igneous rocks in the subsurface is very poorly known. The Magdalena Formation is exposed in most outcrops near hot wells, but no hydrologic information is available for the limestone.

Adequate hydrologic information is unavailable to evaluate potential yields of geothermal wells in the area. Basin-fill sediments appear to contain sufficient coarse fluvial deposits to provide reasonable permeability; however, transmissivities equal to those in coarser deposits adjacent to the Franklin Mountains are unlikely. Fractured bedrock may also be sufficiently permeable, but even less hydrologic information is available on potential bedrock aquifers.

GEOCHEMISTRY

Complete or partial geochemical analyses are available for many wells in the area, including four hot wells. Sources of information include published analyses in the various hydrologic reports on the area, analyses on file at the Texas Department of Water Resources and the U.S. Geological Survey, and new analyses made during this study. Many of the old analyses are incomplete in that they do not provide values for at least pH, Ca, Mg, Na, Cl, SO_4, and HCO_3. Many old analyses also do not provide temperature. Only three of the hot-water analyses include all the major constituents. Also, many of the older analyses are drill-stem tests for which some contamination is probable. Some older analyses also listed NO_3, PO_4, SiO_2, Fe, F, B, or Mn. Samples collected during this study were analyzed for temperature, pH, and HCO_3 in the field, and for Ca, Mg, Na, K, Sr, Cl, SO_4, NO_3, P, B, F, and SiO_2 in the laboratory. All available analyses are listed in appendix B.

Most of the waters, including both thermal and nonthermal, are Na-Cl-(SO_4)-type waters (figs. 8 and 9). Hot waters are commonly the richest in sodium and chloride, but their compositions overlap with those of cold ground waters. Total dissolved solids range from 450 to about 9,000 mg/L for nonthermal waters and from 1,140 mg/L (M-11) to between 8,000 and 9,000 mg/L (49-08-1A and N-11) to an estimated 12,500 mg/L (N-9) for the four thermal waters that were analyzed. Only two nonthermal waters (49-16-101 and N-6) contain dissolved solids greater than 2,600 mg/L. Well 49-16-101 is a deep well containing warm water (36°C). Well N-6 is 2 km (1.2 mi) west of thermal well N-8. No temperature is available, although presumably it is cold. Total dissolved solids in two drill-stem tests from different depths are 2,670 and 9,130 mg/L. Thus, the thermal and nonthermal waters in the area have similar ionic proportions. However, most thermal waters have high dissolved solids, whereas most nearby nonthermal waters have lower dissolved solids.

Complete analyses are available for two thermal wells from the Davis Dome area (M-11, N-11) and one from Texas (49-08-1A). Another thermal well from near Davis Dome (N-9) has a partial analysis. No analysis of any kind is available for the thermal well near the Texas-New Mexico border (N-8). Thermal waters show a large range in dissolved solids, which may partly reflect mixing with cold ground water or the presence of more than one parent thermal water. Water having the highest temperature (N-9; 71°C) also has the highest concentration of dissolved solids (12,500 mg/L estimated from analysis); water having the lowest temperature (M-11, 50°C) also has the lowest concentration of dissolved solids (1,140 mg/L). Water from well N-11 is intermediate in both temperature and dissolved solids (61°C, 8,980 mg/L). Reported temperature (58°C) and dissolved solids (7,850 mg/L) of water from well 49-08-1A are also intermediate (Hoffer, 1978). The parent thermal water for all these wells may be chemically similar to and most like that in well N-9. However, the low dissolved solids concentration in well M-11 water could not simply result from mixing of a saline parent water with cold, dilute ground water. To lower the dissolved solids concentration from either 8,000 or 12,000 mg/L to approximately 1,100 mg/L would require such a large proportion of even dilute cold water that a high temperature could not be maintained. Mixing of a dilute hot water with a very saline cold water also

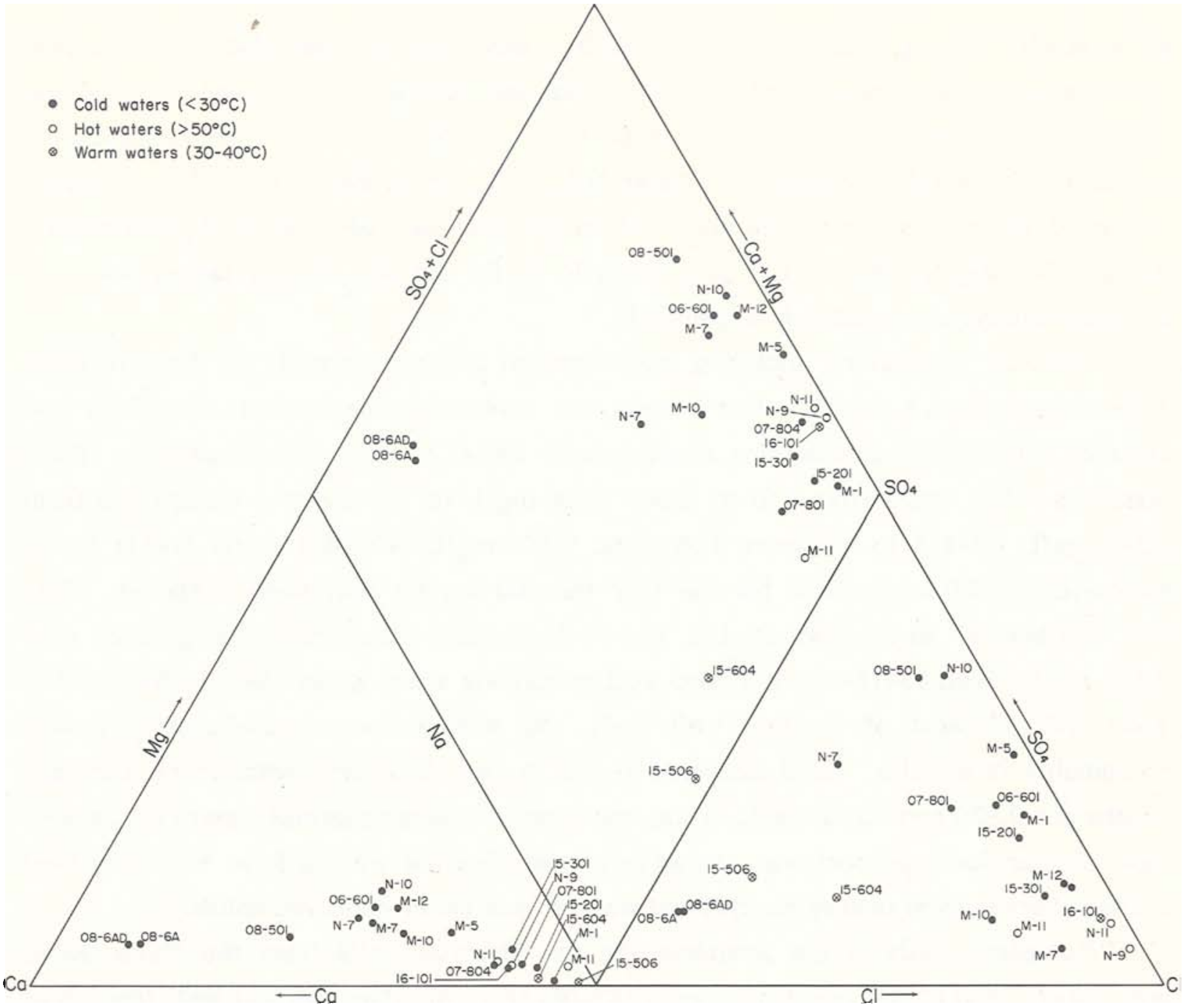

Figure 8. Trilinear diagram of thermal and nonthermal waters.

cannot produce the observed compositions and temperatures. Thus the range in concentrations of dissolved solids cannot reflect mixing alone and remains unexplained.

The high dissolved solids concentrations typical of the thermal waters probably result from one or more of the following events: (1) contact of the waters with evaporite deposits or shale in Paleozoic rocks, (2) contact with evaporites in basin fill of Hueco Bolson, and (3) expulsion of saline waters from deep basin deposits. The latter two explanations may be related in that deep basin waters (which may have up to 50,000 mg/L total dissolved solids; Cliett, 1969) may be saline because they are in contact with evaporites in the basin. Alternatively, deep basin waters may be residual brines formed during closed-basin deposition in Hueco Bolson.

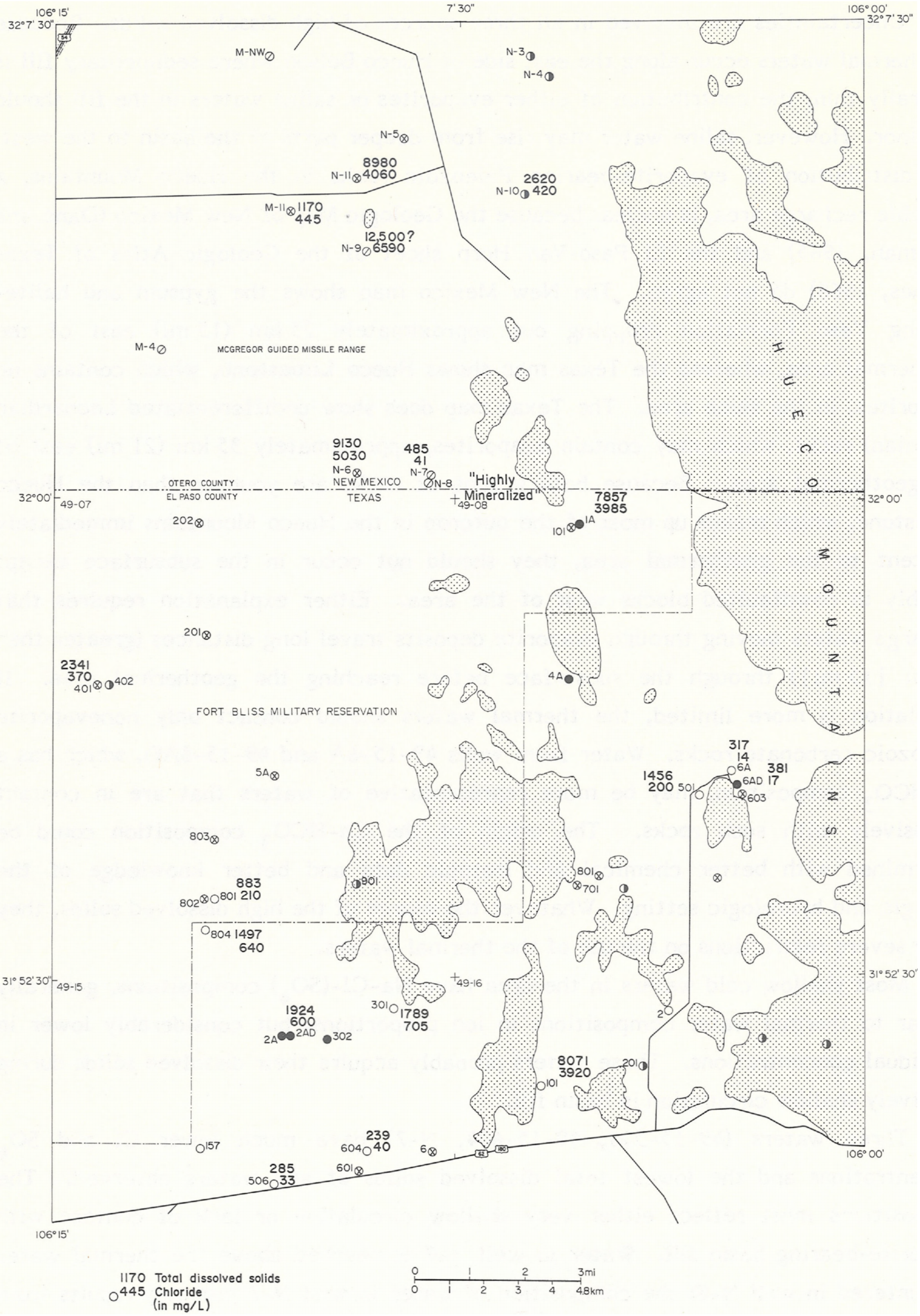

Figure 9. Total dissolved solids and chloride concentrations.

Uncertainties are involved in all three sources of high dissolved solids. Because the thermal waters occur along the east side of Hueco Bolson where sedimentary fill is generally thin, the contribution of either evaporites or saline waters in the fill should be minor. However, saline water may rise from deeper parts of the basin to the west. The distribution of evaporite-bearing Paleozoic rocks in the Hueco Mountains, a probable recharge area, is unclear because the Geologic Map of New Mexico (Dane and Bachman, 1965) and the El Paso-Van Horn sheet of the Geologic Atlas of Texas (Barnes, 1968) do not agree. The New Mexico map shows the gypsum and halite-bearing Yeso Formation cropping out approximately 25 km (15 mi) east of the geothermal area, whereas the Texas map shows Hueco Limestone, which contains no evaporites, in the same area. The Texas map does show undifferentiated Leonardian (Permian) rocks, which may contain evaporites, approximately 35 km (21 mi) east of the geothermal area. Because both groups of rocks are younger than the Hueco Limestone, which makes up most of the outcrop in the Hueco Mountains immediately adjacent to the geothermal area, they should not occur in the subsurface except possibly in downfaulted blocks west of the area. Either explanation requires that recharge waters moving through evaporite deposits travel long distances (greater than 25 km [15 mi]) through the subsurface before reaching the geothermal area. If circulation is more limited, the thermal waters should contact only nonevaporite Paleozoic carbonate rocks. Water from wells 49-15-6A and 49-15-6AD, which has a Ca-HCO_3 composition, may be more representative of waters that are in contact exclusively with such rocks. The origin of the Ca-HCO_3 composition could be determined with better chemical and isotopic data and better knowledge of the geologic and hydrologic setting. Whatever the source of the high dissolved solids, they place severe restrictions on the use of the thermal waters.

Most shallow cold waters in the area have Na-Cl-(SO_4) compositions, generally similar to thermal water compositions in ion proportions, but considerably lower in individual concentrations. These waters probably acquire their dissolved solids during relatively shallow circulation in basin fill.

Three waters (49-15-506, 49-15-604, N-7) have much lower Cl and SO_4 concentrations and the lowest total dissolved solids of any waters observed. The compositions must reflect either very shallow circulation or lack of contact with evaporite-bearing basin fill. Water in well N-7 is perched above the thermal water encountered in well N-8; the composition of water in well N-7 probably results from shallow circulation. Waters from wells 49-15-506 and 49-15-604 are slightly warm (38° and 33.5°C, respectively) and must circulate somewhat deeper to reach these temperatures. Both these wells are in the southwestern part of the area investigated. Basin fill in this area might never have contained evaporites, or the evaporites might have been flushed by older ground water.

Waters from wells 49-15-6A and 49-15-6AD have Ca-HCO_3 compositions distinctly different from those of all the other waters. The driller's log shows that the wells produce from Paleozoic limestone beneath basin fill and adjacent to igneous rock in Hueco Tanks State Park. Recharge to the wells may be through highly fractured igneous rock and into the limestone. The distinctive water composition probably reflects contact with these rocks and not with basin fill.

Saturation indices for a variety of minerals were calculated by the computer program SOLMNEQ. Table 1 lists saturation indices for eight common minerals, including four silica minerals important in geothermometry. Silica saturation is discussed in the section on Geothermometry. Saturation indices for calcite are scattered around zero, there being about an equal number of oversaturated and undersaturated waters. Most ground waters are in equilibrium with calcite. The scatter in saturation indices for these waters may indicate either poor analysis or loss of CO_2 between sample collection and analysis. All waters, including the thermal waters containing a high concentration of dissolved solids, are undersaturated with respect to either halite or gypsum. Halite saturation is unusual even in the most concentrated brines; so its lack of saturation is not surprising. Undersaturation with respect to gypsum probably indicates that (1) the source rocks for the thermal water contained little gypsum, (2) the thermal waters have mixed with cold waters, or (3) calcite has precipitated since the waters contacted gypsum.

GEOTHERMOMETRY

Thermal waters almost invariably lose some heat when they rise to or near the surface. Thus the measured temperature for the waters is a minimum temperature. The maximum temperature may be slightly or significantly higher than the measured values. The maximum temperature can be estimated from the chemical composition if several assumptions are met (Henry, 1979a; Fournier and others, 1974). In this study the most important assumptions are that the waters are in equilibrium with minerals that control dissolved concentrations and that mixing with nonthermal water has not occurred. Probably neither of these conditions is totally met by thermal waters in the Hueco Tanks area.

Table 1. Saturation indices.

Log AP/KT

Well	Quartz	Chalcedony	α-Cristobalite	Amorphous silica	Fluorite	Calcite	Gypsum	Halite
M-1	0.24	-0.19	-0.38	---	-1.55	-0.82	-1.95	-5.45
M-5	0.53	0.09	-0.09	---	-1.49	-0.16	-0.99	-5.02
M-10	0.62	0.19	0.00	-0.34	-1.69	-0.16	-2.29	-6.27
M-11	0.49	0.15	-0.04	---	-1.66	-0.29	-2.90	-5.40
M-12	0.54	0.10	-0.08	---	-1.27	-0.29	-1.54	-5.44
N-7	0.72	0.29	0.10	---	-1.52	0.27	-1.88	-7.05
N-9	0.39	0.09	-0.09	---	---	---	-0.85	---
N-10	0.13	-0.29	-0.48	---	-0.52	0.22	-0.77	-5.38
N-11	0.46	0.15	-0.04	---	0.37	0.24	-1.12	-3.80
49-06-601	0.58	0.15	-0.04	---	-1.47	-0.09	-1.34	-5.72
49-07-801	0.72	0.29	0.10	-0.24	-1.57	-0.15	-1.97	-5.85
49-07-804	0.64	0.22	0.03	-0.31	-1.67	0.19	-1.68	-5.19
49-08-501	0.75	0.33	0.14	-0.20	-1.75	0.15	-0.88	-6.05
49-08-6A	---	---	---	---	-1.60	0.13	-2.18	-8.17
49-08-6AD	---	---	---	---	-1.84	0.13	-2.19	-8.22
49-15-201	0.77	0.34	0.14	-0.20	-1.85	-0.73	-1.67	-5.08
49-15-301	0.51	0.08	-0.11	-0.45	-0.51	-0.14	-1.74	-5.04
49-15-506	0.45	0.07	-0.12	-0.46	-2.45	-0.53	-3.62	-7.07
49-15-604	0.39	-0.01	-0.20	-0.54	-2.68	-0.55	-3.22	-7.11
49-16-101	0.56	0.16	-0.02	-0.37	0.02	0.11	-1.02	-3.79

The two most common geothermometers are the Na/K or Na/K/Ca and the silica geothermometers. The Na/K/Ca geothermometer requires equilibrium with feldspars, a reasonable assumption for most rocks. However, many of the waters of this study have been in contact with evaporites, and the Na/K/Ca geothermometer cannot be applied to them. Although temperatures have been calculated for the usable water analyses that determine all three ions, the calculated temperatures are not meaningful.

The silica geothermometer requires that the water be in equilibrium with some silica mineral, commonly quartz, but equilibrium with more soluble silica minerals such as chalcedony or amorphous silica has been found in some waters (Arnorson, 1975). Many thermal waters in Trans-Pecos Texas and Chihuahua appear to be in equilibrium with chalcedony (Henry, 1979a). The SiO_2 concentration of the water is a function of temperature and the silica mineral with which the water is in equilibrium. Many workers assume equilibrium with quartz, but equilibrium with quartz occurs only in very high temperature waters (greater than $180^{\circ}C$; Arnorson, 1975). Volcanic rocks and basin fill commonly contain some of the more soluble silica minerals, making equilibrium with quartz uncommon. Also, equilibrium at low temperatures is much less likely than at high temperatures. Waters that were never hot are unlikely to be in equilibrium; thus, no geothermometer would work. No geothermometer should be applied uncritically to nonthermal ground water.

We have calculated SiO_2 temperatures assuming equilibrium with four different silica phases: quartz, chalcedony, cristobalite, and amorphous silica (table 2). We believe that equilibrium with chalcedony is most likely for the three thermal waters in the shallow reservoirs; the chalcedony temperatures are probably the best estimates of the maximum temperatures of these waters. Thus, the maximum temperature may be around $80^{\circ}C$. If equilibrium is with quartz, shallow reservoir temperatures may be as high as $110^{\circ}C$.

The large range in dissolved solids suggests that mixing of thermal and nonthermal waters has occurred. The shallow reservoir system may be fed by a parent thermal water that is considerably hotter than any of the observed waters. Evidence of this hotter water would have been destroyed during mixing and by local precipitation, especially of silica minerals, in the shallow reservoir. Thus the observed silica concentrations may reflect only conditions in the shallow reservoir. Data to evaluate this hypothesis or to identify a high-temperature parent water are not available.

Separate K concentrations are not available for any of the old analyses of hot waters, and none of these waters can now be sampled. Therefore, it was impossible to

Table 2. Measured and calculated water temperatures.

Temperatures (^{o}C)

	Measured	SiO_2				Na/K/Ca			
Well		Quartz	Chalcedony	α-Cristobalite	Amorphous silica	Na/K	β=4/3	β=1/3	pCO_2
M-1	25.0*	42.4	9.7	-5.7	-63.0	---	---	---	---
M-5	25.0*	65.3	33.3	16.0	-44.6	46.2	79.5	108.1	35.1
M-10	25.5	75.1	43.5	25.5	-36.5	155.4	77.0	153.2	31.9
M-11	50.0	95.9	65.6	45.7	-19.0	---	---	---	---
M-12	22.2	63.4	31.4	14.3	-46.1	---	---	---	---
N-7	25.0*	84.6	53.6	34.7	-28.6	---	---	---	---
N-9	71.1	108.9	79.5	58.3	-8.0	---	---	---	---
N-10	25.0*	34.4	1.6	-13.1	-69.3	---	---	---	---
N-11	61.1	104.5	74.8	54.1	-11.7	---	---	---	---
49-06-601	25.0*	70.4	38.6	21.0	-40.3	118.3	74.9	138.7	27.7
49-07-801	24.5	83.4	52.2	33.4	-29.6	43.8	77.6	106.3	33.7
49-07-804	28.0	80.8	49.5	30.9	-31.8	35.9	74.0	101.2	37.7
49-08-501	28.0	90.6	59.9	40.4	-23.6	24.3	20.8	78.2	-16.0
49-08-6A	25.0*	---	---	---	---	464.8	45.1	209.7	-0.2
49-08-6AD	25.0*	---	---	---	---	626.8	52.1	235.0	5.1
49-15-201	23.5	85.9	54.9	35.9	-27.5	26.5	89.6	100.5	38.7
49-15-301	24.5	63.4	31.4	14.3	-46.1	83.4	114.7	136.2	53.5
49-15-506	38.0	78.0	46.6	28.3	-34.1	28.3	74.6	97.4	34.1
49-15-604	33.5	65.3	33.3	16.0	-44.6	92.7	74.6	128.2	34.3
49-16-101	36.0	80.8	49.5	30.9	-31.8	108.8	171.4	162.6	76.1

*Estimated

calculate any Na/K or Na/K/Ca temperatures. The temperatures probably would not have been meaningful anyway because the waters probably contacted evaporites.

Water from a shallow well adjacent to hot well N-8 (N-7) has a relatively high SiO_2 concentration and high calculated temperature even though it is a cold well. The high silica concentration may result from mixing with hot water in well N-8. However, well N-7 appears to produce from a perched water table above the thermal water reached by well N-8.

Calculated temperatures for all other cold waters are uncertain. Some of these waters may be in equilibrium with one of the more soluble silica phases; however, it is not possible to tell from the available data. Calculated saturation indices indicate that most of the cold waters are approximately in equilibrium with chalcedony or alpha-cristobalite. More importantly, there is neither geologic nor geochemical evidence that any of the cold waters were ever hot. The best estimates of their temperatures are either measured temperatures (where available) or average annual surface temperature, approximately 20°C. However, because the saturation indices do not indicate consistent equilibrium with either mineral, the waters may simply not be in equilibrium with any silica phase.

Subsurface temperatures can also be evaluated qualitatively by extrapolating the thermal gradients determined by Roy and Taylor (1980). The highest gradient they observed, 300°C/km, was in a 45-m-deep (150-ft) hole near well 49-08-1A. Extrapolating that gradient to the water table at about 152 m (500 ft) and assuming a surface temperature of about 20°C give a temperature at the water table of about 66°C. This agrees fairly well with the value of 58°C reported by Hoffer (1978).

A 300-m (1,000-ft) hole approximately 1 km (0.6 mi) west of well 49-08-1A had a gradient of 142°C/km, and more importantly, showed two inflections in the gradient. The first, at a depth of about 150 m (500 ft) and a temperature of 50°C, may mark the water table. The second was at the bottom of the hole at a temperature of 65°C. The lower temperature at the water table (compared with that of well 49-08-1A) may be due to mixing of the thermal water with cool shallow ground water or to conductive cooling. This would imply that well 49-08-1A is nearer the actual source of hot water. The second inflection may indicate a change to isothermal conditions below 300 m (1,000 ft), an important consideration for determining maximum available temperatures.

Two shallow holes, 45 and 50 m (150 and 165 ft) deep, near hot well N-8 gave gradients of 175° and 157°C/km, respectively. Extrapolation of these gradients to the water table (138 m [450 ft] in well N-8) gives temperatures of 44° and 42°C. Because there is no recorded temperature for well N-8, no comparison can be made.

SUMMARY

The Hueco Tanks geothermal area lies on the east side of Hueco Bolson, an asymmetric graben. Greatest displacement along boundary faults is on the west side adjacent to the Franklin Mountains. Faults, probably with lesser displacement, also form an irregular boundary on the east side of the bolson. We have identified several probable faults that may allow the rise of thermal waters from depth. The existence and location of these faults need to be confirmed by geophysical investigations and by drilling.

Ground water in the central part of Hueco Bolson flows toward the south to the Rio Grande. However, four of the five hot wells occur in a ground-water trough along the eastern margin of the bolson. The trough may be bounded by one of the postulated faults serving as a barrier to ground-water flow. Water-table elevations, direction of flow, and origin of the trough also need to be evaluated.

Little detailed information exists on the permeability of possible geothermal reservoir rocks, including basin fill and bedrock beneath basin fill. By extrapolating data from outside the area, it can be inferred that the permeability of basin fill and fractured bedrock may be sufficient for development of geothermal water.

The concentration of dissolved solids in the geothermal waters varies from 1,100 to at least 12,500 mg/L, but most waters are probably in the higher part of the range. They are Na-Cl-(SO_4) waters and are similar in composition to nonthermal waters in basin fill. The composition probably results from contact of the waters with evaporite deposits either in basin fill or in Paleozoic bedrock. Calculations using the silica geothermometer suggest that shallow reservoirs reach maximum temperatures of about 80° to 110°C, but not much higher. The parent thermal water may be hotter before mixing with nonthermal waters, but almost no data are available to evaluate this hypothesis.

Geothermal water in the Hueco Tanks area could be a significant resource because of its proximity to El Paso. However, at this time, data are too limited to evaluate the resource; even the most basic and essential information such as the maximum temperature and the available quantity of water is deficient. To evaluate the resource adequately, a complete exploration program, including geological, hydrological, and geochemical investigation, will be necessary.

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Appendix A: Well data (all elevations in feet).

New Mexico

Well No.	M-1	M-4	M-5	M-6	M-7	M-10	M-11	M-12	M-NW
Date drilled	ND*	1930	1953	1917	1902	1957	1956	1957	1930's
Date abandoned	1954?	1954		1954?	1954		1956	1957	1950's
Elevation	4,102	4,063	4,061	4,000	4,000	4,000	4,109	3,985	4,122
Depth	441	450	880	400	332	400	502	380	210
Casing (inches)	8	ND	3	13	6	16	None	ND	6-8
Screen	ND	ND	425-435	328-390	320-332	285-400	None	ND	ND
Depth to water level	356	350	348	284	ND	284	366	265	ND
Absolute elevation of well	3,661	3,613	3,181	3,600	3,662	3,600	3,607	3,605	3,912
Absolute elevation of screen	ND	ND	3,631	3,610	3,662	3,600		ND	ND
Absolute water level	3,746	3,713	3,718	3,716	ND	3,716	3,743	3,720	ND
Production (gal/min)	ND	ND	ND	ND	50	ND	0.5	ND	2-3
Date of information	1955	1952	1954	1936	1936	1957	1980	1958	1980
Status**	D	S	C	D	D	O	D	U	C

---

*ND= No data

**B = Blocked O = Operating
C = Capped S = Sanded
D = Destroyed U = Unknown

Appendix A (continued)

New Mexico

Well No.	N-3	N-4	N-5	N-6	N-7	N-8	N-9	N-10	N-11
Date drilled	ND	ND	ND	1953	Old	Old 1900?	1945	1956	1956
Date abandoned	1950's	1950's	1954	1954?	1950's	1950's	1980	1950's	1957
Elevation	4,192	4,219	4,097	4,095	4,095	4,097	4,106	4,209	4,121
Depth	1,000	700	ND	824	350?	1,000?	450	705	745
Casing (inches)	ND	ND	ND	None	ND	ND	ND	ND	None
Screen	ND	ND	ND	None	ND	ND	ND	ND	None
Depth to water level	ND	No water	ND	447	162	411 (1935) 453 (1954)	438	542	450
Absolute elevation of well	3,192	3,519	ND	3,271	3,745	3,097	3,656	3,504	3,376
Absolute elevation of screen	ND	ND	ND		ND	ND	ND	ND	
Absolute water level	ND	ND	ND	3,648	3,933	3,686 3,644	3,668	3,667	3,671
Production (gal/min)	ND	ND	ND	ND	18	ND	ND	ND	ND
Date of information	1952	1952	1954	1954	1954	1954	1957	1958	1958
Status**	U	U	U	U	B	B	S	U	D

Appendix A (continued)

Texas

Well No.	49-06-201	49-06-301	49-06-3A	49-06-601	49-06-602	49-07-201	49-07-202	49-07-401	49-07-402
Date drilled	1953	1971	1968	1953	ND	Old	Old	1965	1965
Date abandoned	1975			1975	1975	1954	1954	1965	1965
Elevation	3,995	4,053	4,053	4,012	4,043	4,073	4,074	4,067	4,067
Depth	800	570	505	1,020	ND	400?	400	400?	2,460
Casing (inches)	ND	16	16	3	6	5	5	None	ND
Screen	ND	407-570	ND	482-502	ND	ND	ND	None	None
Depth to water level	270	365	365	311	337	366	363	361	No water
Absolute elevation of well	3,195	3,483	3,548	2,992	ND	3,673	3,674	3,667	1,607
Absolute elevation of screen	ND	3,483	ND	3,510	ND	ND	ND	ND	
Absolute water level	3,725	3,688	3,688	3,701	3,706	3,707	3,711	3,706	
Production (gal/min)	ND	ND	ND	ND	ND	ND	ND	ND	
Date of information	1975	1980	1980	1972	1975	1958	1935	1966	1977
Status**	D	C	C	D	D	D	U	U	U

Appendix A (continued)

Texas

Well No.	49-07-5A	49-07-801	49-07-802	49-07-803	49-07-804	49-07-901	49-08-101	49-08-1A	49-08-4A
Date drilled	1977	1943	ND	1953	1979	1966	1952	ND	Being drilled
Date abandoned	1977		1954	1954		ND	1954		
Elevation	4,075	4,061	4,059	4,053	4,058	4,300?	4,180?	4,180	4,260
Depth	550	611	410	1,000	710	1,597	ND	>450	600
Casing (inches)	None	11	5	None	12	ND	8	8	6
Screen	None	448-469	ND	None	428-688	ND	ND	ND	
Depth to water level	No water	363	360	358	368	ND	497	ND	
Absolute elevation of well	3,525	3,450	3,649	3,053	3,348	2,700	ND	ND	3,660
Absolute elevation of screen		3,592			3,370	ND	ND	ND	
Absolute water level		3,698	3,699	3,695	3,690	ND	3,683?	ND	
Production (gal/min)		130	ND	ND	ND	ND	ND	ND	
Date of information	1977	1954	1935 1958	1954	1979	1966	1952	1980	1980
Status**	U	O	D	U	O	U	D	C	U

Appendix A (continued)

Texas

Well No.	49-08-501	49-08-601	49-08-603	49-08-6A	49-08-6AD	49-08-701	49-08-801	49-08-8	49-15-2A
Date drilled	1960	1960	1971	1971	1971	1960	1960	ND	1979
Date abandoned		ND	ND			1960	1960	ND	
Elevation	4,465	4,540	4,540	4,550	4,550	4,355	4,360	4,397	4,055
Depth	515	430	450	∿450	600	160	105	>450	493
Casing (inches)	5	10	5	7	5.5	ND	ND	None	6
Screen	465-505	390-430	ND	390-405	ND	ND	ND	None	400-490
Depth to water level	336	380	345 (1972) 365 (1978)	322	369	ND	25	>450	>364
Absolute elevation of well	3,950	4,110	∿4,090	4,100	3,950	4,195	4,255		3,562
Absolute elevation of screen	3,960	4,110	ND	4,145	ND	ND	ND	ND	3,565
Absolute water level	4,129	4,160	4,175	4,228	4,181	ND	4,335		3,685
Production (gal/min)	50	60	10	18	3	ND	ND		
Date of information	1960	1960	1978	1971	1971	1960	1960	1980	1980
Status**	O	U	U	C	O	D	D	U	C

Appendix A (continued)

Texas

Well No.	49-15-2AD	49-15-301	49-15-302	49-15-5	49-15-506	49-15-601	49-15-6	49-15-6A	49-15-603
Date drilled	1979	1976	Old	Old	1979	1953	Old	1979	1977
Data abandoned				1950's		1954	1976?	1979	
Elevation	4,055	4,126	4,075	4,012	4,070	4,073	4,083	4,085	4,075
Depth	500	558	500	ND	480	1,013	1,100	450	500
Casing (inches)	8	12	12	8	6	None	8	ND	6
Screen	406-496	510-550	ND	ND	456-476	None	ND	ND	470-490
Depth to water level	370	545	385	ND	380	394	600	None	385
Absolute elevation of well	3,555	3,568	3,575	ND	3,590	3,060	2,983	3,635	3,575
Absolute elevation of screen	3,559	3,576	ND	ND	3,594		ND	ND	3,585
Absolute water level	3,690	3,581	3,690	ND	3,690	3,679	3,483		3,690
Production (gal/min)	ND	86-100	22?	15	25	ND	ND		22
Date of information	1980	1976	1980		1980	1954	1980	1980	1980
Status**	C	O	C	D	O	D	D	D	O

Appendix A (continued)

Texas

Well No.	49-15-604	49-16-101	49-16-201	49-16-2
Date drilled	1979	1973	ND	Old
Data abandoned			ND	ND
Elevation	4,075	4,280	4,380	4,440
Depth	500	1,082	2,100	1,300
Casing (inches)	6	12	ND	ND
Screen	385-395 480-490	900-1,080	ND	ND
Depth to water level	380	ND	675	ND
Absolute elevation of well	3,575	3,000	2,280	3,140
Absolute elevation of screen	3,585	3,000	ND	ND
Absolute water level	3,695	ND	3,705	ND
Production (gal/min)	25	30	ND	ND
Date of information	1980	1980	1958	1980
Status**	O	O	U	C

Appendix B. Chemical analyses (all concentrations in milligrams per liter).

New Mexico

Well No.	M-1	M-5				M-7	M-10	M-11			
Date	---	5-53	3-53*	3-53*	3-53*	9-35	6-80	10-56*	10-56*	10-56*	10-56*
Depth sampled (ft)	441	435	585-610	715-740	855-880	332	---	400-435	400-435	435-465	435-465
Ca^{++}	27.0	160.0	113.0	34.0	90.0	70.0	47.3	20.0	---	---	31.0
Na^{+}	390	648	534	336	541	133	114	386	---	---	367
K^{+}		12	9.4	4.5	5.6		8.8		---	---	
Mg^{++}	2.4	52.0	26.0	5.7	5.5	17.0	10.9	4.3	---	---	5.5
Cl^{-}	380	710	610	505	950	290	180	294	280	508	502
$SO_4^{=}$	310	901	622	70	44	38	54	363	---	---	85
HCO_3^{-}	76	86	59	81	47	98	118	133	234	115	115
NO_3^{-}	2.0	1.0	0	0	0	5.2	6.1	1.2	---	---	1.8
$PO_4^{=}$	---	0.02	0	---	0	---	---	---	---	---	---
SiO_2	11.0	21.0	5.3	14.0	21.0	---	27	9.2	---	---	14.0
Fe	---	0.01	0	0	0	---	---	---	---	---	---
F	0.9	0.5	0.3	0.7	1.0	---	0.5	1.5	---	---	2.4
B	---	0.24	0.22	0.35	0.36	---	0.06	---	---	---	---
pH	7.6	7.6	7.3	7.4	7.3	---	7.7	7.9	7.7	7.3	7.7
Conductivity	2,350	3,890	3,210	1,930	3,220	---	910	1,930	1,940	1,990	1,980
Temperature (°C)	---	---	---	---	---	---	25.5	---	---	---	---
Total dissolved solids	1,160	2,550	1,950	1,010	1,680	602	504	1,140	---	---	1,070

* Drill-stem test

Appendix B (continued)

New Mexico

Well No.	M-11		M-12	N-6		N-7	N-9	N-10		N-11
Date	10-56*	12-56	1-57	6-53*	6-53*	9-52	?-45	12-56*	12-56	1-57
Depth sampled (ft)	465-504	504	310-380	645-690	775-820	330	451	547-597	635-705	745
Ca^{++}	29.0	9.9	116.0	119	534	50	542	119	223	403
Na^{+}	386	401	279	880	2850	83	---	458	480	2,530
K^{+}				9.3			---			
Mg^{++}	4.7	9.5	43.0	17	61	12	108	40	95	80
Cl^{-}	505	445	550	1,450	5,030	41	6,590	450	420	4,060
$SO_4^{=}$	133	99	215	163	611	136	820	688	1,210	859
HCO_3^{-}	86	223	84	53	62	134	---	126	162	240
NO_3^{-}	1.6	1.2	3.6	0.5	---	54.0	80.0	1.2	2.4	---
$PO_4^{=}$	---	---	---	0	---	---	---	---	---	---
SiO_2	18.0	44.0	20.0	8.7	17.0	34.0	58.0	10.0	8.6	53.0
Fe	---	---	---	0.03	0.02	---	---	---	---	---
F	3.6	1.6	0.6	0.9	0.3	0.6	---	1.1	1.4	4.7
B	---	---	---	0.33	---	---	---	---	---	---
pH	8.0	7.7	7.5	7.4	7.3	8.1	---	7.6	7.6	6.8
Conductivity	2,050	2,030	2,310	4,860	15,100	715	---	2,890	3,590	14,500
Temperature (°C)	50	---	22.2	---	---	---	71.1	20.6	---	61.1
Total dissolved solids	1,120	1,170	1,420	2,670	9,130	485	∿12,500	1,870	2,620	8,980

Appendix B (continued)

Texas

Well No.	49-06-201		49-06-601					49-07-202	49-07-401	49-07-801
Date	3-53*	3-53*	6-53*	6-53*	6-53*	6-53*	8-53	10-35	9-65	6-80
Depth sampled (ft)	506-525	707-732	479-515	772-808	892-952	980-1,020	502	400	450-500?	---
Ca^{++}	149	344	81	122	370	684	118	---	102	29.8
Na^{+}	212	609	256	357	1,940	3,540	231	---	---	276
K^{+}	15		12	8.3			12	---	---	4.9
Mg^{++}	37	78	26	26	62	111	37	---	24	8.2
Cl^{-}	612	1,700	355	405	2,980	5,490	355	90	370	210
$SO_4^{=}$	70	72	316	569	1,110	1,990	340	---	1,019	236
HCO_3^{-}	72	37	77	64	54	53	124	146	---	158
NO_3^{-}	4.0	0.5	3.0	0	---	---	0	---	---	7.8
$PO_4^{=}$	---	---	0.01	0.02	---	---	0	---	---	---
SiO_2	22	2.2	4.3	14.0	12.0	6.8	24	---	---	33
Fe	0.01	0	0.03	0.01	0.02	0.02	0.03	---	0.05	---
F	0.5	---	0.3	0.3	0.3	0.3	0.5	---	0.4	0.8
B	0.36	---	0.25	0.32	---	---	0.25	---	---	0.55
pH	7.5	7.2	6.9	7.1	7.3	7.1	7.5	---	8.1	7.9
Conductivity	2,180	5,160	1,900	2,460	10,500	18,200	1,950	---	---	1,480
Temperature (^{o}C)	---	---	---	---	---	---	---	---	---	24.5
Total dissolved solids	1,160	2,820	1,090	1,530	6,500	11,800	1,180	---	2,341	883

Appendix B (continued)

Texas

Well No.	49-07-802	49-07-803			49-07-804			49-08-1A	49-08-501	49-08-6A
Date	8-35	7-53*	7-53*	7-53*	5-79*	5-79*	6-80	1-71	6-80	11-73
Depth sampled (ft)	410	511-557	603-649	895-946	609-630	680-700	---	---	---	390?
Ca^{++}	---	58	46	535	93	52	75.2	306	214	83
Na^{+}	---	422	370	1,980	312	311	449	2,578	204	18
K^{+}	---	7.2	6.4		---	---	6.9		2.5	8
Mg^{++}	---	12	7.1	40.0	26.0	20.0	14.6	64	27.1	6
Cl^{-}	280	560	488	3,420	529	450	640	3,985	200	14
$SO_4^{=}$	---	212	154	912	181	173	240	831	675	39
HCO_3^{-}	105	106	110	47	102	93	87	189	163	264
NO_3^{-}	---	1.0	1.0	---	---	---	1.0	0	13.1	19
$PO_4^{=}$	---	0	0.01	---	---	---	---	0	---	---
SiO_2	---	12	19	3.9	---	---	31	---	39	---
Fe	---	0.02	0.03	0.03	0.10	0.25	---	0.02	---	---
F	---	0.7	1.0	0.4	0.2	0.2	0.5	5.8	0.3	0.4
B	---	0.49	0.43	---	---	---	0.16	---	0.62	---
pH	---	7.4	7.4	7.3	8.2	8.0	8.1	7.9	7.4	7.4
Conductivity	---	2,480	2,160	11,500	1,400	1,300	2,630	---	2,110	608
Temperature (°C)	---	---	---	---	---	---	28	58?	28	---
Total dissolved solids	---	1,340	1,150	6,910	1,243	1,099	1,497	7,857	1,456	317

Appendix B (continued)

Texas

Well No.	49-08-6AD		49-15-301		49-15-2AD	49-15-506	49-15-601	49-15-604	49-16-101	
Date	11-74	6-80	7-76	6-80	6-80	6-80	7-53*	6-80	2-74	6-80
Depth sampled (ft)	340?	---	---	---	---	---	475-495	---	---	---
Ca^{++}	86	87	56	69.4	53.4	2.8	20	7.1	364	339
Na^{+}	16	15.6	405	572	617	97.8	128	71.5	2,645	2,500
K^{+}	11	9.5	17	19	7.9	1.3	3	2.7		116
Mg^{++}	6	7.9	16	28.1	14.4	0.2	2.1	0.7	44	68.9
Cl^{-}	14	17	461	705	600	33	73	40	4,050	3,920
$SO_4^{=}$	37	42	264	254	417	32.8	88	29.6	787	923
HCO_3^{-}	253	302	221	202	176	158	180	102	---	342
NO_3^{-}	24	22	23	19.6	2.5	10.7	1.5	16.5	---	1.2
$PO_4^{=}$	---	---	---	---	---	---	0	---	0.05	---
SiO_2	---	30	19	20	35	29	12	21	---	31
Fe	0.04	---	---	---	---	---	0.06	---	0.35	---
F	0.3	0.3	2.7	2.0	0.5	0.9	0.9	0.4	3.3	2.7
B	---	<0.05	---	0.18	0.32	0.06	0.24	0.12	---	1.0
pH	7.4	7.3	7.7	7.5	7.4	8.2	8.0	8.0	8.0	6.9
Conductivity	585	520	2,240	3,110	2,500	560	681	458	---	15,100
Temperature (°C)	---	24	26.7	24.5	23.5	38	---	33.5	---	36
Total dissolved solids	319	381	1,370	1,789	1,924	285	422	239	8,271	8,071

Appendix C. Well designations.

	State well-numbering system	Knowles and Kennedy (1958)	Sayre and Livingston (1945)	Local name
New Mexico	25-7-16.121	M-1	---	---
	25-8-32.333	N-11	---	---
	26-6-23.332	M-12	---	---
	26-6-34.130	M-7	141	---
	26-6-34.130A	M-6	140	---
	26-7-1.241	M-11	---	---
	26-7-32.122	M-5	---	---
	26-8-2.131	N-10	---	---
	26-8-5.332	N-9	---	---
	26-8-32.111	N-6	---	---
	26-8-33.120	N-7	154	---
	26-8-33.120	N-8	154A	Hot Well
	---	M-4	152	---
	---	M-10	---	---
	---	M-NW	---	North Well
	---	N-3	---	---
	---	N-4	---	---
	---	N-5	---	---
Texas	49-06-201	S-1	---	---
	301	S-17	---	Palos Pintos #2
	3A	---	---	Palos Pintos #1
	601	S-8	---	---
	602	S-4	---	---
	49-07-X	---	153	---
	201	S-3	---	Joint Well
	202	S-2	---	Old Joint Well
	401	S-16	---	---
	402	S-15	---	---
	5A	---	---	---
	801	S-10	---	---
	802	S-11	155	Nation's East Well
	803	S-9	---	---
	804	---	---	---
	901	T-9	---	---

Appendix C. (continued)

State well-numbering system	Knowles and Kennedy (1958)	Sayre and Livingston (1945)	Local name
49-08-101	T-1	---	---
1A	---	---	Santa Cruz Well
4A	---	---	---
501	T-5	---	---
601	T-7	---	---
603	T-10	---	---
6A	---	---	---
6AD	---	---	---
701	T-6	---	---
801	T-4	---	---
49-15-2A	---	---	---
2AD	---	---	---
301	---	---	---
302	T-8	---	Old Ponder Well
5	---	157	Nation's South Well
506	---	---	---
601	X-1	---	---
6	---	156	Deep Well
603	---	---	---
604	---	---	---
6A	---	---	---
49-16-101	---	---	---
201	T-2	---	---
2	---	---	Mike's Tank Well