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HYDROLOGIC INTERPRETATION OF GEOPHYSICAL DATA FROM THE SOUTHEASTERN HUECO BOLSON, EL PASO AND HUDSPETH COUNTIES, TEXAS

By
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ABSTRACT

Airborne-electromagnetic and earth-resistivity surveys were used to explore for fresh ground water in the Hueco Bolson southeast of El Paso, Texas. Aerial surveys were made along about 500 miles (800 km) of flight line, and 67 resistivity soundings were made along 110 miles (180 km) of profile. The surveys did not indicate the presence of any large bodies of fresh ground water, but several areas may be underlain by small to moderate amounts of fresh to slightly saline water.

The material underlying the flood plain of the Rio Grande is predominantly clay or sand of low resistivity. Along a band on the mesa next to and parallel to the flood plain, more resistive material composed partly of deposits of an ancient river channel extends to depths of about 400 to 1,700 feet (120 to 520 m). Locally, the lower part of this more resistive material is saturated with fresh to slightly saline water. The largest body of fresh to slightly saline ground water detected in this study is between Fabens and Tornillo, Texas, mostly in the sandhill area between the flood plain and the mesa. Under assumed conditions, the total amount of water in storage may be as much as 400,000 to 800,000 acre-feet (500 million to 1 billion m^3).

The resistivity data indicate that the deep artesian zone southwest of Fabens extends from a depth of about 1,200 feet (365 m) to about 2,800 feet (855 m).

INTRODUCTION

Purpose and Scope of the Investigation

Farmers in the irrigated area along the Rio Grande southeast of El Paso have long desired a supplemental source of ground water for use when water from the river is in short supply. During and following the drought of the 1950's, many shallow wells were drilled; but the ground water that has been developed is predominantly slightly saline or of even poorer quality.

In September 1973, the Texas Water Development Board began a study of the ground-water resources of the Hueco Bolson southeast of El Paso, primarily in the valley of the Rio Grande (locally called the El Paso Valley). This study, which is being made in cooperation with the U.S. Bureau of Reclamation on behalf of the El Paso County Water Improvement District No. 1, included a compilation of available ground-water data and the drilling of two test holes in the vicinity of San Elizario (Alvarez and Buckner, 1974; Buckner, 1974).

In September 1974, the U.S. Geological Survey in cooperation with the Texas Water Development Board and the Bureau of Reclamation began a geophysical survey of the El Paso Valley and adjacent parts of the Hueco Bolson. The results of this survey, reported here together with available hydrologic data, will be used to select sites for additional test holes in an effort to locate ground water that can be used for irrigation by the Water Improvement District.

The geophysical work consisted of an airborne-electromagnetic survey, followed by earth-resistivity soundings. The airborne survey included 40 lines perpendicular to the Rio Grande, spaced about 1.5 miles (2.4 km) apart, and totaling about 500 miles (800 km) of flight between Ysleta and Esperanza. The earth-resistivity soundings were made at 67 locations, mostly along 7 profiles totaling 110 miles (180 km). Six profiles were perpendicular to the river at Ysleta, Clint, Fabens, Tornillo, Fort Hancock, and McNary; and one long profile was mostly along the flood plain parallel to the river from Ysleta to Esperanza.

Geography of the Area

The geography of westernmost Texas and adjacent areas in New Mexico and Mexico is characterized by broad structural depressions, commonly called "bolsons," filled with alluvium and roughly delineated by isolated fault-block mountain ranges (fig. 1). The northern part of the Hueco Bolson, in Texas and New Mexico, lies between the Franklin and Hueco Mountains; the southeastern part of the bolson, in Texas and Mexico, lies between several mountain ridges in Mexico on the west and the Diablo Plateau and the Finley, Malone, and Quitman Mountains on the east (fig. 1).

The Rio Grande is entrenched in the Hueco Bolson about 200 to 250 feet (61 to 76 m). The relatively undissected surface of the bolson is commonly termed the "mesa" and the hilly, eroded area between the edge of the mesa and flood plain of the Rio Grande is herein called the "sandhills area" (fig. 2). The flood plain of the Rio Grande on the United States side of the river is locally called the El Paso Valley. The altitude of the river ranges from about 3,700 feet (1,130 m) above mean sea level at El Paso to about 3,450 feet (1,050 m) at the southern end of the bolson.

El Paso, Texas, and Ciudad Juarez, Mexico, are the major cities of the area. The agricultural communities of San Elizario, Clint, Fabens, Tornillo, Fort Hancock, McNary, and Esperanza, Texas, are southeast of El Paso in the El Paso Valley. Ysleta, formerly an agricultural community, is now part of El Paso.

The climate is arid with hot summers and mild winters. The average annual precipitation is about 8 inches (205 mm), which is less than one-tenth of the potential evaporation rate. Agriculture is completely dependent upon irrigation.

Terminology for Water-Quality and Resistivity Data

In general, fresh water is defined as water containing less than 1,000 mg/l (milligrams per liter) dissolved solids. Slightly saline water contains 1,000 to 3,000 mg/l dissolved solids; moderately saline water contains 3,000 to 10,000 mg/l dissolved solids; very saline water contains 10,000 to 35,000 mg/l dissolved solids; and brine contains more than 35,000 mg/l dissolved solids. Commonly, fresh water is suitable for domestic use, municipal supply, and industrial use, and fresh and slightly saline water is suitable for irrigation.

In this report, low resistivity is defined as less than 10 ohmmeters; moderate resistivity as 10-20 ohmmeters; and high resistivity as more than 20 ohmmeters. These definitions are applied to data obtained from the earth-resistivity surveys. The terms high and low resistivity are relative with regard to the airborne-electromagnetic data, and do not imply a specific numerical range.

In general, high resistivities in saturated sand and gravel in the Hueco Bolson commonly indicate the occurrence of fresh ground water; moderate resistivities commonly indicate slightly saline water; and low resistivities commonly indicate clay, or they may indicate sand and gravel saturated with moderately saline or poorer quality water.

Metric Conversions

For those readers interested in using the metric system, the metric equivalents of English units of measurements are given in parentheses. The English units used in this report may be converted to metric units by the following factors:

From		Multiply by	To obtain	
Unit	Abbreviation		Unit	Abbreviation
acre-feet	--	1,233	cubic meters	m^3
feet	--	.3048	meters	m
gallons per minute	gal/min	.06309	liters per second	l/s
inches	--	25.4	millimeters	mm
miles	--	1.609	kilometers	km
square miles	--	2.590	square kilometers	km^2

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H. J. Alvarez and A. W. Buckner of the Texas Water Development Board assisted in planning the earth-resistivity survey and supplied copies of electrical logs of wells and test holes from their files. T. E. Cliett of El Paso Water Utilities provided information on the hydrology and geology of the Hueco Bolson.

SUMMARY OF GEOLOGY

The Hueco Bolson and adjacent areas are in the southeastern part of the Basin and Range physiographic province, in which normal faulting of Tertiary and Quaternary age formed alternating structurally high mountain blocks and structurally low basins. The relatively depressed basins or "bolsons" are commonly filled with unconsolidated alluvial and lacustrine clay, silt, sand, and gravel eroded from the mountain blocks.

Consolidated Rock

The mountains and plateaus adjacent to the Hueco Bolson are composed of rocks of various types and ages. The Franklin Mountains are composed mostly of granite, quartzite, and rhyolite of Precambrian age and carbonates of Paleozoic age. The Hueco Mountains and Diablo Plateau are composed mostly of carbonates and clastics of Paleozoic and Cretaceous age. The Finley and Malone Mountains are composed mostly of carbonates and clastics of Paleozoic, Jurassic, and Cretaceous age; and the Quitman Mountains are composed of carbonates of Cretaceous age and volcanic rocks of Tertiary age. The rocks of the mountain ranges forming the southwestern boundary of the bolson in Mexico are mostly carbonates and clastics of Cretaceous age (DeFord and Haenggi, 1970, p. 175).

Very little information is available on the composition of the consolidated rocks underlying the bolson fill because only a few deep holes have been drilled in the bolson. It is likely, however, that carbonates of Paleozoic age underlie the northern part of the bolson and that carbonates and clastics of Cretaceous age underlie much of the southeastern part of the bolson. The northeastern edge of the Chihuahua trough, a structurally low area filled mostly with deposits of Cretaceous age, underlies the southeastern part of the Hueco Bolson (DeFord, 1969, fig. 2, p. 11).

Unconsolidated Rock

Albritton and Smith (1965, p. 92-102) divided the exposed parts of the bolson fill southeast of McNary, Texas, into (1) older basin deposits; younger basin deposits; and thin deposits of relatively recent age, including gravel and caliche on erosion surfaces; (2) terrace deposits along the Rio Grande; alluvium and colluvium; and (3) windblown sand (table 1). The older basin fill consists of coarse-grained alluvial-fan deposits near the mountains that grade into fine-grained gypsiferous playa deposits toward the axis of the bolson. The younger basin fill is sand and gravel deposited by a river that flowed across the bolson, presumably an ancestral Rio Grande (Albritton and Smith, 1965, p. 92-98). The older and younger fill may correspond to the upper part of the Santa Fe Group along the Rio Grande rift that bisects New Mexico from north to south (Albritton and Smith, 1965, p. 98).

Strain (1966) mapped the equivalents of the older and younger basin deposits on the mesa east of Fort Hancock and McNary, Texas. He assigned the name Fort Hancock Formation to the older, predominantly fine-grained unit and assigned the name Camp Rice Formation to the younger fluvial unit. Strain (1966, p. 10-12) also proposed the name "Lake Cabeza de Vaca" for the large Pleistocene lake that formed in the bolson prior to drainage by the Rio Grande. This lake occupied the southern part of the Mesilla Bolson and adjacent parts of Mexico, the Hueco Bolson, and possibly the Tularosa basin. The Fort Hancock Formation includes the deposits of Lake Cabeza de Vaca and perhaps older lakes. The Camp Rice Formation was deposited by the ancestral Rio Grande when it established its drainage across the Hueco Bolson.

Table 1.--Unconsolidated rocks in the southeastern Hueco Bolson

Age	Unit		Remarks
Holocene and Pleistocene	Rio Grande alluvium		Mostly fluvial sand and gravel deposited along the modern course of the Rio Grande.
Pleistocene, Pliocene, and Miocene(?)	Camp Rice Formation of Strain (1966)	*Bolson deposits*	The Camp Rice is fluvial sand and gravel deposited along an ancient course of the Rio Grande; the Fort Hancock and older bolson deposits are mostly coarse-grained alluvial-fan material deposited around the margins of the bolson and fine-grained playa-lake deposits along the axis of the bolson.
	Fort Hancock Formation of Strain (1966)		

The only information available regarding the unconsolidated fill in the subsurface of the Hueco Bolson is geophysical data and data from test drilling for water and oil. In the southeastern part of the bolson, such information is meager.

In the northern part of the bolson, the maximum thickness of unconsolidated fill was estimated by Mattick (1967, p. D85) from geophysical data to be 9,000 feet (2,740 m). A well drilled by El Paso Water Utilities penetrated 4,363 feet (1,330 m) of bolson fill that was predominantly sand and gravel in the upper 600 feet (180 m), sand and clay in the interval from 600 to 2,300 feet (180 to 700 m), and mostly clay below 2,300 feet (700 m) (Davis and Leggat, 1967, p. 14-16).

In the southeastern part of the bolson, between El Paso and Clint, gravity, seismic, and resistivity data collected prior to this study (Davis and Leggat, 1967, fig. 2). suggest that the thickness of bolson fill ranges from 1,000 to 3,000 feet (305 to 915 m). A number of test holes and wells, which yielded data on the thickness and composition of the bolson fill, have been drilled for water and oil by various individuals, corporations, and governmental agencies. The significant wells and tests drilled in the southeastern part of the Hueco Bolson are shown on figure 2.

Three oil tests have been drilled in the El Paso Valley, JL-49-31-132 and 434 north and southwest of Clint and JL-49-40-201 northeast of Tornillo (fig. 2a). In addition, a stratigraphic test (JL-49-32-102) was drilled on the mesa east of Clint (fig. 2a). The oil test north of Clint encountered consolidated rock below the bolson fill at 1,525 feet (465 m) according to an electrical log; and the oil test southwest of Clint penetrated consolidated rock at 2,040 feet (622 m) according to a sonic log. The stratigraphic test on the mesa east of Clint penetrated consolidated rock at 970 feet (296 m) according to an electrical log. The oil test northeast of Tornillo reportedly (Alvarez and Buckner, 1974, p. 33) was in bolson fill to a depth of about 9,000 feet (2,740 m), but this 9,000-foot (2,740-m) thickness is anomalous because geophysical data collected prior to (Davis and Leggat, 1967) and during this study do not indicate the occurrence of this thickness of fill in the southeastern part of the bolson.

In hydrologic studies, the bolson fill commonly has been divided into the bolson deposits (which correspond to the Camp Rice and Fort Hancock Formations of Strain, 1966, and older deposits) and the Rio Grande alluvium, which comprises the channel deposits of the modern Rio Grande (Knowles and Kennedy, 1958, p. 19-20; Alvarez and Buckner, 1974, p. 33-34). Davis (1967, p. 5) estimated the thickness of the Rio Grande alluvium to be about 200 feet (61 m); and Buckner (1974, p. 22) stated that in the test holes drilled by the Texas Water Development Board near San Elizario, the coarsest material, much of which is probably the Rio Grande alluvium, occurred in the interval between the land surface and a depth of 250 feet (76 m).

El Paso Water Utilities drilled five deep test holes for water in the El Paso Valley between Fabens and the El Paso-Hudspeth County line (JL-49-39-202, 207, and 208; JL-49-40-801; and JL-48-33-703). Drillers' logs of JL-49-39-202 and 208 southwest of Fabens (Alvarez and Buckner, 1974, table 3), indicate that the tests penetrated 70 percent or more of sand and gravel to a depth of about 200 feet (61 m), much of which is Rio Grande alluvium. From 200 feet (61 m) to about 1,300 feet (395 m) the material penetrated by the tests was more than 70 percent clay. From 1,300 feet (395 m) to the maximum depth reached of about 1,900 feet (580 m), the tests penetrated alternating clay and sand (56 percent clay in JL-49-39-202). This zone, which yields slightly saline water under enough artesian pressure to flow at the land surface, has been informally called the "Fabens artesian zone." An electrical log of the test drilled south of Tornillo (JL-49-40-801) indicated material of low resistivity, much of which is clay, from 300 to 2,936 feet (91 to 895 m). A sample log of the test southeast of Tornillo (JL-48-33-703) indicated that the hole penetrated about 80 percent sand and gravel to 200 feet (61 m), about 60 percent clay between 200 and 1,000 feet (61 and 305 m) and more than 80 percent clay from 1,000 to 2,150 feet (305 to 655 m).

The El Paso County Water Control District No. 1 (since taken over by the city of El Paso) drilled five deep test holes to depths between 1,500 and 2,300 feet (460 and 700 m) in the El Paso Valley between Ysleta and Fabens (JL-49-22-206, 401, and 818; JL-49-30-601; and JL-49-31-901). Drillers' logs of these tests (Audsley, 1959, table 2; Alvarez and Buckner, 1974, table 3) indicate mostly coarse-grained material in the first 200 feet (61 m) ranging from about 40 to 95 percent sand and gravel and increasing amounts of clay at greater depths, ranging from about 50 percent to more than 80 percent clay from 200 feet (61 m) to the maximum depth reached, 2,292 feet (699 m). The electrical log of JL-49-30-601, southwest of Clint (fig. 3), indicates some slightly resistive material to a depth of about 170 feet (52 m). Below this depth is material of low resistivity, probably much of which is clay, although the spontaneous-potential log indicates the occurrence of many sand beds, which according to the resistivity log must contain salty water.

The Hudspeth County Conservation and Reclamation District No. 1 drilled three test holes in the El Paso Valley in Hudspeth County (PD-48-41-201, 602, and PD-48-42-703). These tests, which were drilled to 817, 709, and 3,500 feet (249, 216, and 1,067 m), respectively, penetrated some sand in the upper 300 to 400 feet (92 to 120 m) and mostly clay with some sands at greater depths. Drillers' logs of these tests (Alvarez and Buckner, 1974, table 3) showed from 40 to 70 percent sand to depths of 200 feet (61 m), and more than 80 percent clay below 200 feet (61 m).

The Horizon Corporation drilled two deep test holes on the mesa east of the El Paso Valley. Test JL-49-23-503 was drilled to 983 feet (300 m) and JL-49-24-402 to 1,189 feet (362 m) on the south side of Horizon Boulevard northeast of Clint. Drillers' logs of these two tests (Alvarez and Buckner, 1974, table 3) indicate about 70 to 80 percent sand and gravel to 200 feet (61 m) and more than 70 percent clay below that. The electrical log of JL-49-24-402 (fig. 3) indicates high resistivity material from the land surface to the water table at 335 feet (102 m) and some moderately resistive sand beds between the water table and a depth of 620 feet (189 m). Below 620 feet (189 m) is low resistivity material, mostly clay with thin sands containing salty water.

In summary, the unconsolidated deposits in the subsurface of the southeastern Hueco Bolson are mostly fine-grained and probably playa-lake deposits. Only in the upper 200 to 400 feet (61 to 120 m) are there significant amounts of sand and gravel. Under the El Paso Valley, much of this coarser material is Rio Grande alluvium.

GROUND-WATER HYDROLOGY

The ground-water hydrology of the Hueco Bolson has been described in reports by Sayre and Livingston (1945), Knowles and Kennedy (1958), and in a series of progress reports, such as the report by Leggat (1962), prepared by the U.S. Geological Survey in cooperation with the Texas Water Development Board and its predecessor agencies. Davis and Leggat (1965, p. U38 to U63) and Cliett (1969) have summarized much of the hydrogeologic work in the El Paso area in overview reports. Most of these reports, however, are concerned with the northern part of the bolson and the northern end of the El Paso Valley, where the city of El Paso obtains most of its water supply. The following discussion, which is a generalized summary of the ground-water hydrology of the entire bolson, may not apply in detail to a specific location.

The ground-water reservoir of the Hueco Bolson is recharged mainly by infiltration of surface runoff and precipitation along the flanks of the Franklin Mountains, the southern Organ Mountains, and the mountain ranges in Mexico bordering the southwestern edge of the bolson. Lesser amounts of infiltration occur along the mountains and plateaus on the eastern side of the bolson. Meyer (1976, p. 18) estimated recharge under natural conditions to the northern end of the bolson, including the El Paso city artesian area and Ciudad Juarez, to be 6,000 acre-feet (7 million m^3) per year.

Before the Rio Grande established its drainage across the Hueco Bolson, ground water probably discharged to depressions or lakes in the lower parts of the bolson, perhaps in the southeastern part, where it subsequently evaporated or was transpired. After the Rio Grande cut through the Hueco Bolson, ground water discharged to the river.

Northern Hueco Bolson

The largest amount of fresh ground water in the Texas part of the Hueco Bolson occurs in the northern part in a trough-shaped body containing about 10 million acre-feet (12 billion m^3) of water (Meyer, 1976, table 2) in an area about 7 miles (11 km) wide adjacent to and parallel to the east front of the Franklin Mountains. This area of ground-water occurrence is adjacent to the principal recharge area in which coarse debris eroded from the Franklin Mountains was deposited. In addition, the ancestral Rio Grande, which once flowed through Fillmore Pass (fig. 1) and along the east front of the Franklin Mountains (Strain, 1966), deposited additional coarse-grained material in the area.

The combination of a nearby source of recharge and the occurrence of coarse-grained and permeable bolson fill near the Franklin Mountains results in relatively rapid circulation of fresh water. Farther to the east, toward the Hueco Mountains, the fill is finer grained, less permeable, and probably contains more soluble material. In this area, the rate of recharge is less, circulation is slow, and the water contains a greater amount of dissolved minerals.

Southeastern Hueco Bolson

In the southeastern part of the Hueco Bolson in the United States, the older fill is predominantly fine-grained playa-lake deposits, much of which contains soluble gypsum (Albritton and Smith, 1965, p. 94; and Strain, 1966, p. 18). The only exception to this predominance of fine-grained material is within a narrow zone near the Diablo Plateau and the Malone and Finley Mountains on the eastern side of the bolson, where coarser material was deposited. Recharge from the plateau and mountain areas is small, ground-water circulation is slow, and the water quality is generally poor. Figure 4 shows that south of Ysleta, samples of water from the shallow fill commonly contain 1,000 to 5,000 mg/l dissolved solids and samples from the deeper fill contain more than 5,000 mg/l dissolved solids.

El Paso Valley

In the El Paso Valley, ground water occurs under water-table conditions in the Rio Grande alluvium and commonly under artesian conditions where sands occur in the deeper underlying bolson deposits.

City artesian area.--Between El Paso del Norte and Ysleta, including downtown El Paso, the water in the bolson deposits is under artesian pressure. This zone is shown on figure 4 as the interval containing fresh water at the northwestern end of Q-Q'. Near Ysleta, wells such as JL-49-22-122 and 201 encounter fresh water to depths of 300 to 400 feet (92 to 120 m) beneath generally slightly saline water in the Rio Grande alluvium. Davis and Leggat (1965, p. U38) defined this as the city artesian area and speculated that artesian conditions occur along the Rio Grande in the entire El Paso Valley.

Although the city artesian area is included in the El Paso Valley part of the southeastern Hueco Bolson for convenience, the area is perhaps more closely related to the northern part of the bolson because prior to development of the ground water, the city artesian area was probably the point of discharge for much of the water moving south from the northern part of the bolson. The water in the bolson deposits in the city artesian area is fresh because the recharge area is nearby, the fill is relatively coarse, and ground-water circulation is relatively rapid.

Davis and Leggat (1965, p. U40) envisioned the city artesian area as a classic artesian situation in which ground water passes beneath a bed of lower permeability and is confined under pressure. The clay beds in the deposits of the northern part of the bolson, however, are discontinuous lenses; consequently, there is no single confining bed in the city artesian area. The number and aggregate thickness of the clay beds in the city artesian area are probably no greater than in the northern part of the bolson. The increase in pressure with depth in the city artesian area is probably due to upward movement of water in a discharge area, and not to entrapment of water beneath a widespread confining bed.

In much of the city artesian area, pumping of ground water from the bolson deposits has lowered water levels below the water levels in the overlying Rio Grande alluvium, and the natural direction of ground-water movement has been reversed. Water now moves downward from the alluvium to the bolson deposits. This reversal of the direction of ground-water movement has in turn lowered water levels in the alluvium, so that in much of the downtown area the Rio Grande is now a source of recharge to the bolson deposits rather than an area of discharge.

A digital model of the ground-water system in the northern part of the Hueco Bolson (Meyer, 1976, table 1) indicated that the river furnished between 10,000 and 20,000 acre-feet (12 to 25 million m^3) per year of recharge between 1953 and 1973, even though a 4.35-mile (7.0-km) section of the Rio Grande below El Paso del Norte in downtown El Paso was lined with concrete in 1968. This recharge, which did not occur before ground water was developed in the bolson, has been induced by water-level declines caused by pumping in the city artesian area. If this estimate of induced recharge is correct, the amount is greater than the 6,000 acre-feet (7 million m^3) per year of recharge estimated to occur under natural conditions at the northern end of the bolson.

Fabens artesian zone.--In the Fabens artesian zone, the artesian pressure probably is the result of the classical situation of ground-water confinement. The deposits in the artesian zone southwest of Fabens consist of alternating clay and sand containing slightly saline water (958 to 1,540 mg/l dissolved solids) under enough pressure to flow at the land surface. The zone was discovered by two test holes (fig. 2a) drilled by El Paso Water Utilities (JL-49-39-202 in 1957 and JL-49-39-207 in 1959). The first test hole penetrated the zone from 1,280 feet (390 m) to 1,783 feet (543 m), and the second test encountered the zone from 1,370 feet (418 m) to 1,909 feet (582 m). Electrical logs of the tests indicate that the material overlying the artesian zone is predominantly clay that probably forms a thick confining bed.

The Fabens artesian zone was subsequently tapped by wells drilled farther southwest and southeast in Mexico. Hydrologic and earth-resistivity data from the Mexican side of the Rio Grande near Fabens (Hector A. Gameros, Secretaria de Recursos Hidraulicos, written commun., Apr. 24, 1975; and GeoFimex, S. A., 1970) indicate that the top of the artesian zone is shallower there, perhaps at a depth of about 900 feet (275 m). The zone may be composed of coarser sediments eroded from the Sierra del Presidio, Sierra de Guadalupe, and Sierra de San Ignacio to the south in Mexico (fig. 1), which rise to elevations of 6,000 to 7,000 feet (1,830 to 2,130 m) above mean sea level. Davis and Leggat (1965, p. U40) stated that the artesian zone extended only a few miles into the United States.

Bolson deposits in other areas.--In the rest of the El Paso Valley, the bolson deposits are predominantly clay, and the sands that exist commonly contain slightly to very saline water (fig. 4). If any thick water-bearing zones occur in the southeastern part of the Hueco Bolson, they are probably confined by thick clays, and the water will be under artesian pressure. However, the only location where test drilling has encountered such a zone is southwest of Fabens.

The two deep test holes drilled by the El Paso County Water Control and Improvement District No. 1 near Ysleta (JL-49-22-206 and 401) encountered fresh water only in sands to depths of 300 to 400 feet (91 to 120 m). Below that, these tests penetrated mostly clay and some sands containing slightly to very saline water to about 1,500 feet (460 m). The three deep tests drilled by the district to depths of 1,517 to 2,292 feet (462 to 699 m) between Ysleta and Fabens (JL-49-22-818, JL-49-30-601, and JL-49-31-901) did not encounter any sands containing fresh water. The electrical log of JL-49-30-601 (fig. 3) indicates material of low resistivity with no potential for fresh water to 1,762 feet (537 m).

In two test holes drilled by the Texas Water Development Board to 668 feet (204 m) northwest and south of San Elizario (JL-49-30-207 and 623), fresh water was limited to the upper 150 to 200 feet (46 to 61 m), mostly in the Rio Grande alluvium.

Most of the test holes in the El Paso Valley south of San Elizario did not encounter fresh water. The test drilled to 3,000 feet (915 m) by El Paso Water Utilities south of Tornillo (JL-49-40-801) encountered sands containing fresh water only to about 300 feet (91 m). Below this depth, the bolson deposits were predominantly clay with some sands containing slightly to very saline water. The test drilled by El Paso Water Utilities southeast of Tornillo (JL-49-33-703) penetrated some sand beds containing slightly saline water in the upper 300 feet (91 m), then mostly clay with some sands containing slightly to moderately saline water to its total depth of 2,158 feet (658 m).

The three deep tests drilled by the Hudspeth County Conservation and Reclamation District No. 1 in Hudspeth County (PD-48-41-201 and 602 and PD-48-42-703) did not encounter any fresh water to depths as much as 3,500 feet (1,070 m).

Rio Grande alluvium.--Ground water occurs at shallow depths in the Rio Grande alluvium in most areas of the El Paso Valley, and most of the irrigation wells in the valley tap these deposits. Most of the ground water in the alluvium is slightly saline, but in some places it contains more than 3,000 mg/l dissolved solids (Alvarez and Buckner, 1974, figs. 10 and 11). Alvarez and Buckner (1974, p. 17, fig. 11) estimated that about 1,800,000 acre-feet (2.2 billion m^3) of slightly saline water occurs in the alluvium to depths of about 200 feet (61 m), mostly in El Paso County. They assumed that the alluvium had a specific yield of 15 percent and that its entire thickness could be drained. The amount of slightly saline water that is readily recoverable could be as little as 50 percent of this estimated amount if the alluvium contains numerous beds of clay that would yield water slowly.

In the city artesian area at the north end of El Paso Valley, the water in the Rio Grande alluvium is of poorer quality than the water in the underlying bolson deposits, but at many locations in the rest of the valley, the water in the alluvium is of better quality than the water in the underlying fill. In the city artesian area, the slightly saline water in the alluvium extends to an average depth of about 250 feet (76 m), but in places it extends into the bolson deposits to depths of 300 to 500 feet (91 to 150 m).

The poor quality of the water in the Rio Grande alluvium probably results from the concentration of salts through evapotranspiration of shallow ground water during the long period when the river was the area of discharge for ground water moving through the Hueco Bolson. In addition, downward percolation of excess irrigation water in the valley has increased the concentrations of salt in the ground water. In localities where the ground water in the alluvium is of better than usual quality, the alluvium was probably recharged locally by the river at times when the flow was of good quality and surface flooding occurred where there were unsaturated volumes of alluvium.

Along the section of the Rio Grande that has been lined with concrete and in the parts of the city artesian area where the natural upward direction of ground-water flow has been reversed, the concentration of salts by evapotranspiration is no longer a significant problem because the water levels have declined below the effect of evapotranspiration. The predominantly slightly saline water in the alluvium is now moving downward and into the fresh water in the underlying bolson deposits.

Near Fabens, the Rio Grande alluvium contains fresh water to depths of 200 feet (61 m), and the underlying bolson fill contains some fresh ground water (Alvarez and Buckner, 1974, figs. 10-11, table 4). This fresh water may have been recharged by streamflow in San Felipe Arroyo, which passes through Fabens on its course from the mesa to the Rio Grande. Davis and Leggat (1965, p. U60) noted that fresh to slightly saline water occurs above depths of 400 feet (120 m) in some areas where arroyos extend from the mesa across the El Paso Valley.

Mesa and Sandhills Areas

Several test holes and wells have been drilled in the mesa area, and most of them encountered fresh water only in the sands within 200 feet (61 m) of the top of the saturated zone. Ten wells and test holes were drilled by the El Paso Natural Gas Company to depths of up to 660 feet (200 m) on the mesa northeast of Ysleta, two of which, JL-49-15-701 and JL-49-15-802, are shown on figure 2. Well 701 encountered only slightly saline water, but well 802 yields fresh water. About half of the test holes did not yield usable water and were abandoned.

The Horizon Corporation drilled 27 test holes and wells ranging in depth from 495 to 1,189 feet (151 to 362 m) on the mesa northeast of Clint, north and south of Horizon Boulevard. The two deepest tests, JL-49-23-503 to 983 feet (300 m) and JL-49-24-402 to 1,189 feet (362 m), are shown on figure 2. Most of these test holes were abandoned, but at least nine were completed as production wells. These wells yield water containing from about 500 to 2,000 mg/l dissolved solids at rates of from about 80 to 230 gal/min (5 to 15 l/s) (Alvarez and Buckner, 1974, tables 1 and 4). The electrical logs of test holes JL-49-23-503 and JL-49-24-402 illustrate the occurrence of ground water in this part of the mesa. In test JL-49-23-503, some thin sands, probably containing fresh to slightly saline water, occur between the water table at 255 feet (78 m) and a depth of 360 feet (110 m). In test JL-49-24-402 (fig. 3), slightly saline water occurs in sands between the water table at 335 feet (102 m) and a depth of 615 feet (187 m). Below these depths, the electrical logs of the two tests indicate only thin sands containing salty water. Well JL-49-22-213 was drilled to 713 feet (217 m) in the sandhills area north of Ysleta, and the electrical log (fig. 3) indicates the occurrence of some fresh-water sands to a depth of about 440 feet (134 m).

Fresh and slightly saline ground water also occurs in the bolson fill between Fabens and Tornillo, in the sandhills area and under the edge of the adjacent flood plain. Electrical logs of five test holes drilled in the Fabens-Tornillo area by the Horizon Corporation (JL-49-39-344, 345, 346, and JL-49-40-105 and 412) indicate that sands containing fresh or slightly saline water occur between the water table in this area at about 100 feet (30 m) and a depth of at least 570 feet (174 m). The electrical log and water samples from JL-49-39-346 (fig. 3 and Alvarez and Buckner, 1974, table 4) indicate alternating beds of clay and sand containing fresh water, about 50 percent of each between depths of 185 and 560 feet (56 and 171 m). Water samples from depths of 130 to 567 feet (40 to 173 m) in the five tests contained between 700 and 1,597 mg/l dissolved solids (Alvarez and Buckner, 1974, table 4). Water samples from shallower depths contained more dissolved solids--1,846 mg/l at 107 to 123 feet (33 to 37 m) in JL-49-39-346, and 2,136 mg/l at 108 to 126 feet (33 to 38 m) in JL-49-40-105.

Water in Consolidated Rocks

Little is known about ground water in the consolidated rocks underlying the bolson fill. It is unlikely, however, that the consolidated rocks will yield large amounts of fresh water to wells. The circulation of ground water in the consolidated rocks is slow because the rocks are at great depths and because the permeability of the rocks is low. The quality of the water in the consolidated rocks is poor because of the slow ground-water circulation and because the rocks contain soluble material. Yields of wells completed in the consolidated rocks would be small because of the low permeabilities.

The few water samples collected from the consolidated rocks were not fresh and most were of poor quality. For example, a water sample from well JL-49-32-505, which is apparently from consolidated rock, contained more than 10,000 mg/l dissolved solids (Alvarez and Buckner, 1974, tables 1, 3, and 4). Davis and Leggat (1965, p. U60 and table U3) noted that two wells, 356 and 406 feet (109 and 124 m) deep, tapping Cretaceous sandstone about 7 miles (11 km) northeast of Fort Hancock, yield water containing 1,260 and 1,530 mg/l dissolved solids.

Water samples were taken from consolidated rocks in the two oil tests near Clint. Water from a depth of 5,010 to 5,173 feet (1,527 to 1,577 m) in well JL-49-31-132 contained about 9,000 mg/l dissolved solids. Water from a depth of 4,430 to 4,461 feet (1,350 to 1,360 m) in well JL-49-31-434 contained 185,000 mg/l dissolved solids; and water from 8,710 to 8,777 feet (2,655 to 2,675 m) contained 247,000 mg/l dissolved solids (Alvarez and Buckner, 1974, table 4).

GEOPHYSICAL SURVEYS

Methods

Electrical prospecting methods were used to explore for ground water in the southeastern part of the Hueco Bolson. These methods can be used because the ease with which earth materials transmit electrical current is a function of their resistivity, and resistivity in turn can be related to hydrogeologic properties, including lithology, porosity, permeability, water salinity, and water temperature. The two electrical methods used in this study were airborne-electromagnetic surveys and earth-resistivity soundings.

The airborne surveys consisted of 40 flight lines perpendicular to the axis of the El Paso Valley (fig. 5), each 10 to 14 miles (16 to 23 km) long and spaced about 1.5 miles (2.4 km) apart. The surveys were made by using the Barringer[1] INPUT (Induced Pulse Transient) system, which consists of a vertical-axis transmitting coil encircling the aircraft and a horizontal-axis receiving coil that is towed by the aircraft. A repeated, transient, primary magnetic field created by the transmitting coil induces currents in the earth whose magnitudes are a function of earth resistivities. The receiver coil measures the secondary magnetic field resulting from the earth currents at six different times and the results are recorded on six channels. Data from channel 6, the channel that senses resistivity to the greatest average depth, are shown along the flight lines on figure 5. These curves indicate conductivity and therefore vary inversely with resistivity. The INPUT data primarily reflect resistivities to maximum depths of 300 to 400 feet (91 to 120 m).

The INPUT data were examined for significant anomalies and were used to plan the earth-resistivity soundings. Sixty-seven resistivity soundings were made, 60 of which were made along 7 profiles. As shown on figure 2, profile A-A' crosses the El Paso Valley perpendicular to the Rio Grande at Ysleta, B-B' at Clint, C-C' at Fabens, D-D' at Tornillo, E-E' at Fort Hancock, F-F' at McNary, and H-H' mostly along the cultivated flood plain of the Rio Grande from Ysleta to below Esperanza, perpendicular to the first six profiles.

1 The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

The Schlumberger electrode array (Zohdy, Eaton, and Mabey, 1974, p. 11), which consists of a four-electrode array to measure voltage distributions for a known input current, was used for the soundings. A sounding consists of (1) applying a voltage to a pair of electrodes (current electrodes), which induces direct-current flow and an electrical field in the earth; and (2) measuring the resulting voltage at a second pair of electrodes (potential electrodes). A succession of measurements are made with the current-electrode spacing increased for each measurement, from a minimum of about 20 feet (6.1 m) to as much as 16,000 feet (4,880 m). Resistivities for each spacing are computed from formulas derived for the electrode geometry.

Earth resistivities as a function of depth are derived from the sounding curve with the aid of digital-computer programs (Zohdy, 1975). Maximum electrode half-spacings for this survey ranged from 4,000 to 8,000 feet (1,220 to 2,440 m) and the depth of investigation was from about 1,500 feet to more than 5,000 feet (460 to 1,525 m). Profiles showing the interpreted resistivities for each of the sounding profiles are given on figure 6. The locations of seven off-profile soundings made for supplemental control are shown on figure 2, but are not included on the profiles on figure 6.

Interpretation of Airborne-Electromagnetic Data
Flood Plain of the Rio Grande

The INPUT data show a band of low resistivity (or high conductivity) along the flood plain of the Rio Grande from the northernmost line through the southernmost line (fig. 5). This low resistivity in the flood plain indicates that the material to a depth of about 150 to 200 feet (46 to 61 m), much of which is Rio Grande alluvium, is predominantly clay or sand containing salty water. Maps of ground-water quality to a depth of 200 feet (61 m) show that the water contains more than 1,000 mg/l dissolved solids at almost all locations in the El Paso Valley and more than 2,000 mg/l at most locations (Alvarez and Buckner, 1974, figs. 10 to 11). Figure 4 further illustrates the poor quality of the ground water in the alluvium and bolson deposits beneath the Rio Grande flood plain southeast of Ysleta.

Mesa and Sandhills Areas

Northeast of the flood plain, in the adjacent sandhills and mesa areas, the INPUT data show a wide band of higher resistivity from line 40 through line 10, although it is most pronounced from line 34 through line 14. This band of higher resistivity indicates that the bolson fill to depths of about 300 to 400 feet (91 to 120 m) includes more sand and gravel than the adjacent areas of lower resistivity. The band of lower resistivity on lines 30 through 10 on the northeastern margin of the surveyed area indicates that the bolson fill there is predominantly clay. Because the water table in this area is at depths of 300 to 400 feet (91 to 120 m), the material of lower resistivity is clay rather than sand containing salty water.

Electrical logs of wells and test holes in the band of high resistivity (such as that of JL-49-22-213, fig. 3) indicate the thickness of this resistive material, which cannot be interpreted from the INPUT data. From the land surface to the water table (in this well at about 275 feet or 84 m) the average resistivity is high, about 50 ohmmeters; and from the water table to a depth of about 440 feet (135 m), the average resistivity is moderate, 15 to 20 ohmmeters. Below 440 feet (135 m), the resistivity is low, less than 10 ohmmeters; and from 600 to 700 feet (180 to 215 m), the average resistivity is about 3 ohmmeters. The material comprising this resistive band is only a few hundred feet thick and extends at most 100-200 feet (30-61 m) below the water table.

The band of high resistivity east of the flood plain indicates the occurrence of sand and gravel deposited in an older channel of the Rio Grande. Over most of this channel feature, the sand and gravel beds are above the water table. However, in the sandhills and mesa areas around Fabens and Tornillo, and perhaps south to the El Paso-Hudspeth County line, sand and gravel beds extend below the water table and are a source of fresh to slightly saline water. Electrical logs of the five test holes drilled in the sandhills area between Fabens and Tornillo by the Horizon Corporation (such as the log of JL-49-39-346, fig. 3) show that the holes penetrated as much as 570 feet (174 m) of material having average resistivities greater than 10 ohmmeters.

The narrow and resistive zones in the areas of generally low resistivity at the northeast ends of lines 10 through 13 reflect shallow bedrock because the rocks crop out at two locations between these lines. The northeast ends of lines 1 through 4 also show high resistivity related to bedrock because these lines cross the Malone Mountains.

Interpretation of Earth-Resistivity Soundings

The seven resistivity profiles, which were drawn from the interpretations of individual soundings and which do not indicate the occurrence of any large bodies of fresh ground water in the southeastern part of the Hueco Bolson, are shown on figure 6.

On the profiles, the subsurface is divided into resistivity units of less than 5, 5-10, 10-20, 20-40, 40-100, and more than 100 ohmmeters. Very generally, the interpretations of these resistivity units are as follows:

<5 ohmmeters: Clay or sand saturated with moderately saline or poorer quality water (3,000 to 4,000 mg/l or more of dissolved solids).

5-10 ohmmeters: Predominantly clay or sand containing moderately saline or poorer quality water (3,000 to 4,000 mg/l or more dissolved solids), but possibly includes interbedded sands containing fresh or slightly saline water (less than 3,000 mg/l dissolved solids)

10-20 ohmmeters: Clay, sand and gravel containing slightly saline water (about 1,000 to 3,000 mg/l dissolved solids); possibly includes some beds containing fresh water (less than 1,000 mg/l dissolved solids).

20-40 ohmmeters: Predominantly sand and gravel saturated with fresh water, but may include some clay.

40-100 ohmmeters: Sand and gravel containing fresh water or clay, sand, and gravel above the water table.

>100 ohmmeters: Sand and gravel above the water table.

The resistivities of the consolidated rock underlying the bolson fill vary with lithology, porosity, and permeability of the rock and with the quality of the ground water. If a layer with a resistivity of more than 5 to 10 ohmmeters was detected below a considerable thickness of material of lower resistivity, or if the sounding data indicated resistivities greater than 30 to 40 ohmmeters at depth, the material was considered to be consolidated rock.

This general interpretation of resistivity data, which may not apply to areas other than the Hueco Bolson, is based partly on correlations between resistivity and hydrogeology in other parts of the Basin and Range province, and partly on relations between formation resistivity and water quality in the Hueco Bolson, as derived from a comparison of electrical logs and water samples.

The profiles also show the approximate position of the water table, except under the flood plain, where the water table is commonly within 10 feet (3 m) of the land surface. Because the land surface is shown as a level surface perpendicular to the river, instead of rising to the east as it actually does, the water table appears to dip away from the river instead of rising gradually to the east. The water table is not detected by the soundings unless it is marked by a significant change in resistivity. In coarse-grained material containing little clay, there is a significant decrease in resistivity at the water table and its depth can be determined easily. However, if the unsaturated material includes a considerable amount of clay, the change in resistivity at the water table is less noticeable.

Profile H-H' Along the Flood Plain

Profile H-H' (fig. 6) indicates that much of the material underlying the flood plain of the Rio Grande between Ysleta and Esperanza, and from the surface to the presumed depths of consolidated rocks ranging from 1,400 to 4,000 feet (425 to 1,220 m), is mostly clay and sand containing moderately saline or even poorer quality water (more than 3,000 mg/l dissolved solids). In the northern part of the El Paso Valley in El Paso County (from H-1 to H-3) the occurrence of more resistive layers indicate fresh or slightly saline ground water. At the northern end of the section, between H-1 and H-3, resistivities are higher at depths between 160 and 430 feet (49 to 130 m). H-1 is probably the southeastern limit of the fresh water of the city artesian area, and H-3 is probably the limit of significant amounts of fresh water in the Rio Grande alluvium. This resistive zone correlates generally with the zone of fresh water at the northwestern end of Q-Q' (fig. 4). Well JL-49-22-401 on Q-Q' is just 0.5 mile (0.8 km) northwest of sounding A-1. In Hudspeth County, there is no indication of the occurrence of fresh or slightly saline water under the flood plain.

The sounding data collected on the flood plain will not permit differentiation of slightly saline and poorer quality water in the Rio Grande alluvium. A water-quality map prepared by Alvarez and Buckner (1974, fig. 11) shows large areas of the flood plain in El Paso County underlain by slightly saline water to depths of 200 feet (61 m). The resistivity data between soundings H-4 and H-6 (<5 ohmmeters) suggest the occurrence of poorer quality ground water, probably because the interpretation averages the resistivities of sands containing slightly saline water and the low resistivities of the clays.

The only other area of moderate to high resistivity in or near the flood plain on H-H' is in the sandhills area between Fabens and the El Paso-Hudspeth County line (from H-7 through H-11), which is also shown on C-C' at C-3 and C-4 and on D-D' at D-2 to D-4. In this area, resistivities are more than 10 ohmmeters to depths ranging from 400 to 1,400 feet (120 to 425 m). Electrical logs and water samples from the five test holes in the Fabens-Tornillo area show the occurrence of alternating beds of clay and sand containing fresh to slightly saline water to depths of at least 570 feet (174 m).

The extent of the area of moderate to high resistivity between Fabens and the county line (from H-7 to H-12, figs. 6, 2a, and 2b) is not known but is probably 25 to 50 square miles (65 to 130 km^2). If it is assumed that: (1) The average saturated thickness of the resistive material is about 500 feet (150 m); (2) the sands compose about 50 percent of the thickness; and (3) the specific yield is 10 percent, then the total amount of fresh and slightly saline ground water in storage ranges from 400,000 to 800,000 acre-feet (500 million to 1 billion m^3).

Cross Profiles

The six profiles perpendicular to the Rio Grande (A-A' through F-F') all show the occurrence of clay and salty water under the flood plain. At the western end of A-A', the resistivity indicates some shallow fresh or slightly saline water in the Rio Grande alluvium. Some deeper and slightly resistive material reflects the city artesian area, although this far south the water in the bolson deposits is poorer in quality.

The northeastern halves of profiles A-A' through F-F' show significant thicknesses of resistive material that correspond to the zone of high resistivity in the INPUT data. The high-resistivity band in the INPUT data correlates with the high resistivity indicated by the shallow sounding data from A-4 through A-7, from B-5 through B-7 (and probably B-8 although the INPUT data do not extend that far east), C-3, C-4, D-2 through D-4, and E-2 through E-4. Profile F-F' crosses the southern end of the resistive band and with the possible exception of F-4 does not correlate well with it. This resistive material consists largely of sand and gravel above the water table, but at several locations there is a significant thickness of saturated material that probably contains fresh to slightly saline water. Resistive layers of more than 100 ohmmeters, which are almost all above the water table, represent unsaturated sand and gravel. Most of the rest of the unsaturated material has resistivities greater than 40 ohmmeters; although some of the shallow material has low resistivity, notably less than 5 ohmmeters at F-2, F-3, and F-5.

At several locations in the sandhills and mesa areas (profiles A-A' through F-F'), significant thicknesses of moderately to highly resistive material below the water table may be sources of fresh or slightly saline water. These include A-5, A-6, B-5 through B-8, C-3, C-4, D-2 through D-4 in the Fabens-Tornillo area and E-2 through E-4.

Profile A-A'.--At A-5 and A-6, the resistivity is 10 to 20 ohmmeters in the interval from the water table at about 300 to 350 feet (91 to 105 m) to depths of as much as 1,700 feet (520 m). This interval may contain slightly saline water or may contain alternating beds of sand with fresh water and clay. Few well data are available for the area near A-5 and A-6 for correlation with the resistivity. A 350-foot (107-m) well (JL-49-14-801) 2 miles (3.2 km) north of A-5, yielded water containing 1,490 mg/l dissolved solids (Alvarez and Buckner, 1974, table 4). The electrical log of a deeper well (JL-49-22-213, fig. 3), 2 miles (3.2 km) southwest of A-5, indicates the occurrence of resistive sands that may contain fresh water to a depth of only 440 feet (135 m). From 440 to 700 feet (135 to 215 m), the resistivities are less than 10 ohmmeters and average about 3 ohmmeters from 600 to 700 feet (180 to 215 m). This well, however, is closer to A-4 than A-5, and its log correlates fairly well with the resistivity at A-4.

Two wells (JL-49-15-701 and 702, fig. 2), which are 596 and 638 feet (182 and 194 m) deep and 2 miles (3 km) east of A-6, yield slightly to moderately saline water (2,100 to 3,400 mg/l) (Alvarez and Buckner, 1974, table 4). The electrical log of well 701 indicates that below a depth of 500 feet (150 m), the resistivities are less than 10 ohmmeters.

Profile B-B'.--From soundings B-5 through B-8, material with a resistivity greater than 20 ohmmeters extends to depths of as much as 820 feet (250 m), and resistivities greater than 10 ohmmeters extend to 1,000 feet (305 m) at B-5. These values indicate the possible occurrence of fresh and slightly saline water over a considerable length of B-B', from the water table at 300 to 400 feet (91 to 120 m) to depths of about 1,000 feet (305 m). The northwestern extent of this resistive interval is not known, but it apparently does not extend to C-C', 6 to 7 miles (10 to 11 km) to the southeast.

The available hydrologic data near the soundings on B-B' do not indicate this much resistive material or good-quality water. Water obtained with a down-hole sampler from a 560-foot (171-m) well (JL-49-23-902) 0.7 mile (1.1 km) northeast of B-6, was slightly to moderately saline (2,730 to 3,750 mg/l dissolved solids) (Alvarez and Buckner, 1974, table 4). An electrical log of well JL-49-24-404, 500 feet (150 m) from B-8, indicates an average resistivity of 6 to 7 ohmmeters from 370 feet (110 m), just below the water table, to the bottom of the log at 640 feet (195 m). However, sand beds with resistivities up to 20 ohmmeters composed about 20 percent of this interval. An electrical log of well JL-49-24-402 (fig. 3), 0.7 mile (1.1 km) east of B-8, indicates resistivities generally less than 5 ohmmeters from about 620 feet (190 m) to the bottom of the log at 1,186 feet (361 m).

The Horizon Corporation drilled 16 test holes within 1.5 miles (2.4 km) of B-8 to depths ranging from 500 to 1,189 feet (152 to 362 m). Six of these tests, which were completed as production wells above 652 feet (199 m), yield from 80 to 160 gal/min (5 to 10 l/s). Water samples from 8 of the 16 tests, taken from depths between 440 and 605 feet (134 to 184 m), contained from 477 to 745 mg/l dissolved solids. Electrical logs of 13 of these tests, of which 12 extend to depths of less than 651 feet (198 m), indicate that the depth of the water table ranges from 310 to 375 feet (94 to 114 m) below the land surface. Some resistive sands, probably containing fresh water, occur at depths up to 250 feet (76 m) below the water table; but below this depth, the resistivities are low.

Although the sounding data indicate that resistive material that may contain fresh or slightly saline water extends to depths of as much as 1,000 feet (305 m) between B-5 and B-8, the hydrologic data indicate that fresh water is limited to an interval within a few hundred feet (about 100 m) of the water table, and to a depth of less than 600 feet (180 m).

Profile E-E'.--From E-2 through E-4, the sounding data show resistivities of more than 20 ohmmeters to depths of 650 to 1,000 feet (200 to 305 m), of which a thickness of from 330 to 560 feet (100 to 170 m) may be saturated and could contain fresh water. Few hydrologic data are available for the area near E-E' for comparison with the sounding data. The only well in the area that taps the bolson fill is PD-48-34-801, 3.5 miles (5.6 km) northwest of E-4, which is 906 feet (276 m) deep and yields water containing 2,780 mg/l dissolved solids (Alvarez and Buckner, 1974, table 4). Two wells 356 and 406 feet (109 and 124 m) deep tap sandstones of Cretaceous age 0.5 mile (0.8 km) south of E-5 and yield water containing 1,260 and 1,530 mg/l dissolved solids (Davis and Leggat, 1965, table U3).

Fabens Artesian Zone

The only other area in the southeastern part of the Hueco Bolson where significant amounts of usable ground water occur is the Fabens artesian zone, where below a depth of about 1,300 feet (395 m), slightly saline water occurs under artesian pressure. The sounding data from this area do not clearly show the artesian zone because there is little contrast in resistivity between the alternating beds of sand and clay and the overlying material, which is predominantly clay. The resistivity of the artesian zone averages 4 to 6 ohmmeters, as shown by the electrical logs of wells JL-49-39-202 and 207. The resistivity of the overlying clay averages 2 to 3 ohmmeters.

The interpretation of sounding C-1B indicates that the top of the artesian zone is at a depth of about 1,200 feet (365 m) and that the base of the zone is at a depth of about 2,800 feet (855 m). No other soundings on the flood plain, except possibly sounding C-1A, G-5, and G-8 (fig. 2) indicated the artesian zone at depth. Therefore, this zone is apparently confined on the United States side of the Rio Grande to the area immediately south and west of Fabens.

Areas East of the Cross Profiles

All of the cross profiles, except B-B' and D-D', show a general rise in the bedrock surface from west to east, similar to the rise that Mattick (1967, fig. 6) detected by seismic methods in the northern part of the Hueco Bolson. Zohdy (1969, fig. 3) made a series of resistivity soundings along Horizon Boulevard, which showed that the bedrock surface rises steeply, 1 to 2 miles (1.6 to 3.2 km) east of B-8. The bolson fill is most likely thin in the areas east of the sounding profiles.

RELATION BETWEEN GEOPHYSICAL DATA AND THE GEOLOGIC HISTORY OF THE RIO GRANDE

The geologic history of the Rio Grande in southern New Mexico and western Texas has been studied by several researchers, including Kottlowski (1958), Strain (1966, 1970), Hawley and Kottlowski (1969), Hawley (1975), and Lovejoy (1975). As work has progressed, the history of the Rio Grande has been found to be much more complex than was originally supposed.

The river's present course is determined largely by geologic structure. From its headwaters in southwestern Colorado, the river traverses in a generally southward direction, a number of basins in the structurally low Rio Grande rift. At El Paso, it is diverted to a southeastward course, but it continues to follow structural trends. Kottlowski (1958) stated that the Rio Grande developed from north to south in early and middle Pleistocene time, and that by middle or late Pleistocene time, it flowed into the Mesilla Bolson west of the Franklin Mountains and then into the large basin that is the southern continuation of the Mesilla Bolson in northwestern Chihuahua, Mexico. Kottlowski (1958, p. 48) theorized that a tributary of the stream draining the Hueco Bolson subsequently eroded headward through El Paso del Norte between the Franklin Mountains and Sierra de Cristo Rey and captured the Rio Grande, diverting it into the Hueco Bolson and essentially on its present course. The river was subsequently joined with the lower Rio Grande and the Gulf of Mexico.

Strain (1966, 1970) presented evidence to show that the Rio Grande once flowed from the Mesilla Bolson to the Hueco Bolson through Fillmore Pass at the northern end of the Franklin Mountains (fig. 1). Strain (1966, p. 13) stated that the Camp Rice Formation was deposited by the ancestral Rio Grande after it began flowing through Fillmore Pass into the Hueco Bolson. The Fort Hancock Formation, which underlies the Camp Rice Formation, was deposited in Lake Cabeza de Vaca and possibly older lakes before the Hueco Bolson became part of the drainage area of the ancestral Rio Grande. After drainage was established, a tributary of the Rio Grande eroded headward through El Paso del Norte and along the west side of the Franklin Mountains until it captured the Rio Grande west of Fillmore Pass and diverted it to its present course (Strain, 1966, p. 11).

Hawley and Kottlowski (1969) discussed the ways in which the drainage of the Rio Grande could have developed by the successive overflow of basins from north to south, by headward erosion from south to north, or by a combination of these methods. Hawley and others (1969, p. 55) proposed that the fill of the Hueco Bolson be included in the Santa Fe Group of late Tertiary and Quaternary age, which was deposited in the Rio Grande rift in New Mexico. The Camp Rice Formation of Strain (1966) was defined as the uppermost unit of the Santa Fe Group in the Mesilla and Hueco Bolsons.

Hawley (1975), on the basis of new information on the ages of volcanic ash and paleontological data, speculated that the Camp Rice Formation, at least in the Mesilla Bolson, may include material as old as late Pliocene. Much of this material may be equivalent in age to at least part of the Fort Hancock Formation in the Hueco Bolson. Hawley (1975) suggested that the Camp Rice Formation was deposited by the Rio Grande when it terminated in or flowed through the bolsons southwest and southeast of El Paso, and he theorized that deposition of the Camp Rice ended when the upper and lower Rio Grande systems were joined and river-valley entrenchment began (Hawley, 1975, p. 145).

Hawley (1975, p. 146) further speculated that an ancestral Rio Grande existed as early as Pliocene time, and that part of this early system connected the Mesilla Bolson with the Hueco Bolson through Fillmore Pass. From there, the river may have flowed southeast into the Presidio Bolson. Uplift of the Franklin Mountains may have cut off the channel through Fillmore Pass and diverted the Rio Grande into the Mesilla Bolson. Subsequently, the connection between the Mesilla Bolson and the Hueco Bolson was established through El Paso del Norte by overflow or headward erosion.

Lovejoy (1975, p. 266-267) also believed that the ancestral Rio Grande was diverted from its course through Fillmore Pass by uplift on the western side of the Franklin Mountains. He implied that the fresh-water sands that occur at depths of more than 1,000 feet (305 m) east of the Franklin Mountains in the Hueco Bolson may have been deposited by the ancestral Rio Grande and are correlative with part of the Fort Hancock Formation (Lovejoy, 1975, p. 266). However, these fresh-water sands extend to altitudes as low as 2,700 to 3,000 feet (820 to 915 m) above mean sea level along the Franklin Mountains from the New Mexico State line to downtown El Paso. Bedrock occurs beneath Fillmore Pass at an altitude of about 3,250 feet (990 m) above mean sea level, which is about 500 feet (150 m) above the deepest fresh-water sands in the bolson fill. These data suggest that at least 500 feet (150 m) of uplift has occurred or that some of these sands may have been deposited by older streams local to the Hueco Bolson.

The channel feature on the INPUT data (fig. 5) probably represents material deposited by the ancestral Rio Grande on its course through Fillmore Pass and into the southern part of the Hueco Bolson. Much of this resistive zone may correlate with the Camp Rice Formation, which is about 90 feet (27 m) thick near McNary (Strain, 1966, p. 20). The channel feature is continuous on the INPUT data (fig. 5) from line 40 through line 10, and is especially prominent from Clint south (line 34). South of line 10, the feature fades out, possibly because the deposits thin markedly and the channel terminated in a lake, or because the channel shifted south to about the present position of the Rio Grande and its deposits were eroded by the modern course of the river.

The induction-electrical log (fig. 3) of well JL-49-22-213 indicates the thickness of the channel feature shown by the INPUT data. Highly resistive material (averaging about 50 ohmmeters) occurs from the surface to the water table at about 275 feet (84 m), and then moderately resistive material (averaging 15 to 20 ohmmeters) from the water table to a depth of 440 feet (135 m) or an altitude of about 3,500 feet (1,065 m) above mean sea level. Some of the resistive material above the water table may be the Camp Rice Formation, and the deeper resistive zones may be sands in the Fort Hancock Formation.

Near where the resistive channel feature on the mesa appears to swing under the flood plain of the Rio Grande between Fabens and the El Paso-Hudspeth County line, test-hole data, such as the induction-electrical log of JL-41-39-346 (fig. 3), indicate the occurrence of sands of high resistivity (more than 20 ohmmeters) to a depth of at least 500 feet (150 m), or an altitude as low as 3,100 feet (945 m) above sea level. Soundings D-3, D-4, H-10, and H-11 (fig. 6) indicate high resistivity (more than 20 ohmmeters) to depths of as much as 1,100 feet (340 m) and altitudes as low as 2,800 to 3,150 feet (855 to 960 m) above mean sea level. Sounding D-2 indicated moderate resistivity (10 to 18 ohmmeters) to a depth of 1,360 feet (415 m) or an altitude of 2,325 feet (710 m) above mean sea level. These resistive sandy zones between Fabens and the county line may partly represent deposits of an ancestral Rio Grande, but the deeper beds are probably deposits of streams local to the Hueco Bolson.

SUMMARY AND CONCLUSIONS

Electrical methods of geophysical exploration are a rapid and efficient way to initiate search for fresh ground water in the unconsolidated alluvial fill of the Hueco Bolson southeast of El Paso, Texas. Airborne-electromagnetic and earth-resistivity surveys did not indicate any large bodies of fresh ground water (containing less than 1,000 mg/l dissolved solids), but did indicate several areas that may be underlain by small to moderate amounts (1 million acre-feet or 1.2 billion m^3 or less) of fresh or slightly saline water (1,000 to 3,000 mg/l dissolved solids).

Previous surveys using gravity, seismic, and earth-resistivity methods between Ysleta and Clint indicated that the unconsolidated alluvial fill is from 1,000 to 3,000 feet (305 to 915 m) thick; and test holes drilled for oil and water indicated the occurrence of 1,000 to more than 3,500 feet (305 to more than 1,065 m) of fill in the southeastern bolson. One oil test reportedly penetrated about 9,000 feet (2,745 m) of fill. However, the earth-resistivity soundings indicate the occurrence of from less than 1,000 to 5,000 feet (305 to 1,525 m) of fill.

The geophysical surveys showed that most of the unconsolidated alluvial fill in the southeastern part of the Hueco Bolson has low resistivity, and is composed of clay, probably playa-lake deposits, including some sand beds containing poorer quality water. Clay and sand containing slightly to very saline water (1,000 to 35,000 mg/l dissolved solids) underlie much of the flood plain of the Rio Grande and most of the southern end of the bolson. Several interrelated factors, such as low permeability, the presence of soluble minerals, small amounts of recharge, and slow ground-water circulation result in ground water of generally poor quality in the southeastern part of the bolson.

A band of resistive material, which may represent sand and gravel deposited along a channel of the ancestral Rio Grande, occurs along the edge of the mesa next to and roughly parallel to the flood plain. At most locations, this resistive material is above the water table and is not a source of water. In the Fabens-Tornillo area, in the sandhills area between Fabens and the El Paso-Hudspeth County line, however, this channel feature swings under the edge of the flood plain, and a significant thickness below the water table is saturated with usable water. Under assumed conditions this area may contain as much as 400,000 to 800,000 acre-feet (500 million to 1 billion m^3) of fresh and slightly saline ground water.

The geophysical surveys indicated that several other areas on the mesa might be underlain by fresh to slightly saline water, including the area between resistivity soundings A-5 and A-6 northeast of Ysleta, between B-5 and B-8 northeast of Clint, and between E-2 and E-4 northeast of Fort Hancock. In addition, the surveys detected the southeastern end of the El Paso artesian area at Ysleta; and indicated that the Fabens artesian zone extends from a depth of about 1,200 to 2,800 feet (365 to 855 m), but that it is confined to the area between Fabens and the Rio Grande.

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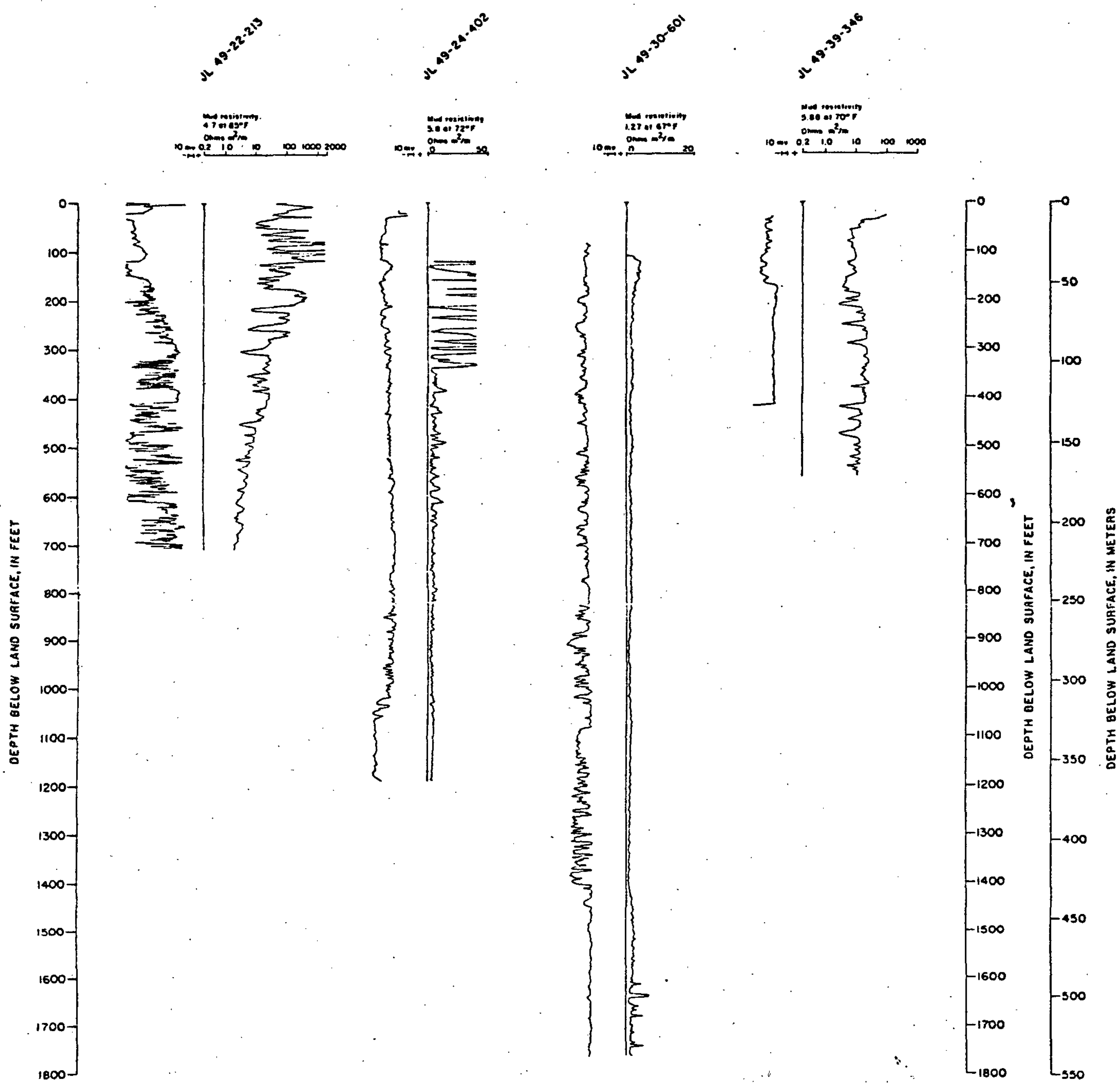

(Well locations shown on figure 2a.)

FIGURE 3.-Electrical logs of four wells and test holes in the southeastern part of the Hueco Bolson

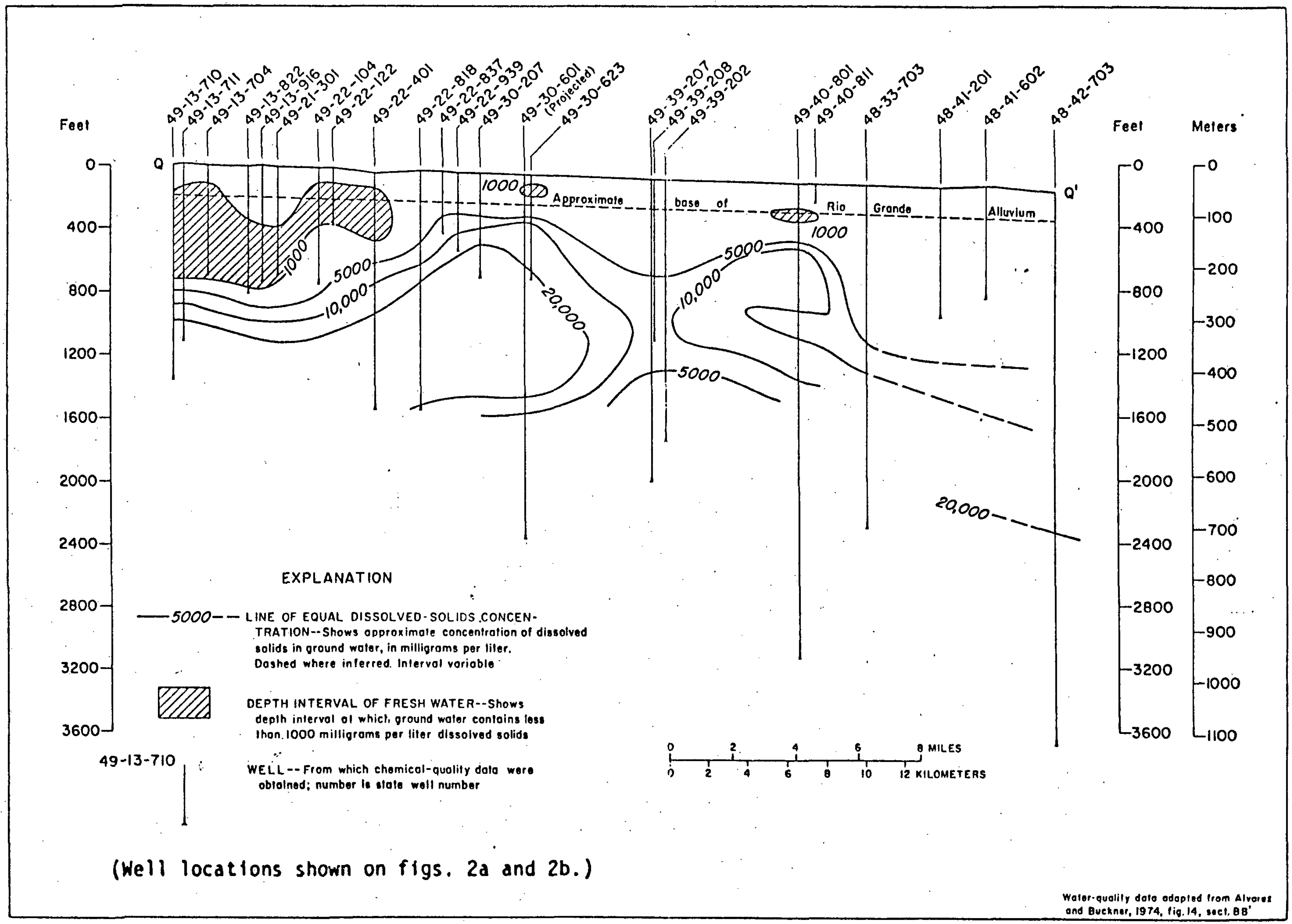

FIGURE 4.-Profile showing quality of ground water between El Paso and Fort Hancock, southeastern Hueco Bolson