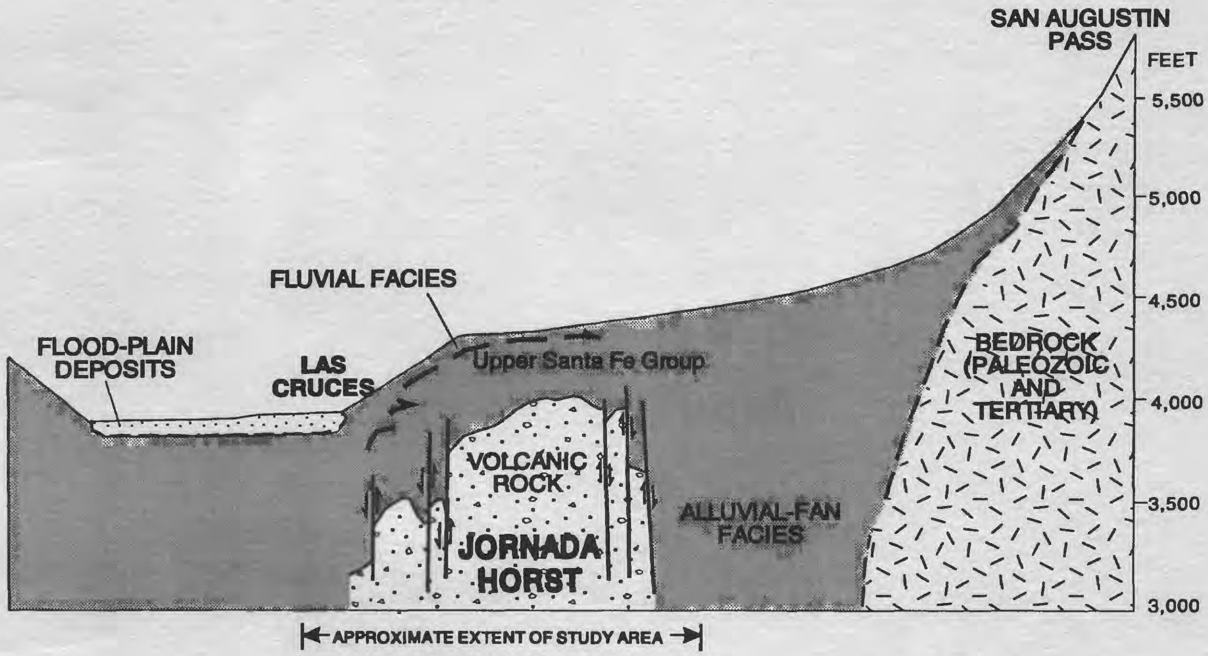
SEISMIC INVESTIGATION OF THE BURIED HORST BETWEEN THE JORNADA DEL MUERTO AND MESILLA GROUND-WATER BASINS NEAR LAS CRUCES, DOÑA ANA COUNTY, NEW MEXICO



U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97-4147

Prepared in cooperation with the CITY OF LAS CRUCES and the NEW MEXICO STATE ENGINEER OFFICE

Albuquerque, New Mexico
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By Dennis G. Woodward and Robert G. Myers

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot	0.3048	meter
mile	1.609	kilometer
acre	4,047	square meter
square mile	2.590	square kilometer
pound	453.6	gram

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

Six seismic reflection profiles were collected in the vicinity of the Jornada Horst between Goat Mountain and Tortugas Mountain (northeast and east of Las Cruces, New Mexico) to delineate more precisely the geometry of the horst and to determine whether large, buried channels have been incised into the top of the horst. The Jornada fault zone separates the southern Jornada del Muerto ground-water basin from the Mesilla ground-water basin in the Mesilla drainage basin.

The upper part of the Jornada Horst is composed of Tertiary volcanic and volcaniclastic rocks; these rocks overlie Permian sedimentary rocks. The horst, in turn, is overlain by unconsolidated sediments of the upper Santa Fe Group. Some test holes indicate that little or no ground water flows from the Jornada del Muerto ground-water basin to the Mesilla ground-water basin over some portions of the horst. However, some ground water flows through the upper Santa Fe Group deposits above some portions of the horst. Ground-water flow immediately east of the horst near U.S. Highway 70 is deflected northward in the southern Jornada del Muerto ground-water basin presumably because of the change from higher hydraulic-conductivity values of aquifer materials in the southern basin to lower hydraulic-conductivity values of materials in the horst. Incised, buried channels, if present on the horst, could be filled with alluvial material with higher hydraulic-conductivity values than those of the material in the horst. Incised, buried channels would allow ground water to readily move from the Jornada del Muerto ground-water basin to the Mesilla ground-water basin.

The gross geometry of the horst--eastern extent, constraints on the western extent, and general altitude of the top--was discerned by interpretations of the seismic profiles. The presence or absence of large channels incised into the top of the horst could not be confirmed by these interpretations. However, the seismic interpretations suggest that the water table is above the top of the horst for most of its extent between U.S. Highway 70 and Tortugas Mountain and that the top of the horst is above the water table and acts as a subsurface flow barrier north of U.S. Highway 70.

INTRODUCTION

Continued growth of the population in the southern Jornada del Muerto Basin and in the city of Las Cruces requires increased water production from the Santa Fe Group aquifer (Hernandez and others, 1987). Currently (1997), several rural water systems and private domestic wells provide most of the water to the area.

The southern Jornada del Muerto ground-water basin and the Mesilla ground-water basin are located in the Mesilla drainage basin (fig. 1) in Doña Ana County, central-southern New Mexico. The Jornada fault zone separates the southern Jornada del Muerto Basin from the Mesilla Basin. A buried horst, bounded on the east by the Jornada fault zone, exists between Goat Mountain and Tortugas Mountain northeast of Las Cruces.

Little is known about subsurface hydrologic conditions between the Jornada del Muerto Basin and the Mesilla Basin near the horst. The altitude of the top of the horst is considered to be close to the water-table altitude in the Jornada del Muerto Basin. Ground water immediately east of the horst near U.S. Highway 70 is deflected northward, and some ground water moves from the Jornada del Muerto Basin to the Mesilla Basin through the upper Santa Fe Group above the horst (Wilson and others, 1981; Stickel, 1991). Very little

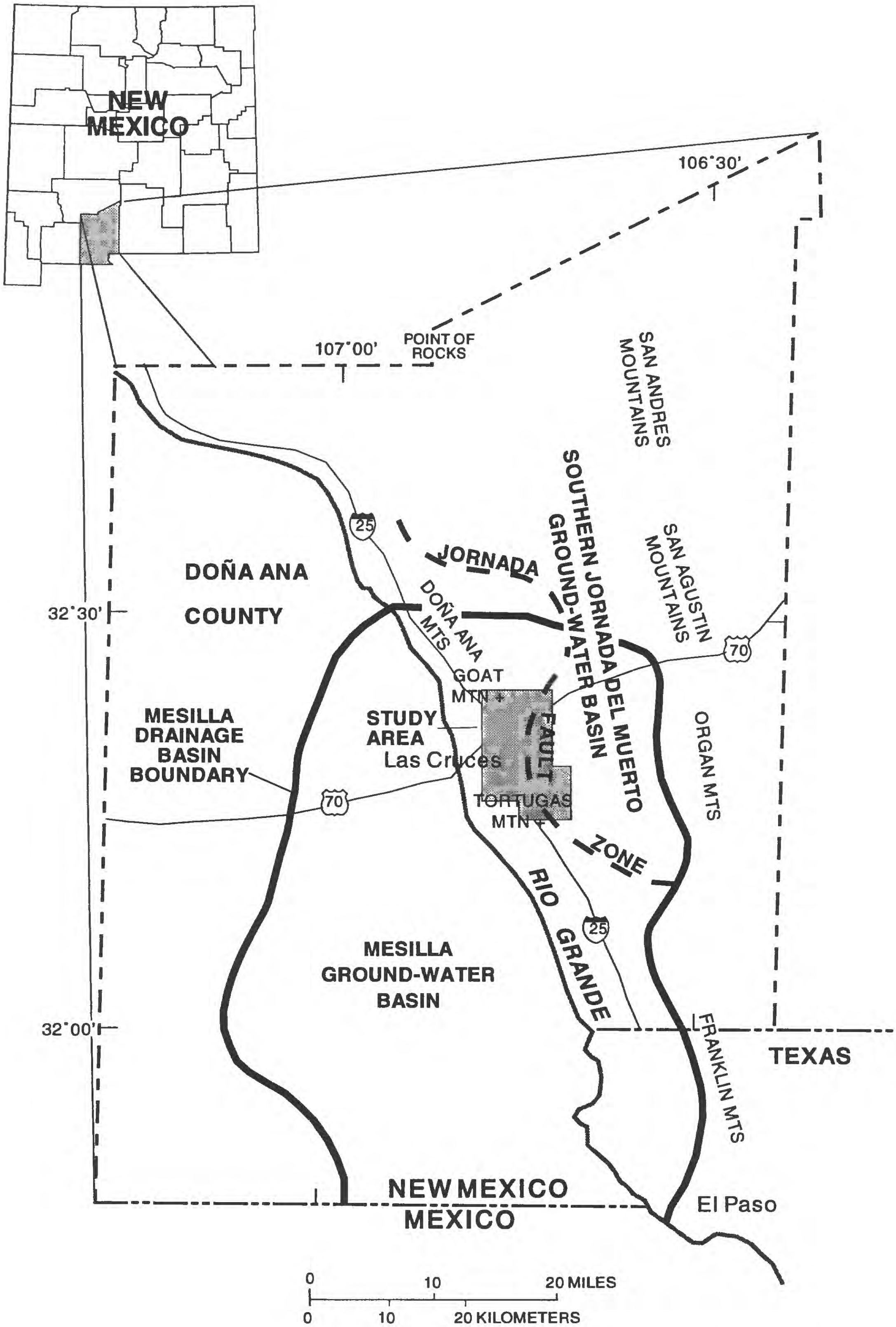


Figure 1.--Major hydrogeologic features in Doña Ana County, New Mexico.

ground water moves from the Jornada Basin to the Mesilla Basin through the lower Santa Fe Group or through the Tertiary volcanic and volcaniclastic rocks and Permian sedimentary rocks in the horst. If buried channels are present in the horst, they may transmit ground water from the Jornada del Muerto Basin to the Mesilla Basin.

A better understanding of the relation between the Jornada del Muerto ground-water basin and the Mesilla ground-water basin near the horst could assist the New Mexico State Engineer Office and the City of Las Cruces in the use and management of the ground-water resources in the area. This report was prepared in cooperation with the City of Las Cruces and the New Mexico State Engineer Office.

Purpose and Scope

The purpose of this report is to present the location and geometry of the buried horst between Goat Mountain and Tortugas Mountain and to discuss the hydrogeologic significance of the horst on the local ground-water-flow system--more precisely, to discuss whether significant bedrock channels are present on the horst surface. If present below the water table, bedrock channels could provide preferred pathways for ground-water movement from the southern Jornada del Muerto ground-water basin to the Mesilla ground-water basin. If large, buried channels are not present, the horst could retard or be a partial barrier to the flow of ground water from the southern Jornada del Muerto ground-water basin to the Mesilla ground-water basin.

This report briefly summarizes previous studies conducted near the buried horst and presents the results of seismic reflection surveys to determine the location, size, and shape of the horst and the presence of any large, buried channels incised into the top of the horst. The 50-square mile study area straddles the buried horst between Goat Mountain and Tortugas Mountain (fig. 2). Three seismic reflection lines were located perpendicular to the horst to locate more accurately the size, shape, and axis of the horst. Three seismic reflection lines were located down the axis of the horst to determine the altitude of the top of the horst and the presence or absence of large, buried channels.

Methodology

Recent advances in seismic reflection geophysics have enabled the investigation of shallow subsurface features. Whereas the predominant use of seismic reflection geophysics has been for petroleum exploration at depths of as much as 20,000 feet, the development of new computer applications and high-frequency seismic sources has promoted the use of seismic reflection geophysics for shallow (commonly at depths from 50 to 2,000 feet) ground-water exploration. The propagation of high-frequency seismic signals in the subsurface is attenuated less by transit through saturated materials than unsaturated materials; conversely, high-frequency seismic signals are attenuated during transit through unsaturated materials, sometimes to the extent that reflected signals cannot be differentiated from "noise" and subsurface characterization cannot be attempted. Because the unsaturated zone above the horst is at least 250 feet thick, the "two-way" travel path of the reflected waves through unsaturated material is at least 500 feet long. The seismic signals could be greatly attenuated transiting this thick unsaturated zone, making it more difficult to discriminate the reflected waves from the "noise" and to interpret the processed record.

Contracts for collecting and analyzing seismic reflection data near or within the city of Las Cruces were awarded ". . . to determine aquifer thickness, distribution, and geologic structure of the buried ridge between the Jornada del Muerto and Mesilla ground-water basins." The contracts specified that optimum geophone spacing shall be used to obtain resolution of buried features in Quaternary and Tertiary sediments at depths ranging from 0 to 2,000 feet and with a horizontal resolution of 100 feet or less. Because the seismic lines were located near populated areas and established roads, explosive seismic sources were not allowed. For the seismic lines shot parallel to the axis of the buried ridge (horst), contract requirements further specified that a geophone group spacing no greater than 50 feet be used.

Two different geophysical contractors were used to acquire seismic reflection profiles in the study area. Each contractor used different energy sources, different geophones, and different field spacing (shotpoint offset distances and geophone spacing) to collect the data, and each used different data processing techniques to construct, analyze, and interpret the profiles. The U.S. Geological Survey (USGS) has not attempted to rectify the seismic profiles as presented by the contractors;

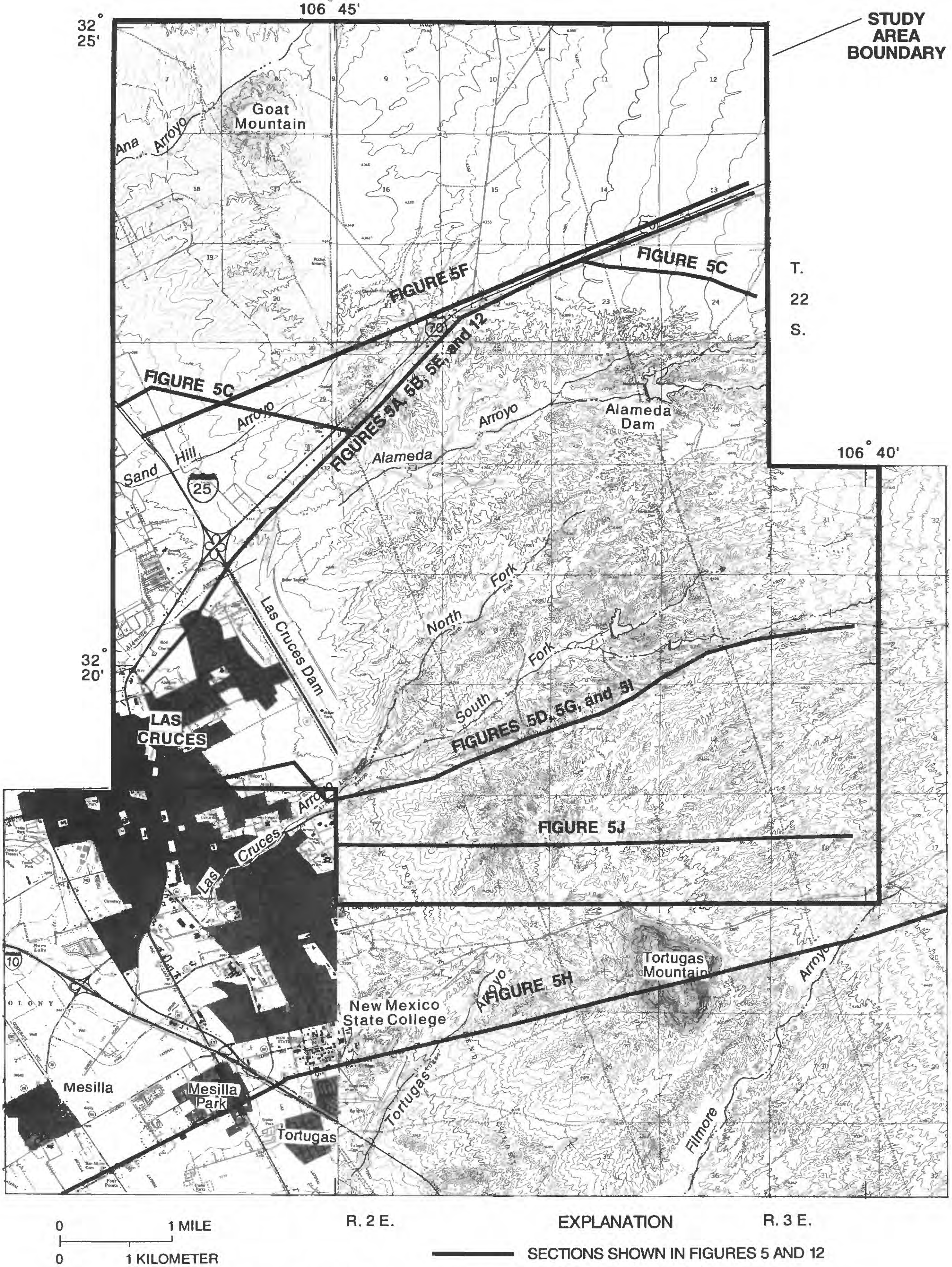


Figure 2.--Location of the study area and traces of geologic sections.

for example, the structural tops and thicknesses of certain units are not consistent at the intersections of seismic profiles that were prepared by the two contractors. The interpretation of seismic profiles is subjective and results in a non-unique solution. The discussion of the contractors' interpreted profiles in this report does not imply endorsement or acceptance by the USGS of the interpretations and conclusions of the contractors. The seismic profiles are in the files of the USGS District Office in Albuquerque and the New Mexico State Engineer Office in Santa Fe.

Well-Numbering System

Wells are located according to the system of common subdivision of sectionized land used throughout the State by the USGS. The number of each well consists of four segments separated by periods and locates the position of a well to the nearest 10-acre tract of land. The four segments denote, respectively, the township south of the New Mexico Base Line, the range east of the New Mexico Principal Meridian, the section, and the particular 10-acre tract within the section.

The fourth segment of the number consists of three digits denoting, respectively, the quarter section or approximate 160-acre tract, the quadrant (approximately 40 acres in size) of the quarter section, and the quadrant (approximately 10 acres in size) of the 40-acre tract in which the well is located. The system of numbering quarter sections and quadrants, which is done in reading order, as well as the usual numbering of sections within a township, is shown below (fig. 3). For example, well 23S.01E.24.344 is located in the SE 1/4 of the SE 1/4 of the SW 1/4 of section 24, Township 23 South, Range 1 East. If more than one well has the same location number, the letter "a" is assigned to the second well, the letter "b" to the third well, and so on.

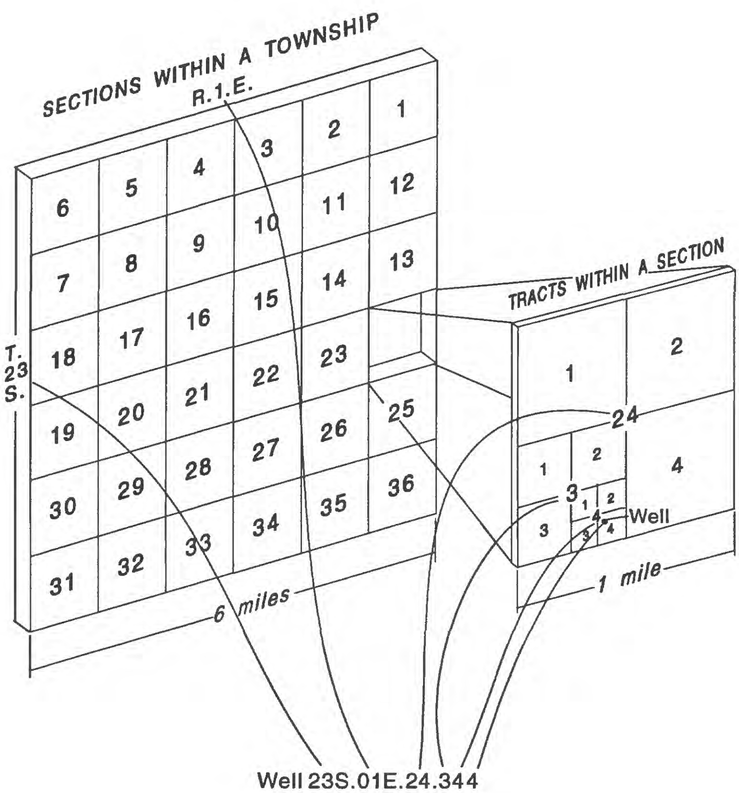


Figure 3.--System of numbering wells in New Mexico.

HYDROGEOLOGIC FRAMEWORK OF THE HORST AREA

The geology and hydrogeology of the area between Las Cruces and the Organ Mountains to the east have been described in a variety of studies. This somewhat desolate area has a rather unassuming surface appearance, but hidden beneath that surface an important buried geologic feature physically separates two regional ground-water basins: the Jornada del Muerto Basin on the east and the Mesilla Basin on the west. That important geologic feature, the Jornada Horst, is an uplifted, north-trending block of bedrock. The altitude of the buried top of this horst is considered to be close to the altitude of the water table in the Jornada del Muerto basin, and the horst could act as a partial barrier to regional ground-water flow.

There is speculation, however, that paleostreams could have eroded channels into the top of the horst and filled those fluvial channels with coarse-grained alluvium. Finer grained, alluvial-fan sediments were deposited throughout the area over the horst and would have buried the speculative bedrock channels. If those buried channels exist and are below the water table in the Jornada del Muerto Basin, they could function as preferred pathways for ground-water flow between the Jornada del Muerto Basin and the Mesilla Basin and could provide substantial subsurface recharge to or discharge from the Mesilla ground-water basin.

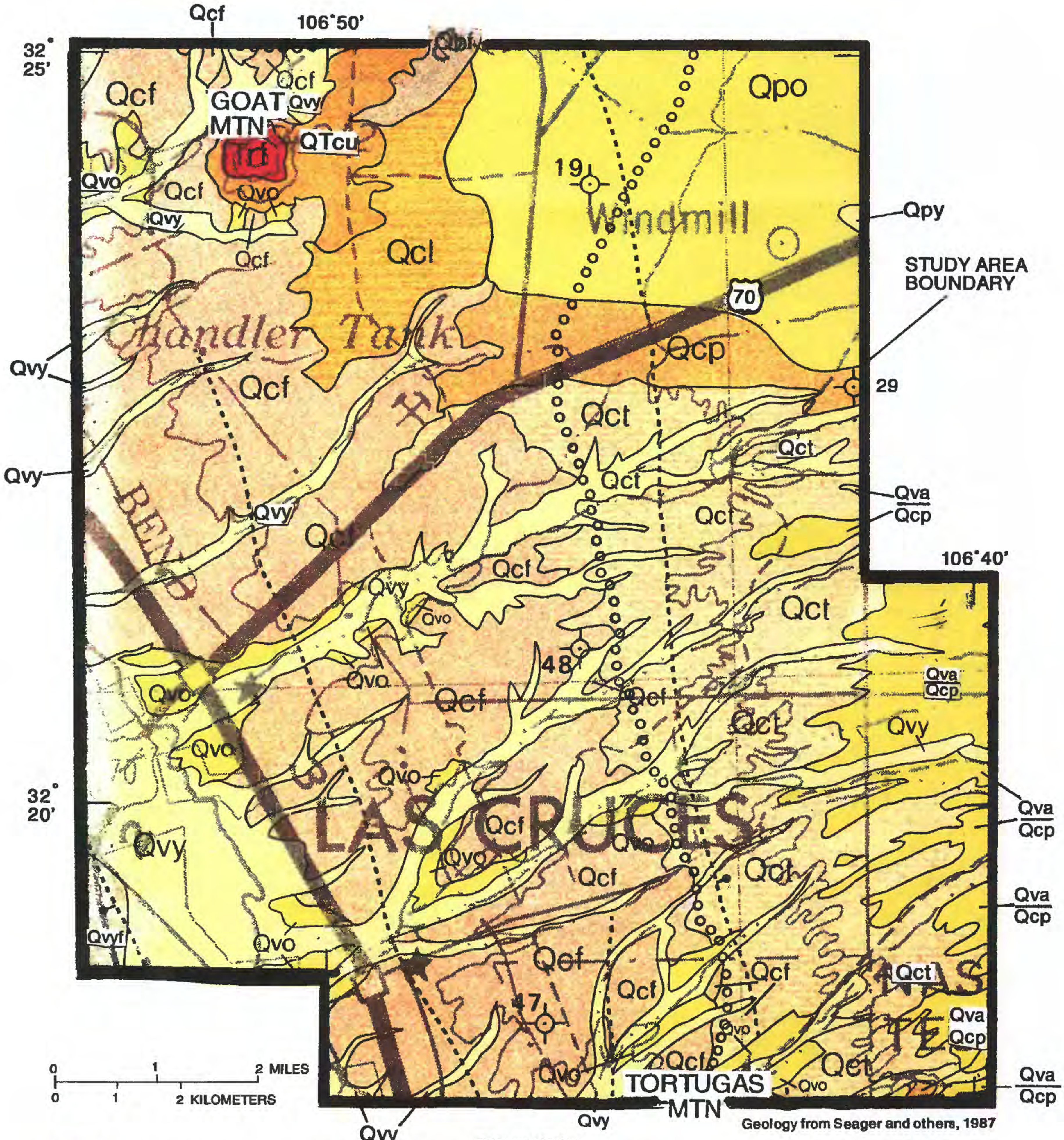
Regional Hydrogeology

In New Mexico, the Mesilla Basin constitutes the southernmost basin in a north-south-trending series of structural basins that compose the Rio Grande Rift. The rift extends from the San Luis Basin in southern Colorado through New Mexico to the Hueco Bolson and Bolson de los Muertos in western Texas and northern Chihuahua, Mexico (Hawley, 1978). The southern Jornada del Muerto Basin is bounded on the north by a structural change from a graben to a syncline near the Point of Rocks at the Doña Ana-Sierra County line; on the east by the San Andres, San Agustin, and Organ Mountains; and on the south and west by the Jornada fault zone (fig. 1). The Santa Fe Group includes all basin fill that was deposited prior to the formation of the Rio Grande Valley in the early to middle Pleistocene. The major aquifer system in the rift basins is composed of the saturated sediments in the upper Santa Fe Group.

The Quaternary and Tertiary Santa Fe Group overlies Tertiary volcanic and associated sedimentary rocks of early Oligocene to Miocene age and underlies Quaternary alluvial deposits that postdate the beginning of the Rio Grande Valley entrenchment in the middle Pleistocene (Hawley and others, 1969, p. 52). The thickness and width of the Santa Fe Group decrease from the north toward the south in the southern Jornada del Muerto Basin (Hawley, 1984; Peterson and others, 1984). Well data and geophysical tests (Doty, 1963; Hawley and Kottlowski, 1965; Taylor, 1967) indicate that the Santa Fe Group is more than 1,000 feet thick in the central part of the southern Jornada del Muerto Basin.

Fluvial deposits in the Santa Fe Group generally are more permeable than alluvial-fan deposits (Wilson and others, 1981). The thickness of fluvial deposits decreases from the western edge of the southern Jornada del Muerto Basin toward the eastern edge of the basin where they are absent. Fluvial deposits in the Jornada del Muerto Basin in the northern part of the basin are not present in the southern end of the basin (Hawley, 1984; Peterson and others, 1984; Mack, 1985). Seager and others (1987) mapped the Santa Fe Group exposed in the vicinity of the horst as consisting of alluvial-fan and fluvial deposits composed of clay, silt, sand, gravel, and caliche of the Camp Rice Formation, which correlates with the upper Santa Fe Group. The regional surficial geology of the study area is mapped in figure 4.

The upper Santa Fe Group (middle Pliocene to middle Pleistocene) in the Mesilla Basin, correlative with the Camp Rice Formation, has been recognized and mapped throughout the Mesilla and Jornada del Muerto Basins. The dominant facies of the Camp Rice Formation consists of fluvial sand and pebbly sand deposited by the ancestral Rio Grande; a secondary facies consists of piedmont-slope deposits composed primarily of fan alluvium (Hawley and Lozinsky, 1992). As shown in figures 5A and 5E, the sediments near the horst consist of upper Santa Fe Group deposits consisting of an upper alluvial-fan facies, a fluvial facies, and a lower alluvial-fan facies. The thickness of the Camp Rice Formation ranges from about 300 to 700 feet in the central basin areas (Hawley and Lozinsky, 1992, p. 27), yet Wilson and others (1981, p. 38) reported a thickness of more than 1,300 feet in test hole 23S.01E.13.411 located just west of the horst near Las Cruces. Wilson and others (1981, p. 40) thought that the saturated thickness of the alluvium on



EXPLANATION

QUATERNARY

- Qvy — ARROYO-CHANNEL, TERRACE, AND FAN DEPOSITS
- Qvyf — RIO GRANDE FLOOD-PLAIN AND CHANNEL DEPOSITS
- Qvo — OLDER RIVER, ARROYO, AND ALLUVIAL-FAN DEPOSITS
- Qpo — OLDER PIEDMONT-SLOPE DEPOSITS
- Qpy — YOUNGER PIEDMONT-SLOPE DEPOSITS
- Qbf — AFTON BASALT
- Qcl — CAMP RICE FORMATION SEDIMENTS ASSOCIATED WITH LA MESA SURFACE
- Qcp — CAMP RICE FORMATION, PIEDMONT-SLOPE FACIES
- Qva/Qcp — UNDIFFERENTIATED Qvy and Qvo CAMP RICE FORMATION PIEDMONT-SLOPE FACIES

TERTIARY QUATERNARY

- Qcf — CAMP RICE FORMATION FLUVIAL FACIES
- Qct — CAMP RICE FORMATION TRANSITIONAL FACIES
- QTcu — CAMP RICE FORMATION, PIEDMONT-SLOPE and FANGLOMERATE FACIES, UNDIVIDED
- Trf — FLOW-BANDED RHYOLITE
- CONTACT
- FAULT--Ball on downthrown side; dashed where inferred at the surface; dotted where buried
- SELECTED OIL OR WATER HOLE
- CAMP RICE FORMATION--Approximate known limits of fluvial deposits

Figure 4.--Regional surficial geology.

top of the horst may be very thin, but also thought it probable that the upper surface of the horst had peaks and troughs. Surface electrical resistivity soundings were made by Wilson and others (1981) to estimate the thickness of the Santa Fe Group near the horst (figs. 5C and 5D). The known total thickness of the upper Santa Fe Group is at least 250 feet on the horst (Mack, 1985, p. 61); the maximum thickness is unknown.

Tertiary volcanic and volcaniclastic rocks underlie the Santa Fe Group (figs. 5A, 5B, and 5E) and overlie Permian sedimentary rocks on the horst (figs. 5F, 5G, and 5J). The approximate location of the horst is known from gravity surveys, surface electrical resistivity surveys, and a few test holes and wells. Tertiary rocks include rhyolitic to andesitic lava flows, ash-flow tuffs, laharic breccias, conglomerates, sandstones, and mudstones (King and others, 1971; Hawley, 1984; Mack, 1985). Almost no work has been done to identify the stratigraphy of the Tertiary volcanic and volcaniclastic rocks on the horst, but W.R. Seager (Mack, 1985) identified cuttings of the Palm Park Formation from one City of Las Cruces test hole (22S.02E.10.444).

The aquifer in the upper Santa Fe Group in the southern Jornada del Muerto Basin is recharged by mountain-front runoff from precipitation and snowmelt from the San Andres, San Agustin, Organ, and Doña Ana Mountains and by percolation of runoff in arroyos and playa lakes. Some runoff occasionally reaches the Mesilla Basin and the Rio Grande. Some ground water flows across the horst from the Jornada del Muerto Basin to the Mesilla Basin; the volume of this flow through the horst is unknown at this time. Buried, incised channels, filled with coarser alluvium (with higher hydraulic conductivities), would potentially allow more ground water to flow from the Jornada del Muerto Basin to the Mesilla Basin.

Previous Understanding of the Buried Horst

The presence of a buried bedrock high east of Las Cruces composed of Tertiary volcanic and volcaniclastic rocks has been known for at least 25 years. The horst, composed of Tertiary volcanic and volcaniclastic rocks, exists roughly between Goat Mountain and Tortuga Mountain northeast of Las Cruces. This Tertiary volcanic high was shown in a geologic section by Hawley and others (1969, fig. 3, p. 57). That section suggested that the buried bedrock barrier formed a ground-water dam; note the data point located in the bedrock high that suggests apparent ground-water flow through the bedrock (fig. 5A). King and others (1971) declared the southern Jornada del Muerto Basin to be a well-defined structural basin separated from the Mesilla Basin by a buried bedrock high extending from the Doña Ana Mountains to Tortugas Mountain. A geologic section presented in their report (King and others, 1971, fig. 5, p. 19) showed the general position of this bedrock high and its marked effect on the water-table configuration (fig. 5B). Furthermore, on the basis of the presence of gravels derived from the Organ Mountains (situated east of the bedrock high) found in wells west of the bedrock high, King and others (1971, p. 20) surmised that (1) the buried uplift is locally breached in the area east of Interstate 25, between U.S. Highway 70 and Tortugas Mountain and (2) the uplift is not a continuous barrier to ground-water movement in the Santa Fe Group basin fill.

Wilson and others (1981) constructed geohydrologic sections of the area based on new well data and surface electrical resistivity surveys; those sections indicate that (1) the bedrock high is bounded on the east and west by faults; (2) the altitude of the water table, 1967-75, approximated the altitude of the bedrock high along a section that crossed the horst along the same transect as U.S. Highway 70 (fig. 5C); and (3) the altitude of the water table, 1967-76, was about 165 feet above the top of the buried bedrock high along a section that crossed the horst about 4 miles south of U.S. Highway 70 (fig. 5D).

In 1979, the City of Las Cruces drilled three test holes (23S.02E.15.322, 22S.02E.34.244, and 22S.02E.10.444) in the area that provided further information about the depth to the top of the Tertiary volcanic and volcaniclastic rocks on the horst or bedrock high (Mack, 1985). Test hole 23S.02E.15.322 was 785 feet deep and did not penetrate bedrock; test hole 22S.02E.34.244 penetrated bedrock at a depth of 250 feet; and test hole 22S.02E.10.444 penetrated bedrock at a depth of 650 feet. The geologic section published by Gile and others (1981) was the first to show the Camp Rice Formation (upper Santa Fe Group) above and adjacent to the upper portion of the horst (fig. 5E). The most detailed geologic sections across the Jornada Horst were presented by Hawley

(1984); he mapped lithofacies in the Santa Fe Group that showed only upper Santa Fe Group deposits directly above and surrounding the upper portion of the Jornada Horst (figs. 5F and 5G). Hawley's sections agree with those of Wilson and others (1981) in that the water-table altitude is shown to be (1) close to the top of the horst in the section close to U.S. Highway 70 (figs. 5C and 5F) and (2) more than 100 feet above the horst in a section about 4 miles south of U.S. Highway 70 (figs. 5D and 5G). Seager and others (1987) presented an east-to-west geologic section through Tortugas Mountain that indicated multiple faults bounding the uplifted bedrock (fig. 5H). The geohydrologic section presented by Frenzel and Kaehler (1992) shows the approximate water table above the top of the bedrock high and suggests ground-water flow partly through the bedrock (fig. 5I). Hawley and Lozinsky (1992) showed the bedrock high, bounded by numerous faults, in a geologic section (fig. 5J) and called the feature the Doña Ana-Tortugas Uplift (buried).

One of the conclusions of a ground-water modeling report of the Mesilla Basin by Peterson and others (1984, p. 135) was that "A northwest-southeast-trending fault block of volcanic and sedimentary bedrock has been elevated in an area just to the east of Las Cruces, creating a submerged horst that acts as a partial barrier to ground-water flow coming from the piedmont slope in the northeast section of the basin. Ground water passes westward over the structure in areas where the top of the bedrock is lower than the others. The 'damming' effect of the horst partly contributes to the steep piezometric head gradient observed in the alluvial facies below the Organ Mountains."

Other previous studies (King and others, 1971; Wilson and others, 1981) indicate that most ground water south of U.S. Highway 70 flows west from the Organ Mountains into the Mesilla ground-water basin. The direction of ground-water flow was based on potentiometric contours constructed from depth-to-water information for wells completed in the Santa Fe Group aquifer. However, well control is sparse in the area of the horst, and consequently very little data are available for that area (fig. 6). Ground-water-level data for the area are primarily from wells near U.S. Highway 70, from wells on the upthrown block east of the major step fault parallel to the Organ Mountains, and from wells on the west side of the horst between Goat Mountain and Tortugas Mountain.

The Jornada Horst affects regional ground-water flow, as indicated by the water-level map (fig. 7) from Wilson and others (1981); the location of the eastern extent of the horst, as delineated from the seismic sections collected for this report, coincides with a deflection of ground-water flow to the north near U.S. Highway 70. This deflection is caused by the change from higher hydraulic-conductivity values in the upper Santa Fe Group to the lower hydraulic-conductivity values of the Tertiary volcanics and volcaniclastics and Permian sedimentary rocks of the horst between Goat Mountain and Tortugas Mountain, thus forcing much of the ground water to flow north. The wells clustered north of U.S. Highway 70 and east of the Jornada fault zone have rather similar water-level altitudes that range from 4,065 to 4,087 feet above sea level (fig. 6). The low water-level gradient in this area contrasts with the steeper gradients elsewhere in the study area and suggests that the horst north of the highway could be a more effective barrier to ground-water flow. The water-table map by King and others (1971) shows a similar ground-water-flow deflection to the north in the same general area. Stickel (1991) determined that the horst alters the direction of ground-water flow in the southern Jornada del Muerto Basin and mentioned that basin fill on top of the horst transmits some ground water from the Jornada del Muerto Basin to the Mesilla Basin in some areas. Table 1 summarizes the geologic-section information from a variety of studies conducted in the area.

In summary, the horst is overlain by upper Santa Fe Group sediments (the Camp Rice Formation); the thinnest cover of sediments on the horst was encountered in City of Las Cruces test hole 22S.02E.34.244, which penetrated bedrock at a depth of 250 feet. Near U.S. Highway 70, the altitude of the top of the horst is close to the water-table altitude, and the top of the horst is higher (figs. 5A, 5B, and 5E). Wilson and others (1981) showed that the top of the horst about 4 miles south of U.S. Highway 70 is at an approximate altitude of 3,750 feet and that the water table (using data from 1967-76) is at least 165 feet above the top of the horst (fig. 5D); thus, the horst in this area would not prevent westward ground-water flow from the southern Jornada del Muerto Basin to the Mesilla Basin.

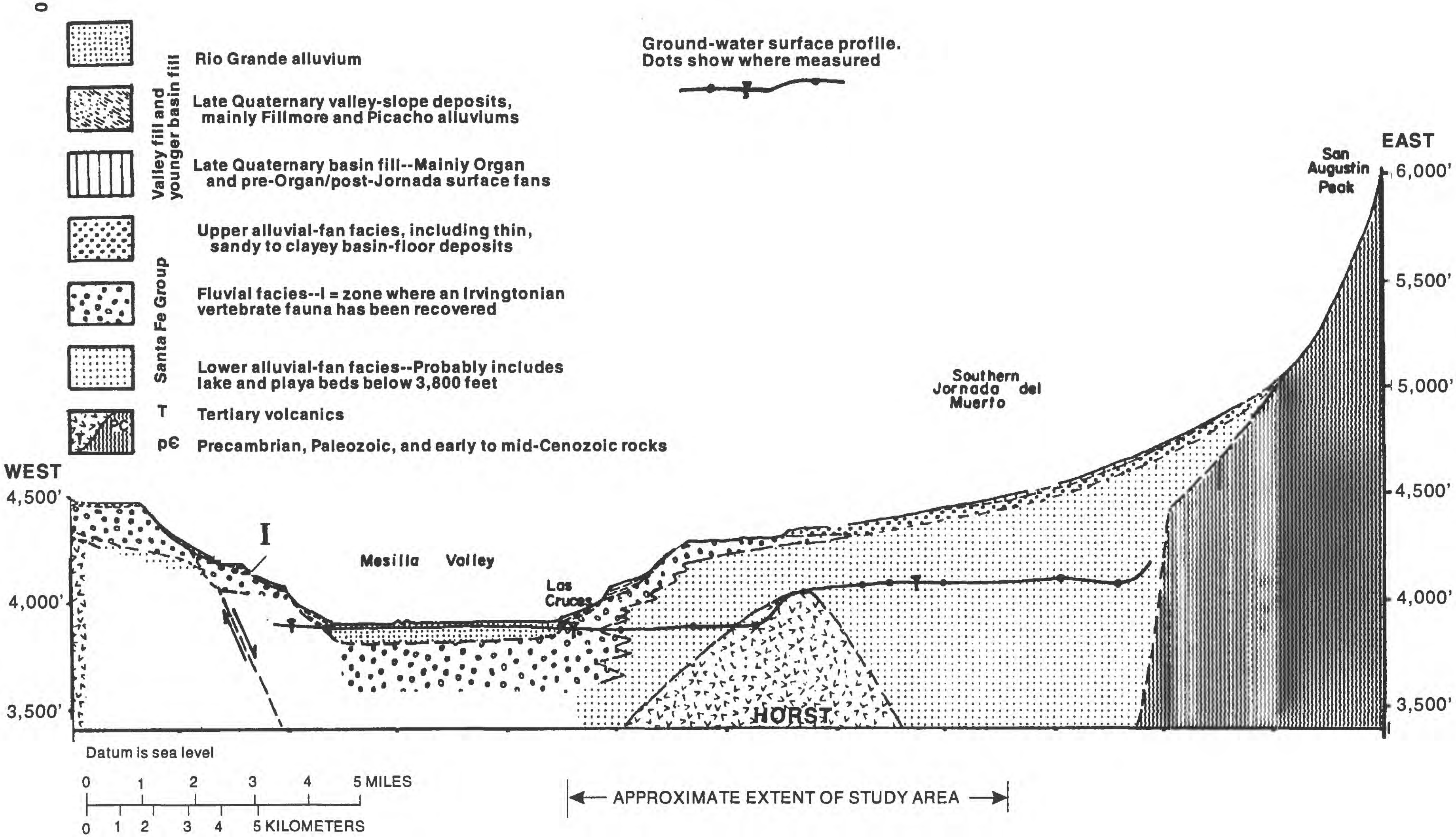


Figure 5A.--Buried horst along U.S. Highway 70 (modified from Hawley and others, 1969). Trace of section shown in figure 2.

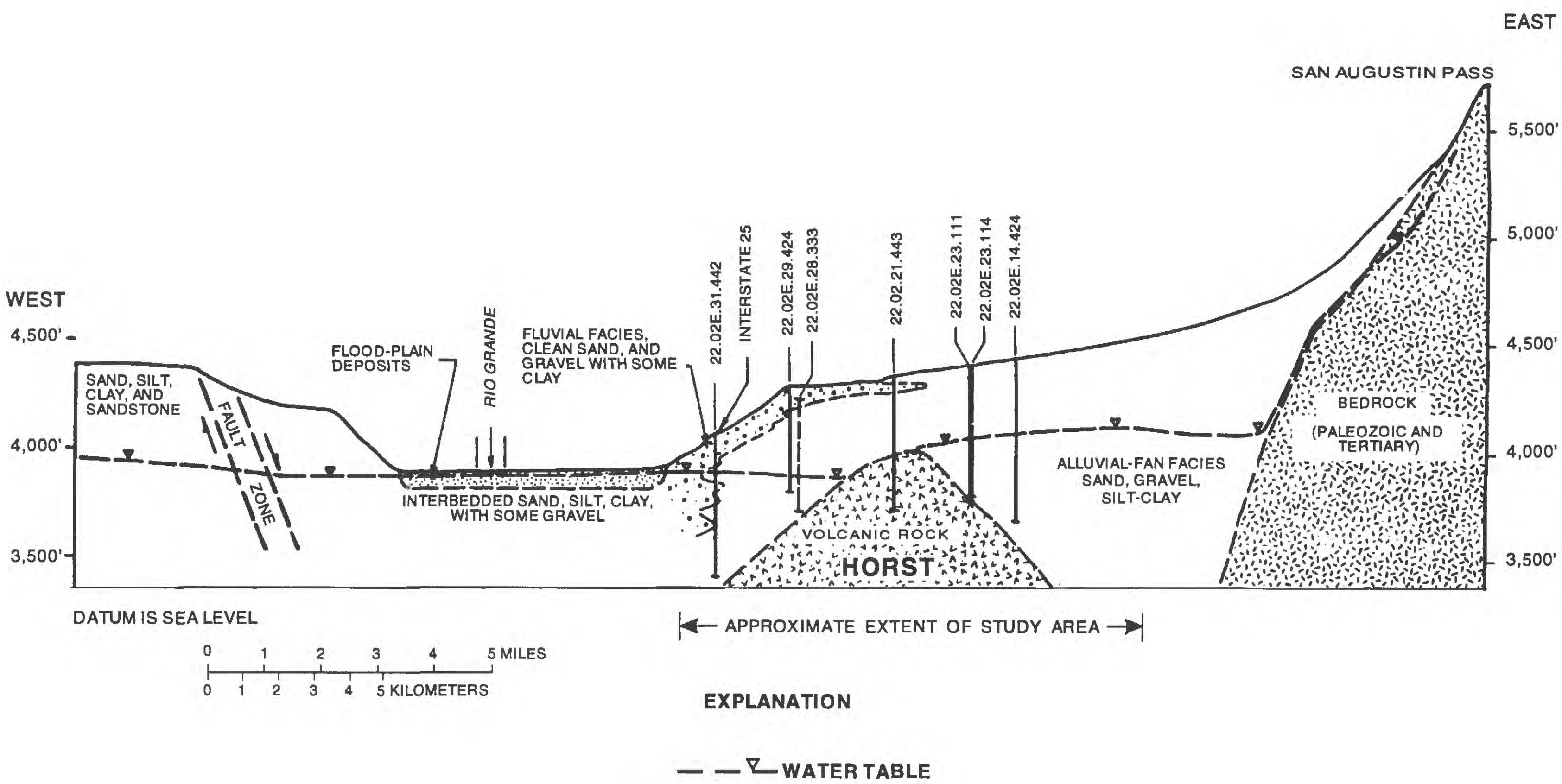


Figure 5B.--Buried horst along U.S. Highway 70 (modified from King and others, 1971). Trace of section shown in figure 2.

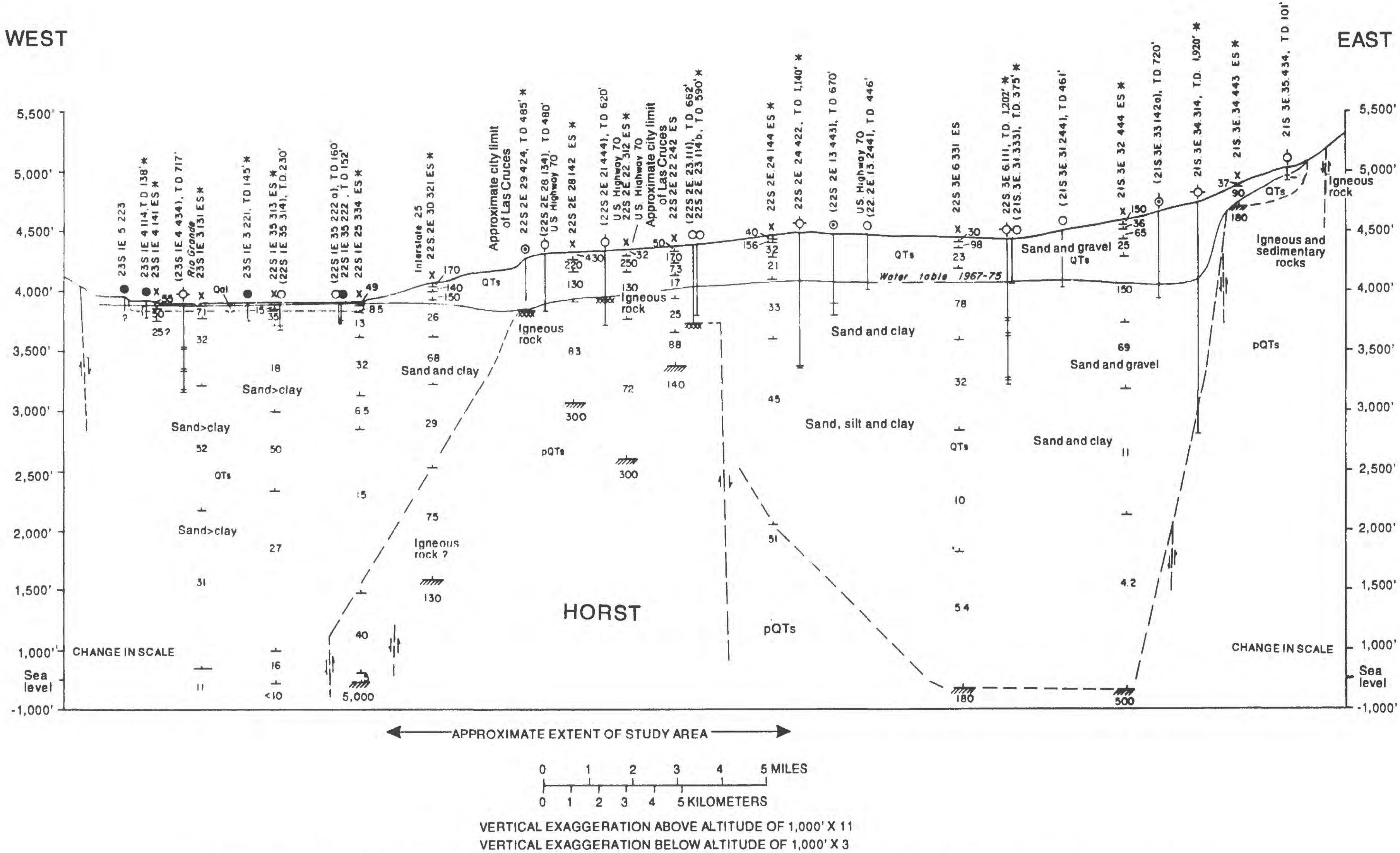


Figure 5C.--Buried horst along U.S. Highway 70 (modified from section D-D' in Wilson and others, 1981). Trace of section shown in figure 2.

EXPLANATION

GEOLOGIC DATA

Qal	Holocene alluvium (Quaternary)	Mainly flood-plain deposits of the Rio Grande and tributaries. Contains clay, silt, sand, and gravel
QTs	Santa Fe Group--Pleistocene to middle Miocene (Quaternary and Tertiary)	Mainly valley-fill deposits composed of clay, silt, sand, gravel, conglomerate, and volcanic rocks
pQTs	Pre-Santa Fe Group--Middie Miocene (Tertiary) to Precambrian rocks	Consists of sedimentary, metamorphic, and igneous rocks. Includes undifferentiated volcanic and intrusive rocks

Probable dominant lithology of units is labeled in selected areas. Sand> clay denotes sand content greater than clay content

-------- Contact — — — — Approximately located or inferred contact

Fault or fault zone; Approximately located or inferred fault. Arrows indicate direction of relative movement

XXXXX Depth in well or test hole where hard, indurated rock (bedrock) was penetrated

WELL DATA

22S.2E.21.444, T.D. 620

TOTAL DEPTH OF WELL, IN FEET

WELL LOCATION NUMBER--Parentheses around the well number indicate the well is projected to the section line at a right angle

- o Domestic
- ● Irrigation
- ⊙ Public-water supply
- -o- Test hole

NOTE: Vertical line through well symbol indicates unused or abandoned well

VERTICAL ELECTRICAL SOUNDING DATA

22S.2E.30.321 ES *

* BEND IN SECTION

ES ELECTRICAL SOUNDING

22S.2E.30.321 LOCATION NUMBER

X VERTICAL ELECTRICAL SOUNDING

170 / 140 / 150 RESISTIVITY--Number is the true resistivity, in ohm-meters, of interval. Intervals separted by —+—. Electrical basement is indicated by ////

Figure 5C.--Buried horst along U.S. Highway 70 (modified from section D-D' in Wilson and others, 1981). Trace of section shown in figure 2--Concluded.

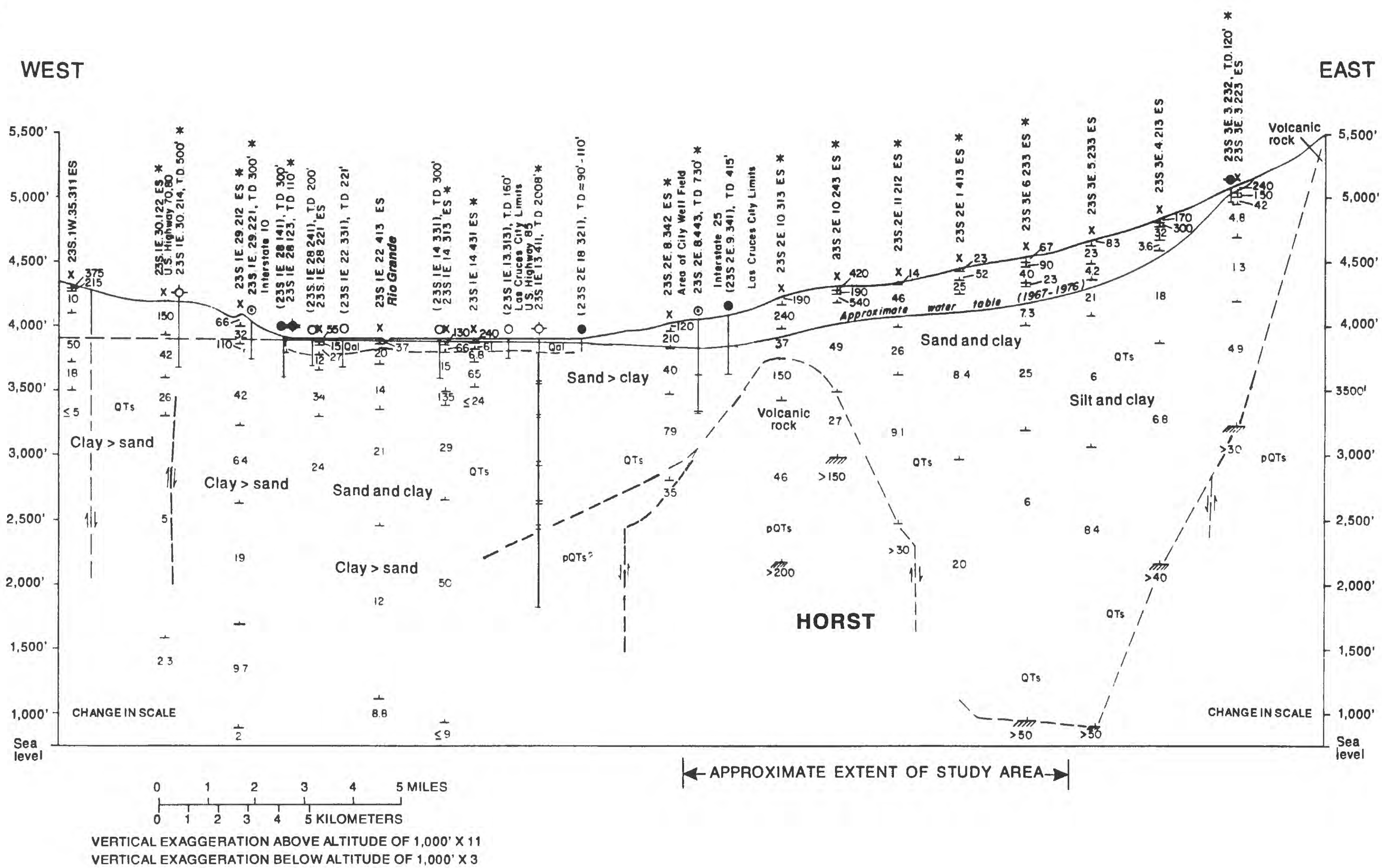


Figure 5D.--Buried horst about 4 miles south of U.S. Highway 70 (modified from section E-E' in Wilson and others, 1981). Trace of section shown in figure 2.

EXPLANATION

GEOLOGIC DATA

Qal	Holocene alluvium (Quaternary)	Mainly flood-plain deposits of the Rio Grande and tributaries. Contains clay, silt, sand, and gravel
QTs	Santa Fe Group--Pleistocene to middle Miocene (Quaternary and Tertiary)	Mainly valley-fill deposits composed of clay, silt, sand, gravel, conglomerate, and volcanic rocks
pQTs	Pre-Santa Fe Group--Middle Miocene (Tertiary) to Precambrian rocks	Consists of sedimentary, metamorphic, and igneous rocks. Includes undifferentiated volcanic and intrusive rocks

Probable dominant lithology of units is labeled in selected areas. Sand > clay denotes sand content greater than clay content

---------- Contact — — — — — Approximately located or inferred contact

Fault or fault zone — Approximately located or inferred fault — Arrows indicate direction of relative movement

XXXXX Depth in well or test hole where hard, indurated rock (bedrock) was penetrated

WELL DATA

23S.1E.28.123, T.D. 110

TOTAL DEPTH OF WELL, IN FEET

WELL LOCATION NUMBER--Parentheses around the well number indicate the well is projected to the section line at a right angle

- Stock
- Domestic
- Irrigation
- Industrial
- Public-water supply
- Test hole

NOTE: Vertical line through well symbol indicates unused or abandoned well

VERTICAL ELECTRICAL SOUNDING DATA

* Bend in section

23S.1E.30.122 ES

ELECTRICAL SOUNDING

LOCATION NUMBER

X — VERTICAL ELECTRICAL SOUNDING

150

42

26

RESISTIVITY--Number is the true resistivity, in ohm-meters, of interval. Intervals separted by ⊥ Electrical basement is indicated by ////

Figure 5D.--Buried horst about 4 miles south of U.S. Highway 70 (modified from section E-E' in Wilson and others, 1981). Trace of section shown in figure 2--Concluded.

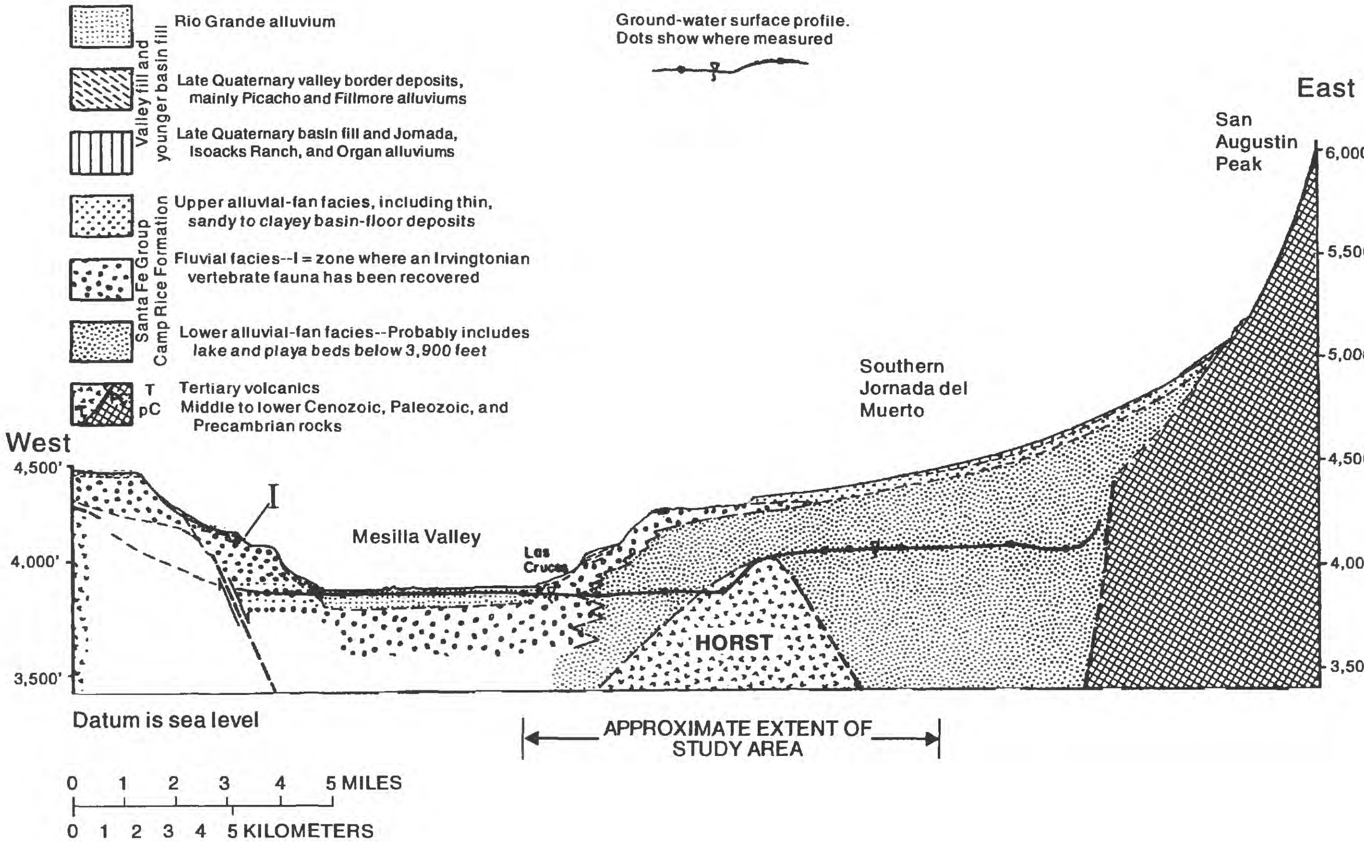
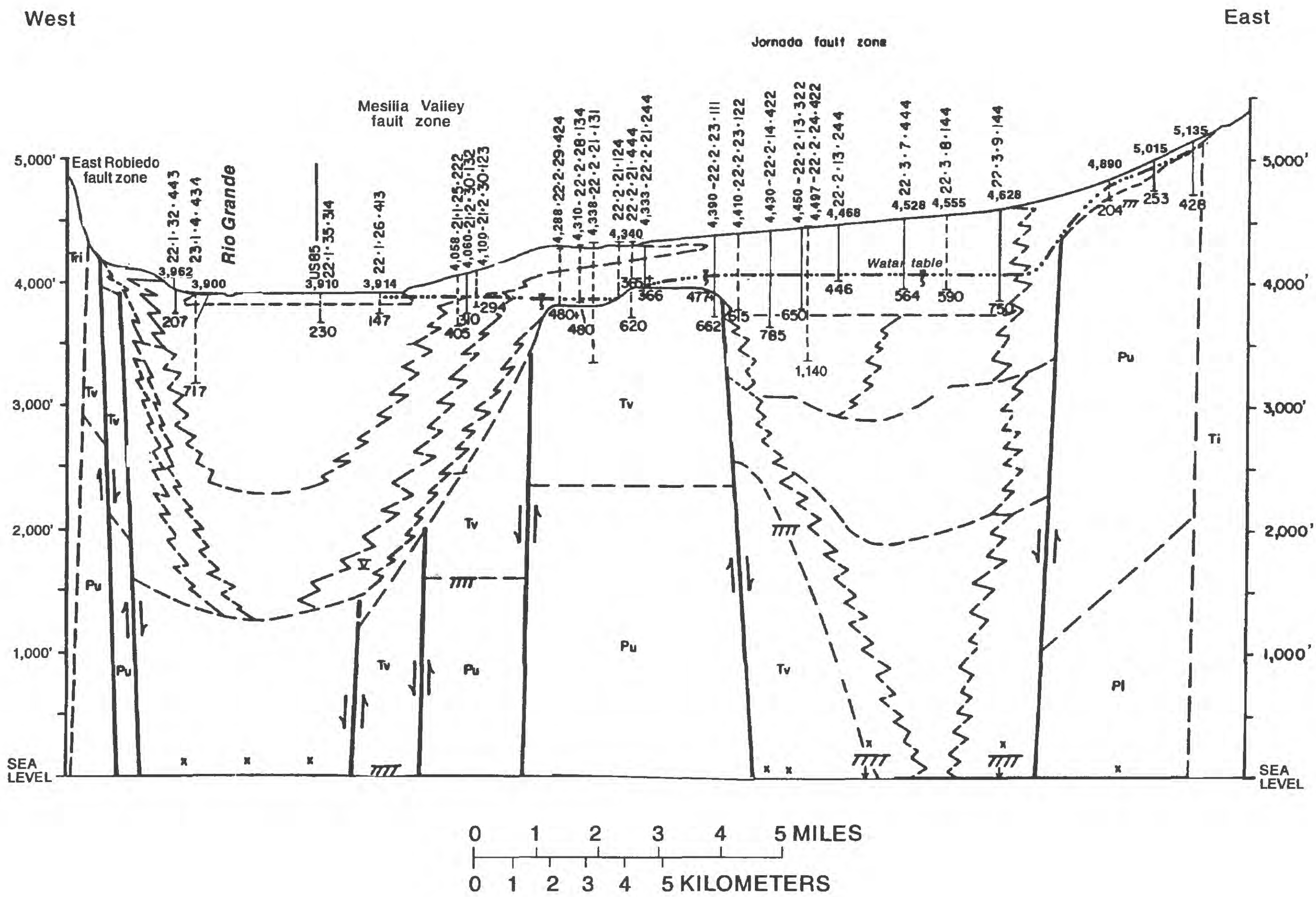


Figure 5E.--Buried horst along U.S. Highway 70 (modified from Gile and others, 1981). Trace of section shown in figure 2.



EXPLANATION

TERTIARY — OLIGOCENE / EOCENE

- **Tri** Rhyolitic intrusive complexes--Mostly sills, plugs, and associated lava domes
- **Ti** Silicic to intermediate plutonic rocks
- **Tv** Andesitic and other intermediate volcanic and volcaniclastic rocks--Includes lavas and laharic breccias

PALEOZOIC

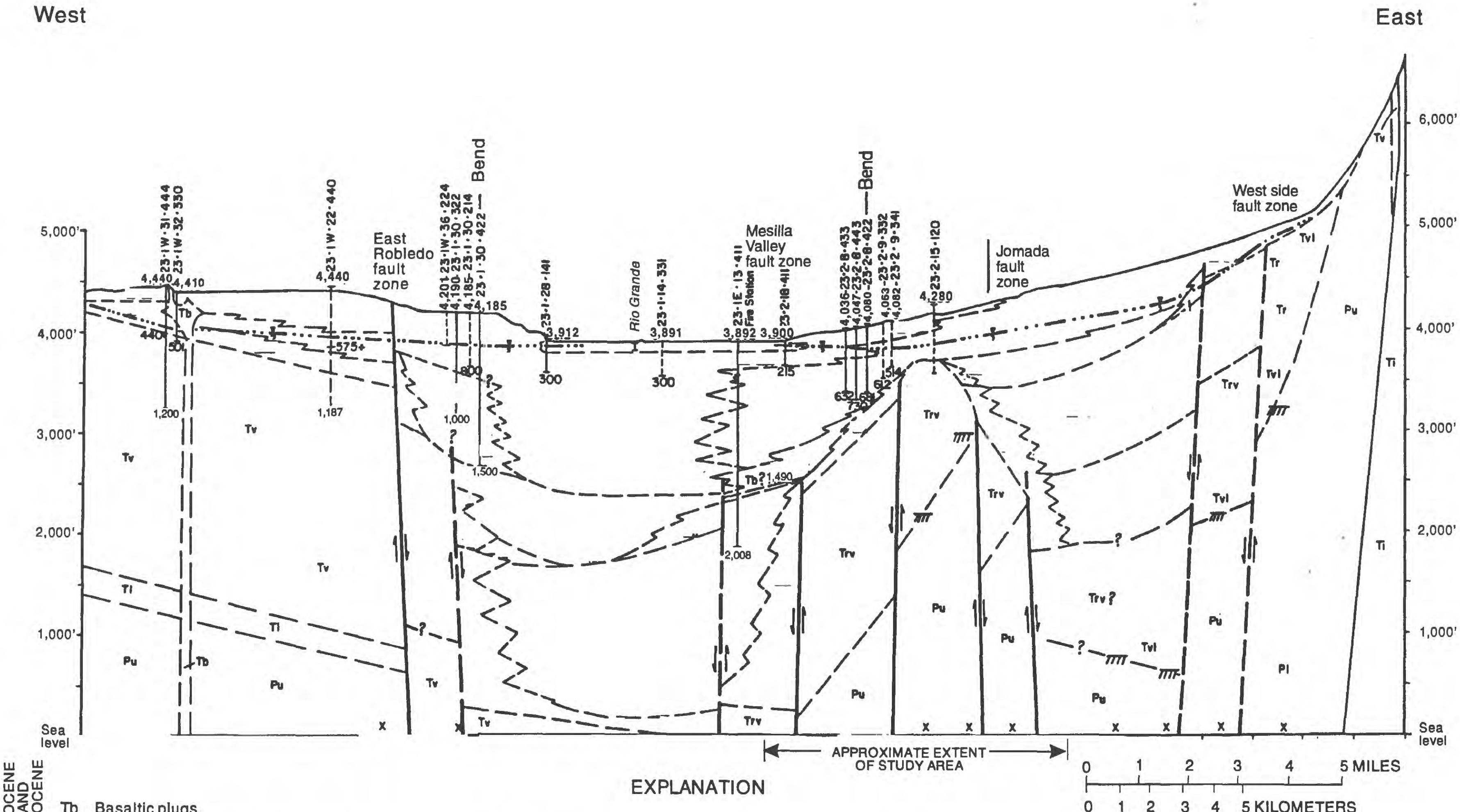
- **Pu** Upper Paleozoic rocks--Includes limestone, shale, and minor sandstone
- **Pl** Lower Paleozoic rocks--Undivided; includes limestone, shale, and minor sandstone

HIGH-ANGLE NORMAL FAULTS--Dashed where inferred; direction of relative displacement

3,900' / 717 — WELL--On or near line of section; land-surface altitude and total depth

ELECTRICAL BASEMENT

Figure 5F.--Buried horst near U.S. Highway 70 (modified from section C-C' in Hawley, 1984). Trace of section shown in figure 2.



EXPLANATION

TERTIARY — MIOCENE AND PLIOCENE

- Tb — Basaltic plugs
- Ti — Silicic to intermediate plutonic rocks

TERTIARY — OLIGOCENE EOCENE

- Tr — Rhyolitic volcanics, with some interbedded sandstone and conglomerate
- Tv — Andesitic and other intermediate volcanic and volcaniclastic rocks
- Trv — Undivided Tr and Tv--Tr, rhyolitic volcanics, with some interbedded sandstone and conglomerate. Tv, andesitic and other intermediate volcanic and volcaniclastic rocks

TERTIARY — EOCENE

- Tl — Mudstone, sandstone, and conglomerate with local gypsum beds
- Tvl — Undivided Tv and Tl

PALEOZOIC

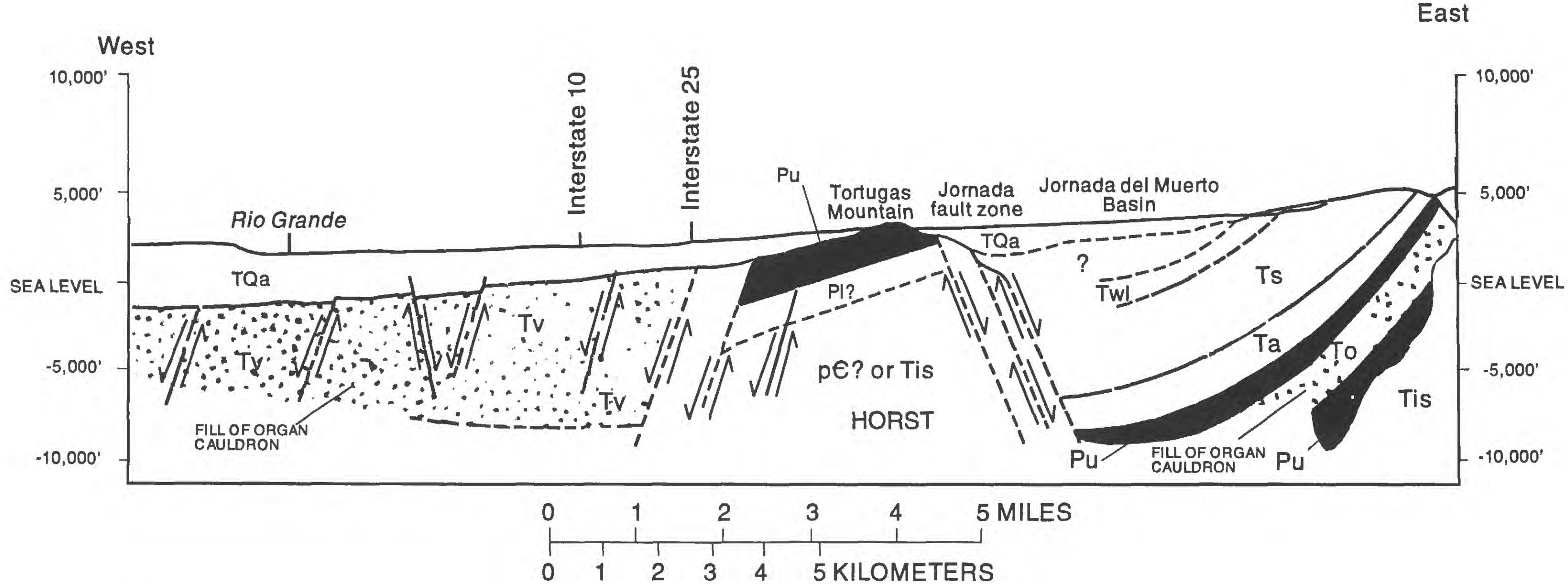
- Pu — Upper Paleozoic rocks--Includes limestone, shale, sandstone, and mudstone, with local gypsum beds
- Pl — Lower Paleozoic rocks undivided--Includes limestone, shale, and minor sandstone

HIGH-ANGLE NORMAL FAULTS--Dashed where inferred; direction of relative displacement

3,900' / 717 — WELL--On or near line of section; land-surface altitude and total depth

ELECTRICAL BASEMENT

Figure 5G.--Buried horst about 4 miles south of U.S. Highway 70 (modified from section D-D' in Hawley, 1984). Trace of section shown in figure 2.



EXPLANATION

QUATERNARY

TQa TERTIARY AND QUATERNARY BASIN FILL AND ALLUVIUM

TERTIARY

Tis SILICIC PLUTONIC ROCKS

VOLCANIC ROCKS OF ORGAN CAULDRON

OLIGOCENE

- Twl West-side lavas
- Ts Tuff of Squaw Mountain
- Ta Tuff of Achenback Park

BELL TOP FORMATION

EOCENE

- To Orejon Andesite

Tv Volcanic rocks

PALEOZOIC

Pu UPPER PALEOZOIC ROCKS--Includes limestone, shale, and minor sandstone

Pl LOWER PALEOZOIC ROCKS--Undivided; includes limestone, shale, and minor sandstone

PRE-CAMBRIAN

p€ PRECAMBRIAN ROCKS--Metasedimentary rocks, metavolcanics, and granite

FAULT--Dashed where inferred; direction of relative displacement

Figure 5H.--Horst at Tortugas Mountain (modified from Seager and others, 1987). Trace of section shown in figure 2.

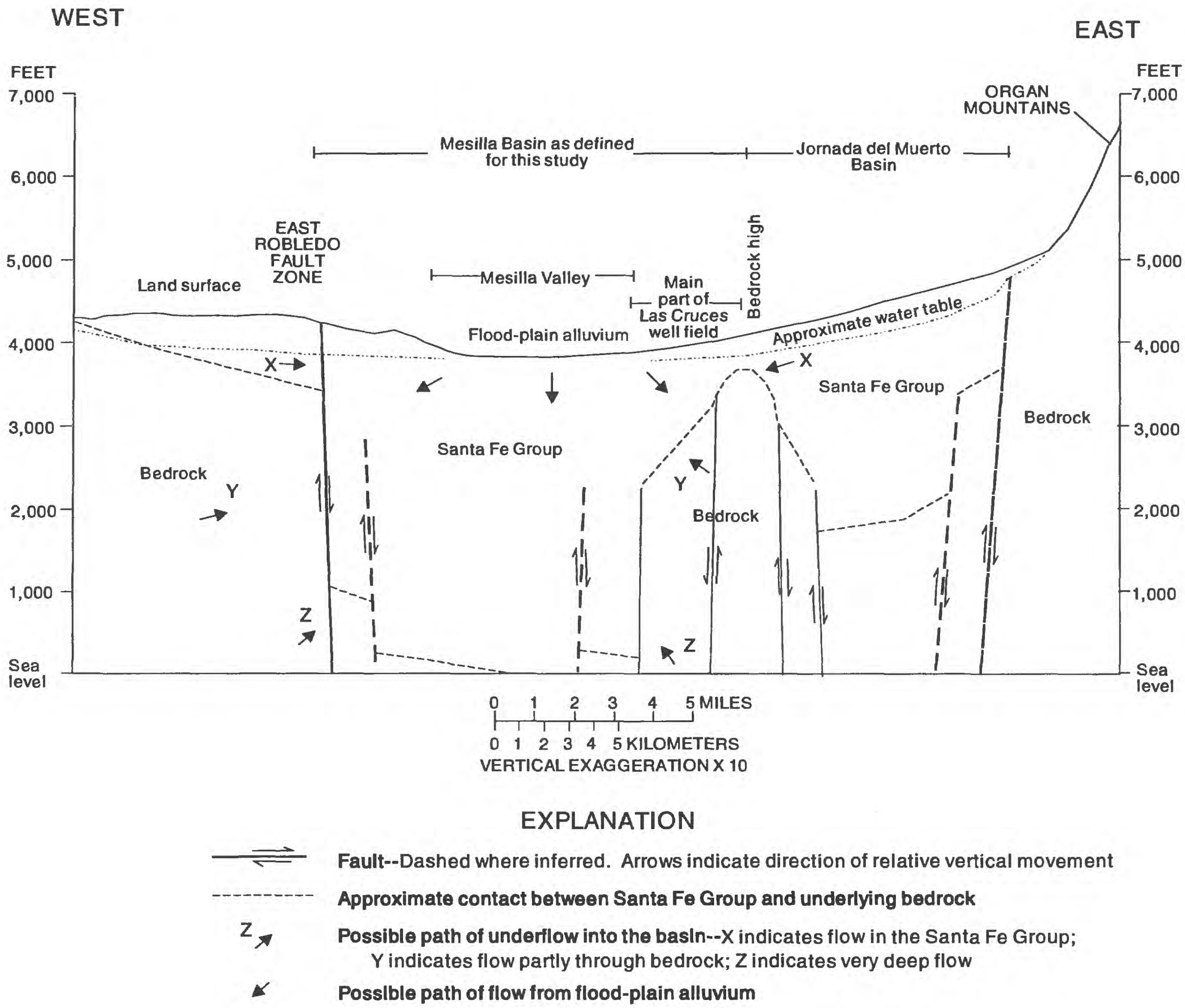


Figure 51.--Buried horst about 4 miles south of U.S. Highway 70 (from section A-A' in Frenzel and Kaehler, 1992). Trace of section shown in figure 2.

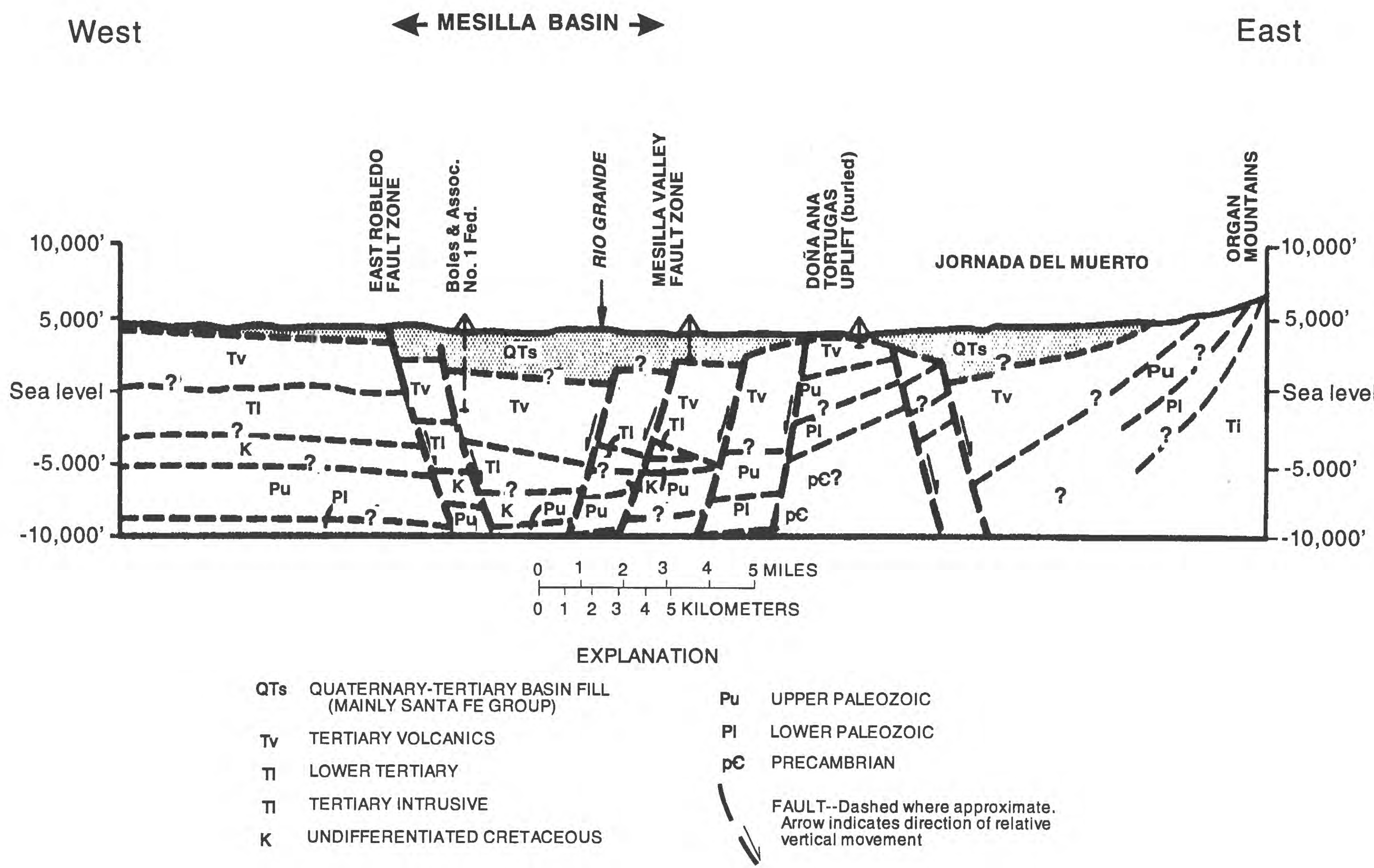
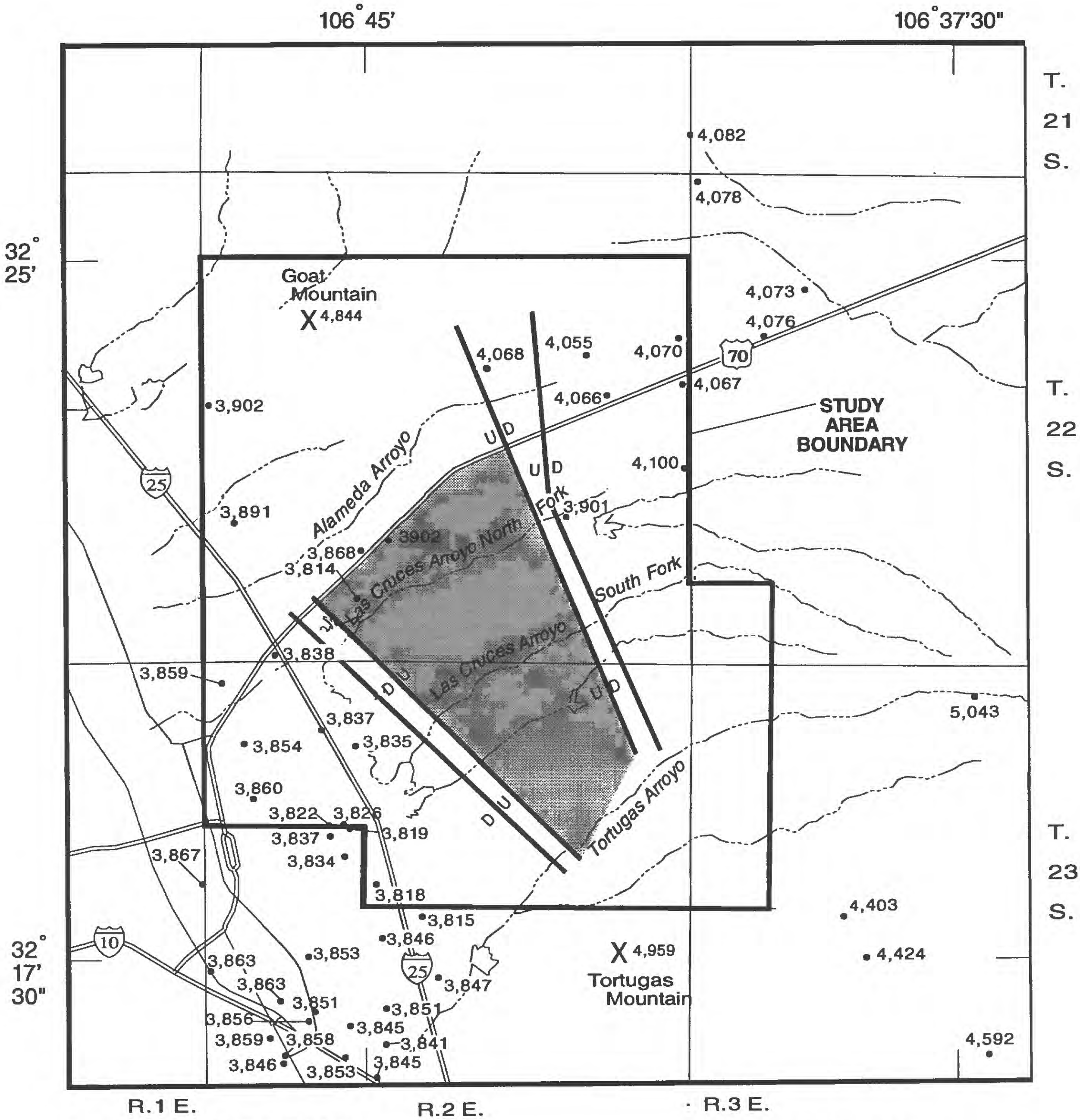


Figure 5J.--Buried horst east of Las Cruces (modified from Hawley and Lozinsky, 1992). Trace of section shown in figure 2.



Base map from USGS digital data, scales 1:100,000 and 1:500,000

0 1 2 3 MILES

0 1 2 3 KILOMETERS

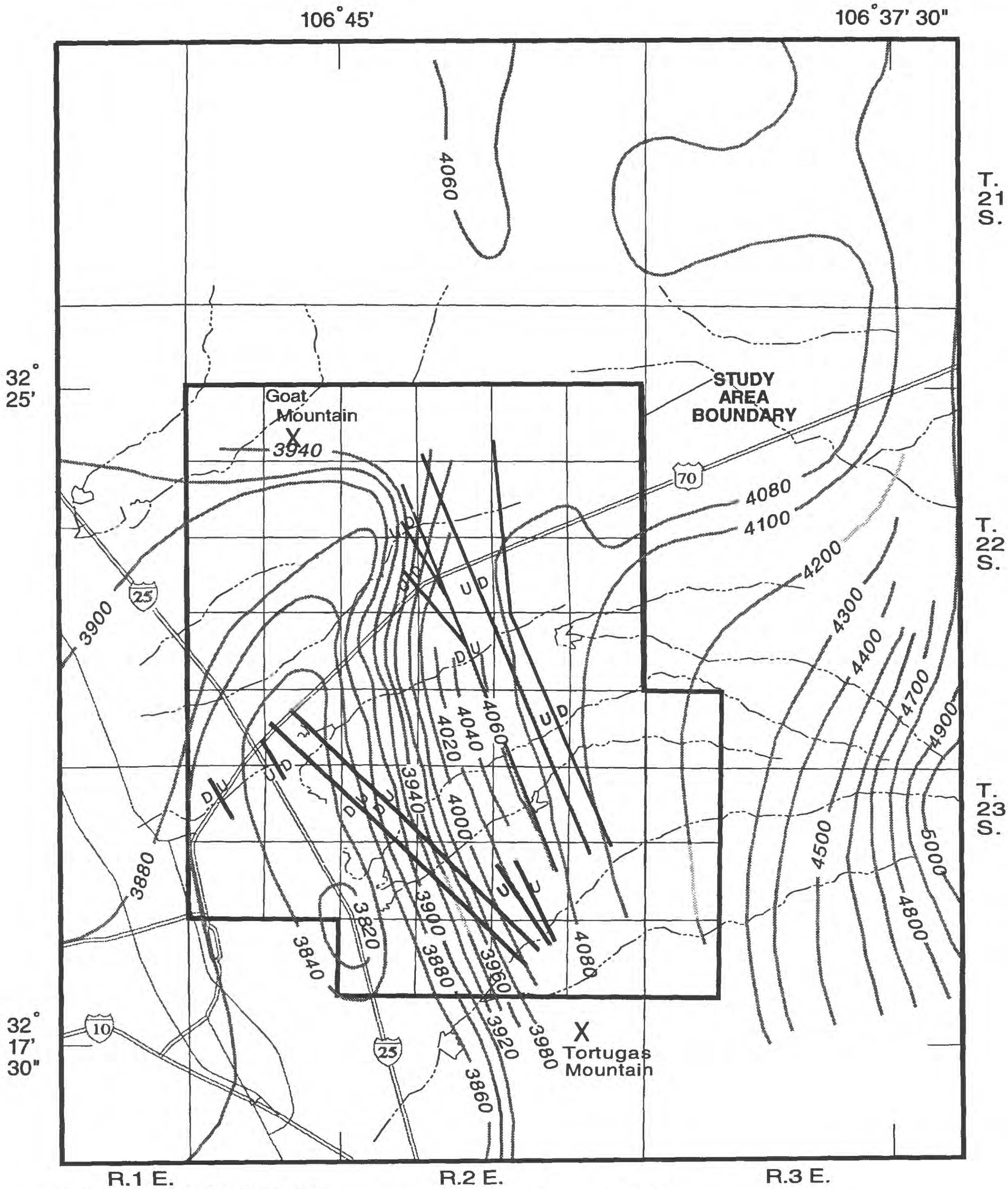
EXPLANATION

HIGHEST AREA OF THE HORST

U D FAULT--Location from seismic interpretation; U, upthrown side; D, downthrown side

• 3,830 WELL OR TEST HOLE--Number is altitude, in feet above sea level, of water table from most recent measurement (1961-94; table 2; Wilson and others, 1981)

Figure 6.--Location and water-table altitude of selected wells and test holes.



Base map from USGS digital data, scales 1:100,000 and 1:500,000

0 1 2 3 MILES

0 1 2 3 KILOMETERS

EXPLANATION

3920 WATER-LEVEL CONTOUR--Intervals 20 and 100 feet. Datum is sea level

U/D FAULT--Location from seismic interpretation. U, upthrown side; D, downthrown side

Figure 7.--Generalized configuration of the water table, 1976 (from Wilson and others, 1981).

Table 1.--Summary of geologic-section information for the Jornada Horst area

[--, no data; Tis, Tertiary intermediate silicic plutonic rocks; QTs, Quaternary and Tertiary sand]

Referenced geologic section	Horst or bedrock high bound by faults?	Description of horst material	Approximate altitude of top of horst above sea level	Relation of water table to horst	Description of material directly above horst
Figure 5A. Section from Hawley and others (1969)	No	Tertiary volcanics	4,060 feet	Coincident with top of horst on east and within horst on west.	Lower alluvial-fan facies in Santa Fe Group
Figure 5B. Section from King and others (1971)	No	Volcanic rock	4,000 feet	Coincident with top of horst on east and within horst on west.	Alluvial-fan facies
Figure 5C. Section from Wilson and others (1981)	Yes	Igneous rock	3,960 feet	Coincident with top of horst.	Sand and gravel
Figure 5D. Section from Wilson and others (1981)	Yes	Volcanic rock	3,750 feet	Water table (1967-76) about 165 feet above top of horst.	Sand and clay
Figure 5F. Section from Hawley (1984)	Yes	Tertiary volcanics	4,000 feet	Water table above horst on east and below on west.	Upper Santa Fe Group
Figure 5G. Section from Hawley (1984)	Yes	Tertiary volcanics	3,700 feet	Water table about 120 feet above top of horst.	Upper Santa Fe Group
Figure 5H. Section from Seager and others (1987)	Yes	Tis	--	Top of horst above land surface.	--
Figure 5I. Section from Frenzel and Kaehler (1992)	Yes	Bedrock	3,750 feet	Water table 160 feet above top of horst.	Santa Fe Group
Figure 5J. Section from Hawley and Lozinsky (1992)	Yes	Tertiary volcanics	--	--	QTs
Figure 12. Seismic sections from this report	Yes	Volcanic rock	4,070 feet	--	Upper Santa Fe Group

1988-89 SEISMIC REFLECTION SURVEY

Charles B. Reynolds and Associates of Albuquerque, New Mexico, recorded four seismic reflection profiles under contract for the USGS during 1988 and 1989; the location of the seismic reflection lines are shown in figure 8. Three of the profiles (A-A', B-B', and C-C') were established perpendicular to the axis of the horst and south of U.S. Highway 70 to locate the highest areas along the axis of the horst. One profile (D-D') was established parallel to the axis of the horst north of U.S. Highway 70 to locate any large, incised, buried arroyo channels (Reynolds, 1989).

Data Collection and Processing

Field instrumentation included a multichannel E.G. & G. Geometrics Nimbus ES1210F seismograph, equipped with frequency filters, and a G724S digital recorder. The geophone array consisted of six Mark Products G-21 10-hertz, gimbal-mounted, self-orienting drag geophones attached to cables towed behind the seismic truck. The seismic energy source was a patented, bounceless weight of 550 pounds dropped 6.5 feet to the ground. The output of each receiver was recorded separately.

The seismic reflection surveys were designed to investigate the subsurface to a depth less than 2,000 feet below land surface (Reynolds, 1989). Field and recording parameters included the following:

(1) The geophones were located at distances of 66, 131, 197, 262, 328, and 394 feet behind the shot (impact) point, and the output of each geophone was recorded separately.

(2) One to three weight drops were made at each shot point, which were located 33 feet apart along the line being recorded.

(3) There were 160 shot points (and subsequent recordings) per mile, resulting in a 600-percent common depth point stacking.

(4) 60-hertz notch filters were used where power lines were close to the seismic line.

(5) The digital record length was 1 second, with a sampling interval of 1 millisecond.

(6) The processing datum selected was land surface.

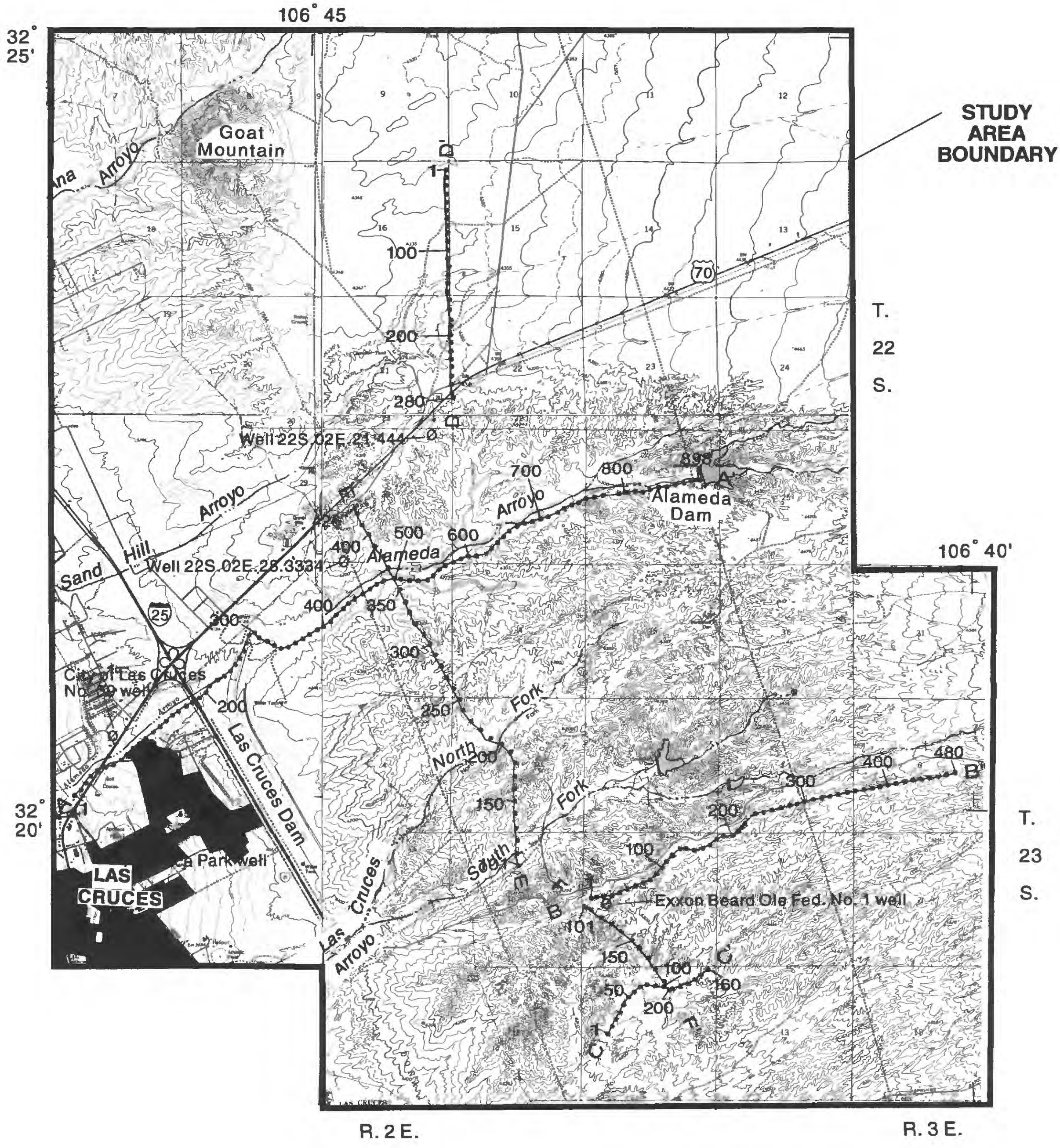
(7) The lines were surveyed and tied to unmarked survey monuments using estimated altitudes from 1:24,000-scale topographic maps for vertical control.

Microcomputer software specifically designed for this system was used to process the seismic data. Processing steps included transcription from the field digital recordings to the computer; reformatting of data to the computer format; verification of data quality and editing; determination of the thickness and velocity of the surface, low-velocity (weathering) layer and the velocity of the subweathering layer by analyzing the refraction returns; application of an F-K filter or velocity filter to remove unwanted "noise" on the recordings; time-variant deconvolution using three operators; 600-percent common depth point stacking; application of datum (static and dynamic) corrections; application of a coherence filter that enhances seismic events dipping less than 20 degrees in either direction; frequency filtering; trace normalization; and variable area-wiggle trace plotting (Reynolds, 1989).

The lengths and mean velocities for profiles A-A', B-B', C-C', and D-D' are:

Seismic profile	Number of shot points	Length of profile (miles)	Mean velocity of surface (weathering) layer (feet per second)	Mean velocity of subweathering layer (feet per second)
A-A'	898	5.61	1,800	3,300
B-B'	480	3.00	2,300	3,600
C-C'	160	1.00	1,800	3,000
D-D'	280	1.75	1,700	2,600

In seismic geophysics, the term "weathering layer" refers to materials at the land surface that have a considerably slower velocity than slightly deeper rocks (Coffeen, 1986). The weathering velocities used in the correction calculations were those measured on each profile, and the replacement (subweathering) velocity used was 3,300 feet per second except on profile D-D', where a velocity of 2,600 feet per second was used. The mean velocities of both layers decreased toward the west on line A-A'.



0 1 MILE
0 1 KILOMETER

EXPLANATION

1 SHOT POINT AND STATION NUMBER

Ø CONTROL WELL --Well subsurface information used
Exxon Beard Ole Fed. No. 1

Figure 8.--Location of the seismic reflection lines.

Data Interpretation

Three geologic boundaries were delineated and traced on the seismic profiles: the base of the upper Santa Fe Group, base of the lower Santa Fe Group (top of the Tertiary volcanics), and base of the Tertiary volcanics. The well control (fig. 8) used by Reynolds (1989) to correlate seismic horizons with geologic boundaries was:

Well	Geologic boundary	Depth, in feet
22S.02E.28.3334	Top of Tertiary volcanics	503
Apodaca Park	Base of upper Santa Fe Group	452
(23S.02E.07.122)	Top of Tertiary volcanics	710
City of Las Cruces No. 39	Base of upper Santa Fe Group	125
(23S.02E.06.240)	Top of Tertiary volcanics	398
Exxon Beard Ole Fed. No. 1	Base of upper Santa Fe Group	167
(23S.02E.11.134)	Top of Tertiary volcanics	476
	Base of Tertiary volcanics	790
22S.02E.21.444	Top of Tertiary volcanics	365

The reflection horizon that correlated with the base of the upper Santa Fe Group, as reported above by Reynolds (1989), was determined by the interpretation of gamma-ray borehole-geophysical logs collected from the three wells listed above. These log picks could possibly represent the base of a facies change within the Camp Rice Formation (upper Santa Fe Group) rather than the base of the upper Santa Fe Group (John Hawley, New Mexico Bureau of Mines and Mineral Resources, oral commun., 1997). Recent well logs (not available at the time of the seismic surveys) show upper Santa Fe Group deposits directly overlying the top and adjacent to the Tertiary volcanics of the upper portion of the Jornada Horst. Geologic interpretation of the seismic profiles in this report modifies the geologic interpretation of the contract geophysicists in that (1) the base of the upper Santa Fe Group in this report does not coincide with the gamma-ray log pick used by the contract geophysicists and (2) the base of the upper Santa Fe Group is assumed to coincide with the top of the Tertiary volcanics.

The interpreted seismic reflection profiles (A-A', B-B', C-C', and D-D') were transformed to geologic sections (figs. 9A-C and 10A) by using a velocity-conversion function developed by Reynolds (1989) for the Jornada del Muerto Basin. This velocity function was calculated by correlating seismic horizons on the profiles to the base of the unconsolidated Tertiary (near top of the Tertiary volcanics) as determined from five wells.

A mean velocity of 9,400 feet per second for a refractor at a depth of 110 feet below land surface was detected at the east end of line B-B' (from stations 315 to 480). Reynolds (1989) interpreted this as a consolidated sandstone, conglomerate, or basalt flow within the upper part of the Santa Fe Group.

1992 SEISMIC REFLECTION SURVEY

Digitec Seismic Corporation of Aurora, Colorado, collected two seismic reflection profiles under contract for the USGS during October 1992. Profiles E-E' and F-F' were located parallel to the axis of the horst south of U.S. Highway 70 (fig. 8) to locate any large, incised, buried arroyo channels (Moriarty, 1992). Both profiles run about northwest to southeast and are separated by about a half mile. Profile E-E' extends from U.S. Highway 70 toward the City of Las Cruces landfill for about 3.1 miles and crosses profile A-A' in Alameda Arroyo. Profile F-F' begins near the City of Las Cruces landfill near the west end of profile B-B' and extends approximately southeast for about 1 mile. Profile F-F' crosses profile C-C'.

Data Collection and Processing

The field instrumentation included a 48-channel Bison Instruments 9048 signal-enhancement seismograph. The geophone array consisted of six Mark Products L-25 30-hertz geophones equally spaced in a line. The seismic energy source was a Bison EWG-3 elastic wave generator, with an accelerated weight drop of 550 pounds.

The seismic reflection surveys were designed to focus on a depth of about 1,200 feet (Moriarty, 1992). Field and recording parameters included the following:

(1) Six geophones were spaced in line 8 feet apart for each recording channel, and the group interval was 50 feet.

(2) Shot points were located 100 feet apart in line, providing a 1,200-percent common depth point stack.

(3) A split spread (24 channels on each side of the shot point), with a two-station gap, resulted in a maximum offset of 1,250 feet.

(4) The record length was 2 seconds, with a sampling interval of 2 milliseconds.

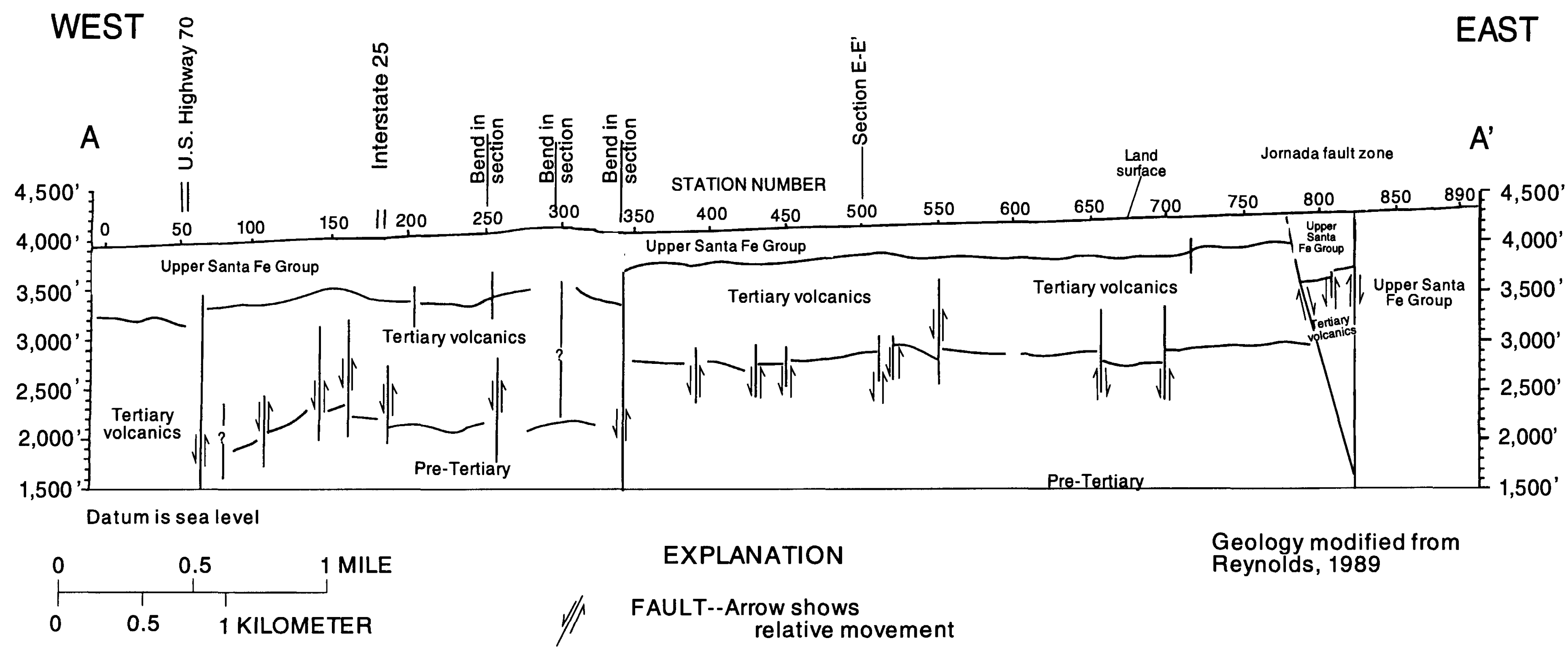


Figure 9A.--Geologic sections derived from interpreted seismic profiles located perpendicular to the axis of the Jornada Horst. Trace of section show in figure 8.

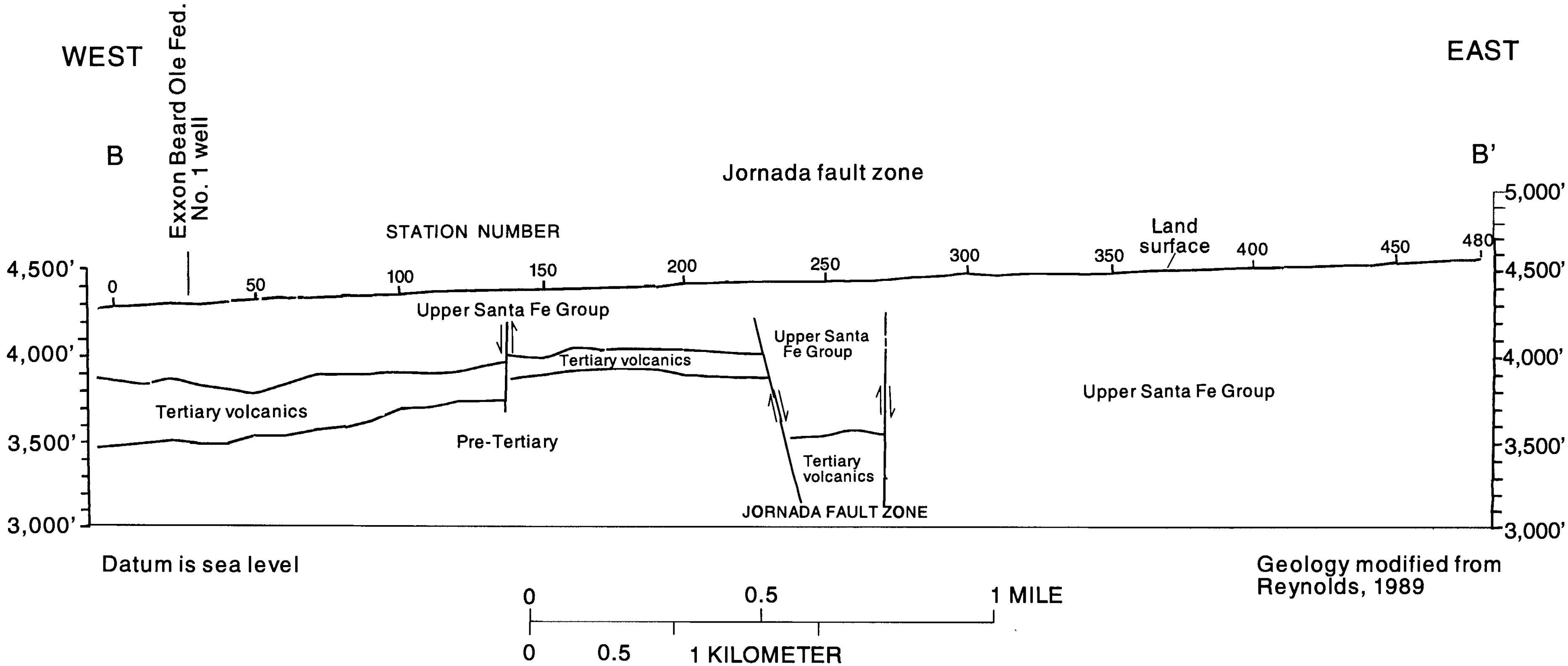


Figure 9B.--Geologic sections derived from interpreted seismic profiles located perpendicular to the axis of the Jornada Horst. Trace of section shown in figure 8--Continued.

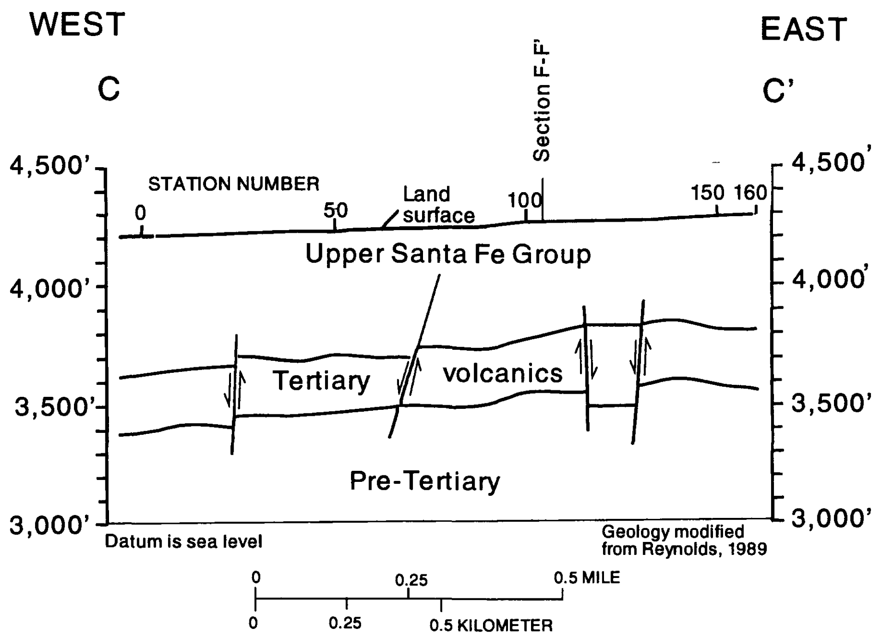


Figure 9C.--Geologic sections derived from interpreted seismic profiles located perpendicular to the axis of the Jornada Horst. Trace of section shown in figure 8--Concluded.

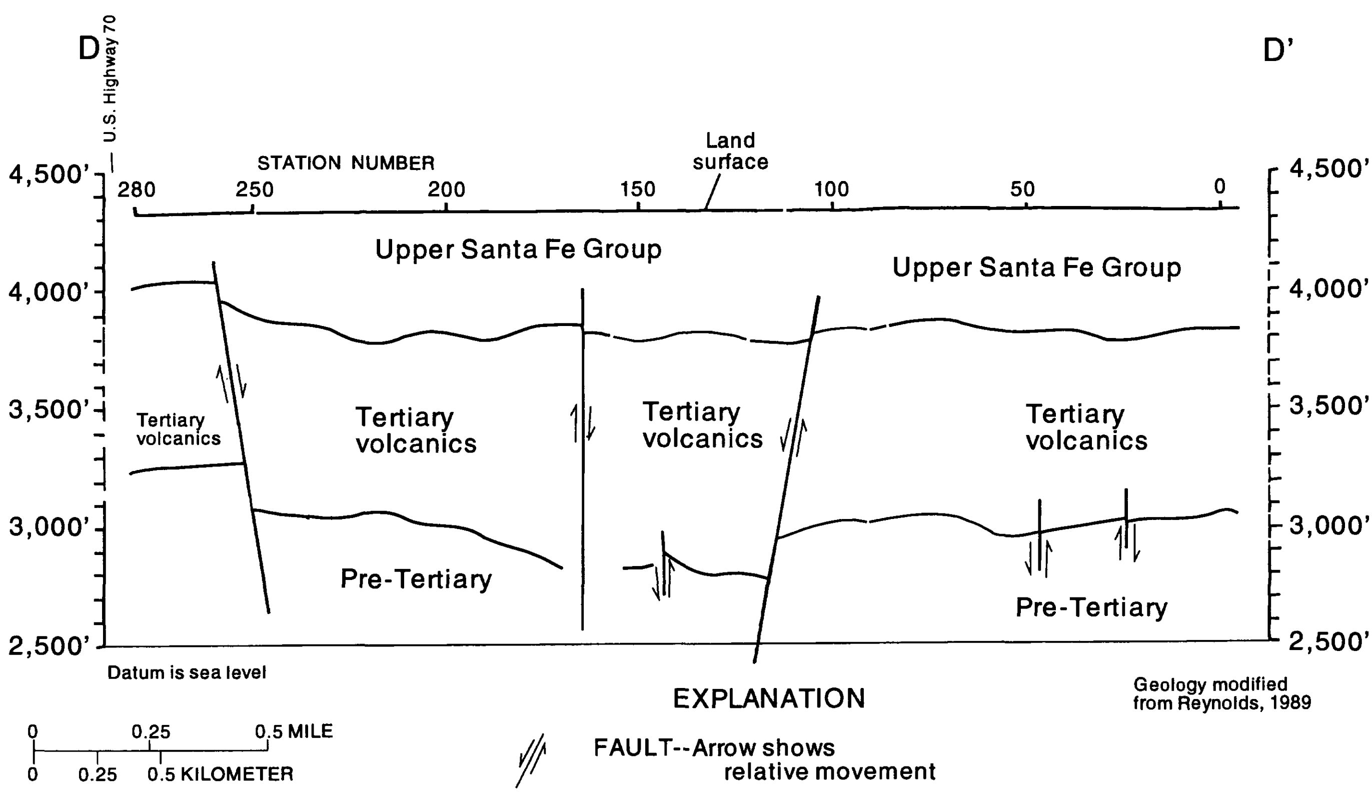


Figure 10A.--Geologic sections derived from interpreted seismic profiles located parallel to the axis of the Jornada Horst. Trace of section shown in figure 8.

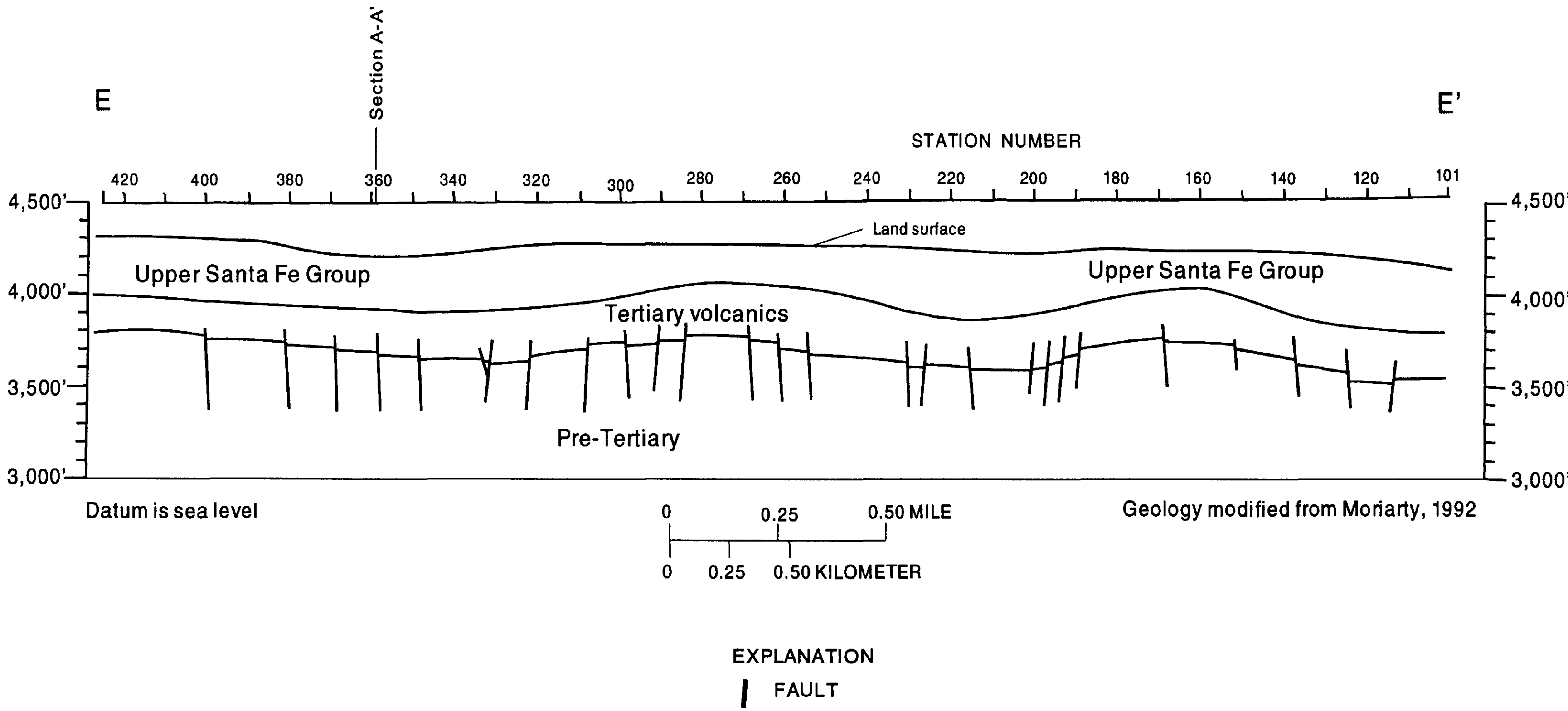


Figure 10B.--Geologic sections derived from interpreted seismic profiles located parallel to the axis of the Jornada Horst. Trace of section shown in figure 8--Continued.

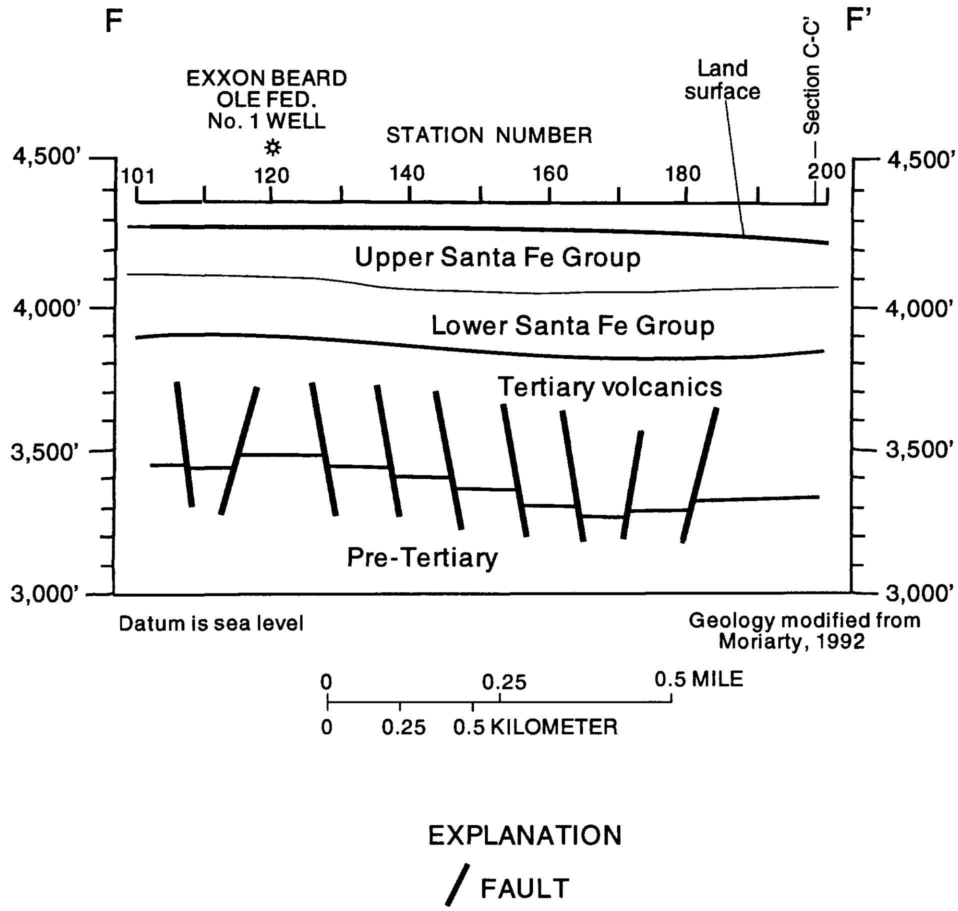


Figure 10C.--Geologic sections derived from interpreted seismic profiles located parallel to the axis of the Jornada Horst. Trace of section shown in figure 8--Concluded.

(5) The processing datum selected was an altitude of 4,300 feet above sea level.
(6) For control, the lines were surveyed and tied to unmarked survey monuments using estimated altitudes from 1:24,000-scale topographic maps.

Seismic processing was completed by H.T. Geophysical of Denver, Colorado. The processing sequence included demultiplexing; trace editing; geometry application; array simulation; spherical divergence and attenuation compensation; pre-deconvolution muting; deconvolution, with surface consistent spiking; datum and refraction statics application; common midpoint sort; spectral equalization; velocity analysis; surface consistent residual statics; velocity analysis; surface consistent residual statics; normal moveout corrections; trim statics; trace balance; common midpoint stack; spectral equalization; F-Y filter; bandpass filter; and trace balance (Moriarty, 1992).

The lengths and mean velocities for profiles E-E' and F-F' are:

Seismic profile	Number of shot points	Length of profile (miles)	Mean velocity of surface (weathering) layer (feet per second)	Mean velocity of subweathering layer (feet per second)
E-E'	325	3.07	3,200	11,000
F-F'	100	0.94	3,200	11,000

The interpreted seismic reflection profiles (E-E' and F-F') were transformed to geologic sections (figs. 10B and C).

Data Interpretation

Due to the long offsets (1,250 feet) and the long shot point interval (100 feet), the shallow layer with a weathering velocity of about 1,700 to 2,300 feet per second (measured in the previously collected profiles; Reynolds, 1989) was not detected during this survey, thus the opportunity to delineate shallow seismic horizons was hampered. Because the continuity of the shallow reflectors was difficult to pick with confidence, Moriarty (1992) selected a deeper seismic horizon as a basis for mapping. According to Moriarty "... the deeper horizon was then 'projected' to shallower elevations."

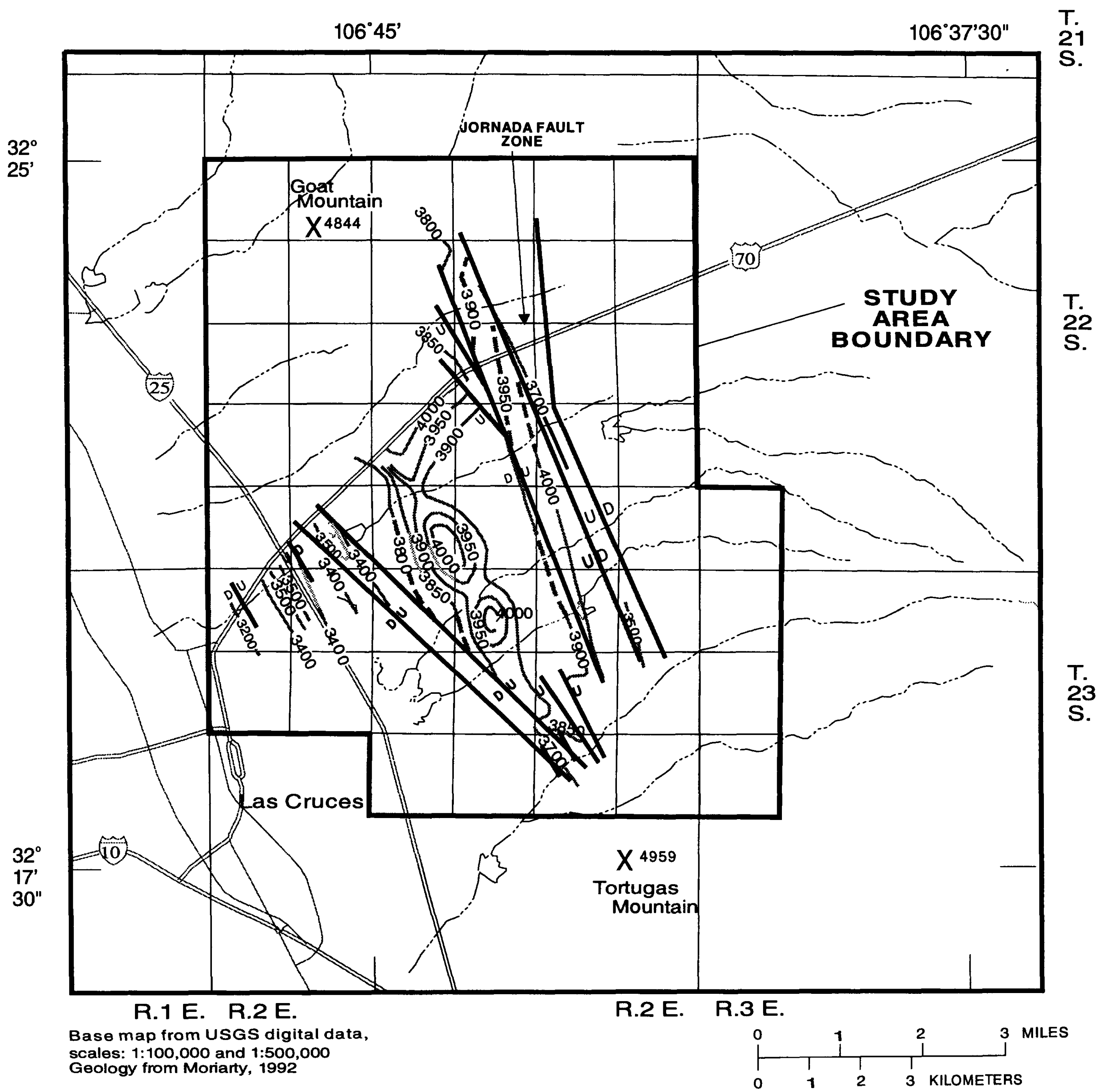
RESULTS OF SEISMIC REFLECTION SURVEYS

Moriarty (1992) integrated the data bases from his 1992 survey and Reynold's 1989 survey, but did not reinterpret the Reynolds (1989) data base. The deeper seismic horizon Moriarty selected was a basis for the geologic sections of lines E-E' and F-F'. A colored seismic section of the amplitude envelope trace attribute was used to follow the faulting patterns to the shallower altitudes in the Tertiary volcanics and the Santa Fe Group (Moriarty, 1992). The thickness of the Tertiary volcanic and volcaniclastic rocks, as reported in the seismic reflection surveys in this report, may vary from 100 to more than 1,000 feet.

The eastern extent of the buried horst has been delineated by interpreted faults shown on profile A-A' (fig. 9A) and profile B-B' (fig. 9B). The Jornada fault zone, which defines the eastern extent of the buried horst, was delineated by the seismic survey (fig. 11). Interpretation of the seismic profiles indicates that the fault zone consists primarily of two normal faults whose traces trend north-northwest; the westernmost fault dips eastward from station 780 on profile A-A' and from station 225 on profile B-B'; and the easternmost fault intersects profile A-A' at station 822 and profile B-B' at station 272 (Reynolds, 1989). The easternmost fault was interpreted to be nearly vertical, to have the greatest vertical displacement, and was presumed to be the master fault in the fault zone.

The western extent of the horst is probably farther west of the study area. The throw of the fault interpreted on profile A-A' at station 65 (fig. 9A) is only about 200 feet on top of the Tertiary volcanics and is too small to be the master fault. Thus, constraints on the western extent of the horst have been determined in that the master fault(s) for the Jornada Horst is west of the study area.

To determine the geometry and altitude of the top of the horst, the geologic sections derived from the interpreted seismic profiles (figs. 9 and 10) were used to pick the top of the Tertiary volcanics for each shot point; the resultant contour map is shown in figure 11. The top of the horst, as depicted from the interpreted seismic profiles, has an irregular surface that has been shaped by a number of faults trending north-northwest (fig. 12).



EXPLANATION

3900 ALTITUDE OF HORST--Dashed where approximate. Interval, in feet, is variable. Datum is sea level

FAULTS--U, upthrown side; D, downthrown side

Figure 11.--Altitude of the top of the Jornada Horst Tertiary volcanics, as determined from the seismic surveys.

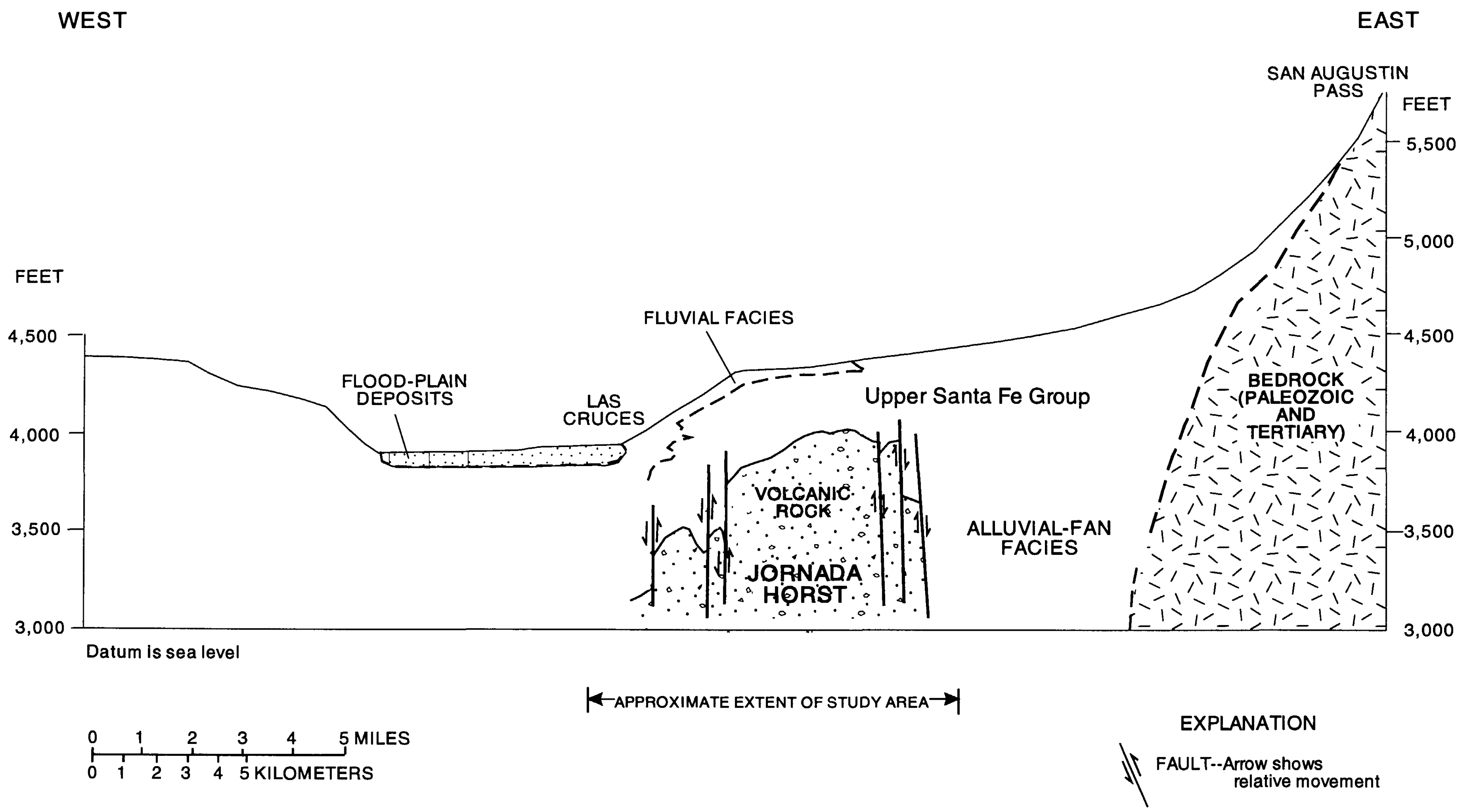


Figure 12.--Buried horst along U.S. Highway 70, as interpreted from the seismic profiles.

The highest parts of the horst appear to be at altitudes of about 4,040 feet at station 160 and about 4,070 feet at stations 270 and 280 on profile E-E' (fig. 10B). Between those highs is a low area at an altitude of about 3,920 feet at stations 210 and 220 (fig. 10B); this interpreted low area on the horst directly underlies the Las Cruces Arroyo North Fork (pl. 1). Another low area is suggested by the interpreted seismic sections at an altitude of 3,910 feet at station 360 on profile E-E' (fig. 10B); this interpreted low area on the horst directly underlies Alameda Arroyo (pl. 1). However, the genesis for these low areas cannot be determined with existing information, and the low areas cannot be concluded to be incised channels. In fact, an argument could be made that the subsurface lows shown on the seismic sections are artifacts of invalid assumptions made in the processing of field records--the weathering layer velocities and thicknesses used in processing may not have been properly adjusted to account for the different surficial materials associated with existing arroyos.

To understand better the potential effect of the Jornada Horst on regional ground-water flow, the interpreted altitude of the top of the horst (from the seismic profiles) has been compared to the water-table altitudes in the area (from Wilson and others, 1981). Ground-water-level data for selected wells and test holes near the study area are compiled in table 2. The resulting map (pl. 1) projects the top of the horst to be higher than the water table in three areas: north of Alameda Arroyo, extending north of U.S. Highway 70; between Alameda Arroyo and the Las Cruces Arroyo North Fork; and a small area between the Las Cruces Arroyo North and South Forks. Although seismic control on the highest part of the horst does not extend north of U.S. Highway 70, the horst probably remains higher than the water table north of the highway; this would account for the apparent "damming" of ground water and the low gradient of the water table east of the horst and north of the highway (pl. 1), as discussed previously.

In summary, the gross geometry of the horst--the eastern extent, constraints on the western extent, and general altitude of the top--was discerned by interpretations of the seismic profiles. The presence or absence of large channels incised into the top of the horst could not be confirmed by those interpretations. The seismic interpretations however, do suggest that the water table is above the top of the horst for most of its extent between U.S. Highway 70 and Tortugas Mountain and that the top of the horst is above the water table and acts as a subsurface flow barrier north of U.S. Highway 70.

SUMMARY AND CONCLUSIONS

Available data indicate that little or no ground water flows from the Jornada del Muerto ground-water basin to the Mesilla ground-water basin over some portions of the Jornada Horst. However, some ground water flows through the upper Santa Fe Group deposits above the horst. Six seismic reflection profiles were collected in the vicinity of the Jornada Horst between Goat Mountain and Tortugas Mountain near Las Cruces, New Mexico, to determine more precisely the geometry of the horst and to determine whether large, buried channels have been incised into the top of the horst. Incised, buried channels, if present on the horst, could be filled with alluvial material with higher hydraulic-conductivity values than those of the material in the horst. Incised, buried channels would allow ground water to readily move from the Jornada del Muerto ground-water basin to the Mesilla ground-water basin.

The upper part of the Jornada Horst is composed of Tertiary volcanic and volcaniclastic rocks; these rocks overlie Permian sedimentary rocks. The horst, in turn, is overlain by unconsolidated sediments of the upper Santa Fe Group as thick as at least 250 feet. Ground-water flow immediately east of the horst near U.S. Highway 70 is deflected northward in the southern Jornada del Muerto ground-water basin presumably because of the change from higher hydraulic-conductivity values of the aquifer materials in the southern basin to lower hydraulic-conductivity values of the materials in the horst.

The gross geometry of the horst--eastern extent, constraints on the western extent, and general altitude of the top--was discerned by interpretations of the seismic profiles. The presence or absence of large channels incised into the top of the horst could not be confirmed by those interpretations. However, the seismic interpretations suggest that the water table is above the top of the horst for most of its extent between U.S. Highway 70 and Tortugas Mountain and that the top of the horst is above the water table and acts as a subsurface flow barrier north of U.S. Highway 70.

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area

[--, no data; R, recently pumped well; P, pumping

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
21S.02E.25.344	322645	1064128	--	--	--	291.02	02-19-82	--	--
21S.03E.19.333	322742	1064055	--	--	--	312.88	02-19-82	--	--
21S.03E.19.343	322737	1064041	382	--	--	334.92	01-18-82	--	--
21S.03E.19.444	322740	1063957	529	01-01-70	4,477.00	393.72	03-21-73	--	4,083.28
						392.70	09-09-76	--	4,084.30
						392.78	11-21-78	--	4,084.22
21S.03E.31.131	322631	1064057	--	--	--	334.09	02-19-82	--	--
21S.03E.31.311	322619	1064054	375	01-01-36	4,420.00	337.83	11-20-78	--	4,082.17
						338.36	02-19-82	--	4,081.64
21S.03E.31.412	322618	1064011	515	--	--	390.76	02-19-82	--	--
22S.02E.11.344	322411	1064228	--	--	4,384.00	318.35	02-14-84	--	4,066
						321.06	02-15-89	--	4,063
						328.95	02-15-94	--	4,055
22S.02E.13.2222	322410	1064057	617	07-16-79	4,465	396	07-16-79	--	4,069
						395.19	02-19-82	--	4,070
22S.02E.13.313	322332	1064157	--	--	4,430.00	349.85	12-16-76	--	4,080.15
						349.76	02-17-77	--	4,080.24
						349.65	01-23-78	--	4,080.35
						350.42	02-02-79	--	4,079.58
						350.89	01-11-80	--	4,079.11
						355.36	03-11-81	--	4,074.64
						355.87	02-15-89	--	4,074.13
						364.24	02-15-94	--	4,065.76
22S.02E.13.411	322342	1064220	548	--	--	393.23	02-19-82	--	--
22S.02E.13.443	322316	1064110	670	01-01-59	4,475.00	408.1	06-03-75	R	4,066.9

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Continued

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
22S.02E.15.142	322352	1064334	--	01-01-65	4,353.00	278.64	03-19-73	--	4,074.36
						279.2	03-16-76	--	4,073.8
						279.02	12-10-76	--	4,073.98
						305.28	02-18-82	--	4,047.72
						280.00	02-14-84	--	4,073.00
						281.55	02-16-89	--	4,071.45
						285.09	02-15-94	--	4,067.91
22S.02E.18.331	322325	1064700	400	01-01-66	4,230.00	328.40	06-11-76	--	3,901.60
22S.02E.24.422	322246	1064058	1,140	01-01-73	4,481.00	397.40	08-31-73	--	4,083.60
						383.34	10-19-73	--	4,097.66
						381.43	03-14-74	--	4,099.57
						381.11	01-28-75	--	4,099.89
						380.9	03-31-76	--	4,100.1
22S.02E.26.124	322214	1064228	93.0	01-01-47	3,915.00	19.35	05- -72	P	3,895.65
						13.68	01-09-76	--	3,901.32
22S.02E.28.134	322202	1064445	480	--	4,320.00	417.00	03-28-73	--	3,903.00
						417.10	12-10-76	--	3,902.90
						417.84	02-17-77	--	3,902.16
						417.41	01-23-78	--	3,902.59
						417.86	02-02-79	--	3,902.14
						417.95	01-11-80	--	3,902.05
						417.00	03-11-81	--	3,903.00
						424.74	03-12-82	--	3,895.26
						418.17	02-14-84	--	3,901.83
22S.02E.29.424	322148	1064502	514	- -63	4,288	420	04-23-65	--	3,868

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Continued

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
22S.02E.30.123	322210	1064640	294	02-01-76	4,100.00	209.02	03-15-76	--	3,890.98
22S.02E.31.444	322045	1064609	596	01-01-66	4,068.00	217.00	01-01-65	--	3,851.00
						237	03-10-72	--	3,831
						277.4	10-18-72	P	3,790.6
						273.7	03-29-73	--	3,794.3
						289	10-16-73	P	3,779
						280.7	03-19-74	P	3,787.3
						227.72	10-11-74	--	3,840.28
						286	02-25-75	P	3,782
						225.6	03-22-75	--	3,842.4
						224.84	10-07-76	--	3,843.16
						227.35	10-07-77	--	3,840.65
						220.73	02-21-78	--	3,847.27
						221.17	03-06-79	--	3,846.83
						229.48	01-15-92	--	3,838.52
						230.16	02-03-93	--	3,837.84
22S.03E.06.111 JORNADA N	322548	1064057	--	09-03-76	4,430	350.00	09-04-76	--	4,080
						352.31	09-05-76	--	4,078
22S.03E.07.444	322410	1063958	564	--	4,528.00	424.00	12-22-67	--	4,104.00
						451.63	03-01-72	--	4,076.37

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Continued

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
22S.03E.07.444	322410	1063958	564	--	4,528.00	452.24	12-12-72	--	4,075.76
						452.07	03-20-73	--	4,075.93
						451.63	03-01-74	--	4,076.37
22S.03E.08.144	322440	1063927	590	01-01-73	4,555.00	480.40	04-10-73	--	4,074.60
						479.5	08-02-73	--	4,075.5
						481.26	12-14-76	--	4,073.74
						481.92	11-27-78	--	4,073.08
23S.02E.05.342	321956	1064537	--	--	--	236.79	07-16-91	--	--
23S.02E.05.342 (LC-28)	321957	1064534	751	02- -71	4,063.00	219.64	03-10-72	--	3,843.36
						223.96	10-18-72	--	3,839.04
						218	03-29-73	--	3,845
						332.5	10-02-73	P	3,730.5
						227.93	03-19-74	--	3,835.07
						233.16	10-11-74	--	3,829.84
						223	02-25-75	--	3,840
						228.6	10-06-75	--	3,834.4
						226.21	03-24-76	--	3,836.79
						230.6	10-06-76	--	3,832.4
						221.06	02-15-77	--	3,841.94
						223.36	10-07-77	--	3,839.64

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Continued

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
23S.02E.05.342 (LC-28)	321957	1064534	751	02- -71	4,063.00	221.08	02-21-78	--	3,841.92
						326.2	03-06-79	P	3,736.8
						236.79	07-16-91	--	3,826.21
						222.88	01-15-92	--	3,840.12
						226.11	02-03-93	--	3,836.89
23S.02E.07.122 (LC-11)	321948	1064632	360	--	3,944.00	77.00	01-01-65	--	3,867.00
						88.27	03-10-72	R	3,855.73
						89.55	10-18-72	--	3,854.45
						88.74	03-28-73	--	3,855.26
						97.68	09-26-73	--	3,846.32
						95.83	03-19-74	--	3,848.17
						96.4	05-28-74	--	3,847.6
						91.69	10-11-74	--	3,852.31
						90.96	02-25-75	--	3,853.04
						93.6	10-06-75	--	3,850.4
						92.42	03-24-76	--	3,851.58
						95	10-06-76	--	3,849
						89.85	01-27-77	--	3,854.15
						91.67	02-15-77	--	3,852.33
						93.65	10-06-77	--	3,850.35

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Continued

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
23S.02E.07.122	321948	1064632	360	--	3,944.00	88.13	02-21-78	--	3,855.87
(LC-11)						93.85	03-06-79	--	3,850.15
						96.51	07-16-91	--	3,847.49
						88.35	01-15-92	--	3,855.65
						89.65	02-03-93	--	3,854.35
23S.02E.07.411									
(LC-10)	321913	1064625	381	06- -51	3,935.00	76.74	03-10-72	--	3,858.26
						78.81	10-18-72	--	3,856.19
						76.81	03-28-73	--	3,858.19
						80.82	09-26-73	--	3,854.18
						79.49	03-19-74	--	3,855.51
						78.91	10-11-74	--	3,856.09
						76.15	02-25-75	--	3,858.85
						75.9	03-17-75	--	3,859. 1
						136.9	03-18-75	P	3,798.1
						116	03-19-75	P	3,819
						78.8	10-06-75	--	3,856.2
						78.28	03-24-76	--	3,856.72
						116.9	10-06-76	P	3,818.1
						76.83	01-27-77	--	3,858.17
						77.23	02-15-77	--	3,857.77

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Continued

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
23S.02E.07.411 (LC-10)	321913	1064625	381	06- -51	3,935.00	79.69	10-07-77	--	3,855.31
						77.97	02-21-78	--	3,857.03
						79.95	03-06-79	--	3,855.05
						73.84	01-15-92	--	3,861.16
						75.20	02-03-93	--	3,859.80
23S.02E.08.224	321947	1064508	550	07-01-73	4,113.00	284	07- -73	--	3,829
						326.4	09-26-73	P	3,786.6
						274.55	03-21-74	--	3,838.45
						278.41	02-14-84	--	3,834.59
23S.02E.08.433	321856	1064528	--	01-01-60	4,036.00	192.00	01-01-61	--	3,844.00
						198.11	03-10-72	--	3,837.89
						203	10-18-72	--	3,833
						196.87	03-29-73	--	3,839.13
						201.72	10-11-74	--	3,834.28
						197.48	02-25-75	--	3,838.52
						199.40	03-23-75	--	3,836.60
						205.50	10-06-75	--	3,830.50
						205.5	10-06-76	--	3,830.5
						198.93	02-15-77	--	3,837.07
						202.50	10-07-77	--	3,833.50

Table 2.--Well-construction and water-level data for selected wells and test holes near the study area--Concluded

Local well number	Latitude	Longitude	Depth of well (feet)	Date well constructed	Altitude of land surface (feet)	Water level (feet)	Water-level date	Water-level status	Altitude of water table (feet)
23S.02E.08.433	321856	1064528	--	01-01-60	4,036.00	198.59	02-21-78	--	3,837.41
						209.89	03-06-79	--	3,826.11
23S.02E.08.443	321855	1064513	352	05-01-47	4,052.00	217.82	03-10-72	--	3,834.18
						221.35	10-18-72	--	3,830.65
						216.84	03-29-73	--	3,835.16
						221.65	04-30-73	R	3,830.35
						224.2	05-31-73	R	3,827.8
						226.90	06-28-73	R	3,825.10
						228.35	08-01-73	--	3,823.65
						233.17	08-31-73	--	3,818.83

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