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BULLETIN 6110

GROUND-WATER RECONNAISSANCE OF THE MARFA AREA, PRESIDIO COUNTY, TEXAS

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GROUND-WATER RECONNAISSANCE OF THE MARFA AREA, PRESIDIO COUNTY, TEXAS

ABSTRACT

The Marfa area consists of about 350 square miles in the northeast corner of Presidio County. The area is part of the erosional remnant of the Davis Mountains volcanic field. The principal water-bearing rocks in the Marfa area are found in a thick succession of volcanic extrusive rocks consisting of tuff, related sediments, and intercalated lava flows of Tertiary age. The Tascotal formation of Goldich and Seward (1948) is the most productive aquifer in the Marfa area, yielding as much as 1,200 gallons per minute to some wells. Small to moderate quantities of water are obtained locally from the Rawls basalt of Goldich and Seward (1948). Except in areas of faulting, the Rawls basalt has a moderate to low permeability. Alluvial deposits in the Marfa area are poorly sorted, contain caliche, and have a low permeability. The alluvium generally supplies small quantities of water for stock and domestic wells, although locally it may produce large quantities.

Ground water occurs under both water-table and artesian conditions in the Marfa area. It moves southwestward from the vicinity of the range of mountains at the east edge of the area, thence southward, paralleling Alamito Creek, toward the Rio Grande.

The ground water in the area is derived from local precipitation. The steep stream gradients and sparse vegetation of the mountainous part of the area allow rapid runoff, and only a small percentage of the water reaches the water table.

Ground water discharges principally by subsurface flow into adjacent areas toward the south. Annual discharge of water from wells in the Marfa area is estimated at 900 acre-feet, which is about a tenth of the total ground-water recharge. Ground-water pumping has caused no appreciable decline in the water table.

The chemical quality of the water of the area makes it suitable for most purposes. The fluoride content, however, is slightly in excess of generally accepted standards, and the silica content is excessive.

The area that appears most favorable for additional ground-water development extends from U. S. Highway 90 southward to the Santa Fe Railroad, and from U. S. Highway 67 eastward to the Antelope Springs ranch road. Well logs and surface exploration indicate that one or more of the three principal aquifers underlie this area.

GROUND-WATER RECONNAISSANCE OF THE MARFA AREA, PRESIDIO COUNTY, TEXAS

INTRODUCTION

Purpose and Scope of Investigation

The inadequacy of ground-water supplies in the vicinity of Alpine, Brewster County, Texas, to meet the increasing demands of an expanding community emphasized the need for an investigation of the ground-water resources of adjoining areas. Consequently, a reconnaissance of the Marfa area was made to determine the source, occurrence, availability, and quality of the ground water. The investigation was made by the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers and the Commissioners' Court of Brewster County.

The study was carried out under the general supervision of A. N. Sayre and P. E. LaMoreaux, successive chiefs of the Ground Water Branch, U. S. Geological Survey, and under the direct supervision of R. W. Sundstrom, district engineer in charge of ground-water investigations in Texas.

Previous Investigations

Previous ground-water investigations in the Marfa area have been limited in scope; they have been confined to small areas or specific problems and are inadequate for a comprehensive program of ground-water exploration.

Bennett (1941) studied the area in the immediate vicinity of Marfa. He concluded that the ground-water supply at Marfa was not overpumped and that additional supplies could be developed.

George and Livingston (1943) summarized the ground-water conditions in the vicinity of the Marfa Army Flying School. They suggested that additional wells should be drilled west of the airfield.

Lang (1943) reported on the results of a pumping test on a well at the Marfa Army Flying School.

Littleton and Audsley (1957) described the ground-water geology of the Alpine area. Their geologic mapping extended about 2 miles into Presidio County and is shown only slightly changed on figure 3 of this report.

Methods of Investigation and Acknowledgments

Field studies in the Marfa area were started in the fall of 1958 and were continued until the summer of 1959. The Marfa area, as defined in this report, includes approximately 350 square miles in the northeast corner of Presidio County. The area is bounded on the north by the Jeff Davis County line, on the east by the Brewster County line, on the south by the 30th parallel, and on the west by a north-south line drawn through a point about 3 miles west of Marfa (figure 1).

The geology of 324 square miles of the area was mapped on aerial photographs, the geology of the remaining 26 square miles being taken primarily from the work of Littleton and Audsley (1957). Data obtained from an inventory of 111 wells in the area are shown in table 3, and logs of 12 wells are given in table 4.

The altitudes of 99 wells were determined by aneroid barometer; the altitudes of 11 wells were interpolated from contours of the topographic map of the Fort Stockton quadrangle.

Appreciation is expressed to the ranchers who furnished information on well locations and permitted entry to their ranches. Special thanks are due Mr. H. S. Hanson and Mr. C. E. King, geologists of the Department of Geology, Sul Ross College, for information on the geology of the area.

Well-Numbering System

The wells in the Marfa area are numbered according to their locations within Presidio County. The county has been divided into 10-minute quadrangles which are lettered alphabetically beginning in the northwest corner of the county. Wells within a quadrangle are numbered consecutively beginning in the northwest corner of the quadrangle. For example, well R-1 is in the northwest corner of quadrangle R.

GEOGRAPHY

Topography and Drainage

The Marfa area occupies approximately 350 square miles of the Marfa plateau which lies in the southwestern part of the Davis Mountains volcanic field. The plateau is bordered on the south, east, and north by escarpments formed largely by silicic and tuffaceous volcanic rocks and intrusive syenite bodies. A broken line of hills capped by basalt partly borders the plateau south of Marfa.

Erosion on the Marfa plateau has reduced most of the upper volcanic rocks to a nearly flat surface, on which a thin mantle of alluvium has been deposited by ephemeral streams. The resultant surface is comparatively flat and featureless, but locally is characterized by broad, gentle hills and shallow depressions or playa lakes. The plateau slopes generally southwestward toward Alamito Creek.

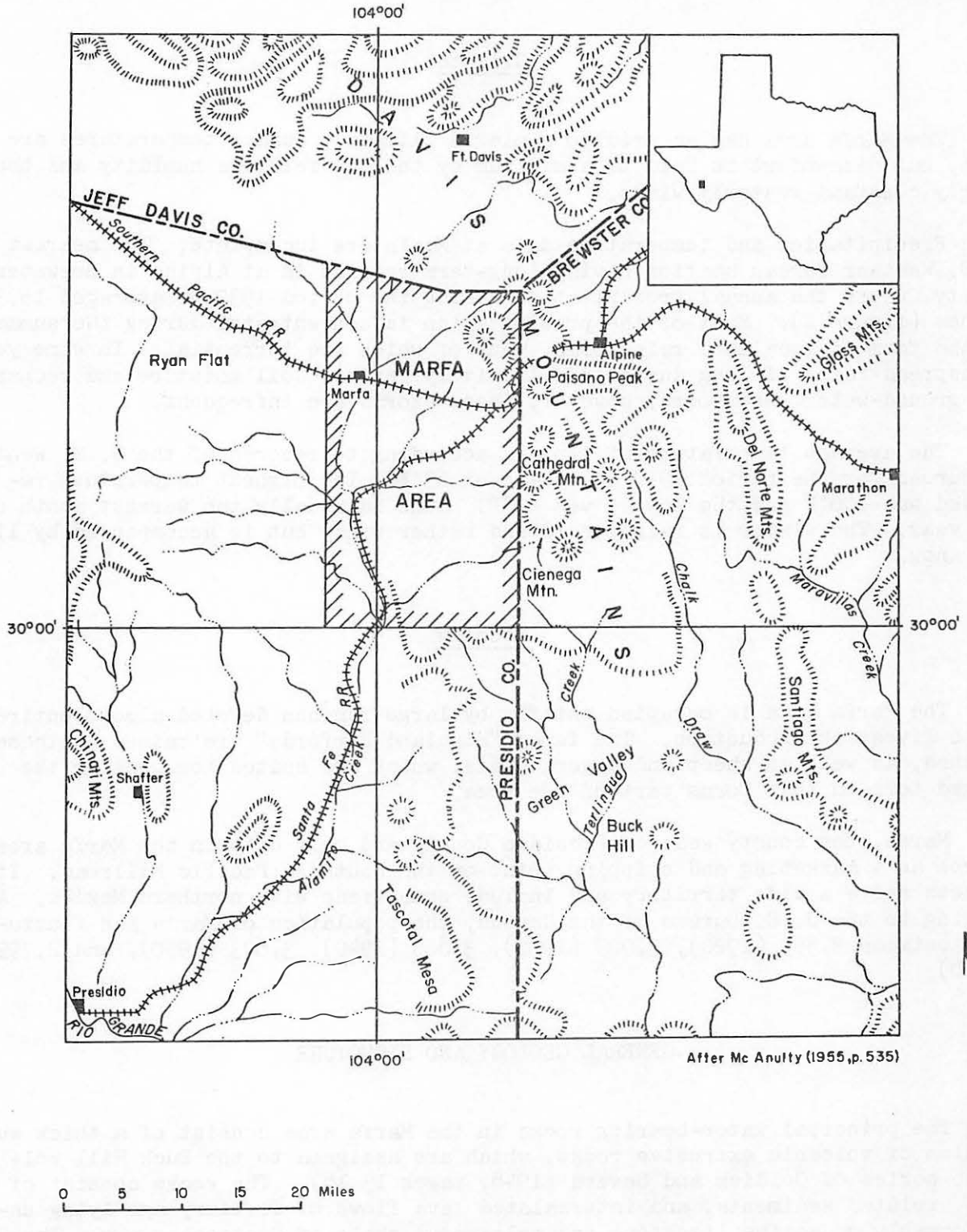


FIGURE 1.– Map of part of Texas showing location of Marfa area

Most of the Marfa area is drained by shallow gullies that join at various points along the west side of the area to form Alamito Creek, an ephemeral stream. Alamito Creek traverses the entire length of Presidio County and drains into the Rio Grande. The northeast edge of the Marfa area is drained by gullies that carry runoff toward the east and northeast into the Pecos River basin.

Climate

The Marfa area has an arid to semiarid climate. Summer temperatures are high, but discomfort is held to a minimum by the low relative humidity and the nearly constant westerly winds.

Precipitation and temperature data at Marfa are incomplete. The nearest U. S. Weather Bureau station having long-term records is at Alpine in Brewster County, where the annual precipitation during the period 1930-58 averaged 15.37 inches (figure 2). Most of the precipitation is concentrated during the summer in the form of localized rainstorms, many of which are torrential. In some years widespread rains of long duration effectively restore soil moisture and recharge the ground-water reservoirs; however, these storms are infrequent.

The average temperature at Alpine, according to records of the U. S. Weather Bureau for the period 1930-58, is about 63°F. The highest temperature recorded was 106°F and the lowest was -2°F. June is usually the warmest month of the year. The winter is fairly cold and rather windy but is accompanied by little snow.

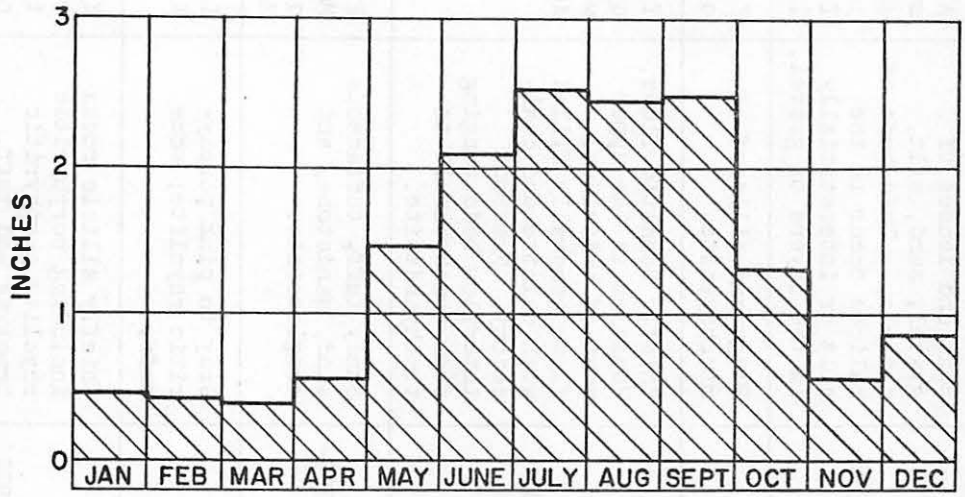
Economy

The Marfa area is occupied chiefly by large ranches devoted almost entirely to livestock production. The famed "Highland Herfords" are raised on these ranches, as well as sheep and angora goats, which are suited for grazing the rugged terrain that forms part of the area.

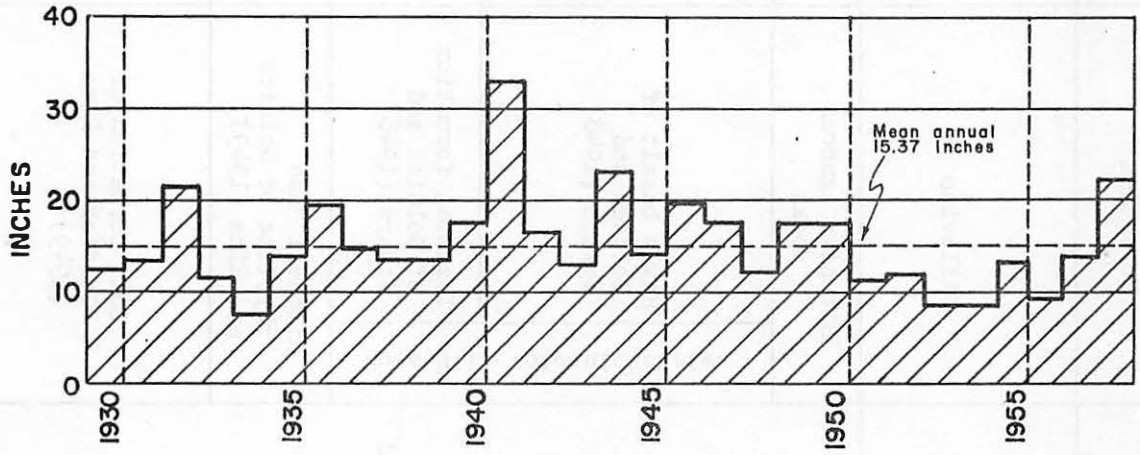
Marfa, the county seat of Presidio County and only city in the Marfa area, serves as a marketing and shipping point on the Southern Pacific Railroad. Its markets serve a wide territory and include some trade with northern Mexico. According to the U. S. Bureau of the Census, the population of Marfa has fluctuated between 3,553 (1920), 3,909 (1930), 3,805 (1940), 3,603 (1950), and 2,799 (1960).

GENERAL GEOLOGY AND STRUCTURE

The principal water-bearing rocks in the Marfa area consist of a thick succession of volcanic extrusive rocks, which are assigned to the Buck Hill volcanic series of Goldich and Seward (1948, pages 13-18). The rocks consist of tuff, related sediments, and intercalated lava flows of Tertiary age lying unconformably on marine limestone and calcareous shale of Cretaceous age. The volcanic rocks are overlain in most places by a veneer of alluvium of Pleistocene and Recent age. Table 1 summarizes the lithology and water-bearing characteristics of the rocks exposed in the Marfa area; figure 3 shows the outcrop areas of the various formations.



Long-term mean monthly precipitation



Annual precipitation, 1930-58

FIGURE 2.—Precipitation at Alpine, Brewster County
(From records of U.S. Weather Bureau)

Table 1.--Rocks exposed in the Marfa area

System	Epoch or series	Formation		Thickness (feet)	Physical characteristics	Water-bearing characteristics
Quaternary	Recent and Pleistocene	Alluvium		0 - 390	Beds and lenses of gravel, sand, silt, and clay. Thin beds of caliche occur in the silt or interstitially in the layers of gravel.	Above water table in much of area. Yields small supplies of water in western part of area. Yields large quantities locally.
Tertiary	Oligocene and younger(?)	Intrusive igneous rocks		-	Plugs and sills of microsyenite.	Yields small quantities of water from fractures.
		Buck Hill volcanic series	Rawls basalt of Goldich and Seward (1948)	0 - 120	Chiefly basaltic flows. Vesicles in the upper part of individual flows generally filled with calcite and chalcedony. Numerous interflow beds ranging from trachybasalt to trachyandesite.	Yields small to moderate quantities of water to wells for stock and domestic use.
			Tascotal formation of Goldich and Seward (1948)	0 - 707+	Sandy tuff, tuffaceous sand, sandstone, and conglomerate.	Principal aquifer in the Marfa area. Yields large quantities of water at Marfa and Tinaja.
		Mitchell Mesa rhyolite of Goldich and Elms (1949)		-	Gray to pink porphyritic rhyolite; some tuff.	Lies above water table in most places.
		Duff formation of Goldich and Elms (1949)		0 -1,500	Chiefly silicic rocks including porphyritic rhyolite porphyritic trachyte and tuff. Also contains tuffaceous clay, silt, sandstone, and conglomerate.	Yields small quantities of water for stock wells in eastern and southern parts of the area.

Local beds of fresh-water limestone and stratification of the tuff beds suggest that most of the sediments of the volcanic series were deposited in basins. Sources of the volcanic ash and lavas have not been determined.

After deposition of the Buck Hill volcanic series, local doming and faulting of the beds were caused by the intrusion of syenite masses. These intrusive bodies, which form the core of the Davis Mountains, crop out along the east edge of the Marfa area where the older extrusive rocks have been removed by erosion.

South of the Marfa area is a broad northwestward-plunging anticline with which is associated a system of northwest-trending faults some of which extend into the Marfa area (Goldich, Elms, and Seward, 1949, page 68). One of the largest structural features associated with the faults is a graben underlying the valley of Alamito Creek south of Alamito Lake (figure 3). The northeast wall of the graben is formed by the Santa Fe fault scarp.

The logs of several wells indicate that another large fault block or graben underlies the area extending from the vicinity of Marfa to the Antelope Springs ranch road. Alluvium deposited by streams draining into the area has filled the valley formed by this depressed block, thus creating an important recharge area.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Marine Sedimentary Rocks

Marine sedimentary rocks do not crop out in the Marfa area. Their stratigraphic position in the subsurface can be inferred only from exposures in adjoining areas and from logs of oil tests. The Argo Oil Corp. drilled an oil test (Z-5) 24 miles southeast of Marfa, penetrating rocks of Cretaceous age at 3,000 feet, Permian rocks at 3,600 feet, and Pennsylvanian rocks at 7,620 feet (table 4). Later deepening of the hole to 15,230 feet failed to penetrate the entire marine section.

Littleton and Audsley (1957, page 13) reported that the Pure Oil Co. drilled an oil test 13 miles southwest of Alpine which penetrated rocks of Cretaceous age at 3,370 feet, rocks of Permian age at 3,614 feet, Ordovician rocks at 4,796 feet, and Precambrian granite wash at 5,545 feet.

Information is not available concerning the water-bearing properties of the marine sedimentary rocks in the Marfa area; however, some of the formations are productive aquifers elsewhere in Texas and may be water bearing in the area. No attempts have been made to obtain water from the marine rocks, because of their relatively great depth and the availability of ground water at shallow depth.

Extrusive Igneous Rocks

Extrusive igneous rocks of the Buck Hill volcanic series (Goldich and Seward, 1948) underlie the Marfa area. The oldest formation of the series recognized on the surface is the Duff formation of Goldich and Elms (1949). Older

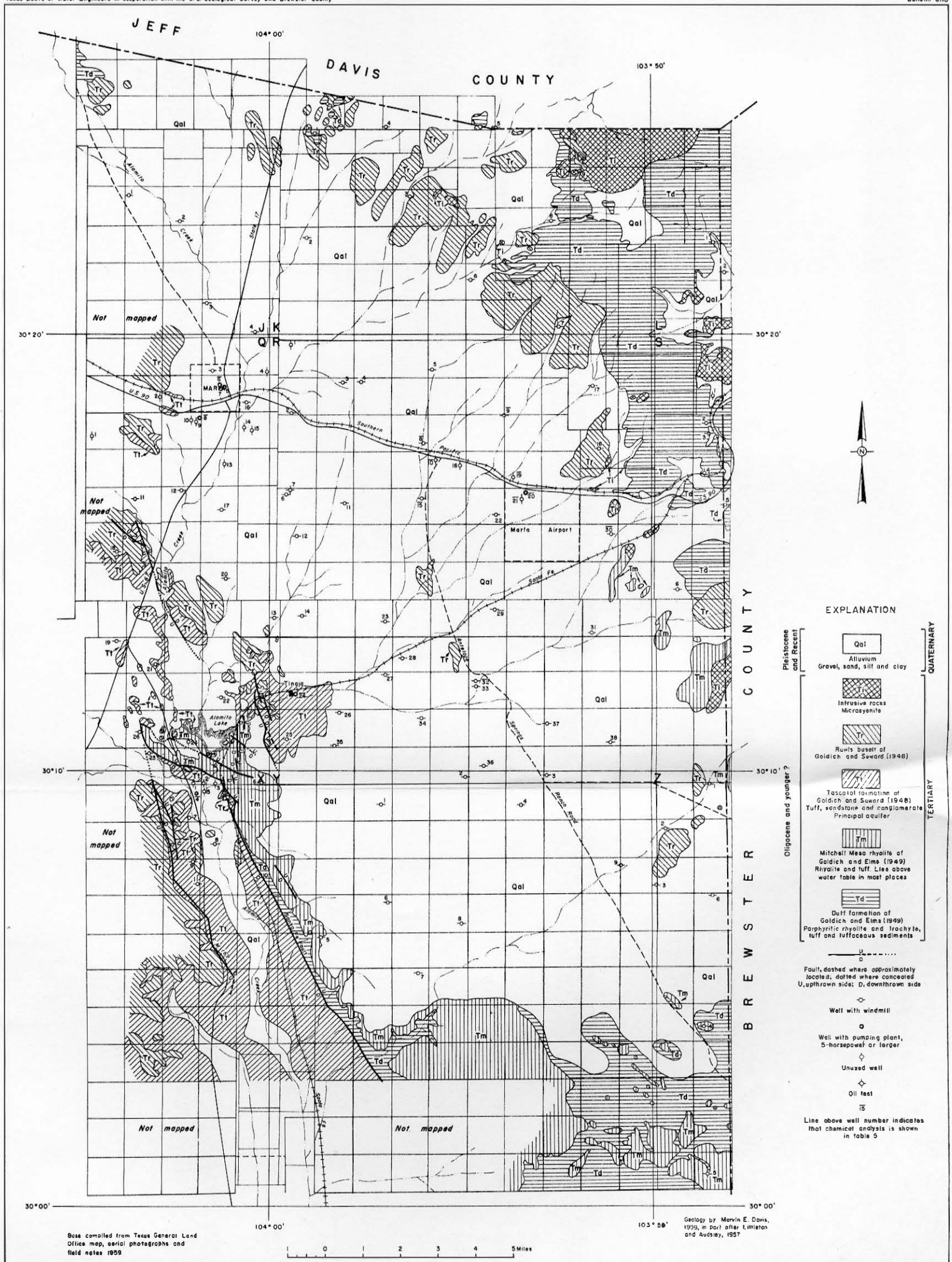


FIGURE 3.—Reconnaissance geologic map showing location of wells in the Marfa area, Presidio County

formations of the series have been recognized in the log of well Z-5, an oil test in the extreme southeast corner of the area; however, little is known concerning their water-bearing properties, and they will not be discussed further in this report.

Duff Formation of Goldich and Elms (1949)

The Duff formation of Goldich and Elms (1949) crops out in the southern, eastern, and northern parts of the Marfa area (figure 3) and probably underlies the rest of the area. The outcrop of the Duff forms most of the rugged surface of the mountainous part of the area. The Duff is probably of Oligocene age (Goldich and Elms, 1949, page 1143).

The lower part of the Duff formation consists of widespread layers of silicic tuff in various stages of alteration. Intercalated in the predominantly tuffaceous section are small flood-plain deposits of tuffaceous clay, silt, sandstone, and conglomerate. The tuff and tuffaceous sediments are gray, tan, pink, and red. The upper part of the formation consists of columnar-jointed flows of porphyritic lava which range in composition from rhyolite to trachyte and generally may be classified as porphyritic felsite.

The thickness of the Duff formation varies widely owing to the irregularity of the surface upon which it was deposited. According to the driller's log of well Z-5, the Duff has a thickness of about 1,500 feet, which is probably its maximum thickness in the Marfa area.

The Duff formation yields small quantities of water to several stock wells in the northern, eastern, and southern parts of the area. It is unlikely that large supplies of ground water can be obtained from this formation, because of the abundance of relatively impermeable tuff and the lenticularity of the sandstone.

Mitchell Mesa Rhyolite of Goldich and Elms (1949)

The Mitchell Mesa rhyolite of Goldich and Elms (1949) forms a caprock in the extreme southern part of the Marfa area. It also caps the cliff formed by the Santa Fe fault scarp (figure 3). Several of the erosional remnants exposed in the eastern part of the area have been mapped as the Mitchell Mesa rhyolite although actually they may be part of the Duff formation. The Mitchell Mesa has not been recognized in the subsurface in the Marfa area, owing possibly to removal by erosion.

The Mitchell Mesa rhyolite has been described as a rhyolite flow containing beds of rhyolitic tuff. Typically, it is hard and brittle, and is reddish gray to pink. Phenocrysts of quartz and feldspar, ranging in composition from sanidine to anorthoclase, are scattered throughout the groundmass. Locally, deposits of loosely welded tuff are associated with the rhyolite.

The thickness of the Mitchell Mesa rhyolite in the Marfa area was not accurately determined, but in the Cathedral Mountain quadrangle, immediately to the east, the thickness ranges from 58 to 134 feet (McAnulty, 1955, page 554). Exposures of the Mitchell Mesa in the Marfa area seem to be within that range of thickness.

In general, the Mitchell Mesa rhyolite lies above the water table; hence it is not an important source of ground water in the Marfa area. Although

records show that well Q-25, which is on the shore of Alamito Lake, obtains water from the Mitchell Mesa rhyolite, the water probably is coming from the nearby lake through cracks in the rhyolite.

Tascotal Formation of Goldich and Seward (1948)

The Tascotal formation of Goldich and Seward (1948) crops out in a belt of irregular width and pattern in the western and southwestern parts of the area. It lies on the eroded surface of the Mitchell Mesa rhyolite of Goldich and Elms (1949) and is overlain by flows of the Rawls basalt of Goldich and Seward (1948). In small areas, where the Rawls basalt is absent, the Tascotal formation has been reduced to small, rounded hills. The Tascotal probably underlies most of the area between the Santa Fe and the Southern Pacific Railroads; north of this area the formation is probably absent; it is not known whether its absence is due to removal by erosion or to lack of deposition.

The Tascotal formation consists predominantly of sandy tuff, tuffaceous sand, and thick beds of sandstone and conglomerate. In the Tascotal Mesa quadrangle south of the Marfa area, Erickson (1953, page 1366) recognized two lithologic facies of the Tascotal, (1) thin-bedded, flaggy sandy light-colored tuff in the lower part and (2) coarse crossbedded tuffaceous gray-buff sandstone and conglomerate in the upper part. These facies seem to correlate generally with the Tascotal formation, as observed in the Marfa area.

The thickness of the Tascotal formation in the Marfa area is not known definitely. According to the driller's log of well R-24, the Tascotal is at least 707 feet thick; however, the well did not completely penetrate the formation. In the Tascotal Mesa quadrangle, Erickson (1953, page 1365) reported a thickness of 797 feet for the Tascotal, and in the Cathedral Mountain quadrangle, east of the Marfa area, McAnulty (1955, page 555) reported a range in thickness from 50 to 462 feet.

The Tascotal formation is the principal aquifer in the Marfa area. Yields of the municipal wells at Marfa (wells Q-5, Q-6, and Q-7) and the well at the Tinaja section house (well R-24) range from 375 to 1,200 gpm (gallons per minute). Most of the wells that obtain water from the Tascotal are used for stock; consequently, the yields are small and are not indicative of the ability of the formation to yield water. During the drilling of well R-7, $2\frac{1}{2}$ miles southeast of Marfa, a large flow of fresh water was reported from a sandy zone, probably of the Tascotal formation, at a depth of about 900 feet. As the well was drilled as an oil test, no attempt was made to determine the water-bearing properties of the Tascotal, and the well was subsequently abandoned.

The wells at the Marfa Airport (wells R-20 and R-21) had yields of 40 and 130 gpm, respectively. These relatively low yields are attributed to a marked decrease in the thickness and in the sand and gravel content of the Tascotal formation in this locality, as compared to the formation in the vicinities of Marfa and Tinaja.

Rawls Basalt of Goldich and Seward (1948)

The Rawls basalt of Goldich and Seward (1948), which is the youngest member of the Buck Hill volcanic series, crops out along the west side of the Marfa area, where it forms a caprock above the Tascotal formation. Along the northern and northeastern border of the area, the Rawls has pinched out against

erosional remnants of the Duff formation (figure 3). Extensive erosion has left remnants of the Rawls in many places in the Marfa area. The basalt has been penetrated by several wells southeast of Marfa. Whether the Rawls occurs extensively in the subsurface cannot be determined from the data available.

The Rawls basalt is a succession of interfingering flows of basalt, trachybasalt, and trachyandesite, with interbeds of tuff, sandstone, and conglomerate. Generally, the basalt is grayish black, is porphyritic to nonporphyritic, and contains olivine and iddingsite. A flow of light-brown dense trachyandesite in the upper part of the basalt probably intruded the older basalt of the Rawls.

Logs of several wells indicate that the Rawls is about 120 feet thick in the vicinity of Marfa. Available data from adjacent areas indicate that the Rawls increases in thickness toward the east and south. In the Tascotal Mesa quadrangle, south of the Marfa area, the thickness of the Rawls basalt ranges from 50 to 937 feet (Erickson, 1953, page 1369), and in the Cathedral Mountain quadrangle to the east the thickness ranges from 30 to 545 feet (McAnulty, 1955, page 556).

The basalt layers have a wide range of porosity and permeability, depending largely upon the degree of brecciation and fracturing, the amount of secondary minerals filling the vesicles, and the percentage of interconnecting interstices. Some zones are highly vesicular, but the vesicles may be filled with calcite or chalcedony, particularly near the upper parts of the individual flows.

The Rawls basalt is the second most important aquifer in the Marfa area. It yields small to moderate quantities of water to wells for stock and domestic purposes. Well Q-8, which had a measured yield of 600 gpm, obtains water from the Rawls and the overlying alluvium. This exceptionally large yield is probably due to the fact that the well penetrated a fault or brecciated zone.

Intrusive Igneous Rocks

Intrusive igneous rocks, chiefly in the form of plugs and sills, crop out irregularly along the east edge of the Marfa area. The intrusive rocks are composed mostly of alkalic microsyenite and are light to dark greenish gray, fine grained, and even textured. They weather to a yellowish brown and characteristically break down by exfoliation.

The intrusive rocks are nearly impermeable, and consequently they yield only small quantities of water. Only the wells tapping fractures produce sufficient water even for stock use.

Alluvium

Alluvium of Quaternary age mantles most of the Marfa area. The alluvium consists of beds and lenses of sand, gravel, silt, and clay which are not continuous over wide areas but, instead, pinch out or grade laterally and vertically into finer or coarser materials. The sand and gravel consist of subrounded to angular fragments derived from igneous rocks of the Davis Mountains. Caliche, a secondary concentration of calcium carbonate, occurs as thin beds in the silt and clay or interstitially in the layers of sand and gravel.

The alluvium in the Marfa area generally thickens toward the west. The observed thickness ranges from 0 where the alluvium pinches out to a maximum of 390 feet in well R-7. In the area south of the Santa Fe Railroad and east of the Antelope Springs ranch road, the alluvium probably is less than 15 feet thick and consists predominantly of silt.

The alluvium lies above the water table in most of the eastern part of the Marfa area and acts chiefly as an infiltration agent for the underlying aquifers. However, on the west side of the area the alluvium yields moderate quantities of water to several stock and domestic wells. In a small area in the valley of Alamito Creek south of Alamito Lake, the alluvium yields moderate to large quantities of water. Well X-4, an irrigation well, had a reported yield of 500 gpm.

GROUND WATER

Occurrence and Movement of Ground Water

The principles of the occurrence and movement of ground water in all types of rocks have been described by many authors, including Meinzer (1923a and b). The occurrence and movement of ground water in the Marfa area are discussed briefly here.

Ground water may occur under either water-table or artesian conditions. Under water-table conditions, the water is unconfined and does not rise in wells above the level at which it is first encountered. Under artesian conditions, the water is confined between relatively impermeable beds, and the pressure may be sufficient to cause the water in the well to rise a considerable distance above the level at which it is first encountered; the well may or may not have a natural flow.

In the Marfa area, the ground water occurs under both water-table and artesian conditions in different places. Although the ground water may occur in different aquifers under either confined or unconfined conditions, the confined water rises to approximately the same general level as the water table of the area, suggesting that the aquifers underlying the area are interconnected. This is indicated further by the similarity of the quality of the water from the several water-bearing formations.

The water table, as shown in figure 4, is, in general, a subdued replica of the topography. The irregularities in its shape may be caused by differences in permeability and thickness of the water-bearing material, or by unequal additions of water to, or removal from, the ground-water reservoir.

Ground water moves by gravity from areas of intake to areas of discharge. In the Marfa area, ground water moves generally southward and westward from the vicinity of the range of mountains on the east edge of the area to the vicinity of Alamito Creek, thence southward toward the Rio Grande.

The rate at which the water moves through the aquifers is affected by the wide range of rock permeabilities and the gradient of the water table. The velocity of movement in materials such as those composing the aquifers in the Marfa area may range from a few feet per year to several feet per day.

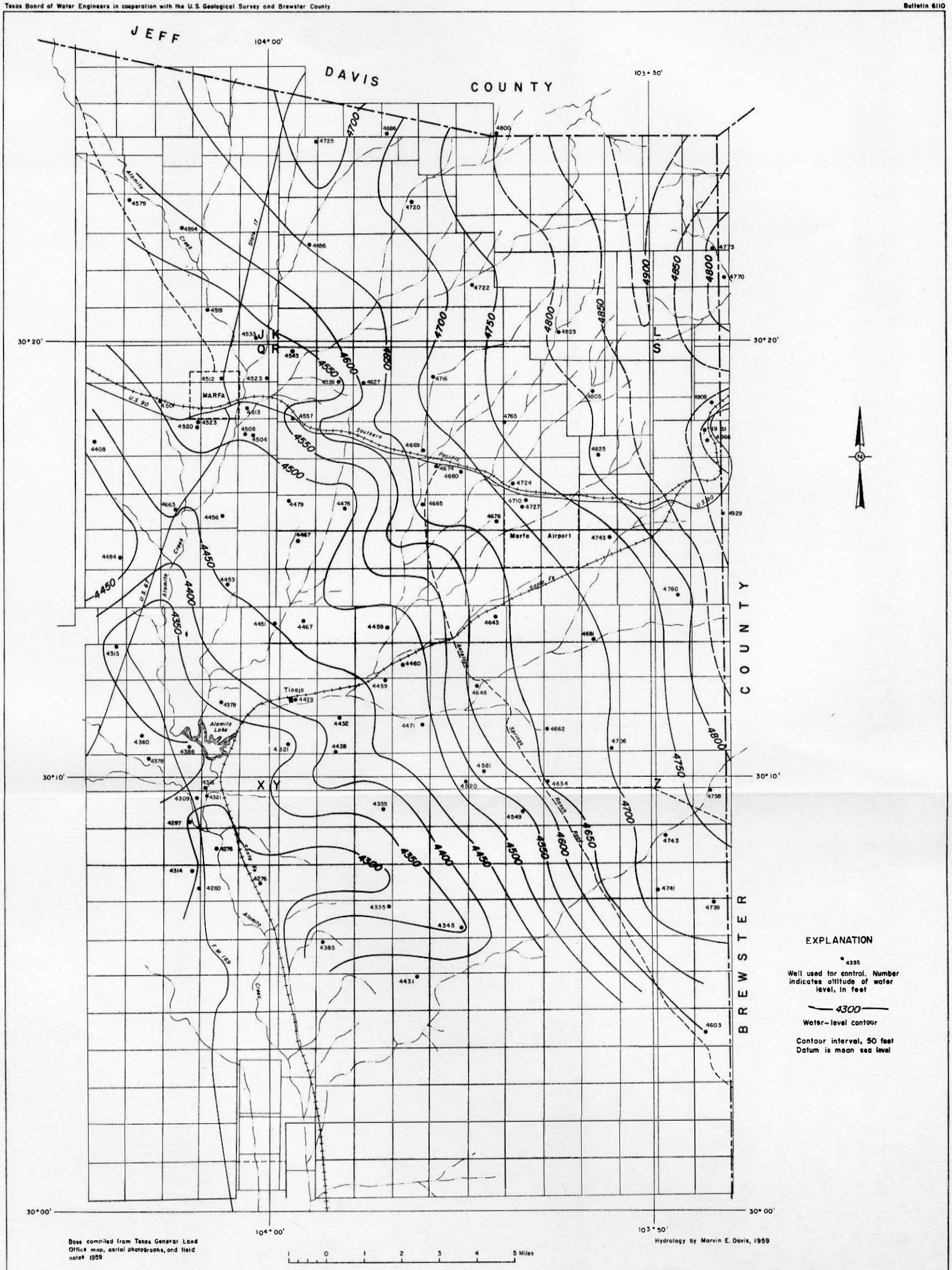


FIGURE 4.- Generalized map of the water table in the Marfa area, Presidio County, 1958-59

Ground-Water Recharge

The ground water in the Marfa area is derived from precipitation on the area. Part of the precipitation is carried away by direct runoff and is lost to streams, and part of it is evaporated or absorbed by vegetation and transpired into the atmosphere. The part that escapes runoff and evapotranspiration percolates slowly downward through the soil and underlying strata until it reaches the water table, thence it moves down the hydraulic gradient of the aquifers toward areas of discharge.

Most of the recharge in the Marfa area comes from runoff from the mountains in the eastern part of the area. This runoff is rapid because of the steep stream gradients and sparse vegetation in the mountainous area. As the streams emerge from the Davis Mountains onto the more gently sloping alluviated plain, the abrupt change in gradient allows flood runoff to spread over a wide surface. Most of the recharge takes place near the mountains, where the alluvium overlying the aquifers is coarse grained and probably very permeable. The amount of recharge per unit of the entire Marfa area, however, is small because the surface deposits in much of the area are poorly sorted, are silty, and locally contain caliche, which retards infiltration.

Most of the recharge in the area probably occurs during the summer, when torrential rains occasionally fall. Soil moisture must be restored by the rains before the water can move downward to the water table; consequently, the lighter rains of short duration probably do not contribute substantially to the recharge.

Precipitation records for the Marfa area are incomplete; therefore, recharge in the area is roughly estimated from records obtained in the neighboring Alpine area in Brewster County. The extent of the recharge area is estimated to be about 130,000 acres. The average annual precipitation of about 15 inches supplies approximately 160,000 acre-feet of water to be disposed of by direct runoff, evapotranspiration, or recharge. Littleton and Audsley (1957, page 26) estimated that in the Alpine area roughly 5 percent of the precipitation recharges the ground-water reservoirs in an average year. On this basis, the recharge from precipitation in the Marfa area would amount to about 8,000 acre-feet per year.

Ground-Water Discharge

Ground water in the Marfa area is discharged principally by subsurface flow into adjacent areas toward the south and by pumping from wells. Prior to the start of pumping, the natural discharge of ground water was approximately balanced by the natural recharge, estimated to be about 8,000 acre-feet annually. This state of approximate equilibrium was slightly upset as pumping from wells began.

Available records show that for the period January 1956 through April 1959 the average total discharge from the 3 municipal wells at Marfa was 706,000 gpd (gallons per day). Irrigation wells at the Eppenaur ranch (Q-8) and the Tinaja section house (R-24) are estimated to discharge 500,000 gpd, when used during the growing season; however, the irrigation wells are used for only short periods. The widely spaced ranch wells yield less than 10 gpm per well when pumped, yielding a total of about 75,000 gpd for about 5,000 head of livestock and the rural residents in the area. On this basis, therefore, the total annual

discharge from wells in the Marfa area is approximately 900 acre-feet of water, which is about a tenth of the estimated natural recharge.

The ground-water development in the Marfa area has caused no appreciable decline in the water table. For example, during the period 1942-59 the water levels in 7 wells showed an average rise of 2.63 feet. During this same period, the wells at the Marfa airport (wells R-20 and R-21) and the Tinaja section house (R-24), which are among the most heavily pumped, showed average declines of 1.8 feet and 6.35 feet, respectively.

Quality of Ground Water

All natural water contains mineral matter dissolved from the rocks and soils with which it has come in contact. The quantity of dissolved mineral matter in the water depends primarily on the type of rock or soil through which the water has passed, the length of time of contact, and the pressure and temperature during contact. In addition to the natural factors controlling the chemical quality of the water, there are others associated with human activities, such as the use of streams and wells for disposal of sewage and industrial waste.

Standards used for judging the suitability of drinking water used on interstate carriers have been established by the U. S. Public Health Service (1946, pages 371-384). These standards have been widely used also in determining the suitability of water for public supply; consequently, municipal and domestic supplies should conform to the standards if possible. Some of the standards are as follows:

Iron (Fe) and manganese (Mn) together should not exceed 0.3 ppm (part per million).

Magnesium (Mg) should not exceed 125 ppm.

Chloride (Cl) should not exceed 250 ppm.

Sulfate (SO_4) should not exceed 250 ppm.

Fluoride (F) must not exceed 1.5 ppm.

Dissolved solids should not exceed 500 ppm in a water of good chemical quality. However, if such water is not available, a dissolved-solids content of 1,000 ppm may be permitted.

The chemical analyses of water samples from 14 wells in the Marfa area are given in table 5, and the analyses are summarized in table 2. Of these samples, 11 were collected during an investigation at the Marfa Army Flying School in 1942-43 (George and Livingston, 1943).

All constituents except fluoride were within the range of Public Health standards. Fluoride exceeded 1.5 ppm in 6 of 7 samples analyzed for this constituent. The principal effect of fluoride in water is on the dental health of children; it is beneficial or detrimental according to the concentration. In concentrations up to about 1.0 ppm, fluoride is believed by many health authorities to reduce the incidence of tooth decay without mottling tooth enamel (Dean,

Table 2.--Range in chemical properties and concentration of chemical constituents in ground water in the Marfa area
(Mineral constituents in parts per million)

Constituent or property	Maximum	Minimum
Silica (SiO_2)	76	40
Iron and manganese (Fe + Mn)	.08	.00
Calcium (Ca)	57	23
Magnesium (Mg)	6.6	2.2
Sodium and potassium (Na + K)	121	22
Bicarbonate (HCO_3)	284	177
Sulfate (SO_4)	116	10
Chloride (Cl)	62	6.2
Fluoride (F)	3.2	.4
Nitrate (NO_3)	22	3.5
Dissolved solids	487	290
Hardness as $CaCO_3$	169	71
Percent sodium	59	14
Sodium-adsorption-ratio (SAR)	6.1	.5
Specific conductance (micromhos at 25°C)	449	410
pH	8.2	7.2

Arnold, and Elvove, 1942, pages 1155-1179), but in concentrations higher than 1.5 ppm it may contribute to permanent mottling of the enamel (Dean, Dixon, and Cohen, 1935, pages 424-442).

The hardness of the water from the wells sampled ranged from 71 to 169 ppm. Water having a hardness of 60 ppm or less is considered as soft. Hardness as much as 150 ppm could not interfere with most uses of water, other than causing a slightly increased consumption of soap. Where the hardness is in excess of about 200 ppm, it is common practice to soften the water for household use. The hardness in the Marfa area is caused largely by compounds of calcium and magnesium, and the water can be softened by the lime-soda process.

The silica content in 8 water samples ranged from 40 to 76 ppm. This relatively high silica concentration reflects the environment of silicic and intermediate volcanic rocks. Silica affects the usefulness of water for industries because it contributes to the formation of boiler scale; however, in a nonindustrialized area such as the Marfa area, the effect of the high silica content would be merely to increase the formation of scale in hot-water heaters and pipes.

CONCLUSIONS

The principal aquifer in the Marfa area is the Tascotal formation, from which moderate to large quantities of ground water are obtained in a few places. Small to moderate quantities of ground water are obtained also from the Rawls basalt and the alluvial deposits.

The ground water in the Marfa area is derived from precipitation on the area, and the natural recharge is estimated to be on the order of 8,000 acre-feet annually. This exceeds the current discharge of ground water by pumping by more than 7,000 acre-feet. Additional moderate to large supplies of ground water probably can be obtained from the aquifers that underlie the part of the area extending from U. S. Highway 90 southward to the Santa Fe Railroad and from U. S. Highway 67 eastward to the Antelope Springs ranch road. The aquifers in this area include the Tascotal formation, the Rawls basalt, and the alluvium, in their relative order of importance. Water-bearing sand may be found at intervals throughout the Tascotal formation, which is more than 700 feet thick in the Tinaja section-house well. Depths to the sand may vary according to the amount of overburden, fault displacement, and lenticularity of the deposits. A more precise delineation of their depth and extent is not possible with the existing data.

Water from the aquifers in the Marfa area is of satisfactory quality for most purposes. The high fluoride and silica content of the water limits its usefulness for certain purposes.

REFERENCES CITED

Bennett, R. R., 1941, Marfa water supply: U. S. Geol. Survey open-file rept., 1 p.

Dean, H. T., Arnold, F. A., and Elvove, Elias, 1942, Domestic water and dental caries: U. S. Public Health Service Public Health Repts., v. 57, p. 1155-1179.

Dean, H. T., Dixon, R. M., and Cohen, Chester, 1935, Mottled enamel in Texas: U. S. Public Health Service Public Health Repts., v. 50, p. 424-442.

Erickson, R. L., 1953, Stratigraphy and petrology of the Tascotal Mesa quadrangle, Texas: Geol. Soc. America Bull., v. 64, no. 12, pt. 1, p. 1353-1386.

George, W. O., and Livingston, Penn, 1943, Ground water in the vicinity of Marfa Army Flying School: U. S. Geol. Survey open-file rept., 12 p.

Goldich, S. S., and Elms, M. A., 1949, Stratigraphy and petrology of Buck Hill quadrangle, Texas: Geol. Soc. America Bull., v. 60, no. 7, p. 1133-1182.

Goldich, S. S., Elms, M. A., and Seward, C. L., 1949, Green Valley-Paradise Valley field trip, in West Texas Geol. Soc. Guidebook Field Trip, No. 1, Nov. 6-9, 1949: p. 63-81.

Goldich, S. S., and Seward, C. L., 1948, West Texas Geol. Soc. Fall Field Trip, p. 13-18.

Lang, J. W., 1943, Supplementary data on well 3, Marfa Army Air Base, Presidio County, Tex.: U. S. Geol. Survey open-file rept., 10 p.

Littleton, R. T., and Audsley, G. L., 1957, Ground-water geology of the Alpine area, Brewster, Jeff Davis, and Presidio Counties, Tex.: Texas Board Water Engineers Bull. 5712, 87 p.

McAnulty, W. N., 1955, Geology of Cathedral Mountain quadrangle, Brewster County, Texas: Geol. Soc. America Bull., v. 66, no. 5, p. 531-578.

Meinzer, O. E., 1923a, The occurrence of ground water in the Uniter States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489, 321 p.

_____, 1923b, Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, 71 p.

U. S. Public Health Service, 1946, Drinking water standards: Public Health Repts., v. 61, no. 11, p. 371-384.

Table 3.--Records of wells in the Marfa area

All wells are drilled unless otherwise noted in Remarks column. Elevations determined by aneroid barometer unless otherwise noted.
Water : Reported water levels given in feet; measured water levels given in feet and tenths.
Method of lift and type of power : C, cylinder; E, electric; G, gasoline, butane, or diesel; N, none; T, turbine; W, windmill. Number indicates horsepower.
Use of water : D, domestic; Irr, irrigation; N, none: P, public supply; S, stock.

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
J-1	W. A. Mims Estate	C. H. Cass	1942	500	6	--	4,906	325.6	Apr. 22, 1959	C,W	S	Cased to bottom.
J-2	do	--	--	--	6	--	4,869	275.0	do	C,W	S	
J-3	do	--	--	--	6	--	4,778	258.0	do	C,W	S	
J-4	F. D. Middleton	--	--	--	6	--	4,780	246.9	Jan. 28, 1959	C,W	S	
K-1	H. C. Espy	--	--	500	6	--	4,985	260.0	June 1, 1959	C,W	D,S	
K-2	C. Gage	--	--	270	8	--	4,856	199.9	Dec. 10, 1958	C,W	S	Cased to bottom.
K-3	D. Ponder	--	--	360	8	Duff formation of Goldich and Elms (1949)	4,990	270.2	Jan. 15, 1959	C,W	S	Weak supply reported.
K-4	do	--	--	--	8	--	5,000	313.7	Jan. 28, 1959	C,W	S	
K-5	do	J. McSpadden	1954	680	8	Duff formation of Goldich and Elms (1949)	5,200	400.0	do	C,W	S	Weak supply reported.
K-6	Main Estate	--	--	280	8	--	4,995	273.3	Nov. 21, 1958	C,W	S	Discharge reported, 12 gpm.
K-7	do	A. H. Mann	1936	330	8	--	5,175	350.5	Dec. 10, 1958	C,W	S	Discharge reported, 10 gpm.
K-8	do	do	1942	466	8	--	5,150	--	--	C,W	S	Cased to bottom. Discharge reported, 12 gpm. Dry to 315 ft. Nov. 21, 1958.
K-9	D. Ponder	J. McSpadden	1953	700	8	--	5,380	--	--	C,W	S	Weak supply reported.
L-1	Mrs. D. G. Forker	E. E. Doyle	1951	210	6	--	4,904	127.9 130.1	Mar. 29, 1955 Apr. 13, 1959	C,W	S	Cased to 25 ft. Well C-17 in Littleton and Audsley (1957, p. 38).
L-2	do	--	--	--	6	--	4,857	87.3 87.2	Mar. 29, 1955 Apr. 13, 1959	C,W	S	Well C-34 in Littleton and Audsley (1957, p. 39).
Q-1	A. R. Eppenaur	R. W. Gooden	1959	682	12	Tascotal formation of Goldich and Seward (1948)	4,711	302	July 1959	N	N	2/

See footnotes at end of table.

Table 3.--Records of wells in the Marfa area--Continued

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
Q-2	H. M. Greenwood	--	--	--	8	--	4,729	227.6	Mar. 18, 1959	C,W	N	
Q-3	W. A. Mims Estate	--	1915	--	6	--	4,732	218.4	Apr. 22, 1959	C,W	D,S	
Q-4	J. Helper Estate	--	--	--	6	--	4,744	221.1	Jan. 28, 1959	N	N	Abandoned.
Q-5	City of Marfa	J. H. Cass	1936	841	10, 8	Tascotal formation of Goldich and Seward (1948)	4,688	--	--	T,E	P	Casing: 10-in. to 306 ft., 8-in. to bottom. Perforated opposite sands from 411 ft. to bottom. Discharge reported, 1,000 gpm. 2/
1/Q-6	do	Layne-Texas Co.	1928	881	16, 10	do	4,688	--	--	T,E	P	Casing: 16-in. to 291 ft., 10-in. to bottom. Perforated from 425 ft. to bottom. Discharge reported 700 gpm. 2/
Q-7	do	E. Harrell	1945	1,100	16, 11	do	4,688	--	--	T,E	P	Casing: 16-in. to 314 ft., 11-in. to bottom. Perforated from 170 to 298, 358 to 570, and 815 to 889 ft. Discharge reported, 375 gpm. 2/
1/Q-8	A. R. Eppenaur	Harrell & Threatt	1949	429	13, 5	Rawls basalt of Goldich and Seward (1948) and alluvium	4,695	171.5	July 30, 1958	T,E	Irr	Cased to bottom. Perforated from 210 ft. to 416 ft. Discharge measured, 600 gpm July 31, 1958. Temp. 78°F.
Q-9	do	--	--	185	8	Alluvium	4,692	172.4	do	C,W	N	Abandoned.
Q-10	do	Harrell & Threatt	1948	1,029	--	--	4,700	--	--	N	N	Insufficient supply. Abandoned. 2/
Q-11	H. B. Holmes	--	1925	220	6	--	--	135	1956	C,E	D	Cased to 10 ft.
Q-12	J. C. Mitchell	--	1937	150	6	--	4,627	164.6	Jan. 23, 1959	C,W	S	Cased to 150 ft.
Q-13	do	--	--	175?	--	--	4,650	--	--	N	N	Old well.
Q-14	do	--	--	--	6	--	4,666	157.7	July 16, 1958	N	N	
Q-15	do	--	--	--	6	--	4,667	162.6	do	N	N	
Q-16	J. W. Espy	--	--	200	6	--	4,685	172.3	Jan. 23, 1959	C,W	S	Strong supply reported. Old well.
Q-17	J. C. Mitchell	--	1930	175	6	--	4,597	140.9	Aug. 4, 1958	C,W	S	Cased to bottom.
Q-18	H. B. Holmes	D. McSpadden	1933	430	6	Rawls basalt of Goldich and Seward (1948)	4,833	350	1956	C,W	S	Cased to 350 ft. Dry to 310 ft. Mar. 19, 1959.

See footnotes at end of table.

Table 3.--Records of wells in the Marfa area--Continued

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
Q-19	J. H. Kirk	--	--	--	6	--	4,521	208.4	Jan. 23, 1959	C,W	S	
Q-20	J. C. Mitchell	E. Doyal	1945	400	6	--	4,709	255.8	July 16, 1958	C,W	S	Cased to 360 ft.
Q-21	K. Mitchell	do	1945	252	6	--	4,496	17.1	June 24, 1959	C,W	S	Cased to 252 ft.
Q-22	do	do	1944	160	6	--	4,466	86.2	Mar. 10, 1959	C,W	S	Cased to 20 ft.
Q-23	J. B. Hubbard	--	--	--	6	--	4,401	46.3	Feb. 19, 1959	C,W	S	
Q-24	M. Robison	--	--	--	6	--	4,475	87.0	Jan. 23, 1959	N	N	
Q-25	do	M. Robison	1958	135	12	Mitchell Mesa rhyolite of Goldich and Elms (1949)	4,459	--	--	T,E	S	Cased to bottom. Perforated from 100 ft. to bottom. Discharge reported 500 gpm.
Q-26	do	--	1920	110	6	--	4,451	90.6	July 8, 1959	C,W	S	
R-1	Presidio County	U. S. Army	1918	270	6	--	4,791	248.7	Jan. 25, 1959	N	N	Supplied water for Army Air Field during World War I.
R-2	J. W. Espy	--	--	250	8	--	4,770	214.0	Jan. 23, 1959	C,W	S	Old well. Reported strong supply.
R-3	do	--	--	--	6	--	4,855	315.2	Mar. 24, 1959	C,W	S	
R-4	C. Gage	J. Freeman	1952	270	8	--	4,872	144.1 245.1	Nov. 21, 1958 Mar. 24, 1959	C,W	S	
R-5	do	--	--	260	8	--	4,858	142.8	Nov. 21, 1958	C,W	S	Old well.
R-6	J. C. Mitchell	--	--	250	6	--	4,719	240.3	July 16, 1958	C,W	S	do
R-7	do	Texas-Ajax Co.	1920	1,715	--	--	4,749	--	--	N	N	Oil test. Reported strong flow of water from sand at 900 ft. Abandoned. 2/
1/R-8	C. Gage	--	--	180	8	--	4,789	120.1 119.6	Aug. 18, 1942 Nov. 21, 1958	C,W	S	Old well.
1/R-9	Mrs. D. G. Forker	--	--	350	8	--	4,934	173.7 168.1	July 28, 1942 July 23, 1959	C,W	S	Strong supply reported.
1/R-10	B. Mitchell	-- Wheeler	1943	1,180	12, 10	--	4,806	139.1 132.7	Aug. 10, 1943 July 17, 1958	N	N	Casing: 12-in. to 681 ft., 10-in. to bottom. Perforated from 275 to 305 ft. and opposite sands from 705 to 1,156 ft. Pumping test Aug. 1943 at 160 gpm for 17 hours with 460 ft. drawdown. Abandoned. Temp. 76°F. 2/

See footnotes at end of table.

Table 3.--Records of wells in the Marfa area--Continued

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
R-11	J. C. Mitchell	E. Doyal	1945	430	6	--	4,762	285.3	July 16, 1958	C,W	S	
R-12	do	--	--	250	6	--	4,662	194.3	do	C,W	S	Old well.
R-13	K. Mitchell	--	--	180	6	--	4,570	118.4	June 18, 1958	T,E	D,S	Old well. Strong supply reported.
R-14	J. C. Mitchell	--	--	250	6	--	4,615	147.2	July 16, 1958	C,W	S	Old well. Cased to 250 ft.
1/R-15	B. Mitchell	--	--	160	6	--	4,735	91.6 70.2	July 28, 1942 Mar. 20, 1959	C,W	D,S	
R-16	do	Layne-Texas Co.	1944	1,115	10	--	4,829	149.6	Dec. 10, 1958	N	N	Abandoned. 2/
R-17	Main Estate	--	--	320	8	--	5,100	294.5	Jan. 18, 1959	C,W	S	Old well.
R-18	Mrs. D. G. Forker	--	--	450	6	--	5,080	255.2	Dec. 10, 1958	C,W	S	
1/R-19	do	--	--	400	6	--	4,891	169.5 166.6	July 28, 1942 Jan. 14, 1959	N	N	
1/R-20	Presidio County	J. R. Watson	1942	840	13, 10, 7, 5	--	4,898	182.0 183.7	June 27, 1942 Jan. 13, 1959	T,E	P	Casing: 13-in. to 319 ft., 10-in. to 429 ft., 7-in. to 818 ft., 5-in. to bottom. Perforated from 667 ft. to bottom. Drawdown reported 200 ft. while pumped at 130 gpm. 2/
1/R-21	do	do	1942	1,735	12, 10, 8	--	4,887	147.0 148.9	Aug. 18, 1942 Jan. 13, 1959	N	N	Casing: 12-in. to 508 ft., 10-in. to 931 ft., 8-in. to 1,517 ft. Perforated from 190 to 210, 762 to 802, 905 to 985, 1,088 to 1,128, and 1,233 to 1,260 ft. Discharge reported, 40 gpm. Temp. 76°F. Abandoned. 2/
R-22	B. Mitchell	--	--	250	6	--	4,784	109.6 108.1	July 28, 1942 July 23, 1958	C,W	S	
R-23	do	--	--	--	8	--	4,599	139.9	July 17, 1958	C,W	S	
1/R-24	Santa Fe Ry.	McSpadden Bros.	1930	800	13, 10	Tascotal formation of Goldich and Seward (1948)	4,502	66.9 73.2	Aug. 8, 1943 July 14, 1958	T,G	Irr	Casing: 13-in. to 200 ft., 10-in. to 766 ft., open hole. Discharge reported, 1,200 gpm. Temp. 75°F. 2/
R-25	J. B. Hubbard	--	--	--	6	--	4,552	231.0	June 24, 1959	C,W	S	
R-26	K. Mitchell	--	--	250	8	--	4,555	122.9	June 19, 1958	C,W	S	Old well. Cased to 20 ft.

See footnotes at end of table.

Table 3.--Records of wells in the Marfa area--Continued

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
R-27	K. Mitchell	J. Williams	1930	160	8	--	4,584	125.2	June 18, 1958	C,W	S	
R-28	Claude Lee	--	--	160	8	--	4,626	165.4	July 28, 1958	C,W	S	
1/R-29	Hendricks Estate	Santa Fe Ry.	1920	300	7	--	4,734	91.8 90.7	July 28, 1942 Jan. 9, 1959	C,W	S	
1/R-30	do	C. H. Cass	1942	225	7	--	4,939	195.2 195.8	July 28, 1942 Jan. 12, 1959	C,W	S	
R-31	do	--	--	300	6	--	4,791	109.4	Jan. 9, 1959	C,W	S	Old well.
1/R-32	Claude Lee	--	--	--	8	--	4,658	10.8 9.4	Aug. 17, 1942 July 28, 1958	C,W	S	
R-33	do	--	--	--	8	--	4,658	9.5	Jan. 12, 1959	C,W	S	
R-34	A. M. McCabe	--	--	--	6	--	4,599	128.3	June 18, 1959	C,W	S	
R-35	do	--	--	400	8	--	4,621	193.5	July 21, 1958	C,W	S	
R-36	Claude Lee	--	--	--	8	--	4,689	107.9	July 28, 1958	C,W	S	
R-37	do	--	--	--	8	--	4,708	45.6	Jan. 8, 1959	C,W	S	
R-38	do	--	--	--	6	--	4,772	64.9	Apr. 2, 1959	C,W	S	
S-1	Mrs. D. G. Forker	--	--	--	48	--	4,943	38.4 35.9 33.8	Mar. 29, 1955 Aug. 30, 1955 Apr. 14, 1959	N	N	Abandoned. Well H-8 in Littleton and Audsley (1957, p. 45).
S-2	do	--	--	75	--	--	4,966	20.2 15.1	Mar. 7, 1955 Dec. 9, 1958	C,W	S	Dug. Well H-12 in Littleton and Audsley (1957, p. 45).
S-3	Vernon McIntyre	--	--	--	4	Alluvium	4,980	27.3 14.0	Mar. 7, 1955 Dec. 9, 1958	C,W	S	Well H-14 in Littleton and Audsley (1957, p. 45).
S-4	Vivian McIntyre	McSpadden Bros.	1929	404	--	Duff formation of Goldich and Elms (1949)	5,074	280.0	Sept. 1, 1929	N	N	Drilled for Southern Pacific Ry. Insufficient supply reported. Abandoned. 2/
S-5	Vernon McIntyre	do	--	550	6	do	5,207	257.8 260.0 278.4	Mar. 7, 1955 Aug. 16, 1955 Apr. 30, 1958	C,W	S	Cased to 420 ft., open hole. Weak supply reported. Well H-17 in Littleton and Audsley (1957, p. 45).
S-6	Hendricks Estate	--	--	450	6	--	4,937	174.9	Apr. 30, 1959	C,W	S	Old well.

See footnotes at end of table.

Table 3.--Records of wells in the Marfa area--Continued

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
X-1	M. Robison	M. Robison	1956	160	--	Alluvium	4,348	39.1	June 17, 1958	N	N	Discharge reported, 125 gpm. Abandoned.
X-2	do	do	1957	190	16	do	4,355	38.7	do	N	N	Cased to 5 ft. Discharge reported 125 gpm. Abandoned.
X-3	do	do	1955	100	12	do	4,374	47.0	do	N	N	Cased to 90 ft. Discharge reported 125 gpm. Abandoned.
1/X-4	do	-- McSpadden	1954	99	20, 16	do	4,338	28.5	Feb. 28, 1958	T,G	Irr	Casing: 20-in. to 50 ft., 16-in. to 80 ft. Discharge reported, 500 gpm. Temp. 67°F.
X-5	do	-- Stratton	1955	170	--	do	4,367	45.7	June 17, 1958	N	N	Discharge reported, 125 gpm. Abandoned.
X-6	J. B. Hubbard	--	--	--	8	Duff formation (?) of Goldich and Elms (1949)	4,591	129.7	Mar. 11, 1959	C,W	S	
X-7	M. Robison	--	1930	--	6	Alluvium	4,347	49.6	Feb. 19, 1959	C,W	S	
X-8	do	--	--	--	6	do	4,302	26.9	do	C,W	S	
X-9	do	--	1920	--	6	Tascotal formation of Goldich and Seward (1948)	4,337	22.9	do	C,W	S	
X-10	do	-- McSpadden	1953	135	8	do	4,301	25.0	June 17, 1958	C,W	S	Cased to 21 ft.
X-11	do	--	--	--	6	do	4,303	43.1	June 25, 1959	C,W	S	
Y-1	A. M. McCabe	--	--	441	6	--	4,632	276.6 280.4	July 21, 1958 July 24, 1959	C,W	S	
Y-2	do	--	--	273	6	--	4,675	154.4	Aug. 6, 1958	C,W	S	
Y-3	Claude Lee	--	--	--	6	--	4,706	52.3	Jan. 8, 1959	C,W	S	
Y-4	C. T. Mitchell	--	--	--	6	--	4,677	127.6	Feb. 18, 1959	C,W	S	North well.
Y-5	do	--	--	--	6	--	4,614	229.7	do	C,W	S	
Y-6	do	-- McSpadden	--	--	6	--	4,612	277.8	Dec. 14, 1958	C,W	S	
Y-7	do	--	--	--	6	--	4,665	233.6	Jan. 14, 1959	C,W	S	

See footnotes at end of table.

Table 3.--Records of wells in the Marfa area--Continued

Well	Owner	Driller	Date completed	Depth of well (ft.)	Diameter of well (in.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Below land-surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
Y-8	C. T. Mitchell	--	--	--	6	--	4,633	288.0	Jan. 13, 1959	C,W	S	
Y-9	do	--	--	--	6	--	4,770	--	--	C,W	S	
Z-1	Mrs. T. C. Crosson	--	--	200	6	--	4,873	114.7	Jan. 8, 1959	C,W	S	Old well. Cased to bottom. Strong supply reported.
Z-2	do	--	--	--	6	--	4,794	51.4	do	C,W	S	Old well. Strong supply reported.
Z-3	do	--	--	330	6	--	4,790	49.2	Apr. 1, 1959	C,W	S	do
Z-4	H. Mitchell	C. H. Cass	1912	443	6	--	4,910	306.9	Jan. 12, 1959	C,W	S	Cased to 20 ft.
Z-5	Mitchell Bros. & State of Texas	Argo Oil Corp.	1953	15,230	--	--	5,338	--	--	N	N	Oil test. Gulf Oil Co. in 1953 deepened this test to 15,230 ft. without penetrating marine section. Abandoned. 2/
Z-6	J. F. Lane	--	--	--	6	--	4,826	88.8	Jan. 13, 1959	C,W	S	

1/ See table 5 for analyses of water from wells in the Marfa area.
2/ See table 4 for drillers' logs of wells in the Marfa area.

Table 4.--Drillers' logs of wells in the Marfa area

Well Q-1

Owner: A. R. Eppenaur. Driller: R. W. Gooden.

Thickness (feet)	Depth (feet)	Thickness (feet)	Depth (feet)
Soil ---------- 8	8	Volcanic ash, gray and pink, sandy ---------- 5	453
Gravel ---------- 10	18	Shale and sand --------- 5	458
Sand ---------- 142	160	Sand ---------- 24	482
Rock, black, hard ----- 105	265	Volcanic ash, gray and pink, sandy ---------- 106	588
Sand (water) ---------- 95	360	Clay, sandy ---------- 22	610
Sand and gray volcanic ash ---------- 25	385	Volcanic ash, gray, sandy ---------- 32	642
Sand, dark ---------- 30	415	Clay, volcanic ash, and sand ---------- 14	656
Shale, sandy ---------- 25	440	Volcanic ash, gray and pink, sandy ---------- 26	682
Sand ---------- 8	448		

Well Q-5

Owner: City of Marfa. Driller: J. H. Cass.

Silt, sand, and gravel- 18	18	Sand ---------- 24	450
Clay ---------- 20	38	Clay, white ---------- 46	496
Sand ---------- 168	206	Rock, hard ---------- 31	527
Sand (water) ---------- 34	240	Clay, brown ---------- 53	580
Sand, hard ---------- 10	250	Shale, sandy ---------- 6	586
Sand and gravel ------- 49	299	Limestone, broken ------ 14	600
Rock, black ---------- 60	359	Sand and shale --------- 50	650
Clay, pink ---------- 3	362	Lava wash ---------- 47	697
Clay, sandy ---------- 49	411	Sand (water) ---------- 21	718
Sand (water) ---------- 15	426	Clay, brown ---------- 29	747

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Table 4.--Drillers' logs of wells in the Marfa area--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Well Q-5--Continued					
Sand (water)	23	770	Sandstone	32	812
Clay, brown	2	772	Clay, sandy	11	823
Sand, coarse	8	780	Sand and gravel (water)	18	841
Well Q-6					
Gravel	8	8	Limestone, broken	25	590
Ash, sandy	181	189	Clay, yellow	10	600
Sand	6	195	Lime and shell	2	602
Shale, sandy	104	299	Clay, yellow	23	625
Gravel	19	318	Lava wash	25	650
Rock, black	54	372	Clay, yellow	165	815
Gravel	53	425	Sand	23	838
Sand and gravel	25	450	Clay	12	850
Clay, sticky	40	490	Sand	2	852
Anhydrite	35	525	Clay	29	881
Clay, yellow	40	565			
Well Q-7					
Clay and soil	30	30	Sand and gravel	222	800
Sand and gravel	268	298	Clay, sticky	30	830
Rock, brown	60	358	Clay and some gravel	20	850
Sand, brown	212	570	Clay	10	860
Rock, red	8	578	Clay and gravel	10	870

Owner: City of Marfa. Driller: Layne-Texas Co.

Owner: City of Marfa. Driller: E. Harrell.

(Continued on next page)

Table 4.--Drillers' logs of wells in the Marfa area--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Well Q-7--Continued					
Sand and gravel	5	875	Lava and clay	25	990
Clay	9	884	Lava, brown	14	1,004
Gravel	5	889	Lava and clay	29	1,033
Clay	1	890	Rock, broken, and clay	67	1,100
Lava, brown	75	965			
Well Q-10					
Owner: A. R. Eppenaur. Driller: Harrell & Threatt.					
Topsoil	5	5	Sand (water)	20	667
Sand	209	214	Clay, sticky	83	750
Sand (water)	33	247	Sand (water)	18	768
Rock, black	94	341	Shale	22	790
Shale	99	440	Sand (water)	52	842
Sand (water)	27	467	Shale, sticky	187	1,029
Shale	180	647			
Well R-7					
Owner: J. C. Mitchell. Driller: Texas-Ajax Co.					
Sand, yellow	75	75	Rock, black, fine, very hard	100	490
Sand, yellow, trace of clay	25	100	Rock, red, coarse	20	510
Sand, yellow, hard	180	280	Shale, red	26	536
Sandstone, yellow	90	370	Shale, white	34	570
Gravel, coarse (water)	5	375	Sand, white, fine	6	576
Sand, blue, very hard	15	390	Shale, white, sandy	79	655

(Continued on next page)

Table 4.--Drillers' logs of wells in the Marfa area--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Well R-7--Continued					
Sand, yellow (water) ---	5	660	Clay, yellow, tough ----	45	1,335
Clay, yellow (trace of water) ----------	110	770	Clay, red ----------	58	1,393
Shale, blue ----------	30	800	Sand (water) ----------	7	1,400
Shale, gray ----------	105	905	Clay, red ----------	5	1,405
Sand (large flow of fresh water) --------	37	942	Clay, light pink to yellow ----------	10	1,415
Clay, yellow, sticky ---	37	979	Clay, red ----------	5	1,420
Sand, fine to coarse (water) ----------	101	1,080	Sand ----------	3	1,423
Sand, black, hard ------	33	1,113	Clay, pink to yellow ---	22	1,445
Sand, red, soft (water)-	3	1,116	Clay, white ----------	45	1,490
Sand, red, sticky ------	24	1,140	Sand (water) ----------	20	1,510
Clay, white ----------	20	1,160	Clay, white ----------	15	1,525
Sand ----------	5	1,165	Clay, pink ----------	15	1,540
Clay, white ----------	20	1,185	Sand ----------	10	1,550
Sand, red ----------	105	1,290	Clay, white ----------	25	1,575
			Clay, red, tough ------	140	1,715

Well R-10

Owner: B. Mitchell. Driller: -- Wheeler.

Soil ----------	7	7	Basalt and coarse sand -	20	85
Sand and gravel --------	6	13	Rock, brown, hard ------	15	100
Rock ----------	9	22	Rock, black ----------	18	118
Sand and gravel --------	9	31	Sand and gravel --------	27	145
Sand and boulders ------	19	50	Rock ----------	11	156
Caliche, gray ----------	15	65	Sandstone ----------	24	180

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Table 4.--Drillers' logs of wells in the Marfa area--Continued

Thickness (feet)	Depth (feet)	Thickness (feet)	Depth (feet)
Well R-10--Continued			
Sand and gravel -------- 20	200	Sand, dark-gray and brown, coarse ---------- 410	875
Sand, very fine, cemented with lime ---------- 50	250	Sand, dark-gray and brown, coarse, cemented with lime ---------- 140	1,015
Sand, medium, variegated 55	305	Rock, variegated, hard - 15	1,030
Sand, brown and black, coarse ---------- 20	325	Rock, white, quartz, and quartzite ---------- 85	1,115
Rock, black, and secondary calcite ---- 75	400	Rock, black, some brown quartz and white calcite grains ------- 65	1,180
Rock, milk-white, hard, noncalcareous -------- 65	465		
Well R-16			
Owner: B. Mitchell. Driller: Layne-Texas Co.			
Soil ---------- 4	4	Shale and gravel ------- 7	365
Caliche ---------- 6	10	Shale and lime --------- 10	375
Gravel and yellow sand - 15	25	Lime, hard ---------- 20	395
Gravel ---------- 3	28	Shale, red ---------- 5	400
Sand and gravel -------- 17	45	Lime, hard ---------- 27	427
Sand, yellow, fine ----- 40	85	Shale ---------- 8	435
Sand, yellowish-gray --- 5	90	Shale and white lime --- 15	450
Sand, yellow ---------- 25	115	Shale ---------- 20	470
Shale and yellow sand -- 35	150	Lime, hard ---------- 11	481
Shale ---------- 15	165	Gravel and sand -------- 11	492
Sand ---------- 135	300	Shale ---------- 8	500
Shale ---------- 25	325	Shale and lime --------- 20	520
Shale and lime --------- 25	350	Shale ---------- 25	545
Shale ---------- 8	358	Shale, yellow ---------- 20	565

(Continued on next page)

Table 4.--Drillers' logs of wells in the Marfa area--Continued

Thickness (feet)	Depth (feet)	Thickness (feet)	Depth (feet)

Well R-16--Continued

Lime and shale	35	600	Lime and shale	74	934
Shale, brown	25	625	Lime, sandy	71	1,005
Lime, sandy	15	640	Sand, coarse	10	1,015
Lime and shale	50	690	Lime, sandy	27	1,042
Lime, sandy	15	705	Lime and coarse, soft, gray sand	58	1,100
Shale	15	720	Lime, fine, hard	15	1,115
Lime, sandy	140	860			

Well R-20

Owner: Presidio County. Driller: J. R. Watson.

Topsoil	6	6	Sand and clay to black shale	10	135
Sand, yellow	11	17	Conglomerate	80	215
Malpais, broken	5	22	Malpais, gravel, clay, and sand	70	285
Rock, brown, broken	23	45	Shale, brown, and dark-brown malpais	435	720
Clay and gravel	19	64	Limestone, gray sand, and boulders (water)	30	750
Malpais, broken	4	68	Sand, washed, pea gravel, and limerock	50	800
Rock, dark-brown	21	89	Clay, dark-red	40	840
Rock, light-brown	15	104			
Malpais, clay, and rock-	21	125			

Well R-21

Owner: Presidio County. Driller: J. R. Watson.

Soil	1	1	Clay and boulders	25	70
Caliche	4	5	Rock, red	30	100
Clay	40	45	Rock, brown, hard	5	105

(Continued on next page)

Table 4.--Drillers' logs of wells in the Marfa area--Continued

	Thickness (feet)	Depth (feet)
Well R-21--Continued		
Bedrock and sandy clay	99	204
Clay, gray, sandy	18	222
Clay and malpais	1	223
Conglomerate, clay, sand, and gravel	96	319
Conglomerate, clay, gravel, and boulders	33	352
Rock, red, clay, and malpais	16	368
Rock, brown, clay, conglomerate and gravel	88	456
Rock, red, malpais, and conglomerate	23	479
Rock, brown, and soapstone	15	494
Clay and gravel	52	546
Clay, sandy, and gravel, sulfur	27	573
Rock, red, and volcanic conglomerate	20	593
Conglomerate	32	625
Rock, red, gray shale, and soapstone	36	661
Rock, red, sand, and clay	8	669
Conglomerate, red clay, and boulders	12	681
Sand, gray, and volcanic ash	104	785
Rock, black, and gray sandy clay	15	800
Clay, red	14	814
Soapstone, sandstone, and milky clay	23	837
Limestone, gray	43	880
Sandstone, red, hard	20	900
Sand, red (water)	31	931
Sandstone, red, blue limestone, and shale	24	955
Limestone, gray	45	1,000
Sandstone, red, hard	6	1,006
Rock, red, flint, and quartz	49	1,055
Conglomerate, flint, red rock, and quartz	43	1,098
Limestone, gray	53	1,151
Rock, red, hard, and quartz	61	1,212
Quartz	9	1,221
Granite, black	4	1,225
Limestone, red, and quartz	45	1,270
Clay and red shale	45	1,315
Clay and shale	13	1,328
Clay, pink	19	1,347
Clay, red, and shale	83	1,430
Sandstone, red, soft	38	1,468
Shale, red, and soapstone	20	1,488

(Continued on next page)

Table 4.--Drillers' logs of wells in the Marfa area--Continued

Thickness (feet)	Depth (feet)	Thickness (feet)	Depth (feet)
Well R-21--Continued			
Rock, red ---------- 22	1,510	Shale, red ---------- 7	1,615
Rock, black ---------- 18	1,528	Sandstone and iron ----- 15	1,630
Rock, red, and clay ---- 48	1,576	Limestone, red --------- 72	1,702
Rock, black ---------- 32	1,608	Sandstone, red, and white clay ---------- 33	1,735
Well R-24			
Owner: Santa Fe Ry. Driller: McSpadden Bros.			
Caliche ---------- 9	9	Sandstone, red --------- 4	634
Loam, red, sandy, fine - 84	93	Clay, yellow ---------- 16	650
Sandstone, red (water) - 3	96	Limestone, white ------- 12	662
Clay, yellow, trace of gravel ---------- 189	285	Clay, sandy ---------- 60	722
Clay, red ---------- 75	360	Sandstone, green, tight- 40	762
Clay, yellow ---------- 140	500	Sandstone, green, very hard ---------- 4	766
Sand, red ---------- 16	516	Sandstone, black and green, very soft and coarse (water) ------- 34	800
Clay, yellow ---------- 114	630		
Well S-4			
Owner: Vivian McIntyre. Driller: McSpadden Bros.			
Loam, sandy ---------- 3	3	Sandstone, red --------- 3	113
Conglomerate ---------- 36	39	Clay, red ---------- 1	114
Limestone ---------- 8	47	Rock, black, and iron -- 12	126
Sandstone, red --------- 20	67	Sandstone, red and clay- 5	131
Clay, red, and gravel -- 8	75	Shale, red ---------- 17	148
Clay, red, and sandstone 35	110	Sandstone, red --------- 5	153

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Table 4.--Drillers' logs of wells in the Marfa area--Continued

Thickness (feet)	Depth (feet)	Thickness (feet)	Depth (feet)
Well S-4--Continued			
Clay, red, some gravel - 45	198	Sandstone ---------- 5	305
Clay, red, hard -------- 14	212	Sandstone (water) ------ 18	323
Shale, red ---------- 5	217	Sandstone, gray, hard -- 13	336
Sandstone, red --------- 39	256	Shale ---------- 7	343
Clay, yellow ---------- 21	277	Limestone ---------- 12	355
Rock, black ---------- 3	280	Sandstone, red --------- 29	384
Sandstone (trace of water) 9	289	Sandstone, hard -------- 15	399
Shale, yellow ---------- 11	300	Limestone ---------- 5	404

Well Z-5 (partial log)

Owner: Mitchell Bros. and State of Texas. Driller: Argo Oil Corp.

Tertiary:			Cretaceous:		
Buck Hill volcanic series of Goldich and Seward (1948)			Limestone ----------	600	3,600
			Permian:		
Duff formation of Goldich and Elms (1949) ----------	1,500	1,500	Guadalupe series -----	510	4,110
			Leonard series -------	770	4,880
Cottonwood Springs basalt of Goldich and Elms (1949) ----	220	1,720	Wolfcamp series ------	2,740	7,620
			Pennsylvanian:	2,373	9,993
Pruett formation of Goldich and Elms (1949) ----------	190	1,910	Total depth ----------		15,230
Crossen trachyte(?) of Goldich and Elms (1949) ----------	350	2,260			
Tuff and fresh-water limestone members ----------	740	3,000			

Table 5.--Analyses of water from wells in the Marfa area

(Analyses are in parts per million except for specific conductance, ph, percent sodium, and sodium-adsorption-ratio)

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
Q-6	City of Marfa	881	July 19, 1948	72	0.05	-	26	2.2	59 13	192	26	17	2.8	4.2	0.20	328	74	59	3.0	442	7.6
Q-6	do	881	July 31, 1959	74	.04	0.00	28	2.2	64 7.3	190	25	20	2.5	11	.19	332	79	61	3.1	447	7.3
Q-8	A. R. Eppenaur	429	July 31, 1958	76	.00	.00	28	3.1	61 8.4	190	27	18	2.8	9.6	.21	336	83	59	2.9	449	7.4
R-8	C. Gage	180	Aug. 17, 1942	-	-	-	-	-	-	282	116	51	-	22	-	-	-	-	-	-	-
R-9	Mrs. D. G. Forker	350	do	-	-	-	-	-	-	210	72	24	-	8.0	-	-	-	-	-	-	-
R-10	B. Mitchell	1,180	Apr. 6, 1943	58	.05	-	24	3.6	121	247	81	28	3.1	5.4	-	487	75	78	6.1	-	8.2
R-15	do	160	Aug. 17, 1942	-	-	-	-	-	-	284	95	35	-	20	-	-	-	-	-	-	-
R-19	Mrs. D. G. Forker	400	do	-	-	-	-	-	-	189	69	37	-	4.5	-	-	-	-	-	-	-
R-20	Presidio County	840	Aug. 18, 1942	40	.05	-	34	3.5	78 3.5	199	48	30	3.2	6.7	-	341	100	63	3.4	-	7.7
R-21	do	1,735	Apr. 12, 1943	42	.08	-	26	3.2	63	177	32	19	3.0	3.5	-	290	78	64	3.1	-	8.4
R-24	Santa Fe Ry.	800	Sept. 8, 1943	-	-	-	23	3.2	63	195	25	13	-	3.8	-	-	71	66	3.3	-	-
R-24	do	800	Aug. 25, 1958	75	.01	-	27	2.9	58 7.2	190	26	16	2.4	5.0	.28	314	79	59	2.8	427	7.7
R-29	H. Mitchell	300	Aug. 17, 1942	-	-	-	-	-	-	207	92	62	-	11	-	-	-	-	-	-	-
R-30	Hendricks Estate	225	do	-	-	-	-	-	-	218	28	22	-	11	-	-	-	-	-	-	-
R-32	Claude Lee	-	do	-	-	-	-	-	-	231	76	34	-	8.2	-	-	-	-	-	-	-
X-4	M. Robison	99	Aug. 3, 1958	65	.01	-	57	6.6	14 8.3	219	10	6.2	.4	8.4	.18	295	169	14	.5	410	7.2