Report 323

Hydrogeology of the Terlingua Area, Texas

March 1990

Texas Water Development Board

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by

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ABSTRACT

The hydrogeology of the Terlingua area in West Texas is both varied and complex. Stratigraphically, rocks of three major geologic eras occur in the study area, with Cenozoic and Mesozoic strata cropping out at the surface, and Paleozoic rocks lying below.

Specific Cenozoic formations around Terlingua include alluvial stream deposits, slope talus, and pediment gravels. Igneous laccoliths and sills of Tertiary age form isolated mountain peaks in both northern and southern parts of the study area.

Mesozoic formations in the Terlingua area are solely of Cretaceous age, and have a composite thickness of 5,000 feet. Lower and middle parts of the Cretaceous section are composed of marine limestones and marls, while upper parts of the section consist mainly of continental shales and sandstones.

There are three relatively shallow aquifers in the Terlingua area that are hydraulically connected in some places and that are separated by thick regional aquitards in others. The aquifers occur in: (1) Quaternary alluvium and terrace deposits; (2) Tertiary intrusive rocks; and (3) Cretaceous strata.

Ground water in the alluvium and terrace deposits is restricted to areas immediately adjacent to Terlingua Creek and its tributaries and moves towards and along stream courses in a southerly direction. The water is slightly saline and is very hard.

Fresh to moderately saline ground water fills joints and fractures in the Tertiary igneous intrusive rocks that form isolated mountain peaks around Terlingua. Fresh water in the igneous aquifers occurs usually near ground surface where exposed laccoliths and sills receive meteoric recharge. Discharge from the aquifers is by cross-formational flow at depth and by surface spring seepage.

Ground water flows through faulted and intruded Cretaceous formations in the study area forming an aquifer system that is both structurally and hydrologically complex. In descending stratigraphic order, specific water-bearing formations in the Cretaceous section around Terlingua include the Boquillas Formation, Buda Limestone, Santa Elena Limestone, Del Carmen Limestone, and Glen Rose Limestone. The water-bearing strata are commonly separated or overlain by thick clay and marl aquitards within which sandstone facies also transmit limited amounts of ground water to certain parts of the study area.

Ground-water movement in Cretaceous formations around Terlingua is generally to the south-southeast along limestone joints, fractures, and bedding planes. There is also substantial water movement through solution cavities that are particularly well developed in upper parts of the Santa Elena Limestone.

Ground water in the Cretaceous aquifer system is slightly to moderately saline, with solute concentrations ranging generally between 1,000 and 5,000 mg/l. The water is typically very hard, and regularly has excessive concentrations of sulfate, chloride, and fluoride. Radioactivity has been detected in water from three wells completed in the Santa Elena Limestone at levels higher than those considered safe for drinking by both state and federal health agencies. Also, many deeper wells and mine shafts completed in the Cretaceous aquifer system around Terlingua produce water with a temperature range between 100 and 113 degrees Fahrenheit.

Future ground-water development in the study area should focus on water in fractured Tertiary intrusive rocks and on undeveloped cavernous intervals in the Cretaceous aquifers, especially in the Santa Elena Limestone. Surface dams and reservoirs may also be constructed in the study area along tributary drainages to Terlingua Creek. There is a substantial demand and need for additional fresh-water supply in the Terlingua area from local residents and from businesses that cater to the estimated one quarter million people who visit nearby Big Bend National Park each year.

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INTRODUCTION

Location and Setting

The Terlingua area is located along the western edge of Big Bend National Park in the Trans-Pecos region of West Texas (Figure 1). It derives its name from the community of Terlingua, a small population center located within the map boundary that was established when mercury ore was discovered in the region during the middle part of the nineteenth century.

The terrain around Terlingua is characterized by isolated volcanic peaks, dissected mesas, and broad alluvial washes. Only scant vegetation covers much of the desert region, with mesquite and catsclaw growing mainly along alluviated stream courses, and creasote brush, lechuguilla, yucca, sotol, and ocotillo growing elsewhere on uplifted mesas and along talus slopes at the base of volcanic peaks and ridges.

Elevations in the rugged desert country range from approximately 2,300 feet to slightly more than 3,800 feet above sea level, with lower elevations lying mostly along Terlingua Creek, the primary drainage in the region. All surface-water runoff into Terlingua Creek flows southward, filtering into surficial alluvial deposits when not draining into the Rio Grande at the east portal of Santa Elena Canyon immediately south of the study area.

Climate

The climate around Terlingua is arid, with precipitation averaging approximately 10 inches per year. Much of the precipitation falls during intermittent, torrential rain storms that occur most frequently in late summer and early fall months, particularly July and September.

The mean annual temperature in the study area is about 65 degrees Fahrenheit (F). However, daytime summer temperatures are regularly higher than 100 degrees F, and sometimes exceed 120 degrees F.

Winter climate is generally invigorating, with days commonly being warm and sunny, and evening temperatures sometimes dropping below freezing. Snow occasionally falls on higher peaks and, more rarely, over lower terrain when winter cold fronts move across the region lowering temperatures below 20 degrees F at times.

Economy

The population of Terlingua and vicinity has never been large, and the economy of the region has been limited mostly to local mineral resource development, ranching, and tourism. Mercury ore was discovered in the region as early as 1850. In 1898, a post office was established at the mining community of

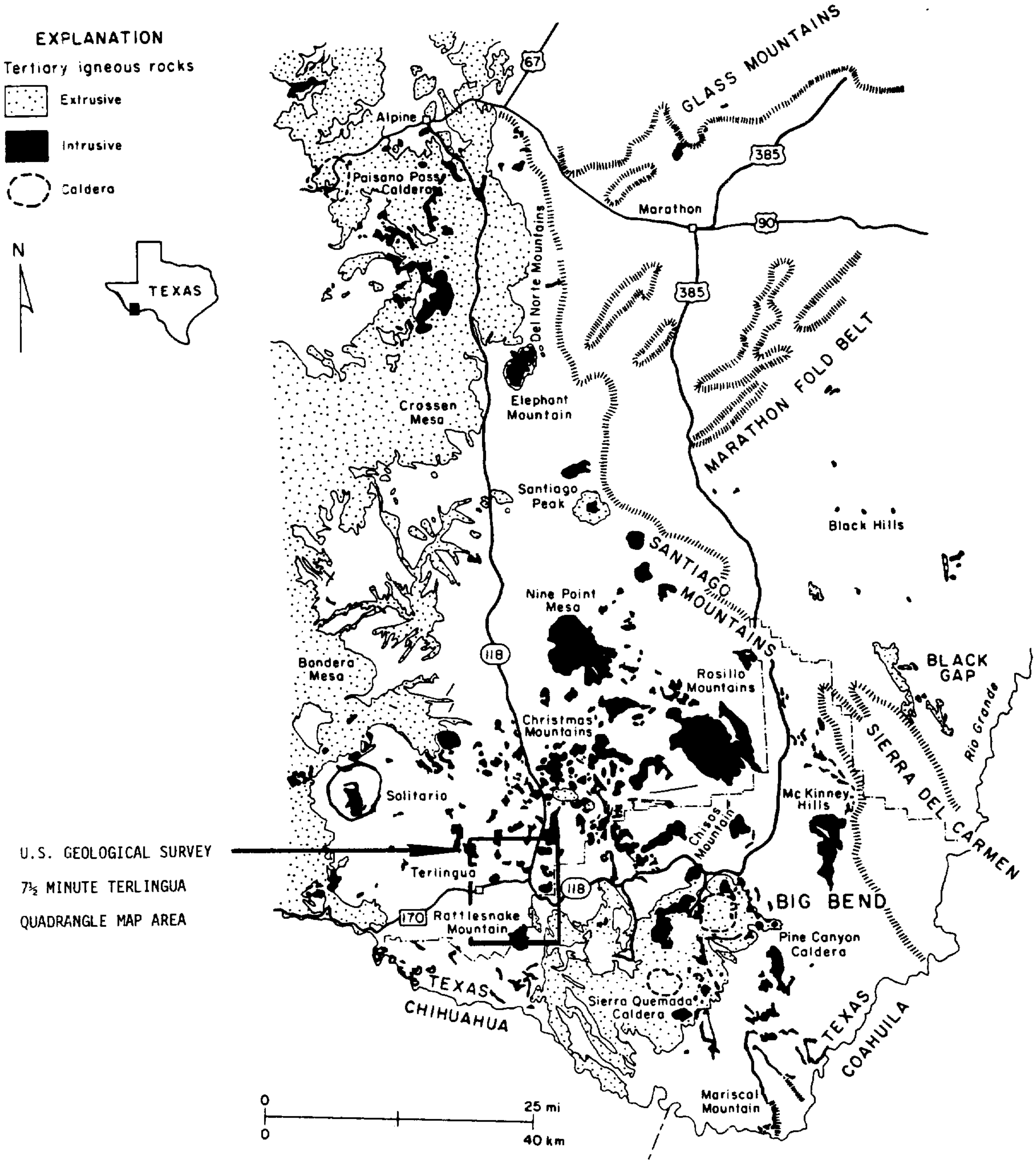


Figure 1

Map Showing the Location of the Terlingua Study Area
(After Price, Henry, Parker and Barker, 1986)

Terlingua. By 1903, upwards to 3,000 people are reported to have been living in and around Terlingua, a number that triples the area's estimated present population of approximately 1,000, which is largely seasonal.

Mining of mercury ore in the Terlingua area was greatest during World Wars I and II, with many mines closing and mine workers departing after the end of each war. Still, the district is reported to have produced more than 150,000 flasks of quicksilver valued at several million dollars before 1947 (Yates and Thompson, 1959) when all mines in the region were effectively shut down due to declining mercury prices and largely depleted ore zones. Only in the late 1950's were any mercury mines in the Terlingua district reactivated for a short period before being closed again in the late 1960's.

Ranches around Terlingua have been active under various ownerships since the mid to late 1800's. Overgrazing occurred during pre-war years in the early 1900's, and as a result, the terrain in and around Terlingua is far too barren to support large herds of livestock today. Sheep are best adapted to the region, and cattle grazing is restricted largely to brushy floodplain areas along Terlingua Creek.

Numerous tourists pass through Terlingua each year to view western ghost town mining ruins and to survey the western limits of Big Bend National Park. Local businesses that cater to the tourist trade are located in Terlingua and Study Butte, the only communities situated inside the study area. Lajitas, immediately to the west, also offers local services to the tourist fare.

Previous Investigations

Numerous articles and reports have been written about the Terlingua district with most of the publications addressing mining developments and geology in the region. In 1896, W.P. Blake reported on mercury ore deposits around Terlingua. B.F. Hill (1902), J.A. Udden (1911), and F.L. Ransome (1917) followed with other published accounts about the region's history, stratigraphy and general geology. Later, in the 1940's, J.T. Lonsdale prepared a report describing igneous rocks in the Terlingua-Solitario area. Then, R.G. Yates and G.A. Thompson (1959) provided an updated description of the geology and quicksilver deposits in the Terlingua district in U.S. Geological Survey Professional Paper 312.

More recent studies of the regional geology around Terlingua include R.A. Maxwell's 1968 guide to rocks, geologic history, and settlers in the Big Bend area; V.E. Barnes' 1979 Geologic Atlas of Texas, Emory Peak-Presidio Sheet; C.D. Henry and J.G. Price's 1985 summary of tectonic developments in Trans-Pecos Texas; D.W. DeCamp's 1985 interpretation of the structural geology of Mesa de Anguila; and R.J. Erdlac, Jr.'s 1988 interpretation of the structural development of the Terlingua uplift in Brewster and Presidio Counties, Texas.

Relatively few reports have been published that address ground water in the Terlingua-Study Butte area. However, a private water-supply study of the Terlingua district was performed by Ed Reed and Associates, consulting hydrologists, in 1972. C.D. Henry also briefly notes the existence of hot ground water in mines and wells around Terlingua in a 1979 report addressing the geologic setting and geochemistry of thermal waters in Trans-Pecos Texas, and Brune (1981) offers short descriptions of Maverick and Joe Black Springs near Study Butte in Springs of Texas. Well log data and water quality analyses for water collected from wells in the study area are on file with the Texas Water Development Board and the Texas Water Commission in Austin.

Acknowledgements

A number of private citizens who live in the greater Terlingua-Study Butte area are to be thanked for contributing time and for providing information incorporated in this report. Professionals who contributed information used in the report include: E. T. Baker, Jr., Geologist, U.S. Geological Survey; Dick Baker, Dick Baker Drilling Company, Marfa, Texas; Jim Bones, Professional Photo Journalist and Guide, Tesuque, New Mexico; Bob Cook, Cook Drilling Company, Monahans, Texas; Steve Dennis, Professional Engineer, Midland, Texas; Pat Dickerson, Professional Geologist, Midland, Texas; Richard Erdlac, Jr., PhD candidate, University of Texas; Eugene Herron, Southern Methodist University; Bill Muehlberger, University of Texas; Gene Thompson, and the staff at Big Bend Motor Inn, Study Butte, Texas; and Ed Reed and Associates, Consulting Hydrologists, Midland, Texas.

GEOLOGY

Stratigraphy

Introduction

Essentially all rocks and sediments exposed at ground surface in the Terlingua area can be classified as either: (1) stream sediments, slope talus, and pediment gravels of Quaternary and Tertiary age; (2) igneous intrusive and extrusive rocks of Tertiary age; or (3) terrestrial and marine strata of Cretaceous age (Table 1, Figure 2). The surficially exposed strata are underlain by rocks of Cenozoic, Mesozoic, Paleozoic, and Pre-cambrian age (Figures 3 and 4).

Cenozoic Rocks

Quaternary and Late Tertiary Sediments

Stream alluvium and terrace deposits of Quaternary age underlie and bound Terlingua Creek and its tributary drainages. The deposits range from less than a foot to more than 60 feet thick and consist of poorly sorted sands, gravels, silts, and clays derived from local limestone, sandstone, clay, and igneous bedrock sources.

Slope talus of Quaternary and Late Tertiary age covers mountain slopes in some parts of the study area. The deposits are estimated to be more than 100 feet thick locally, and are composed mostly of angular, igneous rock debris shed from higher peaks and ridges adjacent to the deposits.

Older terrace gravels and pediment veneer of Quaternary and Late Tertiary age also mantle uplifted mesas and highlands around igneous extrusive and intrusive complexes in the map area. The gravels and pediment veneer are more than 50 feet thick in places and are commonly calichified. The terrace gravels have numerous igneous rock fragments in their sedimentary framework and have been developed locally as a source of road material inside the Big Bend National Park boundary.

Tertiary Igneous Rocks

Igneous extrusive and intrusive rocks form a cluster of isolated mountain peaks and ridges in northern and southeastern parts of the study area. The igneous rocks either were emplaced as sills, dikes, plugs, and laccoliths, or were extruded as lava flows and ash in mid-to late Tertiary time (Figure 5).

Mesozoic Rocks of Cretaceous Age

Introduction

Seven Cretaceous-age formations crop out along incised stream canyons, on uplifted mesas, and around the flanks of igneous mountain peaks. The formations either conformably or disconformably overlie one another and, in descending

Table 1.
Stratigraphic Units and Their Water-Bearing Characteristics

ERA	PERIOD	SERIES	ROCK UNITS	HYDROLOGY
Cenozoic	Quaternary		Alluvium Consolidated Gravels	Yields small to moderate amounts of slightly saline water to shallow wells along Terlingua Creek and its tributaries.
Cenozoic	Tertiary		Consolidated Gravels Basalt Flows Microgranitic Sills and Dikes Gabbroic Sills	Yields small amounts of fresh to moderately saline water to springs and wells.
Mesozoic	Cretaceous	Gulfian	Javelina Formation	Limited aquifers yielding small amounts of moderately saline water from sandstone facies.
Mesozoic	Cretaceous	Gulfian	Aguja Formation	Limited aquifers yielding small amounts of moderately saline water from sandstone facies.
Mesozoic	Cretaceous	Gulfian	Pen Formation	Limited aquifers yielding small amounts of moderately saline water from sandstone facies.
Mesozoic	Cretaceous	Gulfian	Boquillas Formation	Yields small amounts of slightly saline water to wells.
Mesozoic	Cretaceous	Comanchean	Buda Limestone	Yields small amounts of undetermined quality water to wells.
Mesozoic	Cretaceous	Comanchean	Del Rio Clay	Aquitard.
Mesozoic	Cretaceous	Comanchean	Santa Elena Limestone	Yields moderate to large amounts of slightly saline water to wells. May have elevated radioactivity levels.
Mesozoic	Cretaceous	Comanchean	Sue Peaks Formation	Aquitard.
Mesozoic	Cretaceous	Comanchean	Del Carmen Limestone	Aquifer characteristics unknown.
Mesozoic	Cretaceous	Comanchean	Telephone Canyon Formation	Aquitard.
Mesozoic	Cretaceous	Comanchean	Glen Rose Formation	Aquifer characteristics unknown.
Paleozoic	Permian–Cambrian	Wolfcamp–Upper Cambrian	Ouachita Geosynclinal Rocks	Aquifer characteristics unknown.
Precambrian			Amphibolite and Pyroxenite	Aquifer characteristics unknown.

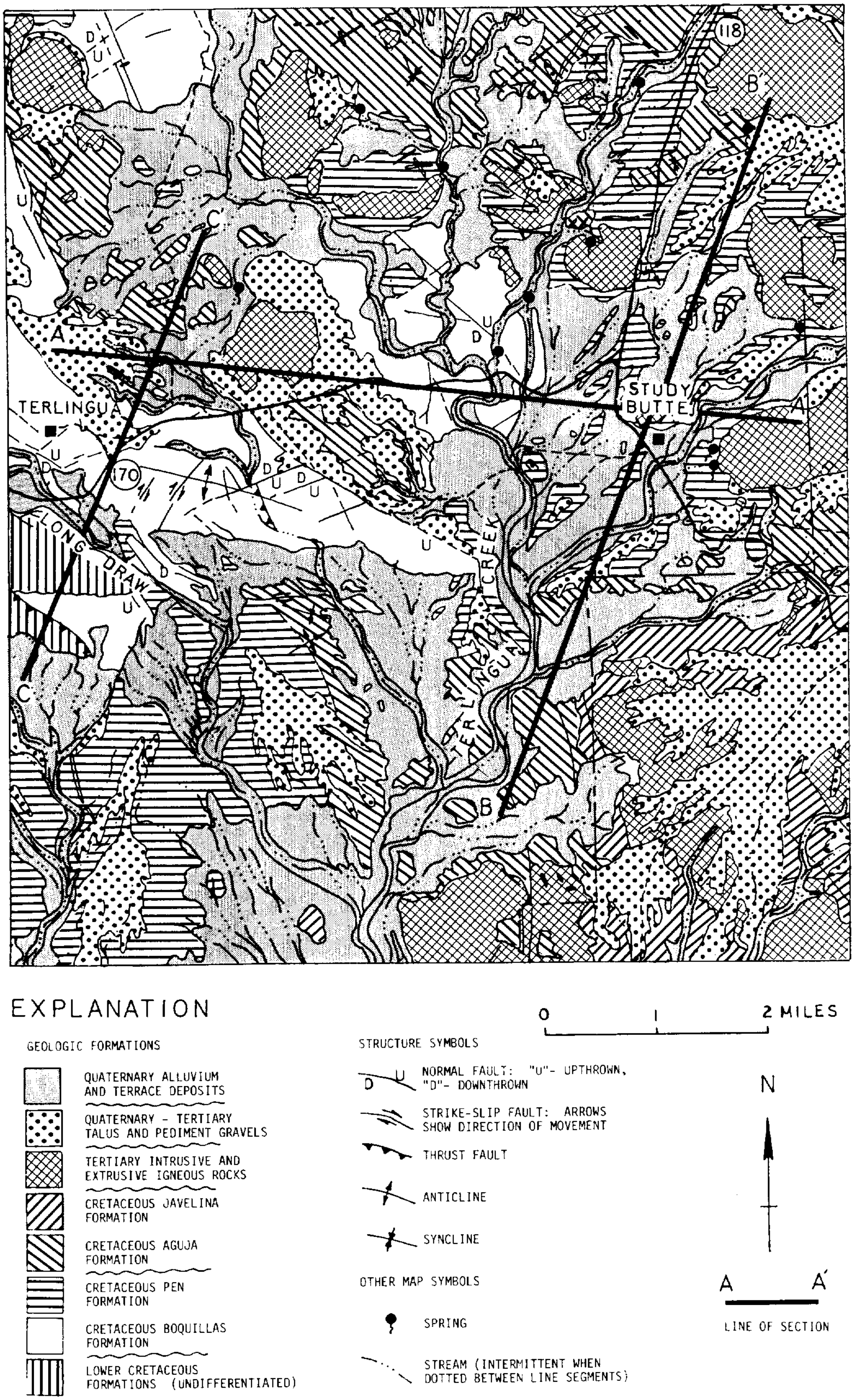
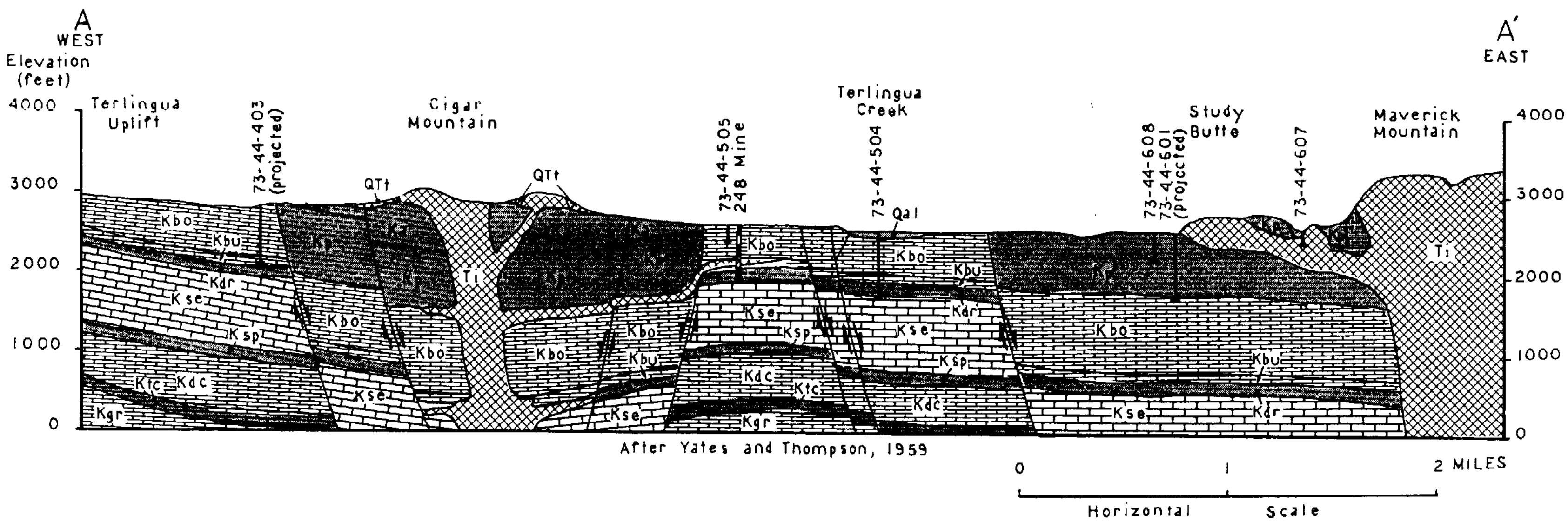


Figure 2

Geologic Map of the U.S. Geological Survey
7 $^1/_2$ - Minute Terlingua Quadrangle
(After Erdlac, Jr., 1988; Maxwell, 1968; and Yates and Thompson, 1959)



EXPLANATION

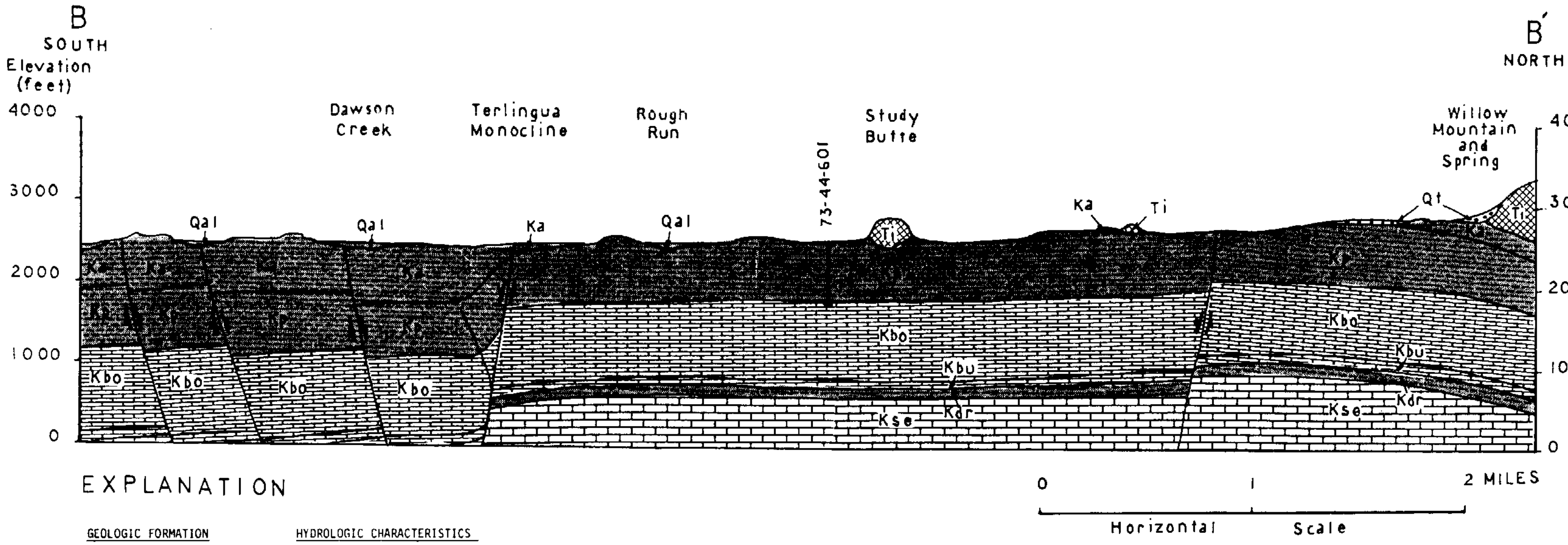
GEOLOGIC FORMATION		HYDROLOGIC CHARACTERISTICS
CENOZOIC	Qal ALLUVIUM	AQUIFER: 10-250 gpm; 1,000-1,400 mg/l tds; Na-SO_4 hydrochemical facies*
	QTt TALUS DEPOSITS	LIMITED AQUIFER:
	Ti IGNEOUS INTRUSIVES AND EXTRUSIVES	AQUIFER: 10-400 gpm; 500-3,000+ mg/l tds; Hydrochemical facies vary with depth.
MESOZOIC	AGUJA FORMATION	LIMITED AQUIFER: Yields small amounts of moderately saline water from sand facies.
	PEN FORMATION	LIMITED AQUIFER: Yields small amounts of moderately saline water from sand facies.
	Kbo BOQUILLAS FORMATION	AQUIFER: 20-80 gpm; 1,600-3,000+ mg/l tds; Na-SO_4 hydrochemical facies.
	Kbu BUDA LIMESTONE	AQUIFER: 10-40 gpm; 1,100-1,300 mg/l tds; Mixed-Mixed hydrochemical facies.
	DEL RIO CLAY	AQUICLUDE:
	Kse SANTA ELENA LIMESTONE	AQUIFER: 100-1,000+ gpm; 1,100-1,300 mg/l tds; Na-Mixed hydrochemical facies.
	SUE PEAKS FORMATION	AQUICLUDE:
	Kdc DEL CARMEN LIMESTONE	AQUIFER:
	TELEPHONE CANYON FORMATION	AQUICLUDE:
	Kgr GLEN ROSE LIMESTONE	AQUIFER:

*Hydrochemical facies are named after the cation and anion that represent more than 50% of the total concentration of cations and anions, respectfully, in a water sample. Mixed facies are assigned when a water sample does not have a prevailing cation or anion concentration.

Figure 3

Geologic Cross Section A-A'

(After Yates and Thompson, 1959)



EXPLANATION

	GEOLOGIC FORMATION	HYDROLOGIC CHARACTERISTICS
CENOZOIC	Qal ALLUVIUM	AQUIFER: 10-250 gpm; 1,000-1,400 mg/l tds; $Na-SO_4$ hydrochemical facies*
	Qt TALUS DEPOSITS	LIMITED AQUIFER:
	Ti IGNEOUS INTRUSIVES AND EXTRUSIVES	AQUIFER: 10-400 gpm; 500-3,000+ mg/l tds; Hydrochemical facies vary with depth.
MESOZOIC	Ka AGUJA FORMATION	LIMITED AQUIFER: Yields small amounts of moderately saline water from sand facies.
	Kp PEN FORMATION	LIMITED AQUIFER: Yields small amounts of moderately saline water from sand facies.
	Kbo BOQUILLAS FORMATION	AQUIFER: 20-80 gpm; 1,600-3,000+ mg/l tds; $Na-SO_4$ hydrochemical facies
	Kbu BUDA LIMESTONE	AQUIFER: 10-40 gpm; 1,100-1,300 mg/l tds; Mixed-Mixed hydrochemical facies.
	Kdr DEL RIO CLAY	AQUICLUDE:
	Kse SANTA ELENA LIMESTONE	AQUIFER: 100-1,000+ gpm; 1,100-1,300 mg/l tds; Na-Mixed hydrochemical facies.
	Ksp SUE PEAKS FORMATION	AQUICLUDE:
	Kdc DEL CARMEN LIMESTONE	AQUIFER:
	Ktc TELEPHONE CANYON FORMATION	AQUICLUDE:
	Kgr GLEN ROSE LIMESTONE	AQUIFER:

*Hydrochemical facies are named after the cation and anion that represent more than 50% of the total concentration of cations and anions, respectfully, in a water sample. Mixed facies are assigned when a water sample does not have a prevailing cation or anion concentration.

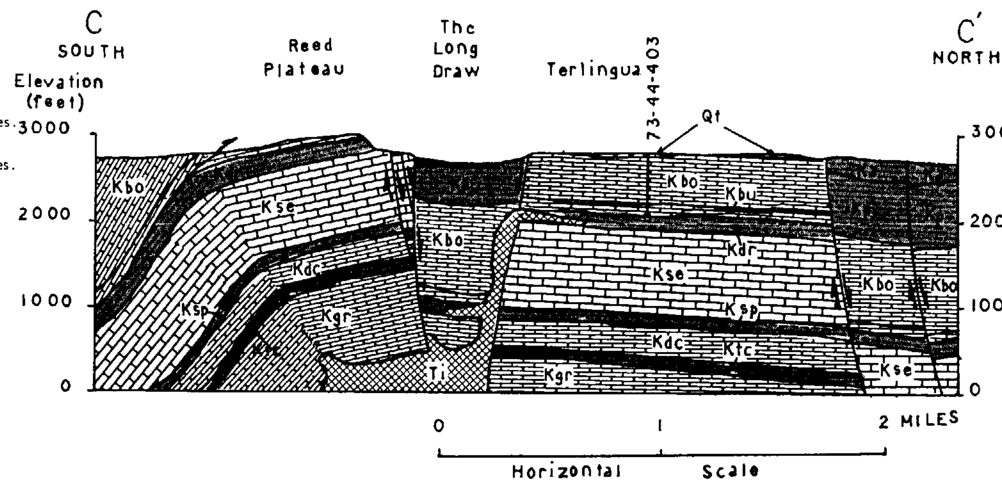


Figure 4

Geologic Cross Sections B-B' and C-C'

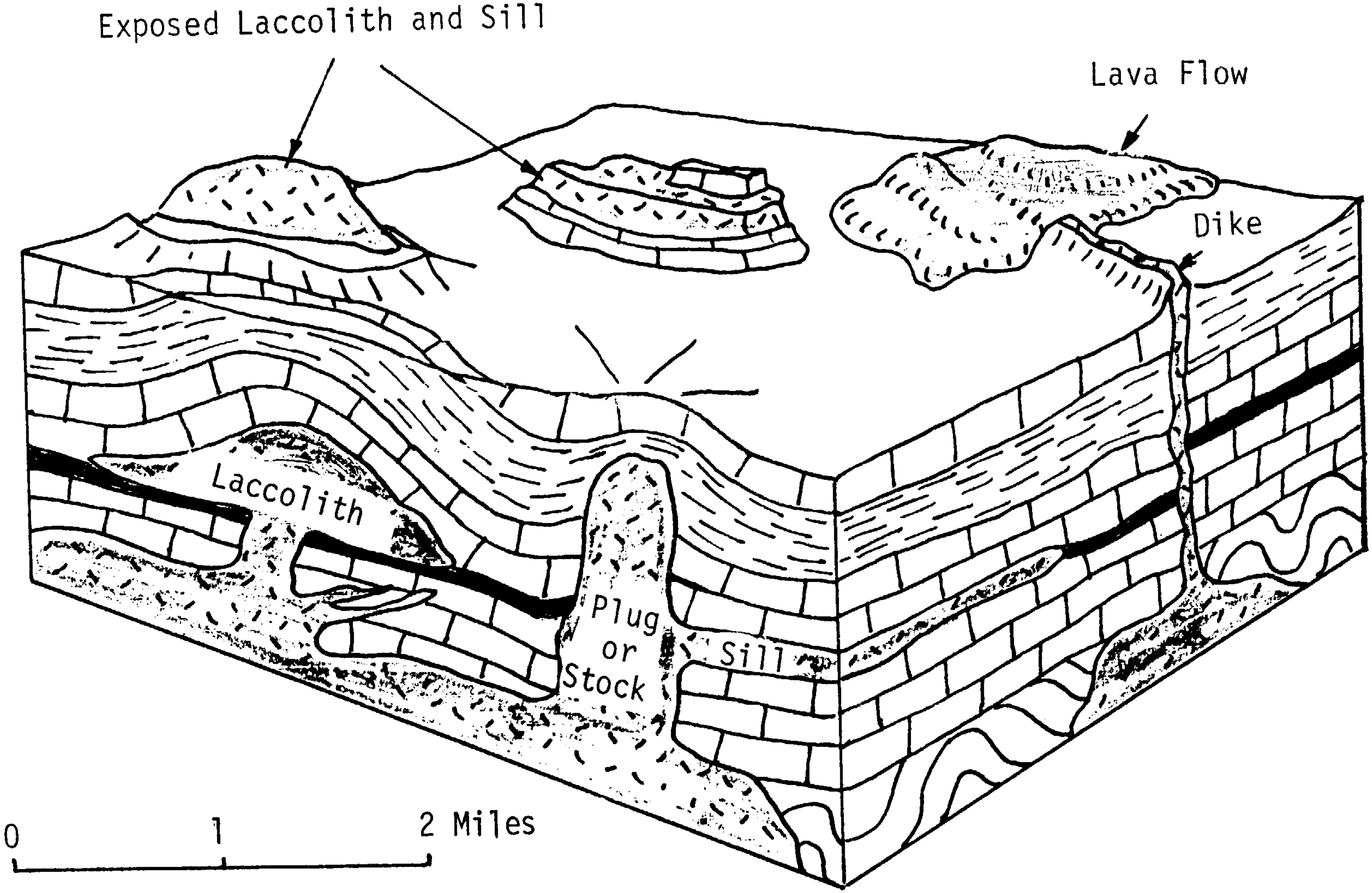


Figure 5

Schematic Block Diagram Showing the Types and Forms of Igneous Extrusions and Intrusions that Occur in the Terlingua Area
(After Maxwell, 1968)

stratigraphic order, include the Javelina Formation, Aguja Formation, Pen Formation, Boquillas Formation, Buda Limestone, Del Rio Clay, and Santa Elena Limestone. Four other Cretaceous-age formations underlie surficially exposed strata in the study area. In descending stratigraphic order, the formations are the Sue Peaks Formation, Del Carmen Limestone, Telephone Canyon Formation, and Glen Rose Limestone.

The Cretaceous section around Terlingua is estimated to have a composite thickness of approximately 5,000 feet. Continental deposits form upper parts of the section, while thick marine sequences form middle and lower stratigraphic intervals.

Javelina Formation

The Javelina Formation is composed of yellow, gray, pink, and maroon bentonitic clay interbedded with a few lenses of yellow-brown, soft, poorly indurated, argillaceous sandstone. It contains dinosaur bone and silicified wood fragments and is a continental deposit that accumulated during Late Cretaceous time (Maxwell, 1968). The formation crops out south of Maverick Mountain and Dawson Creek, mostly inside the Big Bend National Park, in eastern parts of the Terlingua quadrangle map area. It is estimated to be approximately 600 feet thick in the vicinity of Dawson Creek south of Study Butte.

Aguja Formation

The Aguja Formation conformably underlies the Javelina Formation and is composed of yellow-gray to dark brown, medium-grained, carbonaceous sandstone interbedded with yellow-brown and maroon, gypsiferous clay. The Aguja Formation also contains dinosaur bone and silicified wood fragments and is a continental deposit that weathers to form badlands in north- and south-central parts of the study area. The formation has an estimated maximum thickness of 790 feet (Yates and Thompson, 1959).

Pen Formation

The Pen Formation crops out unconformably below the Aguja Formation. It is a blue-gray, calcareous and gypsiferous clay that contains large septarian limestone concretions and fossils of extinct marine organisms, including various kinds of shellfish and marine reptiles. The formation is estimated to be approximately 1,000 feet thick immediately east of Terlingua (Yates and Thompson, 1959) and is particularly well exposed in northern parts of the study area between igneous mountain peaks and ridges.

Boquillas Formation

The Boquillas Formation conformably underlies the Pen Formation and is composed of an upper San Vicente Member and Lower Ernst Member in the study area. The upper San Vicente Member is approximately 500 feet thick and is composed of gray, chalky limestone interbedded with gray to black, flaggy shale. The lower Ernst Member is also approximately 500 feet thick and is composed mostly of yellow-gray to buff, argillaceous limestone, with lesser amounts of gray, chalky shale. The Boquillas Formation crops out mostly in northwest and west-central parts of the Terlingua quadrangle map area, especially along Terlingua Creek and on Cuesta Blanca south of Highway 170.

Buda Limestone

The Buda Limestone disconformably underlies the Boquillas Formation around Terlingua and, according to Yates and Thompson (1959), "...is a white, well-bedded and well-jointed limestone commonly 90 feet thick, but locally as much as 100 or as little as 50 feet thick."

Del Rio Clay

The Del Rio Clay conformably underlies the Buda Limestone and is exposed on Reed Plateau near the western edge of the study area. It is a yellow to yellow-gray, calcareous clay deposit interbedded with a few thin, hard, dark-brown, ferruginous shale beds (Maxwell, 1968). Fossils are abundant in some parts of the formation, which ranges from 100 to 200 feet thick in the Terlingua area.

Santa Elena Limestone

The Santa Elena Limestone, which underlies the Del Rio Clay, is the oldest rock unit to crop out in the Terlingua quadrangle map area. It is exposed on Reed Plateau south of Terlingua and is characteristically a massive, hard, cherty, rudistid-bearing, gray limestone interbedded with a few thin layers of marly and nodular limestone in upper parts of the formation (Maxwell, 1968). The Santa Elena Limestone is estimated to be 1,000 feet thick in the vicinity of Terlingua.

Sue Peaks Formation

The Sue Peaks Formation conformably underlies the Santa Elena Limestone and is composed of yellow to yellow-gray, fossiliferous, calcareous shale interbedded with thin lenses of buff, nodular limestone. It is exposed along the Terlingua fault scarp (Figure 6) that bounds Mesa de Anguila immediately southwest of the study area and is estimated to be between 100 and 150 feet thick.

Del Carmen Limestone

The Del Carmen Limestone, which conformably underlies the Sue Peaks Formation, is a massive, cherty, hard, rudistid-bearing, light brown limestone. The formation is estimated to be approximately 300 feet thick under Terlingua.

Telephone Canyon Formation

The Telephone Canyon Formation, immediately below the Del Carmen Limestone, consists of alternating layers of yellow-gray and buff marl and thin nodular limestone. It is estimated to be approximately 100 feet thick.

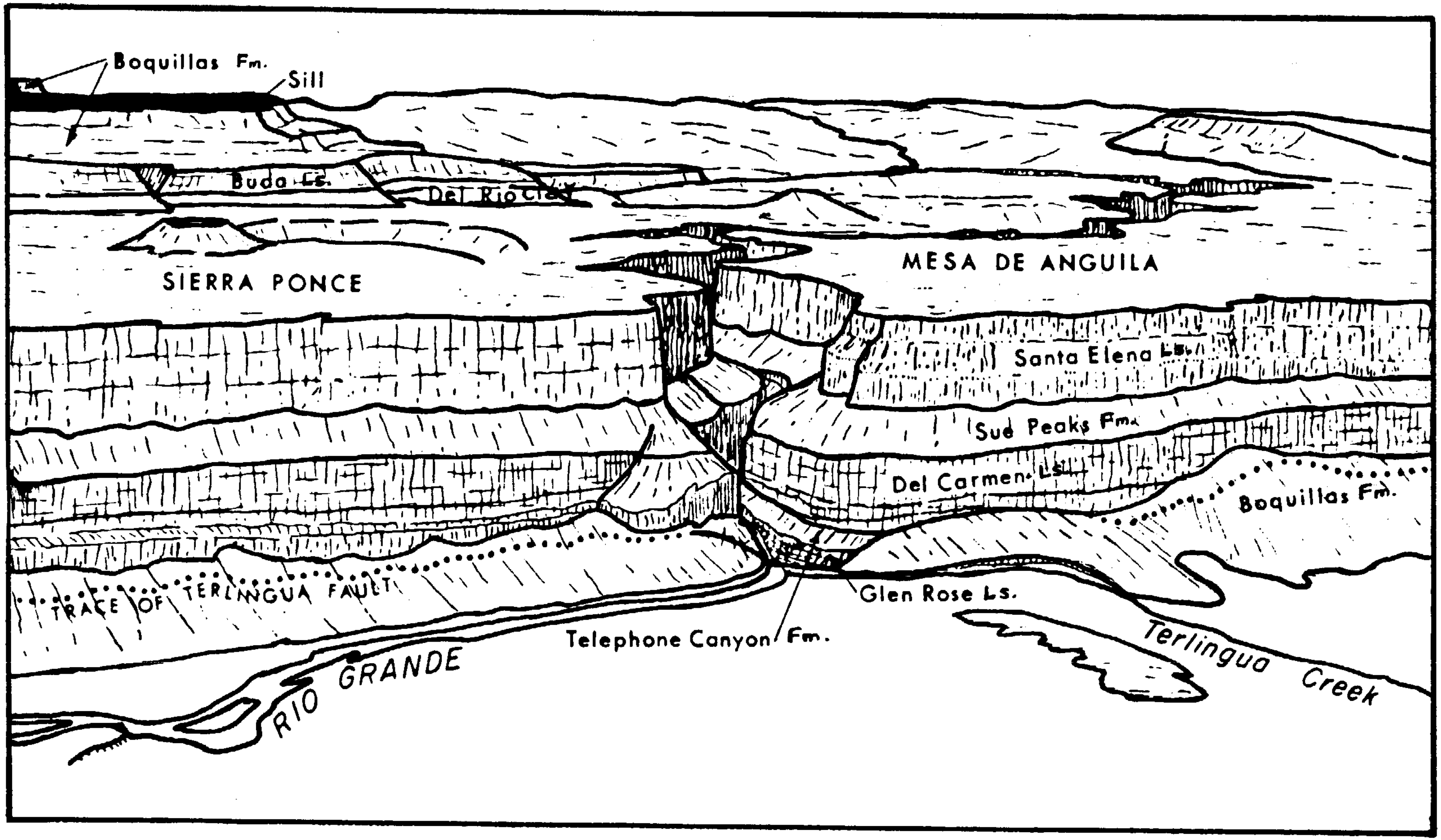


Figure 6

Detailed Sketch of the Terlingua Fault Scarp
Bounding the Northeast Side of Mesa de Anguila
(Source: Maxwell, 1959)

Glen Rose Limestone

The Glen Rose Limestone conformably underlies the Telephone Canyon Formation and is generally composed of massive, hard, dark-gray limestone interbedded with light gray and brown marl. Exceptions occur near its base, where sandstone and conglomerate facies sometimes prevail. It is the oldest Cretaceous-age formation in the western Big Bend region and is estimated to be approximately 1,000 feet thick.

Paleozoic and Precambrian Basement Rocks

Paleozoic rocks of the Ouachita orogenic belt underlie younger Cretaceous sediments (Renfro et al., 1973). The Ouachita rocks crop out below Cretaceous cover near Terlingua in the Marathon basin to the northeast and in the Solatario uplift to the northwest, with structural trends in the Marathon basin projecting directly into the map area. Still older, Precambrian metamorphic rocks also underlie the Paleozoic Strata and occur as xenoliths in Tertiary intrusive rocks near Lajitas immediately west of the study area (Pat Dickerson, 1988, personal communication).

Structure

Regional Setting

The Terlingua area lies primarily within a down-dropped, northwest-trending graben structure that is bound on the west and southwest by the Mesa de Anguila and Terlingua uplifts, and on the east and northeast by the intruded and uplifted cores of the Chisos and Christmas Mountain ranges. Major faults trend northwest, with offsets measuring more than 1,000 feet at some locations. Also, igneous intrusions of Tertiary age have disrupted sedimentary strata in the study area, creating local folds and faults and forming sills, plugs, dikes, and laccoliths.

In a regional sense, the study area lies along the eastern edge of the North American Basin and Range province at the southern end of the Rio Grande Rift system. The Chihuahuan trough and orogenic belt is located immediately to the southwest, and as noted previously, basement rocks in the region are included in the leading edge of the Ouachita overthrust belt.

Local Features

Terlingua Uplift and Monocline

The southwest flank of the Terlingua uplift projects into the west-central part of the study area. Lineament studies of satellite imagery indicate that the upraised structure is crosscut by numerous northwest- and northeast-trending faults and fractures, many of which have been mapped and studied on the surface in some detail (Erdlac, Jr., 1988).

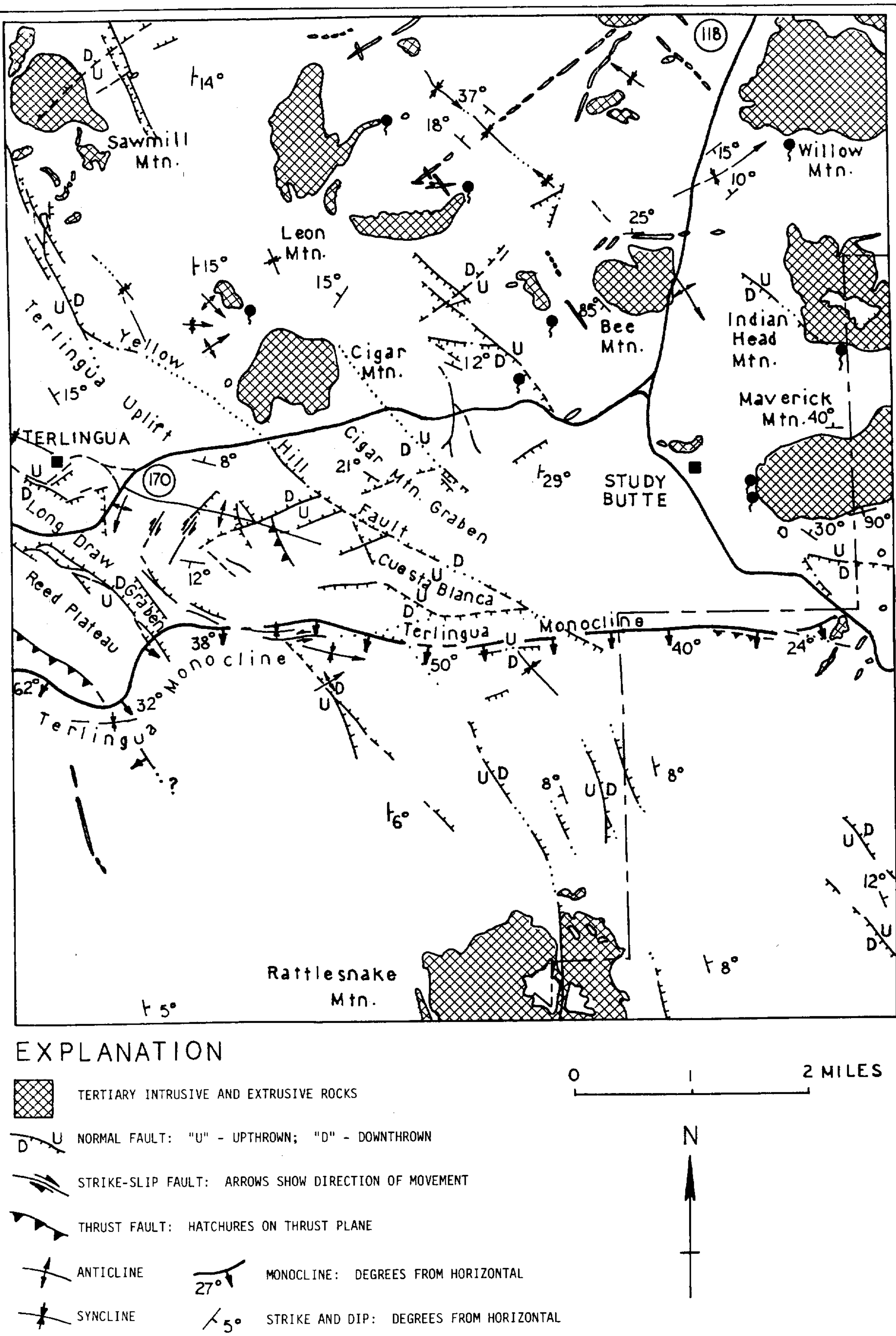


Figure 7

Surface Structure Map of the Terlingua Area

The uplift is bound on the south by the Terlingua monocline and on the east by the Yellow Hill fault (Figure 7). The Long Draw graben also crosses the structure immediately south of Terlingua.

In the study area, there is approximately 2,000 feet of structural downwarp along the Terlingua monocline south of Reed Plateau. Vertical offsets along the Long Draw graben border faults also exceed 1,000 feet in places, diminishing southeastward as the structure crosses the Terlingua monocline.

Faults and Folds

There are numerous faults and folds in Cretaceous strata east of the Terlingua uplift. The majority of faults trend either northwest or northeast, with major offsets occurring primarily along northwest-trending structures. There is also evidence of repeated movements along individual faults in many places, with calcite veins in the structures showing signs of having been broken and displaced, then resealed again.

There is a noticeable lack of large horizontal displacements where intersecting fault trends cross, and fault strikes are commonly angular, suggesting that most movements on larger normal faults in the map area east of the Terlingua uplift have been dip-slip. This contrasts with fault displacements along the southern edge of the Terlingua uplift and monocline, where slickensides and grooves in fault planes often indicate strike-slip components of movement as well.

The northwest-trending Yellow Hill fault, which bounds the east side of the Terlingua uplift, is the longest normal fault structure in the map area. It is also the southwestern border fault of Cigar Mountain graben located approximately midway between Terlingua and Study Butte.

According to Yates and Thompson (1959):

> "The Cigar Mountain graben, striking southeastward from Cigar Mountain, is one of the larger grabens of the Terlingua district. It has a length of about three miles, a width of one mile, and a vertical displacement of 1,000 to 2,000 feet. Its trend projects into the faulted, structurally low area extending northwestward from Cigar Mountain. Cigar Mountain itself is a sill or laccolith intruded during or after the faulting. The southwestern fault of the graben may have served as one of the feeding channels for the intrusion, which protrudes southeastward as a narrow dike for a short distance along the fault."

There are also horst and graben structures in southern parts of the map area, north and east of the Rattlesnake Mountains. The structures trend northwest, basically, although one fault in the system does turn southward as it enters the Rattlesnake Mountains proper. Vertical displacements on the structures exceed 100 feet.

Local folding and faulting is also common around other igneous intrusive bodies. Structural upwarping is particularly apparent along the bounding edge of Maverick Mountain, where Cretaceous strata are tilted vertically in some places, and around the edge of Cigar Mountain, where dips in Cretaceous strata regularly exceed 50 degrees. Cretaceous strata also sag downward below Leon Mountain, perhaps reflecting collapse into an emptied magma chamber at depth (Figure 8).

Solution Features

There are at least two types of solution features in the study area: limestone caverns and breccia pipes. The caverns occur primarily in upper parts of the Santa Elena Limestone, with a few also being located in the Buda Limestone. Some caverns near the top of the Santa Elena Limestone are filled with rocks and sediment that have slumped into them from overlying formations, forming breccia pipes that are known to extend as much as 1,000 feet above the top of the Santa Elena. The caverns have been encountered during deep water well drilling and in mine shafts.

According to Yates and Thompson (1959), there are basically two kinds of open solution cavities in the Santa Elena Limestone: vertical caves developed mainly along fractures, and horizontal caves developed mainly along bedding planes. The vertical caves are usually less than 10 feet wide, but some are locally as much as 50 feet or more in width. The length and height of the vertical caves reaches hundreds of feet in some instances. Horizontal caves, which are numerous, rarely have rooms that are more than 100 feet wide, or have ceilings that are more than 20 feet high.

Breccia pipes (masses of breccia with a vertical pipe-like or chimney-like shape) have been explored for mercury ore at both the '248' and Chisos Mines. The '248' pipe consists of collapsed Boquillas flags at upper levels and intermixed Boquillas and Buda limestone fragments at lower levels. The pipe is nearly circular at ground surface and becomes more elliptical at depth.

The most famous of the Terlingua breccia pipes is the Chisos pipe in the Chisos Mine, if only for its having yielded the largest volume of mercury ore in the Terlingua mining district (Yates and Thompson, 1959). The Chisos pipe does not reach ground surface, but was discovered in mine workings at a depth of 550 feet. The pipe is roughly circular, having a diameter of approximately 75 feet, and is filled by breccia composed of Boquillas flags, Buda Limestone, and Del Rio Clay, all of which have been displaced downward by solution collapses.

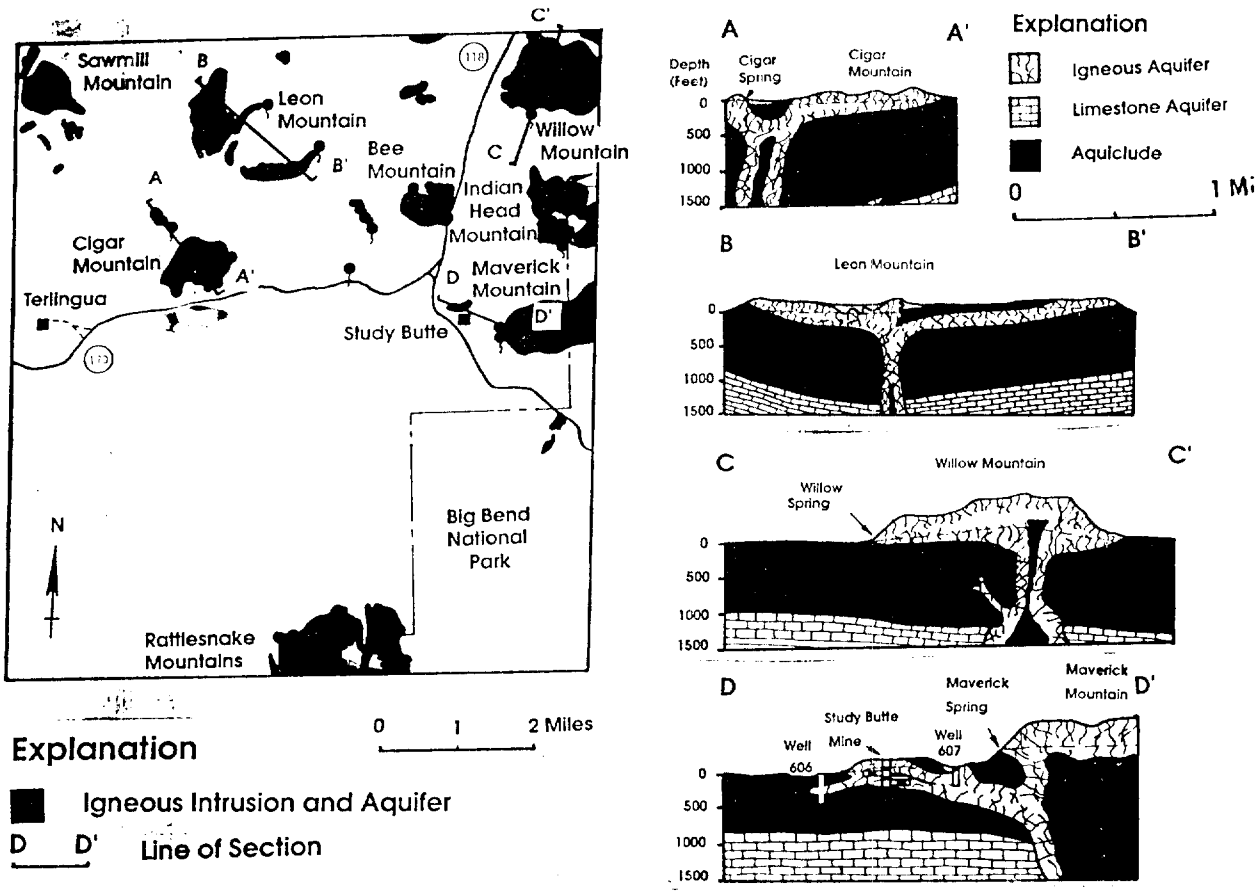


Figure 8 -- Map View and Structural Cross Sections of Willow, Maverick, Cigar and Leo Mountains.

After Yates and Thompson, 1959

HYDROLOGY

Introduction

There are three relatively shallow aquifers in the Terlingua area that are hydraulically connected in some places and that are separated by thick, regional aquitards at other locations. The aquifers occur in: (1) Quaternary alluvial and terrace deposits; (2) Tertiary intrusive rocks; and (3) Cretaceous strata. Deeper aquifers have also been encountered in Paleozoic rocks that underlie Cretaceous strata in the Marfa basin to the north, and undoubtedly also exist in similar Paleozoic rock sequences under Cretaceous aquifers in the study area.

Ground Water in Quaternary Alluvium and Terrace Deposits

General Setting

A shallow aquifer occurs in Quaternary alluvium and terrace deposits that line and underlie Terlingua Creek and its tributaries. The aquifer is restricted areally to deposits immediately adjacent to stream channels and has a saturated interval that is rarely more than 30 feet. Wells that have been drilled through surface colluvium and alluvium in areas removed from major creeks around Terlingua show the deposits to be less than 15 feet thick and usually dry.

Aquifer Dynamics

Ground water in the Quaternary alluvium and terrace deposits is largely unconfined and moves towards and along stream courses, flowing in a southerly direction at a maximum estimated rate of only a few hundred feet per year. The alluvium is recharged by intermittent torrential rainfall and by spring flow along stream courses in northern parts of the map area. Discharge is by underflow out of the study area, by production at well heads, and by plant root sapping along Terlingua Creek and its tributaries.

Aquifer Capacity

Major stream drainages in the study area have a combined length of approximately 10 miles and average width of one mile. The drainages are filled with alluvial and terraced deposits that have an estimated effective porosity of 20 percent and an average saturated thickness of 10 feet, holding up to 12,000 acre-feet of ground water. Annual recharge to the system from springs and rainfall is not expected to exceed 0.1 inch per unit area, or 320 acre-feet per year, an amount roughly equal to that discharged from the aquifer each year by well pumpage, transpiration, and underflow out of the area.

Development

At least 30 shallow alluvial wells have been dug by hand or by backhoe along Terlingua and Dark Canyon Creeks (Figures 9 &

10). The wells are generally 20 to 30 feet deep and are lined typically with either converted road culvert pipe or with connected four-foot lengths of four-foot diameter concrete caisson.

Alluvial well yields reportedly range from less than 10 to more than 200 gallons per minute, with static water levels in wells usually being five to 10 feet below ground surface. The wells supply water for domestic, ranching, and irrigation purposes. Also, one group of alluvial wells around Cedar Springs in Bens Hole Creek just north of Highway 170 is used for public supply, providing water to the Terlingua school, local restaurants, a motel, Terlingua Medics, and a trailer park. Cedar Springs, itself, produces water from fractures in the Boquillas Formation.

Water Quality

Analyses of ground water from five wells completed in alluvial deposits along Terlingua Creek show it to be slightly saline, with dissolved solids generally ranging between 1,000 and 1,500 mg/l. The water has a mixed cation-sulfate hydrochemical signature, with particularly noticeable concentrations of sodium, calcium, bicarbonate, and sulfate. These concentrations probably result from alkali feldspar weathering in igneous rock fragments, dissolution of local gypsum deposits in the Aguja and Pen Formations, and dissolution of calcite in limestone rocks. The ground water also has a relatively neutral pH range (6.6 to 7.9), and is hard, with concentrations of calcium carbonate commonly exceeding 160 mg/l (Table 2).

By Texas Department of Health standards, alluvial water in the Terlingua area has more dissolved solids than the 1,000 mg/l amount recommended to be safe for drinking. High sulfate concentrations give the alluvial water a bitter taste and sometimes have a laxative effect on humans. The water is also objectionably hard and precipitates scale in water heaters and pipes over time.

Ground Water in Tertiary Intrusive Rocks

General Setting

The shallow Tertiary intrusive rocks that form isolated mountain peaks around Terlingua and Study Butte contain some of the best quality ground water in the study area. However, the igneous aquifers are of limited areal extent and project to relatively deep depths at only a few locations, primarily where volcanic necks and plugs extend downward through surrounding strata. Also, water in deeper parts of the igneous rocks is appreciably more mineralized than that at shallower depths.

Aquifer Dynamics

Ground water enters and moves through joint and fracture systems in the igneous rock and is generally unconfined near the surface. The aquifers are recharged by intermittent torrential rainfall. Discharge is primarily to seeps and springs, although cross-formation flow and mixing also undoubtedly occur where

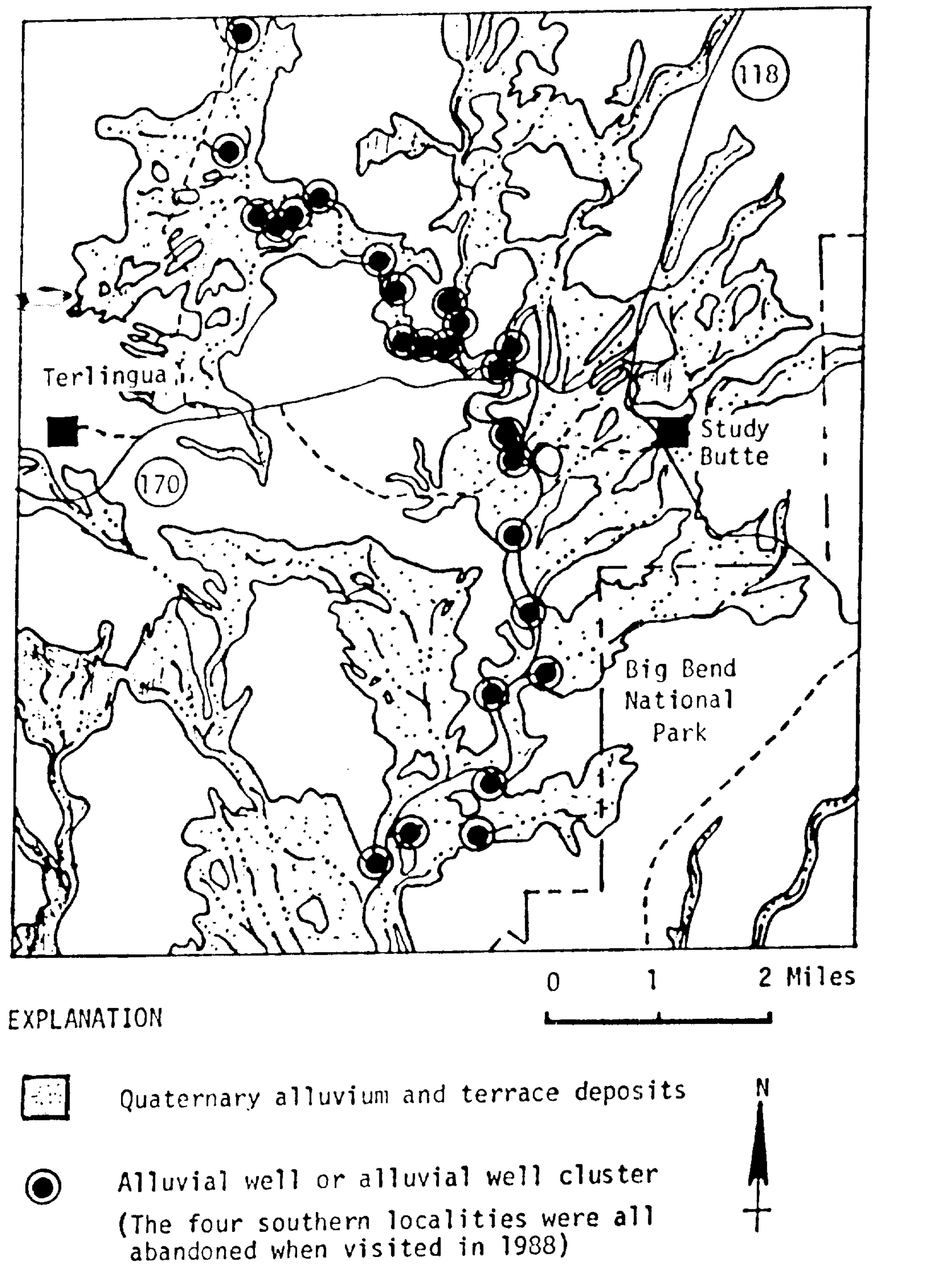


Figure 9 -- Generalized Map Showing the Location of Quaternary Alluvium and Alluvial Wells Along Terlingua and Dark Canyon Creeks.

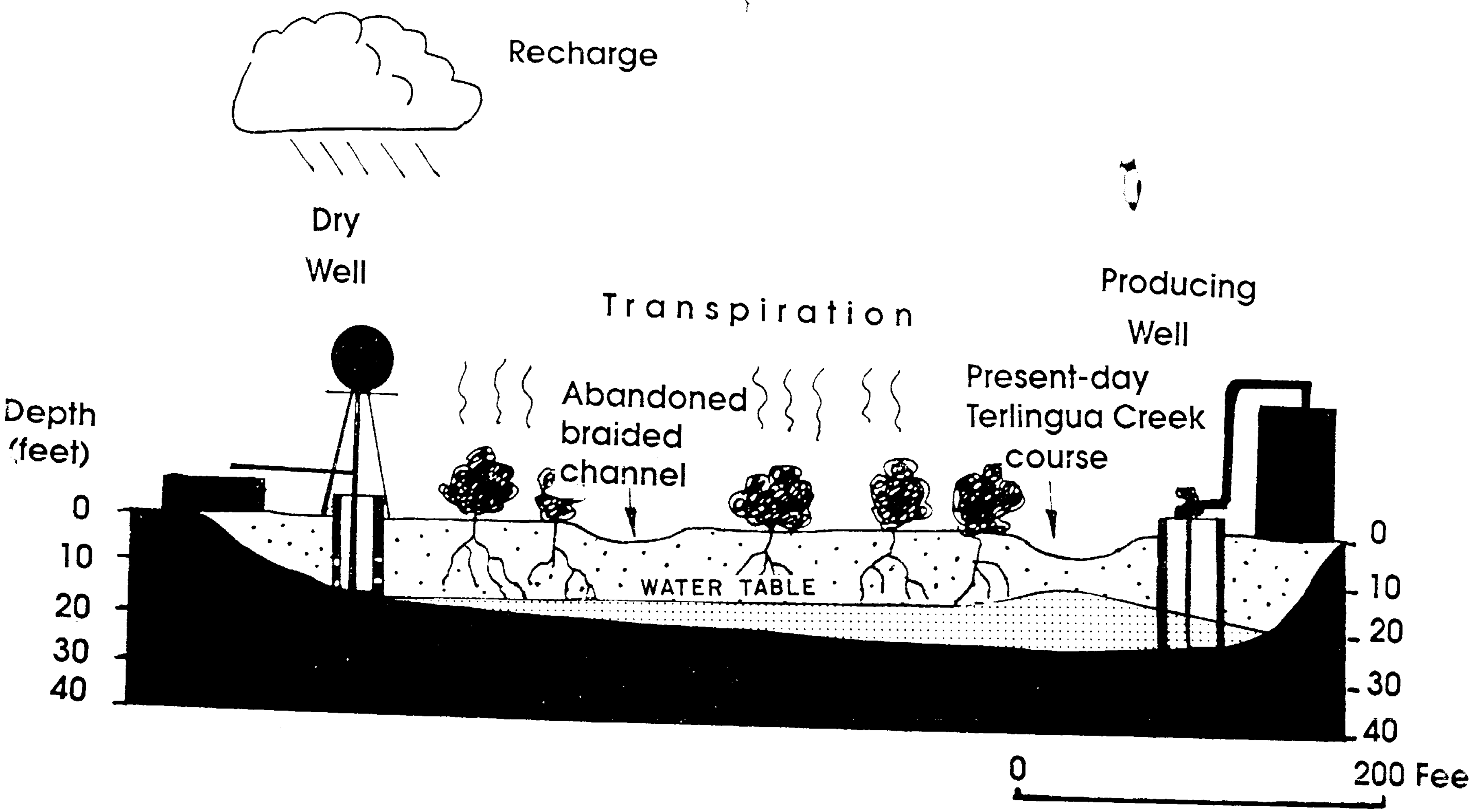


Figure 10 -- Schematic Cross Section Showing the Alluvial Aquifer Underlying Terlingua Creek and Its Relation to Wells Lining the Creek.

Table 2
Chemical Analyses of Ground Water From Wells Completed in Alluvium Along Terlingua and Dark Canyon Creeks.

Well 73-44-205(1987)		Well 73-44-502(1988)		Well 73-44-802(1949)	
Cations	**mg/l**	**Cations**	**mg/l**	**Cations**	**mg/l**
Calcium	160	Calcium	206	Calcium	143
Magnesium	17	Magnesium	46	Magnesium	17
Sodium	189	Sodium	257	Sodium	142
Potassium	--	Potassium	10	Potassium	7
Anions		**Anions**		**Anions**	
Bicarbonate	240	Bicarbonate	167	Bicarbonate	196
Sulfate	632	Sulfate	964	Sulfate	552
Chloride	15	Chloride	16	Chloride	11
Fluoride	--	Fluoride	1.2	Fluoride	1.3
Physical Properties		**Physical Properties**		**Physical Properties**	
pH: 6.8		pH: --		pH: 7.9	
Hardness	470	Hardness	703	Hardness	426
Dissolved Solids	1131	Dissolved Solids	1608	Dissolved Solids	1010

fractured igneous necks and plugs extend downward through saturated intervals in surrounding strata (Figure 8). Almost all major springs in the study area, including Maverick, Willow, Joe Black, and Cigar Springs, issue from the base of igneous rocks that are underlain by Cretaceous shale and clay beds that are structurally tilted so as to provide shallow ground-water flow to them. Cedar Spring, which issues from fractures in the Boquillas Formation near the confluence of Terlingua and Bens Hole Creeks, may also owe its origin to structural deformation generated during igneous intrusive activity.

Aquifer Capacity

Most water-bearing igneous rocks around Terlingua cover approximately one square mile of surface area and have saturated intervals of fresh to slightly saline water that are estimated to be rarely more than 250 feet thick. Effective porosity in the aquifer is perhaps one percent, with overall porosities ranging between two and five percent.

Volumes of ground water in the igneous rocks fluctuate with the climate around Terlingua and Study Butte, declining during extended dry spells and increasing during wet periods. Water flow at Maverick Spring on the west end of Maverick Mountain, for example, is reduced to a trickle during times of drought, reviving only after extended rains fall over the region. Water may seep from surface fractures and joints in igneous rocks for up to a month after heavy rainfall periods in some places (Lester Pres, 1988, personal communication).

Development

Only three wells in the study area have thus far been drilled into igneous intrusive rocks, two of which produce more water from bounding strata of Cretaceous age than from the intrusive rocks themselves. One of the wells (73-44-202) is located approximately one-quarter mile south of Leon Mountain on the Glasscock ranch. It is 180 feet deep and penetrates black basalt from 166 to 188 feet below ground surface. The well yields 30 to 35 gallons per minute, primarily from jointed limestone beds in the Boquillas Formation and Buda Limestone that immediately overlie the black basalt.

A second well (73-44-606) is located just east of the intersection of Highways 118 and 170 immediately north of Study Butte. The well is 685 feet deep and penetrates rhyolite and granite 495 to 665 feet below ground surface. It yields 25 to 30 gallons of water per minute from blue sand and conglomerate that underlie the rhyolite and granite at depths of 665 to 685 feet. Notably, water in the blue sand and conglomerate is under artesian pressure and rises to within 95 feet of ground surface (Gene Thompson, 1988, personal communication).

The third well to penetrate igneous intrusive rocks in the study area is located at the west end of Maverick Mountain (73-44-607). The well is 200 feet deep and produces in excess of 250 gallons per minute from a fracture in trachyte 167 to 174 feet below ground surface. The trachyte fracture is mineralized with pyrite, and water from the well has a sulfate taste and smell. The well was drilled in 1987 and has since been used to supply water for road construction projects in Big Bend National Park.

Springs that issue water from the base of igneous rocks have also been developed for domestic and public supply. Cigar Spring and other seeps along the east side of Cigar Mountain, for example, were used in the late 1800's and early 1900's to supply fresh drinking water to mining camps at Terlingua and Study Butte (Mrs. DeKoninck, 1988, personal communication) and are currently being used for domestic supply.

Willow Spring on the south side of Willow Mountain has also been developed for domestic supply. According to the owner, it provides good quality water for human consumption and other purposes. The spring produces water at an average rate of approximately one and a half gallons per minute.
Maverick Spring, at the west end of Maverick Mountain, supplies water to the Study Butte Store and nearby residences in Study Butte. It has a relatively long history for having supplied water to the Study Butte mining camp in the early 1900's, and to various Indian tribes, including Apaches, Comanches, and Shawnees who lived along Terlingua Creek in years prior to the 1900's. Although the spring has rarely produced more than five gallons per minute in recent times, there are reports indicating it may have produced more in the not so distant past.

Like Cigar Spring to the west and Willow Spring to the north, Maverick Spring heads an intermittent drainage that is tributary to Terlingua Creek. According to James Gillett, foreman of the G-4 ranch, Terlingua Creek in 1885 was a "....bold running stream, studded with cottonwood and was alive with beaver. At the mouth of Rough Run (below Maverick Spring) there was a fine grove of trees, under the shade of which I have seen at least one thousand head of cattle. Today (1933) there is probably not one tree standing on the Terlingua that was there in 1885." Only as more people came into the region and more wells were dug, did many of the local springs begin to fail (Brune, 1981).

Water Quality

Ground water issuing from springs that tap igneous aquifers in the Terlingua-Study Butte area is commonly referred to as "sweet," if only for its lacking an excessive concentration of sulfate that gives most other ground water in the region a bitter taste. The spring water is usually fresh, containing less than 1,000 mg/l dissolved solids, and commonly has a sodium-bicarbonate hydrochemical signature. Table 3 shows a chemical analysis of water collected from Maverick Spring (73-44-610) in 1977.

By primary Texas Department of Health standards, the water collected from Maverick Spring in 1977 was acceptable for safe drinking in all categories tested. Under secondary Department of Health standards, however, it had slightly more fluoride than the recommended lower limit, and it was also very hard.

The quality of ground water in igneous rocks around Terlingua and Study Butte diminishes with depth, especially where the aquifers are hydraulically connected with saline ground water in surrounding strata. Water from the igneous rocks at Study Butte Mine, for example, was analyzed in 1967 and shown to have 2,928 mg/l dissolved solids, with disproportionate amounts of sodium and sulfate giving it a strong sodium-sulfate hydrochemical signature (Table 3). Study Butte Mine is more than 400 feet deep and is completed almost entirely within the igneous intrusive rocks that form Study Butte Mountain.

According to Yates and Thompson (1959), the Study Butte Mine had continuous water flooding problems when it was operating, with constant pumping being necessary to hold water out of the deeper levels of the mine. When the water was not pumped, it would eventually rise until it seeped into the bed of Rough Run Draw nearby.

Water sampled from the igneous aquifer at Study Butte Mine in 1967 had concentrations of calcium carbonate that measured 870 mg/l, making it exceedingly hard. The water also had concentrations of iron exceeding 9 mg/l which, combined with other high mineral solute levels, makes it very undesirable for drinking.

Notably, the Study Butte Mine water is almost identical chemically to water produced from blue sand and conglomerate below intrusive rocks in well 73-44-606 which is located one-half mile northwest of the mine. Water from the well contains 3,013 mg/l dissolved solids, is extremely hard, tests high in total iron (4.6 mg/l), and displays a sodium-sulfate hydrochemical signature, suggesting the water-bearing zone is hydraulically connected with the igneous intrusive aquifer penetrated by mine shafts at the Study Butte Mine.

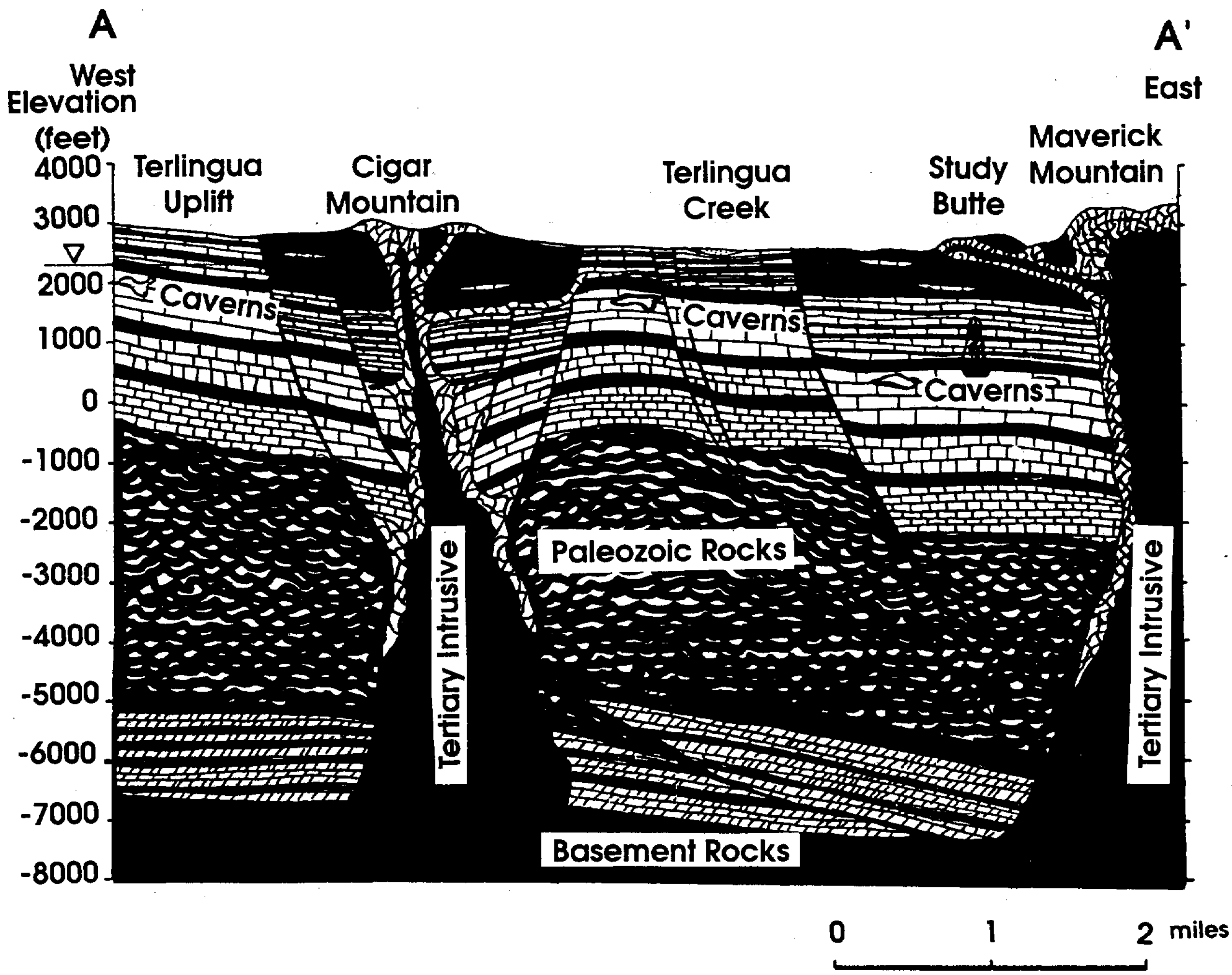
Ground Water in Cretaceous Strata

General Setting

Ground water flows through various Cretaceous limestone formations forming an aquifer system that is both structurally and hydrologically complex. In descending stratigraphic order, specific water-bearing formations in the Cretaceous section include the Boquillas Formation, Buda Limestone, Santa Elena Limestone, Del Carmen Limestone, and Glen Rose Limestone. The water-bearing strata are commonly separated or overlain by clay and marl aquitard intervals of the Cretaceous Javelina Formation, Aguja Formation, Pen Formation, Del Rio Clay, Sue Peaks Formation, and Telephone Canyon Formation. Sandstone facies in the Javelina, Aguja, and Pen Formations also transmit limited amounts of ground water in some parts of the study area.

Table 3
Chemical Analyses of Ground Water Obtained From or Adjacent to Igneous Aquifers in the Terlingua Area. (See Figure 14 for Sample Locations)

Maverick Spring(1977)		Study Butte Mine(1967)		Well 73-44-606(1988)		Well 73-44-607(1988)	
Cations	**mg/l**	**Cations**	**mg/l**	**Cations**	**mg/l**	**Cations**	**mg/l**
Sodium	107	Sodium	603	Sodium	821	Sodium	705
Calcium	55	Calcium	272	Calcium	123	Calcium	273
Magnesium	6	Magnesium	46	Magnesium	32	Magnesium	38
Iron	.05	Iron	9.7	Iron	4.6	Iron	--
Anions		**Anions**		**Anions**		**Anions**	
Chloride	12	Chloride	30	Chloride	38	Chloride	36
Sulfate	156	Sulfate	1819	Sulfate	1848	Sulfate	2019
Bicarbonate	267	Bicarbonate	299	Bicarbonate	305	Bicarbonate	310
Fluoride	2.8	Fluoride	--	Fluoride	--	Fluoride	2.5
Physical Properties		**Physical Properties**		**Physical Properties**		**Physical Properties**	
pH:	8.2	pH:	7.0	pH:	8.0	pH:	8.0
Hardness	163	Hardness	870	Hardness	440	Hardness	840
Dissolved Solids	470	Dissolved Solids	2927	Dissolved Solids	3013	Dissolved Solids	3271



EXPLANATION

AQUICLUDE: Clay, shale, marl, unfractured igneous intrusive rock and sealed fault zones.

AQUIFER: Fluid movement along limestone joints, fractures and bedding planes - and through solution caverns.

AQUIFER: Fluid movement along joint and fracture systems in igneous intrusive rocks.

AQUIFER: Limited fluid movement along secondary joints, fractures and thrust fault planes.

Figure 11

Schematic Cross Section A-A' Showing Spatial Juxtaposition of Aquifers and Aquicludes in the Study Area

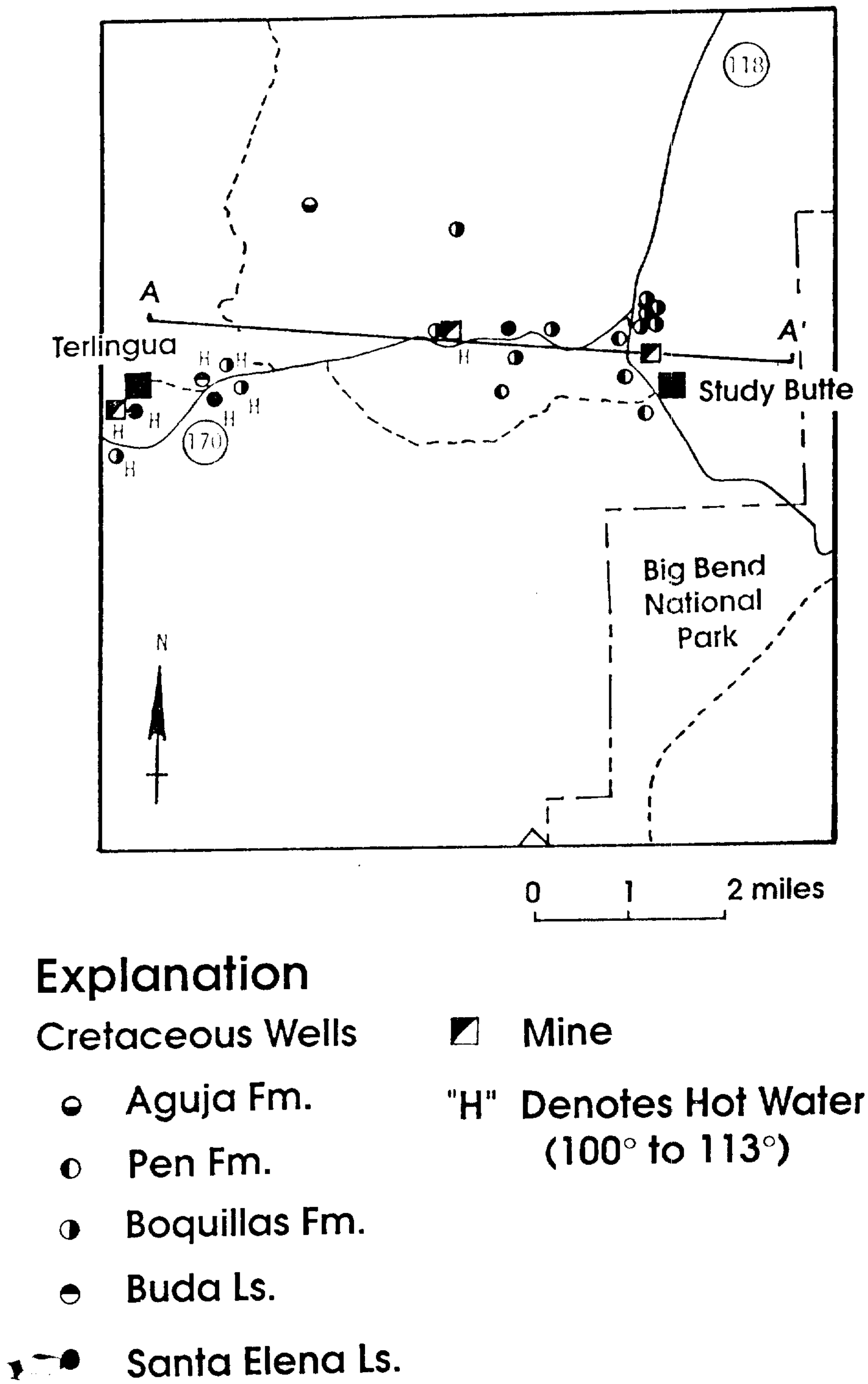


Figure 12 -- Generalized Map Showing the Location of Mines and Located Wells that Penetrate the Cretaceous Aquifer System in the Terlingua Area.

Aquifer Dynamics

Ground-water movement in the Cretaceous aquifer system between Terlingua and Study Butte is generally to the south-southeast in conformance with regional structure and hydraulic head. Most of the fluid movement occurs along limestone joints, fractures and bedding planes, and through solution cavities that are particularly well developed in upper parts of the Santa Elena Limestone.

Rates of movement are estimated to vary from only a few inches or feet per year in dense and marly limestone intervals to potentially hundreds of feet per year through some of the larger solution channels and cavities that exist in the Santa Elena Limestone. Flow movements and rates are also undoubtedly influenced by local structural discordances and igneous intrusions that place dissimilar rock types and formations against one another (Figure 11).

Many water-bearing formations in the Cretaceous aquifer around Terlingua and Study Butte are both confined and tilted structurally, creating artesian conditions within the system. Water rises more than 200 feet above well-completion intervals in the Santa Elena Limestone (wells 73-44-405 and 504) east of the Terlingua ghost town and more than 700 feet above completion intervals in basal sandstone facies of the Pen Formation (well 73-44-601) south of Study Butte (Ed Reed and Associates, 1972; Texas Water Development Board files). Also, water in wells 73-44-406 and 407 rises 128 feet and 230 feet, respectively, above completion intervals in the Boquillas Formation. All of the wells are over 700 feet deep and have aquitard clays, shales, and marls above their completion intervals.

It is also significant that many of the deeper wells and mine shafts completed in Cretaceous aquifers around Terlingua produce water with a temperature exceeding 100 degrees Farenheit (F) (Figure 12). For example, well 73-44-404 at the base of Reed Plateau south of Highway 170 and wells 73-44-405, 406, and 407 east of the Terlingua ghost town all yield water warmer than 103 degrees F, with well 73-44-405 having a stabilized pumping temperature of 108 degrees F (Ed Reed and Associates, 1972). Also, water from well 73-44-402, located one-quarter mile southwest of the old Company Store in the ghost town of Terlingua, is reported to produce water that has a temperature of 113 degrees F (Bob Cook, 1988, personal communication). The Chisos Mine shaft immediately west of this well is flooded at lower levels with ground water that also has a temperature of 113 degrees F (Henry, 1979).

C.D. Henry (1979) notes that hot water in the Cretaceous aquifer around Terlingua and Big Bend "...is apparently heated by relatively shallow circulation in an area of normal heat flow similar to that of the Great Plains. At a thermal gradient of approximately 64 to 84 degrees F per kilometer and an average annual surface temperature of 70 degrees F, circulation to a depth of from 0.7 to one kilometer is sufficient for water to reach 104 degrees F."

Also to be considered is the fact that Cretaceous strata were heated during Tertiary intrusive periods to temperatures sufficiently high enough for local hydrocarbon generation around Terlingua. Wells 73-44-406 and 407 produced small quantities of oil with water from the Boquillas Formation at depths between 700 to 800 feet (Walter Stricker, 1988, personal communication). Also, a sill in the Boquillas Formation southeast of the museum at Lajitas oozes asphalt that appears to have been distilled from the surrounding marls and limestones (Pat Dickerson, 1988, personal communication). Accordingly, there may be some residual heat from the intrusive rocks at depth that is still keeping Cretaceous formations under Terlingua warm.

Recharge to the Cretaceous aquifer system is provided by intermittent rainfall in areas where water-bearing formations crop out at the surface, especially where the formations are cross cut by major joint and fault structures such as the Long Draw graben south and west of Terlingua. Cross-formational flow and mixing also occur in the subsurface in structurally complex zones such as the one developed along Cigar Mountain graben (Figure 11). Discharge is by underflow out of the map area, by producing wells, and by spring seepage from fractures in the Boquillas Formation along Terlingua and Bens Hole Creeks.

Aquifer Capacity

It is estimated that more than 90 percent of the study area is underlain by Cretaceous rocks, an area covering approximately 66 square miles or 42,240 acres. Saturated intervals have a combined thickness of approximately 2,500 feet and an estimated effective porosity of approximately 3 percent, indicating that the system probably holds more than 3,000,000 acre-feet of ground water. However, only a small percentage of the total volume of water in the Cretaceous aquifer is of good enough quality to be considered for most uses.

Development

There are 21 located wells and three developed mine sites that penetrate the Cretaceous aquifer system in the study area (Figure 12). All of the wells and mines are less than 1,000 feet deep, with more than half of the wells being less than 250 feet deep.

Individual Cretaceous well yields reportedly vary from less than 10 to more than 200 gallons per minute, with higher yields coming generally from wells completed in upper cavernous parts of the Santa Elena Limestone. The wells are developed primarily to provide water for domestic and public supply, although marginal to poor water quality prevents some of the wells from being used as a source of safe drinking water. Only three Cretaceous well localities (wells 73-44-402, 73-44-405, and the wells at Cedar Spring in Bens Hole Creek) have been used extensively to supply water for public consumption for any length of time.

Water Quality

Ground water in the Cretaceous aquifer system between Terlingua and Study Butte is generally slightly to moderately saline in character. As a rule, higher solute concentrations occur in water obtained from clayey sandstone facies of the gypsiferous Aguja and Pen Formations and from shaley limestone intervals in the Boquillas Formation than from solution cavities and fracture intervals in the Buda and Santa Elena Limestones. This is to be expected since ground water moves more rapidly through limestone fractures and solution channels than it does through clayey sandstone and shaley limestone intervals, providing less time for the water to react with surrounding strata.

Aguja Formation

Solute concentrations in water from well 73-44-103, located one-half mile north of Cigar Mountain and completed in the Aguja Formation, measure 5,287 mg/l. The moderately saline Aguja water is extremely hard and has a very distinctive mixed cation-sulfate hydrochemical signature, reflecting the absorption of sodium and calcium cations, and sulfate anions derived probably from the dissolution of alkali igneous rock fragments and gypsum deposits in the Aguja Formation.

Pen Formation

Between 1965 and 1985, a basal sandstone bed in the Pen Formation yielded water to well 73-44-601, one-half mile northwest of the Study Butte Store, that contained 2,173 mg/l dissolved solids in 1970. The slightly saline water was both softer and more basic than any other water analyzed in the Terlingua-Study Butte area. It also had high concentrations of fluoride and a very pronounced sodium-sulfate hydrochemical signature. Used sparingly for domestic supply, the well was abandoned in 1985.

Boquillas Formation

The Boquillas Formation generally produces slightly saline water with solute concentrations ranging between 2,000 and 3,000 mg/l. However, exceptions do occur where the formation receives direct meteoric and stream recharge that subsequently re-issues from nearby fractures and joints, forming local springs. Water from fractures in the Boquillas Formation at Cedar Spring in Bens Hole Creek, for example, contains less than 1,300 mg/l dissolved solids, making its solute levels much closer to those found in water from Terlingua, Dark Canyon, and Bens Hole Creeks than to those found in water from deeper parts of the Boquillas aquifer.

All water thus far collected and analyzed from wells completed in the Boquillas Formation has proven to be exceptionally hard, with concentrations of calcium carbonate ranging between 200 and 400 mg/l. The water also has high concentrations of fluoride (3.5-10 mg/l) and commonly displays a sodium-sulfate hydrochemical signature. Concentrations of sulfate measured 1,896 mg/l in water from one well completed in the Boquillas Formation, prompting the owner to consider using it in a sulphur bath spa at Big Bend Motor Inn (Gene Thompson, 1988, personal communication).

Buda Limestone

Only one well (73-44-403) in the study area had been completed solely in the Buda Limestone. The well is located just north of Highway 170 at the turn-in to the Terlingua ghost town. Drilled and abandoned in the early 1980's, the well produced 15 to 18 gallons per minute. The water had a bitter sulfate taste and was deemed unsuitable for drinking (Ken Smith, 1988, personal communication). Better quality water probably exists in other parts of the Buda Limestone, however, especially where solution cavities are well developed in the formation.

Santa Elena Limestone

There are three wells in the study area completed in the Santa Elena Limestone (73-44-402, 73-44-405, and 73-44-504). All of the wells produce slightly saline (1,130-1,303 mg/l dissolved solids) water that has a very distinctive sodium-mixed anion hydrochemical signature and a basic pH range between 7.8 and 8.3. Concentrations of chloride (341-358 mg/l) and fluoride (1.8-3.1) in water from the three wells commonly exceed Texas Department of Health secondary safe drinking standards limits of 300 mg/l chloride and 2.1 mg/l fluoride. The Santa Elena water is also very hard, with concentrations of calcium carbonate measuring between 341 an 358 mg/l.

Significantly, radioactivity has also been detected in water recovered from the Santa Elena Limestone aquifer at levels higher than is considered safe by the Texas Department of Health for drinking purposes. A preliminary scan of water obtained from well 73-44-402 in July 1988 showed it to have a 21 ± 4 picocuries per liter (pCi/l) of alpha-particle activity, and 35 ± 5 pCi/l of beta-particle activity, with more detailed analyses revealing 10 ± 1 pCi/l of radium-226 and 1.3 ± 0.4 pCi/l of radium-228 in the water. Well 73-44-405 was subsequently sampled for radioactivity in August 1988, with its water proving to have even higher levels of gross radiation, i.e., 56 ± 6 pCi/l of alpha-particle activity and 70 ± 11 pCi/l of beta-particle activity. Also, water in well 73-44-504 proved to be radioactive when it was sampled and tested in 1978 (Bob Cook, 1988, personal communication).

Radioactive elements in the Santa Elena Limestone aquifer may be related to igneous intrusions in the Terlingua area and concentrated only locally within the regional ground-water system. Radionuclides as trace elements are commonly found in igneous rocks and are formed principally by the radioactive decay of uranium-238 and thorium-232. The most common radionuclides in ground water are radon-222, radium-226, uranium-238, and uranium-234 of the uranium-238 decay series, and radium-228 of the thorium-232 decay series (Zapecza and Szabo, 1986).

According to the U. S. Environmental Protection Agency's National Interim Primary Drinking-Water Regulations, the maximum contaminant levels for radionuclides are:

Radium-226 and radium-228 combined	5 pCi/l
Gross alpha-particle activity (including radium-226, but excluding uranium and radon	15 pCi/l
Gross beta-particle activity	4 millirems per year

One pCi/l is equal to 0.037 disintegrations of radionuclide per second per liter of fluid.

Consumption of water containing radium and, to a lesser degree, uranium commonly leads to a significant accumulation of the radionuclides in human bone tissue and can ultimately produce bone and head-sinus cancers. A cumulative lifetime risk to one million people, each consuming 5 pCi/l of radium per day, has been estimated to be 9 bone and 12 head cancers for radium-226. Radium-228, which is considered to be twice as hazardous as radium-226, is estimated to produce 22 bone cancers per million people, while lifetime ingestion of 5 pCi/l per day of uranium can induce 1.5 additional bone cancers per million people (Zapecza and Szabo, 1986).

Water from wells 73-44-402 and 73-44-405 has also been analyzed to determine heavy metal content. Findings from these analyses indicated that water from both wells was potable with respect to all metals tested at the Texas Department of Health labs, including mercury which has been produced at nearby mines in Terlingua and Study Butte (Table 4). However, the Mel LaVergne well was also tested in 1972, with the results showing it to have 0.0024 mg/l mercury, an amount slightly above the maximum contaminant level (0.002 mg/l) recommended to be safe for drinking.

Cretaceous Aquifers Below the Santa Elena Limestone

Although no wells in the study area penetrate Cretaceous formations below the Santa Elena Limestone, there is still reason to believe that aquifers exist. Outcrop exposures of the Del Carmen Limestone and the Glen Rose Limestone along the Terlingua fault escarpment immediately southwest of the study area indicate that the formations have sufficient fracture porosity to contain relatively large volumes of ground water, with the Del Carmen Limestone possibly even having well developed solution cavities in rudistid-bearing facies and along larger fracture systems on the south flank of the Terlingua uplift.

The quality of water in the Del Carmen Limestone and the Glen Rose Limestone is probably equal to or poorer than the quality of water in the Santa Elena Limestone, especially if

Table 4
Chemical Analyses of Ground Water for Heavy Metals from Wells Completed in the Terlingua Area.

Primary Metal	M.C.L.*	Well No. 73-44-103 (1988)	Well No. 73-44-202 (1988)	Well No. 73-44-402 (1988)	Well No. 73-44-405 (1988)	Well No. 73-44-405 (1972)	Well No. 73-44-405 (1988)	Well No. 73-44-406 (1988)	Well No. 73-44-502 (1988)	Well No. 73-44-503 (1985)	Well No. 73-44-514 (1978)	Well No. 73-44-607 (1988)
Arsenic	0.05 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l	<0.010 mg/l
Barium	1.0	0.29	<0.20	0.050	0.039	0.300	0.050	0.040	<0.020	<0.100	0.014	<0.020
Cadmium	0.010	<0.010	<0.010	<0.005	<0.010	--	<0.005	<0.010	<0.010	0.500	--	<0.010
Chromium	0.05	<0.020	<0.020	<0.020	<0.020	--	<0.020	<0.020	<0.020	<0.030	<0.004	<0.020
Lead	0.05	<0.050	<0.050	<0.020	<0.050	<0.050	<0.020	<0.050	<0.050	<0.010	--	<0.050
Mercury	0.002	<0.0002	0.0002	<0.0002	<0.0002	0.0024	<0.0002	<0.0002	<0.0002	<0.0005	--	<0.0002
Selenium	0.01	0.025	0.025	<0.002	<0.002	<0.005	<0.002	0.221	0.002	<0.005	<0.0002	<0.002
Silver	0.05	<0.010	<0.010	<0.010	<0.010	--	<0.010	<0.010	<0.010	<0.030	<0.002	<0.010
Secondary Metal	**M.R.C.L.***											
Copper	1.0 mg/l	0.081 mg/l	0.260 mg/l	0.020 mg/l	<0.020 mg/l	--	<0.020 mg/l	0.160 mg/l	0.020 mg/l	0.065 mg/l	<0.002 mg/l	<0.020 mg/l
Iron	0.3	0.095	0.020	0.160	<0.020	0.081	0.220	0.200	0.035	0.149	<0.010	2.680
Manganese	0.05	<0.020	<0.020	<0.020	<0.020	<0.050	<0.020	0.042	<0.020	<0.010	0.002	0.390
Zinc	5.0	0.029	0.440	0.400	0.300	<0.100	1.440	5.460	0.055	<0.500	0.031	0.036

*Note: Standards shown are current U.S.E.P.A. and T.D.H. maximum contaminant levels (M.C.L.) for primary metal constituents and maximum recommended contaminant levels (M.R.C.L.) for secondary metal constituents in public supply water.

balanced amounts of sodium and chloride in Santa Elena water indicate either dilution of original formation water (marine saltwater) or dissolution of natural salt precipitated from sea water. More specifically, if the Santa Elena Limestone has not been flushed completely with fresh meteoric water since it was deposited in marine seas, then it is unlikely that formations below it have been flushed either, leaving only saline water to fill the deeper aquifers. Exceptions may occur, however, on the Terlingua uplift where fresh meteoric recharge has infiltrated into deeper Cretaceous aquifers.

Ground Water and Hydrocarbons in Paleozoic Strata

If the Paleozoic Ouachita section under Terlingua and Study Butte is as well indurated as it is in Marathon Basin outcrop exposures northeast of the study area, then fluid flow through the system has been restricted largely to secondary fault and fracture zones since late Paleozoic time. Deep oil tests in Marfa Basin north of Terlingua indicate brine solutions predominate in the marine Ouachita section, with lowest brine salinities occurring along the more porous and permeable fault and fracture zones. Also, some hydrocarbons can be expected in the Paleozoic section.

Surface Water

Terlingua Creek is the most predominant stream in the study area, even though some stretches of it are dry during arid parts of the year. Between the dry stretches are infrequent spring-fed ponds from which water trickles downstream to be absorbed almost immediately in alluvium and terrace deposits. Only during and immediately after seasonal rainstorms does Terlingua Creek transport steady volumes of surface water.

Terlingua Creek flows in a southerly direction, eventually joining with the Rio Grande several miles south of Terlingua, near the east portal of Santa Elena Canyon. In a few places, the creek is narrowly constricted between upraised limestone canyon walls. Over long stretches, it is a braided stream that moves across broad alluvial flats, its main channel course shifting up to a quarter mile horizontally during flash floods some years.

There are numerous tributary creeks and draws that empty into Terlingua Creek including Willow Creek, Dawson Creek, Rough Run Draw, Bens Hole Draw, Dark Canyon Creek, and The Long Draw. The tributary creeks and draws flow into the larger stream after seasonal rainstorms, turning it into an occasional raging torrent.

Although Terlingua Creek and its major tributary draws do not have permanent dams and reservoirs constructed along them, smaller stock tanks have been constructed in smaller ravines. Also, temporary earthen dams have been constructed across Rough Run Draw north of Study Butte to impound water for road construction projects in Big Bend National Park. A narrow canyon between Maverick and Study Butte Mountains on Rough Run Draw has been the site of the earthen dams, all of which have been washed out or excavated and destroyed after road projects have been completed in the park.

CURRENT DEVELOPMENT TRENDS AND PROSPECTS

Development Trends

A number of different development trends have prompted significant interest in the availability and recoverability of fresh ground water around Terlingua in recent years, especially with fresh surface-water supplies being extremely limited in the region. Since the early 1960's, large tracts of land around Terlingua and Study Butte have been subdivided and sold as private lots, increasing domestic water-supply needs in the study area. Also, local businesses have more than doubled in number since the late 1970's as a result of increased tourist flow into Big Bend National Park, increasing demands on public water-supply systems at the same time. There is also ample reason to expect continued growth around Terlingua and Study Butte in upcoming years.

Mineral deposits such as mercury ore and hydrocarbons have yet to be fully identified and extracted from the region. Also, the Texas Parks and Wildlife Department has purchased the 336 square-mile, 215,000 acre Big Bend Ranch immediately northwest of Terlingua. The ranch includes the Solitario uplift and will be designated as a state natural area. Undoubtedly, the natural area will attract numerous visitors, adding to the already large number (one-quarter million in 1987) of tourists who pass through Terlingua en route to Big Bend National Park each year.

To prepare for future growth and upgrade existing water-supply systems, various business and property owners in the Study Butte area have already taken preliminary steps to form a local water co-op (Suzanne Bailey, 1988, personal communication). As envisioned in July 1988, the co-op will initially serve an urban corridor along Highways 118 and 170 between Study Butte and Terlingua Creek. The corridor includes approximately 136 recreational vehicle sites, 73 motel units, 70 household residences, five restaurants, three service stations, two food stores, two public showers, two washaterias, one medical facility, and Terlingua school, which had a student body of about 60 in 1987. Although no water-supply source for the co-op was identified in July 1988, local ground-water formations were a major consideration.

Prospects

As noted in preceding sections of this report, known fresh ground water is restricted largely to fractured Tertiary intrusive rocks that form isolated mountains in the region. The aquifers are relatively small in size and have limited volumes of fresh ground water that fluctuate with regional climate trends. Hence, it is doubtful that they can be relied upon to provide adequate water for public-supply systems by themselves alone. However, two or three of the igneous bodies at Bee, Cigar, and Maverick Mountains might be developed and used to augment and even improve the quality of water obtained from other aquifers.

There may also be substantial volumes of relatively fresh ground water in unexplored parts of Cretaceous aquifers, especially in cavernous intervals of the Santa Elena Limestone along the southern and eastern edges of the Terlingua uplift and in horst block structures east of Cigar Mountain graben (Figure 13). The Terlingua uplift region, itself, has received fresh meteoric recharge for many millions of years, primarily through exposed fault and fracture systems in the Santa Elena Limestone. Regional ground-water movement over the same time period has been largely to the south and southeast towards the Terlingua monocline and more southerly Rio Grande drainageway. Any Santa Elena ground water discovered in the study area, however, should be tested for radioactivity, since water from the formation has already proven to be radioactive at three locations.

Historically, exploration programs seeking to penetrate potential fresh-water intervals in the Santa Elena Limestone around Terlingua have been designed to locate well sites in areas where the top of the formation is below the water table. Or at least such was the exploration policy used for locating the LaVernge well (73-44-405) that currently supplies water to the Terlingua Store (Ed Reed and Associates, 1972). Notably, there are three wells very near the LaVernge well, 73-44-403, 406, and 407, where water quality and production might be improved if the wells are deepened and completed in the Santa Elena Limestone. The well sites are located in areas where the water table is within 200 feet of the top of the cavernous formation. Similarly, water quality and production might also be enhanced at the Glasscock well (73-44-202) south of Leon Mountain if it is deepened and completed in the Santa Elena Limestone aquifer.

Construction of surface-water dams and reservoirs on tributary drainages to Terlingua Creek would also provide a source of fresh water. One possible site for a surface dam and reservoir is located immediately north of Maverick Mountain along Rough Run Draw. Surface contours indicate that a reservoir covering approximately one square mile and averaging 50 feet in depth can be constructed at the site, offering storage for more than 30,000 acre-feet of fresh water when full. A reservoir dam might be located across Rough Run Draw in the narrow canyon that separates Maverick and Study Butte Mountains, with igneous intrusive rocks providing secure anchorage and footing for the dam foundation. Aquiclude clays and shales in the Pen Formation underlie the main reservoir area behind the proposed dam site.

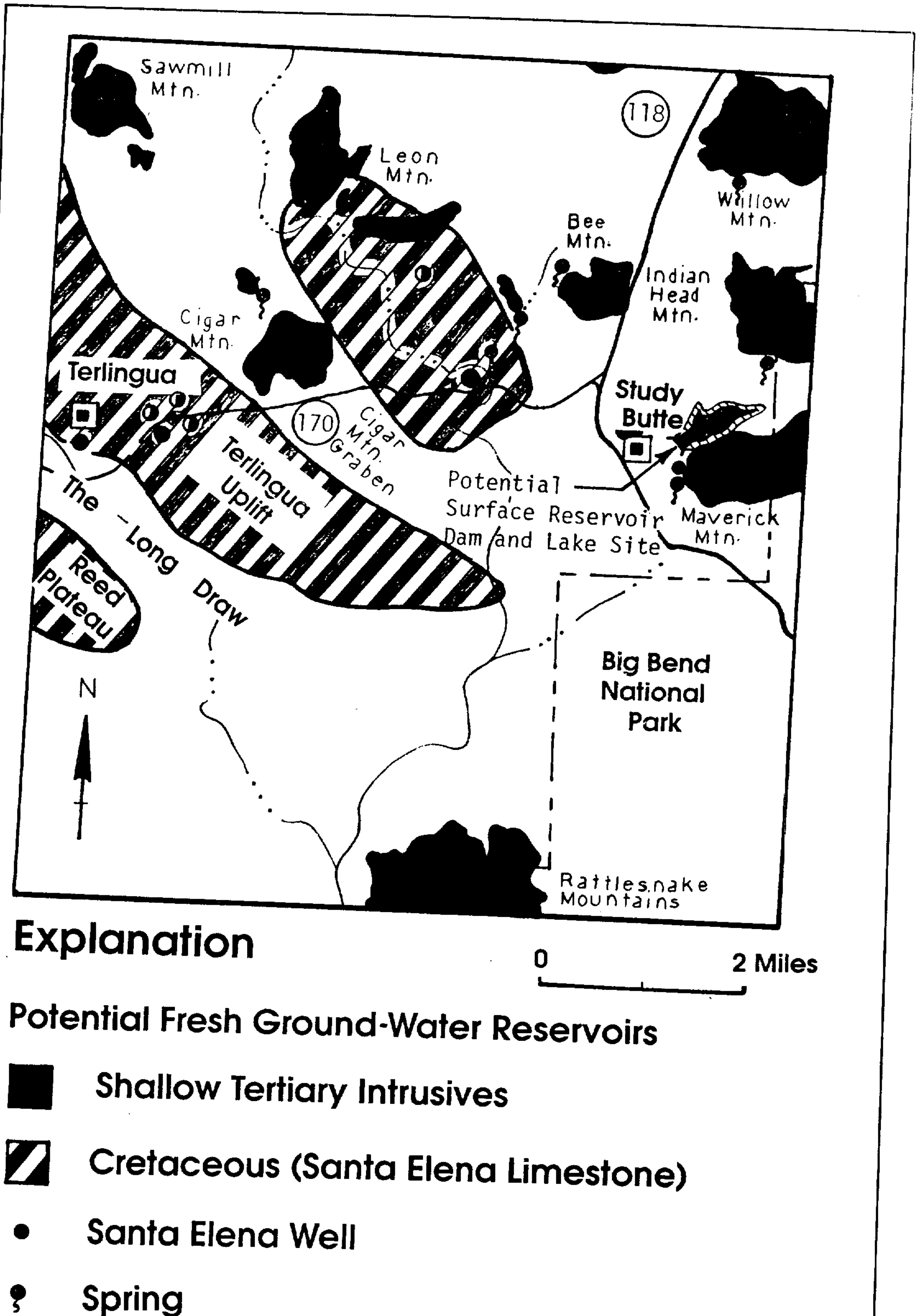


Figure 13

Map showing the Location of Potential Ground-Water Sources in the Terlingua Area

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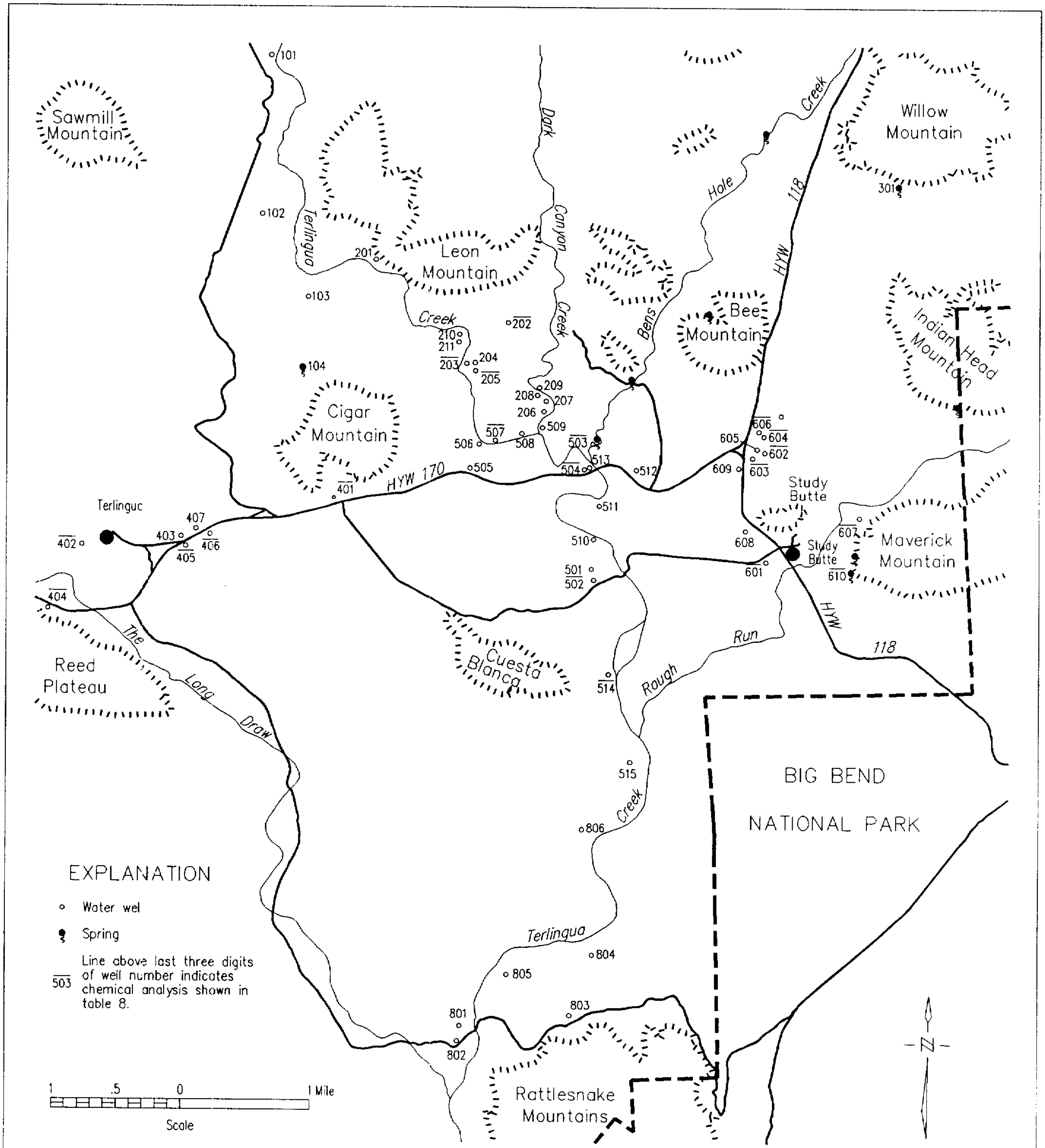

Figure 14

MAP SHOWING THE LOCATION OF WELLS AND SPRINGS IN THE TERLINGUA AREA

Table 5

Records of Water Wells and Springs

Well	Aquifer	Well Depth (Feet)	Date of Collection	pH	Silica (SiO_2) MG/L	Calcium (Ca) MG/L	Magnesium (Mg) MG/L	Sodium (Na) MG/L	Potassium (K) MG/L	Carbonate (CO_3) MG/L	Bicarb. (HCO_3) MG/L	Sulfate (SO_4) MG/L	Chloride (Cl) MG/L	Fluoride (F) MG/L	Nitrate (NO_3) MG/L	Dissolved Solids MG/L	Spec. Cond. (micromhos)	Hardness as $CaCO_3$ MG/L	Percent Sodium	SAR	RSC
73 44 103	211AGUJ	175	07/15/1988	6.2	35	855	13	752	12	0	264	3453	25	1.0	10.1	5287		2194	43	7.0	0
73 44 202	211BQLS	180	07/11/1988	8.1	22	200	43	196	7	0	257	848	12	1.1	1.1	1458	2528	677	38	3.3	0
73 44 203	100ALVM	20	08/06/1987 U	7.0		148	20	207		0	228	649	25			1161		450	49	4.2	0
73 44 205	100ALVM	20	08/06/1987 U	6.8		160	17	189		0	240	632	15			1131		470	46	3.8	0
73 44 401	211CRCSU	336	01/21/1976	8.3	10	6	1	491		0	600	479	72	2.5	0.6	1359	2448	21	98	48.5	9.5
73 44 401	211CRCSU	336	08/08/1978	8.3	13	10	3	543		0	593	630	68	2.0	1.0	1561	2688	37	96	38.7	9.0
73 44 401	211CRCSU	336	06/10/1985	8.5	13	9	1	544	3	6	575	591	67	2.1	0.1	1518	2688	26	97	45.5	9.1
73 44 402	218SNEL	850	06/10/1985	8.3	29	97	24	305	27	0	270	268	374	2.9	<.1	1259	2448	340	66	7.2	0
73 44 402	218SNEL	850	06/09/1988 U																		
73 44 402	218SNEL	850	07/12/1988 U																		
73 44 404	211BQLS	840	07/14/1988	8.1	27	99	16	310	26	0	261	275	383	2.9	<.0	1267	2416	313	66	7.6	0
73 44 405	218SNEL	865	03/24/1972	7.8		94	30	312		0	274	271	376	1.8	0.5	1220	1756	358	65	7.2	0
73 44 405	218SNEL	865	06/09/1988 U																		
73 44 405	218SNEL	865	07/13/1988	7.9	26	111	20	305	26	0	279	303	370	2.9	1.3	1303	2512	360	62	7.0	0
73 44 405	218SNEL	865	08/26/1988	0.0	0	0	0	0	0	0	0	0	0	0.0	0.0	0	0	0	0	0.0	0
73 44 406	211BQLS	789	07/12/1988	7.6	17	632	365	420	20	0	538	3156	150	1.2	100.3	5127	9296	3084	22	3.3	0
73 44 502	100ALVM	25	07/14/1988		25	206	46	257	10	0	167	964	16	1.2	0.7	1608		703	44	4.2	0
73 44 503	212PEN	15	07/22/1966 U	7.2						0	352	548	8	1.4			1540	508			
73 44 503	212PEN	15	04/19/1969 U	7.6		135	46			0	230	724	8				1670	526			0
73 44 503	212PEN	15	06/10/1986	7.9		181	35	178		0	317	708	9	1.3	0.0	1274	2262	596	39	3.2	0
73 44 504	218SNEL	800	08/03/1978	7.9	27	99	24	320		0	287	258	379	3.1	<.4	1252	2430	344	67	7.5	0
73 44 504	218SNEL	800	06/10/1985	8.0	24	160	28	164	6	0	242	623	10	1.0	0.5	1135	1984	519	41	3.1	0
73 44 507	100ALVM	20	04/03/1987 U	6.6		130	31	244		0	444	559	20			1202		450	53	5.0	0
73 44 507	100ALVM	20	05/02/1987 U	7.3		167	23	172		0	217	663	13		8.9	1154		512	42	3.3	0
73 44 514	100ALVM	20	02/08/1978 U	7.4	11	131	26	182	7	0	244	671					1492	431	47	3.8	0

* Depth value here reflects the bottom of the SAMPLED INTERVAL which was different from the completed well depth

U after date of collection signifies unbalanced or partial chemical analysis

Table 5

Records of Water Wells and Springs – continued

WELL	OWNER	DRILLER	DATE COMPLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAMETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASUREMENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
73-44-210	Lonnie Glasscock III		1986	20	C	48	0	16	100ALVM	2565		- -		H S	Estimated yield 20 GPM.
					S	48	16	20				- -			
73-44-211	Lonnie Glasscock III		1986	20	C	48	0	16	100ALVM	2565		- -		H S	Estimated yield 20 GPM.
					S	48	16	20				- -			
73-44-301	Joe Fedler								120IVIG	2820		- -		H S	Willow Spring. Estimated flow 7/88 was 2 GPM.
												- -			
73-44-401	Hilario Acosta	Lee Murphy	1963	336					211CRCSU	2717		- -	S E	H	Reported yield 35 GPM with 2 feet drawdown after pumping 48 hours in 1963.
												- -			
73-44-402	Bill Ivey	Cook Drilling Co.	1984	850					218SNEL	2900		- -	S E	H P	Reported temperature 113 degrees F. Supplies water to Terlingua Ghost Town businesses.
												- -	2.		
73-44-403	Billy Pat McKinney	Dick Baker Drilling Co.	1983	690	C	8	0	20	211BUDA	2820		- -	N	U	
					C	5	0	607				- -			
					S	5	607	690							
73-44-404	Edwin L. Hickinbottom	Dick Baker Drilling Co.	1983	840	C	8	0	40	211BQLS	2790		- -	S E	H	Slotted at unknown interval below 680 feet. Temperature reported to be 110 degrees F.
					C	5	0	837				- -			
73-44-405	Mel Lavergne Interest	Lee Murphy	1972	865	C	7	0	861	218SNEL	2808	-653.95	04-04-1972	S E	H S I	No drawdown while pumping 52 GPM during development test.
					O	0	861	865				- -			
73-44-406	Arturo White	Walter Stricker	1987	789	C	6	0	775	211BQLS	2808		- -	S E	H S	Estimated yield 20 GPM. Oil in lower part of hole. Originally drilled to 800 feet and plugged back. Sulfate taste.
					O	0	775	789				- -			
73-44-407	Hector Moreno	Walter Stricker	1987	740					211BQLS	2800	-505.00	09-10-1987	N	U	Reported yield 30 GPM. Some oil in water. Water in gray sand from 735 to 740 feet according to owner.
												- -			
73-44-501	F. C. Fulcher	E. F. Doyle		100	C	6	0	100	212PEN	2497	-15.40	10-26-1949	P W	H S	Reported yield 50 GPM.
												- -			
73-44-502	F. C. Fulcher		1930	25					100ALVM	2495	-22.80	10-26-1949	S E	H	Reported yield 30 GPM in 1943.
												- -			

Table 5

Records of Water Wells and Springs – continued

WELL	OWNER	DRILLER	DATE COMPLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAMETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASUREMENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
73-44-503	Rex Ivey		1960	15	C	48	0	15	212PEN	2550		- -	C E	P	
												- -			
73-44-504	Texas Dept of Hwy & Public Transportation	E.F. Doyle	1978	800	O	0	0	800	218SNEL	2525		- -	S E	P	
												- -			
73-44-505	Gilbert Felts	J.D. Killingsworth	1944	200	C	5	0	6	211BQLS	2660	-72.00	04-22-1984	S E	H I	No drawdown pumping 40 GPM in 1984.
					O	0	6	200				- -			
73-44-506	Lonnie Glasscock III		1986	30					211BQLS	2540		- -		H I	Estimated yield 30 GPM.
												- -			
73-44-507	Lonnie Glasscock III		1986	20	C	48	0	16	100ALVM	2540		- -		H	Estimated yield 30 GPM in 1986.
					S	48	16	20				- -			
73-44-508	Lonnie Glasscock III		1986	20	C	48	0	16	100ALVM	2540		- -		H	Estimated yield 30 GPM. Sulfate taste.
					S	48	16	20				- -			
73-44-509	Lonnie Glasscock III		1986	20	C	48	0	16	100ALVM	2540		- -		H	Estimated yield 30 GPM in 1986. Sulfate taste.
					S	48	16	20				- -			
73-44-510	E. Fulcher		1987	20	C	48	0	16	100ALVM	2495		- -		S	Reported yield 30 GPM.
					S	48	16	20				- -			
73-44-511	Benji Bell	J.D. Killingsworth	1983	270					211BQLS	2540		- -	S E	H	
												- -			
73-44-512	Darlene Leonhard	Cook Drilling Co.	1984	99					211BQLS	2555		- -		H	
												- -			
73-44-513	Texas Dept. of HWY & Public Transportation		1960	28	C	48	0	28	100ALVM	2520		- -	S E	H	Reported yield 40 GPM.
												- -			
73-44-514	Joe Moss		1970	20	C	20	0	20	100ALVM	2465	-7.20	07-11-1988	T E	H I	Reported yield 70 GPM.
												- -			
73-44-515	John Morelock		1980	20	C	48	0	20	100ALVM	2450		- -	C G	H	Well dry on 7-11-88.
												- -	2.		
73-44-601	Carl Thain	Alton Hess	1965	826	C	9	0	8	212PEN	2538	-2.00	09-30-1965	P E	U	Diamond Shamrock Mine. Water reported at 818 to 824 feet in sand.
					C	7	0	274			-57.83	01-27-1976			

Records of Water Wells and Springs – continued

WELL	OWNER	DRILLER	DATE COMPLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAMETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASUREMENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
73-44-601 (Continued)					O	0	274	826							Open hole 274 to 826 feet.
73-44-602	Gene Thompson Invest.	Dick Baker Drilling Co.	1985	180	C	8	0	20	211BQLS	2620		- -	S E	C H	Reported yield 60 GPM in 1985. Water supply for motel.
					C	5	0	180				- -			
73-44-603	Gene Thompson Invest.	Dick Baker Drilling Co.	1987	120	C	5	0	120	211BQLS	2600		- -	S E	C	Estimated yield 8 GPM.
												- -			
73-44-604	Big Bend Motor Inn	Dick Baker Drilling Co.	1988	240	C	7	0	13	211BQLS	2638		- -	N	U	Unused motel supply well.
					C	5	0	200				- -			
					S	5	200	240							
73-44-605	Big Bend Motor Inn	Dick Baker Drilling Co.	1988	240	C	8	0	220	211BQLS	2640		- -	N	U	Unused motel supply well. Sulfate taste.
												- -			
73-44-606	Big Bend Motor Inn	Dick Baker Drilling Co.	1988	685	C	8	0	12	211BQLS	2620		- -	N	U	Unused motel supply well.
					C	5	0	440				- -			
					O	0	440	685							
73-44-607	Rex Ivey	Walter Skinner	1987	200	C	7	0	90	120IVIG	2570		- -	S E	N	Pumping level 50 feet with no draw-down at 300 GPM when drilled.
					C	4	0	120				- -			
					S	4	120	190							
					C	4	190	200							
73-44-608	Beard & Elliot	Anton Hess	1965	345	C	7	0	310	212PEN	2550		- -	S E	H	Reported yield 10 GPM
					S	7	310	345				- -	3.		
73-44-609	Billy Pat McKinney			800					211BQLS	2585		- -	S E	H	
												- -			
73-44-610	Rex Ivey								120IVIG	2600		- -		H P	Maverick Spring. Reported flow 2 to 5 GPM
												- -			
73-44-801	Charlie Burman		1940	32		48	0	32	100ALVM	2360		- -	W	H S	Estimated yield 5 GPM. Destroyed.
												- -			
73-44-802	H. W. Patterson	H. W. Patterson	1940	33		60	0	33	100ALVM	2360		- -	W	H S	Estimated yield 8 GPM. Destroyed.
												- -			
73-44-803	A. B. Valenzuela		1940			48	0	0	100ALVM	2380		- -	W	H S	Estimated yield 20 GPM. Destroyed.
												- -			
73-44-804	A. B. Valenzuela		1939	11		36	0	0	100ALVM	2388		- -	W	H S	Estimated yield 10 GPM. Measured yield 90 GPM with centrifugal pump.
												- -			

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Table 5

Records of Water Wells and Springs – continued

WELL	OWNER	DRILLER	DATE COM-PLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAM-ETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASURE-MENT FROM LSD (FT)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
73-44-805	Evelyn Fulcher			102					100ALVM	2360		- -	W	S	
												- -			

Water Bearing Units

100ALVM	Alluvium
120IVIG	Intrusive Rocks
211AGUJ	Aguja Formation
211BQLS	Boquillas Formation
211BUDA	Buda Limestone
211CRCSU	Upper Cretaceous Series
212PEN	Pen Formation
218SNEL	Santa Elena Limestone

Table 6

Chemical Analyses of Water from Wells and Springs

WELL	OWNER	DRILLER	DATE COM-PLETED	DEPTH OF WELL (FT.)	CASING AND SCREEN DATA: CASING OR SCREEN	DIAM-ETER (IN.)	TOP DEPTH (FT.)	BOT DEPTH (FT.)	WATER BEARING UNIT	ALTITUDE OF LAND SURFACE (FT.)	WATER LEVEL: MEASURE-MENT FROM LSD (FT.)	DATE	METHOD OF LIFT AND POWER	USE OF WATER	REMARKS
73-44-101	3 Bar Ranch			20					100ALVM	2640		- -	C G	S I	Estimated yield 30 GPM.
												- -			
73-44-102	James Wayne Burr		1980	20	C	24	0	20	100ALVM	2620	-7.20	07-11-1988	C G	H I	Estimated yield 30 GPM.
												- -			
73-44-103	Pierre DeKoninck		1982	175	C	6	0	20	211AGUJ	2620	-26.00	07-13-1988	J E	H	Reported yield 10 GPM. Caved in to 30 feet.
					S	6	20	28				- -			
73-44-104	Gilbert Felts								120IVIG	2640		- -		H	Cigar spring. Estimated flow 7/88 was 1 GPM.
												- -			
73-44-201	Lester Press			15					100ALVM	2645		- -	S E	H	Limited use. Reported yield 40 GPM.
												- -			
73-44-202	Lonnie Glasscock III	Dick Baker Drilling Co.	1979	180					211BQLS	2600	-38.00	07-12-1988	W	S	Sulfur taste. Estimated yield 30 - 35 GPM.
												- -			
73-44-203	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2560		- -	N	H S I	Estimated yield 200 GPM.
					S	48	16	20				- -			
73-44-204	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2568		- -		H S	Estimated yield 150 GPM.
					S	48	16	20				- -			
73-44-205	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2560		- -		H S	Estimated yield 100 GPM.
					S	48	16	20				- -			
73-44-206	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2540		- -		H S	Estimated yield 30 GPM.
					S	48	16	20				- -			
73-44-207	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2540		- -		H S	Estimated yield 30 GPM.
					S	48	16	20				- -			
73-44-208	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2560		- -		H S	Estimated yield 20 GPM.
					S	48	16	20				- -			
73-44-209	Lonnie Glasscock III		1987	20	C	48	0	16	100ALVM	2560		- -		H S	Estimated yield 20 GPM.
					S	48	16	20				- -			

Table 6

Chemical Analyses of Water from Wells and Springs - continued

Well	Aquifer	Well Depth (Feet)	Date of Collection	pH	Silica (SiO2) MG/L	Calcium (Ca) MG/L	Magnesium (Mg) MG/L	Sodium (Na) MG/L	Potassium (K) MG/L	Carbonate (CO3) MG/L	Bicarb. (HCO3) MG/L	Sulfate (SO4) MG/L	Chloride (Cl) MG/L	Fluoride (F) MG/L	Nitrate (NO3) MG/L	Dissolved Solids MG/L	Spec. Cond. (micromhos)	Hardness as CaCO3 MG/L	Percent Sodium	SAR	RSC
73 44 601	212PEN	826	01/10/1970	8.9	1	5	5	730		32	469	1140	24	5.0	<.4	2173	3822	33	97	55.7	8.1
73 44 602	211BQLS	180	09/16/1985 U	7.8		44	33	920		0	389	2050	60	5.0	0.3	3304		237	89	25.5	1.4
73 44 603	211BQLS	120	05/18/1987	8.1		58	14	669		0	288	1360	28	3.6	0.0	2275	4004	201	87	20.5	0.7
73 44 603	211BQLS	120	05/19/1987 U	7.5		60	15	610		0	293	1400	27	10.0	<.0	2266		210	86	18.3	0.6
73 44 604	211BQLS	240	04/04/1988 U	8.3		120		620		0	476	1600	33	4.9	1.2	2613		380			
73 44 606	211BQLS	685	07/22/1986	8.4		55	39	949		2	406	1896	39	3.5	<.0	3183	5544	299	87	24.0	0.8
73 44 606	211BQLS	685	04/15/1988 U	8.0		123	32	821		0	305	1848	38		0.9	3013		440	80	17.1	0
73 44 607	120IVIG	200	07/12/1988	6.9	39	262	46	758	13	0	310	2019	36	2.5	<.0		4200	840	66	11.4	0
73 44 608	212PEN	345	04/19/1969 U	7.7		88	94			0	368	1160	13					606			0
73 44 610	120IVIG		07/18/1934 U			102	17	109		0	316	273	13		0.2	670		325	42	2.6	0
73 44 610	120IVIG		02/08/1977	8.2		55	6	107		0	267	156	12	2.8	<.4	470	852	163	59	3.7	1.2
73 44 802	100ALVM	33	09/22/1949	7.9	29	143	17	142	7	0	196	552	11	1.3	11.2	1010	1356	426	41	3.0	0

Water Bearing Units

100ALVM	Alluvium
120IVIG	Intrusive Rocks
211AGUJ	Aguja Formation
211BQLS	Boquillas Formation
211BUDA	Buda Limestone
211CRCSU	Upper Cretaceous Series
212PEN	Pen Formation
218SNEL	Santa Elena Limestone

* Depth value here reflects the bottom of the SAMPLED INTERVAL which was different from the completed well depth
U after date of collection signifies unbalanced or partial chemical analysis