Texas Water Development Board

Report 325

Test Well Drilling Investigation to Delineate the Downdip Limits of Usable-Quality Ground Water in the Edwards Aquifer in the Austin Region, Texas

by

Robert Flores, Geologist

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G. E. (Sonny) Kretzschmar, Executive Administrator

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ABSTRACT

The Edwards aquifer is the principal source of ground water for the Georgetown and Round Rock areas. In addition, Barton Springs is an important natural feature of the Edwards aquifer that provides a significant recreational facility for Austin area residents. As the need for further water development becomes pressing, it is useful to know in more detail the quantitative aspect of ground-water resources in the Edwards. Only a very limited amount of water-quality data is available to define the eastern downdip boundary of the Edwards aquifer within this area. To better delineate the downdip limits of usable-quality ground water in the Edwards aquifer in the Austin region, a test well drilling investigation was initiated in December, 1985.

The Texas Water Development Board's modified Failing 1500 drill rig, two water trucks, and drilling crew drilled eight test holes in Travis, Williamson, and Bell Counties. Additional well data was gathered on existing water wells.

The field investigation included the following: (a) a total of 6,613 feet was drilled; (b) 2,232 feet was drilled in the Edwards aquifer; (c) 417 feet of the Edwards Limestone was cored with approximately 90 percent core recovery; (d) 938 feet of surface casing and 432 feet of liner pipe was set.

Chemical analyses of formation waters from the test holes and other selected wells indicate that the "bad-water" line, where the aquifer contains water of 3,000 milligrams per liter or more dissolved solids, of the Edwards aquifer is generally further west than indicated by previous information. Additionally, core study and testing, geophysical logging, and hydrogeologic tests indicate the following: (a) where present, the Regional Dense Member of the Person Formation represents a hydrogeologic boundary dividing the aquifer into upper and lower units which contributes to variation in the chemical quality of the aquifer waters; and (b) the porosity of the lower unit is more consistent and uniform than the upper unit.

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INTRODUCTION

Purpose and Scope

The Edwards aquifer (Austin region) is the principal source of ground water in parts of Hays, Travis, Williamson, and Bell Counties. As the need for further water development becomes pressing, it is useful to know in more detail the quantitative aspect of the ground-water resources of the Edwards aquifer within the Austin region.

Because only a limited amount of water-quality data is available, a test-well drilling investigation was initiated in December of 1985 to acquire information to more accurately define the downdip limits of usable-quality water in the Edwards aquifer.

The Texas Water Development Board's drill rig was used to drill eight test holes to evaluate the aquifer's chemical and lithologic characteristics. Test hole sites were located where water quality data was limited or unavailable and where equipment limitations would not be prohibitive. When feasible, additional water samples were collected from existing wells, and the Board's pump equipment was used to obtain water samples from any non-equipped wells in the region.

Additional objectives of this study were to evaluate the Board's recently acquired geophysical sonic tool; and it's ability to interpret formation porosity in a carbonate aquifer, which will be presented in another report. The sonic tool was used to confirm the extent and lithologic characteristics of the Regional Dense Member of the Person Formation. These objectives required the laboratory analysis of cored sections recovered from the Edwards Limestone.

This report represents the results obtained from this investigation conducted between December 1985 and December 1987. In addition to the information provided in this report, further data on the individual wells used in the investigation is on file and available from the Board.

Location and Extent

The Austin region, as used in this report, encompasses a segment of the Edwards aquifer which extended from near Kyle in Hays County to near Belton in Bell County, a distance of 80 miles, and has an irregular width of from 4 to 30 miles. The study area includes parts of Hays, Travis, Williamson, and Bell Counties (Figure 1) where the Edwards aquifer contains water of less than 3,000 milligrams per liter (mg/l) dissolved solids based on current information. The locations of test holes and other selected well sites, are shown in Figure 5.

Previous Investigations

The Texas Water Development Board, U. S. Geological Survey, and other governmental entities, as well as private consultants, have gathered ground-water data in parts of the Austin Region for regional, countywide, or local investigations. The more detailed investigations dealing with the geology and related subjects in Hays, Travis, Williamson, and Bell Counties are listed in the references at the end of this report.

Personnel

This investigation was conducted with personnel of the Planning Division of the Texas Water Development Board, under the general direction of Tommy Knowles, Division Director, and Henry Alvarez, Chief of the Ground Water Section. Direct supervision was provided by Bernie Baker, Leader of the North Texas Ground Water Study Group.

The author served as rig geologist. Quality assurance management was provided by Gail Duffin and John B. Ashworth, both geologists with the Ground Water Section. Geophysical logging was conducted by Doug Crim and Steve Gifford of the Ground Water Section, and by John R. Hoyt of the Edwards Underground Water District in San Antonio.

The Board's Materials Laboratory and Core Drill Unit conducted the drilling and testing process under the supervision of Marion Striegler. The drilling crew consisted of Lewis Barnes, Chris R. Bufkin, Tony Connell, Chad Danner, and Mark E. Hayes. Finally, Steve Gifford drafted the illustrations.

Acknowledgements

Generous assistance was provided by the Texas State Department of Highways and Public Transportation in allowing some test holes to be drilled on State highway rights-of-way. Also, the Texas State School for the Deaf provided invaluable material assistance such as welding and cutting equipment, and casing coupling, as well as a drilling site.

In addition, Mr. Ken Henderson of Pflugerville generously provided his property for drilling site 4 (58-36-503 in the statewide well-numbering grid system), and the U. S. Army Corps of Engineers provided drilling site 5 (58-22-402). The author would also like to thank the many property owners and interested citizens for providing information on local subsurface geologic and hydrologic conditions. The cities of Austin, Buda, and Pflugerville provided the necessary supplies of water for the drilling operations.

The Edwards Underground Water District provided timely assistance by logging the initial intervals of test wells 2 (58-58-213) and 4 (58-36-503).

STRATIGRAPHY

The Edwards aquifer is composed of hard, porous, and fossiliferous limestones and dolomites and is confined between two relatively impervious formations, the overlying Del Rio Clay and underlying Walnut Clay. Collectively these limestones are considered the principal aquifer and include, in ascending order: the Comanche Peak Limestone; the Edwards Limestone, consisting of the Kainer Formation, and the Person, the Kiamichi and Duck Creek Formations where present; and the Georgetown Limestone. The stratigraphic units associated with the Edwards aquifer in the Austin region are shown in Table 1.

The various members of the Walnut Clay combine to make up a gray to tan, soft to very hard limestone. The formation consists of fine- to medium-grained fossiliferous limestones with layers of fine-grained marl, marly limestone, clays, and nodular limestone. The formation yeilds little or no water.

The Commanche Peak Limestone consists of a marly, grayish-white limestone containing nodules and fossils. It has considerable flaking and jointing which gives it a fractured appearance. The maximum thickness of the Comanche Peak in the study area is 100 feet, but it pinches out to the east and south. The Comanche Peak does not appear to be present south of the Colorado River. Because it is believed to be hydrologically connected with the Edwards Limestone, the Comanche Peak is included in the Edwards aquifer hydrologic network, although it yields little or no water to wells.

The Person and Kainer Formations consist of 200 to 470 feet of brittle, thickbedded to massive limestones, commonly dolomitic, containing minor beds of shale, clay, and siliceous limestones. Beds of chert and flint are common. "Honeycomb" limestone beds are also common and contain numerous voids, many interconnected, from which shell material has been dissolved. Dolomitic beds commonly have a sugary texture and often are designated as "sandstone" or "sandy limestone" by many drillers.

There are several solution-collapse zones which represent former beds of gypsum (originally anhydrite) that have been removed by solution. About 60 to 80 feet from the base of the Kainer Formation is a 5 to 10 foot thick solution-collapse zone. Higher in the aquifer, a 20 foot thick, iron-stained, cavernous, solution-collapse zone containing brecciated limestone, dolomite, chert, crystalline calcite, and residual red clay is present in the Kainer Formation. This widespread zone in Central Texas represents the former extent of a thick gypsum and anydrite unit called the Kirschberg Evaporite. Where the gypsum and anhydrite have largely been removed, it is called the Kirschberg Solution Zone. Near the top of the Person Formation is another thin solution zone. These solution-collapse zones, especially the Kirschberg, are the main water-bearing horizons in the Edwards Limestone. Well yields range from small (5 to 25 gallons per minute) to large (over 200 gallons per minute).

A 5 to 25 foot section of marl, clay, argillaceous limestone, and shell aggregates make up the "Regional Dense Bed" (Rose, 1972). This bed occurs within the Edwards in the southern portion of the study area and is a part of the Person Formation. It effectively separates the Persont hydrologically from the underlying Kainer Formation (Table 1). In northern Travis County the eroded Person Formation (including the Regional Dense Member) is represented by the Kiamichi and Duck Creek Formations which hydrologically separate the remaining Edwards Limestone from the overylying Georgetown Limestone.

The Georgetown Limestone is a nodular, usually gray to tan, massive limestone, interbedded with layers of marl or marly shale. The limestone commonly contains burrows filled with fossil fragments, and some minor solution zones. Downdip the formation ranges from 40 to 110 feet thick. The Georgetown and Edwards Limestones are in hydrologic continuity in the southern study area. Where the Person Formation has been eroded away, the Duck Creek and Kiamichi can provide a hydrologic barrier between the remaining Edwards Limestone and the Georgetown Limestone. In this report, the Edwards aquifer is divided into two hydrogeologic units referred to as the upper and lower units, with the Regional Dense Member and Kiamichi and Duck Creek Formations forming the hydrogeologic boundary. This is done to show the various aquifer characteristics of the units and to follow previous stratigraphic nomenclature (Rose, 1968). The hydrologic characteristics of the various geologic units which make up the Edwards aquifer are shown in Table 1.

The Del Rio Clay is a greenish-gray to olive-brown, selenitic, calcareous, pyritic, and fossiliferous clay. Kaolinite comprises about 50 percent of the clay mineral fraction. Illite is generally present in unweathered samples in much larger quantities than montmorillonite. This suggests that during the weathering process illite apparently alters to montmorillonite, since weathered samples contain only small quantities of illite. The clay obtains a maximum thickness of 85 feet within the study area.

The Buda Limestone consists of an upper hard, resistant, fine-grained, burrowed, glauconitic, shell-fragment limestone and a lower marly, nodular, and less resistant limestone. Total thickness of the Buda in the Austin region is about 50 feet, with the unit thining northward. Freshly exposed surfaces of the Buda are characteristically colored shades of tan to orange-brown that resemble discolorations caused by heating. Many early descriptions of this unit termed it the "burnt" limestone.

The Woodbine Group is represented by a thin shale facies in the northernmost part of the study area, east of any faulting. It thins southward and is difficult to distinguish in most of the region.

In the Austin region the Eagle Ford Group is predominantly a calcareous shale with a middle silty limestone and an upper shale. Montmorillonitic clay is abundant throughout.

The Austin Chalk consists of a gray chalk, limy marl, and chalky limestone. Some bentonite, glauconite, and pyrite nodules are also present in the unit. Near igneous intrusions and extrusions, such as

Table 1
Geologic Units and Their Water-Bearing Characteristics

System	Series	Group	Stratigraphic Unit	Hydrologic Characteristic	Maximum Thickness	Character of the Rocks	Water-Bearing Characteristics*
Cretaceous	Gulf	Navarro Taylor		Aquifer	1200	Massive beds of shale and marl with clayey chalk, clays and some sand. Nodular and phosphatic zones.	Very small amounts of fresh to moderately saline water.
			Igneous Rocks	Aquifer	700	Altered pyroclastics, basalt intrusions and flows.	Very small quantities of fresh water locally.
			Austin Chalk	Aquifer	600	Massive beds of chalk and marl with bentonitic seams, glauconite, and pyrite.	Small to very small quanities of fresh water.
		Eagle Ford		Confining Unit	110	Calcareous shale with thin beds of silty and sandy, flaggly limestone.	Not known to yield water.
		Woodbine		Aquifer	25	Shale, clay, some lignite and gypsum.	Not known to yield water in study area.
	Comanche	Washita	Buda Limestone	Aquifer	50	Massive, fine-grained, shell-fragment limestone.	Little or no water.
			Del Rio Clay	Confining Unit	85	Clay and marl with gypsum, pyrite and some siltstone and sandstone beds.	Not known to yield water.
			Georgetown Limestone	Upper Edwards Aquifer	110	Thin interbeds of richly fossiliferous, nodular, massive fine-grained limestone and marl.	Small to very large quantities of fresh water, especially from fractures and cavernous zones in or near the Edwards Limestone.
		Fredericksburg	Edwards Limestone: Person Formation; Duck Creek Fm.	Upper Edwards Aquifer	150; 50	The Person and Kainer Formations are massive, brittle, vugular limestone and dolomite with nodular chert, gypsum and anhydrite, and solution-collapse features.	The Person and Kainer yield small to very large quantities of fresh to moderately saline water especially from cavernous zones.
			Edwards Limestone: Regional Dense Member; Kiamichi Fm.	Confining Unit	25; 50		
			Kainer Formation	Lower Edwards Aquifer	300	The Regional Dense Member, Duck Creek Formation, and Kiamichi Formation consist of argillaceous, marly limestone and shell aggregate.	The Regional Dense Member, Duck Creek, and Kiamichi are not known to yield water.
			Comanche Peak Limestone	Lower Edwards Aquifer	100	Where present, a fine-grained, fairly hard, nodular, burrowed limestone.	Little or no water.
			Walnut Clay	Confining Unit	120	Hard and soft limestone, marl, and clay.	Little or no water.

* Yields of Wells: Small – less than 25 gallons per minute (gpm)
Moderate – 25 to 200 gpm
Large – more than 200 gpm

Chemical Quality of Water: Fresh – less than 1,000 milligrams per liter (mg/l)
Slightly Saline – 1,000 to 3,000 mg/l
Moderately Saline – 3,000 to 10,000 mg/l
Very Saline – 10,000 to 35,000 mg/l
Brine – more than 35,000 mg/l

Modified from Rose, 1968

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those around Pilot Knob in the southeast part of Travis County, the Austin Chalk is partially metamorphosed into a recrystallized limestone. Downdip, it's thickness ranges from 300 to 600 feet. In the outcrop, the thickness is considerably less.

The Austin Chalk outcrop trends northeast to southwest completely across Texas, and it has a surface exposure primarily in the Balcones fault zone through the Austin region.

Lithologically, the Taylor and Navarro Groups are very similar and are treated in this report as a single unit. They consist of massive beds of shale, siltstone, marl, and chalk with some clay.

For the purposes of this report, Figure 1 illustrates the outcrop areas of rocks older and younger than those comprising the Edwards aquifer. Those older rocks include of the Walnut Clay and others not discribed here. Younger rocks include the Del Rio Clay, Buda Limestone, Woodbine Group, Eagle Ford Group, Austin Chalk, and Taylor and Navarro Groups.

HYDROGEOLOGIC FRAMEWORK

This discussion is limited to the hydrogeologic framework of the Edwards aquifer. A description of the rocks from the land surface down through the Edwards aquifer is presented by drillers' logs of test wells in Appendix 1.

The Edwards aquifer, for the purposes of this report, includes the Kainer Formation, the Regional Dense Member, the Kiamichi Formation, the Person Formation, the Duck Creek Formation, the underlying Comanche Peak Limestone, and the overlying Georgetown Limestone, all of early Cretaceous age.

The disruption of the Edwards aquifer by the intense faulting along the Balcones fault zone (Figure 1) has limited the occurrence of fresh to slightly saline water. Consequently, the area of usable quality water is smaller in Hays and Travis Counties where the faulting is more prevalent than in Williamson and southern Bell Counties (Baker and others, 1986).

Knowledge of the local depth to the top and base of the aquifer provides a practical guideline for drilling wells and, in general, for properly managing the orderly development and protection of the aquifer. The Edwards aquifer within this area varies in depth, but variations are generally gradual except in the areas of intense faulting.

The altitude of the top of the Edwards aquifer throughout the report area is illustrated in Figure 2. The depth to the top is given at selected well locations, based on available data. An approximate depth to the top at any particular location can be determined by subtracting the altitude of the top of the aquifer, as estimated from contour lines on the map, from the altitude of the land surface at that particular location. The outcrop of the Edwards aquifer represents the aquifer's eroded top that is exposed at the land surface.

The aquifer dips to the east-southeast at an average slope of 70 to 75 feet per mile. The slope of the aquifer surface, as well as its depth and elevation, varies significantly over short distances in areas of intense faulting. The faulting has caused the aquifer surface to be highly irregular.

The greatest depth to the top of the Edwards aquifer, where it still contains water having generally less than 3,000 mg/l of dissolved solids, is approximately 1,200 feet below land surface at the City of Taylor in eastern Williamson County. The shallowest occurrence of water having generally 3,000 mg/l or less of dissolved-solids concentration occurs midway between Interstate Highway 35 and the Barton Creek confluence with the Colorado River in Austin. At this location, the top of the aquifer is only about 150 feet deep.

The top of the aquifer is identified in the subsurface by an abrupt change in the character of the rocks. Drillers' logs and geophysical logs of boreholes show a marked change in lithology at the contact of the overlying Del Rio Clay and the hard Georgetown Limestone at the top of the aquifer (Baker and others, 1986).

The configuration of the base of the Edwards aquifer is shown in Figure 3. The base, which generally dips toward the east-southeast at a slope of 70 to 75 feet per mile, is cut by numerous faults. These faults have caused the base to be offset a few feet to several hundreds of feet along the fault planes. The individual faults extend laterally for distances ranging from a fraction of a mile to more than 10 miles.

The base of the Edwards aquifer extends from the land surface at many places along the western edge of the aquifer's outcrop to depths of hundreds of feet east of the outcrop. The depth to the base, where the aquifer contains water having generally 3,000 mg/l or less of dissolved solids, ranges from about 1,500 feet below land surface at Taylor to about 550 feet below land surface about 1 mile west of Interstate Highway 35 at the Colorado River in Austin (Baker and others, 1986).

The base of the aquifer is less discernible than the top in the subsurface. Drillers' logs and geophysical logs of the boreholes do not show a sharp break in the lithologic character of the rocks. The rocks underlying the Edwards aquifer—the Walnut Clay or its various members—are composed of marly limestone and, thus, are somewhat similar in lithology to the aquifer in Williamson and Bell Counties. In Travis and Hays Counties, these underlying units are thinner and more difficult to identify in the subsurface.

The Edwards aquifer yields water much more readily than the underlying rocks because of its greater secondary permeability. Consequently, the base of the Edwards aquifer is defined as the base of the rocks having the greater wateryielding capabilities.

The uneroded thickness of the Edwards aquifer decreases overall from south to north along the strike, and in many areas increases from west to east downdip (Figure 4). Within the Austin region from Kyle to Belton, the uneroded thickness of the Edwards aquifer decreases from about 470 feet in eastern Hays County to about 225 feet in southern Bell County.

Along the outcrop, where the aquifer's thickness is influenced by erosion as well as faulting, the thickness ranges from zero to a maximum of about 470 feet.

METHODS OF INVESTIGATION

Drilling Investigation

Drilling began in December 1985. Drill sites were based on drilling depth limitations and proximity to the Edwards aquifer "bad-water" line. This limited the test hole sites in Travis County because of large fault displacements within a few miles from the aquifer outcrop. Locations of test holes and other selected wells are shown on Figure 5. The drilling investigation was completed in December 1987.

Eight test holes totaling a depth of 6,613 feet were drilled. Detailed stratigraphic logs were written for each (Appendix 1). When possible all test holes were drilled through the Edwards aquifer and into the top of the Walnut Clay. The desired coring interval was preselected to provide samples of the entire aquifer sequence, from the base of the Del Rio Clay to the top of the Walnut Clay. Approximately 417 feet of recovered core was taken from test holes 1, 4, and 7.

The Board's proposal was to core one test well south of the Colorado River and another north of the Colorado River in Travis County. This approach was used to determine the consistency and characteristics of the aquifer, and extent of the Regional Dense Member in an area of suspected transition. This also allowed correlation between test holes through the use of geophysical logs. This approach saved time and expense while allowing maximum data acquisition.

Cores obtained in Travis County from test well 1 (58-50-603), south of the Colorado River, provide quantitative results concerning the hydrogeologic boundaries of the Regional Dense Member (between the upper and lower Edwards aquifer), the Georgetown Limestone, and the Person and Kainer Formations. Cores from test well 7 (40-61-705), in Bell County, do not indicate an equivalent confining layer. An attempt to recover representative cores in the Edwards was unsuccessful in test well 4 (58-36-503) in Travis County due to the poor quality of the water encountered in the top of the Edwards as well as the drilling rig's depth limitations. The desired comparison cannot be completed until core is recovered north of the Colorado River where the Regional Dense Member or its equivalent may occur.

The Texas Water Development Board's drilling rig was used for all test drilling and has a maximum practical depth limit of 1,200 feet. The drilling rig's equipment consists of a modified (extended mast, large mud pump, and break-out table) Failing 1500 drilling rig, two water trucks, and two pickups which carry support equipment and supplies.

The test wells were drilled with bits that were changed to suit various lithologies, and drill speeds. The size of these bits ranged from 6-1/4 to 8-5/8 inches. Flush jointed drill pipe with a 4-inch outside diameter was used to drill all test holes. Some test holes were drilled with the aid of drill collars. A Christensen 5 3/4-inch by 4-inch core barrel with a diamond drill bit was used to retrieve core samples. The Board's rubber packer and nitrogen gas system was used with a 1-inch air jetting pipe to isolate and recover water samples.

With few exceptions, the drilling procedure remained the same throughout the study. Test holes were drilled from the surface to the top of the Georgetown Limestone using either a 7-7/8 or 8-5/8 inch roller bit. A Gamma Ray log was produced to confirm the formations penetrated and to determine an appropriate amount of casing.

When possible, steel casing was set to the base of the Del Rio Clay allowing the clay to squeeze around the casing. This process isolated the Edwards aquifer from any formational water in overlying units and allowed some of the casing to be recovered.

A smaller drill button bit was used below the casing point to obtain a straight hole and to allow for the safe passage of drilling mud, cuttings, water sampling and geophysical tools. Bits were changed periodically when encountering significantly different formation characteristics. Beds containing chert nodules required short knobby bits while very soft marls and shales required a wing bit. Drill collars were used to increase drill speed and insure a straight hole. Reaming was done when required.

A 10-foot double-walled core barrel was used to core the Edwards aquifer. The inner barrel is a thin-walled tube with a core catcher attached to the bottom to hold the core in the tube. The outer barrel rotates and cuts the rock with a 5-inch diamond tipped core bit.

A constant supply of drilling fluid (fresh water or mud) was used to cool the drill bits. Fresh water was delivered to each test hole by the Board's 900 and 2,000-gallon water trucks. Water was then unloaded into adjacent mud pits to provide a large fluid reserve. Circulation of the drilling fluid could not be maintained while drilling in the Edwards aquifer in test well 1 (58-50-603), and "lost circulation drilling" was required. In "lost circulation drilling", drilling fluid is still pumped to the drill bit while drilling, coring, or reaming and then is lost to the porous rock formation.

The majority of the Edwards aquifer sections, below the casing point, were drilled with mud. The mud lubricated the well bore and provided buoyancy for the cuttings to be pushed out into the formation. It should be noted that a new foam for air drilling was used on test well 4 (58-36-503), called "Super-Mud." This increased the drilling speed while removing large cuttings from the borehole.

When possible, drilling continued through the entire Edwards aquifer and into the top of the Walnut Clay. This procedure ensured that the entire Edwards Limestone would be reflected on geophysical logs of the test holes.

Problems encountered during the drilling investigation were as follows:

(a) maintaining an adequate supply of water;
(b) slow drilling rates in intervals of chert and other hard rock;
(c) variable lithology and the fracturing tendency of the Edwards aquifer, which caused some poor core recovery; and
(d) obstructions such as chert nodules, sometimes leading to equipment damage.

Well Site Procedure

A very important part of the test hole investigation was the well-site descriptive log prepared by the rig geologist. These logs represent a continuous lithologic description of both the core and cutting samples. The description of the cuttings and core at the drill site was divided into the following:

1. *Identification of rock as to its stratigraphic unit.* The stratigraphic nomenclature used to identify the various units is illustrated in Table 1 and on all well logs in the Appendices.
2. *Description of rock material.* When practical, this included the dominant rock type, color, particle size, roundness, matrix, inclusions, occasionally fossil content, and depositional texture (as shown in Appendix 1).
3. *Classification of porosity.* Classification parameters for estimated porosity are also described in Table 2.

A record of drilling time was kept by means of a geolograph. The geolograph does not reflect the varying amount of drill-bit pressure, but the weight of the drill stem alone.

Core recovery was determined for all core runs and recorded as a percentage for each 10-foot interval. All of these data are presented in the descriptive log for each hole and are shown in Appendix 1.

Water samples were collected as drilling progressed and after other waterbearing formations had been sealed off. The point of collection was a discharge pipe which directed water into the mud pits.

Water samples were retrieved up by placing a 1-inch pipe inside the open-ended drill stem. Air was forced down the smaller pipe and out into a larger diameter drill stem, lifting the water flow to the surface through the discharge pipe. Two types of sealants were used to insure accurate water samples. One way to obtain a water sample was to set casing opposite any water-bearing formations that may have influenced a test. Another way was utilizing a rubber-packer system using nitrogen gas to expand a rubber seal outwards, thereby sealing off any water influence from formations above or below the desired interval.

Field conductivity, temperature, and pH testing were conducted at the well site. Test holes were air jetted for various lengths of time until it was determined that the water sample being collected had stabilized by providing consistent conductivity, temperature, and pH values; and was representative of the Edwards aquifer and did not contain any fresh mud or mud cake from the borehole. All water samples were sent to the Texas Department of Health for a more detailed laboratory analysis.

Finally, some water samples were obtained from existing wells using the Board's pump-pulling unit. When possible, this unit would remove old broken pumps and lower the Board's own pump into the well to retrieve a water sample. All such wells were logged to confirm total depth, producing formations, and well completion and condition.

Table 2
Classification Systems
Archie's System of Classifying Matrix Porosity

Texture of Matrix	Appearance of Hand Sample	Appearance under Microscope 10X	Matrix [1]	Percent Porosity
Type I Compact Crystalline	Crystalline, hard, dense, sharp edges, and smooth faces on breaking. Resinous.	Matrix made up of crystals tightly interlocking, allowing no visible pore space between crystals, commonly producing "feather edge" on breaking due to fracturing of clusters of crystals in thin flakes.	IA IB	< 1-3 1-4
Type II Chalky	Dull, earthy, or "chalky." Crystalline appearance absent because small crystals are less tightly interlocked,thus reflecting light in different directions, or made up of extremely fine granulles or sea organisms. May be siliceous or argillaceous.	Crystals less effectively interlocking than the foregoing, joining at different angles. Extremely fine texture may still appear "chalky" under this power but others may begin to appear crystalline.	IIA	1-5
		Grain size for this type is less than about 0.05 millimeter. Coarser textures classed as Type III.	IIB	2-8
Type III Granlular	Sandy or sugary appearing (Sucrosic). Size of crystals or granules classed as: Very fine < 0.05 millimeter Fine < 0.10 millimeter Medium < 1.0 millimeter	Crystals interlocking at different angles, generally allowing space for considerable porosity between crystals. Oolitic and other granular textures fall in this class.	IIIA IIIB IIIC	< 1-3 2-8 5-15

Modified by Sieh, 1975

[1] The visible pore size may be classed as follows:

- Class A: No visible porosity under about 10-power microscope, or pore size is less than about 0.01 millimeter in diameter.
- Class B: Visible porosity greater than 0.01 millimeter, but less than 1.0 millimeter.
- Class C: Visible porosoity greater than 1.0 millimeter, but less than 4.0 millimeters.

Table 2-*continued*
Classification Systems
Waldschmidt's Classification of Fractures in Cores

Type	Orientation	Deposition of Minerals	Angle
Open	Vertical	Manganese	Parallel
Partially Filled	Horizontal	Iron	Intersection
Filled	Random	Calcite	
Closed	High Angle	Calcite Crystals	
		Asphalt	

Modified by Sieh, 1975

Table 2-*continued*
Classification Systems
Choquette and Pray's System of Identifying Porosity Types

Basic Porosity Types

Fabric Selective		Not Fabric Selective	
	Interparticle		Fracture
	Intraparticle		Channel
	Moldic		Vugular
	Fenestral		Cavity or Cavern

Modifying Terms

Time of Formation	Process	Direction of Stage	Classes	Range (mm) [1]
Primary	Solution	Enlarged	Megapore large	35-256
Secondary	Cementation	Reduced	Megapore small	4-32
	Internal Sediment	Filled	Mesopore large	1-4
			Mesopore small	1/8-1
			Microspore	< 1/8

[1] Range of pore sizes average diameter in millimeters.

Modified by Sieh, 1975

The laboratory results of the water sampling are shown on Figure 5. Field conductivity and pH tests were taken on the fluid in the mud pits to monitor any change in chemical quality. This was done to avoid discharging any undesirable water into the surface environment.

Core Testing

Cores were taken from test wells 1 (58-50-603), 4 (58-36-503), and 7 (58-36-503) to get a detailed lithologic description of the Edwards aquifer. Due to the poor quality of the formation water encountered, test hole 4 (58-36-503) was abandoned after minimal core recovery. The rig geologist selected certain sections in each core run to be tested by the Board's Materials Testing Laboratory. Only the more competent sections of the Edwards aquifer were tested, due to breakage of less competent sections in the core barrel and lack of core recovery. Tabulations of the core analysis tests on test holes 1 and 7 are shown on Tables 3 and 4.

Field tests to determine the calcite/dolomite ratio of selected intervals of core were performed. The test method is a color-reaction/time experiment which employs the use of a reagent on a crushed sample. Pure dolomite being identified by its reaction time in conjunction with a 15 percent diluted HCl acid solution. The method and chemicals used are described in Shell Oil Company's Sample Examination Manual (Swanson, 1981).

The Board's Materials Testing Laboratory conducted the following tests on the core samples for analysis:

Bulk Density: the weight per unit of volume, measured in pounds per cubic foot.

Porosity: the ratio of the volume of the interstices to the tested or bulk volume of the sample, expressed as a percentage of the total volume occupied by the interconnecting interstices.

Vertical permeability: the measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient, the flow rate measured in gallons per day/ per square foot at 60° F (gal/day/ft^2 at 60° F).

Disposition of Core

After testing at the Board's Materials Testing Laboratory, all usable cores and core fragments were marked and stored in cardboard boxes. These were then sent to the Bureau of Economic Geology's Well Sample and Core Library located at the Balcones Research Center in Austin, Texas.

Geophysical Logs

The Texas Water Development Board's logging unit and the Edwards Underground Water District logger (San Antonio) ran borehole geophysical logs on all test wells. The geophysical logs completed on each test well are shown in Appendix 2. These logs can be studied in conjunction with the well site descriptive logs and core

Table 3

Laboratory Core Anaylsis of Test Hole 1 (58-50-603)

Depth (feetof 6" cores)	Bulk Density (lb/ft ^{3})	Porosity Percent	Vertical Permeability (gal/day/ft.^{2})
331	2.41	0.08	imp.
335	2.41	0.07	imp.
337	2.42	0.07	imp.
340	2.49	0.04	imp.
411	1.96	0.17	imp.
413	1.91	0.32	imp.
415	1.93	0.39	.082
416	2.00	0.37	.100
418	2.06	0.39	.010
420	2.64	0.02	imp.
422	2.07	0.25	.025
424	2.53	0.06	imp.
426	2.41	0.05	imp.
433	2.52	0.13	imp.
444	2.52	0.08	imp.
471	2.16	0.27	.508
475	2.20	0.30	.110
477	2.14	0.29	.990
479	2.00	0.32	.150
483	2.25	0.16	.002
487	2.29	0.10	imp.
489	2.26	0.20	.167
490	2.25	0.20	.001
494	2.24	0.18	imp.
497	2.16	0.21	.020
499	2.15	0.22	.008
500	2.16	0.24	.033
511	2.33	0.21	.002
515	2.49	0.09	imp.
516	2.41	0.14	imp.
517	2.40	0.13	imp.
519	2.26	0.26	imp.
520	2.99	0.09	imp.
522	2.18	0.16	.095
524	2.34	0.17	.180
527	2.13	0.22	.196
530	2.04	0.20	.420
532	2.68	0.17	imp.
533	2.18	0.26	.047
535	2.40	0.19	imp.
537	2.37	0.17	.008
538	2.26	0.21	.309
539	2.18	0.19	.450
540	2.29	0.12	.077
542	2.14	0.28	.504

Table 4

Laboratory Core Anaylsis of Test Hole 7 (40-61-705)

Depth (feet of 6" cores)	Bulk Density (lb/ft^3)	Porosity Percent	Vertical Permeability ($gal/day/ft^2$)
37	2.48	0.12	0.001
40	2.44	0.20	0.002
60	2.51	0.13	0.002
69	2.55	0.10	0.001
70	2.50	0.12	imp.
85	2.29	0.18	0.006
86	2.30	0.26	0.008
89	2.55	0.08	0.002
94	2.37	0.24	0.003
95	2.09	0.34	0.170
96	2.19	0.34	0 .053
98	2.10	0.41	0.105
106	2.16	0.32	2.240
114	2.07	0.42	3.180
117	2.06	0.41	12.210
119	2.11	0.31	2.870
130	2.05	0.43	0.660
134	2.00	0.43	9.650
135	1.96	0.44	6.050
136	2.03	0.52	11.930
137	1.98	0.44	2.360
140	1.99	0.40	1.850
141	2.04	0.42	6.170
145	2.00	0.47	0.290
146	2.01	0.46	1.720
149	2.02	0.42	0.770
151	2.02	0.41	2.010
158	2.50	0.18	imp.
167	2.45	0.12	0.001
174	2.46	0.15	0.006
180	2.48	0.17	0.002

analysis of each test hole. These logs provided stratigraphic and hydrogeologic data. The following is a listing of the borehole geophysical logs with a short description of their capabilities:

Spontaneous Potential: recording of the differences between the potential of a moveable electrode in the borehole and the fixed potential of a surface electrode; used to detect the permeable beds, geologic correlations, and to determine values of a formation's resistivity.

Gamma Ray : a record of the amount of natural radioactivity within the formations penetrated by a borehole; used for geologic correlation in open or cased holes.

Neutron: responds primarily to the amount of hydrogen present in the formation; a reflection of the amount of liquid-filled porosity.

Gamma-Gamma: records the intensity of gamma radiation from a source in the probe after it is backscattered and altered within the borehole and surrounding rocks; used to measure bulk density and porosity.

Caliper: measures average borehole diameter to select packer settings, calculate cement volume, and check mud cake.

Resistivity: currents are passed through the formation via electrodes, and voltages are measured between other electrodes. These measured voltages provide the resistivity determinations; these logs are used for defining formations, correlations, and for qualitative and quantitative analyses in terms of saturation and porosity.

Sonic: a record of the transit time of an a acoustic pulse between transmitters and receivers in a probe; used for the measurement of porosity and the identification of fractures.

The Sonic log porosity values (ϕ) were derived using the formula:

$$\phi = \frac{{}^{\Delta t}\log - {}^{\Delta t}\,ma}{{}^{\Delta t}f - {}^{\Delta t}\,ma}$$

Where ${}^{\Delta t}\,ma$ (travel time of the matrix) is 47.6 μs/ft (microseconds per foot), and because of the limestone nature of the material involved, ${}^{\Delta t}f$ (fluid medium transit time) is 218 μs/ft. The value 218 μs/ft was used instead of the common 189 μs/ft because it better represents the travel time (${}^{\Delta t}$) in a "fresh" water medium as opposed to brine water.

RESULTS

The following section summarizes the physical aspects of the test hole investigation and illustrates the data collected. The drilling and coring statistics for each test hole can be found in Table 5. Figure 5 represents the end product of this investigation and shows the chemical analyses of selected wells. Appendix 2 illustrates the various geophysical logs for each test hole, while Appendix 3 shows the well schematic, lithology, water quality, and completion intervals of each test hole.

The well schematics in Appendix 3 also show the zones from which water samples were obtained in each of the test holes along with the chemical results (in total dissolved solids) and the yields. Of particular interest are the individually sampled zones in test wells 1 and 3. Figure 5 shows the locations of all test holes and the sulfate, chloride, and total dissolved solids content of the water for each well.

Figure 6 illustrates the "bad-water" line of Baker and others (1986), and a modified line using the data acquired during this investigation. This figure also shows the net gains and losses of area for the Edwards aquifer by comparison of the two "bad-water" lines.

Table 5

Drilling and Coring Statistics

Test Hole Number	State Well Number	County	Total Depth (feet)	Footage Drilled	Footage Cored	Percent Core Recovered	Water Used (gallons)
1	58-50-603	Tavis	779	519	260	90.4%	37,000
2	58-58-213	Travis	1,009	1,009	---	---	30,000
3	58-42-927	Travis	561	561	---	---	40,000
4	58-36-503	Travis	858	848	10	85%	23,000
5	58-22-402	Williamson	1,222	1,222	---	---	27,000
6	58-13-301	Bell	1,140	1,140	---	---	22,000
7	40-61-705	Bell	180	33	147	95%	6,000
8	58-12-901	Williamson	864	864	---	---	10,000
TOTALS			6,613	6,196	417	90%	195,000

CONCLUSIONS

The Board's Failing 1500 drill rig with extended mast, large mud pump, and break-out table proved adequate to drill the Edwards aquifer test holes near the outcrop. However, more desirable drilling locations were neglected due to the rig's depth limitations. The two water trucks (900 and 2,000 gallon capacities) provided enough water for both normal drilling operations and for "lost circulation" drilling. Bit wear-out was considered normal for the material encountered, with the average being one roller bit for 200 feet of subsurface drilled. The core barrel, using diamond-tipped core drill bits, was satisfactory for coring the Edwards aquifer. Chert nodules proved to be the only material that could substantially retard or halt the drilling and coring progress. Overall, core recovery exceeded 90 percent.

The use of drilling mud provided a reliable way to remove cuttings and support the borehole; however, on one test hole an excessive amount of mud buildup caused long delays in obtaining water samples. When mudcake buildup moves far out into the formation, a lengthy amount of time for jetting is needed to remove any influence on water sample quality. "Super-Mud", a foam additive used in conjunction with air drilling, helped in obtaining a remarkable rate of penetration and by bringing up larger cutting samples for analysis. The Board's nitrogen-filled rubber packer system was adequate for obtaining water samples.

The following generalizations with respect to the Edwards aquifer, Austin region, were determined from drilling, coring, lab analysis, and log interpretation during this investigation:

1. Water in the Edwards aquifer containing less than 3,000 mg/l dissolved solids in the Austin region shows a significant loss of area from earlier estimates. This is illustrated in Figure 6 where the new delineation of the 3,000 mg/l boundary, which was developed using the data gathered during this investigation, is superimposed upon the old line (Baker and others, 1986). The "bad-water" line is now generally established further west. This loss of area can result in a corresponding decrease of approximately 5 percent in the estimates of total water availability, or 9 percent of the available water in the artesian portion of the aquifer.

2. Core analysis, laboratory tests, and water quality sampling suggest that where the Regional Dense Member occurs, it hydraulically separates the Edwards aquifer into upper and lower units. In some instances, fault displacement may circumvent the barrier effects of this relatively thin bed.

3. Core analysis and log interpretation suggest that the average effective porosity is greater in the upper Edwards aquifer than in the lower. This is the case even though the lower aquifer commonly has a greater occurrence of secondary porosity (channels, fractures,

vugs). The effect may be the result of a greater abundance of recrystallized rocks in the lower aquifer (Appendix 1).

4. The upper Edwards aquifer, where present, exhibits more diverse value of total porosity, having both the lowest and highest values, while the lower aqifer has more homogenous porosity.

5. Many of the sucrosic samples (matrix type III) exhibit the same type of secondary porosity, and may have been formed by the filling of vugs and channels. The presence of silt and sand usually indicates a higher porosity.

6. Where the Regional Dense Member is not present above the Kainer Formation, the rock matrix is more homogenous. This is particularly noticeable with regard to an increase in dolomite and dolomitic limestone northward from the area of occurrence of the Dense Member, at the expense of gypsiferous matrix.

7. Where the Regional Dense Member is present, the lower Edwards can be more productive. The lower aquifer can also exhibit better quality water than the upper aquifer. This is attributed to the occurrence of solution zones which can contribute enough water of better quality to substantially alter the overall results. However, productivity can vary within a small distance as the Edwards is very anisotropic.

8. Fluoride concentrations along the "bad-water" line ranged from 1.6 to 8.5 mg/l. The average well near the line had 4.7 mg/l of flouride. The Texas Department of Health's primary standards suggest a limit of 1.6 mg/l.

9. Quality and quantity of aquifer waters at a well site may vary substantially at different horizons, particularly where the aquifer matrix is heterogenous (i.e. where the Regional Dense Bed occurs). Better yields and better quality can occur in the lower aquifer.

The Board's logging van provided most of the geophysical logs used in this investigation. The gamma ray log continues to be the most widely used geophysical borehole log for making lithologic determinations. The Board's Sonic tool can provide an accurate determination of lithology and porosity, particularly of the Edwards aquifer (as shown by Rose, 1972). This tool can also provide an acceptable accuracy for the "on site" log interpretation that is necessary when locating depth intervals of high porosity for packer testing.

RECOMMENDATIONS

The Board should establish monitoring wells adjacent to a pumping well and near the "bad-water" line to determine the extent of movement in the line during periods of heavy pumpage.

New wells drilled where the Regional Dense Member occurs within the Edwards Limestone should penetrate into the lower aquifer to increase yield. This is especially desirable since the lower member may yield better quality water.

Cooperation with local water well drillers should be maintained on a steady basis concerning the immediate availability of data on any wells completed in the Edwards aquifer. Wells that have already been drilled and abandoned should be considered for possible workover efforts by the Board in areas where aquifer characteristics have not been documented. Consideration should also be given to hiring local well drillers to provide workover services that the Board cannot provide.

In regard to future test drilling, the following recommendations are made in conjunction with those drilling procedures already outlined:

1. Preparations should be made in advance when a test site is located on the Navarro/Taylor Group outcrop. The exposed clay of these groups has a tendency to become extremely soft during wet weather, so a caliche base or platforms should be used to support the drill rig and ensure a straight hole. Also, a piece of casing should be temporarily installed below the surface of the ground to support the borehole.

2. The actual borehole should always be covered when drilling operations cease to prevent material or objects from falling inside the hole.

3. Inspection of equipment should be performed on a regular basis, involving such things as drill stem fatigue before adding additional drill stem, and checking all connecting threads on stem and casing.

4. Mud viscosity should be monitored regularly, so that a minimal amount of mud is used when drilling within the aquifer rock.

5. Pit water and mud should be monitored on a continuous basis to anticipate any problems dealing with a possible overflow of unacceptable water or mud.

6. If there is an overflow from the mud pit, a discharge or dump site should have been pre-selected.

7. To insure a straight borehole, drill collars should be used.

8. The casing joints set above the Del Rio Clay should be loosely tack welded in an attempt to recover as much casing as possible.

9. Any mud cake should be thoroughly flushed out with fresh water or air before water sampling and only after casing is set. This will ensure the packer seal and shorten the amount of overall time to collect water samples by eliminating long periods of air jetting to clean up the selected depth intervals.

10. A final logging sweep should take place after the mud cake is flushed. This prohibits mud filtrate effects on geophysical logging.

11. "Super-Mud" should be further tested because of the speed associated with its drilling and minimal mud invasion effects. Its use should be limited to sites with adequate foam storage capabilities, and to sites where drilling begins in hard overburdens, such as the Austin Chalk, to minimize sloughing and to shorten jetting time.

Finally, future test well drilling in the Austin region should encompass (a) stressing the aquifer at the "bad water" line to examine the effects of pumpage on the movement of the line, (b) better delineate the Regional Dense Member of the Edwards Limestone, and (c) futher examine the effects of the Dense member upon availability, water level fluctuations, and water quality.

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APPENDICES

Appendix I

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

(For well locations, see Figure 5)

Interval (Feet)	Formation	Description
0 - 1/2		Topsoil
1/2 - 4	Top of the Austin Chalk at .5 feet	Limestone, white to tan, soft to hard, oolithic, matrix III/A, sphericity .9, roundness .3 - .7, well sorted, hard streak at 4 ft.
4 - 41		Limestone, gray to green, matrix II/III A, well sorted, chalky, some montmorillonite clay, calcitic content
41 - 60		Limestone, gray-green, matrix II/III A, chalky to nodular, some argillaceous material (silt grade), well sorted
60 - 77		Limestone, gray, matrix I/III A, oolithic, hard, well sorted, bentonitic seams, pyrite nodules, some amounts calcitic cementation
77 - 101		Limestone, tan, hard, matrix III/A, oosparite to dismicrite, calcitic cementation, fossiliferous, pyrite, biosparite
101 - 122		Limestone, gray, hard, matrix I/III A, well sorted, sphericity .7 - .9, roundness .5 - .9, well sorted, nodular toward bottom, carbonaceous, small amount of calcite, very hard at bottom
122 - 166		Limestone, dark gray, hard, matrix I/III A, sphericity .5 - .7, roundness .1 - .3, mostly grainstone, some boundstone and compact crystalline material, limonite, pyrite, carboniferous sparite
166 - 202	Top of the Eagle Ford Group at 166 feet	Shale, black claystone, matrix II/III A,montmorillonite, pyrite, small amounts of limestone near bottom, petroliferous
202 - 212	Top of the Buda Limestone at 202 feet	Limestone, gray, hard, matrix I/III A, sphericity .5 - .7, roundness .3 - .5, well sorted, argillaceous, micrite matrix still some shale, pyrite, Globigerina, and calcispheres

Appendix I--*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
212 - 240		Limestone, gray to some tan-orange (burnt), hard, matrix I/B, well sorted, bottom somewhat nodular
240 - 251	Top of the Del Rio Clay at 240 feet	Clay, gray-green, calcareous, matrix II/A, fossiliferous, approx. 50% kaolinite, 50% montmorillonite, pyrite, limonite in small percentage, small clams
251 - 300		same as above, but with some dark clay
300 - 301	Top of the George-town Limestone at 300 feet	Limestone, gray to white, hard, oosparite, matrix I/III A, nodular, calcite, pyrite, small amount of argillaceous wispy, mollusk biomicrite, Globigerina and calcispheres, glauconite
		TOP OF CORED INTERVAL
301 - 311 (85% core recovered)		Limestone (90%), dark gray to light gray, to white, texture is mostly compact crystalline to grainstone, matrix I B/C, vitreous, total porosity about 8 percent grainstone portion has .3 - .5 roundness and .7 - .9 sphericity, calcitic and pyritic throughout, some argillaceous micrite, mollusc shells, Globigerina, carbonaceous streaks — 303 marly limestone, glauconitic material, small fissures — 303-1/2 marly limestone, carbonaceous — 303-1/2 to 306 lighter in color, mega-fossils — 306 large pyrite nodules — 308 fissures, carbonaceous, some moldic porosity
311 - 317 (60% core recovered)		Limestone (70%), light gray to white, grain-stone, matrix I/A, vitreous, total porosity about 6 percent, .7 - .9 sphericity, .3 - .5 roundness, — 313 somewhat marly, dark gray — 315 same as above
317- 320 (80% core recovered)		Limestone (80%), light gray to white at base, grainstone, matrix I A/B, vitreous, total porosity about 6-8%, fractured and moldic porosity, calcitic and pyritic, shells — 317 to 317-1/2 pitted surfaces — 318 mollusc fossils starting in slightly marly section — 318-1/2 shale and marl — 319 pyrite becoming abundant — 319-1/2 very dark gray-green shale

Appendix I--*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
320 - 330 (100% core recovered)		Limestone, gray, grainstone, matrix I/A, resinous, sphericity .7 - .9, roundness .3 - .5, calcite and pyrite, marly lenses, fossils, surface pitted, total porosity about 8% — 320 to 321 abundant fossils
330 - 340 (90% core recovered)		Limestone, gray to white, mostly grainstone, matrix I A/B, total porosity about 8%, pyrite and calcite throughout, abundant fossils such as Neospirifer, Exogy. arietina, Globigerina — 336 fractured and moldic porosity — 338 stromatolitic crusts
340 - 342 (100% core recovered)		same as above
342 - 350 (100% core recovered)	Top of the Person Formation at 342 feet	Limestone and Dolomitic Limestone, cream to buff, grainstone to compact crystalline, matrix I/III A/B, resinous to vitreous, .7 - .9 sphericity, .3 - .5 roundness, intra-micrite and mollusc-fragment biomicrite, total porosity about 12%, calcitic, glauconitic — 348-1/2 hydrocarbon shows — 349-1/2 hydrocarbon shows — 345 to 346-1/2 higher porosity, about 17% porosity
350 - 360 (100% core recovered)		Limestone and Dolomitic Limestone, cream to buff, grainstone to compact crystalline,matrix I/III A/ B resinous to vitreous, .7 - .9 sphericity, .3 - .5 roundness, fossiliferous 15-20% porosity — 357 mud-filled cavities, small vugs — 358 extensive fossils, calcitic seams, total porosity about 10%, leached-mollusc dolomite — 357 mud-filled cavities, small vugs — 358 extensive fossils, calcitic seams, total porosity about 10%, leached-mollusc dolomite
360 - 370 (100% core recovered)		Limestone and Dolomitic Limestone, tan to white, grainstone to compact crystalline, matrix I/III B/C, F-C, .5 - .7 sphericity, .1 - .3 roundness, total porosity about 15%, petroliferous, milliolid biomicrite

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
		— 360 fossils, bivalves — 361 to 363-1/2 vugular, moldic porosity about 18% — 363-1/2 to 364-1/2 fossils — 367 petroliferous section — 368 calcitic fill fissures — 369 millinods, total porosity about 12%
370 - 380 (100% core recovered)		Limestone and Calcitic Dolomite, light gray to cream, micrite microspar, matrix I/III A/B, sphericity .5 - .7, roundness .1 - .3, total porosity about 12% — 370 hard, dense calcitic deposits — 371-1/2 broken-up secondary porosity, about 15% porosity — 372 intraparticle — 373-1/2 somewhat marly, total porosity about 8% — 375 chalky — 376-1/2 calcite fissures, hard and dense material, total porosity about 8%
380 - 390 (100% core recovered)		Limestone, dark gray to light gray, micrite to microspar, matrix I/III A-C, total porosity about 15%, chalky sections, calcitic, biosparite, cherty — 380 hard, dense, calcitic — 381-1/2 calcitic filled fissures, pyrite specs, total porosity about 8% — 382 calcitic, pyrite, solution channels, total porosity about 20% — 385-1/2 small vugs, pyrite, total porosity about 18% — 385-1/2 to 390 nodular, pyrite and stromatolithic crusts
390 - 400 (90% core recovered)		Limestone, light gray to white, micrite to microspar, matrix I/III A-B, total porosity about 12%, sparry calcite deposits, secondary porosity, carboniferous, soft mud lumps, somewhat marly — 390 hard, dense pitted surface — 392-1/2 vugular, total porosity about 15% — 393 marly — 395 secondary porosity, sparry fractured, stromatolithic crusts, total porosity about 15%,lithoclasts — 396 chalky — 397 marly — 399 chalky, fossiliferous

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
400 - 410 (100% core recovered)		Limestone and Dolomitic Limestone, same as above but with some wispiness — 406 dolomitic, vugular, mud filled — 408 fracture, total porosity about 20% — 409 to 410 wispy unit, very dense
410 - 420 (85% core recovered)		Limestone and Dolomitic Limestone, gray to tan to cream, micrite to microspar, matrix I/III A-B, sparry calcite-filled voids, crossbedding — 410 to 413 hard, dense, fine interbedding — 413 to 414 dolomitic lithoclasts — 414 to 414-1/2 cherty with fractures — 414-1/2 to 415-1/2 cross bedding — 415-1/2 to 419 dolomitic, vugular, carbonaceous lenses, calcitic seams
420 - 430 (100% core recovered)		Limestone and Dolomitic Limestone, dark brownish-gray to cream, micrite, matrix I/III B-C, fossiliferous, carboniferous — 420 reworked material — 420 to 421-1/2 hard, dense limestone, carbonaceous — 421-1/2 to 424-1/2 hard, dense, cross bedding, carbonaceous, wispy structure, some pitted and moldic porosity near bottom. Calcite — 424-1/2 to 425 hard, dense, cross bedding — 425 to 426-1/2 hard, dense, crystalline carbonate, dolomitic lithoclasts, carbonaceous lenses — 426-1/2 to 427 cross bedding, wispy, carbonaceous — 427 to 430 gray, vuggy, flaggy, broken up. Secondary porosity not uniform
430 - 440 (100% core recovered)	Top of the Regional Dense Member at 430 feet	Limestone, dark to light gray, matrix I/A, argillaceous and wispy, dense, nodular in places, cross bedding. fossiliferous — 430 to 430-1/2 same as above — 430-1/2 to 437-1/2 cross bedded limestone, sparfilled fractures — 437-1/2 to 440 cross bedded, marly, nodular limestone and mud clasts

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
440 - 450 (100% core recovered)		Limestone, light gray to cream, matrix I/A, hard, compact, wispy micrite, carbonaceous. Oysters, calcitic — 440 to 444 oysters and Toucasia scattered
450 - 460 (100% core recovered)	Base of the Regional Dense Member and the Top of the Kainer Formation at 450 feet	Limestone and Dolomitic Limestone, light gray to tan to brown, matrix I/III A, grainstone to crystalline carbonate, bio-mircrite matrix, wispy and carbonaceous, sparry calcite filled fractures — 450 to 451 hard, dense gray limestone with calcitic seams — 451 to 452-3/4 finely bedded limestone, nodular patches, chert, carbonaceous at bottom — 452-3/4 to 454 hard, dense wispy limestone — 454 to 456-1/2 slightly dolomitic, brownish limestone, secondary porosity, calcite-filled fissures and fractures, matrix III A, grainstone — 456-1/2 to 458-1/4 tan, vuggy limestone, wispy, carbonaceous lens at bottom — 458-1/4 to 460 hard, dense limestone, large millolid biomicrite
460 - 470 (95% core recovered)		Limestone and Dolomitic Limestone, gray to brownish-gray, matrix I/III A-B, grainstone to crystalline carbonate, spar, crystalfilled vugs and fractures, cherty, wispy structure and oysters — 460 to 461 same as above, with sparry calcite growths, hard, dense — 461 to 462-1/2 broken up, slightly vuggy, large stromatolitic crust, laminated micrite, collapsed cracks, carbonaceous and cherty at bottom — 462 to 464 hard, dense dolomitic limestone, cherty nodules — 464 to 470 hard, crystalline dolomitic limestone, micrite, wispy fractures

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
470 - 480 (100% core recovered)		Limestone, light to medium brown, medium grained grainstone, well sorted, intrasparite, matrix I/III B, slightly dolomitic, some biomicrite, cherty in places — 470 to 470-1/2 same as above — 470-1/2 to 473 pitted vuggy limestone, fracturing — 473 to 473-1/2 carbonaceous, vuggy, current laminated unit — 473-1/2 to 475-1/2 slightly vuggy, nodular limestone — 475-1/2 to 476-1/2 cross bedding, carbonaceous, breccia at top — 476-1/2 to 478 granular, vuggy limestone, calcitic — 478 to 478-1/2 sparry calcite-filled vugs, lithoclastic — 478-1/2 to 479 finely bedded, slightly nodular — 479 large chert nodule — 480 vuggy limestone
480 - 490 (85% core recovered)		Limestone and Dolomitic Limestone, brownish gray, matrix III A-B, micritic, vuggy at top, calcite — 480 to 486 dolomitic, very vuggy, fossiliferous, cherty, large crystal patterns, gypsum crystal — 486 to 490 finer limestone, large crystal lithoclasts
490 - 500 (100% core recovered)		Limestone, brownish gray, grainstone, matrix I/III A-B, wispy and current laminated bottom third, micritic, vuggy and moldic porosity — 490 to 497-1/2 interparticle, vuggy and moldic porosity, calcite — 497-1/2 to 498 gray limestone, hard, dense — 498 to 499 fractures, wispy — 499 to 500 very fine, hard, dense
500 - 510 (95% core recovered)		Limestone and Dolomite, tan to brownish gray, grainstone to compact crystalline, matrix III B-C, sparry calcite, micrite in some places, secondary porosity, moldic porosity — 500 to 501 wispy — 501 to 503 dolomitic, vuggy, total porosity about 15% — 503 to 503-1/2 nodular, carboniferous, total porosity about 10% — 503-1/2 to 510 collapsed features, breccia, spar-filled vugs and fractures, large crystalline growth, total porosity about 25%

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
510 - 520 (100% core recovered)		Limestone and Dolomitic Limestone, tan to gray, grainstone to compact crystalline, matrix III/B-C, calcitic fillings, vuggy — 510 to 510-1/2 dense, wispy, carbon aceous, total porosity about 8% — 510-1/2 to 514 vuggy, total porosity about 2% — 514 to 516 dense again — 516 to 518 dolomitic limestone, sparry calcite, total porosity about 25% — 518 to 519-1/2 pitted surface total porosity about 12% — 519-1/2 to 520 vuggy, total porosity about 17%
520 - 530 (100% core recovered)		Limestone, tan to brownish, grainstone to compact crystalline, matrix III/B-C, some dolomite, granular, calcitic — 520 to 522-1/2 vuggy, total porosity about 20% — 522-1/2 to 525 dense, pitted, total porosity about 15% — 525 to 525-1/2 calcitic seams — 525-1/2 to 527 vuggy, carbonaceous, total porosity about 22% — 527 to 528-1/2 total porosity about 17% — 528-1/2 to 530 same as above
530 - 540 (100% core recovered)		Limestone, brown to tan, grainstone to compact crystalline, micrite to microspar, matrix I/III A-C, carbonaceous, wispy, cherty lithoclasts — 530 to 530-1/2 vuggy, total porosity about 20% — 530-1/2 to 532 crystalline, secondary porosity, total porosity about 15% — 532 to 532-1/2 pitted — 532-1/2 to 533 wispy, total porosity about 12% — 533 to 536 lithoclasts, crystalline growth, total porosity about 8% — 536 to 538 breccia, total porosity about 8% — 538-539 wispy — 539-540 vuggy, about 15%
540 - 550 (60% core recovered)		Limestone, tan to brownish gray, grainstone to compact crystalline, matarix I/III B-C, some carbonaceous streaks, somewhat wispy — 540 to 543 crystalline growth, secondary total porosity about 15% — 543 to 547 wispy and carbonaceous

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 1 (58-50-603)

Interval (Feet)	Formation	Description
550 - 560 (no recovery)		LOST CIRCULATION at 548 feet

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 2 (58-58-213)

Interval (Feet)	Formation	Description
0 - 3		Topsoil, very black, sandy, rich
3 - 9	Top of the Navarro/Taylor Groups at 3 feet	Clay, tan to orange in color, (Pecan Gap), sandy, VF*
9 - 42		Clay, tan to orange, marly, granlular calcite in a clay matric. Montmorillonite.
42 - 135		Color change from tan to orange to gray, Ozan or Sprinkle Formation. Calcareous, montmorillonite, some glauconite, calcite fragments, pyrite nodules
135 - 140	Top of the Austin Chalk at 135 feet	Limestone, oolithic, gray, matrix I/A, clay, montmorillonite, "chalk"
140 - 255		Limestone, gray, matrix I/A, calcareous, montmorillonite clay. Micritic-sparite, carboniferous
255 - 289		Limestone, oolithic, hard gray, matrix I/A, more argillaceous at 280 feet
289 - 390		Limestone, marly, gray, matrix I/A, argillaceous
390 - 412	Top of the Eagle Ford Group at 390 feet	Shale, black claystone, montmorillonite clay, carboniferous
412 - 424 1/2		Shale, black claystone, hard, blue montmorillonite clay, carboniferous material, calcitic, some light gray limestone oolithi, soft
424 1/2-431	Top of the Buda Limestone at	Limestone, hard, gray, matrix I/A, argillaceous, micritic, some shale, black claystone, matrix II/A, soft
431 - 445		Limestone, hard, compact, gray, matrix I/A, argillaceous, micrite, pyrite, some "burnt orange" limestone
445 - 465		Limestone, hard, gray, matrix I/A, micritic, some orange pieces, well sorted
465 - 467	Top of the Del Rio Clay at 465 feet	Shale, dark gray to black, carbonaceous, limonite, clay petroliferous. Blue shale bits, kaolinite
467 - 469		Same as above

* ***Note*** – abbreviations are as follows: ***VC*** – very coarse; ***C*** – coarse; ***F*** – fine; ***VF*** – very fine; ***XF*** – extremely fine

Appendix I-*continued*

Descriptive Logs of Test Wells-

Test Well 2 (58-58-213)

Interval (Feet)	Formation	Description
469 - 477		Shale, calcareous, gray-green to black, granular, matrix I/A, pyrite
477 - 500		Shale, 80%, calcareous, soft gray-green, matrix II/A, VF, mostly kaolinite, mostly kalonite clay, montmorillonite, limonitic, some pyrite, 10% dark brown to yellow
500 - 515		Clay 100%, calcareous, soft, gray to dark gray, matrix II/A, VF, mostly kaolinite. Limonite, some pyrite, 10% dark brown to yellow clay, montmorillonite
515 - 525	Top of the Georgetown Limestone at 515 feet	Limestone, 80%, hard, light gray, matrix I/A, VF-F, compact crystalline carbonate to grainstone, oosparite, compact, argillaceous, micrite, carbonaceous streaks, mud lumps
525 - 527		Limestone, dark gray to light gray to white, hard grainstone to crystalline carbonate, matrix I/A, argillaceous micrite
527 - 550		Limestone, marly, gray to white, matrix I/A, grainstone to mudstone, pieces of calcite
550 - 553		Limestone, marly, gray with some buff to tan-colored mudstone pieces, matrix I/III A/B
553 - 565		Limestone, cream to buff in color, matrix I/III A/B, marly (mudstone to grainstone), calcitic, carboniferous, micrite matrix, soft mudlumps, molluse biomicrite
565 - 572	Top of the Person Formation at at 565 feet	Limestone and Dolomitic Limestone, brownish, matrix III B/C, dolomitic, micraite to microspar, sparry calcite, soft mud lumps, breccia
572 - 602		Limestone, gray to white, matrix I/III A/B, mudstone to mostly grainstone, spar, microspar, micrite, somewhat marly pieces, carbonaceous, limonite
602 - 622		Limestone and Dolomitic Limestone, grayish brown, matrix I/III A/B, biosparite/biomicrite
622 - 660		Limestone and Dolomitic Limestone, brownish-gray, matrix I/III A/B, coarse grainstone, biomicraite, sparry calcite, calcitic

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 2 (58-58-213)

Interval (Feet)	Formation	Description
660 - 667	Top of the Regional Dense Member at 660 feet	Limestone, dark gray to cream with some tan/orange, argillaceous marly limestone I/A, grainstone, intramicrite, marl and shale lenses, some hard white streaks present
667 - 677		Limestone, blue gray,matrix I/A, grainstone, some shale, blue to tan and brown argillaceous/marly limestone, calciatic pieces present
677 - 683		Limestone, marly, multicolored gray to tan, matrix I/A, argillaceous, fragments of shells, clasts
683 - 730	Base of the Regional Dense Member and the Top of the Kainer Formation at 683 feet	Limestone and Dolomitic Limestone, mostly brownish-gray/grayish-brown, matrix I/III B, grainstone, intrasparite, some micrite matrix
730 - 750		Missed cuttings
750 - 760		Limestone, grayish-brown, matrix I/III A/B, micrite, soft mud lumps, wispy, granular, carbonaceous, almost marly
760 - 777		Limestone, gray, matrix I/III A/B, grainstone to compact crystalline, intrasparite, calcitic
777 - 793		Limestone and Dolomitic Limestone, grayish-brown, matrix I A/B, compact crystalline (80%) to small grainstone (20%), intrasparite, calcitic, tan soft mud lumps
793 - 799		Limestone, gray to brown, marly, matrix I/III A/B, well sorted, mostly grainstone to compact crystalline, micrite matrix, intrasparite, somewhat argillaceous and shaley (blue in color)
799 - 805		Limestone, gray to brown, marly, matrix I/III A/B, micrite, calcitic, slightly argillaceous, some blue-gray shale
805 - 823		Limestone and Dolomitic Limestone, dark gray to brown, marly, matrix I/III A/B, micrite, gypsum and anhydrite crystals, calcitic, some silty red weathred material
823 - 833		Missed cuttings

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 2 (58-58-213)

Interval (Feet)	Formation	Description
833 - 840		Limestone, dark gray to brown, matrix I/III A/B, micrite matrix, weathered material
840 - 841		Dolomitic Limestone, dark gray to white, matrix I/III A/B, intrasparite, anhydrite crystals, residual weathered material
841 - 843		Limestone, grayish brown, hard, grainstone to to compact crystalline, matrix I/III A/C, well sorted, micritic
843 - 850		Dolomitic Limestone, grayish-brown, grainstone to compact crystalline, matarix I/III A/B, intrasparite, well sorted
850 - 865		Dolomitic Limestone, light grayish-brown to tan, grainstone to compact crystalline, matrix III/A/B, intrasparite, well sorted, calcitic, cherty
865 - 875		Limestone and Dolomitic Limestone, light grayish-brown, hard, matrix III A/B, intra-sparite, well sorted anhydrite
875 - 885		Dolomitic Limestone, brownish-gray, medium grained, matrix III A/B, well sorted, coated aggregates, slightly micritic, stromatolithic crusts, anhydrite, dolomite

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 3 (58-42-927)

Interval (Feet)	Formation	Description
0 - 4		Topsoil, dark, rich, some small amounts of clay
4 - 8		Marl, Sand, and Clay, tan to light brown, very clayey, maybe some alluvium, silty and with some gravel, siliceous, cherty
8 - 13	Top of the Austin Chalk at 8 feet	Limestone, tan to white, oolithic, hard, matrix I/A, slightly nodular
13 - 16		Limestone, gray-green, some tan, matrix I/II, hard oolithic, calcareous, chalky
16 - 30		Limestone, gray, matrix I/III A, medium to hard, oosparite, chalky
30 - 45		Limestone, gray to white, matrix I/III A, chalky, micritic
45 - 51		Limestone, dark gray to some orange-tan, matrix I/III A, slightly argillaceous, calcitic, micritic/oolithic
51 - 62	Top of the Eagle Ford Group at 51	Shale, greenish-black claystone, montmorillonitic clay, pyritic, very carboniferous and petroliferous
62 - 68		Shale, greenish-black claystone, some montmorillonite gray clay, carboniferous and petroliferous, somewhat silty in makeup
68 - 91		Shale, black claystone, montmorillonitic clay, some tan to orange limestone (2%), very carbonaceous with hydrocarbon shows
91 - 96	Top of the Buda Limestone at 91 feet	Limestone, gray to mostly white with some pale orange bits, matrix I/A, micritic, glauconitic, pyritic, very hard, still some black claystone (5), Globigerina
96 - 106		Limestone, tan to pale orange, matrix I/A, micrite matrix, glauconitic, slightly pyritic, extremely hard, nodular, well sorted, about 2% black claystone
106 - 122		Limestone, white with some pale orange, matrix I/A, micrite, well sorted
122 - 125		Limestone, gray to dark gray with some larger pieces or pale orange cuttings, matrix I/A, micritic, well sorted, fine cuttings, some shale (black) bits with strong odor, calcitic

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 3 (58-42-927)

Interval (Feet)	Formation	Description
125 - 129		Limestone, soft, gray to dark gray, matrix I/III A, argillaceous
129 - 132		Missed cuttings
132 - 148	Top of the Del Rio Clay at 130 feet	Clay, gray-green to bluish, matrix I/A, silty to clay, kaolinite and montmorillonite, calcareous, gypsiferous
148 - 164		Clay, dark gray to black, matrix I/A, siltstone, some bits of pale orange limestone, limonite pyrite
164 - 167		Clay, grayish-blue, matrix I/A, calcareous
167 - 187		Clay, kaolinitic with some montmorillonite, calcareous, mostly grayish-blue, some brownish-gray
187 - 191		Clay, kaolinitic, white to gray, matrix I/A, slightly silty, small bits of limestone (2%)
191 - 203	Top of the Georgetown Limestone at 191 feet	Limestone, white to medium gray, matrix I/A, hard packstone to crystalline carbonate, calcitic, micrite matrix, slightly marly
203 - 211		Limestone, light gray to medium, matrix I/A, micrite, argillaceous, hard, compact, mostly packstone
211 - 220		Limestone, light to dark gray, matrix I/A, very marly, soft, bits of hard tan streaks
220 - 227		Limestone, gray, matrix I/A, hard, compact micrite matrix, well sorted, some blue-green clay, slightly limey, argillaceous
227 - 250	Top of the Person Formation at 227 feet	Limestone, mostly gray (60%) to tan/brownish gray (40%), matrix I/III A, hard, compact, well sorted biomicrite
250 -275		Limestone, brownish gray (60%) to white (40%), dolomitic, matrix I/III A, micrite, well sorted, calcitic
275 - 280	Top of the Kiamichi Formation/ Regional Dense Member at 275 feet	Limestone & Dolomite, tan to white,matrix I/A, hard, well sorted, micritic, limonite, white, maybe gypsum

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 3 (58-42-927)

Interval (Feet)	Formation	Description
280 - 283		Limestone, tan to white, matrix I/III A, dolomitic, hard, well sorted, calcitic, packstone
283 - 293		Limestone, dark gray to tan, matrix I/III A, hard, well sorted, micrite, calcitic. Packstone to crystalline carbonate
293 - 300		Limestone, dark gray (75%) to white (20%) to tan (5%), matrix III/A, dolomitic, biomicrite, coarse grained, somewhat argillaceous
300 - 305		Dolomitic Limestone, gray to tan with dark brown mud lumps, matrix III/A, biomicrite, hard, well sorted, argillaceous
305 - 310		Limestone, dark brown to gray, matrix III/A, hard, well sorted, micrite, some brown mud lumps
310 - 315		Limestone, dark gray, matrix III/A-C, well sorted, biomicrite, limonite, calcitic, soft mud lumps, slightly argillaceous
315 - 320	Top of the Kainer Formation at 315 feet	Limestone, tan to orange, matrix I/III A-B, well sorted, mudstone to packstone, calcitic, shell material
320 - 322		Dolomitic Limestone, brownish gray to gray, matrix III/A, micritic, well sorted, coarse
322 - 325		Dolomitic Limestone, tan, matrix III/A, well sorted, micritic
325 - 335		Missed cuttings
335 - 340		Limestone Dolomite, tan to white, matrix I/III A-B, grainstone to compact crystalline, biomicritic
340 - 351		Dolomitic Limestone, dark brown to tan, matrix III/A, medium to hard, boundstone to compact crystalline, calcitic, biomicritic
351 - 360		Limestone, white to tan to gray, matrix I/III A-C, medium to hard, boundstone to compact crystalline, F-XF, somewhat cherty, argillaceous
360 -363		Limestone, brown to tan, matrix I/III A-C, biomicrite, compact crystalline, fine cuttings, some gypsum, dolomite, anhydrite, microspar, some celestite

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 3 (58-42-927)

Interval (Feet)	Formation	Description
363 - 377		Limestone and Dolomite, tan to brown, matrix I/III A, micrite, compact crystalline to grainstone, well sorted, large dolomite crystals
377 - 400		Limestone and Dolomite, brown to tan to white, matrix I/III A, biomicrite to microspar, compact crystalline, stromatolitic crusts, large dolomite crystals, anhydrite
400 - 416		Limestone, tan to white, matrix I/III A-B, micrite, well sorted, some dolomite
416 - 418		Dolomite and Dolomitic Limestone, tan to brownish gray, matrix III/A, micrite to biomicrite, well sorted, lots of gypsum, calcium and dolomite crystals, stromatolitic
418 - 420		Dolomite, dark brown crystals, some gypsum
420 - 428		Dolomitic Limestone, brown to tan, matrix I/III A-B, packstone to compact crystalline, micritic, some chert
428 - 430		Dolomitic Limestone, tan to white, matrix III/A-C, micrite, well sorted, gypsum, some weathered material (red silt)
430 - 434		Limestone, tan to cream, matrix I/III A-B, biomicrite, fine cuttings, packstone to compact crystalline, shale streaks, cherty
434 - 436		Chert and Gypsum Nodules
436 - 452		Limestone and Dolomitic Limestone, brown to gray to tan, matrix I/III A-C, micrite and biosparite, packstone to compact crystalline, some blue-gray argillaceous material, gypsum, chert
452 - 482		Limestone and Dolomitic Limestone, tan to white to brownish gray, matrix III A, pack stone to compact crystalline, well sorted, biomicrite to biosparite, calcitic, large dolomite crystals, gypsum
482 - 490		Same as above, with some hard crystalline streaks
490 - 520		Limestone and Dolomitic Limestone, gray to brownish gray, matrix I/III A, packstone to boundstone, fine cuttings, some argillaceous material, gypsum

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 3 (58-42-927)

Interval (Feet)	Formation	Description
520 - 526		Limestone and Dolomitic Limestone, white to tan, hard, matrix I/III A, micrite, packstone to boundstone, somewhat argillaceous, gypsum, pale yellow nodular bits
526 - 545		Dolomitic Limestone, tan to brownish gray, matrix III/A, biosparite, packstone to compact crystalline, large crystal growth
545 - 561		Dolomitic Limestone, white to tan to brownish gray, matrix III/A, micrite and biosparite, medium to hard, sucrosic, some gypsum
		Well drilling discontinued due to obstruction, possibly chert nodule

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 4 (58-36-503)

Interval (Feet)	Formation	Description
0 - 6		Topsoil, marly, calcareous, calcitic (only slightly), "Sprinkle Formation"
6 - 8	Alluvial Cap	Caliche, flintrock, gravel, silt and clay, chert and quartz
8 - 10		Caliche, flintrock, gravel, silt and clay, chert and quartz
10 - 21	Top of the Navarro/Taylor Groups at 12 feet	Missed cutting
21 - 35		Clay, tan to orange, calcareous, montmorillonite, silty quartz, calcite fragments
35 - 50		Clay, grayish orange to dark gray, calcareous, montmorillonite, calcite bits, few phosphate nodules, slightly marly
50 - 65		Clay, grayish green, marly, calcareous, some glauconite, calcite fragments
65 - 70		Clay, grayish green, marly, calcareous, some glauconite, calcite fragments
70 - 90		Clay, grayish green, marly, calcareous, some glauconite, calcite fragments
90 - 100		Clay, grayish green, calcareous, mostly montmorillonite, but some glauconite, calcite fragments
100 - 122		Clay, grayish green, calcareous, mostly montmorillonite, but some glauconite, calcite fragments
122 - 135	Top of the Austin Chalk at 122 feet	Limey Marl, light gray, oolithic, matrix IIA/III, about 3% porosity, very sandy, some montmorillonite clay, calcitic
135 - 150		Chalk, grayish white, oolithic, matrix II/A, 1-2% porosity, fissile, calcareous, calcitic
150 - 185		Chalk, grayish white, oolithic, matrix II/A, 1-3% porosity, fissile, calcareous, calcitic
185 - 200		Chalk, grayish white, oolithic, matrix II/A, 1-3% porosity, fissile, calcareous, calcitic, more marly

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 4 (58-36-503)

Interval (Feet)	Formation	Description
200 - 215		Limestone, gray, oolithic packstone, matrix I/A, calcareous, micritic
215 - 265		No cuttings
265 - 340		Limestone, gray, oolithlic packstone, matrix I/A, calcareous, micritic
340 - 350		Limestone, gray-dark gray, oolithic, medium hard, matrix I/IIIA, micrite, calcareous, some pyrite
350 - 360		Limestone, white to gray, marly, matrix IA/IIIA, calcareous, pyrite micritic
360 - 400		No cuttings
400 - 420		Limestone, white to gray, oolithic, matrix IA/IIIA, calcareous, micritic
420 - 460		Limestone, gray to white, oolithic, marly and soft, matrix III/A, calcareous, pyrite
460 - 480		Limestone, white to gray, oolithic, medium to hard, matrix IA/IIIA, calcareous, micritic, bentonitic, some pyrite, carboniferous
480 - 530		No cuttings
530 - 563		Limestone, gray to dark gray, oolithic, hard,matrix I/IIA, 1-3% porosity, calcitic seams indicating fracturing, micritic, carboniferous, pyrite
563 - 580	Top of the Eagle Ford Group at 563 feet	Shale, black to olive-black, claystone, silty, matrix II/IIIA, compact
580 - 601		Shale, black to olive-black, claystone to siltstone, flaggy, carboniferous
601 - 625	Top of the Buda Limestone at 601 feet	Limestone, light gray, hard, matrix I/A, argillaceous micrite, pyrite
625 - 636		Limestone, light gray, hard, matrix I/A, calcitic, micritic, slightly marly in spots

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 4 (58-36-503)

Interval (Feet)	Formation	Description
636 - 671	Top of the Del Rio Clay at 636 feet	Clay, dark gray to dark brownish-gray, wispy and granular, calcareous and slightly shaley, matrix I/A, a lot of pyrite
671 - 695		Clay, gray green to black, very soft, kaolinite, limonite
695 - 704		Clay, gray green to black, slightly shaley, wispy and carbonaceous
704 - 714	Top of the Georgetown Limestone at 704 feet	No cuttings coming up, drilled very hard at 704 feet (basis for pick)
714 - 724		No cuttings
724 - 734		Limestone, gray-white, grainstone, matrix I/A, about 4% porosity, slightly argillaceous, micrite, calcitic, hematile
734 - 740		Limestone, white to gray to dark gray, pack-stone to grainstone, matrix I/A-B, argillaceous micrite, limonite, calcitic, porosity about 3-5%, small amount of blue-green montmorillonitic clay
740 - 754		Missed cuttings
754 - 756		Limestone, white (30%) to gray, softer to medium, mudstone to grainstone, matrix I/A, porosity about 3%, argillaceous, calcitic, shell fragments
756 - 758		Limestone, gray (65%) to light brown (35%), soft, mudstone to grainstone, matrix I/IIIA-B, argillaceous and micritic, wispy and slightly carbonaceous, calcitic
758 - 764		Limestone, light gray to brownish gray, compact, hard, matrix I/III/A/B, porosity about 6%, compact crystalline, intramicrite
764 - 770		Limestone, white (5%), gray (35%) and brownish-gray, compact to mudstone, matrix I/IIIB, argillaceous, about 8% porosity, calcite, glauconitic
770 - 779		Limestone, white to tan w/some dark gray (10%), grainstone, matrix I/III A-B, intramicrite, argillaceous, carboniferous, calcitic seams and microspar

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 4 (58-36-503)

Interval (Feet)	Formation	Description
779 - 784	Top of the Duck Creek Formation at 779 feet	Limestone, gray to brownish gray, compact crystalline to grainstone, matrix I/III A-B, intramicrite, calcite, pyrite, carbonaceous slightly argillaceous
784 - 795		Same as above, but with weathered material and gypsiferous material
795 - 798	Top of the Kiamichi Formation at 795 feet	Limestone, brownish-gray, medium to hard, grainstone to compact crystalline, matrix I/III A-B, intramicritic and argillaceous, sparry calcite, carbonaceous
798 - 805		Limestone, brownish-gray, some white, hard, packstone to compact crystalline, matrix I/III A-B, micritic and biomicrite, argillaceous, sparry calcite, carbonaceous, gypsum
805 - 814	Top of the Kainer Formation at 805 feet	Limestone and Dolomitic Limestone, white (5%) to tan, hard, packstone to compact crystalline, matrix I/A and some III/B, sparrycalcite, gypsum, carboniferous
814 - 825		Limestone, cream to tan, packstone to grainstone to compact crystalline, matrix I/A, biomicrite and intramicrite, calcitic seam features
825 - 830		Limestone and Dolomitic Limestone, cream to tan, hard, packstone to grainstone to compact crystalline, matrix I/III A-B, gypsum, sparry calcite, carbonaceous material, small amount of blue-green clay
830 - 836		Same as above, plus very brittle biostromes, biosparite, dolomitic plates, probably in the leached and collapsed members (stromatolithic crusts)
836 - 847		Limestone, dark brownish-gray, hard to medium, matrix III/A-B (some IA), pyrite, intramicrite and argillaceous, still a lot of dolomite
847 - 852		Missed cuttings
852 - 853		Limestone, gray to brownish gray, hard, grainstone to compact crystalline, matrix I/III A-B, intramicrite, slightly dolomitic, wispy and some crossbedding, 10% porosity, slightly vuggy, calcitic

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 4 (58-36-503)

Interval (Feet)	Formation	Description
853 - 854		Same as above, with some breccia, crossbedding, porosity about 8%
854 - 855		Limestone, brownish-gray, medium to hard, mudstone to packstone to compact crystalline, matrix I/III A-B, calcitic, crossbedding, porosity about 6-8%
855 - 856		Limestone, brownish-gray, hard, packstone to compact crystalline, matrix I/III A-B, porosity about 10%, slightly vuggy, intrinsic porosity and moldic, pyrite
856 - 857		Limestone, brownish-gray, hard, compact crystalline, matrix I/B, vuggy porosity about 10% porosity, pyrite and wispy
857 - 858		Same as above, but with large chert nodule at base
		Well discontinued due to poor quality of initial water sample

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 5 (58-22-402)

Interval (Feet)	Formation	Description
0 - 10	Terrace Deposits	Gravel and Clay, orange and white, dolomitic and cherty; tan clay, silty and sandy
10 - 14		Gravel, orange and white, siliceous, chert and marl
14 - 24		Clay, tan to dark gray, montmorillonitic, silt-sized quartz
24 - 72	Top of the Navarro/Taylor Groups at 24 feet	Marl, light brown to red, calcareous, calcite fragments
72 - 87		Same as above, but silty texture
87 - 366		Clay, dark gray, calcareous, montmorillonitic, becoming fissle with depth; pyrite and hematite decreasing with depth
366 - 385	Top of the Austin Chalk at 366 feet	Marl, gray to light gray, some glauconitic clay
385 - 560		Limestone, gray to white, micritic, marly streaks; limonite and pyrite associated with carbonaceous streaks throughout
560 - 680		Chalk, white, marly with bentonitic seams and pyrite
680 - 712		Limestone and Chalk, dark gray, weathered, micro-granular calcite with prisms (inoceranus), bentonitic seams; fissle shale and generally very fossiliferous
712 - 897		Chalk, light gray with some weathered yellow tint, soft biomicritic, becoming nodular with shale and pyrite more abundant with depth
897 - 947	Top of the Eagle at 897 feet	Siltstone and Shale, dark olive-green, fissle, gypsiferous with shale streaks
947 - 961	Top of the Buda Limestone at 947 feet	Limestone, light gray to brownish-gray, hard, argillaceous, cherty with microspherulites and mollusc fragments; some yellow marl
961 - 992		Missed cuttings
992 - 1054	Top of the Del Rio Clay at 992 feet	Clay, dark gray, calcareous, pyritic with seams of siltstone

Appendix I

Descriptive Logs of Test Wells-

Test Well 5 (58-22-402)

Interval (Feet)	Formation	Description
1054 - 1070	Top of the Georgetown Limestone at 1054 feet	Limestone, light grayish-brown, grainstone and packstone, matrix I A/B, argillaceous, biomicritic, calcispheres, pyrite associated with carbonaceous units
1070 - 1079		Limestone and Shale, brownish-gray, argillaceous, matrix I A/B, biomicrite; black shale throughout
1079 - 1083		Limestone, light gray to brownish-gray, argillaceous, matrix I A/B
1083 - 1090		Shale and Limestone, black shale with soft yellow streaks; brownish-gray, argillaceous limestone, some what cherty
1090 - 1100		Same as above, but gas bubbles occurring in mud pit
1100 - 1110		Limestone, brownish-gray to gray, packstone to boundstone, matrix I A/B, biomicrite, argillaceous, small bits of chert with white marl mixed in, carbonaceous throughout
1110 - 1120		Same as above, but becoming sucrosic
1120 - 1146		Limestone, gray, hard packstone, matrix I A/B, fine, biomicritic with silicified fossil bits and limonite
1146 - 1170	Top of the Edwards at 1146 feet	Limestone, light gray to brown, fine, bound Limestone stone to crystalline carbonate, matrix I/III A, marly in sections
1170 - 1180		Limestone, dark brown to cream, probably bioclastic, grainstone to boundstone, matrix I/III A, porcellaneous micrite, but mostly argillaceous biomicrite, some glauconite and gypsiferous material, pyrite
1180 - 1200		Same as above, but oil stained at 1185 feet
1200 - 1210		Limestone and Dolomitic Limestone, cream to brown, fine sucrosic, matrix III A/B, gypsiferous
1210 - 1222		Same as above

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 6 (58-13-301)

Interval (Feet)	Formation	Description
0 - 7	Top Soil	Black Soil
7 - 23	Top of the Terrace Deposits at 7 feet	Conglomerate, small peat gravel, silty clay, chert
23 - 30		Clay, mostly clay, light gray to tan
30 - 94		Clay, tan to orange silt and calcareous clay
94 - 130	Top of the Navarro/Taylor Groups at 94 feet	Clay, dark gray, montmorillitic, with some hematite
130 - 180		Same as above, but light gray
180 - 200		Clay, gray, glauconitic, clacite fragments
200 - 279		Same as above
279 - 353	Top of the Austin Chalk at 279 feet	Chalk, light gray to white, soft calcium carbonate with bentonitic seams, limonite throughout
353 - 379		Chalk, light gray, soft to medium, biomicritic, limestone
379 - 490		Limestone and Chalk, light gray, biomicritic, fine argillaceous material, limonite, and shale
490 - 540		Chalk and Limestone, white to light gray, marly chalk, argillaceous limestone with limonite, some oil shows at base
540 - 680		Chalk and Limestone, gray, soft, biomicritic, bentonitic seams, limonite, pyrite, some blue shaley streaks at base
680 - 720		Chalk, gray, soft, and marly with calcitic fragments
720 - 735		Chalk and Siltstone, soft marly gray chalk with calcareous siltstone
735 - 741		Limestone, gray to green-gray, soft to medium, some flaggy siltstone, yellow to brown with shale streaks
741 - 746	Top of the Eagle Ford Group at 741 feet	Siltstone, brown to green, fissle with shale streaks throughout

Appendix I-*continued*

Descriptive Logs of Test Wells

Test Well 6 (58-13-301)

Interval (Feet)	Formation	Description
746 - 775		Shale and Siltstone, black calcareous shale, very soft siltstone with oil stains
775 - 811		Shale, olive to black, oil stains
811 - 846		Same as above
846 - 866	Top of the Buda Limestone at 846 feet	Limestone, light gray, very hard, argillaceous micrite, some black claystone
866 - 944	Top of the Del Rio Clay at 866 feet	Clay and Shale, blue-gray, gypsiferous, bentonitic gray clay, fossiliferous
944 - 957	Top of the George-town Limestone at 944 feet	Limestone, light gray, packstone to mudstone, biomicritic, matrix I A/B, pyritic
957 - 974		Limestone, gray to brownish-gray, biomicritic to biosparite, packstone, matrix I/II A/B, black shale throughout
974 - 983		Same as above, but cherty
983 - 1005		Limestone, brownish-gray, biomicritic, pack-stone, matrix III A/B, some glauconitic material
1005 - 1050		Limestone, gray to dark gray, mudstone to packstone, matrix I/III A/B, calcispheres
1050 - 1063	Top of the Edwards Limestone at 1050 feet	Limestone and Dolomitic Limestone, brownish-gray to gray, intramicritic to biomicritic, packstone, matrix I/II A/B, mud balls present
1063 - 1070		Dolomitic Limestone, dark brown to dark gray, packstone and boundstone, matrix III A/B, gypsiferous
1070 - 1094		Limestone and Dolomitic Limestone, gray to dark gray, biomicritic, packstone to crystalline carbonate, matrix I/III A/B, oolithic, cherty
1094 - 1121		Dolomitic Limestone, brownish-gray, packstone to crystalline carbonate, matrix I/III A/B, blue shale streaks
1121 - 1136		Same as above
1136 - 1140		Free fall, no cuttings

Appendix I--*continued*

Descriptive Logs of Test Wells

Test Well 7 (40-61-705)

Interval (Feet)	Formation	Description
0 - 3	Topsoil	Black Soil
3 - 31	Top of the Terrace Deposits	Conglomerate, fluvial deposits of gravel, sand, and silt containing silicates and some at 2 feet quartz deposits and white, very thin limestone beds; very little clay
31 - 34	Top of the Georgetown Limestone at 31 feet	Limestone, light gray to white grainstone, mud clasts
34 - 36 (100% core recovered)		Limestone, medium to hard, light gray to white, matrix IA, very fine, mudstone to grainstone, oosparite, nodular, wispy, molluse biomiuite, Globigerina, pyrite and mud clasts throughout
36 - 45 (72% core recovered)		Limestone, medium to hard, gray to white, matrix IA, fine, mudstone to grainstone, oosparite, nodular, wispy, pyrite nodules
45 - 50 (100% core recovered)		Limestone, hard, gray to white, grainstone to compact crystalline, matrix I/III A/B, resinous to vitreous, intramiaite and mullosc fragmented biomicrite abundant fossils such as Exogy. arietina, Globigerina – 45 mass of fossils and pyrite – 47 soft mud lumps
50 - 60 (100% core recovered)		Limestone, mostly white, grainstone to compact crystalline, matrix I/III A/B, resinous to vitreous, nodular top half, thin crossbedding in bottom half, pyrite throughout – 56 shale streak – 59 fractured and poorly bedded, secondary porosity
60 - 70 (100% core recovered)		Same as above – 62 very nodular – 69 fracturing
70 - 80 (100% core recovered)		Limestone, white, mudstone to compact crystalline, matrix I/III A/B, sucrosic thin bedding, some pyrite
80 - 90 (100% core recovered)	Top of the Edwards Limestone at 83 feet	Limestone and Dolomite Limestone, top 3 same as above, tan to brownish-gray, grainstone to compact crystalline, matrix I/III A/B, biomicritic, fossiliferous (millinods) -- 82-1/2 green shale streak -- 86 pitted porosity and fracturing -- 88-1/2 massive fossil bed

Appendix I--*continued*

Descriptive Logs of Test Wells

Test Well 7 (40-61-705)

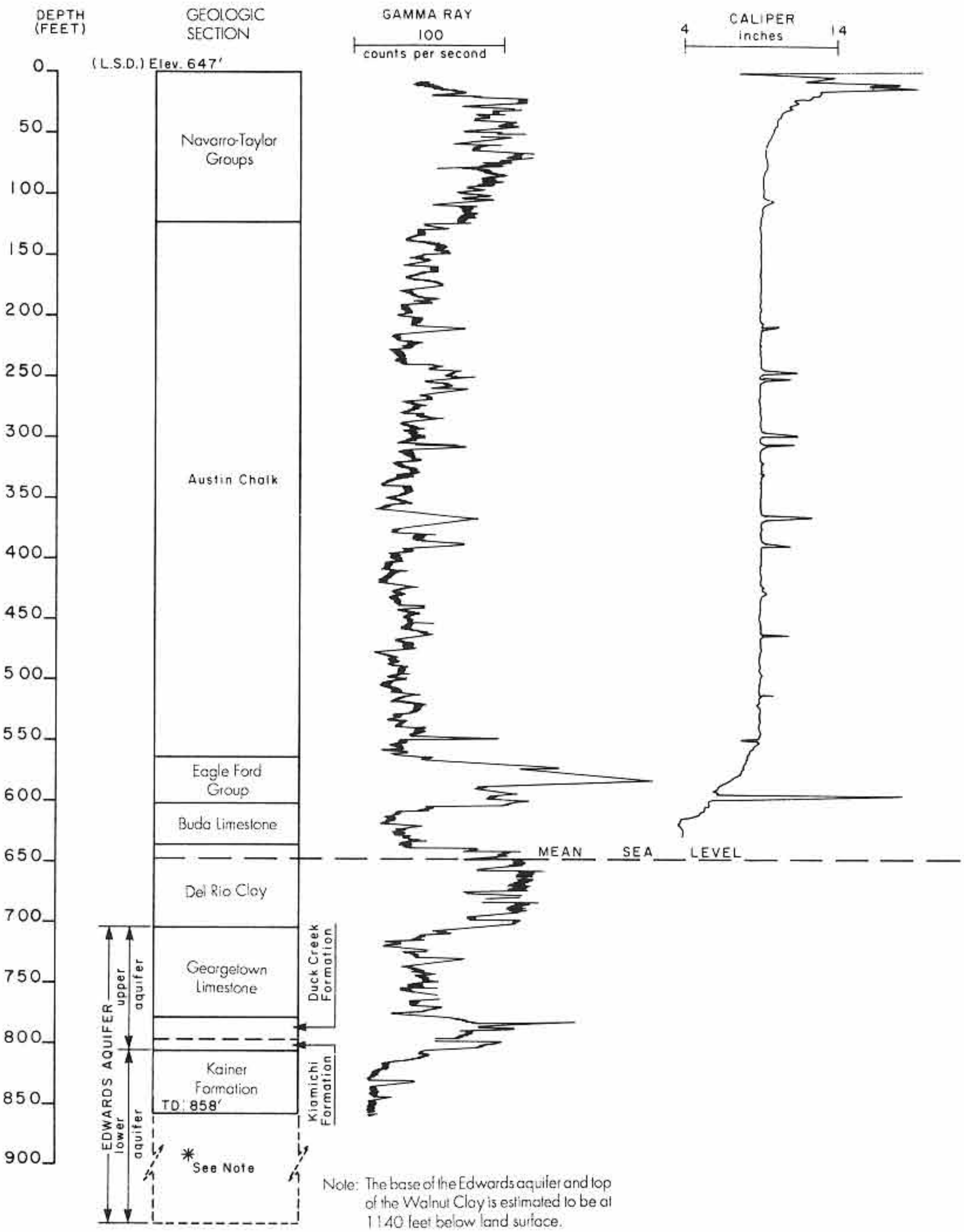
Interval (Feet)	Formation	Description
90 - 93 (100% core recovered)		Same as above – 91 & 93 pits with black patches of oil -- 92 stramotolitic crust
93 - 101 1/2 (87% core recovered)		Dolomitic Limestone, brown, compact crystalline, matrix III A/B, biomicritic, fossiliferous, pitted porosity – 93 chert bed, slow cutting – 96-1/2 thin bedding
101 1/2 - 110 (75% core recovered)		Same as above – 102-1/2 wispy – 106-1/2 chert
110 - 119 (100% core recovered)		Same as above – 112 chert – 117-1/2 nodular with pitted porosity
119 - 130 (110% core recovered)		Dolomitic Limestone, brown grainstone to compact crystalline, matrix I/III A/B, – 119-121 fractured porosity – 123-1/2 crystalline crusts with fossils – 127-1/2 cherty nodules
130 - 141 (90% core recovered)		Same as above – 132-1/2 - 134 pitted porosity – 135 collaspse zone remnants – 137-1/2 wispy
141 - 151 (97% core recovered)		Same as above
151 - 160 (90% core recovered)	Top of the Comanche Peak Limestone at 155 feet	Limestone and Dolomitic Limestone, top (to 155 feet) same as above, from 155 feet down white, hard, dense limestone, slightly argillaceous, wispy, some spar filled fractures
160 - 170		Same as above
170 - 180		Same as above

Appendix I-*continued*

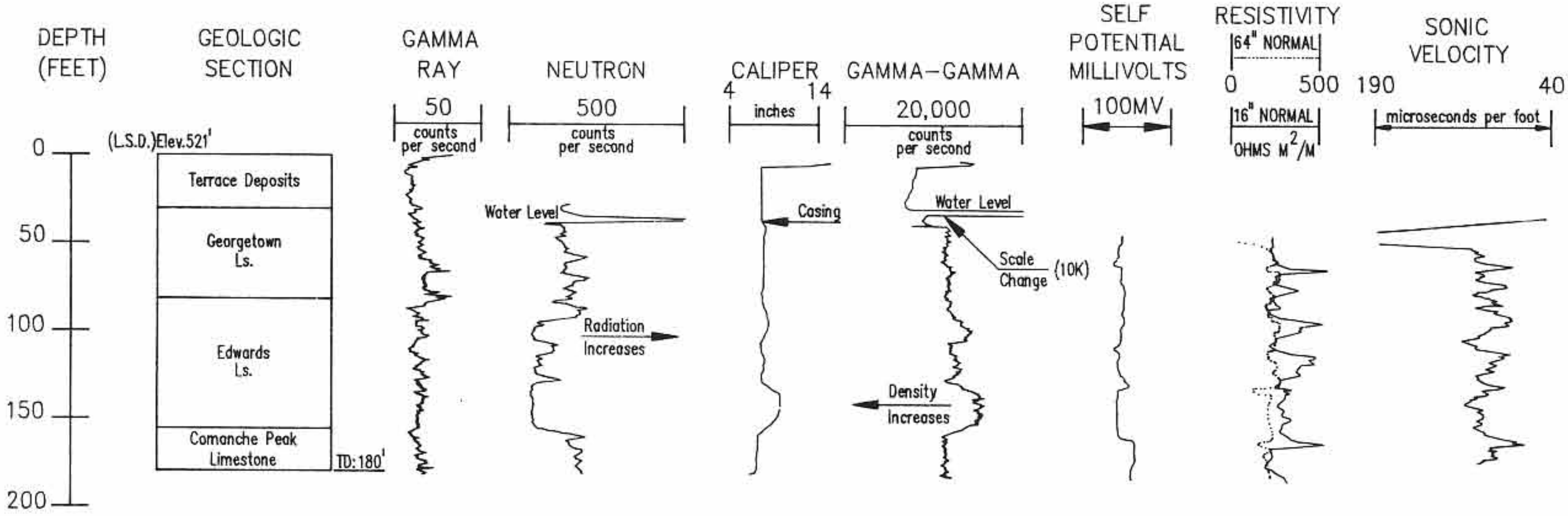
Descriptive Logs of Test Wells

Test Well 8 (58-12-901)

No cutting collected for this test well.



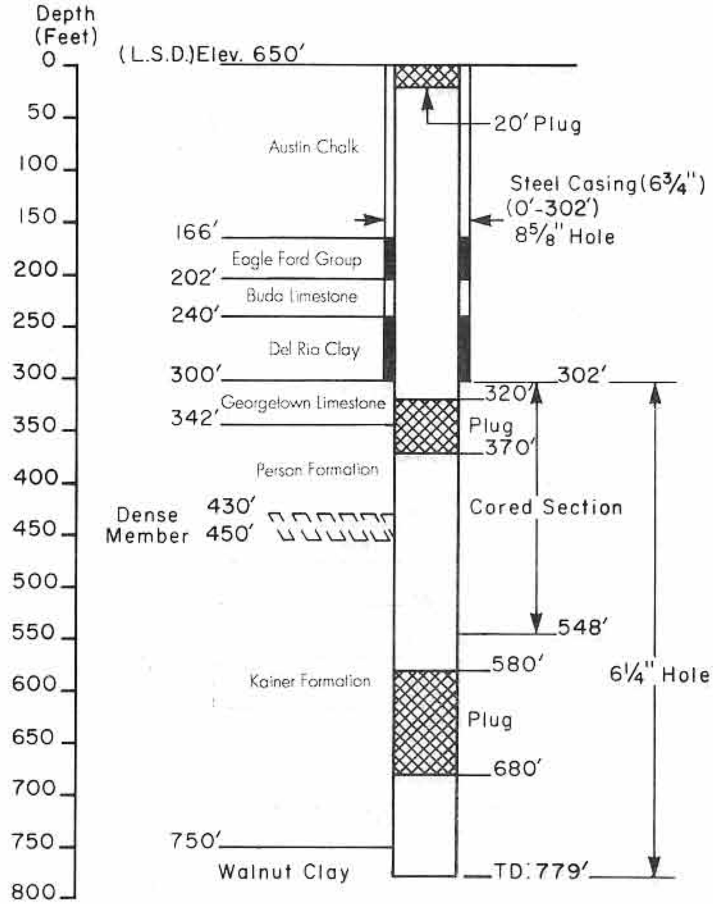
Appendix 2 - continued
Geophysical Logs, Test Well 4 (58-36-503)



Note: Sonic Porosity (ϕ) is based on the following formula.

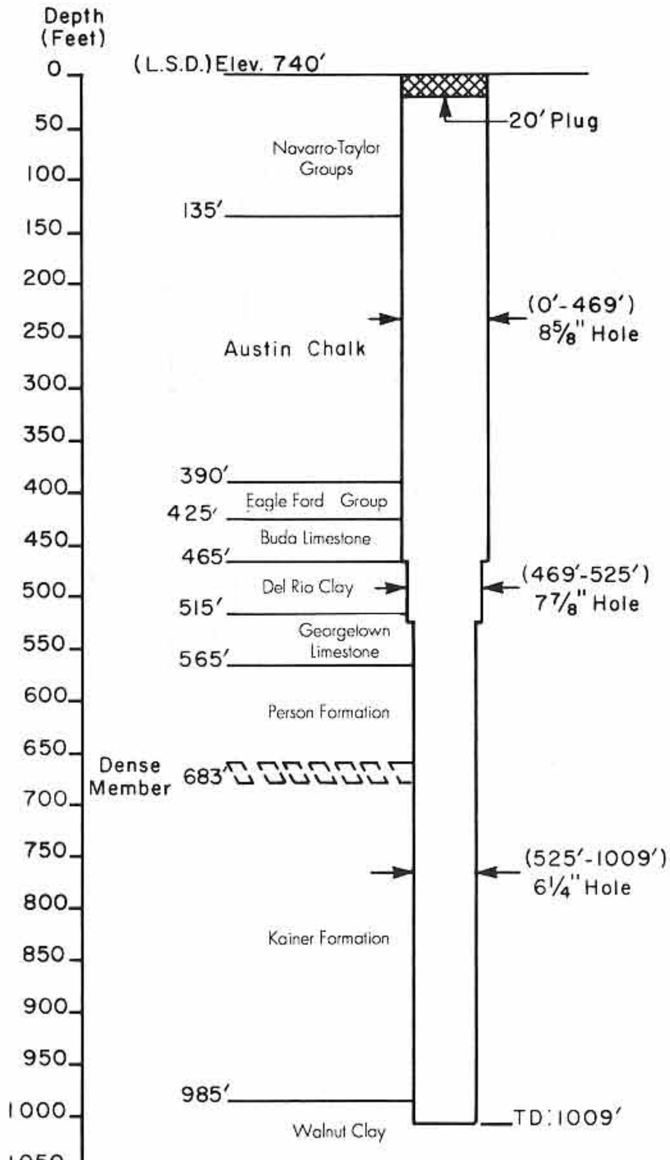
$$\phi = \frac{^{\Delta t}\log - ^{\Delta t}ma}{^{\Delta t}f - ^{\Delta t}ma} = \frac{^{\Delta t}\log - 47.6}{218 - 47.6} = \frac{^{\Delta t}\log - 47.6}{170.4}$$

Appendix 2 – continued
Geophysical Logs, Test Well 7 (40-61-705)



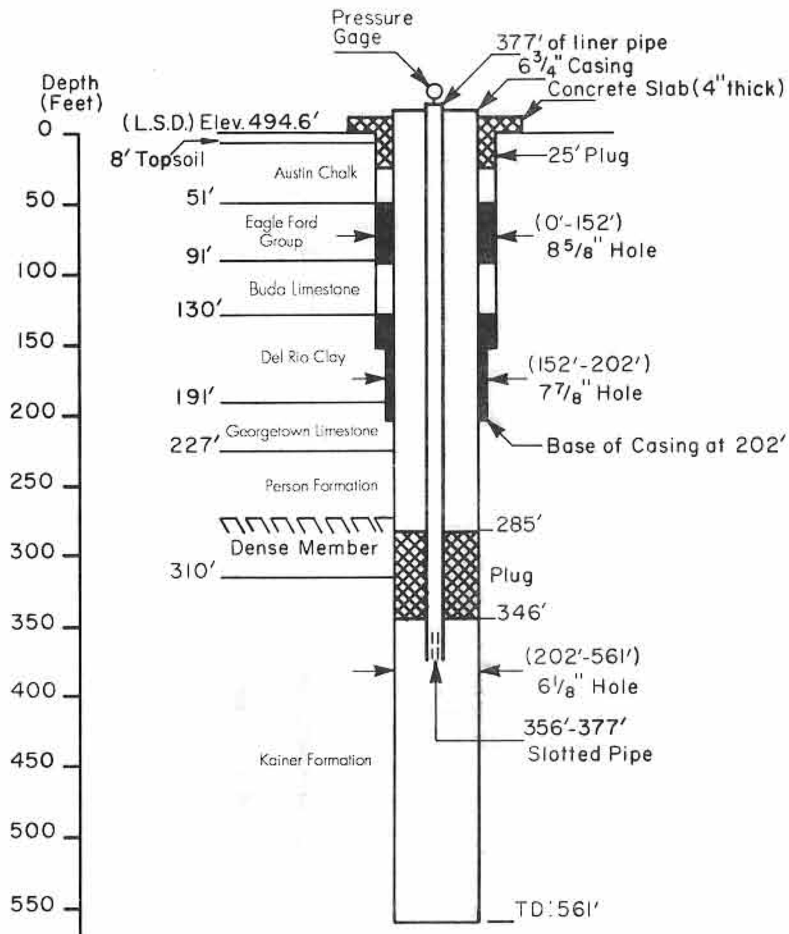
Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
350-360	5	2850
420-460	2	740
520-560	12	450
580-620	5	840
680-720	5	4000
301-779	20	704

Appendix 3
Schematic, Test Well 1 (58-50-603)



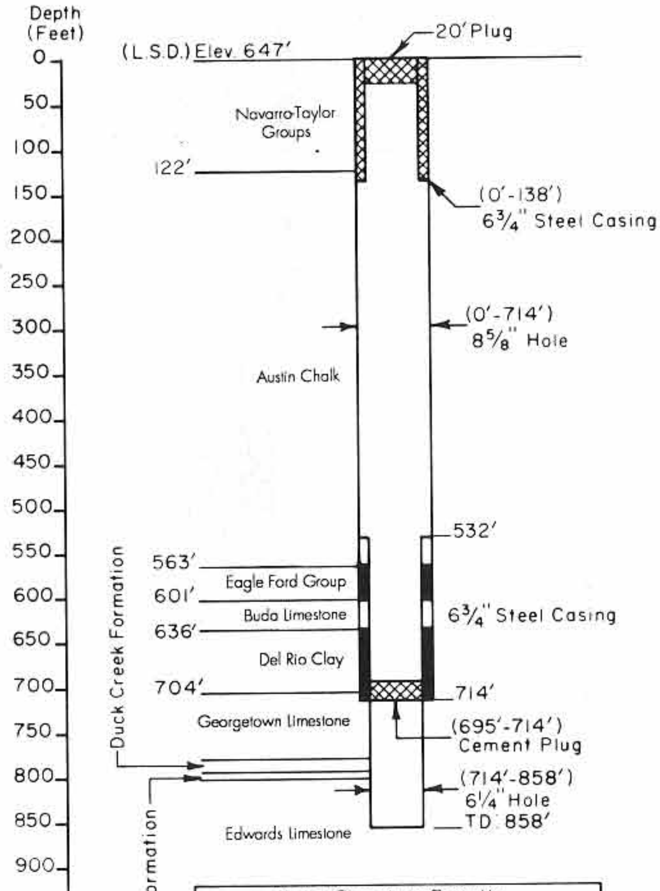
Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
515-985	8	1234

Appendix 3 – continued
Schematic, Test Well 2 (58-58-213)



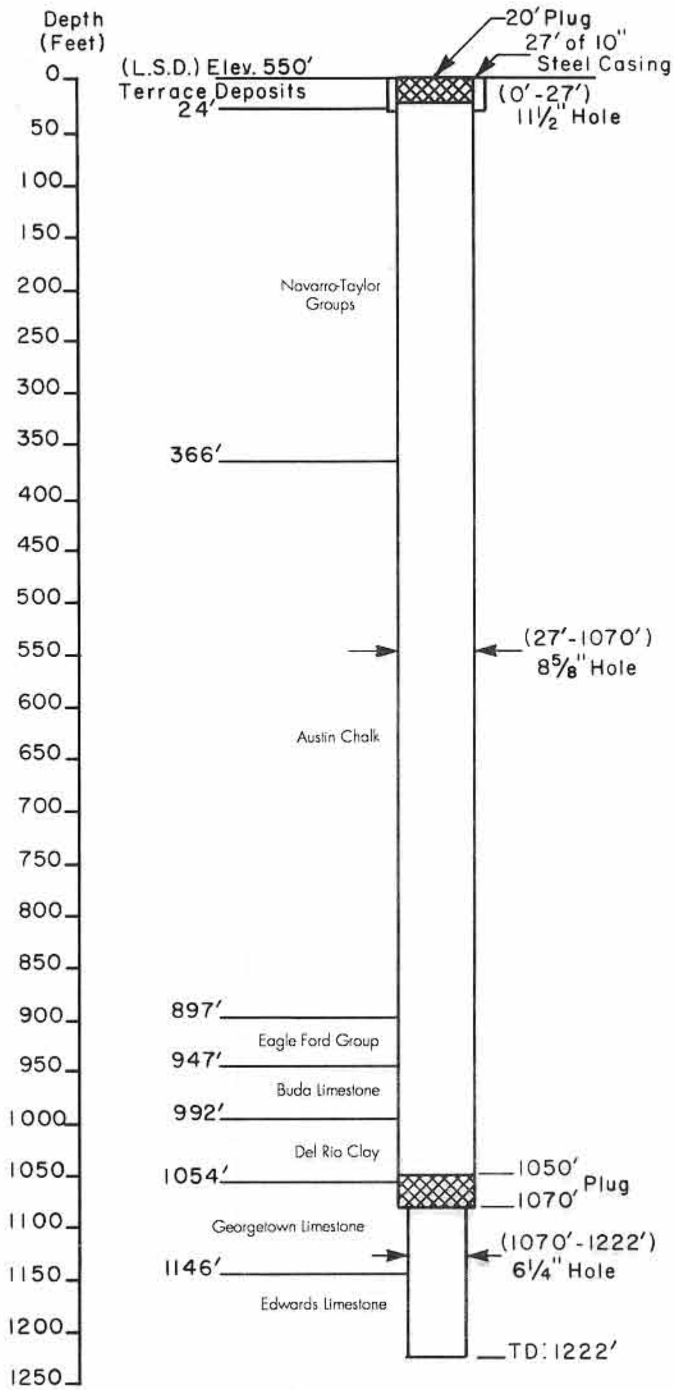
Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
260-270	3	5450
315-561	22	8210
COMPOSITE SAMPLE		
202-561	18	7924

Appendix 3 – continued
Schematic, Test Well 3 (58-42-927)



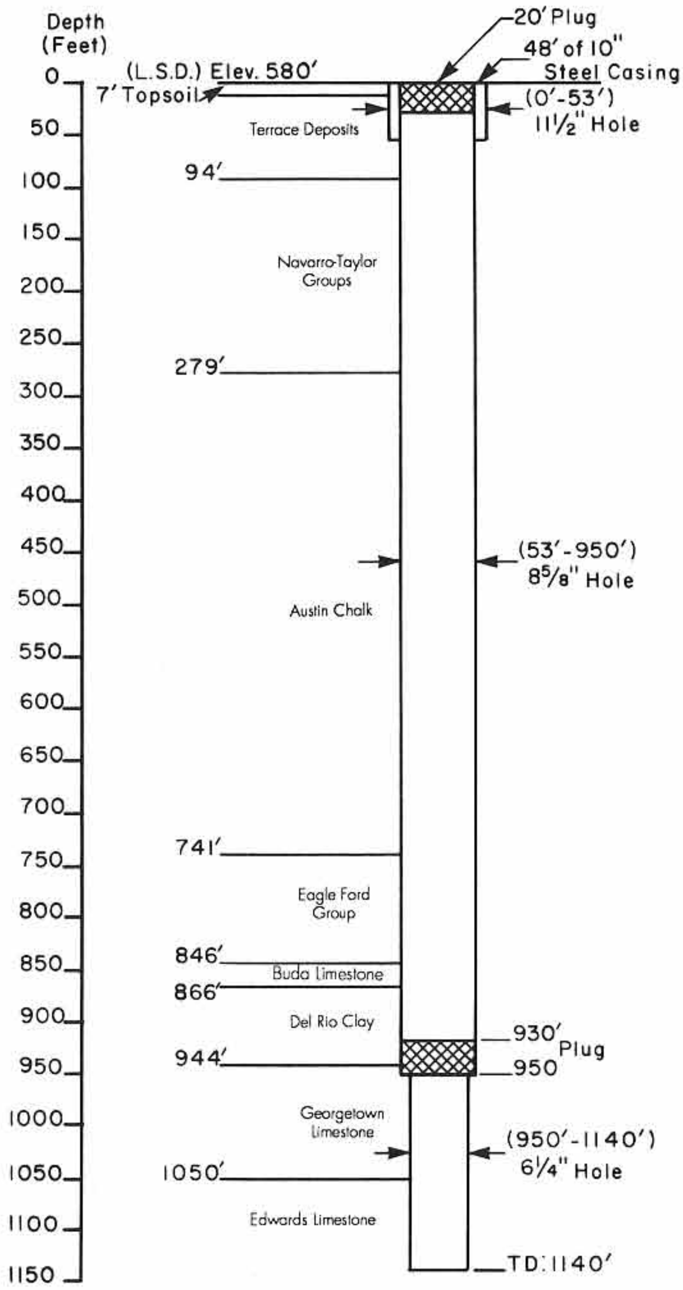
Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
748-858	20	12,930

Appendix 3 – continued
Schematic, Test Well 4 (58-36-503)



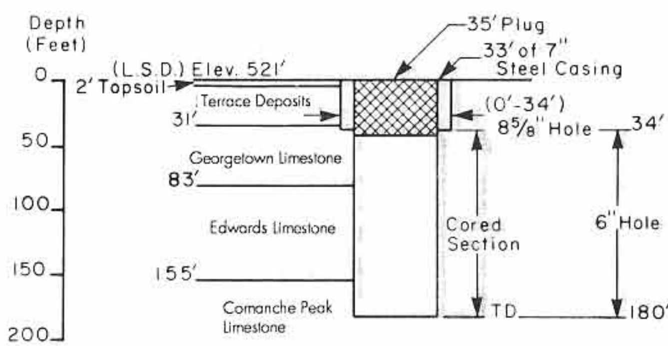
Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
1054-1222	11	6098

Appendix 3 – continued
Schematic, Test Well 5 (58-22-402)



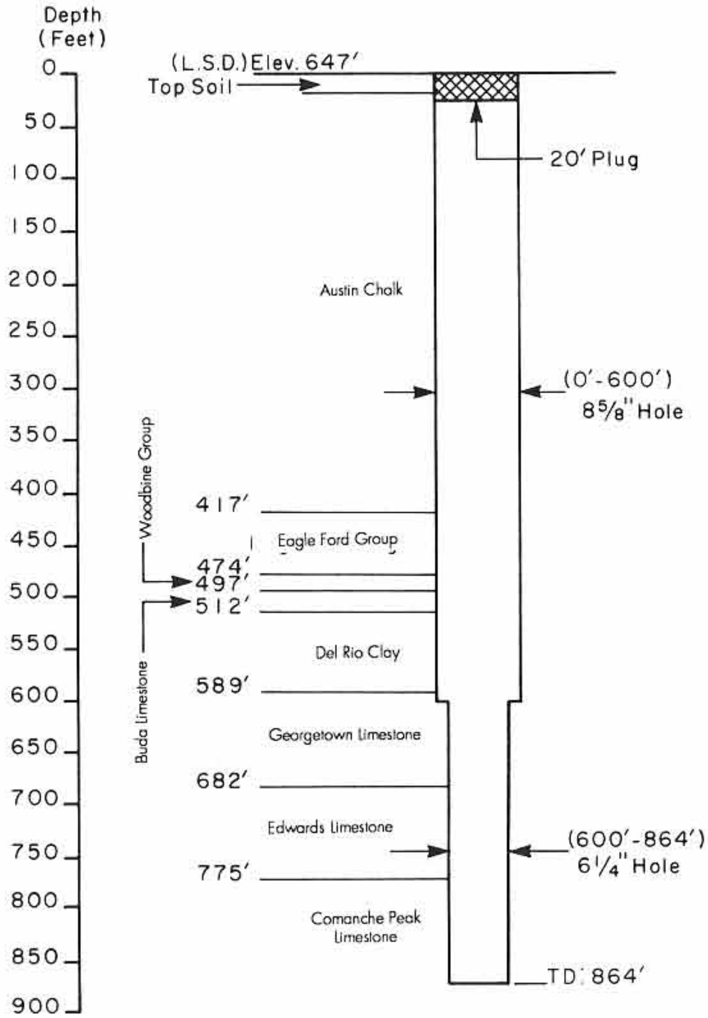
Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
980-1140	5	4265

Appendix 3 – continued
Schematic, Test Well 6 (58-13-301)



Water Sampling Results		
Interval (Feet)	Yield (gpm)	Total Dissolved Solids (mg/l)
34-180	1-2	691

Appendix 3 – continued
Schematic, Test Well 7 (40-61-705)



Water Sampling Results		
Interval (Feet)	Yield gpm	Total Dissolved Solids (mg/l)
580-804	22	981

Appendix 3 – continued
Schematic, Test Well 8 (58-12-901)