Texas Water Development Board

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Hydrogeology of Lower Cretaceous Strata Under the Southern High Plains of Texas and New Mexico

by
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ABSTRACT

Lower Cretaceous strata underlie approximately 10,000 square miles of the Southern High Plains of Texas and New Mexico. The strata lie below the regional water table in most places, and are included in the greater High Plains aquifer system, one of the major sources of ground water used for irrigation purposes in the United States.

A typical Lower Cretaceous section under the Southern High Plains includes a relatively thin (zero to 60 feet) sand and sandstone deposit overlain by marls, clays, and associated marine limestones of varying (zero to 200 feet) thickness. Stratigraphically and in ascending order, the deposits correlate with the Antlers, Walnut, Comanche Peak, Edwards, Kiamichi, and Duck Creek Formations of west-central Texas. The strata are covered largely by sand, silt, clay, and gravel deposits that make up the Ogallala Formation (Tertiary), a major water-bearing unit in the High Plains aquifer system. Shale, siltstone, and sandstone of Late Triassic age underlie the Lower Cretaceous deposits.

There are two distinct ground-water aquifers in Lower Cretaceous strata under the Southern High Plains. One occurs in the Antlers Formation, a basal sand and sandstone deposit. The sandstone aquifer: (1) underlies approximately 9,000 square miles of the Southern High Plains; (2) occurs generally 200 to 350 feet below ground surface; (3) comprises an irregular sheet deposit that pinches and swells in thickness while thinning regionally to the northwest; and (4) is confined largely by bounding shale and marl beds. Ground water in the Antlers is almost always under artesian pressure, and numerous wells have flowed at ground surface when completed in it.

A second Lower Cretaceous aquifer under the Southern High Plains is formed by jointed limestones of the Comanche Peak and Edwards Formations. The carbonate aquifer: (1) underlies approximately 8,000 square miles of southern and eastern parts of the Southern High Plains; (2) occurs generally between 20 and 250 feet below ground surface; (3) is in deposits that combine to form a thin, arcuate wedge that tapers to the northwest; and (4) is largely unconfined along its eastern edge. Ground water in the limestone occurs primarily in joints, solution cavities, and along bedding planes, and water-table conditions prevail throughout unconfined parts of the system.

Ground-water movement through both of the Lower Cretaceous aquifers under the Southern High Plains is generally to the east-southeast in conformance with hydraulic head distribution and regional structure. Flow rates are estimated to vary from a few feet per year in lower sandstones to more than a hundred feet per day sometimes where solution cavities and joint systems are well developed in limestone intervals along the Southern High Plains escarpment.

Recharge to the Lower Cretaceous aquifers occurs directly from the bounding Ogallala Formation along northern and western parts of

the subcrop area, and by downward percolation from overlying ground-water units at other locations. Discharge is to well heads in Texas and New Mexico; to streams, springs, and seeps along the Southern High Plains escarpment in Texas; and to surrounding formations.

Ground water in the Lower Cretaceous aquifers is generally fresh (less than 1,000 mg/l dissolved solids) to slightly saline (1,000 to 3,000 mg/l dissolved solids) in character, and usually has either a mixed-cation-bicarbonate, calcium-bicarbonate, or sodium-bicarbonate hydrochemical signature. However, water quality decreases in areas where saline lakes and the gypsiferous Tahoka and Double Lakes Formations (Pleistocene) overlie them, becoming moderately saline (3,000 to 10,000 mg/l dissolved solids) in character and exhibiting either a sodium-sulfate or a sodium-chloride hydrochemical signature.

Yields from wells completed in Lower Cretaceous aquifers under the Southern High Plains generally range between 50 and 200 gallons per minute, although production of more than 1,000 gallons per minute has been reported from isolated localities. The higher yield wells are completed in thick, channel-fill sandstone sections of the Antlers Formation in the Causey-Lingo area, New Mexico, and in the Antlers, Comanche Peak, and Edwards Formations in Hale and Lubbock Counties, Texas. Wells dually completed in both Ogallala and Lower Cretaceous strata are also common over southern and eastern parts of the Southern High Plains.

It is estimated that Lower Cretaceous aquifers under the Southern High Plains contain approximately 13 million acre-feet of ground water when full. Annual production from both aquifers is estimated to have exceeded 15 thousand acre-feet in recent years, with the ground water being used primarily for crop irrigation.

Areas where Lower Cretaceous aquifers indicate potential for further development include parts of Cochran, Hockley, and Terry Counties, Texas, and Lea County, New Mexico, where the basal Antlers Formation is particularly thick in erosion channels cut into underlying Triassic strata. Expanded development of the Comanche Peak-Edwards limestone aquifers also appears feasible in east-central Lubbock and northeastern Lynn Counties, Texas.

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INTRODUCTION

Purpose and Scope

The primary purpose of this report is to describe the hydrogeology of Lower Cretaceous strata under the Southern High Plains. The Lower Cretaceous strata are incorporated in the High Plains aquifer system that provides essentially all of the ground water used for crop irrigation purposes on the Southern High Plains.

Significantly, clay and marl intervals in the Lower Cretaceous section under the Southern High Plains form regional aquicludes in the High Plains aquifer system. The aquicludes separate individual ground-water flow zones in the Lower Cretaceous section, forming boundaries between aquifers that have unique hydraulic characteristics, and that are discussed individually under separate headings in this report.

The report pertains to all areas where Lower Cretaceous strata are know to exist under the Southern High Plains (Figure 1), including parts of southeastern New Mexico as well as Texas. This allows for the presentation of New Mexico data that have a direct bearing on flow dynamics, ground-water chemistry, and other hydrologic properties of Lower Cretaceous aquifers in Texas. The report stems largely from field, lab, and office investigations made by the author and other individuals cited in the text.

Approximately 1,000 well logs from commercial and other drilling sources were analyzed to determine and map subsurface facies characteristics, regional thicknesses, and areal extent of Lower Cretaceous strata shown in the report. Well log information supplied from numerous oil, gas, and ground-water investigations made in the study area was obtained largely from office files located at the New Mexico State Engineer's Office in Roswell, New Mexico, and at the Texas Water Development Board (TWDB) in Austin, Texas. Regional cross-sections presented with the text were also constructed from select information recorded on drillers' logs filed with the New Mexico State Engineer's Office, the Texas Water Commission (TWC), and from descriptions of formation outcrops measured in the field. Water samples collected from wells tapping the Lower Cretaceous strata were analyzed at the Texas Department of Health Laboratories in Austin, Texas, for data used in the report.

As part of the High Plains aquifer system, discrete aquifer intervals in the Lower Cretaceous section under the Southern High Plains are developed locally as a source of fresh to slightly saline ground water. Accordingly, findings in this report have applications to projects addressing ground-water inventory, development, and management on the Southern High Plains.

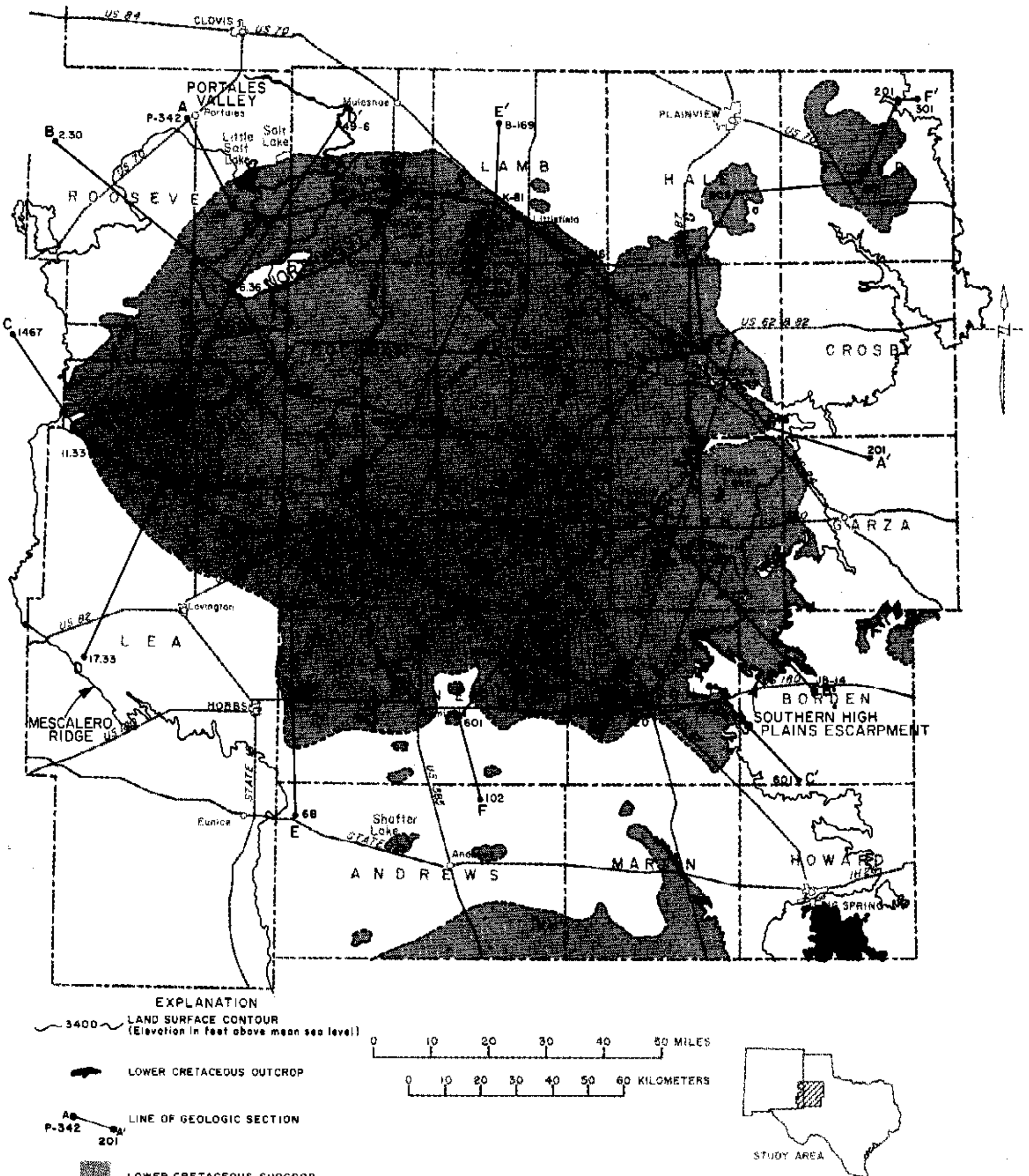


Figure 1

Study Area Location Map

Previous Investigations

Investigative studies describing the geology of Lower Cretaceous strata under the Southern High Plains are limited. Sellards and others (1932) briefly notes that Lower Cretaceous strata are present in the southern Texas Panhandle, with the Edwards Formation extending "...westward to the cap of the Llano Estacado." Brand (1950, 1953) also addresses Cretaceous outcrops on the Llano Estacado of Texas in a University of Texas Ph.D. dissertation and other publications.

Local and regional hydrogeologic surveys that offer short discussions of Lower Cretaceous strata in the study area include reports by Leggat (1952), Cronin and Wells (1960), Mount and others (1967), Knowles and others (1984), and others listed in the Selected References section of this report. Basic ground-water information for the Southern High Plains is also recorded in various State and Federal reports, including annual U.S. Geological Survey publications listing water levels and artesian pressures in the United States.

Location and General Features

Lower Cretaceous strata underlie approximately 10,000 square miles of the Southern High Plains, including areas under all or parts of Bailey, Borden, Cochran, Dawson, Gaines, Garza, Hale, Hockley, Lamb, Lubbock, Lynn, Terry, and Yoakum Counties, Texas, and of Lea and Roosevelt Counties, New Mexico. The strata are covered largely by the Ogallala Formation (Neogene) and other surficial deposits. However, limited outcrops of the Mesozoic rocks are exposed along the margins of isolated playa depressions, and along escarpments demarking eastern and western edges of the Southern High Plains physiographic province.

As an elevated plateau region, the Southern High Plains is characterized by flat, treeless terrain. Shallow playa depressions and sand dunes are also typical features in certain parts of the province. The plains slope imperceptibly to the southeast and are generally devoid of major drainage systems. Native vegetation in the region includes numerous dryland grasses and more localized growths of shinoak, sagebrush, mesquite, and yucca. Farm crops are cultivated over much of the Southern High Plains, primarily during late spring and summer months.

Economic Development

The Southern High Plains economy is based largely on agricultural development and the production of oil and gas. Large-scale irrigation farming began in the region during the 1930's and 1940's, primarily with the development of water-bearing formations within the High Plains aquifer. At about the same time, large oil and gas deposits were discovered in various Permian Basin reservoirs underlying the study area.

Today, the Southern High Plains is one of the most intensively cultivated areas in the North American mid-continent. Crops grown in the study area include cotton, grain sorghums, soybeans, wheat, barley, oats, corn, and assorted vegetables. Beef cattle are also raised in the region, often being penned and fattened in feedlots that have expanded over the province since the early 1960's.

Oil and gas development is extensive on the Southern High Plains. Collectively, oilfields in the study area contain more than 12 billion barrels of oil in place, making them the single largest oil play in the southern mid-continent area (Galloway, et. al., 1983). The oilfields are particularly well developed in southern parts of the study area where oil reservoirs are defined in carbonate rocks that were deposited on the northern shelf of a Permian-age basin. Many of the fields are in secondary phases of production and some of the world's largest enhanced oil recovery (EOR) projects utilizing injected water and carbon dioxide as hydrocarbon displacement agents are currently operating in the region.

Satellite industries supporting oil, gas, and agricultural development also contribute to the overall economy of the study area. The support industries usually have home or field offices located in local Southern High Plains cities such as Lubbock, Levelland, Brownfield, Plains, Lamesa, Denver City, and Seminole, Texas.

Climate

The Southern High Plains has a semiarid climate, with precipitation generally measuring between 14 and 20 inches a year. Precipitation is usually light during winter months, increasing in the late spring and early fall. Temperatures typically range from the low to mid-90's (degrees F) in the summer and from the low to mid-50's in the winter.

Weather patterns are sometimes extreme over the Southern High Plains. Temperatures can drop as much as 60 F over short periods of time when "blue northers" blow across the region, sometimes depositing light snows in the winter. Low humidity and strong southeasterly breezes commonly accompany higher summer temperatures, resulting in high surface evaporation rates and generating periodic dust storms across the Plains. Thunderstorms crossing the area during rainy periods occasionally produce hail and tornadoes, especially during late spring and summer months.

Acknowledgements

Numerous farmers, ranchers, and other land holders on the Southern High Plains permitted access to their properties and supplied ground-water information integrated in this report. Also, well drillers, pump companies, and municipal officials in the study area provided drillers' logs, pump test information, and municipal well data that were helpful in defining the subsurface character of Lower Cretaceous strata and their contained waters. Private ground-water consultants provided assistance in helping locate drillers' logs and other information used in the report, especially Sherman Galloway of Roswell, New Mexico.

State and Federal personnel who helped locate well log and quality of ground-water data, or who provided other useful information related to the geology and chemistry of ground water in the study area, included Steve Seni and Ronit Nativ of the Bureau of Economic Geology in Austin, Texas; Arthur Mason of the New Mexico State Engineer's Office in Roswell, New Mexico; and Don Hart of the U.S. Geological Survey Water Resource Division in Albuquerque, New Mexico. Also, earlier researchers who analyzed and published data related to the geology and hydrology of the Southern High Plains are to be credited, with special acknowledgements going to John Brand, Edward Leggat, and James Cronin.

The need for a more comprehensive regional geologic and hydrologic study of Lower Cretaceous strata under the Southern High Plains was brought to the author's attention by Phil Nordstrom of the TWDB. Tommy Knowles, Chief of the Board's Water Availability Data and Studies Section of the TWDB, was subsequently apprised of the need and provided administrative support for the investigation. Manuscript typing and drafting are credited to Yolanda Briones and Steve Gifford respectively of the Board.

Geology

Regional Setting

A variety of rock types and different sedimentary formations representing all major geologic eras underlie the Southern High Plains. The rocks include deeply buried and structurally complex Precambrian metamorphic and igneous assemblages that generally range from 0.8 to 1.7 million years in age, and occupy a failed rift system that first projected into the southern cratonic area of North America during Proterozoic time. The rocks fringe on the Greenville-Llano tectonic front to the south and are bound by older Canadian Shield provinces to the north.

Early and middle Paleozoic formations under the Southern High Plains are composed largely of shallow marine shelf carbonates that range from 3,000 to 6,000 feet thick. The strata have numerous regional and sub-regional unconformities, suggesting that extensive and frequent epeirogenic crustal movements affected depositional environments during early and middle Paleozoic time.

Late Paleozoic strata in the study area include marine carbonate and evaporite sequences of Permian age that measure over 8,000 feet thick in places. The strata accumulated in and around a shallow structural depression or basin that developed over older Precambrian rift zones in northwest Texas during the Permian.

Mesozoic strata under the Southern High Plains include Late Triassic redbed sequences composed primarily of lacustrine mudstones, and fluvial-deltaic sandstones and shales (Table 1). The continental redbeds are up to 2,000 feet thick in places, and are unconformably overlain by the erosional outliers of Lower Cretaceous marine rocks that are described in more detail in following sections of this report.

Strata capping Mesozoic and older rock units under the Southern High Plains include the Ogallala Formation and younger surficial deposits. The Ogallala Formation is a near-surface deposit of sand, silt, clay, and gravel that accumulated in fluvial, eolian, and alluvial fan depositional environments during Neogene time. Localized fluvial, eolian, and lacustrine deposits forming the Tahoka, Double Lakes, and Blackwater Draw Formations, as well as modern day stream alluvium and dune sand, cover the Ogallala Formation at most locations.

Tectonic History

The tectonic history of the Southern High Plains is varied and complex. During early and middle Paleozoic time, epicontinental seas periodically transgressed over the region in response to epeirogenic downwarping along what is now North America's southern cratonic boundary. Sediments deposited or precipitated in the marine environments included constructional shallow marine carbonates and lesser amounts of clean sandstone and shale (Fallin, 1985; Nicholas and Rozendal, 1975).

Table 1. - *Physical and Water-Bearing Characteristics of Cenozoic and Mesozoic Strata Under the Southern High Plains.*

System	Series	Group	Formation	Approximate maximum thickness (feet)	Physical character of rocks	Water-bearing characteristics*	
Quaternary	Pleistocene to Recent		Alluvium, eolian and lacustrine deposits	60	Windblown sand and silt, stream alluvium, and silt and clay playa lake deposits.	Yields small amounts of water to wells.	
Tertiary	Late Miocene to Pliocene		Ogallala	600	Composite accumulation of tan, yellow, and reddish-brown silt, clay, sand and gravel that is generally coarser-grained near the base of the formation. Caliche caprock and calcic paleosols occur in fine-grained deposits near the top of the formation.	Yields moderate to large amounts of water to wells. The principal aquifer in the study area with yields of some wells in excess of 1,000 gal/min.	
Cretaceous	Comanche	Washita	Duck Creek	50	Yellow, sandy shale and thin gray to yellowish-brown, argillaceous limestone beds.	Yields small amounts of water locally to wells.	
		Fredericksburg	Kiamichi	110	Thinly laminated, sometimes sandy, gray to yellowish-brown shale with interbeds of thin, gray, argillaceous limestone and thin, yellow sandstone.	Yields small amounts of water locally to wells.	
			Edwards Limestone	35	Light-gray to yellowish-gray, thick bedded to massive, fine to coarse-grained limestone.	Yields moderate to large amounts of water locally to wells from fractures and solution cavities.	Yields small amounts of water to wells.
			Comanche Peak Limestone	85	Light-gray to yellowish-brown, irregularly bedded, argillaceous limestone and thin interbeds of light-gray shale.		Yields small amounts of water to wells.
			Walnut	30	Light-gray to yellowish-brown, fine- to medium-grained, argillaceous sandstone; thin bedded, gray to grayish-yellow, calcareous shale; and light-gray to grayish-yellow, argillaceous limestone.	Not known to yield water to wells.	
		Trinity	Antlers	60	White, gray, yellowish-brown to purple, fine- to coarse-grained, argillaceous, loosely cemented sand, sandstone, and conglomerate with interbeds of siltstone and clay.	Yields small to moderate amounts of water to wells in the study area.	
Triassic	Upper	Dockum	Undivided	2,000	Upper unit, varicolored siltstone, claystone, conglomerate, fine-grained sandstone, and limestone. Lower unit, varicolored, fine to medium-grained sandstone with some claystone and interbedded shale.	Yields small to moderate amounts of water to wells. Water quality variable with stratigraphic position and depth.	

* Yields of wells: small = <50 GPM, moderate = 50-500 GPM, large = >500 GPM.

The convergence and collision of North and South America in the late Paleozoic Era subsequently displaced open marine seas along the southern edge of the North American craton, first into interior sag basins and other depressions bordering the Ouachita tectonic belt, then away from the region entirely. Cut off from open ocean currents, inland seas overlying the Permian Basin in the Southern High Plains region ultimately evaporated, leaving behind large deposits of halite, potash salts, and anhydrite.

In the early Mesozoic Era, fresh water lake basins developed over the mid-continent region, leading to the accumulation of lacustrine and fluvial-deltaic deposits that make up the Dockum Group (Late Triassic). Major source areas contributing sediments to the lake basins included the Ouachita tectonic belt to the south and east, a structural remnant from the collision of North and South America (Granata, 1981).

The separation of North and South America and consequent opening of the Gulf of Mexico followed, with crustal subsidence around the edge of the Gulf tilting and draining mid-continent lake basins to the southeast during the Jurassic Period. At about the same time, compressional orogenic events in western North America, e.g., the Nevadan orogeny, downwarped the entire mid-continent region, permitting oscillating seas to transgress over the study area in the Early Cretaceous Period and to deposit the Lower Cretaceous strata that are the subject of this report.

Laramide uplift and other tectonic events associated with Tertiary doming along the Rio Grande rift system to the west subsequently elevated the Southern High Plains above sea level again, tilting the region to the southeast at the same time. Partial draining and erosion of Cretaceous and older formations accompanied the uplift, exposing the strata to direct fresh-water recharge in some places and depositing younger, fresh water-bearing sediments (i.e., the Ogallala Formation) on top of the units in others. Today, eroded outliers of Lower Cretaceous and younger strata continue to mantle older rock units under uplifted portions of the Southern High Plains.

Cretaceous System

Introduction

A typical Lower Cretaceous section under the Southern High Plains includes a basal sand and sandstone deposit overlain by marine marls, clays, and associated limestones. Deposited on eroded Late Triassic terrain and covered largely by Tertiary-age sediments, the Lower Cretaceous strata form buried mesas with more than 250 feet of subsurface relief at some locations. The buried mesas are erosional outliers of a system of rocks that are much more extensively preserved and exposed in the Edwards Plateau region of South-Central Texas.

The regional unconformities that bound Lower Cretaceous strata under the Southern High Plains are irregular surfaces crosscut with erosional channels at some locations (Figures 2 and 3). The channels trend east-southeast across the study area, with upper

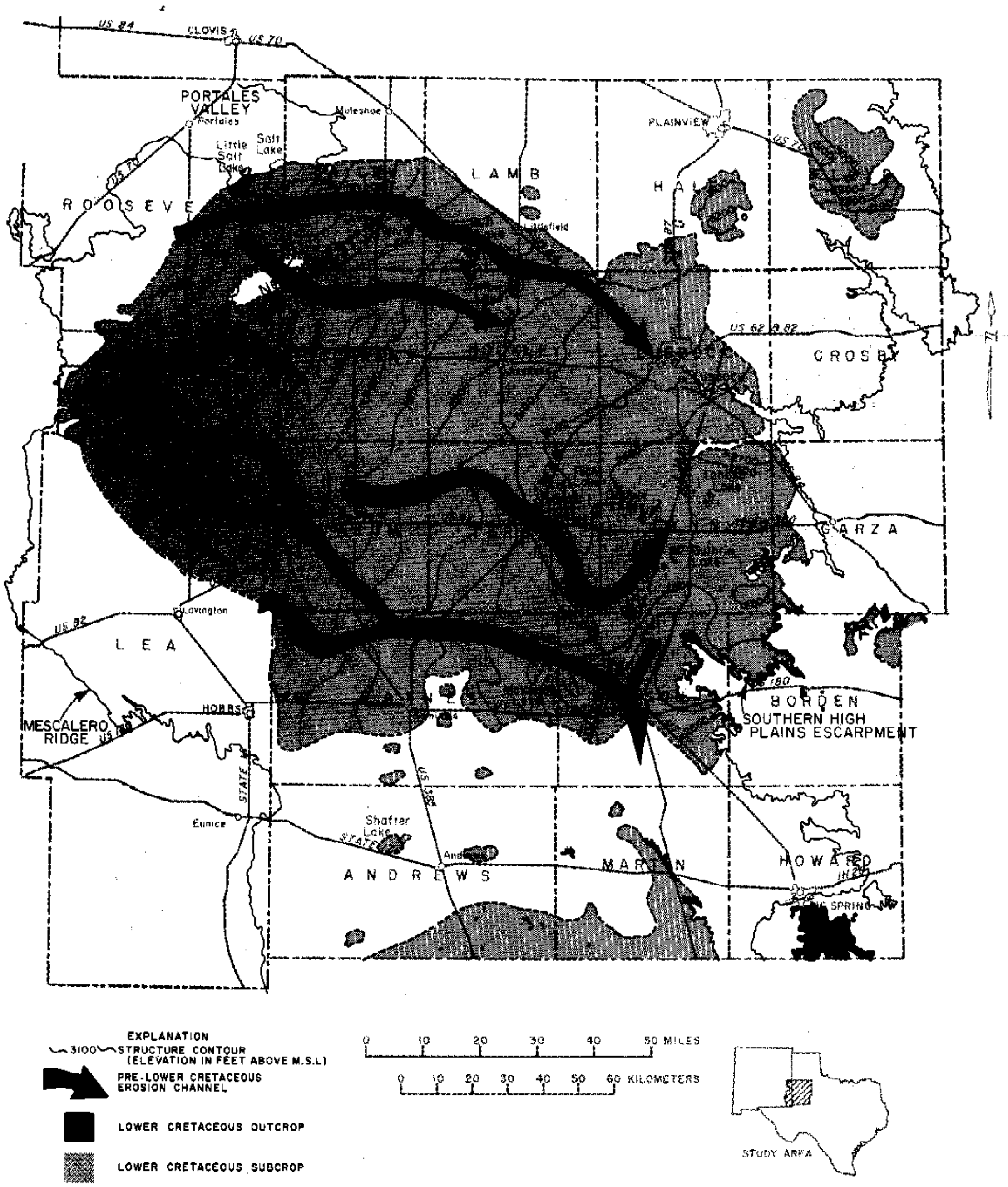


Figure 2

Structure Contour Map Showing the Altitude of the Base of Lower Cretaceous Strata Under the Southern High Plains

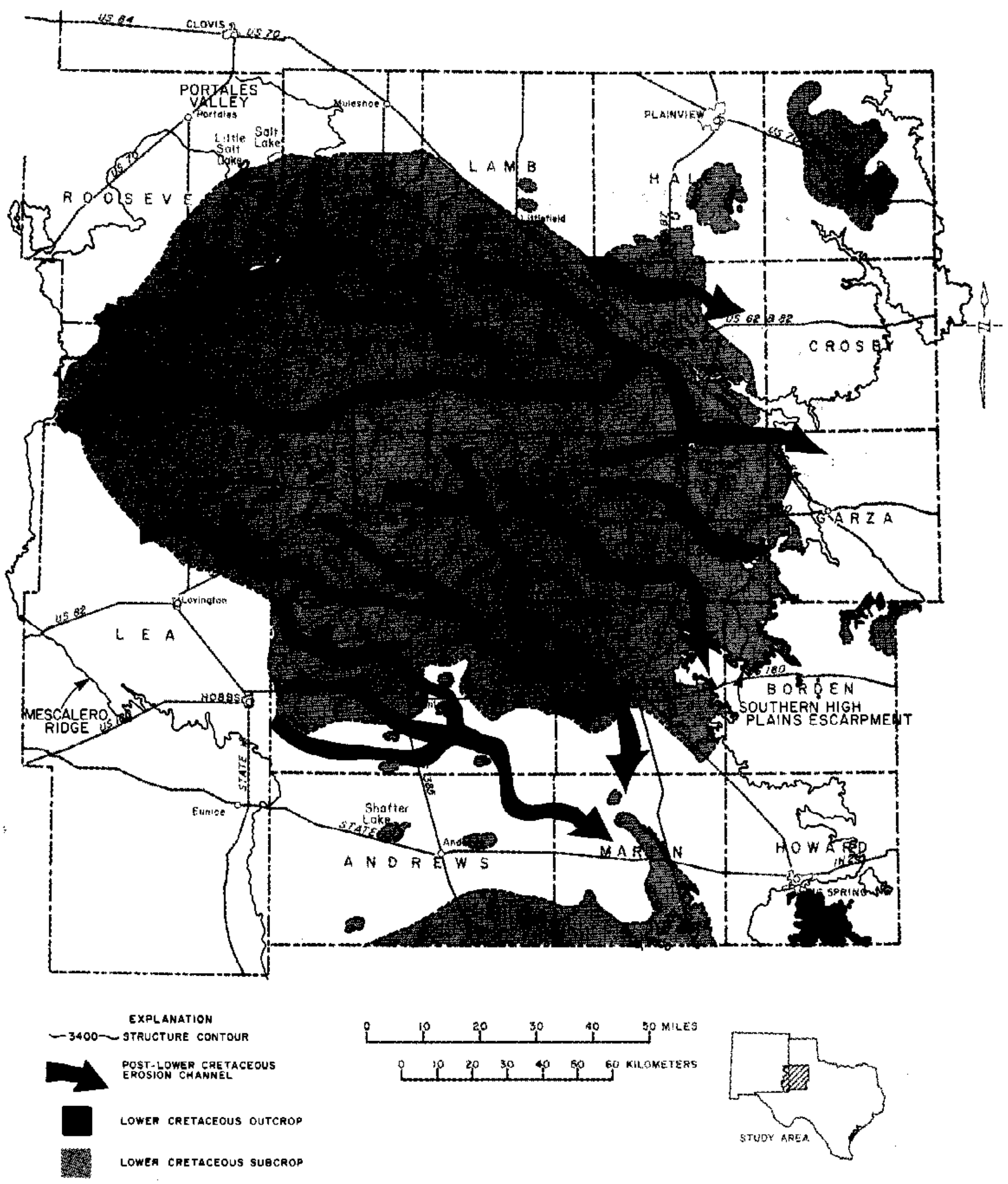


Figure 3

Structure Contour Map Showing the Altitude of the Top of Lower Cretaceous Strata Under the Southern High Plains

channel courses sometimes cutting entirely through the Lower Cretaceous section (e.g., Slaton Channel, southeast Lubbock County, Texas).

Strata immediately underlying the regional unconformities are discolored at many locations, reflecting the effects of subaerial weathering during hiatal periods that bounded Lower Cretaceous depositional events. Reddish-brown mudstones are commonly tinted blue-green one to two feet below the Late Triassic-Lower Cretaceous unconformity, and blue-gray limestones and clays in upper parts of the Lower Cretaceous section are often oxidized yellow to a depth of 10 or more feet immediately below the Ogallala Formation.

Stratigraphy

As many as six Lower Cretaceous formations have been described under the Southern High Plains. The formations define parts of the Trinity, Fredericksburg, and Washita Groups of the Gulf Coast Comanchean Series in North America. Biostratigraphic zonation of the sequence is based primarily upon the occurrence of ammonites and other marine fossils in the stratigraphic section (Brand, 1953).

Trinity Group

In the Southern High Plains region, the Trinity Group is represented by the Antlers Formation, a white to purple, unconsolidated to moderately well cemented, fine- to coarse-grained quartz sand and sandstone. In the study area, the Antlers Formation is interbedded locally with green clay and pink siltstone, and has scattered lenses of gravel that include well-rounded quartz pebbles and claystone clasts derived from underlying Late Triassic strata. Quartz grains in the Antlers Formation are typically well rounded and frosted in appearance, both characteristics associated with near-shore marine, beach and dune sand deposits.

As an irregular sheet deposit, the Antlers Formation pinches and swells in thickness while thinning regionally to the northwest (Figures 4 and 5). Measured sections of the unit range from less than one to more than 60 feet thick under the Southern High Plains. In eastern New Mexico and more northern parts of the study area in Texas, the Antlers Formation is locally absent, having been removed by post-depositional erosion at some locations.

Fredericksburg Group

The Fredericksburg Group under the Southern High Plains includes the Walnut, Comanche Peak, Edwards, and Kiamichi Formations. Also, part of the time transgressive Antlers Formation is probably of Fredericksburg age in northwestern parts of the study area.

Lithologically, the Walnut Formation is composed of light gray, calcareous shale, fine- to medium-grained sandstone, and light gray, argillaceous limestones. It grades abruptly upward into thicker, more massive, light gray, argillaceous limestones and interbedded marls of the Comanche Peak Formation.

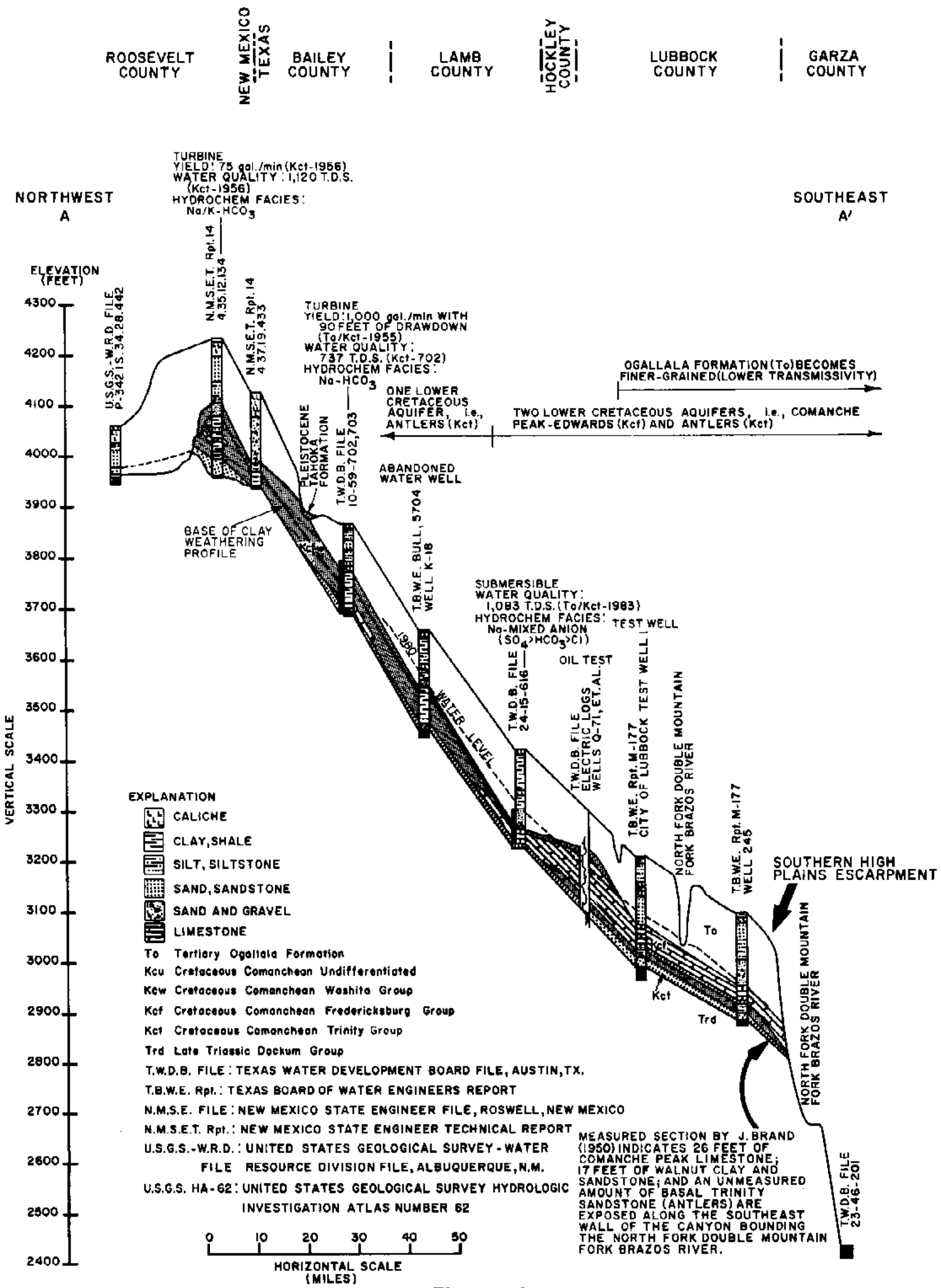


Figure 4

Geologic Section A - A'
Showing Dip Profile of Lower Cretaceous Strata Under the Southern High Plains

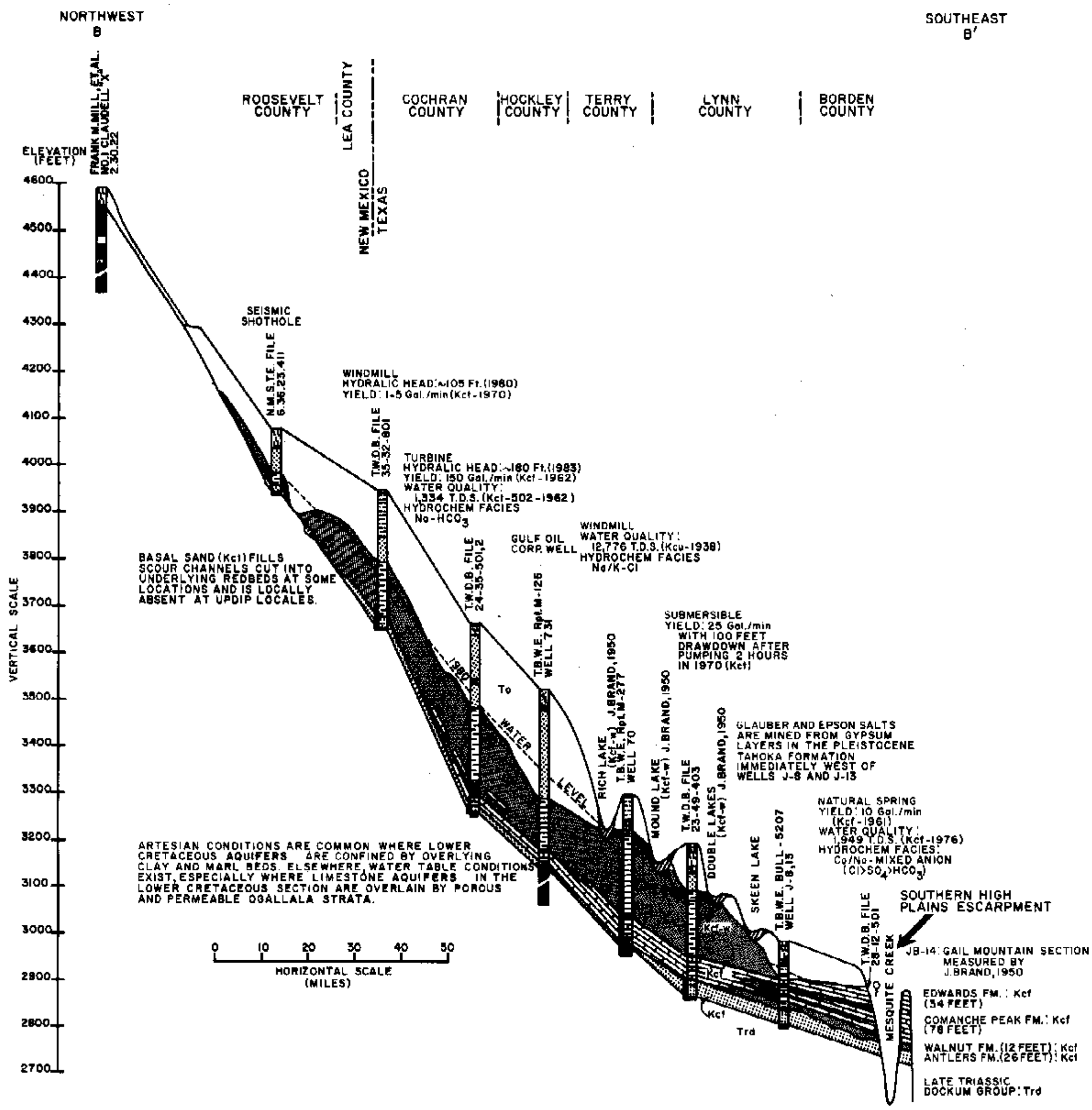


Figure 5

Geologic Section B - B'
Showing Dip Profile of Lower Cretaceous Strata Under the Southern High Plains

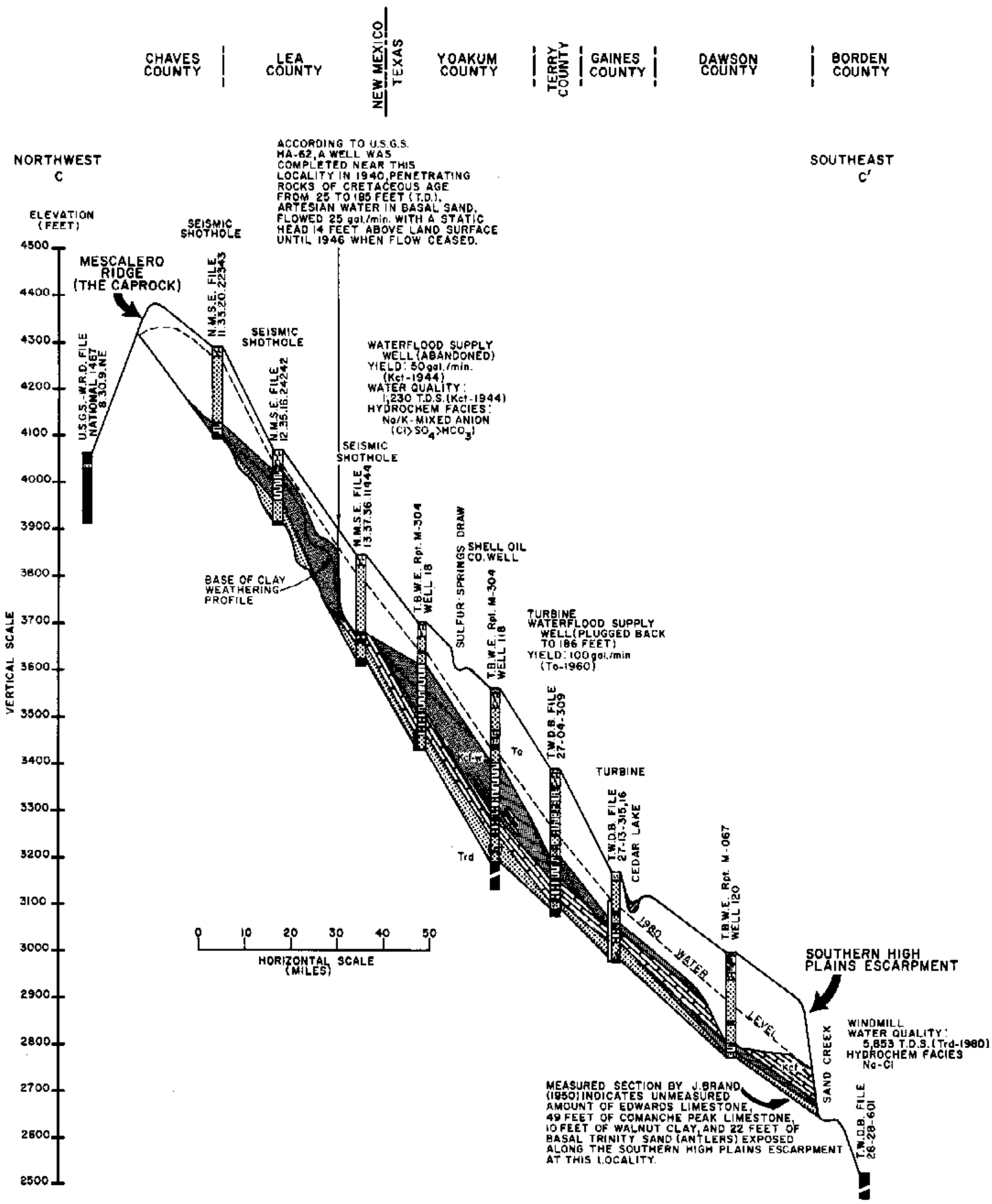


Figure 6

Geologic Section C - C' Showing Dip Profile of Lower Cretaceous Strata Under the Southern High Plains

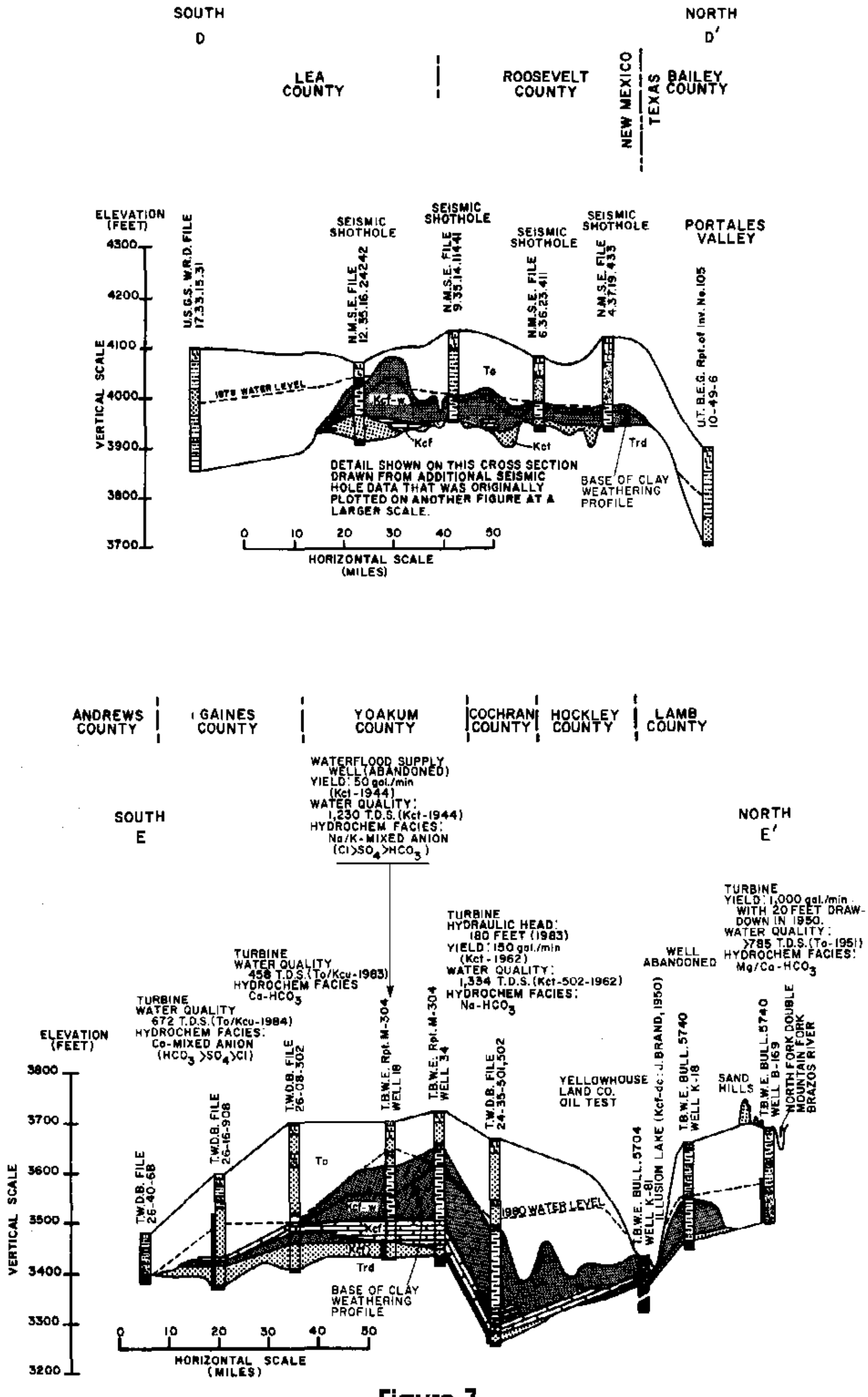


Figure 7

Geologic Sections D - D' and E - E' Showing Strike Profiles of Lower Cretaceous Strata Under the Southern High Plains

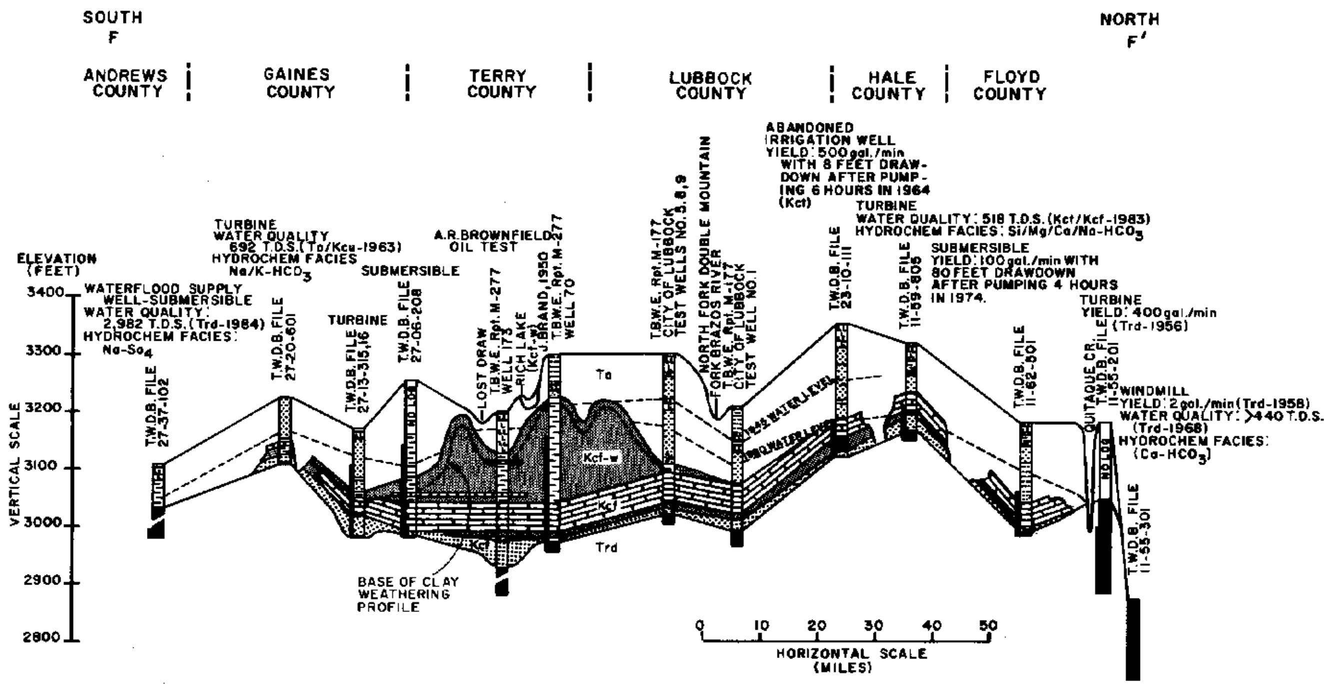


Figure 8

Geologic Section F - F'
Showing Strike Profile of Lower Cretaceous Strata Under the Southern High Plains

Under southeastern parts of the Southern High Plains, the Walnut Formation exceeds 30 feet in thickness, while the Comanche Peak Formation is as much as 85 feet thick. However, like the underlying Antlers Formation, both the Walnut and Comanche Peak Formations thin appreciably to the northwest, disappearing entirely at some locations.

The Edwards Formation overlies the Comanche Peak Formation in the southeast part of the Southern High Plains. It is profiled in steeper parts of the High Plains escarpment, and is a light gray to yellow, thick-bedded "Rudist" limestone that is honeycombed locally with solution cavities.

The Edwards Formation measures as much as 35 feet thick along the High Plains escarpment. However, the formation pinches out abruptly to the northwest, signaling the edge of a platform reef complex that developed over much of the central Texas region during the Early Cretaceous Period.

The Kiamichi Formation is the uppermost stratigraphic unit of the Fredericksburg Group. It is composed primarily of yellow-brown to dark blue-gray shale, but also has thin interbeds of gray, argillaceous limestone and yellow, fine-grained sandstone.

Where completely preserved, the Kiamichi Formation is at least 110 feet thick under the Southern High Plains. However, part or all of the formation is missing in some parts of the study area due to post-depositional erosion.

Washita Group

The Washita Group overlies the Fredericksburg Group and is represented by the Duck Creek Formation under the Southern High Plains. The Duck Creek Formation is composed of yellow-brown shale interbedded with thin lenses of argillaceous limestone and fine-grained sandstone.

Data from isolated wells suggest that the Duck Creek Formation probably exceeds 50 feet in thickness under the Southern High Plains. However, like the underlying Kiamichi Formation, it has been thinned or completely removed by post-depositional erosion at many locations. Undifferentiated sections of the Duck Creek and Kiamichi Formations generally thicken to the north and northwest in marked contrast to other Lower Cretaceous stratigraphic intervals in the study area.

Depositional History

Facies analyses and other geologic criteria indicate that Lower Cretaceous strata in the study area accumulated as epicontinental seas moved over the region from the southeast. The basal Antlers Formation accumulated during Early to Middle Albian time (Figure 9) in near-shore marine, beach, and coastal sand dune environments, sometimes being reworked as seas transgressed, regressed, then transgressed over the study area again. During latter parts of the same depositional period, the Walnut and Comanche Peak

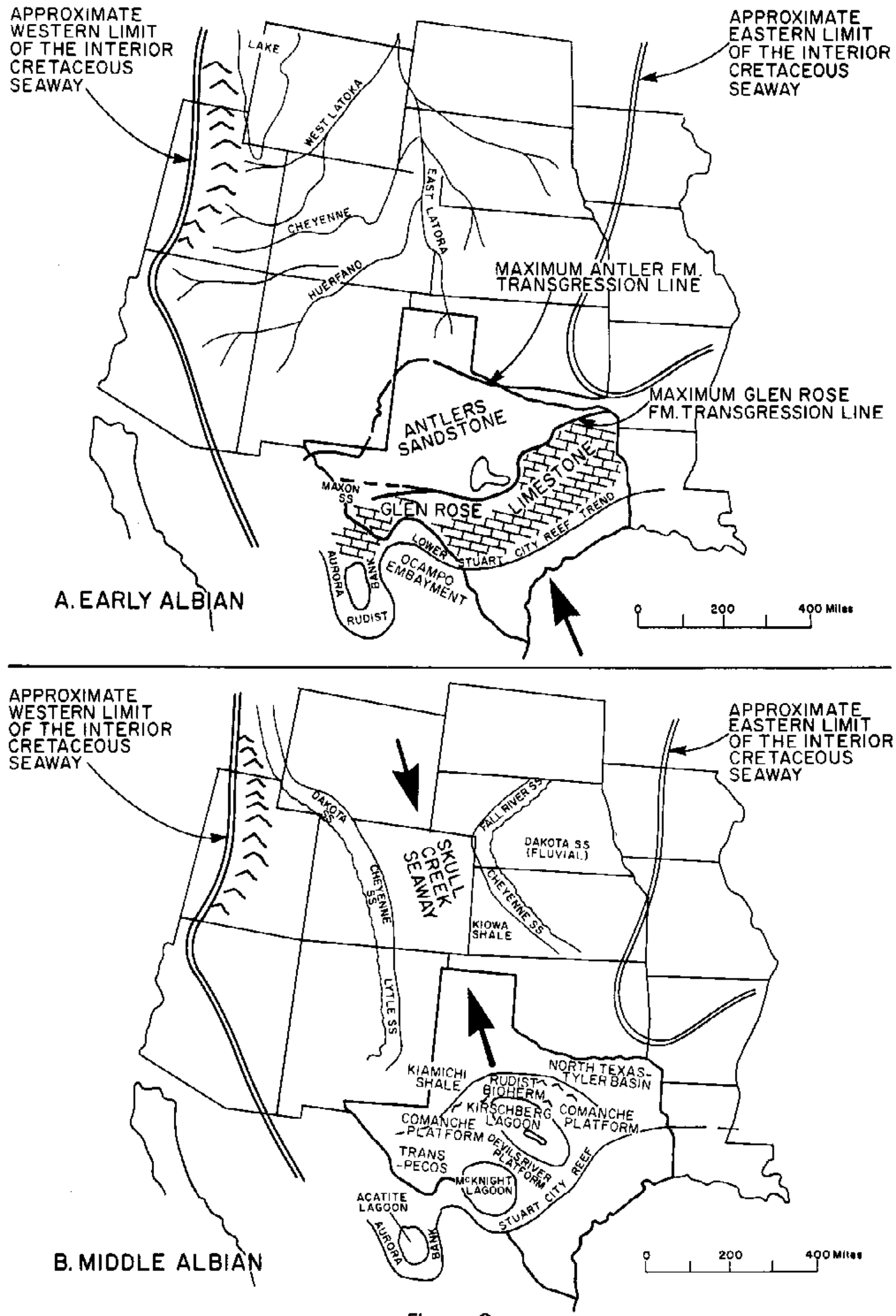


Figure 9

Early and Middle Albian Paleogeographic Maps of the Southern Mid-Continent Region of North America After West Texas Geological Society, 1981; (Mallory, 1972; Fisher and Rodda, 1969)

Formations accumulated offshore in shallow lagoon and carbonate platform environments. Then, as Mesozoic seas stabilized in early Middle Albian time, a more extensive platform and lagoonal complex developed over much of Central Texas. **Rudist** bioherms grew over and along the edges of the platform, ultimately defining the Edwards Formation that crops out along the southeastern High Plains escarpment and over the Edwards Plateau region of South-Central Texas.

Following Edwards deposition, the Southern High Plains was subaerially exposed in areas where major Edwards bioherms were developed. Then Middle Albian seas transgressed over the region again, eventually covering the entire mid-continent area of North America. The Kiamichi Formation and other lithostratigraphic equivalents (e.g., basal parts of the Tucumcari Shale in New Mexico) accumulated mostly in the expanded shallow marine sea before more stagnant lagoonal environments developed over the study area near the end of Fredericksburg time.

Renewed transgression subsequently opened the mid-continent seaway again, forming a shallow, open marine environment in which the Duck Creek Formation accumulated. Gulfward retreat of Upper Comanchean seas followed, bringing to an end all Lower Cretaceous deposition over the Southern High Plains.

Hydrology

Introduction

Essentially all Lower Cretaceous strata under the Southern High Plains occur below the regional water table, and are saturated with fresh to moderately saline ground water. Only in limited updip recharge areas of eastern New Mexico, and downdip drain areas along the Southern High Plains escarpment in Texas does the regional water table drop below the upper surface of the Lower Cretaceous subcrop.

The Lower Cretaceous strata are in hydraulic continuity with other water-bearing formations in the region, and are considered to be part of the High Plains aquifer. Basal sandstone beds in the Antlers Formation, and solution cavities, fractures, joints, and bedding planes in limestone portions of the Comanche Peak and Edwards Formations define ground-water aquifers in the Lower Cretaceous section. However, limestone and sandstone stringers in the Kiamichi and Duck Creek Formations also transmit limited amounts of ground water through the system at some locations.

Aquiclude intervals in the Lower Cretaceous section include thick clay and marl beds that form major parts of the Walnut, Kiamichi, and Duck Creek Formations. Yielding little, if any, ground water to wells and springs in the study area, the fine-grained strata serve to confine ground-water aquifers in the High Plains aquifer at some locations, while also diverting regional ground-water flow around and over much of the Lower Cretaceous subcrop.

Ground-water movement and drainage through the Lower Cretaceous strata is generally to the east-southeast in conformance with head distribution and structural dip (Figure 10). Intraformational facies changes, joint patterns, local cementation, and sinuosity of underlying scour channels, however, prompt local deviations in flow patterns.

Ground-water flow rates in the Lower Cretaceous strata are estimated to vary from a few feet per year in lower sandstone sections to more than 100 feet per day sometimes where solution cavities and joint systems are particularly well developed in limestone intervals. Discharge from these aquifers is to well heads in Texas and New Mexico; to streams, springs, and seeps along the Southern High Plains escarpment in Texas; and to surrounding formations. Recharge to the system occurs directly from bounding Ogallala deposits along northern and western parts of the subcrop area, and indirectly by downward percolation or infiltration from the overlying Ogallala at other locations (Figure 11). Precipitation is the principal source of recharge to the bounding and overlying Ogallala Formation, with ground-water renewal rates to the Ogallala generally averaging less than one half inch per year when semiarid climatic conditions prevail over the Southern High Plains.

Overall well yields from Lower Cretaceous strata under the Southern High Plains range from less than 50 to more than 1,000 gallons per minute. Highest yield rates have thus far come from isolated wells completed in the Antlers Formation in the Causey-Lingo area of Roosevelt County, New Mexico, and from wells completed in the Antlers, Comanche Peak, and Edwards Formations in Hale and Lubbock Counties, Texas. Wells dually completed in Ogallala and Lower Cretaceous rocks are common in many parts of the study area, particularly where the Comanche Peak and Edwards Formations are well developed in the Lower Cretaceous section.

The content of dissolved solids in ground water in Lower Cretaceous rocks is shown in Figure 12. The water is generally characterized by either a mixed-cation-bicarbonate (mixed-HCO_3) or sodium-bicarbonate (Na-HCO_3) hydrochemical signature (Figure 13). However, in areas overlain by saline lakes and the gypsiferous Tahoka and Double Lakes Formations (Pleistocene), either sodium-chloride (Na-Cl) or sodium-sulfate (Na-SO_4) hydrochemical facies usually prevail. Ground water in the Lower Cretaceous section is slightly basic, with pH values ranging between 7.5 and 8.5. The water is moderately to extremely hard, with equivalent concentrations of calcium carbonate typically ranging between 100 and 1,000 milligrams per liter.

As part of the High Plains aquifer, Lower Cretaceous strata have a pronounced effect on regional ground-water movement under the Southern High Plains. More specifically, the baffling effect of Lower Cretaceous clay and marl intervals, and the less extensive development of porous and permeable deposits (i.e., the Ogallala Formation) over the areas of Lower Cretaceous subcrop, serve to restrict regional ground-water flow in the aquifer system. As a consequence, well yields and water quality are somewhat diminished in the study area when compared to most other regions producing from the High Plains aquifer. Ponding of ground water in the Ogallala Formation behind buried Lower Cretaceous subcrop highs is also apparent, particularly in Lea County, New Mexico, where updip Ogallala deposits are buttressed against Lower Cretaceous clay and marl intervals (Figure 6), and in Cochran, Hockley, and Lubbock Counties, Texas, where regional water levels are measurably offset from adjoining areas to the north and south (Figures 7 and 8).

Regional Aquifer Characteristics

Antlers Formation

General Features

As a relatively thin, irregular sheet deposit that decreases in overall thickness to the northwest, the Antlers Formation is limited as an aquifer throughout much of the study area. Only in western and southern subcrop areas where thicker than usual sections

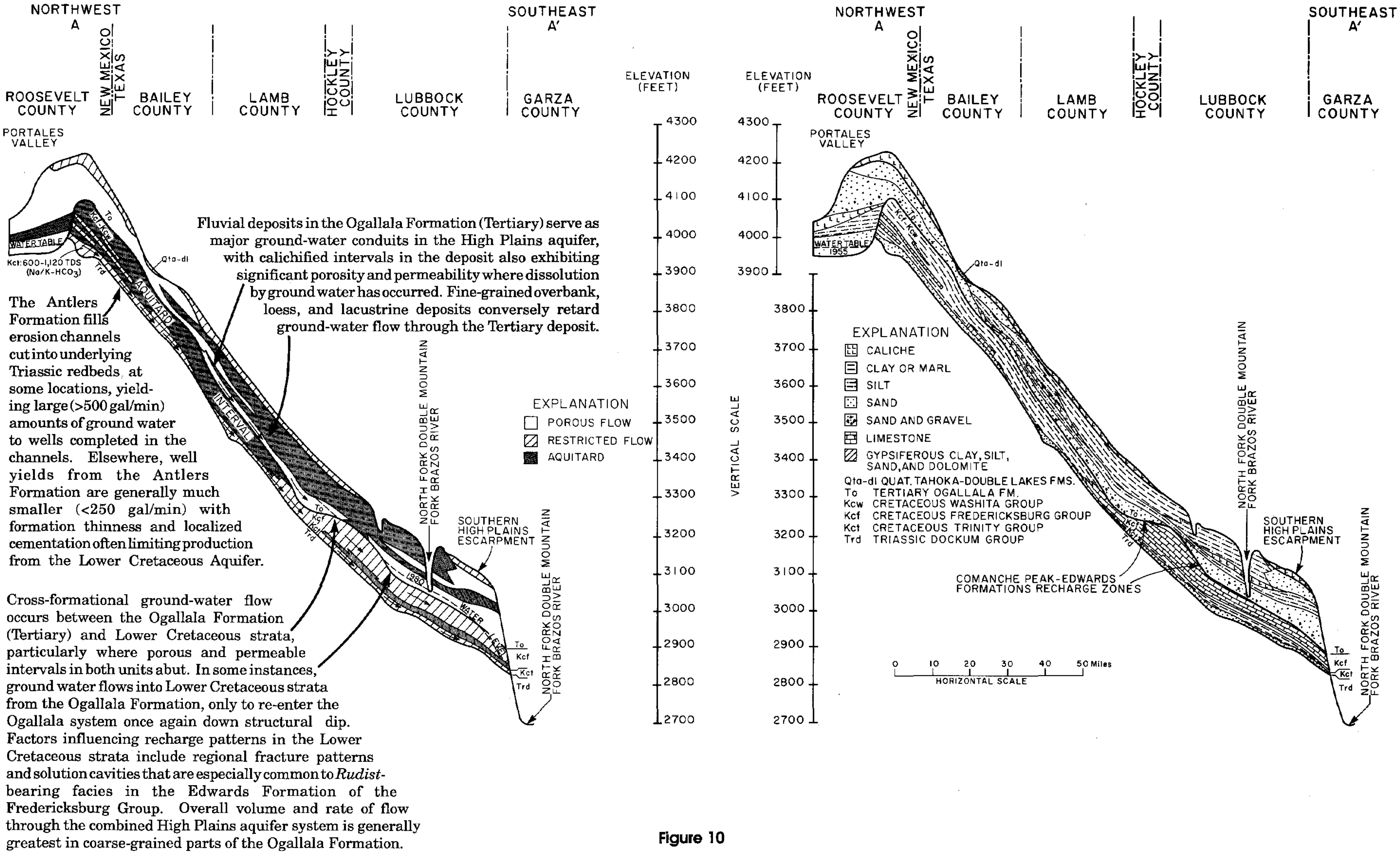
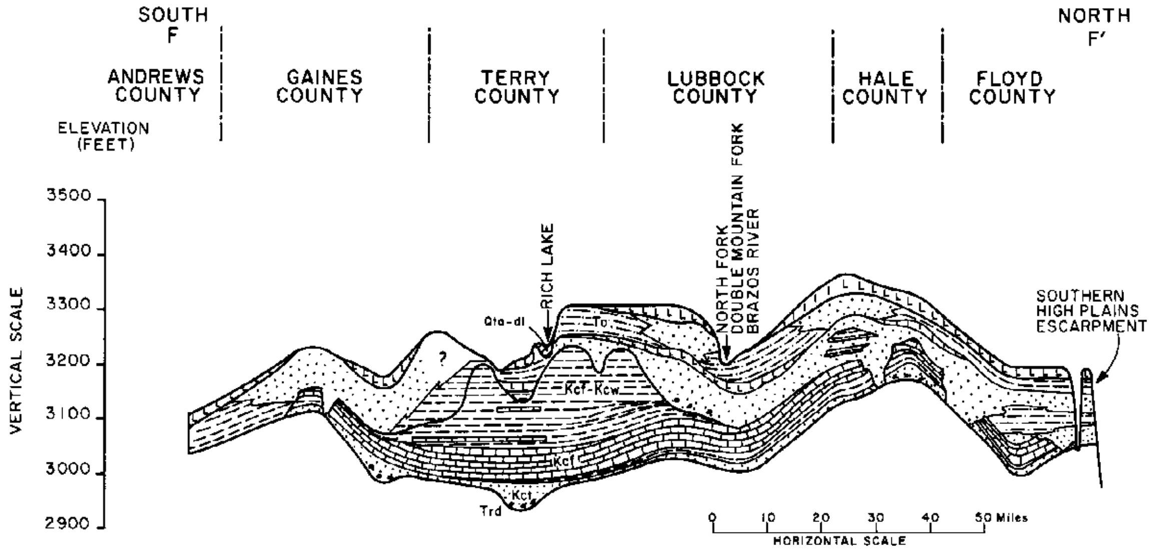


Figure 10

Facies Distribution and Ground-Water Flow Paths in the Southern High Plains Aquifer: Section A - A'



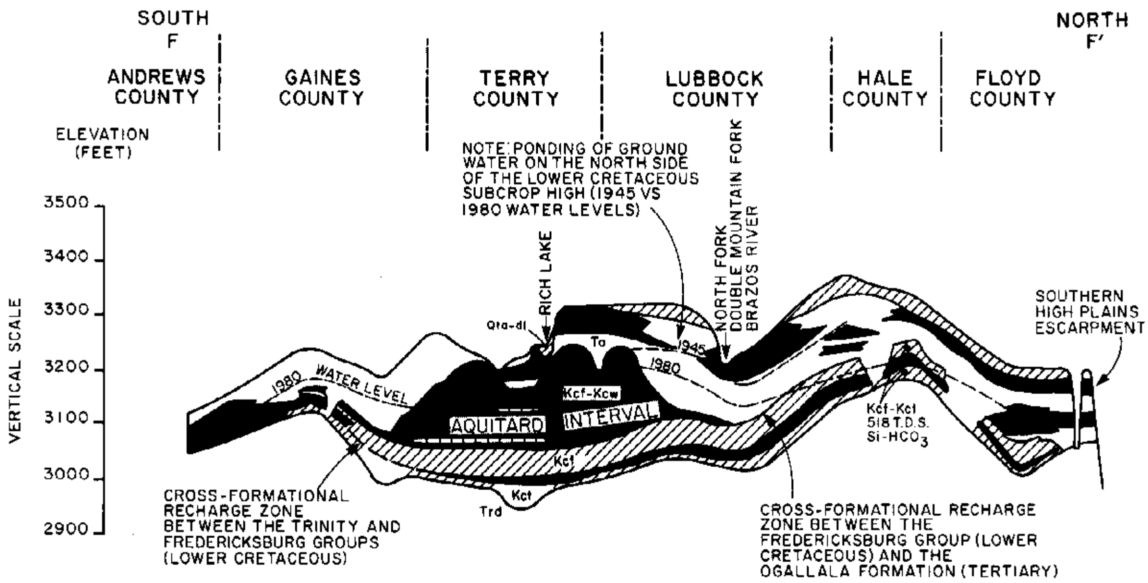


Figure 11

Facies Distribution and Ground-Water Flow Paths in the Southern High Plains Aquifer: Section F - F'

(See Figure 10 for Explanation of Symbols and Patterns)

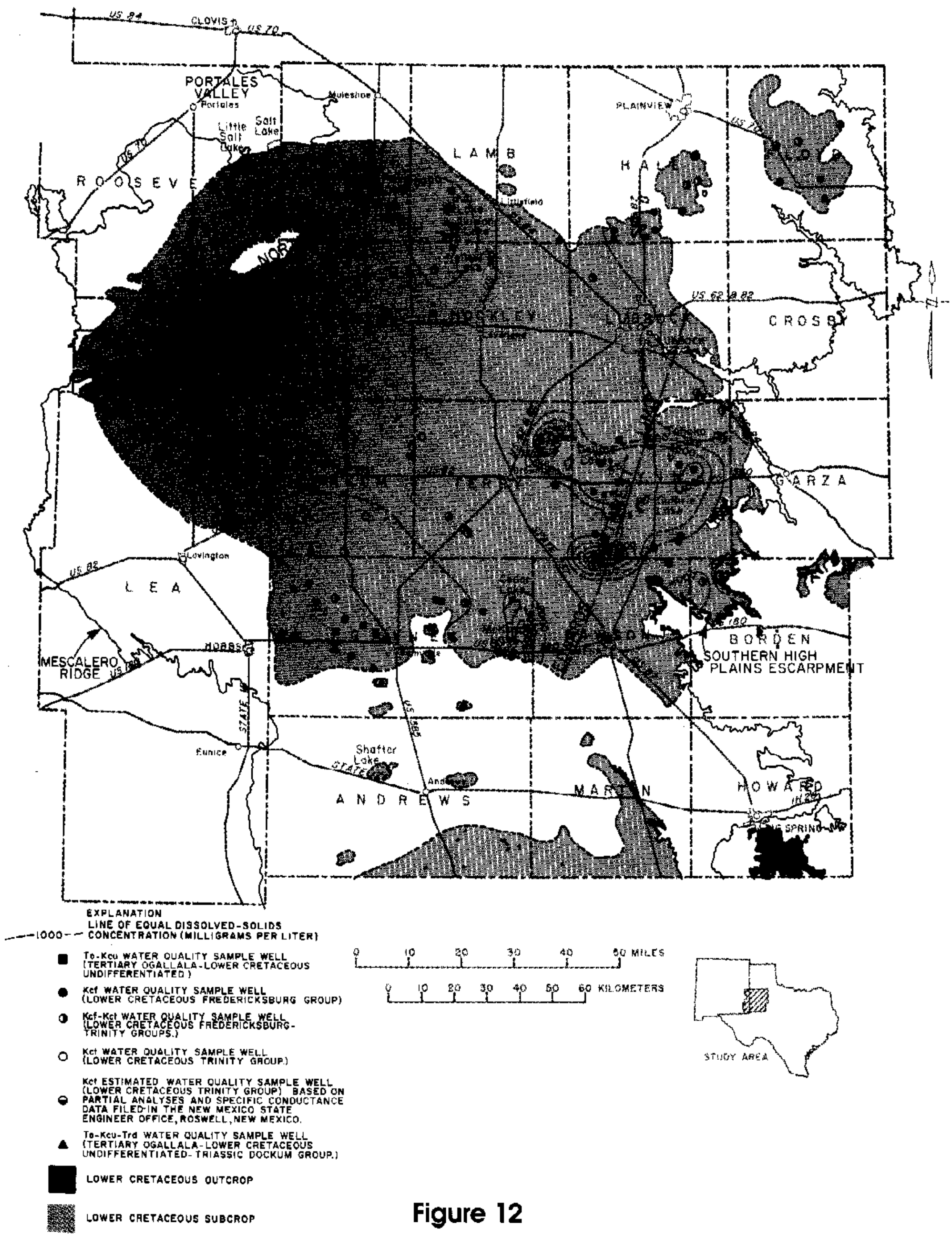


Figure 12

Water Quality Map of Lower Cretaceous Aquifers Under the Southern High Plains

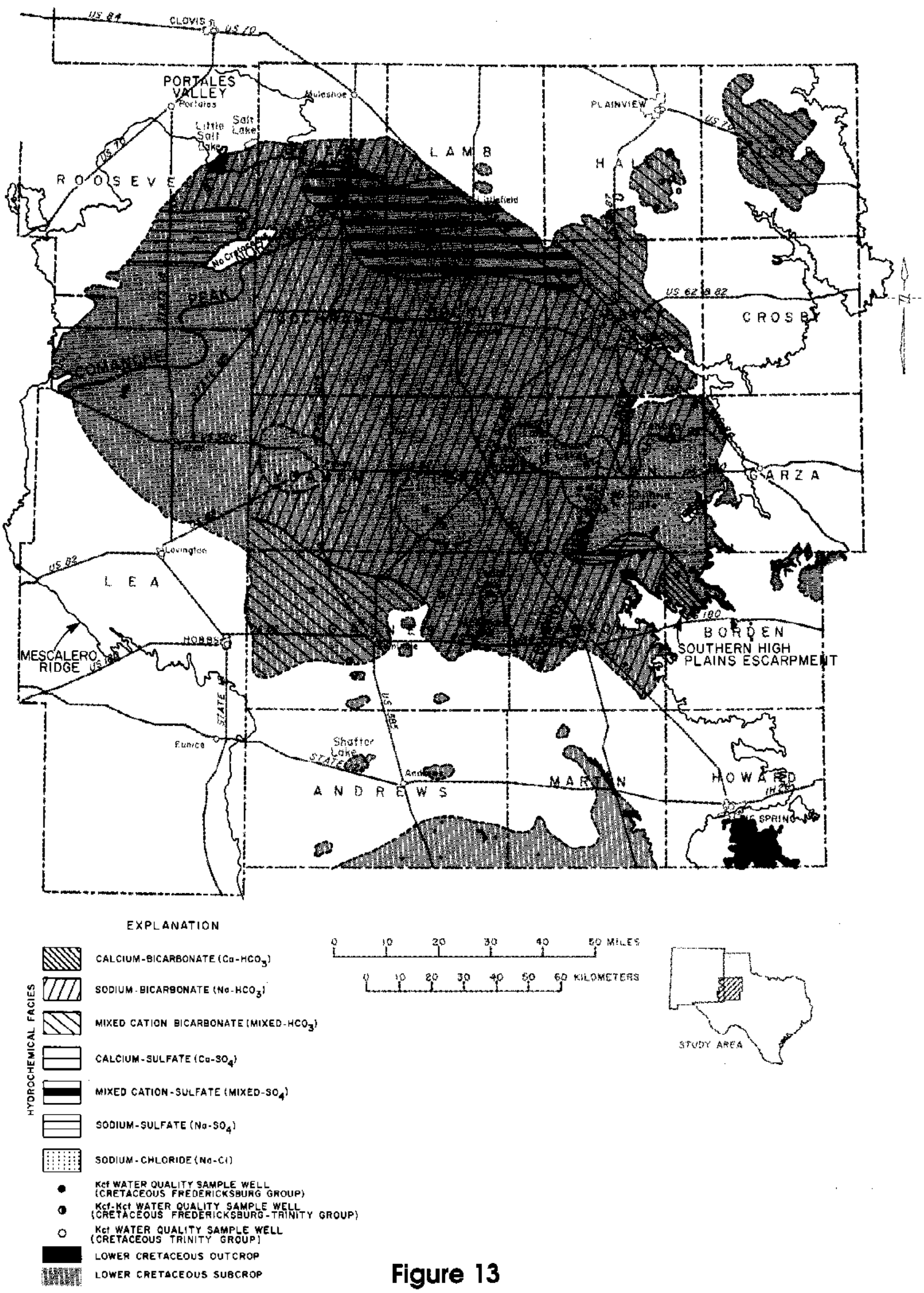


Figure 13

Generalized Hydrochemical Facies Map of Lower Cretaceous Aquifers Under the Southern High Plains

occur in erosion channels cut into the underlying Triassic section do wells generally produce more than 100 gallons per minute from the basal Lower Cretaceous aquifer.

Stratigraphically, the Antlers Formation is almost everywhere bound by underlying mudstone sequences in the Dockum Group, and by overlying clay or marl beds in the Walnut, Comanche Peak, and Kiamichi Formations. As a consequence, ground water in the formation is usually confined, and artesian pressures are common to the system. Exceptions occur in areas such as eastern New Mexico where numerous uncased seismic holes have been drilled into the Lower Cretaceous strata, allowing confined ground water to leak upward into the overlying Ogallala Formation while decreasing hydraulic pressures in the Antlers Formation below (Ash, 1963).

Regional ground-water flow through the Antlers Formation is generally to the east-southeast in conformance with regional structure dips. Calcite and more limited quartz cementation, however, influences flow patterns through certain parts of the formation, restricting and even preventing water movement at some locations. The cementation is only locally well developed, and loose sand also occurs within the stratigraphic unit. In fact, unconsolidated to only weakly cemented intervals in the basal Lower Cretaceous Formation measure more than 60 feet thick at some locations in southeast Roosevelt County, New Mexico, and in northwest Gaines County, Texas. Another factor that influences regional ground-water movement through the Antlers Formation is eroded channel courses cut into the underlying Late Triassic section. Funneling water in a sinuous east-southeasterly direction, deposits in the paleo-drainage courses are particularly well defined under parts of Lea and Roosevelt Counties, New Mexico, and under parts of Cochran, Dawson, Gaines, Lynn, and Terry Counties, Texas (Figure 2).

The Antlers Formation generally occurs 200 to 350 feet below land surface under the Southern High Plains, and wells tapping it are often dually completed in the overlying Ogallala Formation for additional yield. Actual production from wells completed solely in the Antlers Formation ranges from less than 50 to more than 1,000 gallons of water per minute in the study area, with highest yields thus far coming exclusively from wells completed in thicker-than-average sections filling erosion channels cut into the underlying Dockum Group in Roosevelt County, New Mexico.

Pump Test Data

Pump test data for wells completed in the Antlers Formation varies from location to location. The specific capacity of one well completed in the formation 10 miles south of Whiteface in Cochran County, Texas, was 1.63 gallons per minute per foot of drawdown after it was pumped for 27 hours at a rate of 150 gallons per minute in 1962 (Rayner, 1963). A cone of depression was calculated to extend several miles around the Cochran County well, and it was determined that the aquifer possesses very low recoverable artesian storage characteristics at the investigation site. Similarly, another well in Yoakum County, Texas, also indicated limited transmissivity values for the Antlers Formation, having a specific capacity of only 1.1 gallons per minute per foot of drawdown while pumping 65 gallons per minute over a period of time (Mount and others, 1967). Elsewhere, hydraulic conductivity in the formation is clearly better developed, since some wells in Roosevelt County, New Mexico, have produced as much as 1,200 gallons per minute from the Antlers for extended periods of time, then have recovered relatively quickly after pumping has ceased.

Water Quality and Chemistry

Limited analyses suggest that ground-water quality in the Antlers Formation generally ranges from fresh to slightly saline in character, and exhibits either a calcium-bicarbonate or sodium-bicarbonate hydrochemical signature. However, in areas overlain by saline lakes and where the near-surface gypsiferous Tahoka and Double Lakes Formations are present, water quality in the Antlers and in the High Plains aquifer as a whole, is diminished, with dissolved solids exceeding 6,000 mg/l in places, and either sodium-sulfate or sodium-chloride hydrochemical facies prevailing.

Regional Storage

Core, well log, and outcrop data indicate that the Antlers Formation under the Southern High Plains has an average stratigraphic thickness of 15 feet, an average porosity of 15 percent, and an areal extent of about 9,000 square miles, suggesting the formation contains approximately 12 million acre-feet of ground water. Approximately 90 percent of the aquifer underlies Texas, where the storage capacity below specific surface drainage basins is estimated as follows: Colorado River Basin, 7,348,320 acre-feet, and Brazos River Basin, 3,149,280 acre-feet. It is estimated that approximately 25 percent of all ground water stored in the Antlers Formation may be economically recoverable. Finite replenishment rates, overall formation thinness, and low coefficient of storage values will most assuredly limit any sustained, long-term production from the aquifer.

Comanche Peak and Edwards Formations

General Features

Limestone intervals in the Comanche Peak and Edwards Formations combine to form an effective aquifer system under the Southern High Plains, especially where the stratigraphic units are maximally developed along the southern and eastern edges of the study area in Borden, Dawson, Floyd, Hale, Gaines, Lubbock, and Lynn Counties, Texas. Filling solution cavities, fractures, joints, and bedding planes, ground water in the limestone formations generally flows in a southeasterly direction, sometimes issuing at springs and seeps along the eastern edge of the Southern High Plains escarpment.

Stratigraphically, the Comanche Peak-Edwards aquifer is usually underlain by the Walnut Formation, and overlain by either the Kiamichi or Ogallala Formations. Calcareous shales in the Comanche Peak and Walnut Formations generally form an effective aquiclude that separates the aquifer from artesian ground-water zones in the Antlers Formation below them. In eastern parts of the study area, sand and gravel beds in the Ogallala Formation commonly cover the limestone aquifer, making the system upwardly unconfined. The upward unconfinement permits ground water to occur under water-table conditions throughout most of the area where the aquifer is maximally developed under the Southern High Plains.

Producing intervals in the Comanche Peak-Edwards aquifer range from less than 10 to more than 60 feet thick in the study area, and wells are generally designed to accept water under open-hole or slotted-casing conditions from the entire water-yielding section upon completion. As to be expected, wells completed along zones of major fracture concentrations, or in cavernous parts of the section, yield substantially more water than wells completed in unfractured or uncavernous parts of the limestone aquifer (Figure 14). In the study area, surface lineament studies suggest that major fracture trends in the Comanche Peak-Edwards aquifer are oriented northwest-southeast, and to a lesser extent, northeast-southwest. The fracture trends are especially well developed in Bordon, Dawson, Hale, Hockley, Lubbock, and Terry Counties, Texas (Figure 14). For additional yield purposes, many wells completed in the limestones also draw water from producing intervals in the underlying Antlers Formation and overlying Ogallala Formation.

The Comanche Peak-Edwards aquifer usually occurs between 20 and 250 feet below the land surface along the eastern edge of the study area, with the shallowest parts of the system being located immediately adjacent to the Southern High Plains escarpment in Borden, Dawson, and Lynn Counties, Texas. Well yields from the reservoir range from less than 50 to more than 800 gallons per minute, with highest production having thus far come from well sites in Hale and Lubbock Counties, Texas.

Pump Test Data

Pump tests show that the specific capacity of the Comanche Peak-Edwards aquifer system varies from one locality to the next, reflecting the uneven distribution and development of cavity-prone **Rudist** facies, and other porous and permeable zones in the stratigraphic section over the study area. In Hale County, Texas, where individual well yields regularly exceed 250 gallons per minute, five separate pump tests have indicated the system's specific capacity to be 2.1, 35.3, 62.5, 22.7, and 5.9 gallons of per minute per foot of drawdown, respectively. Another pump test in Lamb County, Texas, showed a specific capacity of 2.2 gallons per minute per foot of drawdown for a well producing 65 gallons per minute from the aquifer. Also, a well completed solely in the Edwards Formation four miles east of O'Donnell on the Lynn-Dawson county line was drawn down only 0.69 foot when pumped at a rate of 810

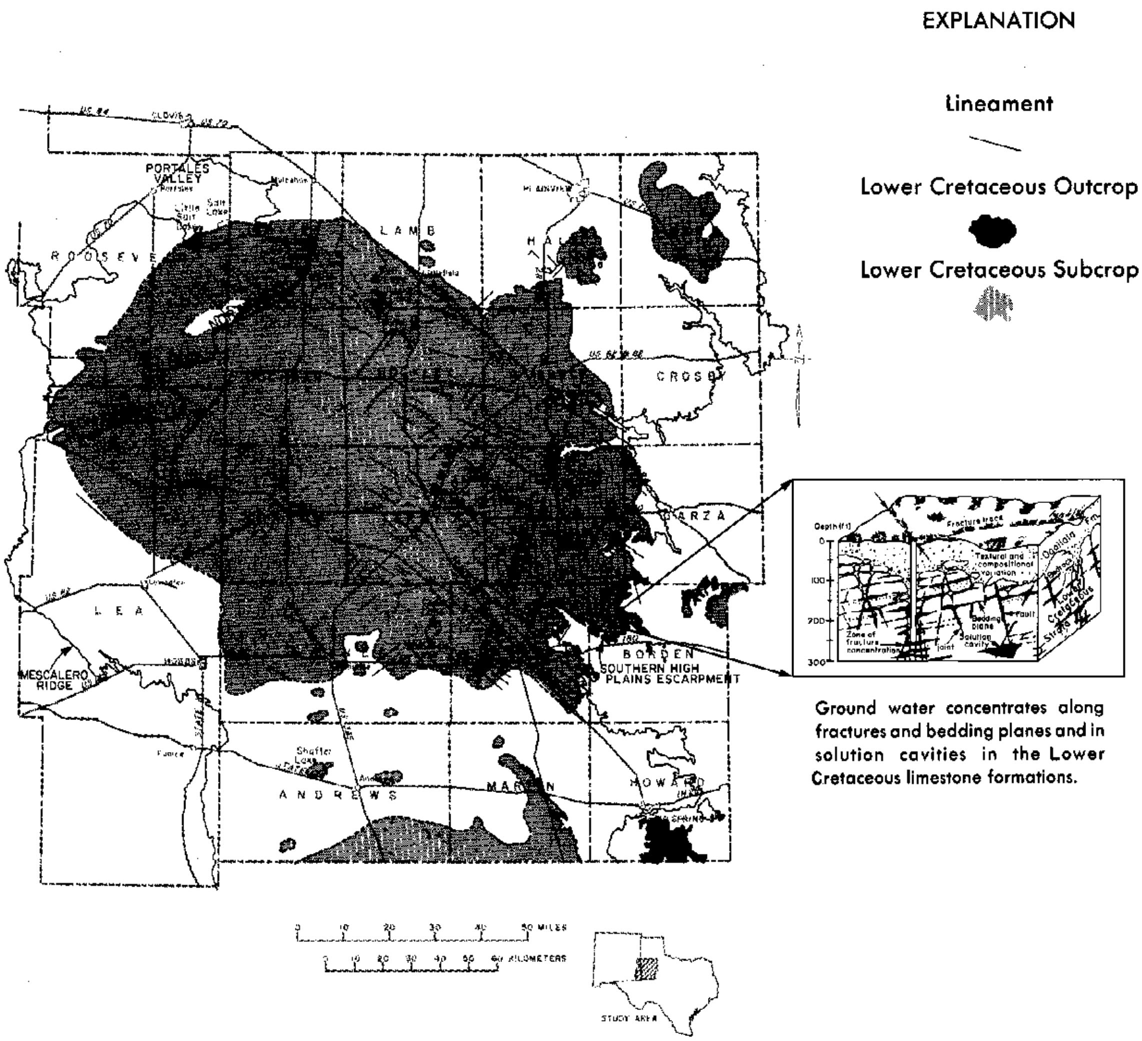


Figure 14
Study Area Surface Lineation Map, and
Block Diagram Inset Showing Ground-Water
Concentrations in Fractured Carbonate Terrain
(After Finley and Gustavson, 1981; Lattman and Parizek, 1964)

gallons per minute for an hour and twenty minutes in 1950, indicating the aquifer's local specific capacity to be 1,175 gallons per minute per foot of drawdown (Leggat, 1952). Significantly, the latter well is thought to have drawn much of its production from a cavity receiving water from the Ogallala Formation.

Water Quality and Chemistry

Ground water in the Comanche Peak-Edwards system is generally fresh to slightly saline and usually has either a mixed-cation-bicarbonate or sodium-bicarbonate hydrochemical signature. However, as in the underlying Antlers Formation, water quality in the Comanche Peak-Edwards system is diminished in areas overlain by saline lakes, and where the near-surface gypsiferous Tahoka and Double Lakes Formations are present. In northeast Gaines County, and most of Lynn County, Texas, where numerous saline lakes exist and the Tahoka and Double Lakes Formations are widespread, the amount of dissolved solids in ground water from the Comanche Peak-Edwards aquifer regularly exceeds 3,000 mg/l, with either sodium-sulfate or sodium-chloride hydrochemical facies prevailing.

Regional Storage

Core, well log, and outcrop data indicate that the Comanche Peak - Edwards system has an average saturated thickness of 20 feet and average porosity of 1.5 percent, suggesting that the aquifer stores approximately 1.5 million acre-feet of ground water in the 8,000 square mile area where it is maximally developed under the Southern High Plains. Essentially all of the effective storage underlies Texas, 95 percent (1,459,200 acre-feet) being located under the Brazos River Basin. Full aquifer storage capacity under the Colorado River Basin is estimated to be 76,800 acre-feet.

Kiamichi and Duck Creek Formations

In the south-central part of the Southern High Plains, where both the Antlers and Comanche Peak-Edwards systems are poorly developed, ground water is in places transmitted through thin limestone and sandstone beds in the Lower Cretaceous Kiamichi and Duck Creek Formations. The thin, discontinuous strata have limited yield and storage capacities, and are typically separated by thicker shale and clay intervals in the stratigraphic section. Accordingly, wells draw from multiple horizons when producing from the Kiamichi and Duck Creek Formations, with overall yield usually augmenting larger production from the overlying Ogallala Formation.

Regional Recharge and Discharge

The primary source of natural ground-water recharge to Lower Cretaceous strata under the Southern High Plains is inflow from the bounding and overlying Ogallala Formation (Figure 11). The Ogallala Formation, in turn, receives most of its water supply via infiltration of surface precipitation, and runoff that periodically fills playa lakes and other ephemeral drainage systems over the study area, a source of limited and often overdrawn supply in recent years.

Cross-formational recharge between Tertiary and Lower Cretaceous strata occurs most readily where saturated sand and gravel beds in the Ogallala Formation abut against, or overlie porous and permeable parts of the Antlers, Comanche Peak, and Edwards Formations. Saturated sand and gravel beds in the Ogallala Formation, in turn, occur most frequently in lower parts of the formation along paleovalley courses that were scoured into underlying strata in pre-Ogallala time.

Under the Southern High Plains, pre-Ogallala paleovalley courses are best developed immediately north of the Lower Cretaceous subcrop area, and to a lesser extent, over and around certain parts of the subcrop area itself. Acting as natural ground-water conduits in the High Plains aquifer, Ogallala deposits filling the paleovalley courses distribute ground water in an east-southeasterly direction to, around, and over the Lower Cretaceous subcrop (Figure 3). Subcrop exposures of the basal Lower Cretaceous Antlers Formation thus receive water directly from the Ogallala in Lea and Roosevelt Counties, New Mexico, and in Floyd, Gaines, Hale, and Lamb Counties, Texas, where the Antlers Formation is best developed. The Comanche Peak and Edwards Formations are recharged mostly along subcrop exposures in Dawson, Floyd, Hale, Lubbock, and Lynn Counties, Texas, with joints, fractures, and solution cavities providing infiltration routes through the section.

Tertiary and Lower Cretaceous ground-water aquifers under the Southern High Plains are also recharged directly and indirectly by surface water spreading basins and dual-purpose well systems. Surface water spreading basins are generally limited to areas where high-permeability sediments occur at or near the ground surface, or where major distributary channel trends are best developed in the Ogallala Formation.

Dual-purpose wells, i.e., wells designed for both subsurface injection and ground-water withdrawal purposes, provide an effective means of recharging the High Plains aquifer where low-permeability zones occur between the land surface and the regional water table. The wells are generally constructed in and around playa lake basins in order to take advantage of ponded rain water on a seasonal basis. Life spans of dual-purpose wells rarely exceed 10 years, with sediment clogging usually diminishing system effectiveness over time.

In use since the 1940's, there were as many as 200 dual-purpose recharge wells operating in and around the study area in the early 1970's, 28 being located in Borden County, Texas. Overall use of the dual-purpose well recharge system has declined in the study area since the 1970's, however, and only a few pump systems installed during the 1970's remain operative today.

Discharge from Lower Cretaceous aquifers in the study area is primarily to well heads in Texas and New Mexico, and to streams, springs, and seeps along the Southern High Plains escarpment in

Texas. Annual well pumpage from the Lower Cretaceous ground-water system is estimated to have exceeded 15,000 acre-feet in recent years, although exact figures are difficult to calculate since numerous wells over the Southern High Plains are dually completed in Lower Cretaceous and Ogallala sections, with the component yields from each being undetermined.

Springs and seeps draining from Lower Cretaceous strata in the Southern High Plains are particularly well developed in Borden County, Texas, along the Southern High Plains escarpment. There are also several springs and seeps along the North Fork Double Mountain Fork of the Brazos River that drain from Lower Cretaceous strata in Yellow House Canyon, Lubbock County, Texas. Yields from individual springs in the study area rarely exceed 10 gallons per minute, except when prolonged rainy periods over the plains rejuvenate local systems briefly.

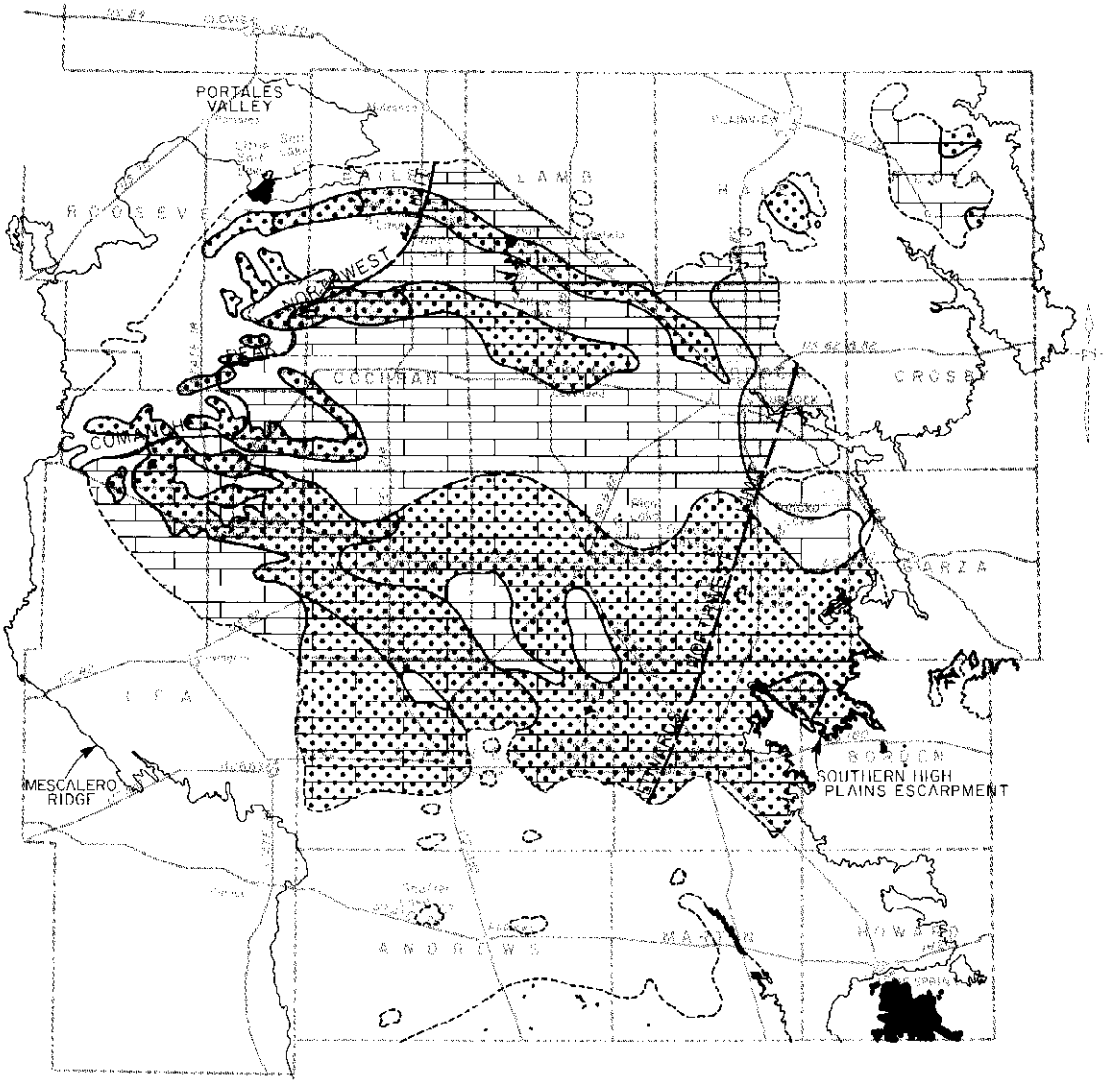
Significantly, Lower Cretaceous strata also discharge some ground water into other, bounding formations. In Floyd County, Texas, the Lower Cretaceous subcrop is completely surrounded by saturated, coarse-grained Ogallala deposits. As ground water flows from the Ogallala deposits into porous updip intervals of the Lower Cretaceous section, it continues to move downdip, ultimately to flow back into the Ogallala system once again. Vertical leakage into the underlying Dockum Group also occurs at isolated locations, particularly in parts of Borden, Cochran, Dawson, Floyd, and Yoakum Counties, Texas, and in Lea and Roosevelt Counties, New Mexico, where coarse-grained fluvial-deltaic deposits occur in upper parts of the Late Triassic section.

Utilization and Development

Wells completed in the Lower Cretaceous section under the Southern High Plains supply water for a number of different surface uses. Of 250 located wells in the study area, 30 are listed as domestic or stock wells, 35 as industrial wells (used primarily to augment waterflood projects in West Texas oilfields, and to supply glauber and epsom salt mining operations), and 180 as irrigation wells. The communities of Seminole in Gaines County, Wellman in Terry County, Abernathy in Hale County, and O'Donnell in Lynn County, Texas, also draw part of their public water supply from wells completed in the Lower Cretaceous section, as do various residents and public schools in the Causey Lingo area of Roosevelt County, New Mexico.

Spread widely over the study area, wells drawing from Lower Cretaceous strata under the Southern High Plains are mostly concentrated in parts of Floyd, Gaines, Hale, and Lynn Counties, Texas, and in the Causey-Lingo area of Roosevelt County, New Mexico. Undeveloped areas showing potential for further development include parts of Bailey, Cochran, Gaines, and Yoakum Counties, Texas, and northern areas in Lea County, New Mexico, where the basal Lower Cretaceous Antlers Formation fills erosional channels cut into the underlying Dockum Group (Figure 15). Also, the

Comanche Peak-Edwards-Antlers aquifer system appears to have potential for further development in east-central Lubbock and northeast Lynn Counties, Texas, where fresh-water recharge occurs directly by downward percolation from the overlying Ogallala Formation and by lateral infiltration of Ogallala waters along the deeply eroded and buried Slaton channel course (Figure 15).



EXPLANATION

- Antlers Formation present and estimated to be over 20 feet thick
- Comanche Peak Formation present
- Edwards and Comanche Peak Formations present
- Area where Lower Cretaceous aquifer is relatively undeveloped, where Lower Cretaceous water quality is generally fresh, and where Lower Cretaceous well yields will probably exceed 200 gal/min
- Lower Cretaceous Outcrop

Figure 15

Map Showing the Areal Extent of Lower Cretaceous Aquifers Under the Southern High Plains, With Underdeveloped Areas Having Potential Fresh Ground-Water Reserves Highlighted

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