Chapter 11

The Geology and Hydrogeology of the Capitan Aquifer: A Brief Overview

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Introduction

The Capitan aquifer occurs in the Capitan Reef Complex, an ancient reef that formed around the margins of the Delaware Basin (fig. 11-1) (Ashworth and Hopkins, 1995). The Delaware Basin was an embayment covered by a shallow sea that persisted throughout most of the Permian. Most of the reef complex was buried by tectonism and subsequent sedimentation; however, relatively undeformed remains of the reef are exposed in West Texas and New Mexico, with exceptional exposures in Guadalupe Mountains National Park (Bebout and Kerans, 1993). Remnants of the reef are also exposed in the Apache and Glass Mountains of West Texas.

This paper provides a brief overview of the structural history and stratigraphy of the Delaware Basin. The hydrostratigraphic relations between the Capitan Reef Complex and the other basin facies are also discussed. Groundwater occurrence and flow within the Capitan Reef Complex, as well as water-quality trends, are also addressed.

Delaware Basin Structural History

During the Early Pennsylvanian Period, the North American and South American plates slammed into each other in a tectonic train wreck known as the Ouachita collision (Muehlberger and Dickerson, 1989). This event was responsible for the formation of a regional structure called the Ouachita-Marathon fold-thrust belt (fig. 11-2), which formed the southern shore of the Delaware Basin. Structurally high areas called the Diablo and Central Basin Platforms flanked the east and southwest edges of the basin. After convergence of the North and South American plates ceased in the Early Permian, extensive deposition of carbonates and siliciclastics occurred throughout the remainder of the Permian. In the later part of the Permian, the basin was cut off from the ocean, and evaporite deposition filled in the basin. By the latest Permian, the shallow seas that

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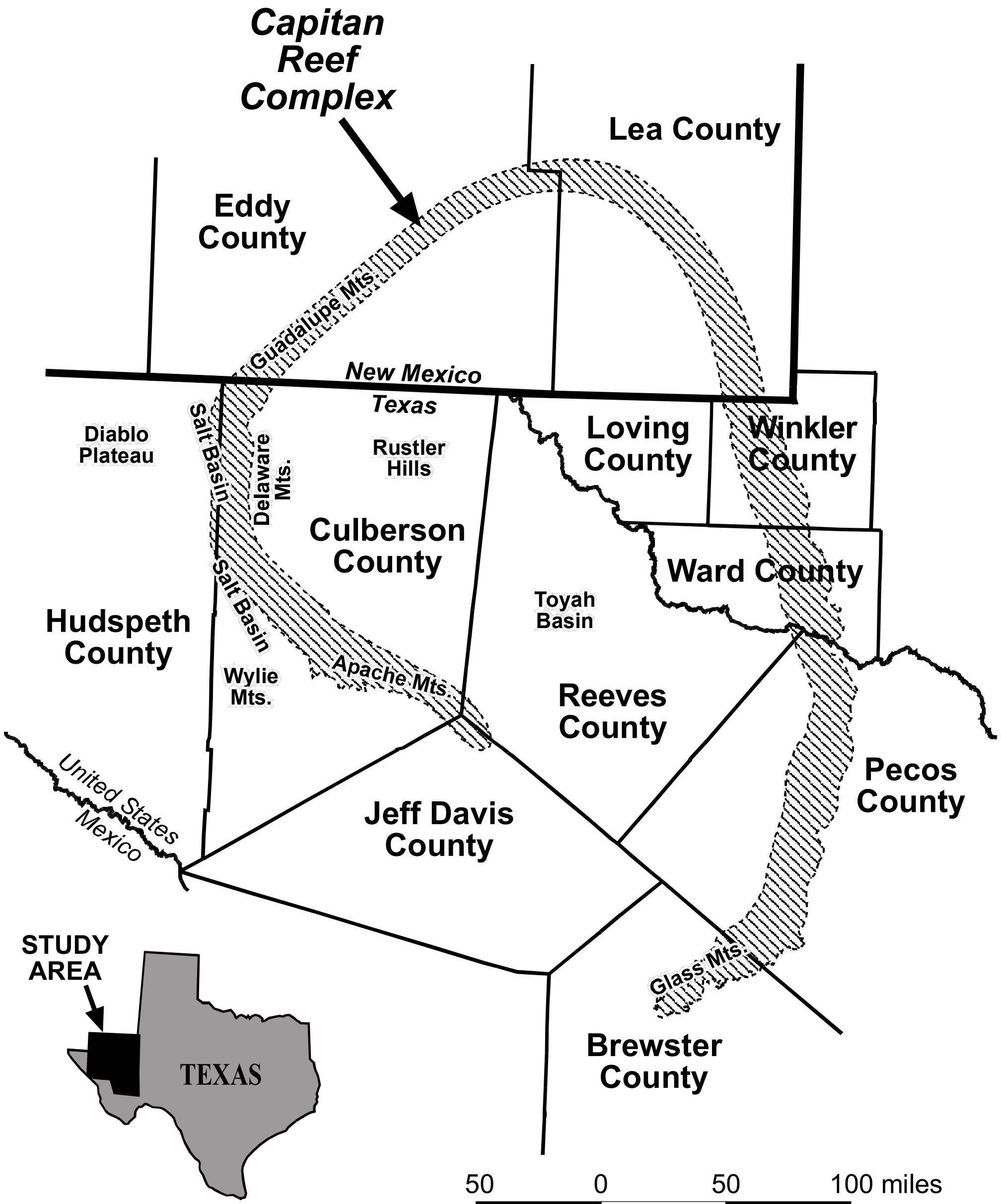

Figure 11-1: Location of the Capitan Reef Complex in western Texas and New Mexico (modified from Ashworth and Hopkins, 1995, and Dutton and others, 1999).

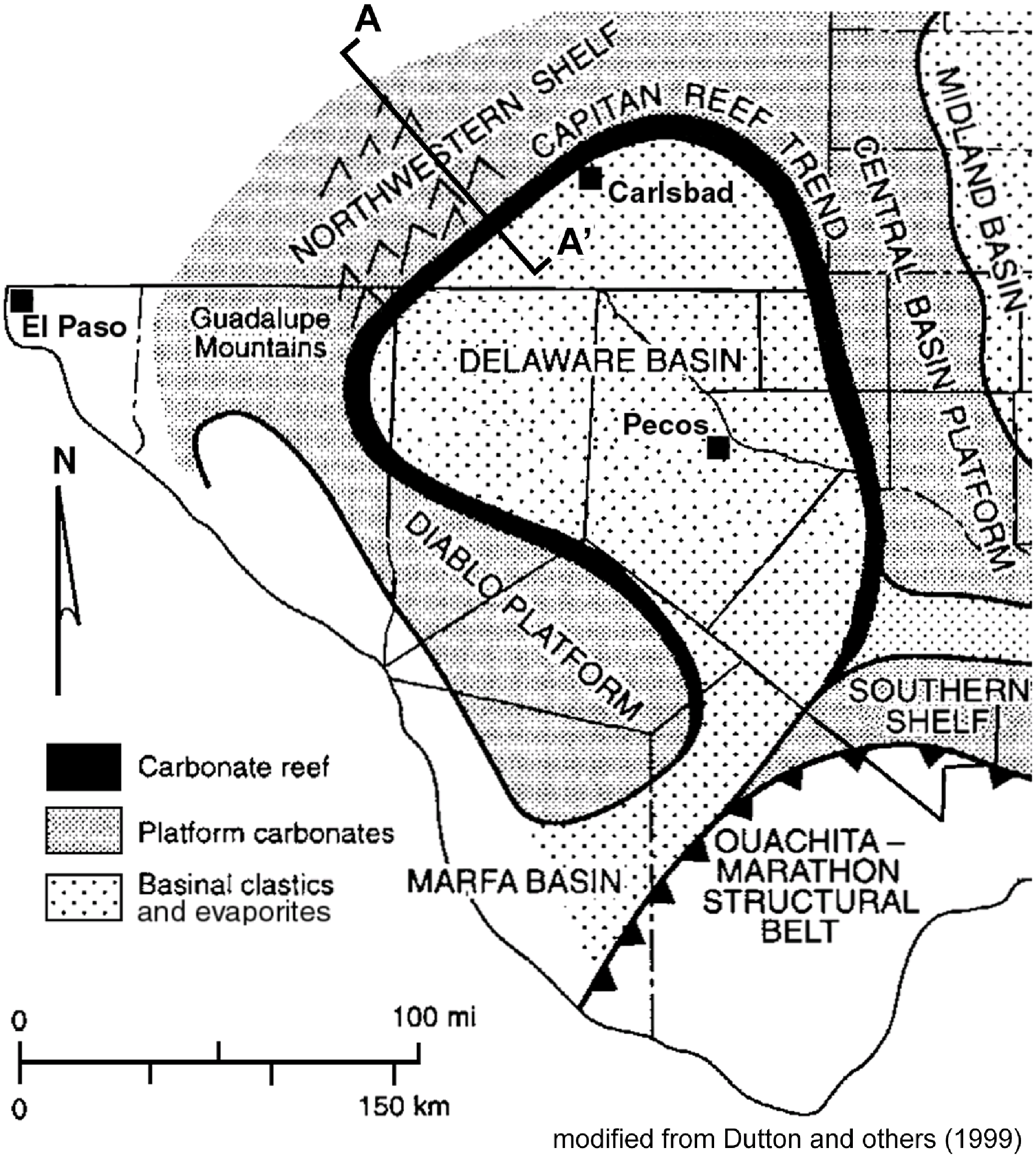

Figure 11-2: Paleogeographic setting of the Delaware Basin during the Late Permian.covered the region had completely withdrawn, and significant deposition of sedimentary strata would not occur in this area again until the Cretaceous.

Delaware Basin Hydrostratigraphy

The Permian strata in the study area are divided into four series—the Wolfcampian, Leonardian, Guadalupian, and Ochoan (fig. 11-3). These series can be subdivided into three hydrostratigraphic facies on the basis of location relative to the center of the basin (fig. 11-4) (Hiss, 1975). The Capitan aquifer is composed of Guadalupian shelf-margin reef facies that include the Capitan Formation, parts of the Goat Seep Formation, and the Carlsbad Formation (Hiss, 1980). High primary porosity, high permeability, and extensive karst mark the reef facies of the Guadalupian.

The Leonardian and Wolfcampian shelf units of the Victorio Peak Limestone, Goat Seep Formation, and the Carlsbad Formation constitute the shelf aquifers (Hiss, 1980). The shelf facies are generally characterized by highly variable fracture-dependent permeability.

The Guadalupian and Ochoan basin facies of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations of the Delaware Mountain Group make up the basin aquifers (Hiss, 1980). These units are primarily siliciclastic fill deposited in the Delaware Basin and generally have much lower well yields and poorer water quality than the Capitan. Evaporites (anhydrite and gypsum) and some carbonates associated with the Castile and Rustler Formations and the Dewey Lake Redbeds of the Ochoan Series overlie the Guadalupian rocks in the Rustler Hills.

Hydraulic Parameters and Water Occurrence

Transmissivities averaging 0.0624 ft^2/s (0.0058 m^2/s) (Gates and others, 1980) and as high as 0.1872 ft^2/s (0.0174 m^2/s) (Reed, 1965) have been measured in the Capitan aquifer. The high primary porosities and permeabilities of the reef facies are most likely augmented by extensive karstification, as exemplified in Carlsbad Caverns in southeastern New Mexico. In the Guadalupe Mountains of New Mexico, the aquifer is capable of providing large quantities of fresh water and is a significant water source for the City of Carlsbad (Ashworth and Hopkins, 1995). However, water quality throughout the reef facies in Texas is generally poor (Armstrong and McMillion, 1961; White, 1971; Richey and others, 1985).

Wells drilled into the Permian shelf facies exhibit highly variable yields, suggesting that permeability in the shelf aquifer units is dependent on fracture and karst porosity (Nielson and Sharp, 1990; Mayer and Sharp, 1998). High well yields and good water quality in the shelf facies are associated with regional fracture trends (Mayer and Sharp, 1998). Average transmissivities of wells drilled into cavernous zones in the shelf facies have been reported at 0.247 ft^2/s (0.023 m^2/s) (Davis and Leggat, 1965) and 0.387 ft^2/s (0.036 m^2/s) (Scalapino, 1950). However, the shelf facies generally are lower permeability and tend to yield lower quality water than do the reef facies.

		Diablo Plateau	Guadalupe Mts.	Rustler Hills/ Delaware Mts.	Wylie Mts.	Apache Mts.
PERMIAN	Ochoa			Castile Fm		
				Rustler Fm.		
				Castile Fm.		
				Dewey Lake Redbeds		
	Guadalupe		Carlsbad Fm. / Capitan Fm.	undivided: Bell Canyon Fm.		Tansill Fm. / Yates Fm. / Seven Rivers Fm. / Capitan Fm.
		Goat Seep Fm.	Goat Seep Fm.	Cherry Canyon Fm.		Munn Fm.
			Brushy Canyon Fm.	Brushy Canyon Fm.		
	Leonard	Cutoff Shale	Cutoff Shale			
		Victorio Peak Ls.	Victorio Peak Ls.		Victorio Peak Ls.	Victorio Peak Ls.
		Bone Springs Fm.	Bone Springs Fm.	Bone Springs Fm.	?	
	Wolfcamp	Hueco Ls.				

Figure 11-3: Stratigraphy of the Permian Delaware Basin.

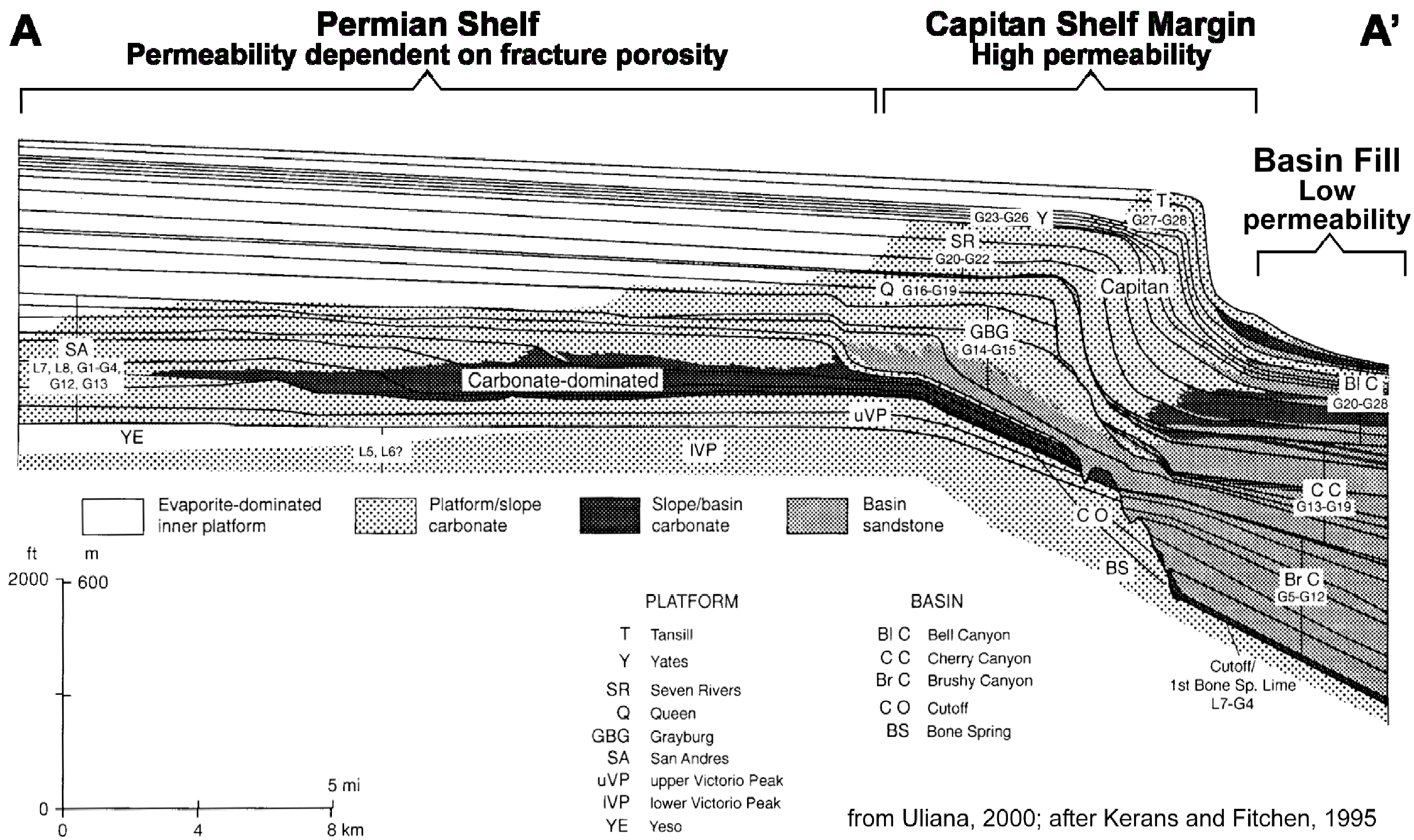

Figure 11-4: Generalized cross section of Delaware Basin showing the stratigraphic relationship between the three hydrostratigraphic facies (cross-section location shown on figure 11-2).

Basin sediments deposited during the Permian form aquifer units with low permeabilities, poor-quality water, and low well yields that range from 5 to 20 gpm (0.003 to 0.0012 m^3/s). The average hydraulic conductivity of the basin-fill facies is generally one to two orders of magnitude lower than the reef facies (Hiss, 1980; Nielson and Sharp, 1985), and the quality of water in the basin facies is generally much lower than the reef facies (Hiss, 1980).

Published transmissivity values from wells in the Delaware Basin are presented in table 11-1.

Hydraulic Gradients and Groundwater Flow Paths

Hiss (1975, 1980) looked at the movement of groundwater in the Delaware Basin strata and examined the relationship between flow in the Capitan aquifer and in the surrounding basin and shelf facies. In general, groundwater flow in the basin and shelf facies is primarily toward the east. The high permeability of the Capitan aquifer results in concentrated flow along the trend of the reef, generally toward the north and northeast. Following uplift of the Guadalupe and Glass Mountains and before the excavation of the Pecos River Valley, flow in the Capitan aquifer was north and east to a main discharge point near present-day Hobbs, New Mexico (fig. 11-5a). Water exiting the Capitan aquifer discharged into the San Andres Limestone, where it then moved eastward to eventually discharge into streams draining to the Gulf of Mexico.

Following the deposition of the Ogallala Formation, the Pecos River Valley began to form across the Capitan Reef trend. The river valley eroded into the Permian and developed a hydraulic connection with the aquifer and eventually incised deep enough to drain water from the aquifer and reverse flow paths in the aquifer between Hobbs and Carlsbad, New Mexico (fig. 11-5b). Draining of the Capitan aquifer by the river also changed the hydraulic gradients and flow paths in the shelf and basin facies surrounding the aquifer. Development of the petroleum and groundwater resources in the area during the last 70 yr has drained additional water from the Capitan aquifer and has affected the gradients so much that the original terminal discharge area is now bypassed (fig. 11-5c).

West of the Apache and Guadalupe Mountains, the Capitan aquifer has been displaced into the subsurface by faulting and covered by up to 750 m of alluvial sediment in the Salt Basin. Kreitler and others (1990) speculated that groundwater in the Diablo Plateau of Hudspeth County may be flowing toward the southeast through the reef facies at depth.

Neilson and Sharp (1985) suggested that the high-permeability reef facies of the Capitan aquifer may provide a conduit for regional water flow through the Apache Mountains into the Toyah Basin. Although the geochemical and isotopic evidence presented by Uliana (2000) and Uliana and Sharp (2001) supports the regional-flow hypothesis, cross sections of the Apache Mountains published by Wood (1965) (fig. 11-6) indicate that the exposed reef facies are above the water table and that flow is most likely in fractures in the underlying basin facies.

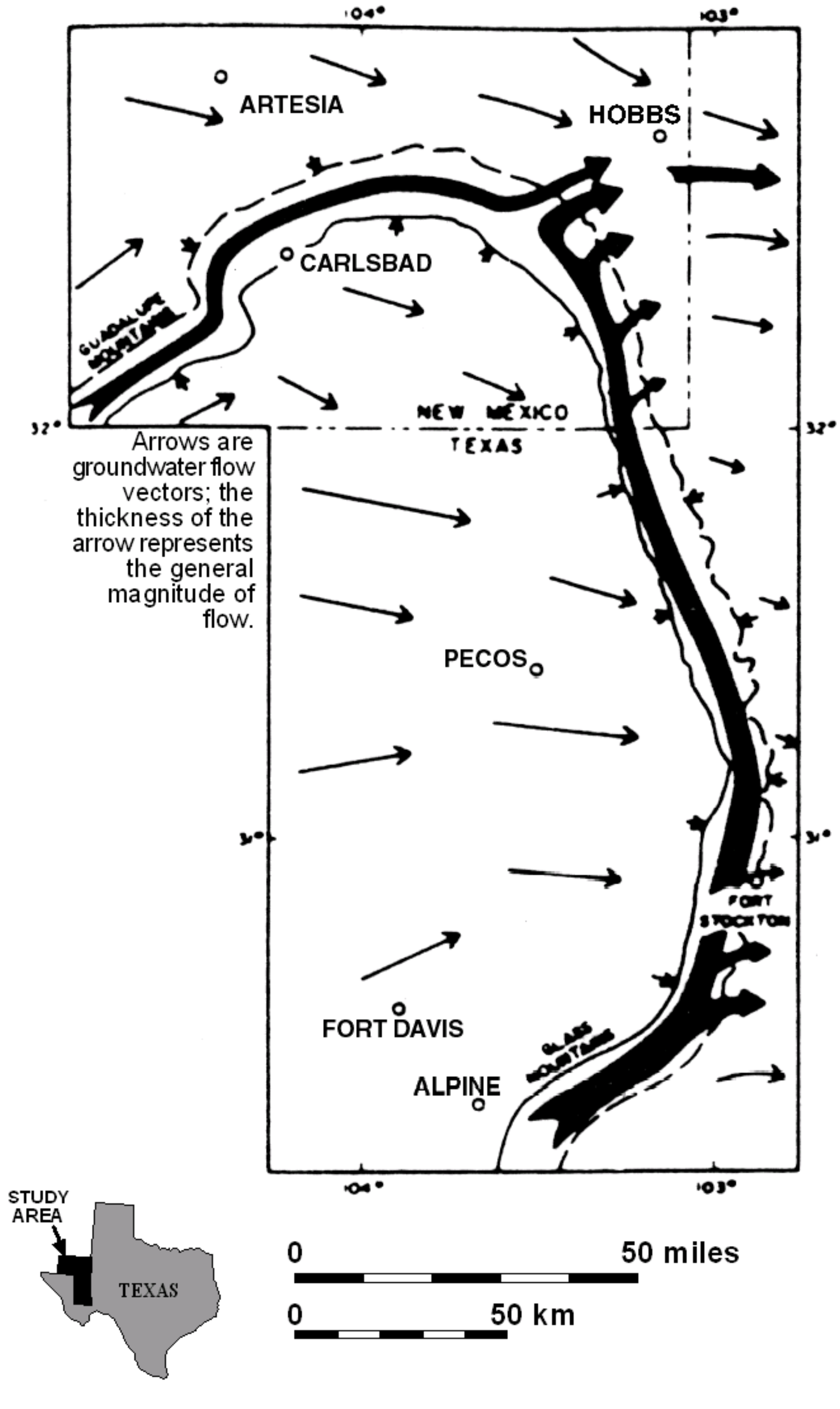

Figure 11-5a: Groundwater flow regimen prior to incision of the Pecos River and development of the oil and groundwater in the Delaware Basin (from Hiss, 1980).

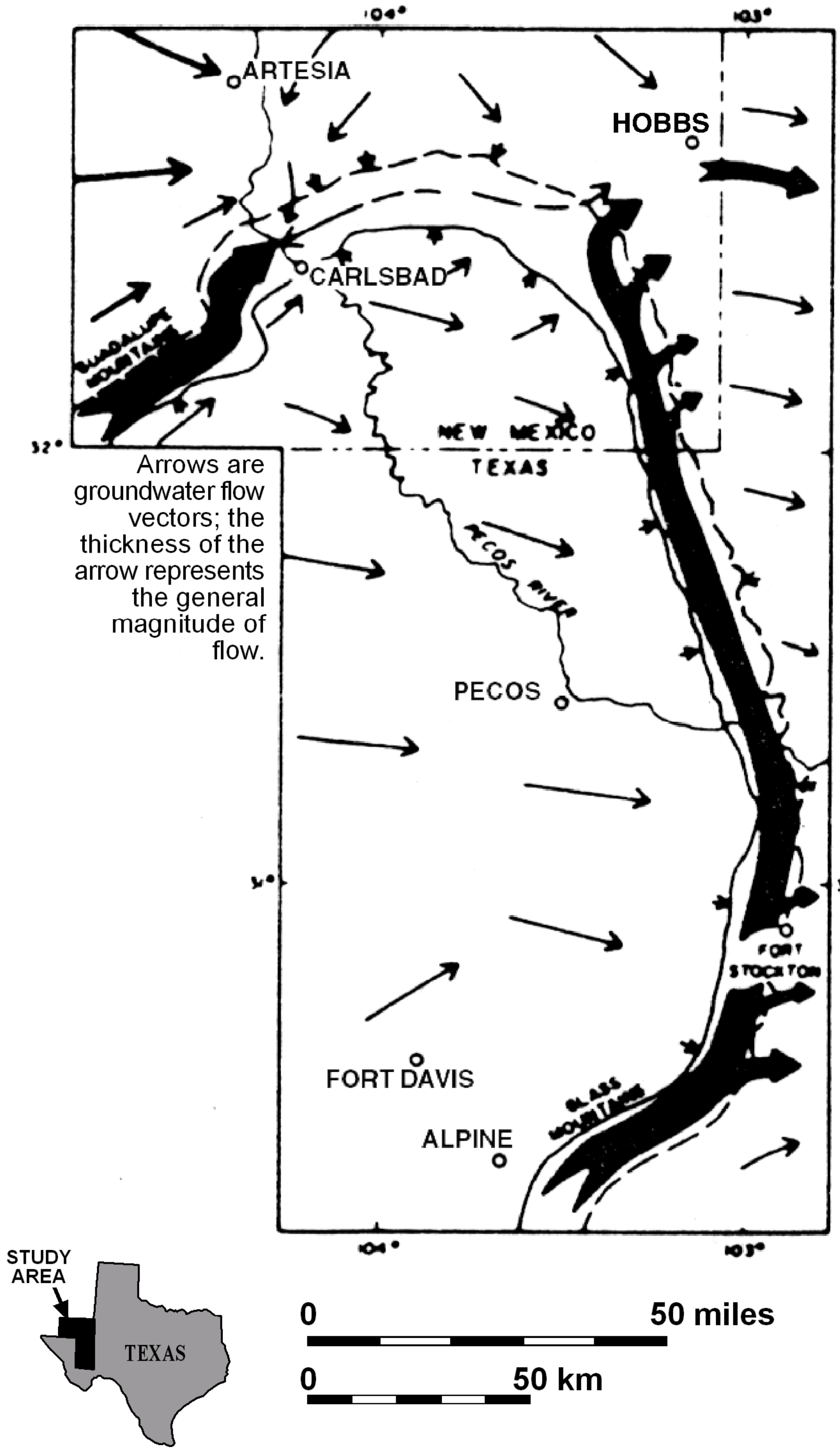

Figure 11-5b: Groundwater flow regimen influenced by incision of the Pecos River at Carlsbad into hydraulic communication with the Capitan aquifer (from Hiss, 1980).

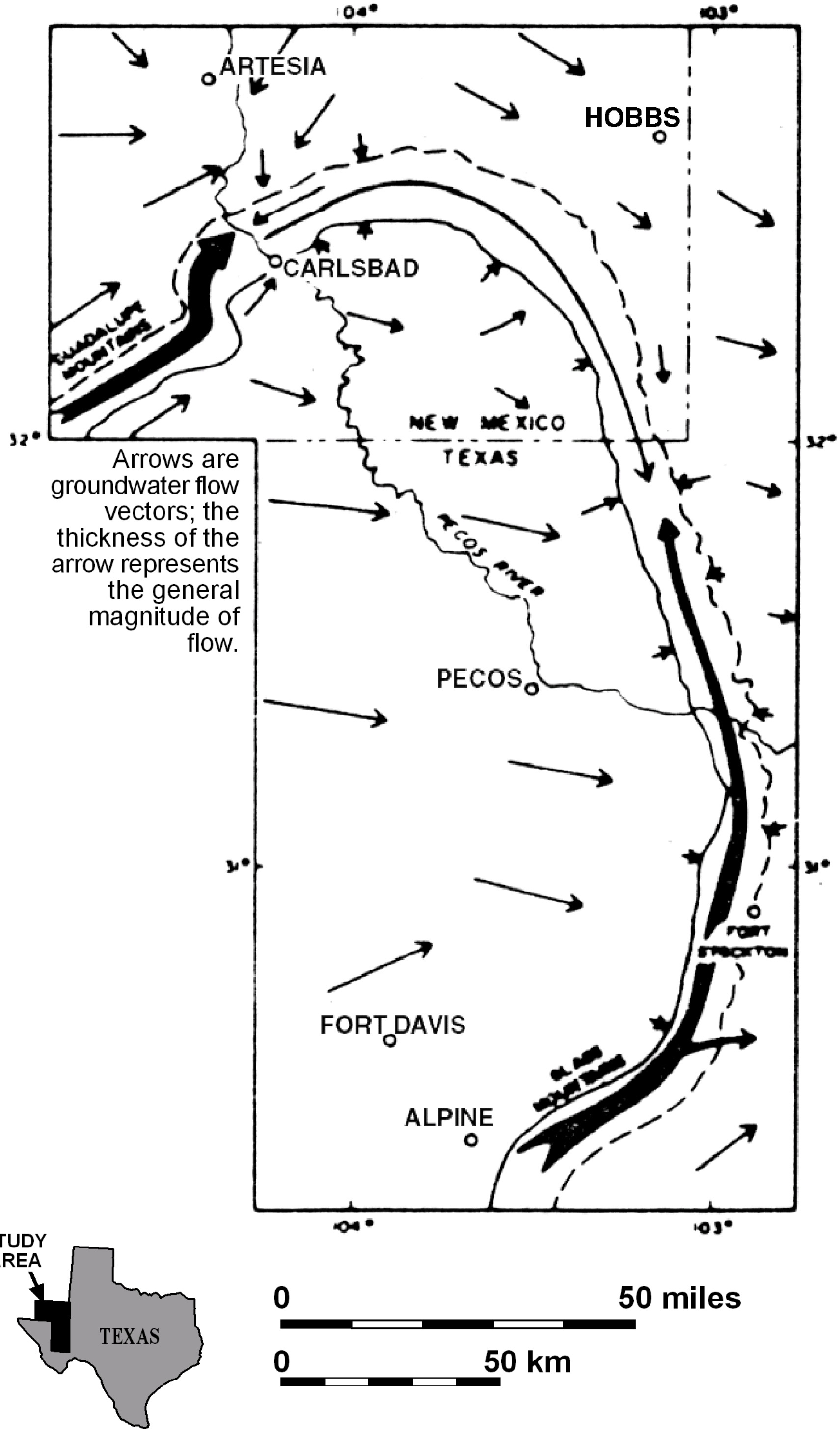

Figure 11-5c: Groundwater flow regimen influenced by both incision of the Pecos River and exploitation of oil and groundwater in the Delaware Basin (from Hiss, 1980).

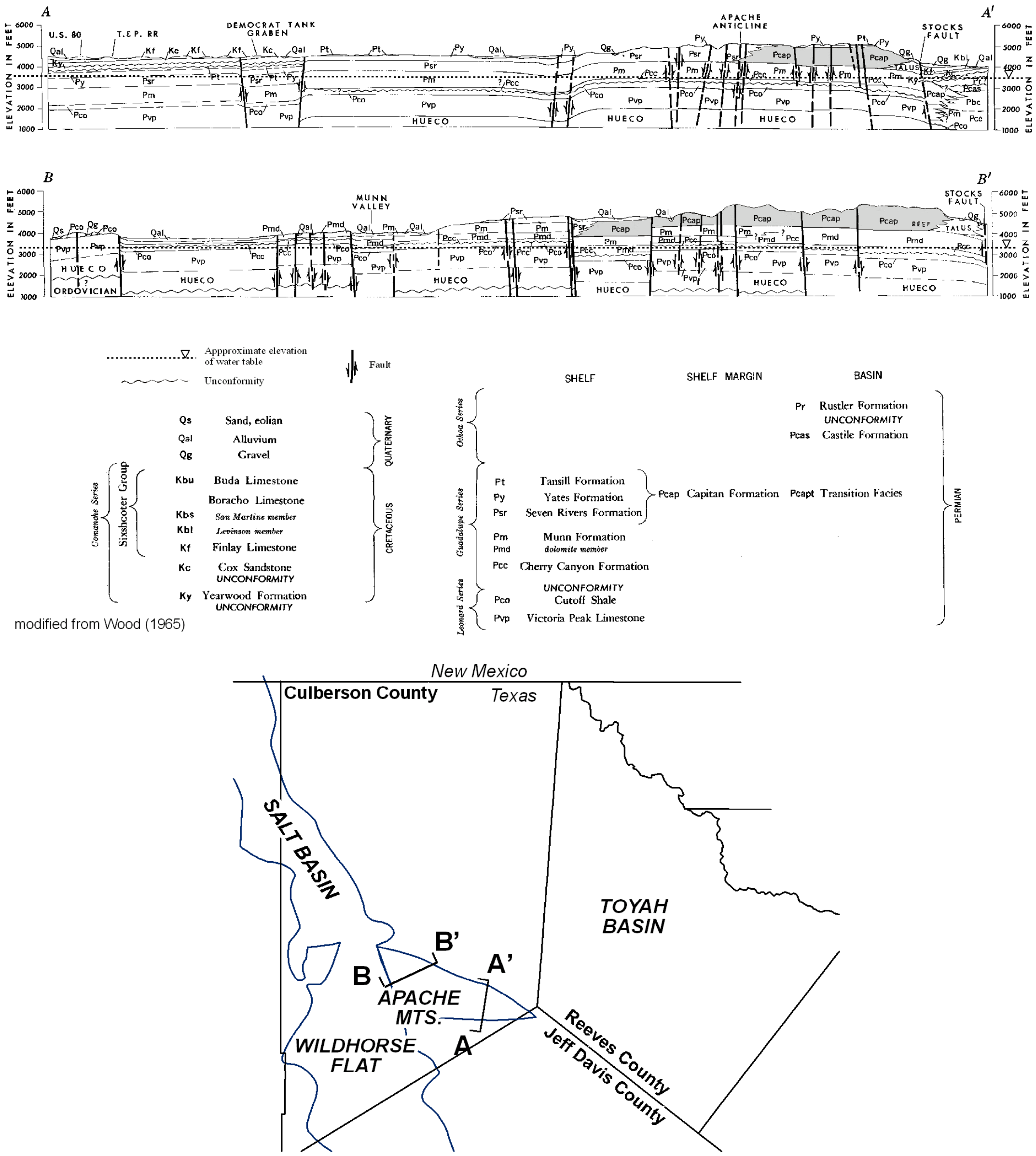

Figure 11-6: Apache Mountains cross sections showing the Capitan Reef facies and groundwater levels (water levels from Sharp, 1989).

Water Quality

The aquifer generally contains water of poor quality and yields small to large quantities of moderately saline to brine water. Analysis of water samples from 17 reef facies wells in Texas indicates an average total dissolved solids concentration (TDS) of 3,059 mg/L and an average chloride concentration of 881 mg/L (Brown, 1997). These samples also indicate that the primary constituents are sodium, chloride, and sulfate. Because of the low quality, water pumped from the Capitan aquifer in Texas is primarily used for oil-reservoir waterflooding operations in Ward and Winkler Counties, with a small amount used for irrigation of salt-tolerant crops in Pecos and Culberson Counties (Ashworth and Hopkins, 1995). Water of the freshest quality is located on and near areas of recharge where the reef is exposed at the surface in the Guadalupe and Glass Mountains. The city of Carlsbad, New Mexico, uses Capitan water for a municipal supply.

Conclusions

The Capitan aquifer is the remains of a vast reef that surrounded the Delaware Basin during the Permian. Permeability and well yields are generally high, but water quality tends to be too poor for municipal or irrigation use. The exception is in the areas where the reef is exposed, such as the Guadalupe Mountains of New Mexico. The regional flow paths in the aquifer have been affected by incision of the Pecos River and by development of the groundwater and petroleum resources in the area. The water is primarily sodium-chloride-sulfate water with an average TDS greater than 3,000 mg/L.

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