Final Report

Characterization of Bedded Salt for Storage Caverns—A Case Study from the Midland Basin, Texas

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ABSTRACT

The geometry of Permian bedded salt in the Midland Basin is a product of interaction between depositional facies and postdepositional modification by salt dissolution. Mapping high-frequency cycle patterns in cross section and map view using wireline logs documents the salt geometry. Geologically based interpretation of depositional and dissolution processes provides a powerful tool for mapping the geometry of salt to assess the suitability of sites for development of solution-mined storage caverns. In addition, this process-based description of salt geometry complements existing data about the evolution of one of the best-known sedimentary basins in the world, and can serve as a genetic model to assist in interpreting other salt basins.

Solution-mined caverns in salt in the Midland Basin Salado Formation are low-cost, large-volume storage facilities used for chemical feedstock . Caverns are also created when salt is dissolved to produce NaCl brine for drilling mud and other applications. Recently, solution-mined caverns have been used for disposal of oil-field wastes. This log-based regional analysis of salt character provides basic descriptive information on the geometry of salt needed to site and regulate the development, use, and decommissioning of these facilities in the context of an exploration of facies relationships and implications for depositional history in this part of the Permian Basin.

Three regional trends are recognized in the Permian Salado Formation of the Midland Basin. (1) The thickest (700 ft of net salt) and most extensive salt units in the lower part of Salado Formation shows a strong and consistent regional thickening toward the southwest across the Central Basin Platform toward the Delaware Basin, reflecting accommodation because of subsidence in the Delaware Basin depocenter. Typical salt beds (10 to 30 ft thick) are interbedded with mudstone and mud-salt beds (3 to 10 ft thick). Anhydrite beds (2 to 30 ft thick) separate the salt-mudstone units into 5 to 10 intervals (50 to 350 ft thick). (2) Toward the upper part of the Salado Formation, salt beds are variable in thickness, discontinuous in lateral extent, and pinch out toward the Midland Basin margins. This geometry is interpreted as the result of complex

depositional patterns that developed toward the end of basin filling as well as salt dissolution beneath the sequence boundaries preceding and following Alibates deposition. (3) Salt beds have been thinned as a result of ongoing postdepositional dissolution toward the east structural margin of the Midland Basin where salt is near the surface.

Focused salt dissolution is noted in four areas: (1) over the structural high at the south end of the Central Basin Platform, (2) on the south side of the Howard–Glasscock high; (3) from both the top and the bottom of the Salado salt over the Capitan Reef rimming the Delaware Basin, and (4) over the southern Central Basin Platform structural high in the modern Pecos valley. This fourth relationship is attributed to localization of the drainage in depressions caused by enhanced salt dissolution where salt is at shallow depth.

INTRODUCTION

Bedded salt is a geologic resource used internationally to host large underground storage facilities. Large caverns can be created economically by solution mining. In Texas, 648 solution-mined caverns are currently licensed, with about 200 in bedded salt areas (Seni and others, 1995). The Railroad Commission's records for 78 of these caverns in the Midland Basin were examined during this study. Storage caverns are used by the chemical and petrochemical industry for storage of product and chemical feedstock. Exploration for sites for cavern development continues, with emphasis on locating suitable salt near facilities such as pipelines and industrial users. Other caverns have been created only to extract brine used by drilling and chemical industries. In addition, salt caverns have been licensed for subsurface disposal of oil-production waste in the Midland Basin..

Salt is a unique host material for cavern development because its solubility in water permits low-cost, highly flexible, and rapid creation of caverns. Brine resulting from the mining can be sold as a product. Salt has very low permeability, making it an ideal medium for containment of stored materials. If material should leak from the cavern, transport away from the facility would generally be slow. Preservation of soluble bedded salt over geologic time demonstrates the relatively inactive hydrologic setting

Salt is deposited as horizontal beds but, in some settings, deformation forms salt diapirs (Jackson, 1997). In Texas, the two main types of salt available to host caverns are piercement domes of the Gulf Coast and East Texas Basin and bedded salt in the Permian Basin of the Texas Panhandle (fig. 1). In this study, I describe the characteristics of bedded salt in the Midland Basin, one of the sub-basins of the Permian Basin (fig. 2).

The characteristics of bedded salt and domal salt are quite different. Typical Texas domal salt in the East Texas and Gulf Coast basins is derived from the Jurassic Louann Salt and is relatively pure and homogeneous, however , the lateral extent of domes is limited. Domal salt has flowed

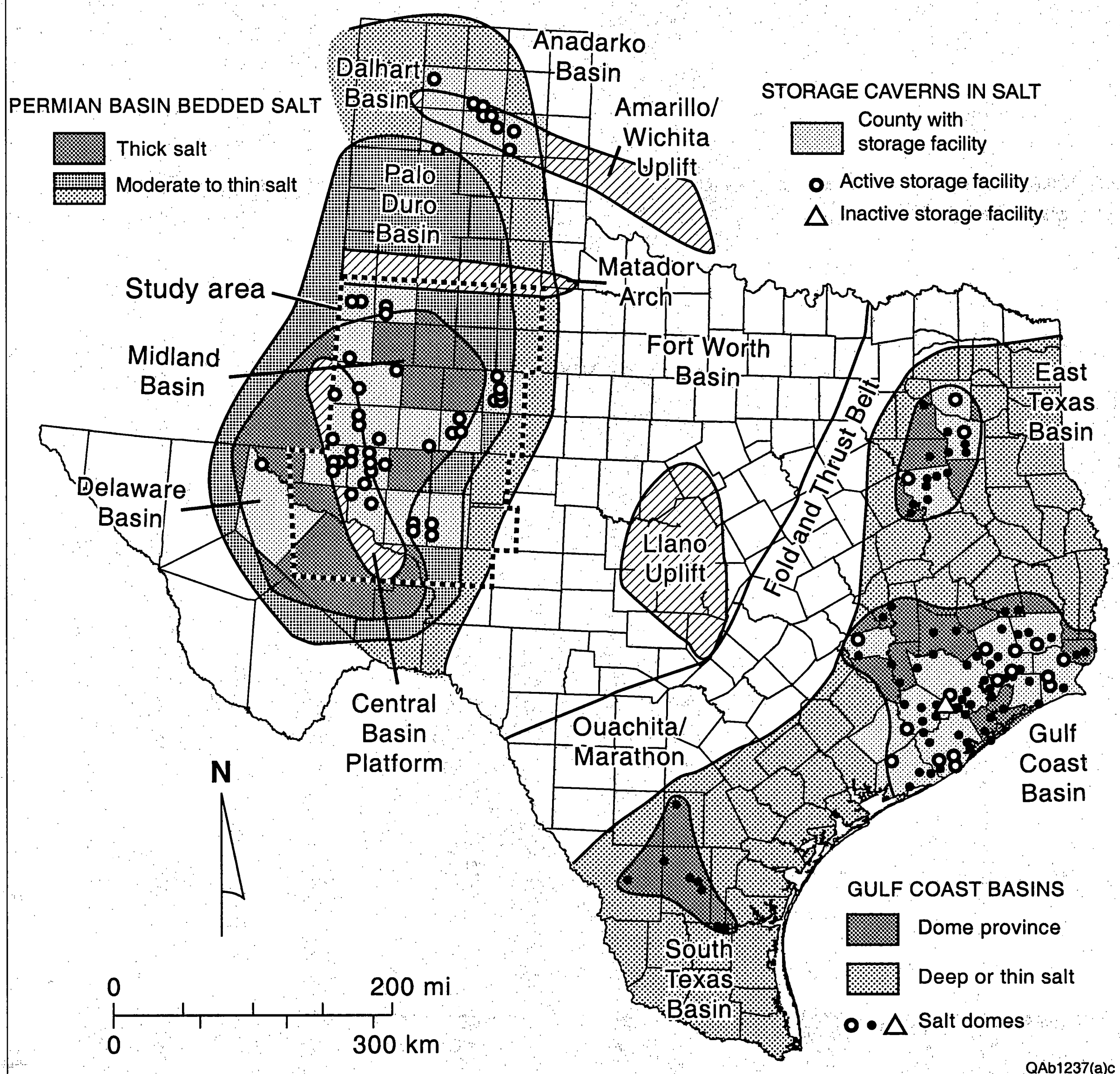


Figure 1. Location of salt in Texas and distribution of permitted salt caverns based on data from the Railroad Commission of Texas (Seni and others, 1995). Box shows the Midland Basin study area.

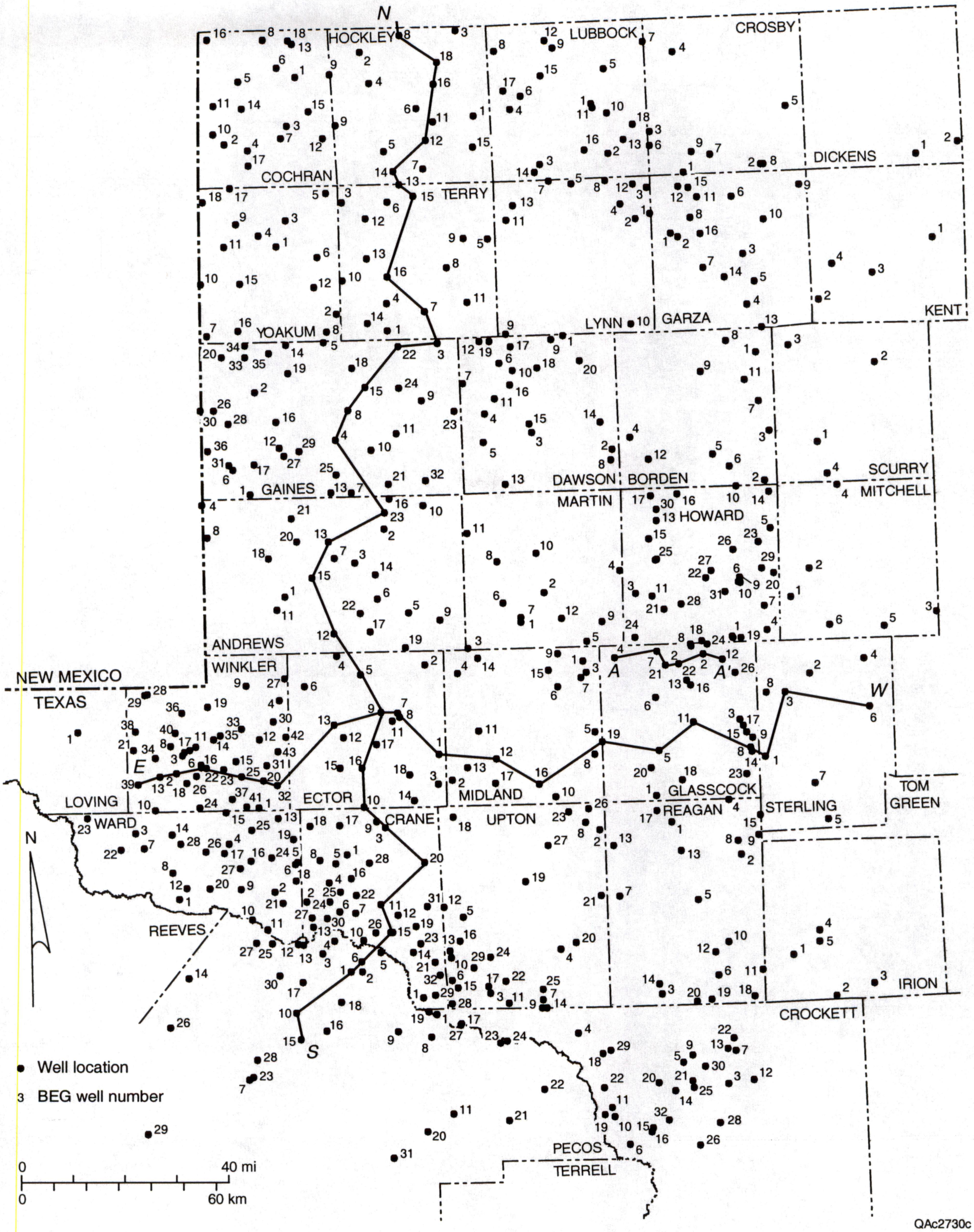


Figure 2. Well and cross-section location map of the 31-county study area.

upward to the surface and has been dissolved where it is in contact with fresh water. Concentration of the impurities in salt produces cap rock at the top and, in some locations, sides of the domes. Cap rock may have low permeability and armor the dome against dissolution or it may be permeable (Kreitler and Dutton, 1983). Structurally introduced anisotropy such as internal-boundary shear zones, foliation, bedding, mineralogy, moisture content, and grain-size variation may be features of concern in solution mining (Seni and others, 1995).

Bedded salt of the Permian Basin is much less pure than Texas dome salt. Permian salt is interbedded with limestone, dolomite, anhydrite, polyhalite ($Na_2MgK_2(SO_4)_4 \cdot H_2O$), and fine-grained siliciclastic red beds (mudstone, siltstone, and sandstone). The distribution of these low-solubility impurities is one of the limitations of engineering solution-mined caverns, and characterizing impurities is one major focus of this study. Salt beds are typically continuous over large areas, so that experience with solution mining in one property may be a good indicator of what to expect at a nearby site. However, salt beds thin, pinch out, or change facies laterally into other rock types; in this study I document the various types of lateral changes in bedded salt. Permian salt, like domal salt, has been dissolved where it has been in contact with fresh water. In the Permian Basin, concentration of impurities does not form a cap rock but, rather, forms a heterogeneous and mechanically weak insoluble residue. In this paper, I describe the geometries and criteria for identifying salt thinning as a result of dissolution.

Purpose and Scope of Study

The purpose of this report is to present data specific to bedded salt that will be of interest to both industrial operators and to government regulators in the context of salt-cavern development. This information is intended to be both a regional description of bedded salt in the Midland Basin and a template for useful and geologically based description of salt in other basins worldwide. In particular, the objectives are to: (1) create and compile maps and cross sections documenting the regional extent, thickness, geometry, and quality of salt resources potentially suitable for cavern development in the Midland Basin of Texas; and (2) identify some of the geologic factors that make specific sites more or less suitable for cavern development. To meet the second objective, I present conceptual models and interpretations that support and explain the descriptive data. The stratigraphic distribution and history of salt caverns in the Midland Basin were examined by compiling permit, sonar, and pressure tests in the Railroad Commission files.

Some potential applications from this data set are to: (1) provide basic descriptive information such as stratigraphic nomenclature and log characteristics for describing existing or newly developed facilities; (2) match areas where storage or disposal facilities are needed with areas of salt of optimal characteristics in terms of thickness, depth, purity, and stability; (3) to provide context for comparing the history and performance of one solution-mined cavern with another; and (4) provide criteria useful for detailed site characterization of existing or newly developed facilities.

The data presented here builds upon a previous study (Hovorka, 1997) of gross salt thickness in the Midland Basin. The maps presented in this report supersede the reconnaissance results of that study. High-quality well location, increased well density, improved log interpretation, and integration with previous salt dissolution and hydrologic studies are the principle areas of improvement upon the previous study.

Methods

Map and cross-section compilation through the bedded salt section in the Midland Basin included a 31-county area (fig. 2). Basic materials used in this study are 558 photocopied wireline logs from the Bureau of Economic Geology historic log library (appendix 1). This data set was selected because (1) older logs more commonly include curves from the salt section, compared with modern log suites, that focus more on the subsalt-producing intervals, (2) it includes many wildcat wells and wells from productive fields and, therefore, provides regional coverage, and (3) it is available at no cost. Previous experience suggested that the most useful logs for West Texas bedded-salt mapping are gamma-ray, caliper, sonic combinations. If these log types were not available in the log files, neutron or resistivity logs were used. SP logs are of minimal use in salt. The log data base assembled is not exhaustive; thousands more logs through the salt interval are commercially available but were not incorporated because of the regional scope of the study. Denser well data were collected in areas where reconnaissance investigation (Hovorka, 1997) showed complex geometry.

We purchased identification information (API numbers) from Petroleum Information/Dwight's and georeferenced latitude–longitude locations from Tobin Data Graphics to improve well-spotting accuracy and to register the data on a 1:24,000-scale georeferenced U.S. Geological Survey (USGS) county base using ArcInfo[1] Geographic Information System (GIS). The 90 wells for which the API number search was unsuccessful were located on a blueprint survey base (Midland Map Company, 1995) using survey information from the log header. Datum elevations were extracted from the log header or from a 1:250,000-scale USGS topographic map. Well location and elevation data were checked by comparing the elevation of the top of the Yates to a published regional structure map (Geomap, 1986), and logs with erroneous header data were corrected or discarded. Stratigraphic units were marked on log photocopies and the datum and unit tops were entered into a spreadsheet and used to calculate unit thickness and structural elevation. These data were plotted on maps using ArcView GIS. Hand contouring was used to optimize interpretation of the regional data, using the published Yates structure map (Geomap, 1986), USGS 1:250,000-scale topographic maps, and surface geology (Barnes, 1992), in coordination with conceptual models to guide interpolation.

To supplement interpretation of this data, I have drawn on previous published and unpublished investigations elsewhere in the Permian Basin (fig. 3). Salt cores collected by the U.S. Department of Energy (DOE) investigations of bedded salt in the Palo Duro Basin (Hovorka, 1994), cores collected by U.S. Army Corps of Engineers in an area of salt dissolution in the Hollis Basin (Hovorka and Granger, 1988), and the Gulf Research PDB-03 core from Loving County,

[1]Environmental Systems Research Institute, Redlands, California

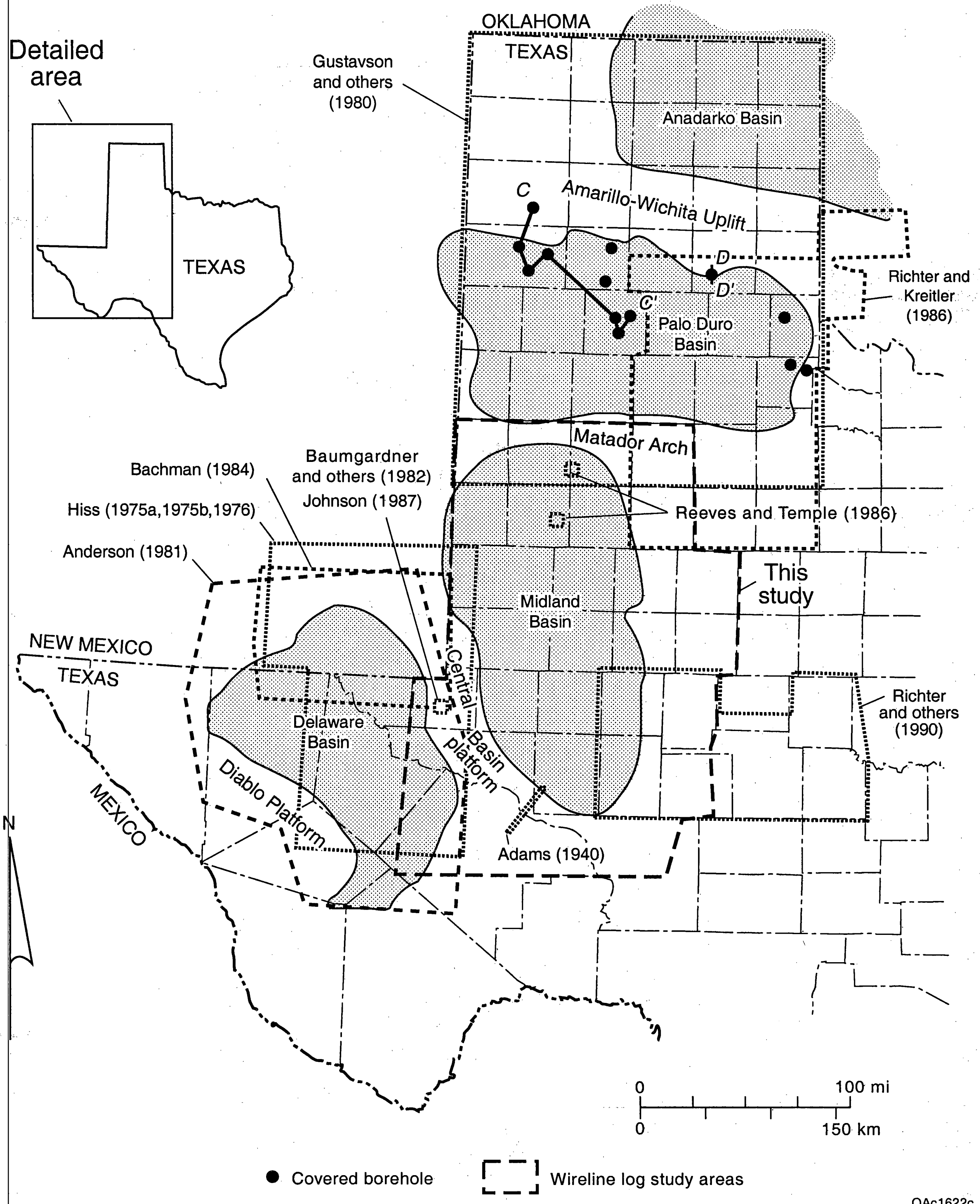


Figure 3. Regional data used for interpreting the geometry of salt in the Midland Basin.

Texas (Hovorka, 1989; 1990) are outside the Midland Basin study area but provide background information used to interpret the log response and geometric relationships seen in the Midland Basin. These cores are stored at the University of Texas Bureau of Economic Geology Core Research Center. Descriptions of salt geometry in the Delaware Basin used for this study include Adams (1944), Bachman (1984), Anderson and others (1972), and Snider (1966).

Areas in the Midland Basin were selected for case studies to document salt characteristics and hydrologic processes that are thought to affect the suitability of salt for hosting caverns and detailed cross sections were prepared across these areas. We used a literature search to document the hydrologic setting.

In order to assess the relationships between the characteristics of the Salado Formation and effective design options for storage caverns, we compiled historic and descriptive data including information on well construction, cavern development, use, monitoring history, and maintenance of storage and brine-production caverns from Railroad Commission of Texas files and industry sources. We focused on caverns that are currently or have been recently in operation, because they contained more information.

PREVIOUS WORK: GEOLOGIC SETTING OF THE BEDDED SALT IN THE PERMIAN BASIN

The evolution of the Permian Basin is very well known because of the long and intense history of hydrocarbon exploration in the sub-salt section. The Permian Basin formed as an area of rapid Mississippian-Pennsylvanian subsidence in the foreland of the Ouachita Foldbelt. Faulting, created areas of slower subsidence that became platforms or arches and subdivided the Permian Basin. Subdivisions of significance to this report are, from southwest to northeast: the Diablo Platform, Delaware Basin, Central Basin Platform, Sheffield Channel, Midland Basin, Ozona Platform, Matador Arch, and Palo Duro Basin (fig. 4).

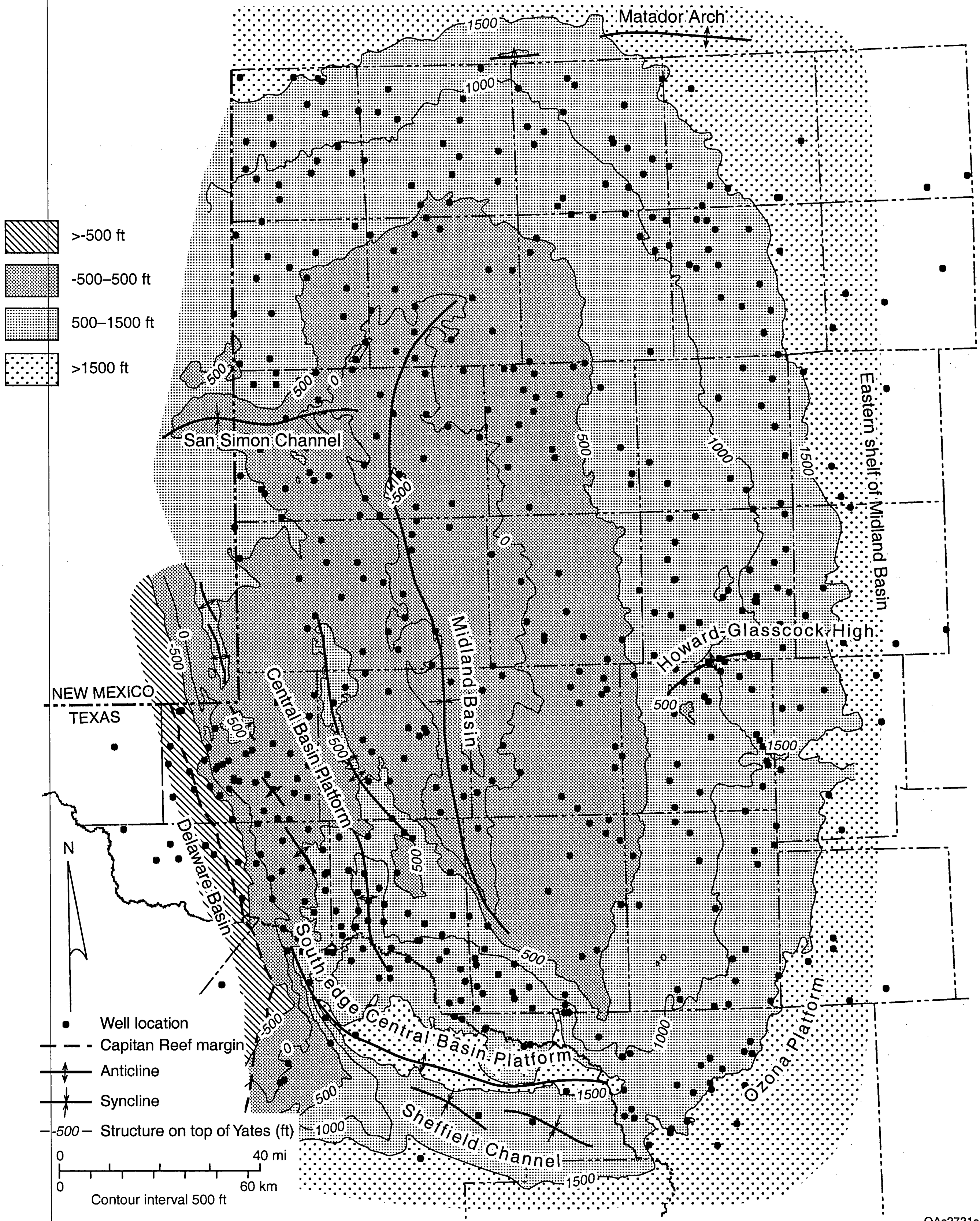


Figure 4. Tectonic elements that controlled depositional facies and salt dissolution in the Midland Basin. Structure contours on the top of Yates Formation modified from Geomap, 1986. Present structure is a net result of Permian subsidence, Mesozoic warping, and Cenozoic uplift. Location of Capitan Reef from Hiss (1975a).

The geometry, quality, and stability of salt depend on interactions among the depositional character, thickness, and composition of the salt; postdepositional uplift and subsidence; and landscape development and resulting ground-water circulation patterns. Few studies have described the salt within the Midland Basin. Extensive research on the salts in the adjacent Delaware and Palo Duro Basins, conducted during characterization of the salts in these areas as potential hosts for radioactive waste, can be readily applied to understanding the similar salt in the Midland Basin.

Permian basin filling began with Pennsylvanian marine shales, limestones, and arkoses (Cys and Gibson, 1988). By early to middle Permian (Leonardian), the north and east parts of the Permian Basin had been infilled with sediments. The Delaware Basin, at the western edge of the study area, was a structural and topographic basin that provided the inlet for marine water during most of the Permian (fig. 3). Connection with marine environments to the west became poorer through the Permian and saline brines began to form, first in the marginal parts of the Permian Basin and then, progressively, throughout the entire basin. Sedimentary patterns show that by the Leonardian, sedimentation had mostly leveled topography east of the Delaware Basin, so that the major structural elements such as the Central Basin Platform, Midland Basin, Northern Shelf, Matador Arch, Eastern Shelf, and Ozona Platform (fig. 4) were expressed only by subtle contrasts in subsidence rates. This relationship is apparent in the continuity of strata across structural positive areas with only minor changes in thickness or composition (Adams, 1968; Feldman, 1962; Matchus and Jones, 1984; Fracasso and Hovorka, 1986). The classic and extensively studied Capitan Reef is a strongly aggradational Guadalupian carbonate accumulation that rims the Delaware Basin (King, 1942; Garber and others, 1989; Bebout and Kerans, 1993, Kerans and Kempter, in press)

During the Leonardian, evaporite sediments, initially anhydrite and then halite, began to accumulate in the Palo Duro Basin (Wichita and Clear Fork Groups and lower San Andres Formation). During the Guadalupian, salt precipitation began in the Midland Basin; salt occurs in the Grayburg, Queen, and Seven Rivers Formations (fig. 5). The thickest salts are generally

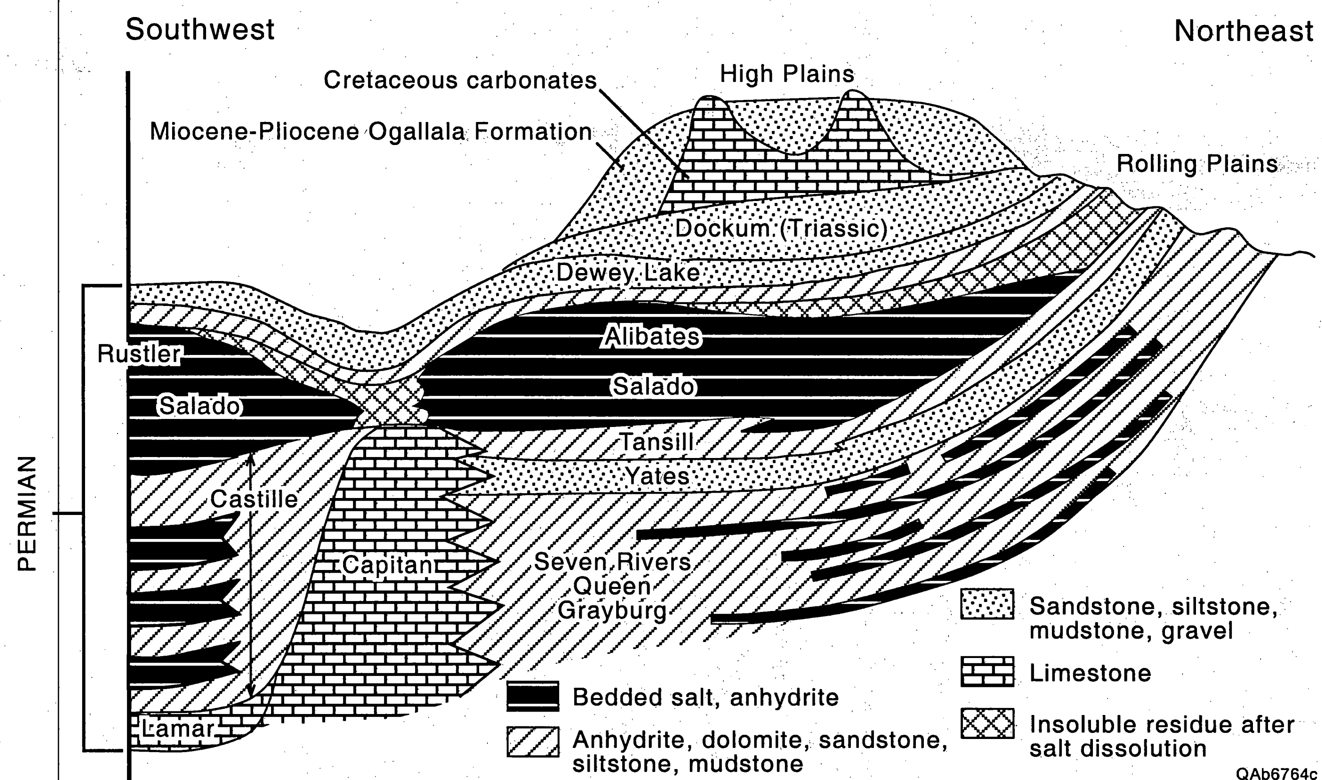


Figure 5. Permian Basin stratigraphy, Leonardian through Quaternary, emphasizing units described in the text.

observed on the parts of the shelf away from the Delaware Basin toward the east and north. Several cycles of sandstones, anhydrite, and halite of the Yates Formation were deposited across the platform during a sea-level lowstand; the corresponding deposits in the Delaware Basin are in the Bell Canyon Formation. The deposits of the following highstand, also composed of a number of cycles, are carbonate, anhydrite, halite, and sandstone of the Tansill Formation. The Lamar Limestone at the top of the Bell Canyon Formation is the basinal equivalent to the Tansill (Garber and others, 1989; Bebout and Kerans, 1993; Kerans and Kempter, in press).

During the Ochoan, evaporites began to precipitate in the Delaware Basin. The topographic depression was filled by the Castile Formation (Snider, 1966; Adams, 1944; Anderson and others, 1972). Deposition of thick salts in the Salado Formation followed. The Salado Formation, like preceding Permian units throughout the Permian Basin (Meissner, 1972; Fracasso and Hovorka, 1986; Hovorka, 1987), is highly cyclic on a meter scale throughout the Permian Basin (Dean and Anderson, 1978; Lowenstein and Hardie, 1985; Lowenstein, 1988; Hovorka, 1990; Holt and Powers, 1990). Cycles began with a flooding event that typically precipitated anhydrite. Sediment aggradation caused restriction, limiting water movement and causing halite precipitation. In the Salado Formation, highly evaporated brines ponded on the saline flat altered previously deposited gypsum to polyhalite. Mud, silt, and sand deposited by eolian and arid-region fluvial processes are interbedded with the halite. Interbedding of anhydrite, polyhalite, halite, and fine-grained clastics on a centimeter scale reflects the variation in the depositional environment (Fracasso and Hovorka, 1986; Lowenstein, 1988; Hovorka, 1990; Hovorka, 1994). Facies within the salt-depositional environment control variations in the amount, mineralogy, and distribution of impurities; in the crystal size, shape, and interrelationships; and in the amount, distribution, and chemistry of included water. The facies are complex vertically and horizontally; however, analysis of the facies relationships can be used to map the characteristics of the salt (Kendall, 1992; Hovorka and others, 1993).

Salt deposition within most of the Permian Basin ended with a major transgression that deposited the Alibates Formation. This unit contains thin but extensive carbonate and anhydrite beds separated by a siltstone or sandstone (McGillis and Presley, 1981). Although Stratigraphic nomenclature and relationships are complex in the Delaware Basin (Powers and Holt, 1990) genetic equivalence and correlation of the upper Rustler carbonate-anhydrite unit (Magenta and Forty-Niner Members) with the upper carbonate-anhydrite unit of the Alibates appears reasonable. Overlying the Alibates and the upper Rustler anhydrite are fine sandstones, siltstones, and mudstones of the Dewey Lake Formation, or equivalent upper Rustler Formation that were the final Permian deposits.

Basin evolution after evaporite deposition is significant for salt cavern siting because the salt geometry was modified by burial dissolution. Triassic deposition of lake-deposited mudstones and fluvial sandstones of the Dockum Formation occurred following subtle warping and reconfiguration of the basin to a large centripetally draining lake basin (McGowen and others, 1979). Inferred uplift along the margins may have permitted salt dissolution to begin at this time, although no dissolution features that unequivocally formed at this time have been identified. Complex sedimentation within the Dockum Group and later crosscutting episodes of salt dissolution have obscured the record of any dissolution that occurred at this time.

A long unconformity followed Dockum deposition and is represented by erosion and truncation preceding deposition of Cretaceous sandstones and carbonates over most of the area (fig. 5). Dissolution prior to Cretaceous deposition is reported in many parts of the Permian Basin (Adams, 1940; Gustavson and others, 1980; Wessel, 1992a). Regional uplift occurred during the Cenozoic, and gravel, sand, and finer grained clastics of the Miocene–Pliocene Ogallala Formation were deposited in fluvial and upland eolian settings (Seni, 1980; Gustavson, 1996). Other significant Cenozoic deposits include Pecos River gravel (Bachman, 1984) and surficial sand, terrace, and colluvial deposits (Barnes, 1992). The current structure of this region (fig. 6) is the result of post-Cretaceous uplift and tilting that reactivated structural elements with the same sense of motion as they had during the Permian (McGookey, 1984), so that, for example, beneath the Southern High Plains and in the center of the Midland Basin the top of the Alibates is at 500 ft above sea level, while over the Eastern Shelf of the Midland Basin at shallow depths beneath the

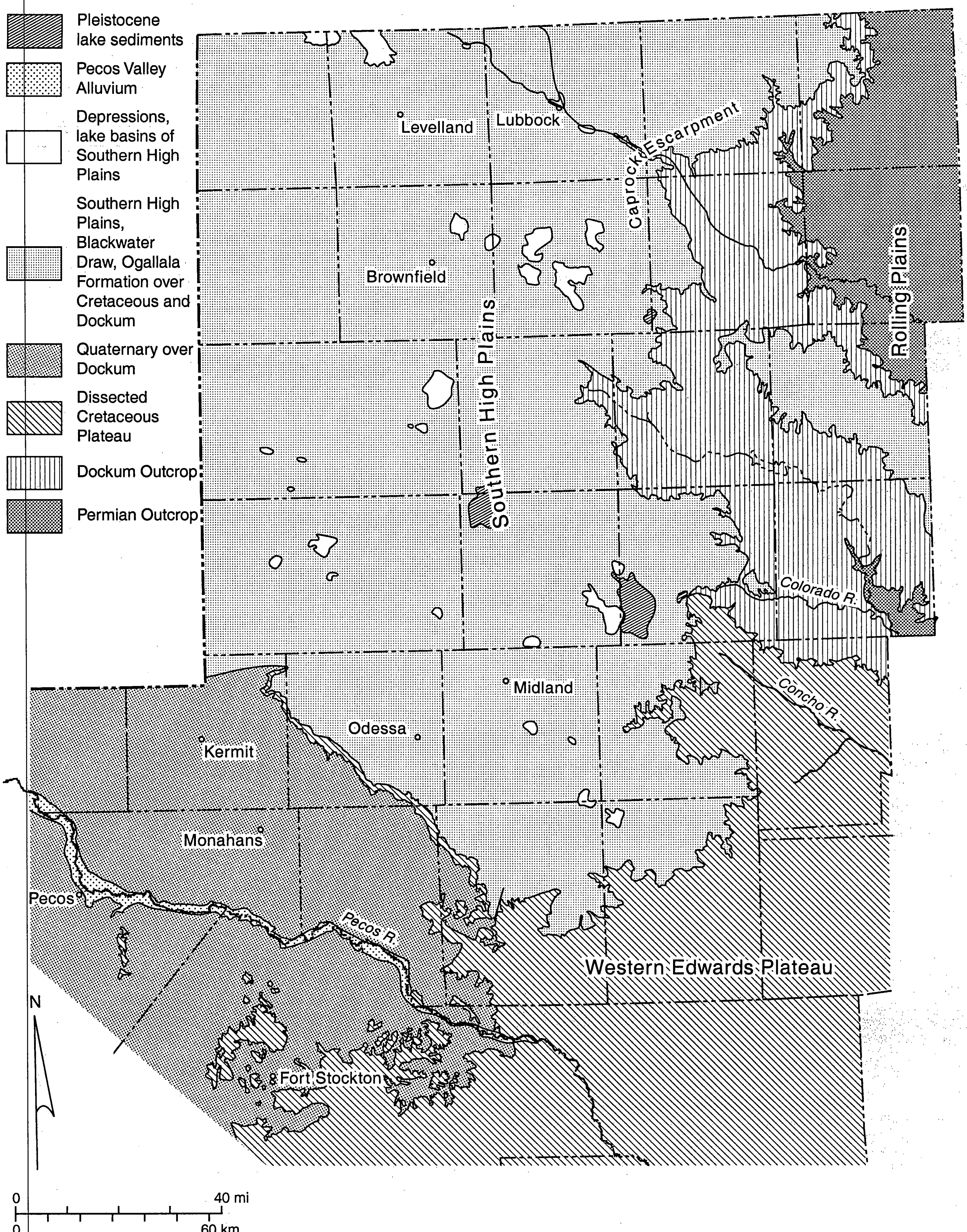


Figure 6. Generalized geologic map of the study area, showing generalized subcrop patterns beneath surficial units.

Rolling Plains it has been lifted to 1,800 ft above sea level. The Permian has also been uplifted over the Central Platform where it lies beneath Triassic units in the Pecos valley. In the Delaware Basin, Permian rocks dip gently toward the east; in the Eastern Shelf, Permian rocks dip gently toward the west. Cretaceous rocks are preserved only in the southeast part of the study area, and Permian, Triassic, and Cretaceous units have been partly covered by Cenozoic deposits. These units are now undergoing erosion to create the Caprock Escarpment that rims the Southern High Plains (fig. 6).

REGIONAL GEOMETRY OF BEDDED SALT IN THE MIDLAND BASIN

Midland Basin Stratigraphy

Stratigraphic units selected for mapping in the Midland Basin were adapted from cross sections and stratigraphic studies (Adams, 1944; 1968; Herald, 1957; Humble Oil and Refining, 1960; 1964a; 1964b; Tait and others; 1962; Feldman, 1962; Vertrees, 1962–1963; Snider, 1966; McKee and others, 1967; Mear, 1968; Johnson, 1978; Presley, 1981; Matchus and Jones, 1984; Borns and Shaffer, 1985; McGookey and others, 1988; Hovorka, 1990). The Ochoan Dewey Lake, Alibates, and Salado Formations; and Guadalupian Tansill, Yates, and Seven Rivers Formations are readily identified in the Midland Basin and across the Central Basin Platform. Complex changes in the character and thickness of stratigraphic units reflecting the results of both facies changes and salt dissolution are noted near and across the west margin of the Central Basin Platform/east margin of the Delaware Basin. These changes are discussed further in following sections. The Seven Rivers, Yates, and Tansill Formations are laterally equivalent to the Capitan Limestone Reef facies that forms the aggradational and progradational shelf margin of the Delaware Basin. Within the Delaware Basin, stratigraphic units are the Ochoan Rustler, Salado, and Castile Formations and the Guadalupian Lamar and Bell Canyon Formations.

Log analysis and preparation of cross sections from the Midland Basin show the lithologies and facies relationships in each of these units. Cores through the evaporite sections in the Midland

Basin were not available for this study, therefore lithologies have been identified by matching Midland Basin log pattern to logs of cored sections in the Palo Duro and Delaware Basins. The Seven Rivers Formation is composed of cyclically interbedded mudstones, salt, anhydrite, and dolomite (fig. 7). Several thick anhydrite beds at the top of the Seven Rivers Formation were the most extensive units in the section and were useful stratigraphic markers toward the basin margins.

Overlying the Seven Rivers Formation is the Yates Formation, a 100- to 175-ft-thick siliciclastic unit. The moderately high gamma-ray character (fig. 7), regional extent, and consistent thickness make this unit an optimum stratigraphic marker. Several anhydrite beds of subregional extent within the Yates provide additional log character. Interpretation of the depositional environment of the Yates from log character alone is problematic. Cores through the Yates in the Palo Duro Basin north of the study area contain massive to disrupted (haloturbated) silt and very fine sandstone with illuviated clays. These fabrics suggest that incipient soil formation occurred in as eolian flat facies accumulated as water level rose during a period of generally low sea level. Outcrops of the Yates near the Capitan Reef margin in the Guadalupe Mountains show back reef carbonate laterally equivalent to Capitan Reef facies (Bebout and Kerans, 1993). On the Central Basin Platform in Ward-Estes Field a complex interbedding of sandstone, carbonate, and anhydrite document migration of subtidal, intertidal, beach ridge, and hypersaline facies belts (Andreason, 1992).

The overlying Tansill Formation is a highly cyclic and laterally heterogeneous unit about 100 ft thick across most of the Midland Basin. Toward the Delaware Basin, the Tansill Formation is dominated by anhydrite with or without dolomite and siliciclastic interbeds. In depositional updip environments toward the east and north margins of the Midland Basin, the Tansill Formation is composed of halite with abundant siliciclastic interbeds. In the middle of the Midland Basin, the basal part of the Tansill Formation is dominantly anhydrite or dolomite, siliciclastics with halite interbeds becoming more dominant upward. The log character (fig. 7) of the Tansill is distinguished from the overlying Salado Formation because it contains more thin cycles and more abundant thin siliciclastic beds producing multiple closely spaced peaks on the gamma-ray log.

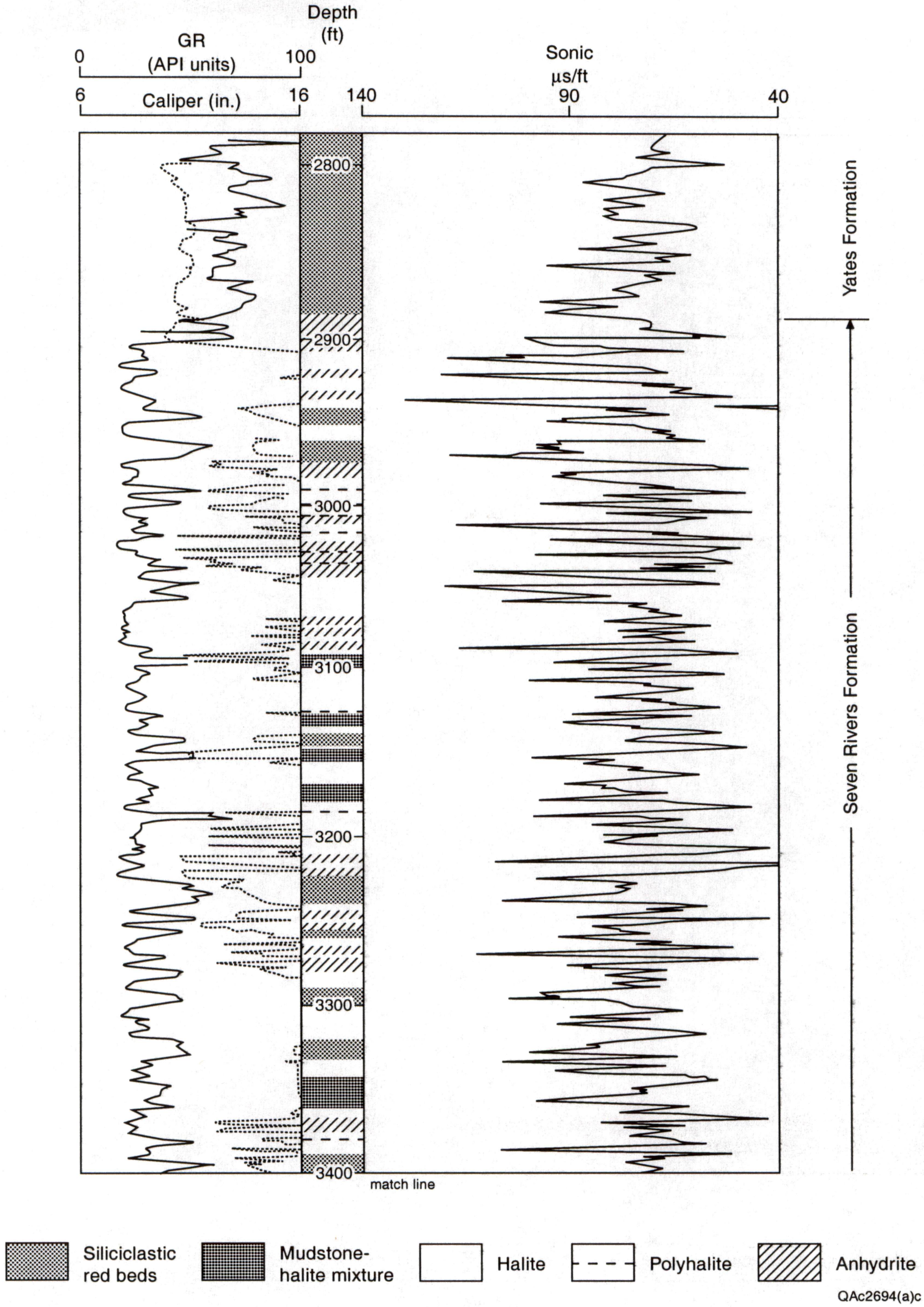


Figure 7. Type log through the Seven Rivers Formation. Cochran 14; Champlin Oil and Refining Company George E. Bensen No. 1, contains numerous salt beds in the Guadalupian section.

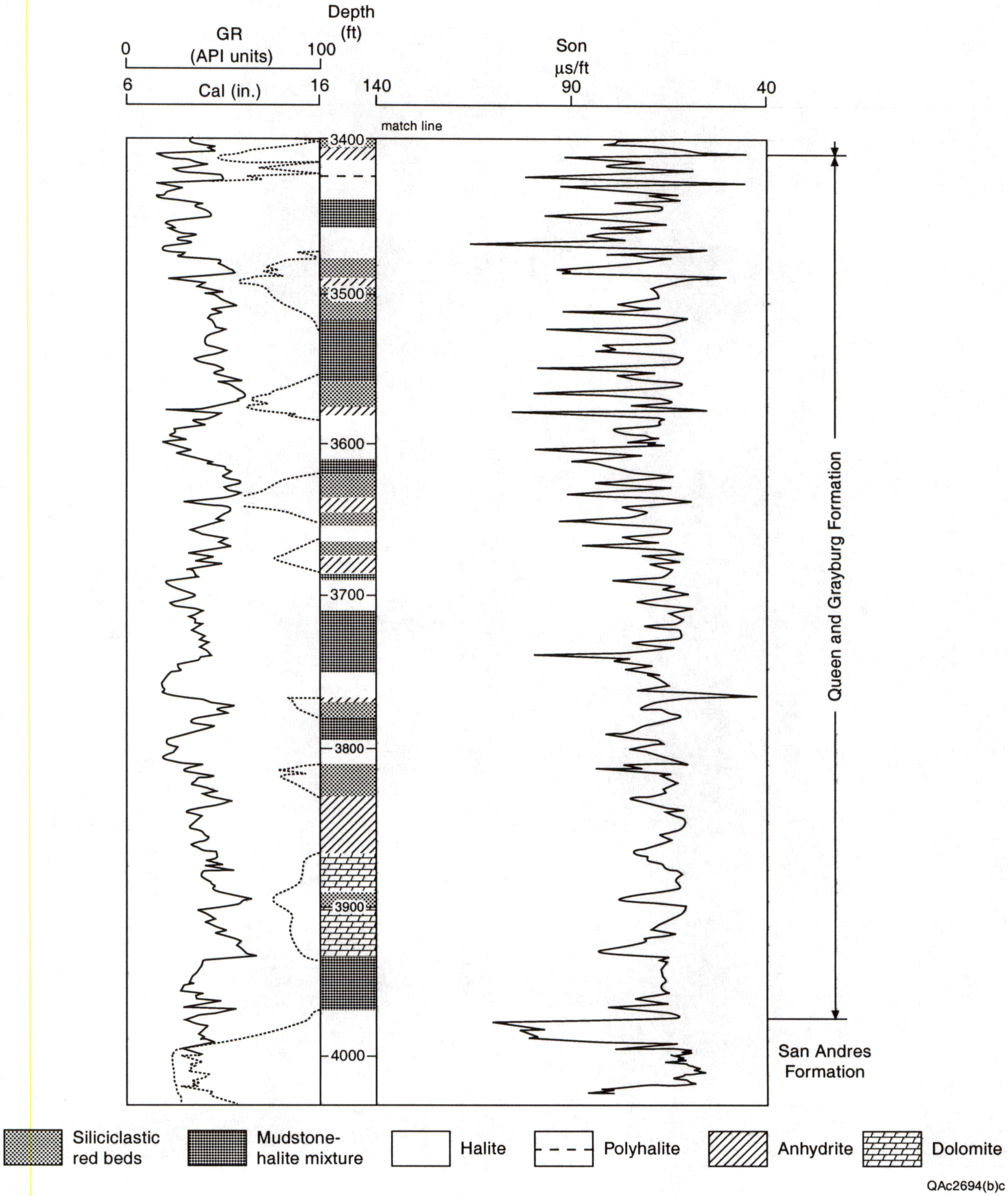


Figure 7 (cont.).

Because of the cyclic nature of the sediments, however, no adequate stratigraphic marker was identified to regionally map the Tansill separately from the Salado Formation. Close to the shelf margin in outcrop in the Guadalupe Mountains, Tansill facies are dominated by carbonate-sandstone cycles (Bebout and Kerans, 1993).

The Salado Formation is the dominant halite-bearing unit of the Midland Basin, hosts all the solution-mined caverns inventoried during this study, and therefore was mapped in detail. Based on a model of salinity-controlled anhydrite-halite-mudstone depositional cycles (Hovorka, 1994), I used anhydrite beds as the major stratigraphic markers. Anhydrite represents the most-flooded, least-restricted conditions over the evaporite shelf where wind, storm, and seasonal circulation was adequate to maintain gypsum deposition. Overlying anhydrite beds are halite, polyhalite, and mudstone beds.

Anhydrite beds are recognized by low response on gamma-ray logs, normal bore-hole diameter on caliper logs (in contrast, halite is commonly strongly embayed because it is dissolved in contact with undersaturated drilling mud), high count on neutron logs, high velocity on sonic logs, and high density log response. Anhydrite is typically fairly pure, although bed thickness limits log response from attaining the theoretical values for the thinner beds. Each anhydrite bed was flagged, correlated, and numbered. Regionally traceable beds were numbered 20, 30, 40, 50, and 60, and beds of more local extent were assigned intervening numbers (number 10 and 15 were used to subdivide Tansill stratigraphy, and 80 and 90 were used for anhydrite beds in the overlying Alibates Formation). Anhydrite bed 20 was identified across the entire study area and is distinctive because, in most areas, a thin insoluble residue of mudstone occurs at the base (fig. 7). Overlying anhydrite beds pinch out toward the basin margins or are included in insoluble residue where intervening halite has been dissolved.

Anhydrite in the Salado Formation has been partly replaced in some intervals by polyhalite ($Na_2MgK_2(SO_4)_4 \cdot H_2O$). In core in the Palo Duro Basin and the Delaware Basin, polyhalite is observed to occur as needles and fine-grained masses that are typically red or pink because of thin iron-oxide coatings on polyhalite crystals. It is an early diagenetic replacement of gypsum as a result of interaction with pore water in the subaerial or shallow burial environment. The distribution of polyhalite is irregular on a fine scale, where it forms fabric-specific replacement textures and nodules, and on an intermediate scale, where it may replace only the floors of large polygons (Robert Holt, IT Corporation, 1990, personal communication), as well as on a regional scale. Although polyhalite is mined commercially as a potassium source in the Delaware Basin east of Carlsbad, New Mexico, no commercial uses are noted in the Midland Basin.

Polyhalite produces a strong gamma-ray-log response (fig. 7). Polyhalite has relatively low solubility in brine, so polyhalite beds are intervals of normal hole size on caliper logs, although thin beds within salt are commonly mechanically broken. Neutron-log response is variable because common admixture with anhydrite offsets the log response to the hydrous mineral. Polyhalite is admixed with mudstone in some settings, and these are also difficult to accurately separate.

Bedded halite is the most common lithology in the Salado Formation. In cores from adjacent basins (Lowenstein, 1988; Hovorka, 1990; 1994), bedded halite contains 5 to 15 percent anhydrite and mudstone as disseminated impurities and as millimeter- to centimeter-thick laminae. Log response and cycle structure suggests that halite in the Midland Basin probably has similar composition and fabric. Halite is identified in logs by a low gamma-ray response similar to anhydrite, oversized hole on caliper log, variable moderate-low neutron response, moderate and variable density and sonic log response, and high resistivity. In boreholes drilled with halite-saturated brine, halite beds produce little or no caliper log deviation.

Bedded halite is transitional into mudstone-halite mixtures and into mudstone. Mudstone in cores from the Palo Duro Basin (Hovorka, 1990; 1994) is composed of subequal mixtures of arkosic silt and illite-montmorillonite-dominated clays. Mudstone-halite mixtures or "chaotic mud-salt" (Handford, 1982) are beds composed of poorly or nonbedded mixtures of euhedral or corroded halite crystals and mudstone matrix. Mudstone-halite mixtures are transitional into mudstone beds with minor inclusions of halite as euhedral or corroded halite crystals. Mudstone beds in turn are transitional by inclusion of less clay into siltstone and very fine sandstone. All these fine-grained clastics are collectively known as siliciclastic red beds.

Mudstone and mudstone-halite beds formed during periods of prolonged exposure of the halite flat (Fracasso and Hovorka, 1986; Hovorka, 1994). Siliciclastics were transported onto the flat by sequential dust storm transport of fine materials, reworking by rainfall, and reworking by marine-derived saline-storm floodwater. Exposure and water-table drop caused formation of karst pits in halite, and these pits were filled with mudstone and mixtures of mudstone and halite. The resulting distribution of mud is heterogeneous on a fine scale because pit fillings may be several feet thick adjacent to areas between pits where mudstone is thin or missing.

Log response to siliciclastic intervals (fig. 7) is characterized by higher gamma-ray-log response than anhydrite and halite, and distinctly low neutron-log response because of high clay lattice and capillary water content. Sonic-log response is also generally low. Permeability of mudstones is generally considered to be very low because of high clay content; siltstone and sandstone porosity is typically occluded by halite cement, although investigation of the extent to which these generalities are true at a site scale may be needed. Borehole size as shown by caliper-log response in siliciclastic red-bed intervals is variable depending on drilling conditions and mud composition; in some boreholes, mudstones, and even siltstones and sandstones, are as strongly washed out as halite; in other boreholes, many siliciclastic beds form smaller borehole diameters than adjacent halite. Log suites were not adequate to consistently separate mudstone-halite mixtures from mudstone beds or mudstone beds from silty or sandy siliciclastic red beds.

Above the halite-bearing part of the Salado Formation is an interval of insoluble residue. Insoluble residue thickness varies depending on the amount of salt dissolved and the impurity content of the salt. In cores from the Palo Duro and Delaware Basins, examination of the insoluble residue showed that this interval is composed of impurities in the salt, including anhydrite beds, mudstone beds, and impurities disseminated within the salt. Water sampling from this interval in the Palo Duro Basin (Dutton, 1987) showed that the insoluble residue contained brines that have dissolved evaporite but are not saturated with respect to halite. Anhydrite beds within insoluble residue are partly to completely altered to gypsum. The insoluble residue interval is commonly slightly to strongly brecciated containing horizontal fractures, small faults, high-angle fractures, abundant joints, or collapse breccia. Because the insoluble residue is commonly poorly understood and because it is a potential engineering challenge for caverns sited in the underlying salt interval, insoluble residues, and the salt dissolution process are described in a following separate section.

Insoluble residue is recognized on logs by high gamma-ray-log response reflecting concentration of clayey and arkosic mudstone, low resistivity because of saline pore water in residue, which is more permeable than the underlying salt, and cycle skipping in sonic logs as a result of fracturing (fig. 9). Comparison of insoluble residue intervals with adjacent logs where salt is preserved shows condensed thickness and concentration of anhydrite beds as intervening salt has been removed. Where anhydrite has been partly hydrated to gypsum, increased water content causes higher neutron count rates. As discussed in detail in a later section, salt dissolution in most areas is coincident with depositional changes in unit thickness and facies; this is one of the challenges in understanding these variations. As well as the common occurrence of insoluble residue at the top of the Salado, salt has also locally been dissolved from the base of the formation.

The uppermost evaporite units in the Midland Basin are a pair of anhydrite beds of the Alibates Formation. These 10- to 50-ft-thick anhydrite beds and the siliciclastic interval that separates them form a stratigraphic marker across most of the study area (fig. 8). Where this unit has been examined in core in the Palo Duro, the anhydrite beds are similar to other anhydrite beds in the section. They contain abundant pseudomorphs after bottom-grown gypsum, indicating that the unit formed in shallow, areally extensive brine pools. The pair of anhydrite beds of the Alibates are homogeneous and widespread over most of the basin. Complexities noted in this pattern include local thinning or absence of one or both anhydrite beds and change in log character, suggesting replacement of anhydrite by less dense, more porous, and more radioactive carbonate or chert. Thinning and compositional changes are common toward the north and east Midland Basin margins. More than two thick carbonate-anhydrite beds are common in the areas over and adjacent to the Capitan Reef but the geometry of these units was not resolved in this study.

Where they have been examined in the Palo Duro Basin, diagenetic alteration in Alibates anhydrite beds has followed a more complex path than diagenesis of other anhydrite beds

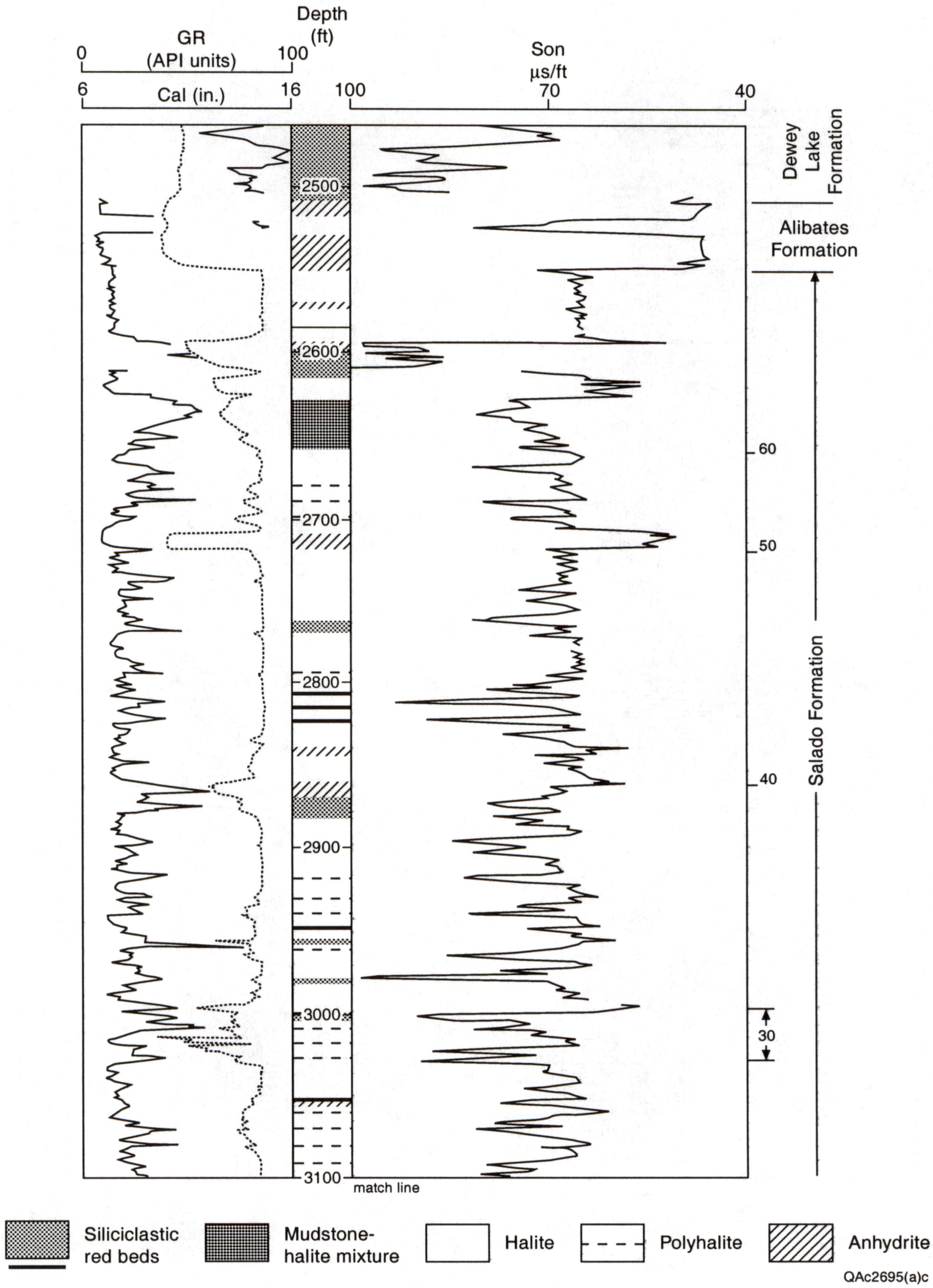
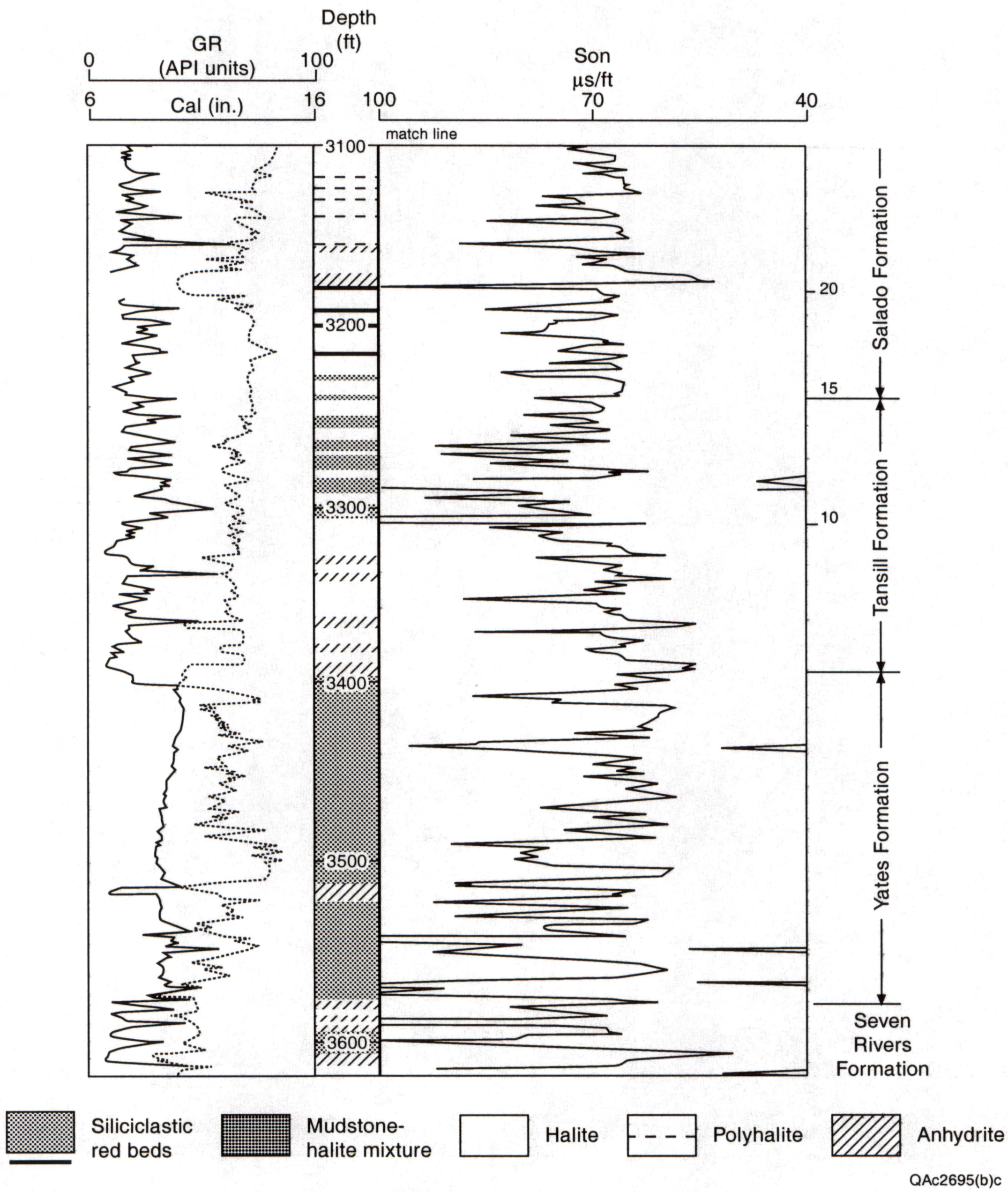


Figure 8. Type log through the Yates, Tansill, Salado, and Alibates Formations. Terry 16, Mobil Oil Corporation No. 1 Texas Tech University.



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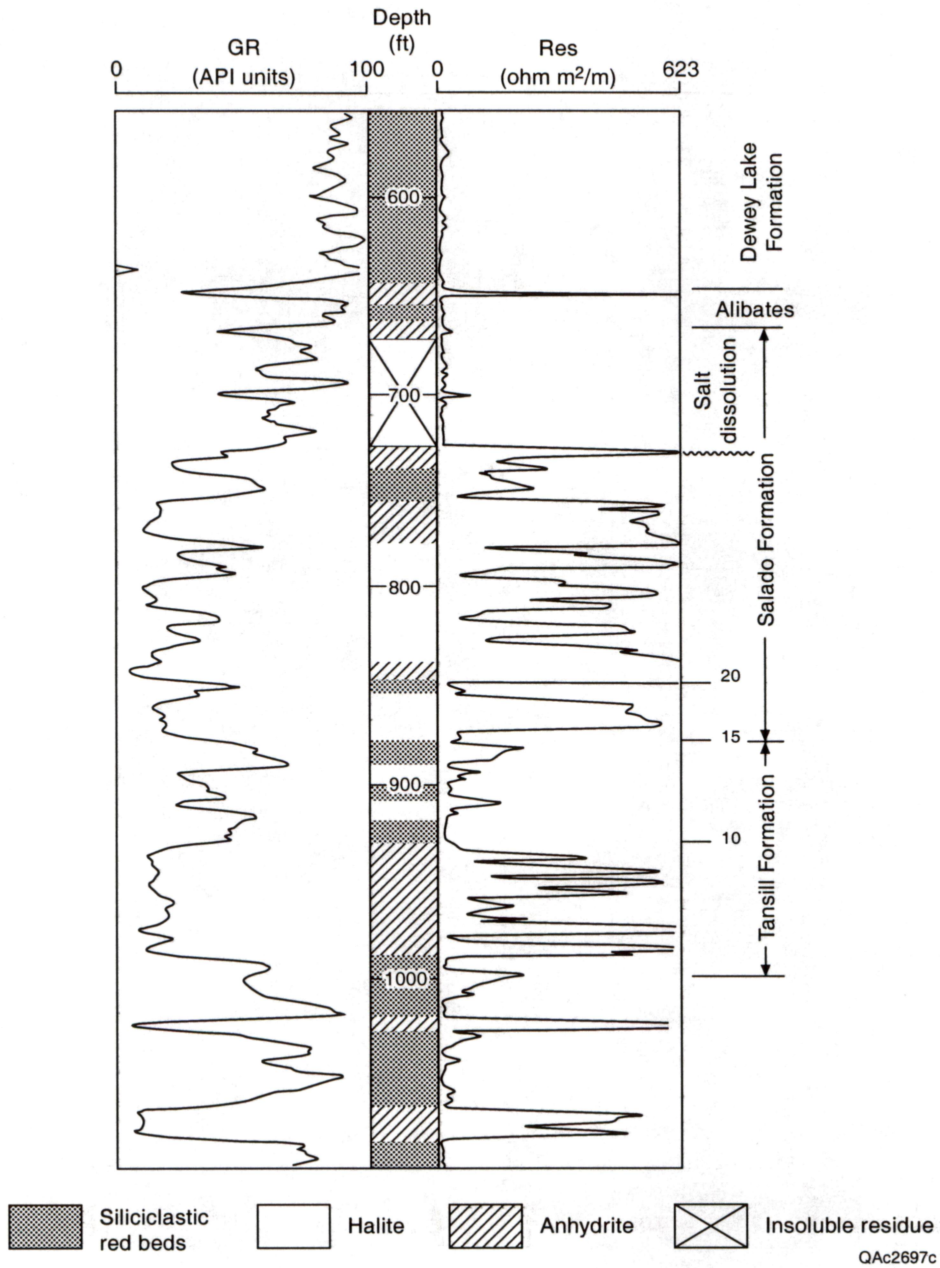

Figure 9. Type logs through insoluble residues. (a) Garza 13 John J. Eisner No. 1A Porter shows resistivity log response to dissolution.

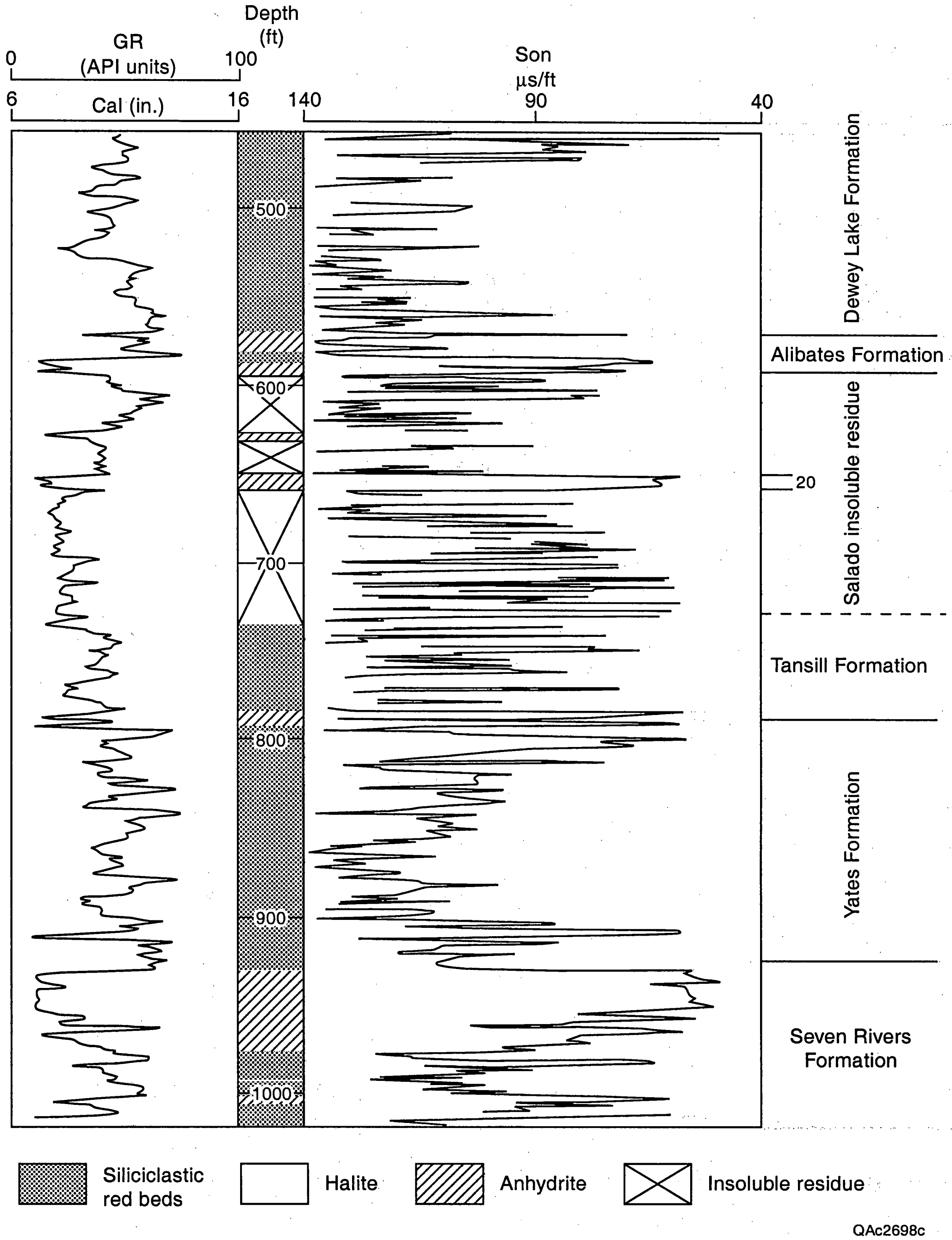

Figure 9 (cont). Type logs through insoluble residues. (b) Crane 5, W. H. Black No. 1 Shannon Estate, shows sonic-log response to fracturing and collapse.

(Hovorka, 1992). In the Alibates, gypsum has been pseudomorphically replaced by dolomite, so that in places, the Alibates is a carbonate unit (McGillis and Presley, 1981). Locally in the Palo Duro Basin, the Alibates has been extensively replaced by chert. Silicification is a common diagenetic alteration of anhydrite but is very minor in other Permian anhydrite beds. In core from the Oldham nose structural positive on the northwest margin of the Palo Duro Basin, I observed cross-bedded, reworked, doubly-terminated quartz crystals with anhydrite inclusions in the upper Alibates dolomite bed. I have never observed halite overlying Alibates anhydrite beds, but brecciated, corroded, diagenetically altered anhydrite-siliciclastic contacts are areas where original halite may have been dissolved. This complex diagenesis is significant because it shows that Alibates deposition was preceded by an episode of reworking and silicification of older evaporites at least locally on the basin margins. Conforming to current stratigraphic nomenclature, this break is described as a sequence boundary. Additional alteration throughout the Alibates but not penetrating far into the underlying salt suggests that periods of alteration occurred before substantial warping of the Alibates, before or during Dewey Lake or Dockum deposition. These observations provide context in which to interpret heterogeneities observed within and beneath the Alibates in the Midland Basin.

Overlying the Alibates is the Dewey Lake Formation, a 100- to 200-ft-thick siliciclastic red-bed sequence. This interval has moderately high, fairly uniform gamma-ray-log response. In the Palo Duro Basin, where this unit was examined in core, it is composed of siltstone and very fine sandstone deposited in pedogenically modified eolian-flat and cross-bedded wadi-channel environments.

Delaware Basin Stratigraphy

This brief discussion is for the purpose of setting the context for understanding the relationship of the Midland Basin salts to the Delaware Basin adjacent to the study area. More detailed descriptions are presented elsewhere (for example, Adams, 1944; Anderson and others, 1972; Snider, 1966; Lowenstein, 1988; and Hovorka, 1990). The upper Guadalupian section is composed of the Bell Canyon Formation, capped by the Lamar limestone, a finely laminated, organic-rich, silty limestone deposited prior to evaporite precipitation. The Bell Canyon Formation is the deep-water basinal equivalent of the Seven Rivers, Yates, and Tansill Formations on the Platform (Garber and others, 1989). Because of its high gamma-ray-log response and sharp contact with overlying Castile Anhydrite I, this contact serves as an excellent stratigraphic marker.

Anhydrite beds of the Castile Formation are laminated like the Lamar, but the laminae are much thicker, corresponding to more rapid rates of gypsum precipitation. The Castile Formation has been divided into four anhydrite units designated with Roman numerals (Snider, 1966), separated by laminated halite having dominantly recrystallized cumulate textures (Hovorka, 1990). Anhydrite beds I, II, and III and their overlying halite units can be traced widely over the Delaware Basin (Snider, 1966; Anderson and others, 1972), but near the Capitan Reef in the study area, the halite units pinch out or are laterally equivalent to anhydrite. Anhydrite bed IV is a composite of multiple genetic units and, therefore, the stratigraphy and facies relationships are complex over much of the Delaware Basin as well as all of the study area (Hovorka, 1990); it is therefore difficult to identify and correlate a contact between the Castile and the Salado Formations. For this study, I used a unit tentatively correlated with the lower Salado MB 134 of Snider (1966) as a genetic break between the Salado and the Castile Formations (fig. 10). This unit was selected because, based on previous work on the PDB-03 core from Pinial Dome in Loving County, Texas, Salado MB 134 was observed to be an inflection point in the gradual upward-shallowing facies observed in the upper part of anhydrite IV and the lower Salado Formation. Above this marker, fabrics indicating shallow-water deposition and intermittent exposure are dominant in the halite as well as the anhydrite. A dolomite and magnesite bed within Salado MB 134 provided a moderately traceable gamma-ray-log kick, but, in some logs close to the Capitan Reef, the position of this anhydrite had to be estimated.

The exact equivalence between the Delaware Basin units and the Midland Basin units remains somewhat problematic. Time and facies relationships require that the units equivalent to the Castile

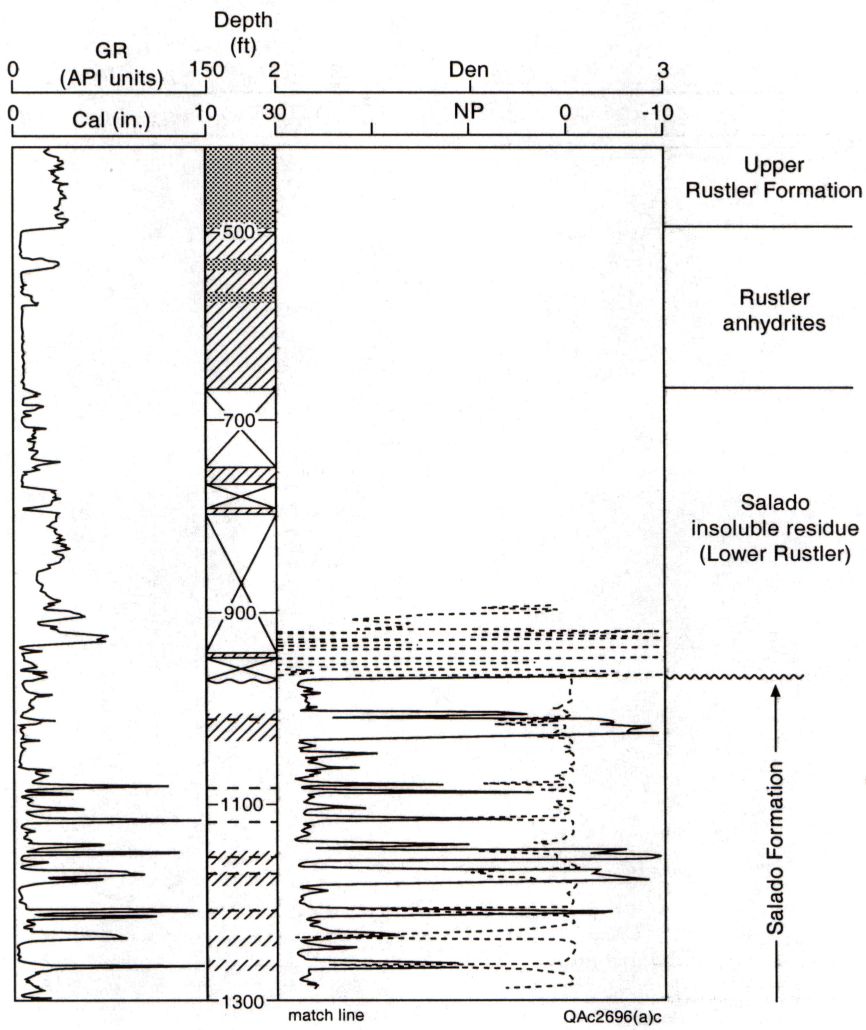

Figure 10. Type log in the Delaware Basin. Loving 1; Gulf Research PDB 03.

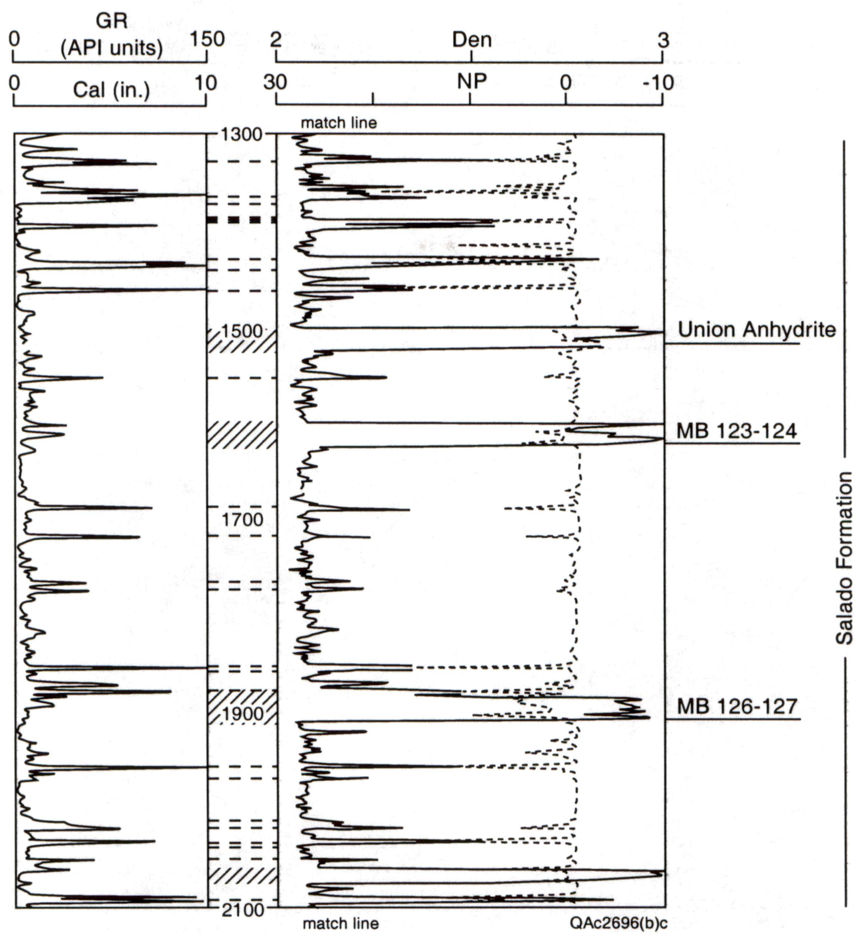

Figure 10 (cont.).

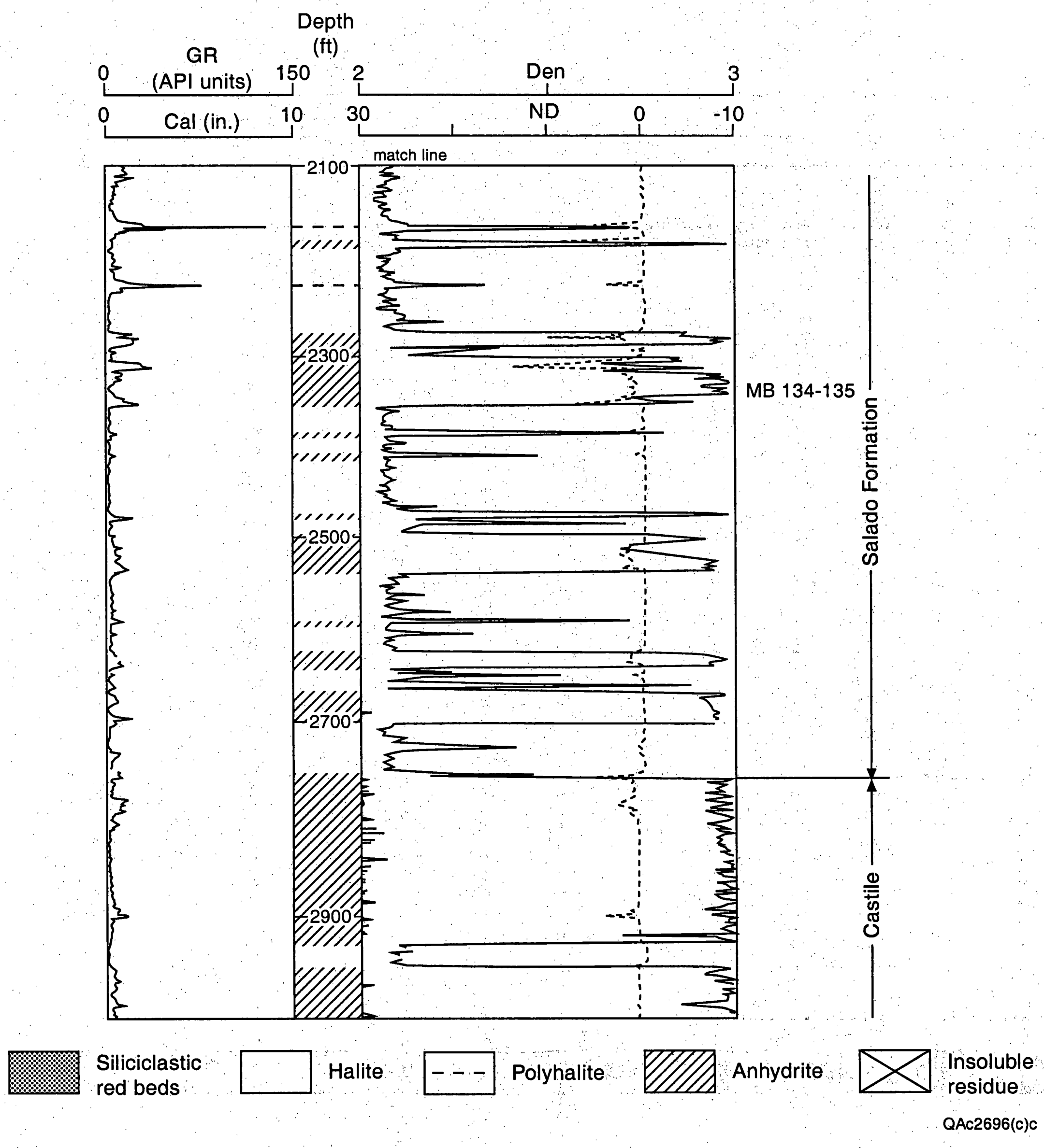

Figure 10 (cont.).

Formation are thin or missing on the shelf (fig. 11). The Castile evaporite in the basin was deposited very rapidly because of relatively high $CaSO_4$ concentrations in marine –derived evaporite brine and accommodation in the deep basin.

I interpret that the most likely stratigraphic equivalent to the Castile is the stacked high-frequency anhydrite cycles in the lower anhydritic part of the Tansill Formation (fig. 11). The lithologies in this interval (commonly called the Fletcher Anhydrite)as observed in the Gulf PDB-04 core from the Capitan Reef in New Mexico (Garber and others, 1989) include anhydrite, minor carbonate, and red mudstone. I interpret the textures in this core as the product of repeated episodes of brine-pool deposition followed by diagenetic modification of brine-pool gypsum in a vadose-to-hypersaline ground-water environment. Bottom-grown textures in gypsum have been intensely modified during exposure episodes. Red mud within the gypsum was introduced during exposure. Abundant displacive gypsum sand crystals formed in a shallow ground-water environment, further disrupting primary fabrics. This interpretation fits an interpretation of an alternately flooded and exposed shelf that accumulated condensed cycles at the same time the basin was rapidly filling with gypsum and halite.

If this correlation is accepted, then the shallow-water halite of the Salado Formation above MB134 in the Delaware Basin is approximately correlated with the halite-siliciclastic cycles at the top of the Tansill and base of the Salado Formations of the Central Basin Platform and Midland Basin. Tentative correlations of groups of Salado polyhalite beds and individual anhydrite beds can then be made from the Delaware Basin into the Salado Formation on the Central Basin Platform.

In the Delaware Basin, insoluble residue is commonly included within the lower clastic unit of the Rustler Formation (Holt and Powers, 1987). The two regionally traceable anhydrite-dolomite beds of the Rustler Formation are tentatively correlated with the two anhydrite-dolomite beds of the Alibates Formation, and similarly the siliciclastics of the Dewey Lake with upper Rustler siliciclastics. Additional stratigraphic complexity observed elsewhere in the Rustler Formation (Holt and Powers, 1987) may be important for resolving the evolution of this part of the section but is outside the scope of this study.

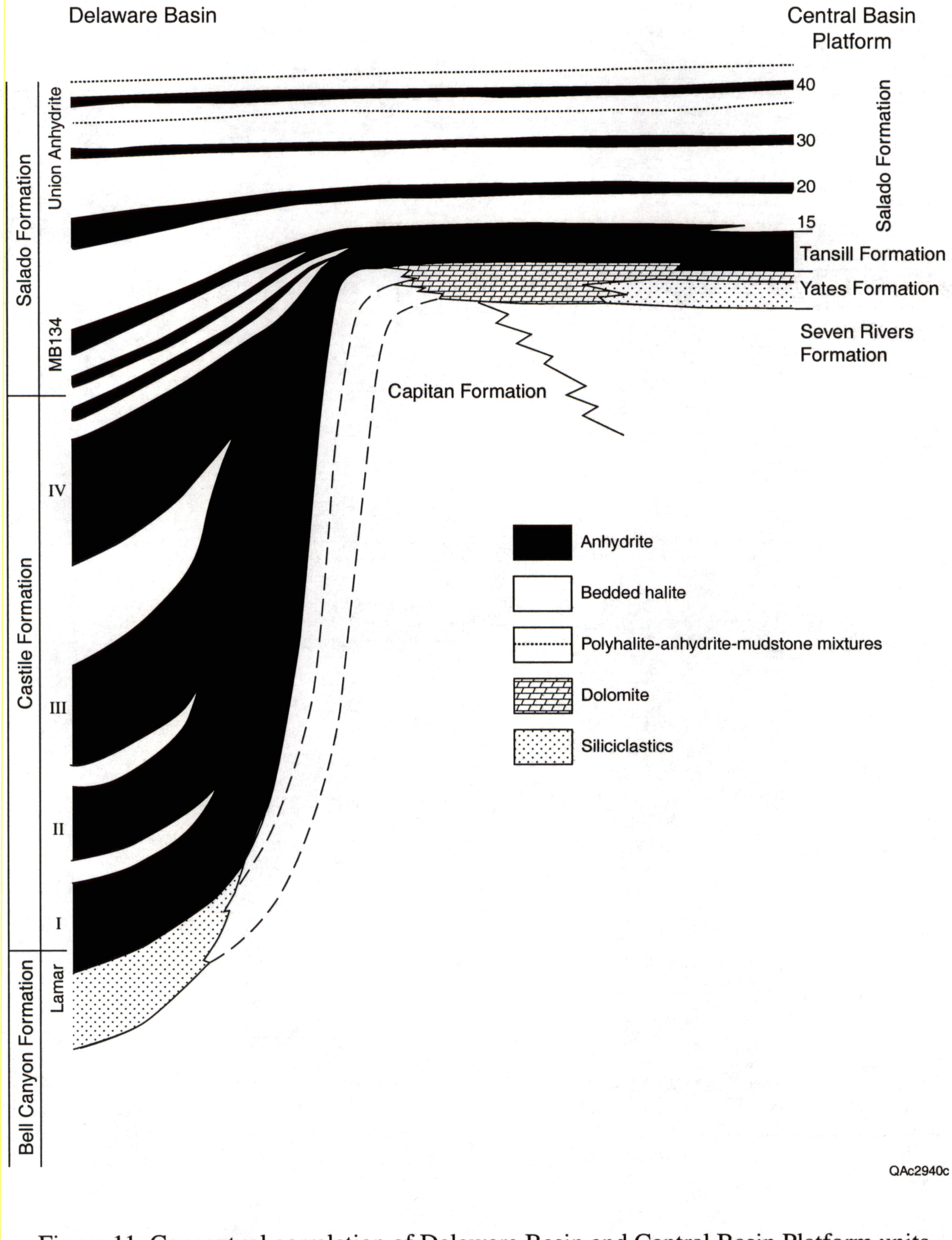

Figure 11. Conceptual correlation of Delaware Basin and Central Basin Platform units.

Stratigraphic Cross Sections: Midland Basin

Two regional cross sections were prepared to examine the internal stratigraphy of the Salado Formation and to develop a model for changes in salt thickness and salt quality observed in the Midland Basin. The north–south cross section (fig. 12) extends from the Sheffield Channel in Pecos County, across the south end of the Central Basin Platform, across the Pecos River, and up the axis of the Midland Basin to the north limit of the Midland Basin. The east–west cross section (fig. 13) extends from the east edge of the Delaware Basin across the Capitan Reef and the associated salt dissolution and collapse area, across the Central Basin Platform, the axis of the Midland Basin, and to the east basin margin.

A number of significant trends can be noted to complement the stratigraphic observations already made. These are discussed in terms of cycle styles (salt-bed thickness) and cycle continuity.

The basic genetic cycle style recognized in the Leonardian through Guadalupian of the Palo Duro Basin (Fracasso and Hovorka, 1986; Hovorka, 1994) and the Salado Formation of the Delaware Basin (Lowenstein, 1988; Hovorka, 1990) is also well displayed in the Midland Basin and provides the facies architecture needed to describe the thickness and continuity of salt beds and the distribution of impurities within them. Anhydrite beds formed during relative water-level rise form the bases of master cycles. Bundled between them are multiple intermediate cycles composed of halite, mudstone-halite, and mudstone.

The <200-ft-thick lower part of the Tansill Formation contains three to five mapped cycles of anhydrite overlain by mudstone. Log character suggests that the mapped cycles are probably composites of more thin, anhydrite-dominated cycles. Cycles lack halite except in the north and east parts of the Midland Basin, indicating that although the shelf was frequently and extensively flooded, accommodation was limited and halite either did not accumulate or was dissolved during exposure at the end of each cycle. Anhydrite thickens and contains more dolomite toward the

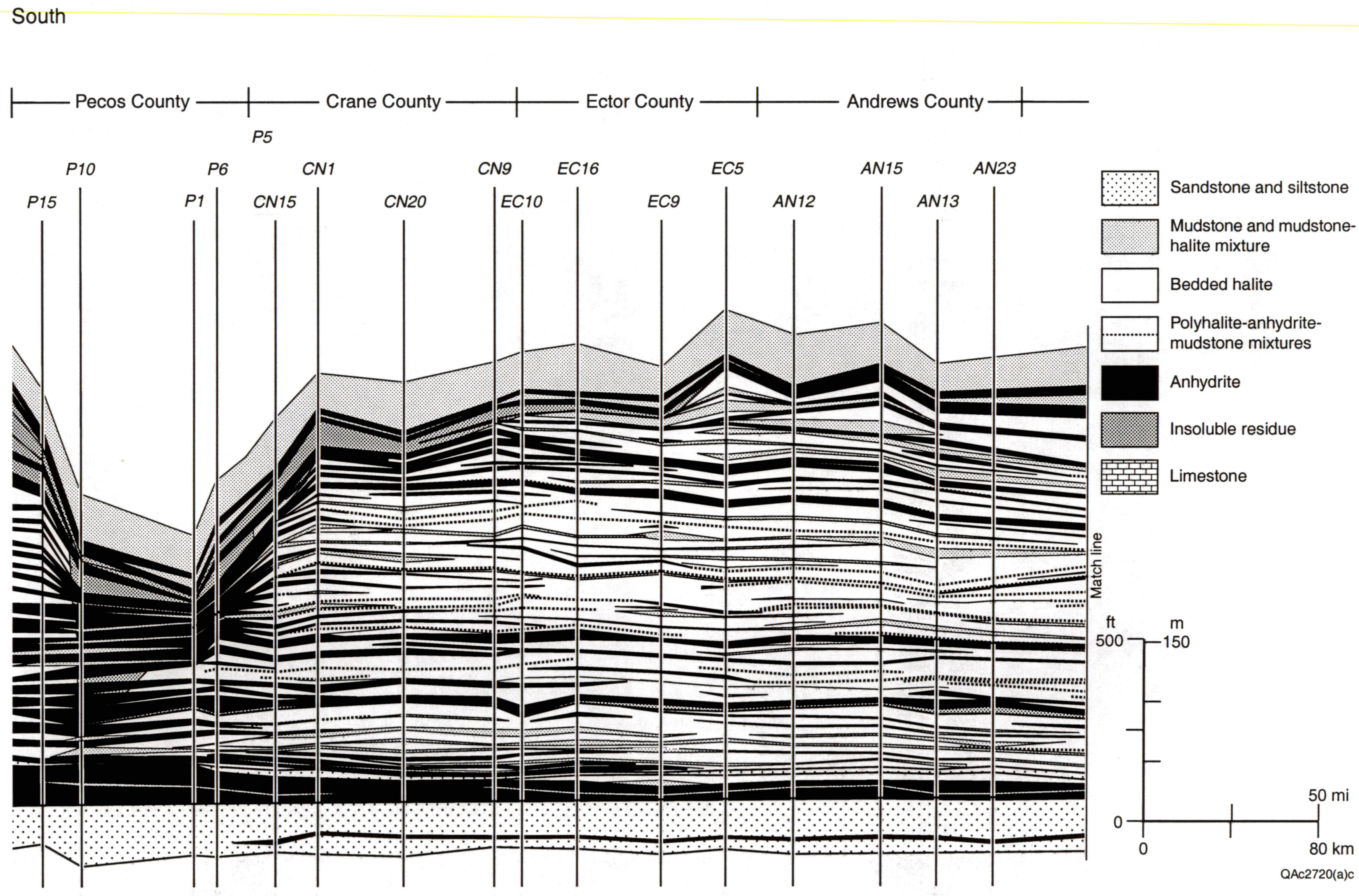

Figure 12. North–south cross section of the Salado Formation and associated units in the Midland Basin. Location of cross section shown in figure 2.

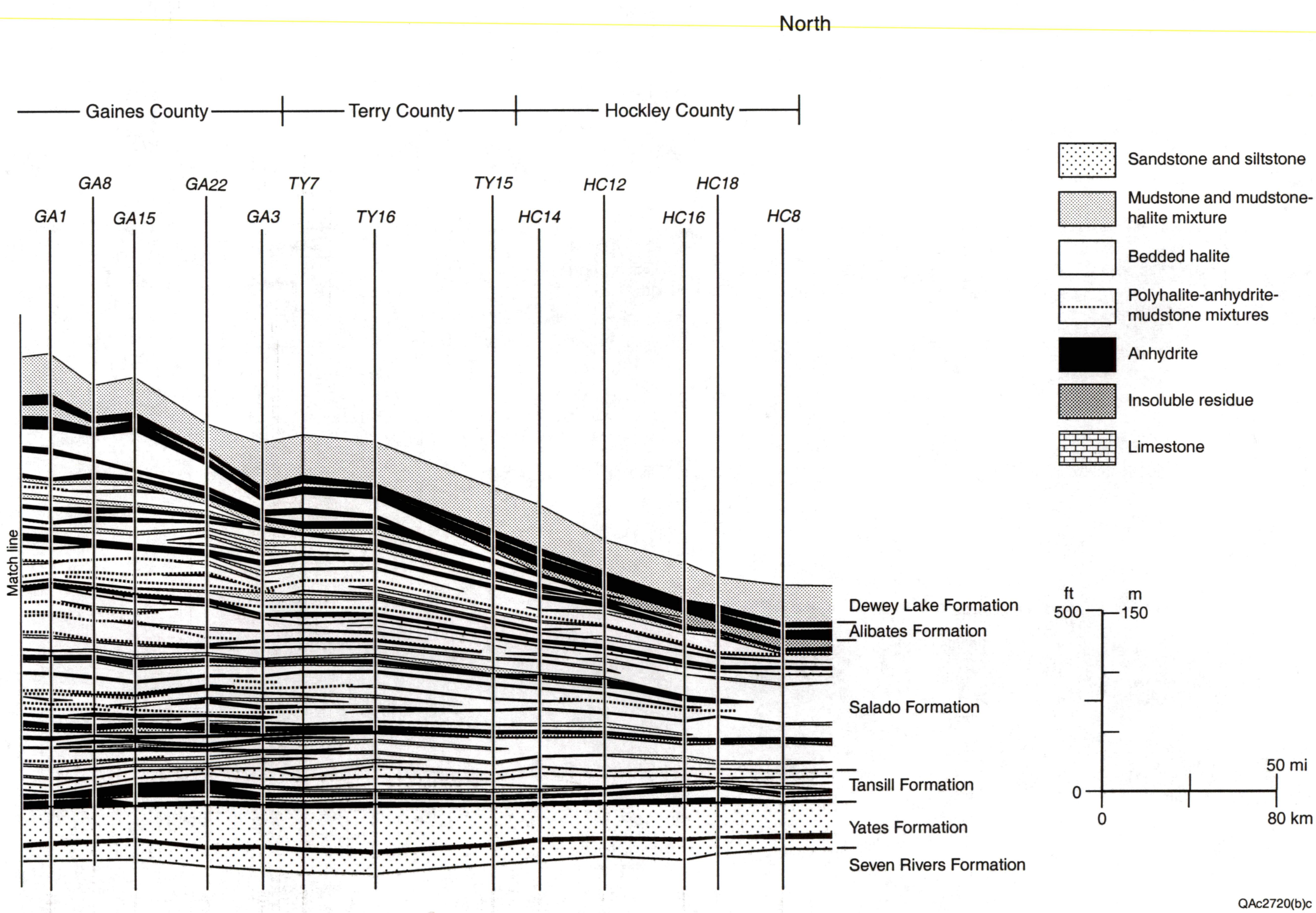

Figure 12 (cont.).

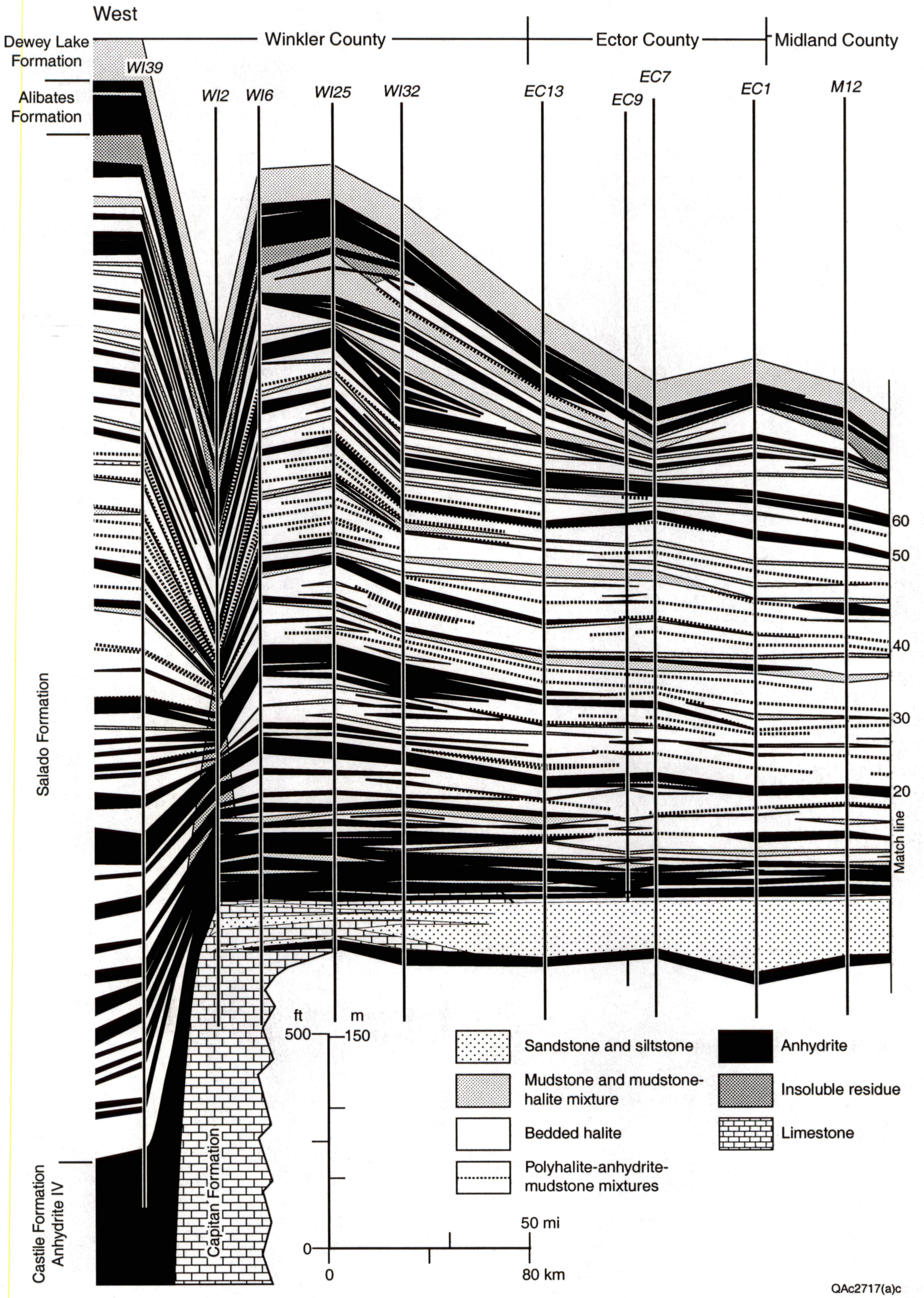

Figure 13. East–west cross section of the Salado Formation and associated units in the Midland Basin. Location of cross section shown in figure 2.

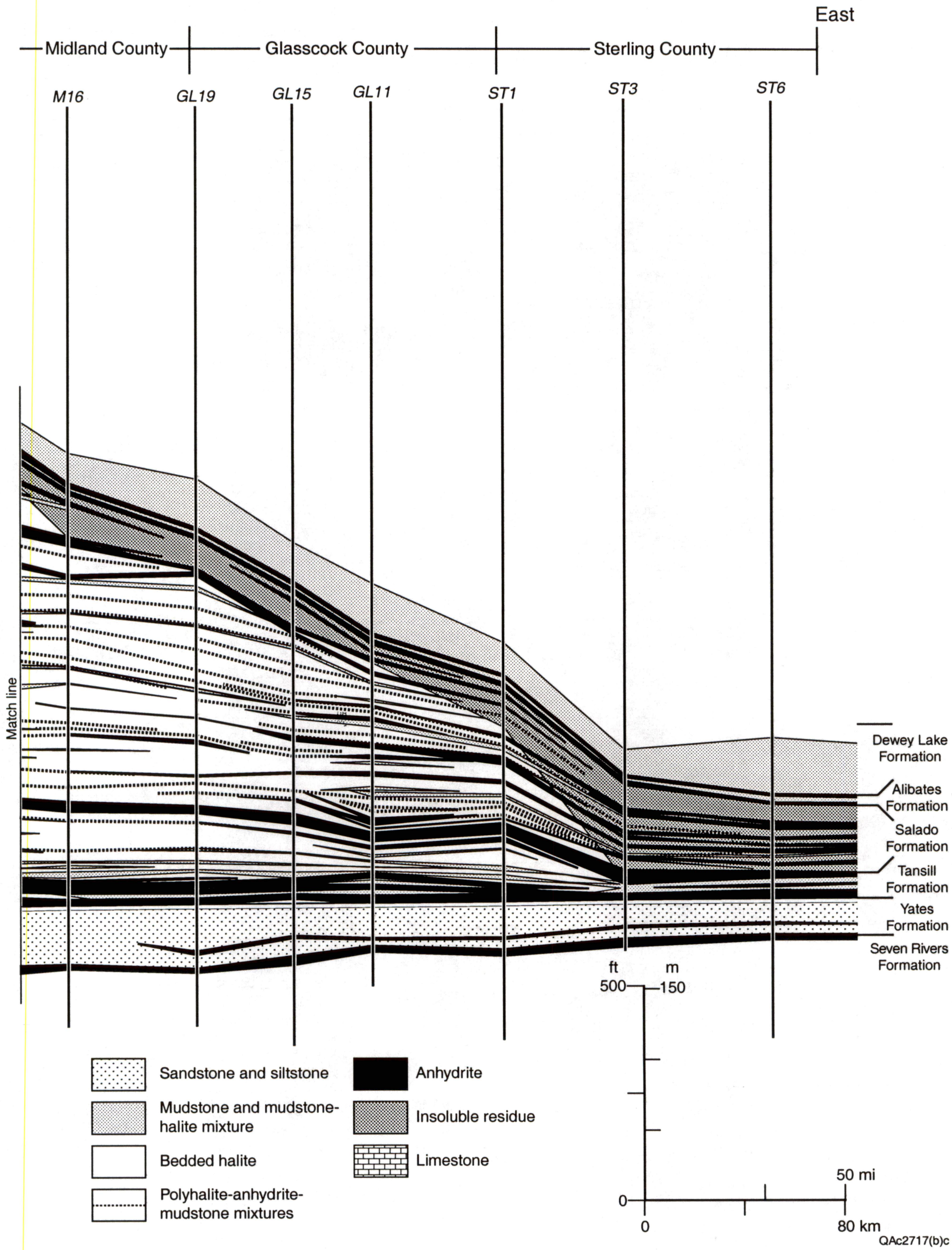

Figure 13 (cont.).

Delaware Basin and the Sheffield Channel. The upper Tansill contains three or four halite-siliciclastic cycles that thin toward the Delaware Basin and the Sheffield Channel.

The cycle pattern in Salado Formation in the Midland Basin is composed of six regionally traceable master cycles overlain by multiple complex cycles at the top. Master cycles are defined by a regionally traceable flooding event that deposited an anhydrite overlain by multiple halite-mudstone cycles. The lowest master cycle (50 to 150 ft thick) has a thin and discontinuous anhydrite or anhydrite-polyhalite bed (bed 15) at the base; the flooding event initiating this cycle was sufficient to end siliciclastic deposition characteristic of the upper Tansill cycles but only locally deposited an anhydrite bed.

The next master cycle is about 175 ft thick and is defined by anhydrite bed 20 at the base. This anhydrite bed is one of the thickest (5 to 30 ft) and most distinctive beds in the Salado Formation. A persistent siliciclastic interval, interpreted as an insoluble residue at the cycle base, gives bed 20 a distinctive log character. It is commonly labeled Cowden anhydrite on published and marked logs, but the relationship of bed 20 in the Midland Basin to the named Salado anhydrite units of New Mexico has not been investigated in this study and, therefore, that nomenclature is not applied. Five or six traceable mudstone-halite cycles are present within this master cycle, and several locally traceable thin anhydrite beds are mapped within it. Polyhalite has replaced anhydrite in several of the mudstone-halite cycles in the central Midland Basin.

Anhydrite bed 30 defines the base of the next 50- to 200-ft-thick master cycle. It shows more rapid lateral facies relationships than the underlying master cycle, including the occurrence of multiple and thicker anhydrite beds in the south part of the Midland Basin and greater changes in thickness across the Midland Basin. A maximum of nine polyhalite± anhydrite-halite-mudstone cycles are found in the thick part of the master cycle. Polyhalite replacement increases westward across the Central Basin Platform and this interval is correlated with an interval containing polyhalite beds in the Delaware Basin.

Anhydrite bed 40, which defines the base of the next 100- to 200-ft-thick master cycle, is discontinuous across the basin, and correlation of beds within this interval is therefore somewhat arbitrary. This interval contains abundant polyhalite beds that are correlated to an interval with abundant polyhalite beds in the Delaware Basin. Six to ten cycles are found in the master cycle. This bed is tentatively correlated with the Union anhydrite of the Delaware Basin (Snider, 1966).

Anhydrite bed 50 is continuous and well defined across the Central Basin Platform and Midland Basin and forms the base of the 75-ft-thick master cycle containing three to five halite-mudstone cycles. This master cycle remains fairly consistent in thickness over much of the area, forming a stratigraphic marker. The master cycle thins in the northernmost tier of counties of the study area and there, anhydrite bed 50 lies near the top of the Salado halite section. Polyhalite is minor in this interval.

Anhydrite bed 60 parallels bed 50 throughout its extent and pinches out toward the north edge of the Midland Basin. Above bed 60, the cycle pattern breaks up, and interpretation of cycle correlation is unclear. The typical character of the anhydrite bed 60 to the base of the Alibates interval varies regionally across the study area. This interval is 175 to 225 ft thick in the center of the Midland Basin (northwest Ector, east Andrews, east Gaines, and Midland Counties). There it contains two of three halite-mudstone cycles with thicker-than-average mudstone beds, overlain by several cycles with thin anhydrite beds and unusually thick (as much as 100 ft), relatively clean halite beds. In some areas halite directly underlies the lower Alibates anhydrite bed. Over the northern Central Basin Platform (west Andrews and most of Winkler County), the anhydrite bed 60 to base Alibates interval thickens, but much of it is composed of thick mudstone and mudstone-halite beds, as well as thicker anhydrite beds than in the Midland Basin. Over the southern Central Basin Platform, this interval is thinner and dominated by mudstone and insoluble residue. In the north and east parts of the Midland Basin, the interval is thin and also composed of mudstone and insoluble residue. In the Delaware Basin, several hundred feet of fairly typical anhydrite-halite-mudstone cycles with minor polyhalite are correlated with this interval.

Stacking of these master cycles produces a systematic regional thickening of halite from the north and east margins of the Midland Basin across the Central Basin Platform, toward the Delaware Basin. The conspicuous dissolution-induced variations in this trend over the Capitan

Reef, Pecos River, and south Central Basin Platform area are discussed in following sections. Inspection of cycle patterns shows no major systematic change in salt quality with respect to salt purity, bed thickness, or spacing of anhydrite beds across the Midland Basin and Central Basin Platform. Anhydrite beds are gradually thicker and more numerous toward the Delaware Basin, but changes in anhydrite-bed thickness are specific to each master cycle, and no evidence for a consistent break is identified within the limits of the techniques used.

Geometry of Salt: Midland Basin

To look at the regional geometry of salt in map view, I selected key regional markers across the study area to map. The top of the Yates Formation below the Salado salt and top of the Alibates Formation (fig. 14) above it are the best-defined regional stratigraphic markers and are used to define the geometry of the salt. The structure on the top of the Yates Formation (fig. 4) shows the sum of all the post-Guadalupian deformation in the study area. Facies in the Yates Formation siliciclastic red beds indicate that it was deposited over the entire area at an elevation near sea-level. The geometry of widespread anhydrite beds in the Salado Formation above the Yates support the concept that the Yates was deposited over a low-relief surface. However, at the end of the Guadalupian significant topographic relief was present at the Delaware Basin margin.

At present, the structural center of the Midland Basin the top of the Yates Formation lies at 500 ft below sea level. East of the axis of Midland Basin, the top of the Yates Formation rises toward elevations of 2,000 ft above sea level in the Permian outcrop area in the Rolling Plains. Several areas of anomalous structure are noted within the Midland Basin: an isolated uplift in Reagan County; a closed depression in Midland County; and several uplifts and a depression at the Howard-Glasscock High. The top of the Yates also rises to 1,500 ft at the Matador Arch that defines the north edge of the Midland Basin. Elevation of the Yates Formation rises abruptly over the Central Basin Platform on the south and east edges of the Midland Basin, reaching 1,000 ft above sea level over the north part of the Central Basin Platform and 1,800 ft above sea level in the

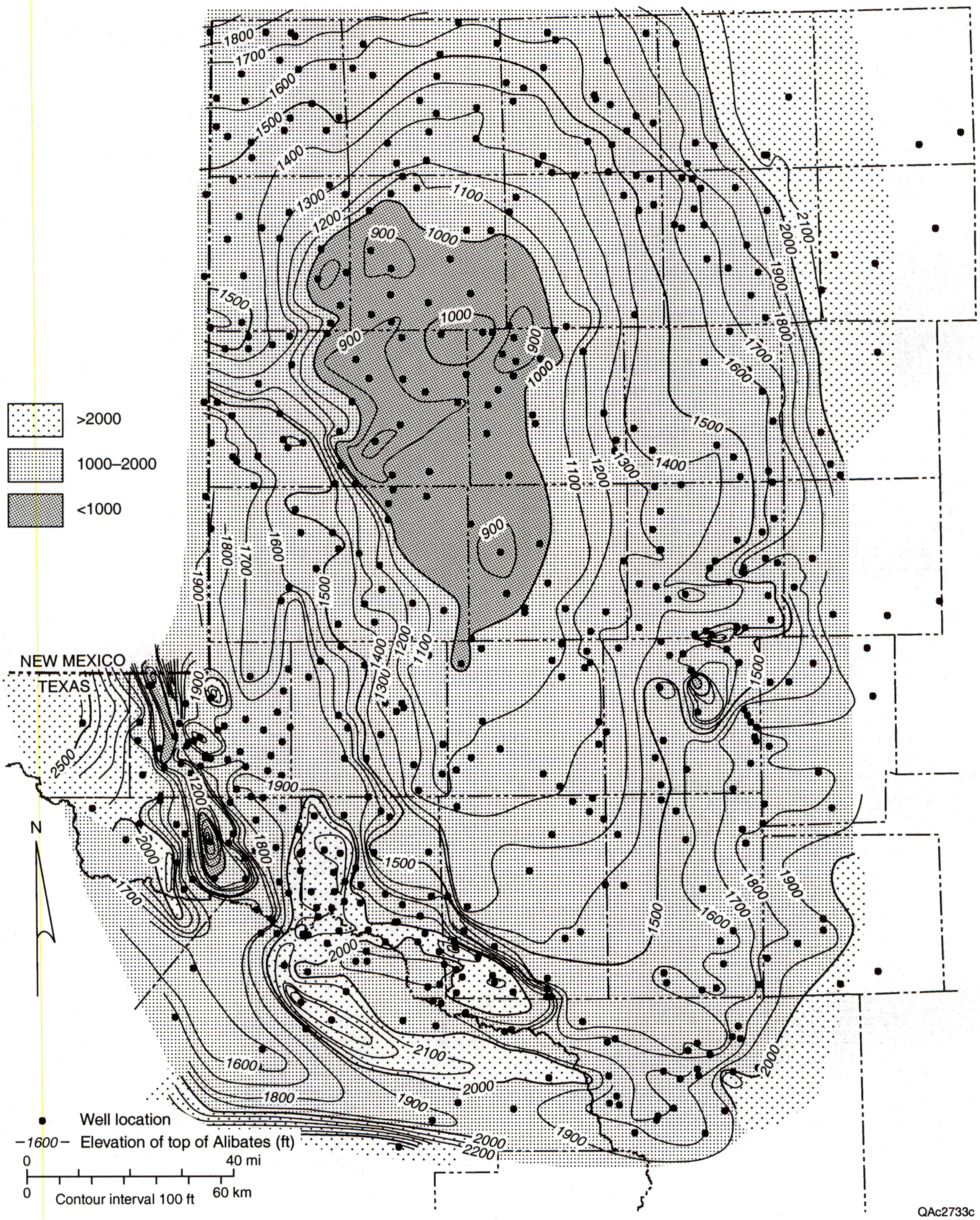

Figure 14. Structure on the top of the Salado salt-bearing interval. Top Alibates Formation and equivalent top of upper Rustler anhydrite are used as markers. Prominent salt-dissolution features can be identified in Winkler, Ward, and Howard counties.

south edge of the Central Basin Platform. The complex pattern of uplifts that defines the structure of the Central Basin Platform and creates numerous structural traps is apparent even in the generalized regional view shown.

Structure on top of the Alibates (fig. 14) shows the effect that deposition and partial dissolution of bedded salt as well as postdepositional structural deformation had on the overlying stratigraphic marker. All of the major structural elements identified in figure 4 are also visible on the top Alibates structure, showing that the major components of the deformation postdate Alibates deposition. Many structural features, for example the east edge of the Central Basin Platform, are more subdued on the top Alibates structure than the top Yates structure, showing that some of the deformation seen on the Yates occurred during Salado deposition and created accommodation reflected in Ochoan thickness. Synsedimentary structure influences the Alibates-Salado Tansill isopach (fig. 15), which shows a general area of thick accumulation along the present structural axis of the Midland Basin. Comparison of the map view with cross sections shows that much of this thickening results from a combination of (1) regional thickening throughout the Salado from the north and east basin margins toward the west and (2) accumulation of thick Salado units at the top of the formation above bed 60.

The thickest interval in the Alibates-Salado Tansill isopach (2,000 to 4,000 ft) is in the Delaware Basin in the southwest part of the study area (western Pecos, Ward, and Winkler counties). The lower half of this interval is composed of anhydrite and halite of the Castile Formation. A thick Ochoan interval (>1,200 ft) also fills the San Simon channel (western Gaines County).

In addition to the structural elements seen on the top Yates structure map, the top Alibates structure map (fig. 14) and Alibates-Salado Tansill isopach map (fig. 15) show additional depressions corresponding to salt thins. One deep depression on top Alibates and thin in the isopach is found in central Winkler and Ward Counties. This corresponds to regionally mapped thin, absent, and dissolved salt along the Capitan Reef trend (Girard, 1952; Hiss, 1976; Baumgardner and others, 1982; Johnson, 1987; 1989a). Depressions are also found along the

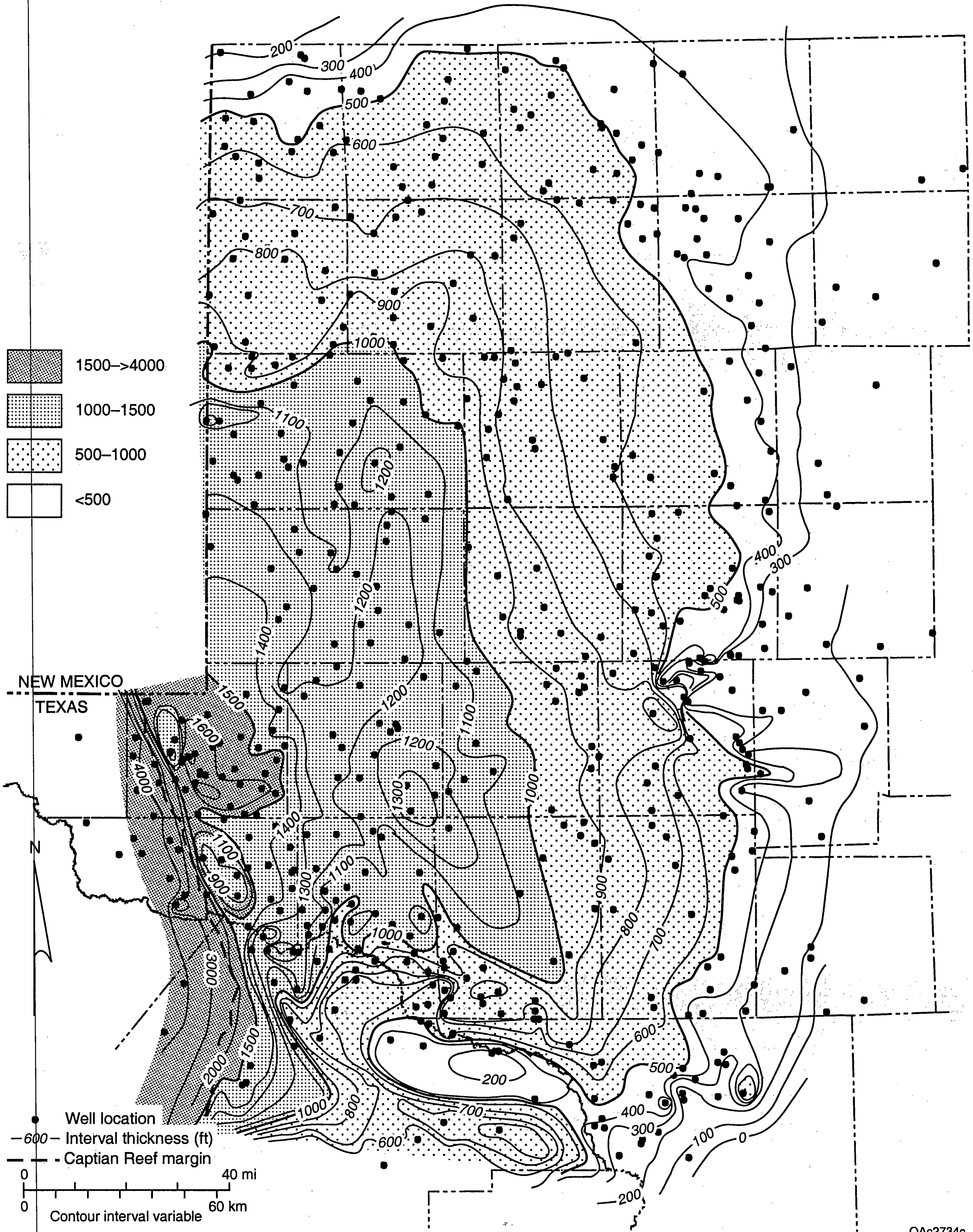

Figure 15. Thickness of interval containing Salado salt from the top of Alibates Formation and equivalent top of upper Rustler anhydrite to top of Yates Formation and top of Lamar Limestone.

Capitan Reef trend into New Mexico (Bachman, 1984; Hiss, 1976). Southward along a related trend is a large depression in the Alibates structure and corresponding thin in the Alibates-Salado-Tansill interval that lies above the south part of the Central Basin Platform in east Pecos and west Crockett counties extending east to the Yates oil field area (Adams, 1940; Wessel, 1988a; 1988b; 1992a; 1992b).

Other areas of thinning over short distances are noted over structural features marking the Midland Basin margins. Thinning is noted in Crockett County over the Ozona Platform. Regional cross sections (Humble Oil and Refining Company, 1960; 1964a; Vertrees, 1962–1963) show erosional truncation of the Permian beneath the Cretaceous in this area. Thinning of the interval to 300 or 200 ft corresponds to complete dissolution of the salt in the interval toward its truncated edge, leaving only the Tansill, Alibates, and insoluble residue after salt dissolution.

The trend of thinning of the salt-bearing interval continues along the eastern shelf (Reagan, Glasscock, Howard, Borden, Garza, and Crosby Counties). Depositional thinning, salt dissolution, and erosional truncation beneath the Cretaceous and toward the outcrop are all factors in this thinning. Some areas of abrupt lateral thinning and complex geometries are noted in Glasscock and Howard counties, generally corresponding to a structurally high area (Humble Oil and Refining Company, 1960; Vertrees, 1962–1963; Geomap, 1986). Another area of salt thinning lies south of the Howard-Glasscock high. The thin area in the isopach is on the north side of a structural depression in both the top Yates and top Alibates structure, so that both the closed depression in the top Alibates is larger than in the top Yates because the interval thins along the northeast edge of the structural depression. A general trend in salt thinning continues around the north of the Midland Basin along the Matador Arch and Northern Shelf structural and depositional positive elements. No areas of abrupt thinning were noted in this area.

A map showing the depth of the Alibates below the surface (fig. 16) was prepared as a simple way of separating the areas where active salt dissolution processes are probable (near surface settings) from areas where salt thinning may be relict from paleohydrologic conditions (deeply buried). Salt occurs near the surface (<1,000 ft deep) along the east edge of the study area and

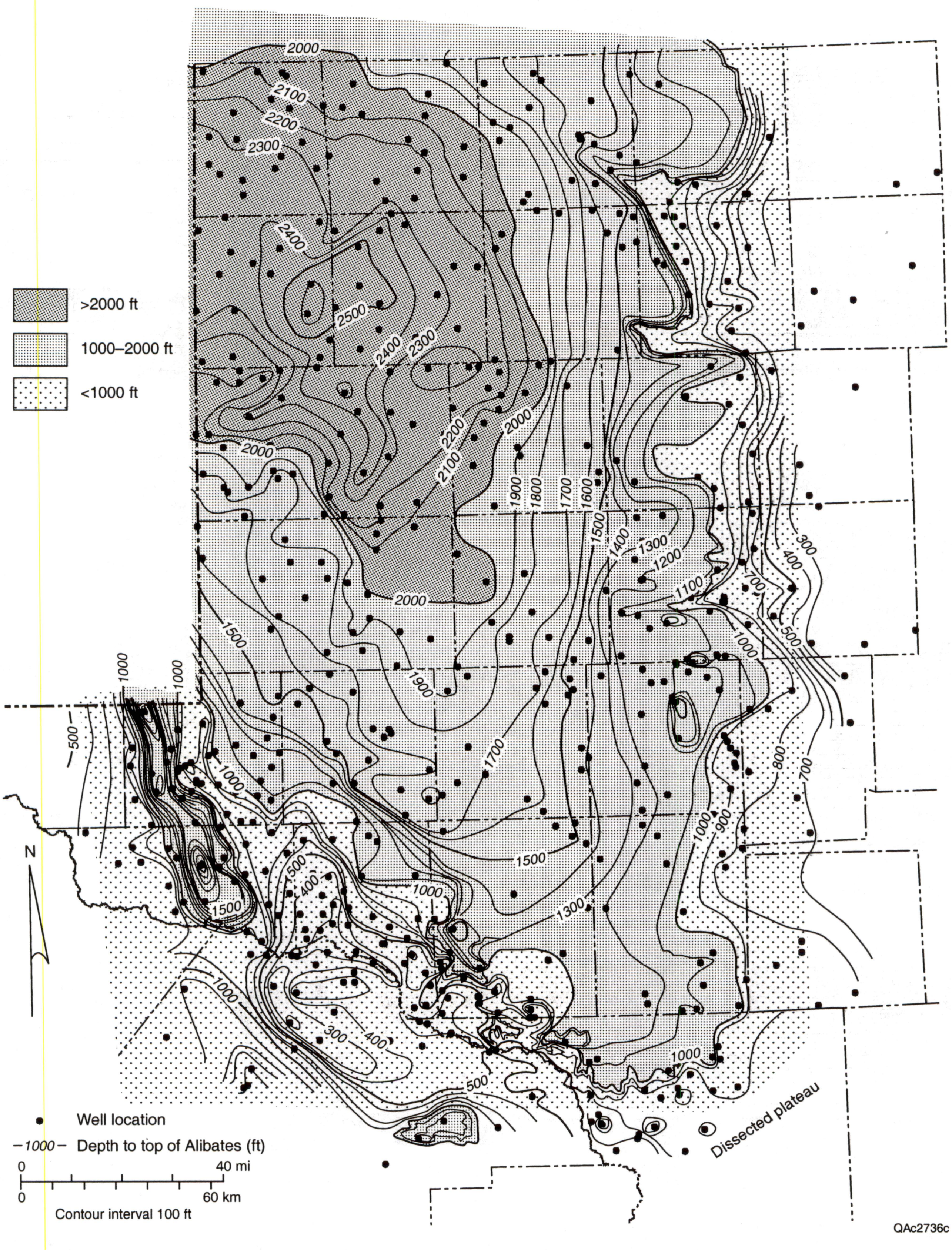

Figure 16. Generalized depth to top of Salado salt-bearing interval from approximate land surface based on log datum and generalized 1:250,000-scale topographic maps to top Alibates Formation.

along the trend of the Central Basin Platform, especially in Crane and north-central Pecos Counties (Yates oil field area). Salt is deeply buried by Triassic and Tertiary sediments along the Midland Basin, Northern Shelf, and Matador Arch structural elements. There is a prominent increase in depth to salt that corresponds to the prominent salt thin (fig. 15) and depression in the top Alibates structure (fig. 14) in central Winkler and Ward Counties. In the western Delaware Basin, burial to the top of the salt-bearing interval is moderate, generally >1,000 ft, but complicated by dissolution along the course of the modern and paleo Pecos River (Bachman, 1984).

Log quality was sufficient to directly measure the amount of Salado salt in 55 logs in the study area, generally because caliper-log response made it possible to reproducibly separate anhydrite from clean salt. Uncertainties remain in distinguishing mudstone-halite mixtures from mudstone in wells where the borehole has been enlarged in both lithologies. Additional measurement uncertainty is introduced by imprecise bed-thickness estimates in typical finely interbedded lithologies. Comparison of measurements from adjacent logs suggests that error of about 5 to 10 percent in measuring cumulative salt thickness is expected. In addition to measured salt thickness, dramatically thinned intervals with high gamma-ray-log response were interpreted as beds from which halite has been dissolved and used for defining the top of salt. From measured salt thickness, the percent of salt from the salt-bearing intervals was calculated, and results ranged from 53 to 84 percent. The salt-bearing interval selected for this calculation was a minimum, from top salt to top Tansill . This removes the insoluble material in the Alibates and above-salt insoluble residue and variable amounts of anhydrite and siliciclastic beds in the Tansill from the calculation. Typical values of percent salt were contoured, with the lowest percent salt (<70) over the Central Basin Platform and the highest percent salt (>75) toward the north and east updip edges of the Midland Basin (fig. 17). Inspection of the cross sections (figs. 12 and 13) suggests that thicker and more abundant anhydrite beds are the reason for increased impurities on the Central Basin Platform; in updip areas, decreased anhydrite bed abundance and thickness is partly but not wholly offset by increased abundance of siliciclastic beds.

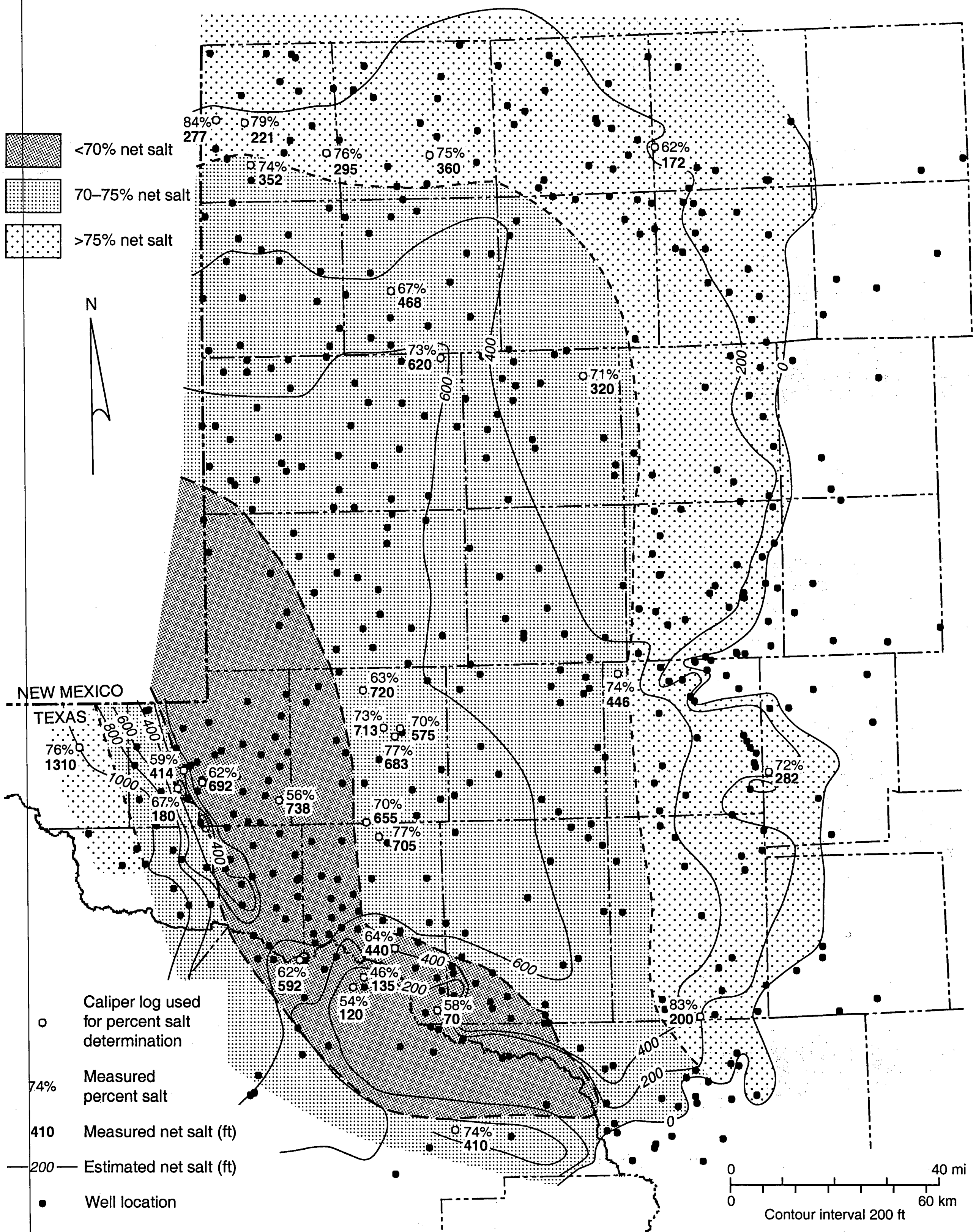

Figure 17. Salado net salt and percent salt. Direct measurements of cumulative salt-bed thickness from wells with caliper logs in useful log suites are posted. Percent salt is calculated on the interval from top upper Tansill (marker 15) to the top of salt. Other thickness values are based on regional percent-salt average and the top salt to top Tansill interval thickness where it could be determined.

The generalized percent salt in the salt-bearing interval was then used to estimate the salt thickness in logs from which salt beds could not be directly measured. The thickness from top salt to top Tansill siliciclastics was multiplied by the decimal percent salt mapped for the area and the estimated salt thickness calculated. In some logs top salt or top Tansill was difficult to pick and no value was posted. Resistivity logs are particularly useful in defining this interval because the salt section has low permeability and, therefore, has high resistivity, in contrast to the conductive saline-water-bearing insoluble residue and Tansill siliciclastics. The Alibates-Salado-Tansill isopach was used to guide the contouring of the net salt (fig. 17), and a large contour interval was used because of the measurement uncertainties.

The net salt map, like the Alibates-Salado-Tansill isopach, shows thick salt in the Midland Basin Center. Even though the percent salt decreases slightly over the Central Basin Platform, the net salt continues to increase because the Salado thickness increases toward the Delaware Basin. In the Delaware Basin, the base of salt stratigraphically equivalent to the Salado Formation of the Midland Basin was approximated using the top of MB134, as the base of the Salado shows a moderate thickness increase. Salado thickness in the Delaware Basin is the result of increased accommodation in a dominantly shallow-water environment in a subsiding basin.

Toward the east margin of the Midland Basin, the net salt decreases fairly abruptly between 200 and 0 ft of salt, and this is where the depositional trend toward decreased interval thickness is overprinted by cross-cutting near-surface salt dissolution. A large zero-salt area is mapped over the south end of the Central Basin Platform and a small area is mapped over the Howard-Glasscock High. Thin salt was intersected by wells in the depression over the Capitan Reef, so in this area salt has not been completely removed.

EVALUATION OF SALT: PROCESSES

The number, thickness, and purity of salt beds reflects the cumulative effects of depositional processes, early modification, and multiple episodes of subsurface dissolution. In this section, I document the relationships between processes in the sedimentary and burial environment and their effect on salt quality.

Depositional Processes

Initial variations in thickness and quality of salt are introduced in the depositional environment. Sedimentary fabrics in halite (Hovorka, 1994) show that halite is typically deposited rapidly, producing large clear crystals. Impurities are introduced when environmental conditions shift, and halite deposition pauses. In shallow water, halite precipitates on the brine pool floor as crusts of crystals that average a centimeter in height (fig. 18b). When the brine pool is flooded by less highly evaporated marine water or by fresh rainwater (fig 18a), minor amounts of halite dissolve from the floor of the brine pool. Impurities within the halite accumulate as a lag on the brine pool floor. If the floodwater is marine, a thin bed of gypsum commonly precipitates before halite precipitation resumes (fig. 19). When the water level in the evaporite basin falls below the surface of previously deposited halite, halite is exposed to vadose processes (fig. 18c). Halite is dissolved by rainwater and dew and reprecipitates from shallow ground water as cements and displacive crystals and capillary crusts (fig. 20a). Dissolution forms microkarst pits several feet deep (fig. 20b). Siliciclastic mudstone is transported across the dry flat by eolian and sheetwash processes and is concentrated because of halite dissolution. Repeated dissolution and precipitation of halite in this low-accommodation environment creates chaotic mixtures of halite and mudstone (Handford, 1982; Rosen, 1989).

In contrast, syndepositional dissolution is suppressed in high-accommodation settings. In water more than a few feet deep, both precipitation and dissolution on the basin floor are limited. The dense, stratified brine reduces communication between the surface of the water mass, where

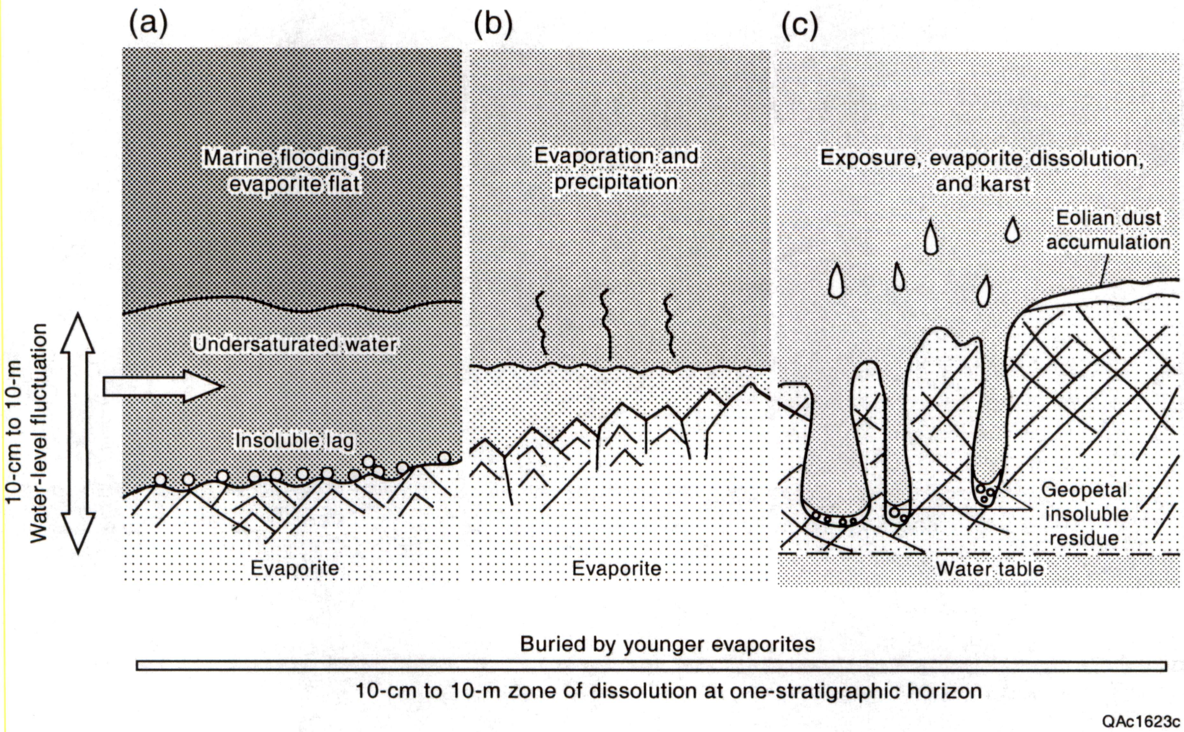

Figure 18. Dissolution processes active in the salt-depositional environment. (a) Marine water flooding a shallow-water halite brine pool, resulting in dissolution of previously deposited halite. (b) Halite precipitation in a brine pool. (c) Halite dissolution, development of karst, and accumulation of siliciclastics transported by eolian and surface transport.

(a)

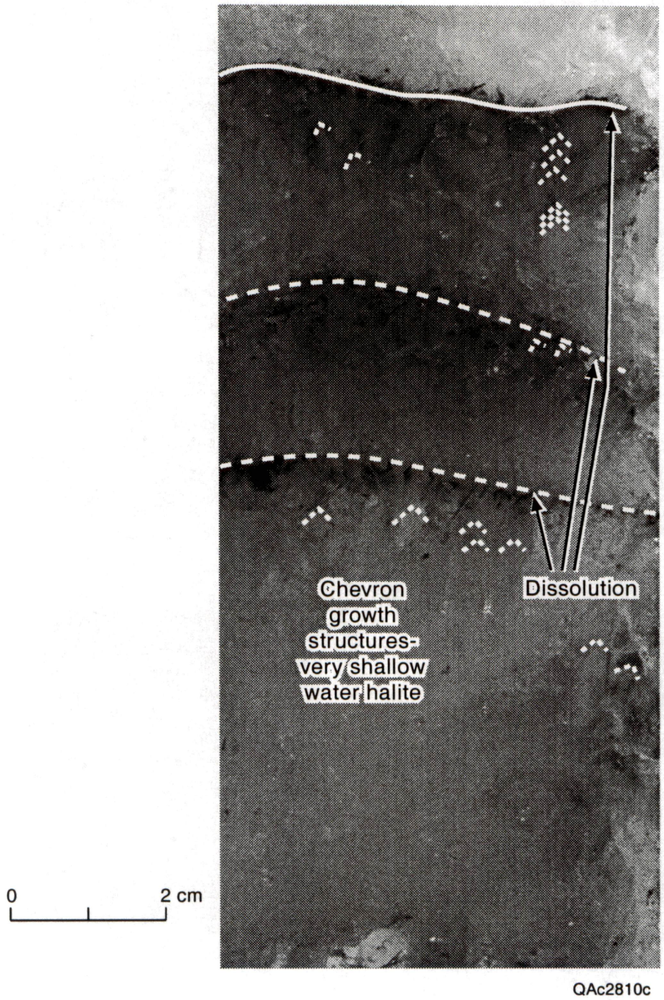

Figure 19. Halite dissolution in the depositional environment as a result of flooding. Halite on the brine-pool floor dissolved when the flat was flooded by marine water. (a) truncation of halite crystals contain chevron-grown structures defined by fluid inclusions, accumulation of impurities forming dark bands in Gulf PDB 03 core, 2,398 ft below datum.

(b)

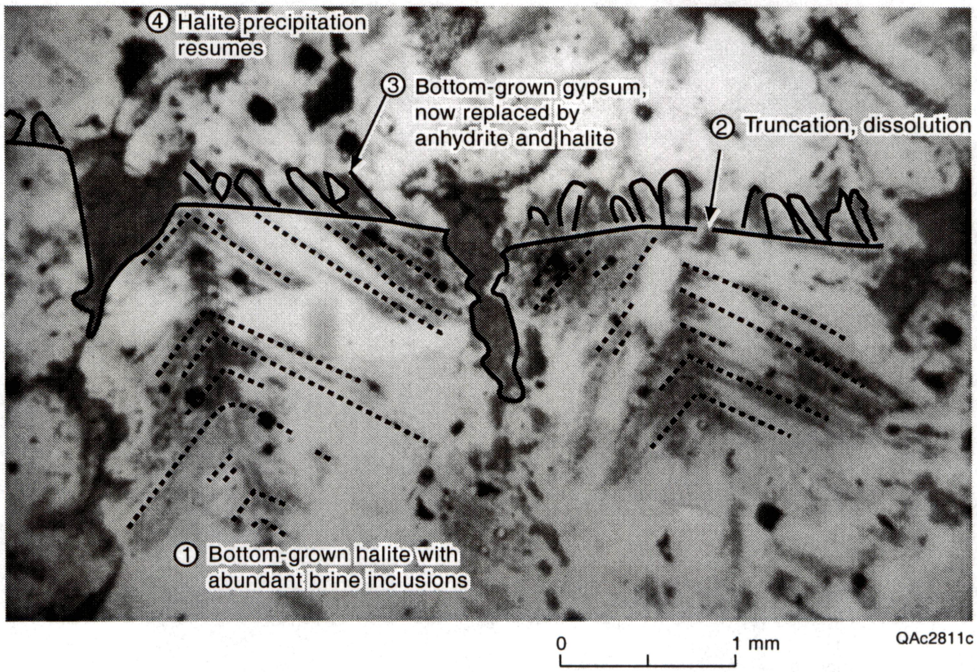

Figure 19 (cont.). Halite dissolution in the depositional environment as a result of flooding. Halite on the brine-pool floor dissolved when the flat was flooded by marine water. (b) Photomicrograph showing dissolution of halite (note truncated growth bands defined by fluid inclusion), followed by precipitation of gypsum (now replaced pseudomorphically by anhydrite and halite) before halite precipitation resumed. DOE-Stone and Webster G. Friemel core, 2,522 ft below datum.

(a)

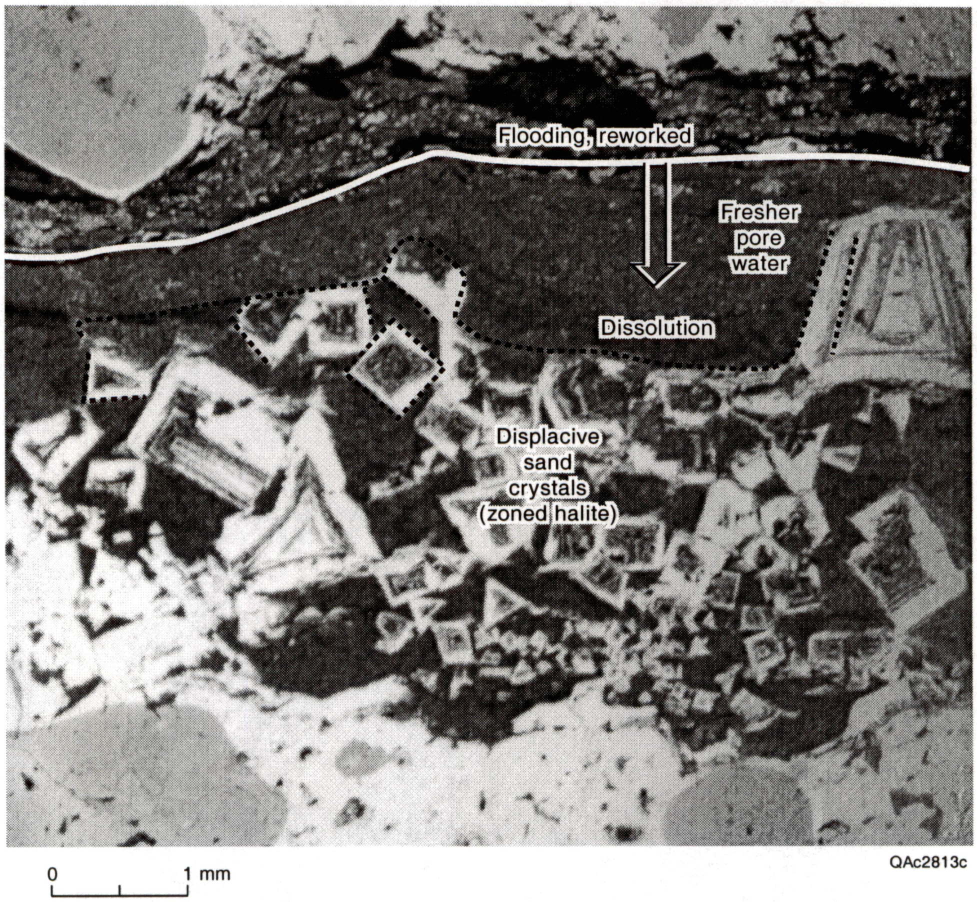

Figure 20. Halite dissolution in the depositional environment as a result of exposure. (a) Photomicrograph of displacive halite formed by ground-water precipitation in sandstone, then dissolved by fresh water that flooded the surface. Dissolution of overlying halite has formed an insoluble residue. Gruy Federal Rex White, 1,879 ft below datum.

(b)

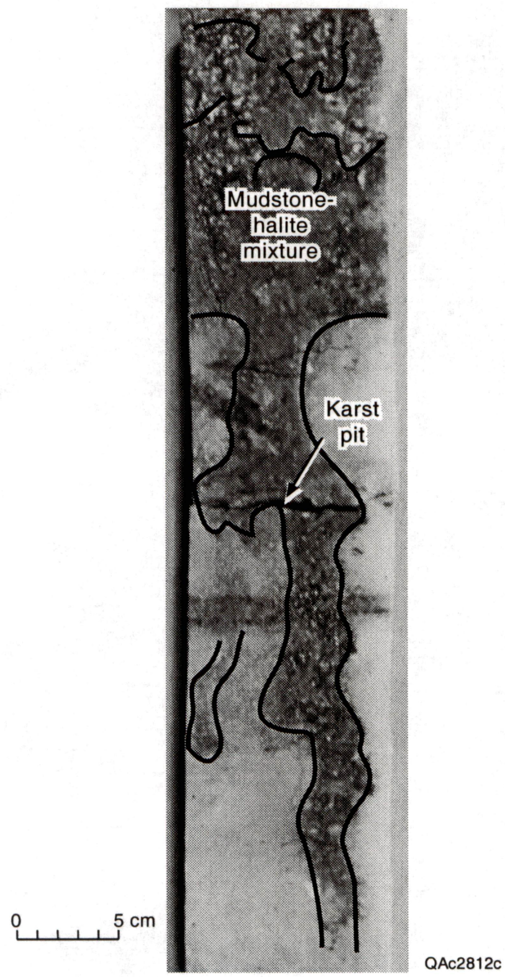

Figure 20 (cont.). Halite dissolution in the depositional environment as a result of exposure. (b) Karst pit dissolved in halite in the vadose environment during exposure is filled with mudstone and displacive halite. Core from DOE Stone and Webster G. Friemel, 2,531.7 ft below datum.

evaporation and dilution occur, and sediments on the brine pool floor. Halite precipitates at the brine-air interface where it forms floating crystals and rafts of crystals (Hovorka, 1994). These crystals founder and form cumulates of millimeter-diameter crystals on the floor of the water body. When less saline water floods a deep-water basin, it floats on top of the dense brine already present and does not dissolve previously precipitated halite on the floor of the water body. Gypsum that precipitates at the surface as floodwater evaporates falls to the basin floor as another cumulate layer, forming finely laminated, fine-grained halite with anhydrite laminae. Castile halite units in the Delaware Basin exhibit this deep-water texture and document the rapid accumulation of evaporites when accommodation is not limited by water depth (Hovorka, 1990).

Based on understanding of the effects of depositional environment on salt quality in the Palo Duro and Delaware Basins we can infer the effect of synsedimentary dissolution on salt quality in the Midland Basin. Observed updip increases in the amount of mudstone-halite and mudstone beds (fig. 12 and 13) is related to decreased accommodation and increased exposure in these settings. Gradual thinning of salt beds toward the basin margins is also most likely related to accommodation by a synsedimentary dissolution mechanism. Increased salt-bed thickness as well as relatively high salt purity are expected in areas of high accommodation such as the Delaware Basin.

Base of Cycle Dissolution

Dissolution also occurs at the base of high-frequency cycles and at sequence boundaries (fig. 21). Influx of marine water during short- or long-term sea-level rise partly or completely dissolves the salt from the top of the previous cycle, and forms an insoluble residue at the base of the transgressive deposit (fig. 21a). Insoluble residues are composed of disseminated impurities and mudstone and anhydrite interbeds from halite (Hovorka, 1994). As halite is dissolved from the top of the bed by undersaturated water, impurities accumulate first as a lag on the floor of the water body, and then as dissolution proceeds downward, as wavy-laminated impurities accreted to the

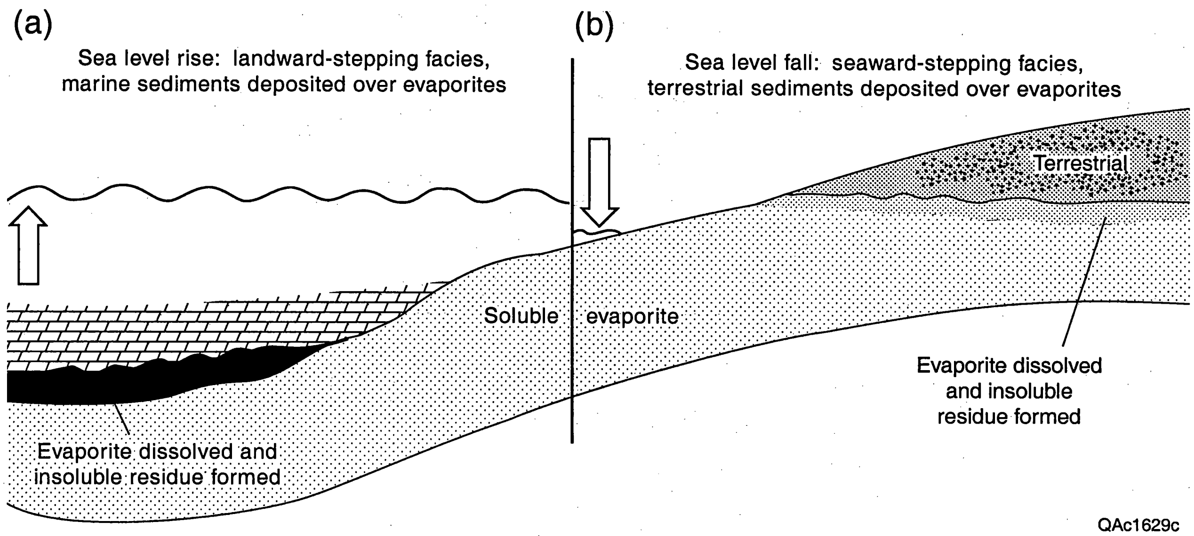

Figure 21. Dissolution at the bases of cycle or sequence. (a) Dissolution of halite from the top of the previous cycle during transgression. (b) Dissolution of halite from the top of the previous cycle during regression.

bottom of the insoluble residue bed (fig. 22). Criteria for recognizing base of cycle dissolution are (1) a concentration of insoluble impurities at the base of a transgressive deposit and (2) distinctive accreted wavy-laminated texture. Under ideal circumstances, a relationship can be observed between the residue thickness and the amount and duration of freshening in the overlying cycle, so that thick residues are found downdip beneath thick carbonate beds, and thin residues are found updip beneath thin anhydrite beds (Hovorka, 1994). Dissolution of halite during transgression increases accommodation and bed thickness for the sediments deposited during transgression.

The mudstone bed at the base of Salado anhydrite 20 in the Midland Basin is tentatively identified as a base-of-cycle insoluble residue. Across the Central Basin Platform, base-of-cycle dissolution during transgression is the probable mechanism for forming abundant, relatively thick anhydrite beds in the Salado Formation (figs. 12 and 13). Multiple episodes of base-of-cycle dissolution is the mechanism proposed for reducing the percent halite to <70 across the Central Basin Platform (fig. 17). This is an area where subsidence during Salado time created high accommodation (fig. 15).

Freshening of ground water at the base of a regressive depositional sequence can also result in dissolution of halite (fig. 21b). A probable example of this process may be seen in the upper part of the Salado Formation above bed 60. Several episodes of accumulation of anhydrite beds and thick halite units along the structural axis of the Midland Basin are seen in cross section (figs. 12 and 13). Salado facies equivalent to this interval along the north and east parts of the Midland Basin are thin mudstone beds or muddy insoluble residue. Marginal areas may have had salt dissolved while thick salt accumulated in the basin center. This interpretation is made uncertain by the probability that this interval has been attacked by undersaturated water at later times, during Alibates or Dockum deposition.

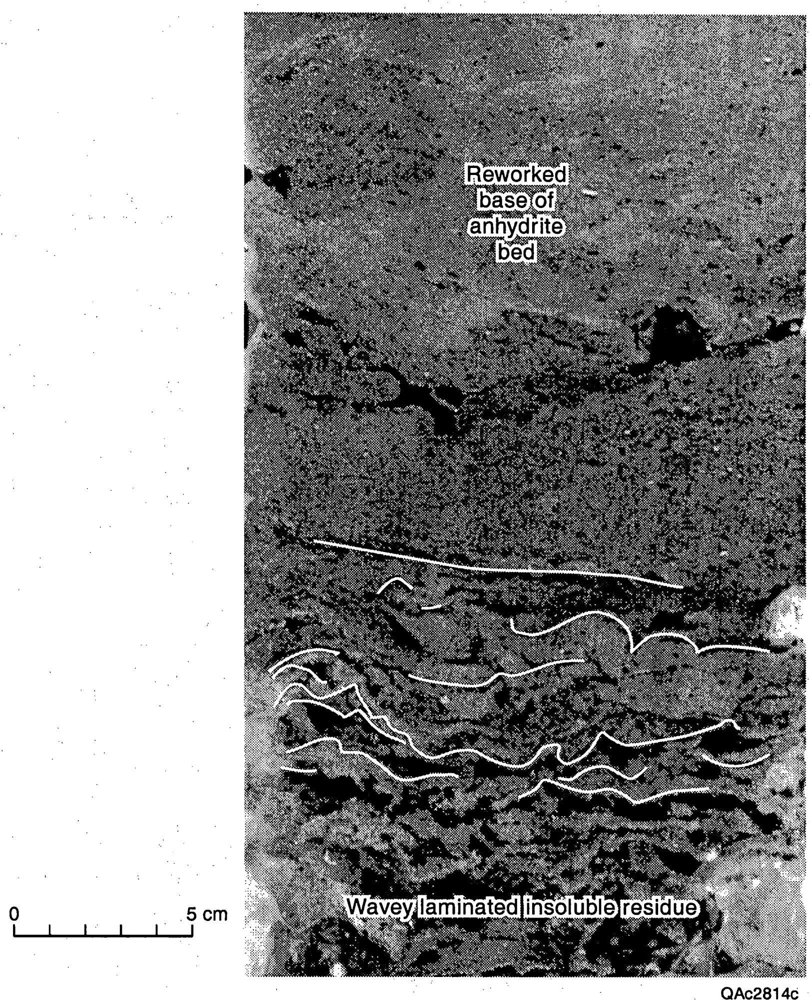

Figure 22. Wavy-laminated base-of-cycle insoluble residue. This is one of the lowest Salado cycles in the Delaware basin to exhibit base-of-cycle residue, and indicates that sediment accumulation has shallowed that basin to the depth at which dissolution can occur. Gulf Research PDB-03 core, 2,360 ft below datum.

Post-Permian Salt Dissolution under Burial Conditions

Halite that accumulated in Permian evaporite environments came under attack by undersaturated ground water after evaporite-forming conditions ended. The rate and process by which burial dissolution occurs depends on the rate and direction of ground-water flow.

Commonly, undersaturated ground water moves downward at recharge areas, horizontally for long distances through aquifers, and upward at discharge points. Where salt has been dissolved in this kind of ground-water regime, the upper surface of the salt approximately parallels the flow lines and lies at a low angle to the land surface. One example of this geometry is seen in the Palo Duro Basin, where the top of salt lies at 800 to 1,000 ft in depth and approximately parallels the low-relief Southern High Plains surface (fig. 23). This salt-dissolution surface regionally crosscuts stratigraphy, so that in the northwest, the Seven Rivers Formation is the uppermost salt-bearing unit and overlying salts have been slowly dissolved; down hydrologic gradient to the southeast Salado halite is partly preserved.

The processes involved in salt dissolution are phased depending on how long the evaporites have been in contact with invading undersaturated ground water (fig. 24). These phases were identified during examination of suites of cores across the Palo Duro Basin and into eastward into Oklahoma (Hovorka and Granger, 1988). Initial alteration at the base of the salt-dissolution zone where undersaturated downward-moving water encounters halite is dominated by halite dissolution. Halite is removed from halite beds, forming beds of insoluble residue. Halite cements are also removed from other lithologies, increasing porosity and greatly enhancing permeability. This increase in porosity allows recognition of salt dissolution on resistivity logs.

In evaporite-residue sections that have been in longer contact with undersaturated brines, gypsum alteration is important in creating textures. Anhydrite is hydrated to gypsum in undersaturated brines (Gustavson and others, 1994). Accompanying density change requires that volume-for-volume hydration of anhydrite to gypsum release large amounts of calcium sulfate to solution. Observed textures in core indicate that volume-for-volume hydration of anhydrite to

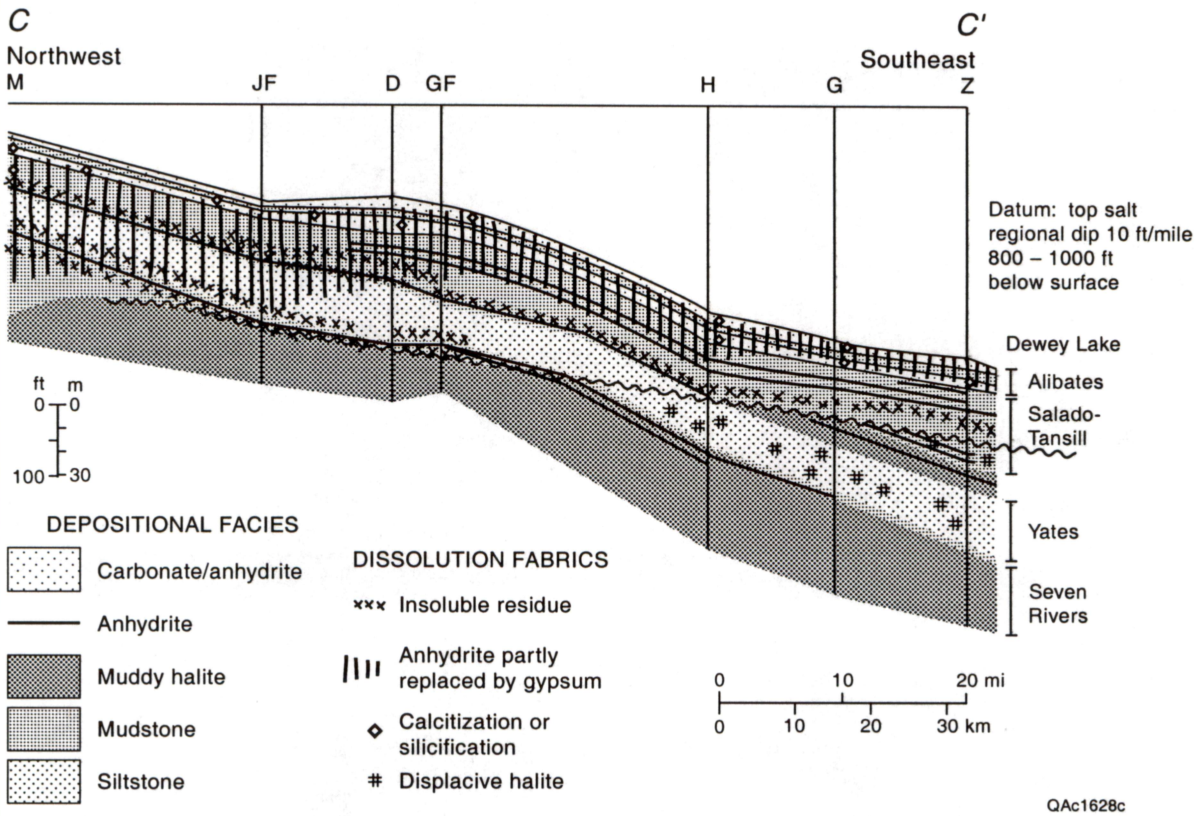

Figure 23. Top of salt forms a low-relief surface paralleling the regional hydrologic gradient. Cross section based on data from Hovorka and others, 1988. Cross section location shown in figure 3.

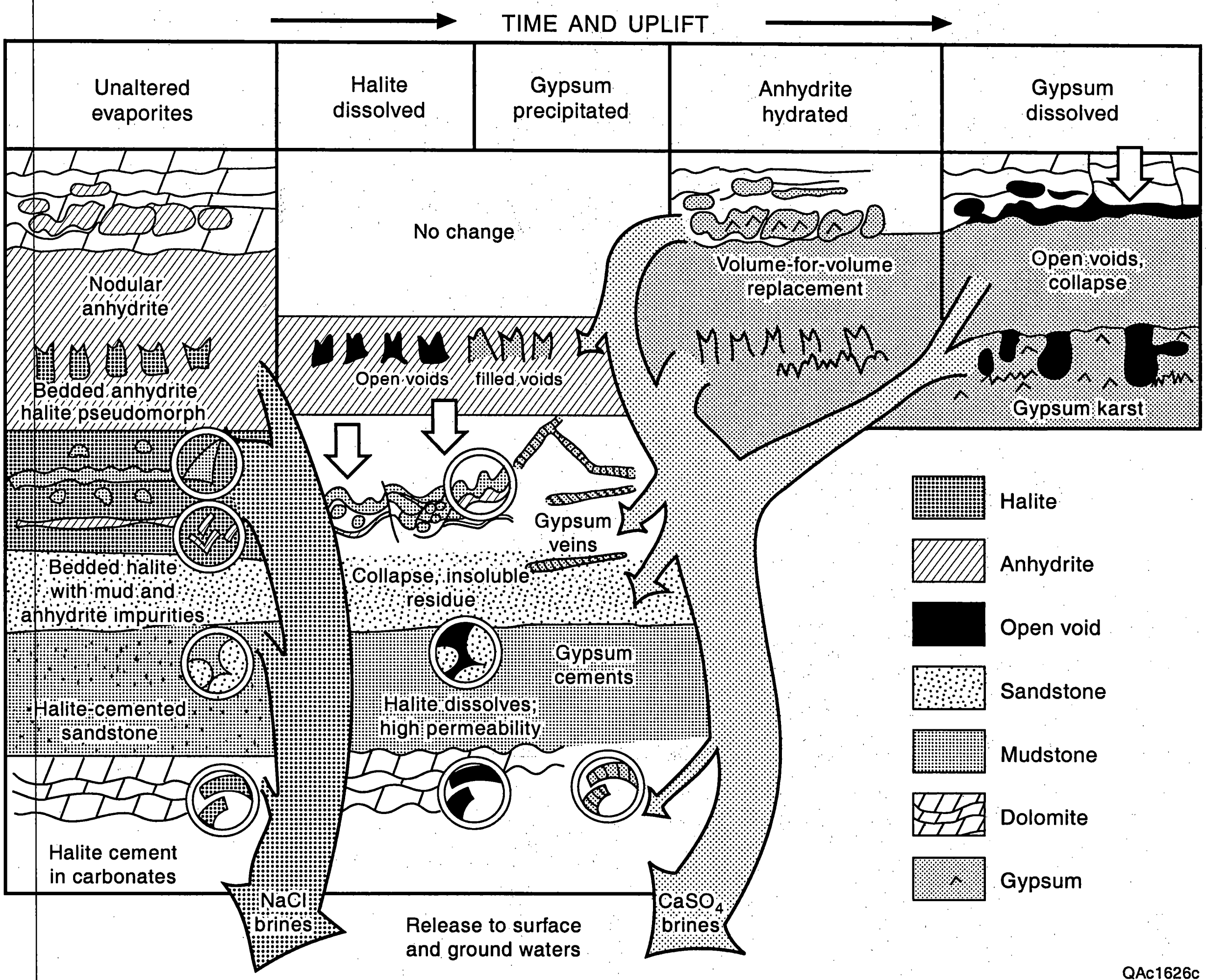

Figure 24. Salt-dissolution processes. The processes and alteration of evaporites in the presence of undersaturated water. Unaltered evaporite is shown on the left, initial alteration in contact with undersaturated water in the middle, and intense alteration after prolonged contact with undersaturated water is shown on the right.

gypsum is the dominant replacement mechanism, and show that gypsum cement is precipitated as fracture and void fillings. Sulfate is also removed in solution. This alteration is characteristic of the dissolution zone from several feet above the top of the uppermost salt to near land surface. Near land surface and in high-flow, high-transmissivity intervals, gypsum has been extensively dissolved, producing gypsum karst. The phased nature of evaporite dissolution is important for understanding log relationships observed in cross sections. Anhydrite and gypsum beds are commonly well-preserved in areas where halite has been dissolved and can be traced through the dissolution zone to their depositional or erosional edge.

Examination of the residues left after regional low-angle salt dissolution in the Palo Duro Basin shows that salt has dissolved and residue formed by incremental dissolution of the uppermost salt over a wide area accompanied by passive subsidence of overlying strata (fig. 25). Horizontal fractures in overlying strata are evidence of a vertical extension, syntaxial gypsum fillings (Gustavson and others, 1994) show that the fracture opening occurred incrementally as underlying salt was dissolved, and that creation of voids leading to catastrophic collapse did not occur in this setting. Insoluble residues are identified as evidence that impure salt beds have been dissolved (fig. 26). Diagnostic features of regional low-angle salt dissolution are: (1) mixtures of insoluble components from halite with unusual wavy lamination as a result of accretion of newly released insoluble components against existing insoluble residue (fig. 26a), (2) beds in positions laterally equivalent to preserved salt, and (3) syntaxial horizontal gypsum-filled fractures in overlying units. In the Palo Duro Basin, inclusion of late diagenetic minerals formed in halite in the insoluble residue, in particular limpid dolomite (fig. 26b and c), indicate that halite dissolution occurred in the burial environment after dolomite precipitation (Gao and others, 1990). Integration of evaporite diagenesis with dissolution-zone processes is an important tool for separating burial dissolution from syndepositional and base-of-cycle dissolution.

In the Midland Basin, regional low-angle salt dissolution and passive letdown of overlying strata is a probable mechanism for salt thinning over areas on the east edge of the basin and over the south part of the Central Basin Platform.

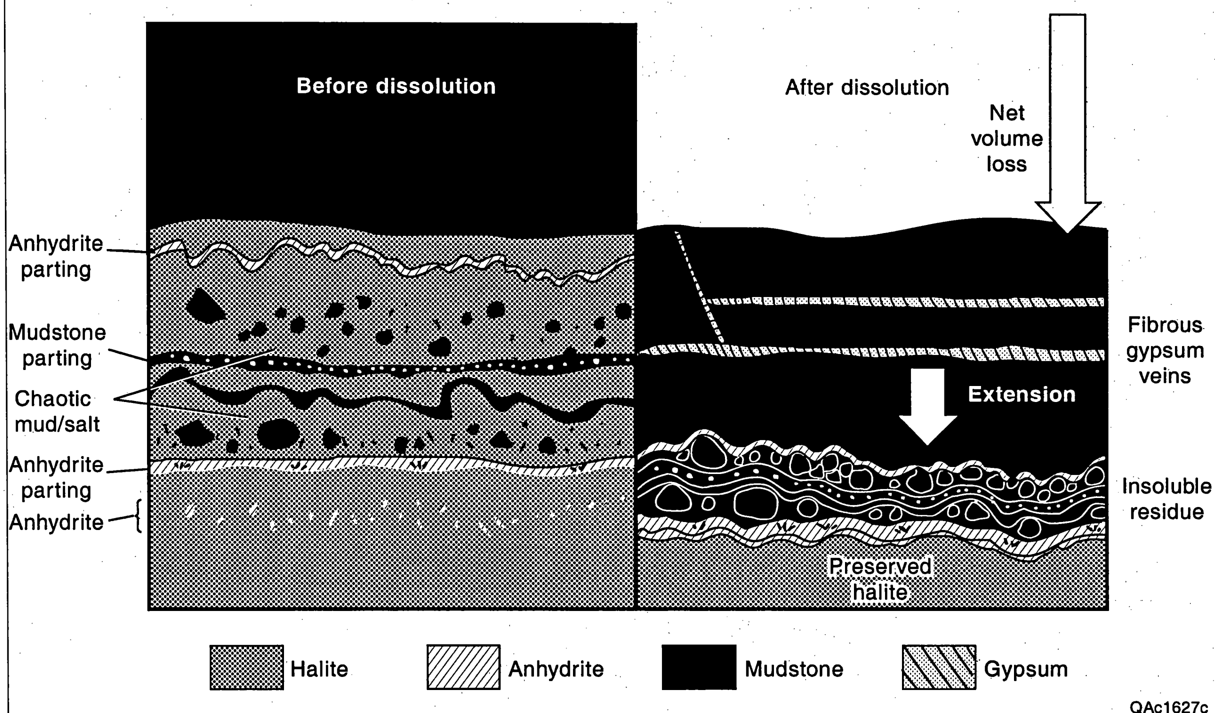

Figure 25. Schematic diagram showing processes of formation of insoluble residue under conditions of regional low-angle salt dissolution and passive letdown of overlying strata.

(a)

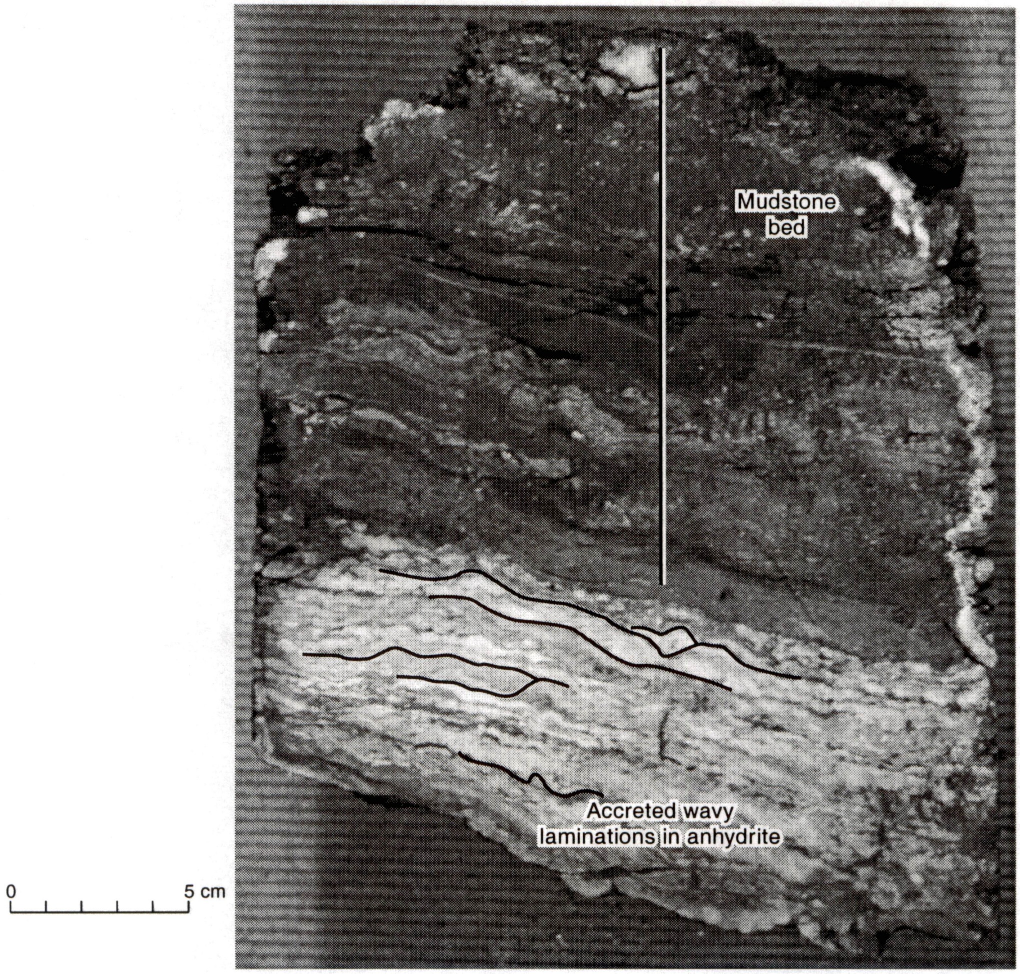

Figure 26. Typical textures diagnostic of insoluble residue formed under conditions of regional low-angle salt dissolution and passive letdown of overlying strata. (a) Wavy-laminated mudstone and anhydrite insoluble residue formed after dissolution of halite. DOE Stone and Webster Sawyer core, 833.7 ft below datum.

(b)

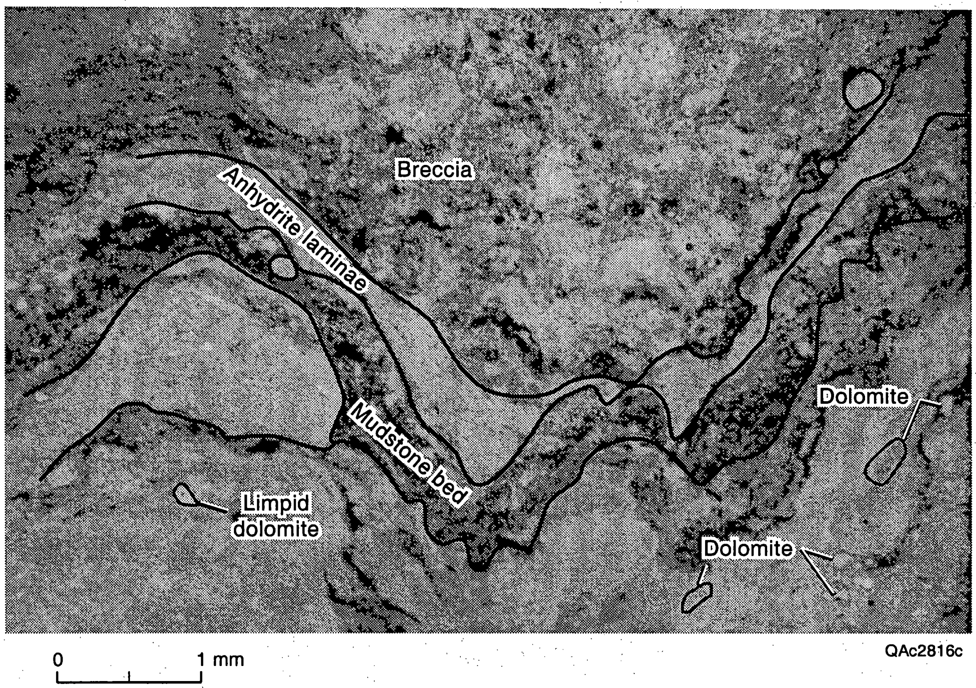

Figure 26 (cont.). Typical textures diagnostic of insoluble residue formed under conditions of regional low-angle salt dissolution and passive letdown of overlying strata. (b) Photomicrograph of the same samples showing diagnostic insoluble residue textures.

(c)

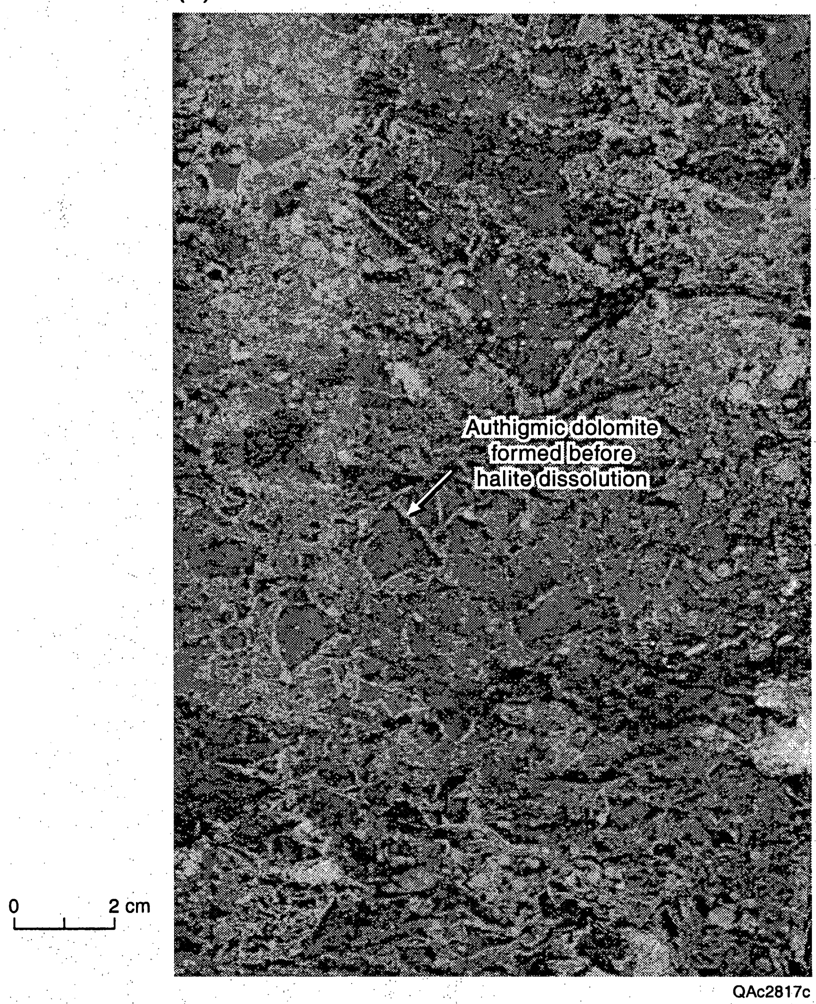

Figure 26 (cont.). Typical textures diagnostic of insoluble residue formed under conditions of regional low-angle salt dissolution and passive letdown of overlying strata. (c) Insoluble residue formed by dissolution of mudstone-halite mixtures. Gruy Federal Rex White core, 613 ft below datum.

In areas where hydrologic complexities are found, salt dissolution may be irregular and complex. Focused dissolution may remove salt from one small area and leave it intact in an adjacent area. Focused dissolution and irregular subsidence favors creation of abundant and potentially well-connected fracture systems (Goldstein and Collins, 1984; Collins and Luneau, 1986). Thick intervals of permeable residue strata and more fracturing will focus flow and propagate further irregular dissolution patterns. In the Palo Duro Basin, cored collapse breccia (fig. 27) is interpreted as a result of formation and subsequent collapse of natural caverns in the salt in an area of complex salt dissolution over a structural positive in the Rolling Plains, an area of recognized salt-dissolution collapse (Baumgardner and others, 1982). In cross section (fig. 28), focused dissolution and collapse results in steeper-than-regional dips and irregular unit thickness.

Hydrologic complexities with the potential to cause focused dissolution include enhanced permeability along faults and fractures or permeable strata and high hydrologic gradient related to topographic relief or to different hydrologic head in poorly connected aquifers. Although rigorous hydrologic analysis has not been undertaken for this study, the hydrologic regime in various parts of the study area are noted.

Several areas in the Midland Basin have characteristics that suggest past or ongoing focused dissolution. Irregular unit thickness (fig. 14) corresponding to rapid lateral changes in salt thickness (fig. 15) around the Howard-Glasscock positive, particularly the closed structure contours on the Alibates on the south side of the positive and northeast of the graben (fig. 14), suggest that focused salt dissolution may have occurred in this area. Another area where salt dissolution appears to have removed salt is the south part of the Central Basin Platform. On the north side of this structure, closely spaced contours in the net salt and interval isopach (figs. 16 and 17) near the Pecos River suggest the potential for focused dissolution.

The best-documented area of focused dissolution in the study area is the Winkler and Ward County area over the Capitan Reef. Focused dissolution is thought to have contributed to modern and ongoing salt dissolution, subsidence and collapse at the Wink Sink (Baumgardner and others, 1982; Johnson, 1987; 1989a) in central Winkler County (fig. 3). Topographic maps of the Winkler

(a)

Figure 27. Breccia interpreted as a result of formation and collapse of natural salt caverns. (a) Breccia on the floor of a small cavern, DOE Stone and Webster Sawyer core, 446 ft below datum.

(b)

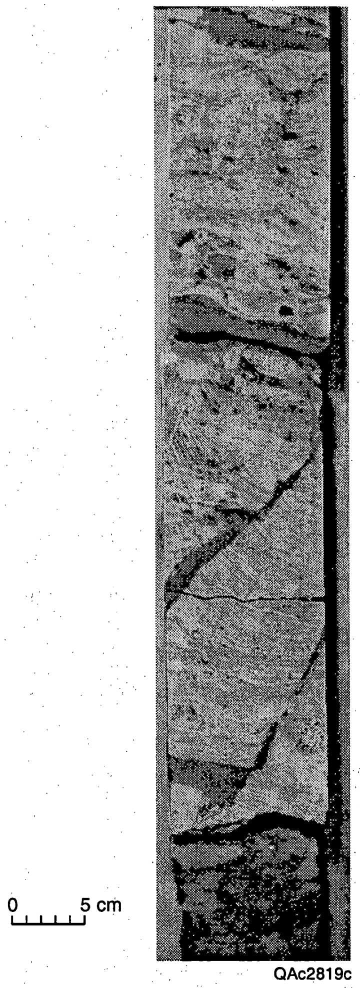

Figure 27 (cont.). Breccia interpreted as a result of formation and collapse of natural salt caverns. (b) Open fractures and rotated blocks above a large collapsed salt cavern, DOE Stone and Webster Sawyer core, 674 ft below datum.

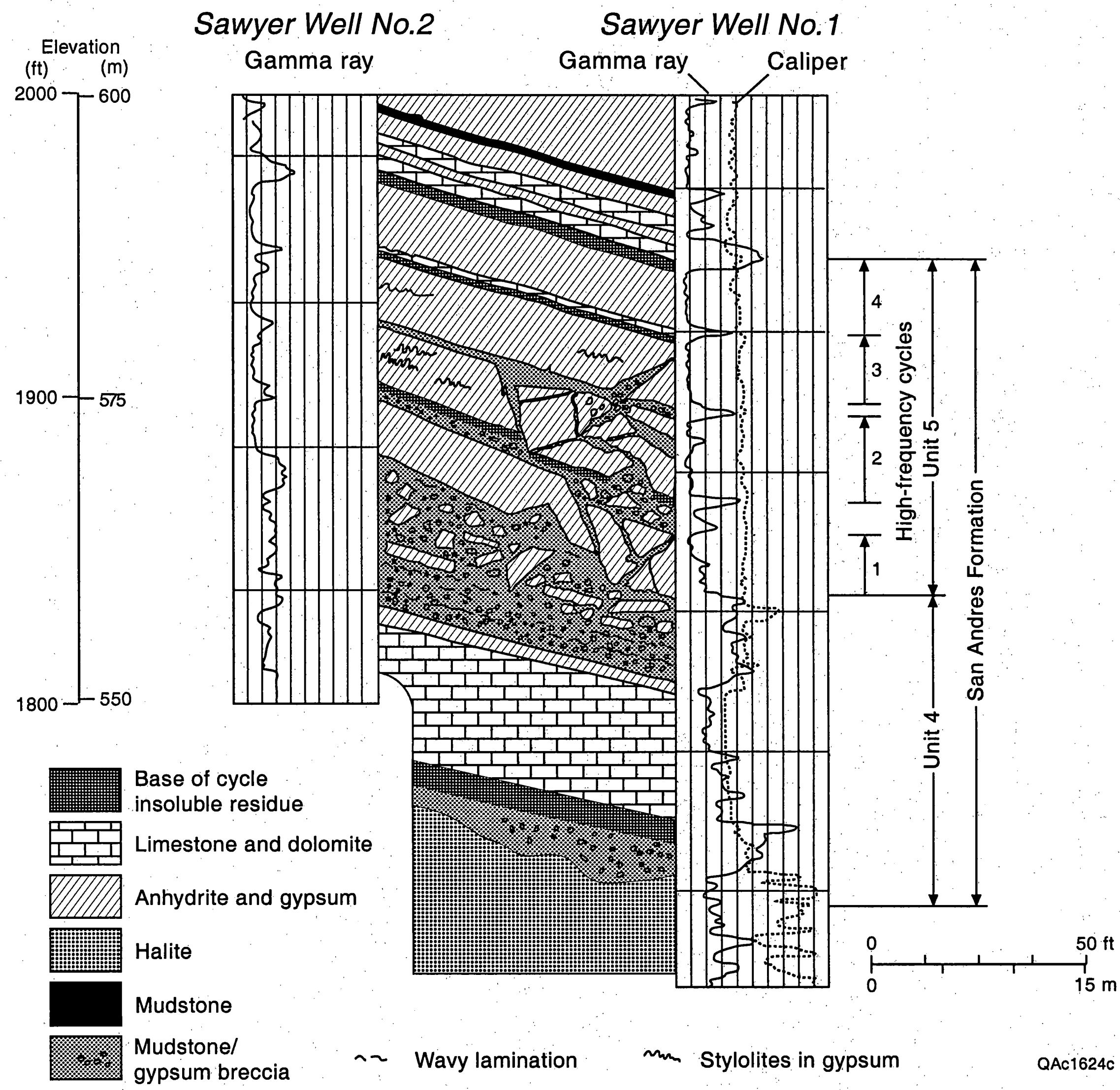

Figure 28. Detailed cross section between two closely spaced wells, in an area of complex salt dissolution. Location D–D′ shown in figure 3.

County area note numerous sinkholes, although the unit being dissolved is not known. Several other salt-dissolution chimneys (Chimney C and San Simon Sink) that appear to be part of a trend of focused salt dissolution around the Capitan Reef crest in New Mexico have been described (Bachman, 1984). Over the Capitan Reef, detailed cycle correlations (fig. 13) show that dissolution has occurred both from the bottom and from the top of the Salado Formation.

Dissolution at the base or intrastratally within the salt may occur elsewhere within the Midland Basin. During this study, I tentatively identified several areas on the east margin of the Midland Basin in the Permian outcrop belt where resistivity logs show highly conductive units in the base of the Salado, suggesting that dissolving water may have moved beneath the salt through the Yates and Tansill Formations. If hydrologic gradient exists, basinal brines that are undersaturated with respect to halite or fresh surface water can move along natural or man-made conduits and dissolve salt. Modeling suggests that subsalt dissolution might occur elsewhere in the Permian Basin (Anderson, 1981; Howard, 1987).

Timing of Salt Dissolution under Burial Conditions

Across the Permian Basin, dissolution has occurred during the Triassic, Cretaceous, and Cenozoic and continues in the present. The extent of salt dissolution during these times has been only locally determined because the effects of ancient and recent dissolution are difficult to separate.

Much of the dissolution over the crest of the southern Central Basin Platform occurred before the Cretaceous, because these units are minimally deformed across and on the south edge of the uplift (Adams, 1940; Wessel, 1988a, b). In a detailed study of the Yates field, Wessel (1988a) showed that Cretaceous strata are warped downward and faulted along the Pecos River in the area of the Alibates-Salado-Tansill interval thinning and salt pinch out, showing that dissolution continued in this area after the Cretaceous. Although similar high-resolution data have not been collected and interpreted in the Howard-Glasscock area, slight dips on Cretaceous strata and complex Quaternary deposits (Eifler and others, 1974), suggest that deformation may have occurred before, as well as after the Cretaceous.

A major regional episode of salt dissolution occurred during regional Cenozoic uplift when the entire area was uplifted from near sea level to its present elevation (Baker, 1977; Gustavson and others, 1980; 1982; Johnson, 1981; Boyd and Murphy, 1984; DeConto and Murphy, 1986; Goldstein and Collins, 1984; Gustavson, 1986; Johnson, 1989b). Like earlier dissolution episodes, Cenozoic dissolution was more pronounced over structural positive features than basins. In the Rolling Plains (Permian outcrop belt), Cenozoic dissolution has removed salt to depths of about 1,000 ft below land surface. Beneath the Southern High Plains (Midland Basin area), where the Permian units are overlain by Triassic, Cretaceous, and Cenozoic strata, dissolution has removed less salt than in the Permian outcrop. Cenozoic dissolution has also been documented along the Pecos valley, overlying the Central Basin Platform structurally positive feature (Adams, 1940), and above the Capitan Reef trend in Winkler County (Bachman, 1984).

Depressions on the Southern High Plains surface that host large lakes have been interpreted as locations of focused salt dissolution (Reeves and Temple, 1986; Ateiga, 1990; Paine, 1994). The relationship between surface depression and salt dissolution and the timing and process involved are complex and poorly understood. Not all lakes overlie areas of salt dissolution, and the timing and rates of dissolution appear to be variable.

Dissolution continues today throughout the Permian Basin. Ground-water chemistry and saline-spring discharges provide evidence of current dissolution (Howard and Love, 1945; Rawson, 1982; Richter and Kreitler, 1986; Dutton, 1987; Richter and others, 1990; Paine and others, 1994; James and others, 1995). Collapse and subsidence features and rates can be identified using a variety of assumptions and dating techniques to determine the probable rate and process of salt dissolution (Swenson, 1974; Gustavson and others, 1980; Gustavson and Simpkins 1989, Paine and others, 1994).

CASE STUDIES

In this section I present four case studies showing the relationships between variations in salt thickness and the processes of salt deposition and dissolution. These are: (1) Permian facies controls on salt thickness on the north margin of the Midland Basin, (2) post-Permian dissolution at a structural positive on the east basin margin, (3) post-Permian dissolution over the Central Basin Platform in the Pecos valley area, and (4) post-Permian dissolution over the Capitan Reef.

Case Study 1: Permian Facies Controls on the North Margin of the Midland Basin

Thinning is observed in the salt-bearing interval near the north edge of the Midland Basin (fig. 29). The structure on the Yates (fig. 4) shows that the structural margin of the Midland Basin is defined by the Matador Arch and Roosevelt positive. The following change in salt thickness and quality are noted along a dip section on this Permian structure. Between Terry well 16 and Hockley well 8, the salt section below the top of salt and above the Tansill siliciclastics thins from 650 to 320 ft. Most of this thinning occurs gradually, with each individual bed decreasing in thickness by about one half. For example, anhydrite bed 20 decreases from about 8 to about 2 ft thick, and the overlying halite decreases from 150 to 100 ft thick. Anhydrite bed 30 and several thin polyhalite beds pinch out or decrease to a thickness that does not produce a recognizable signature on logs. Above anhydrite bed 50 the thickness changes follow a different pattern. The upper 150 ft of the salt section in Terry County, containing four anhydrite beds and two mudstone intervals, thins to 40 ft of mudstone with one recognizable anhydrite bed at the north edge of Hockley County. The halite beds pinch out sequentially into mudstone to the north, so that the top of the halite climbs up the stratigraphic section toward the south. Anhydrite beds extend further to the north than the halite, but they also pinch out. The two Alibates anhydrite beds can be traced across the area with little change in thickness.

Thickness changes below bed 50 are interpreted as the result of depositional effects related to slower Permian subsidence, and, therefore, creation of less accommodation toward the

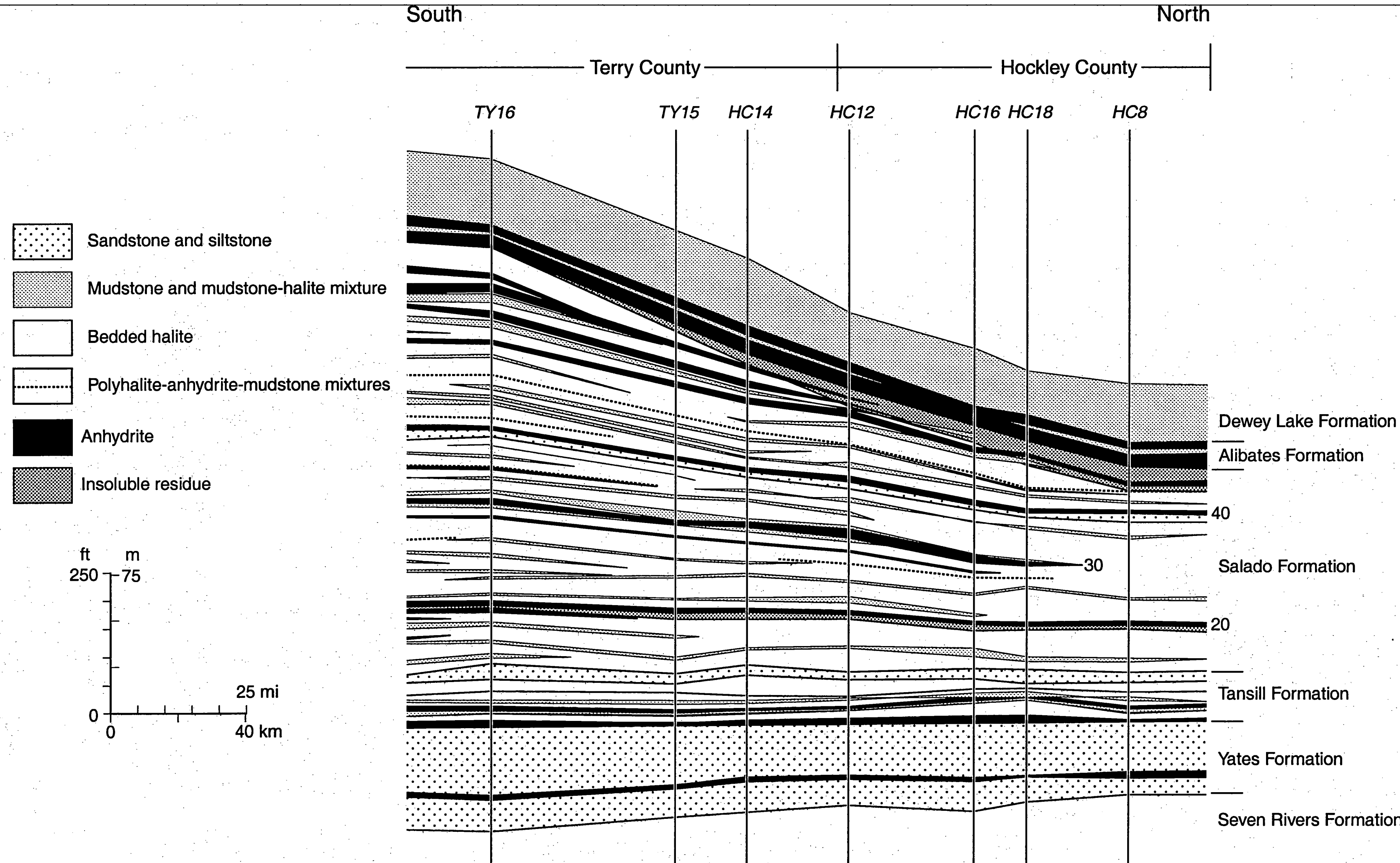

Figure 29. Detail of north–south cross-stratigraphic section in the deep part of the northern Midland Basin showing salt-character changes controlled by Permian facies change and base of sequence dissolution. Location shown on figure 2.

depositional basin margin. Decreased accommodation did not result in formation of more mudstone-halite, indicating that variation in the depositional environment was subtle. In fact, salt quality in the area of less accommodation may be superior for some salt-cavern designs because anhydrite beds are thinner and less abundant in the area of thinner salt section.

Thickness changes observed above bed 50 could be interpreted several ways: (1) as the result of salt nondeposition, (2) base of cycle dissolution, or (3) regional dissolution. Current depth of salt >1,900 ft below surface (fig. 16) suggests that modern dissolution is not a likely process. Observed map distribution of the salt beds corresponds closely to Midland Basin structure. I tentatively propose that the observed thickness changes correspond to a change in deposition style during the final stages of Salado deposition in which salt deposition was focused in the topographically low areas in the basin center. Evidence to support this is the unusually clean profile (low gamma-ray log profile) of these upper salt beds, which suggests a change to rapid episodic salt deposition in isolated depocenters. Additional fabric and geochemical evidence is needed to support this interpretation. Any thin salt beds deposited toward the basin margin could then have been removed by base of cycle dissolution, or by dissolution under burial conditions prior to Alibates deposition, at the end of the Permian, or during the Mesozoic.

Case Study 2: Post-Permian Dissolution at a Structural Positive on the Eastern Basin Margin

Regionally, the salt and salt-bearing interval thins toward the east edge of the Midland Basin. This east–west structural cross section across the Howard-Glasscock high shows salt character changes in this area. Structure on top Yates (fig. 4) shows that the gentle west-dipping basin structure is complicated in this area by a well-defined east–west striking uplift along the Howard-Glasscock county line. South of this uplift, irregularities on the Yates surface suggest a complex structure at depth, interpreted to be a graben.

The Salado salt-bearing interval progressively thins from 580 ft off structure at the west end of the cross section (fig. 30), to no salt at the east end. Structure on the Alibates shows a reversal

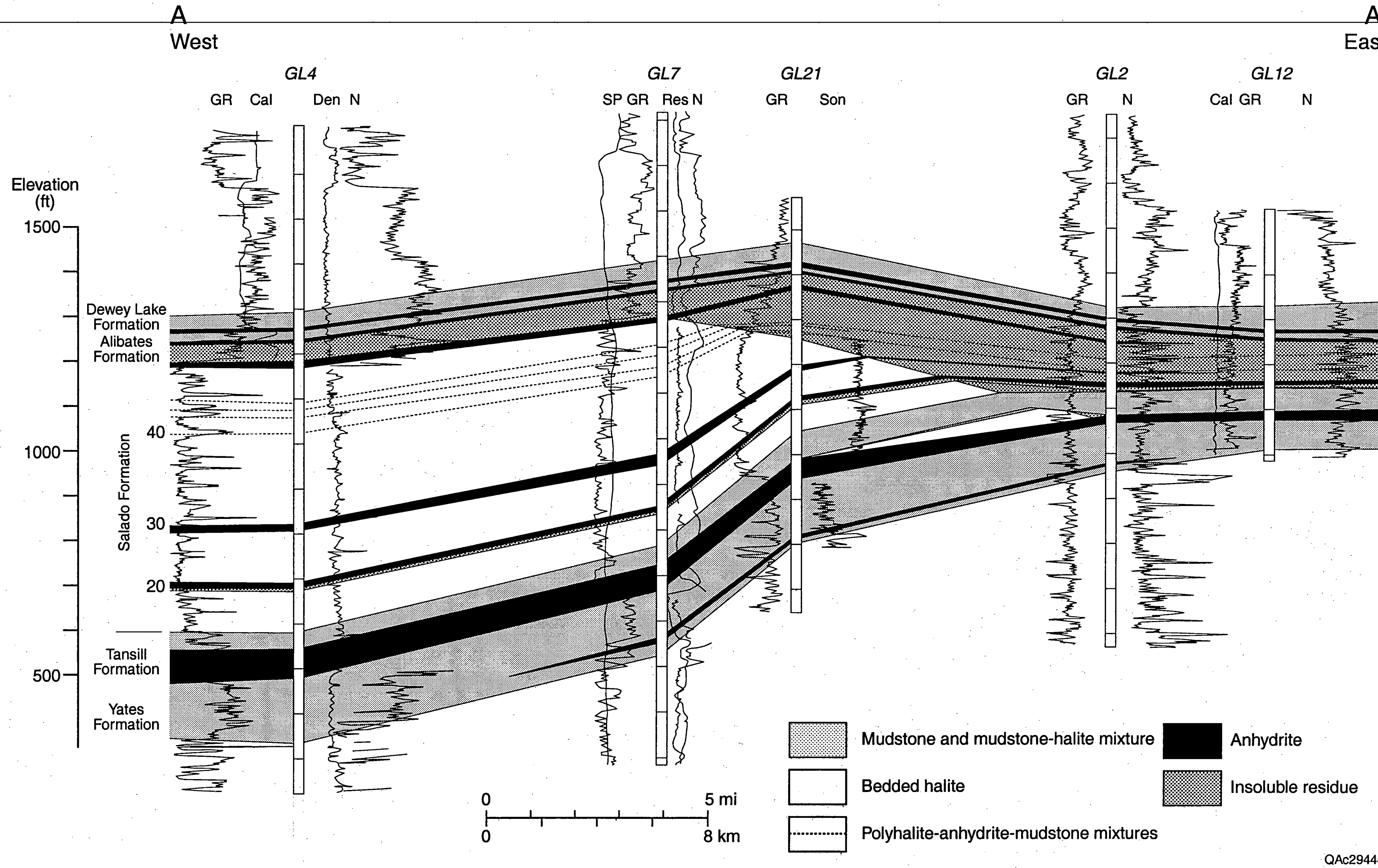

Figure 30. East–west structural cross section near the east edge of the Midland Basin showing salt-character changes controlled by post-Permian dissolution overprinted on Permian facies changes. Location shown on figure 2.

of dip from the regional trend and from the dip in the Yates in the area of no salt. This is the typical geometry produced by salt dissolution in the burial environment. Anhydrite and polyhalite beds within the salt-bearing interval can be traced into the insoluble residue. Closer inspection shows that the burial dissolution crosscuts a Permian trend toward thinner units, most clearly seen in the lower Tansill carbonate-anhydrite unit. The lower Tansill thins from 65 ft off structure to 15 ft on the east end of the cross section. The salt-bearing interval also thins by 100 ft between the two westernmost wells, and relationships between the top salt and correlated horizons within the salt show that this is not the result of dissolution of the uppermost salt but of incremental thinning of each unit, a pattern similar to that seen toward the north basin margin in case study 1. The siliciclastic unit in the upper Tansill shows a reverse trend, becoming thicker on the structural high. This is partly an effect of merging insoluble residue with mudstone beds, but may also include an effect of increased mudstone thickness toward the paleo-high, reflecting more exposure in an area of decreased accommodation. A calculation to approximate the amount of residue expected from dissolution of 580 ft of salt from GL4, at typical regional values of 75 percent salt and 25 percent insoluble (fig. 17), yields a residue thickness of 145 ft. The measured thickness of residue between markers in the easternmost well GL 12 equivalent to the 580 ft of salt section in the GL 4 well is only about 100 ft, further supporting an interpretation of a depositional thinning trend that parallels and is accentuated by burial dissolution.

Post-Permian dissolution overprints on Permian facies changes are common in the Midland Basin. Where this relationship exists, it indicates that the post-Permian uplift responsible for exposing the salt in a near surface setting where it underwent dissolution has reactivated the structures that caused reduced subsidence during the Permian. Post-Permian dissolution overprints on Permian facies changes were seen throughout the eastern shelf beneath the Rolling Plains and on the Ozona Platform beneath west Edwards Plateau.

The area of dissolution and subsidence south of the Howard-Glasscock high lies at depths of 1,500 ft below land surface, which makes it one of the deepest areas of salt dissolution seen in the study area. Surface geology at a 1:250,000 scale (Eifler and others, 1994) shows relatively flatlying Cretaceous strata at the surface above the salt dissolution area, suggesting that most of the salt dissolution in this area preceded the deposition of Cretaceous units. This timing might also indicate that dissolution took place under shallower burial conditions than presently exist. Complex Pleistocene deposits in this area may be indicators of post-Cretaceous salt dissolution in this area but further study is needed to confirm salt dissolution in this area. Deformation of Cretaceous strata can be seen in exposures at the spring in Big Spring, Howard County.

Case Study 3: Post-Permian Dissolution over the Central Basin Platform in the Pecos Valley Area

The Central Basin Platform (fig. 4) was a very significant feature during the Permian. During the Leonardian and Guadalupian, it was an area of slower subsidence compared to the flanking basins and it accumulated shallow-water carbonate sediments. Postdepositional warping has draped these carbonates over structural highs and produced the structural and stratigraphic traps that form the prolific Central Basin Platform oil fields. The Ochoan isopach (fig. 15) shows (setting aside areas of focused salt dissolution discussed in case 4) that by the Ochoan, most of the north part of the Central Basin Platform was subsiding more rapidly than the Midland Basin, although not as rapidly as the Delaware Basin to the west. The evolution of the south part of the Central Basin Platform, however, is difficult to determine. Ochoan strata are very shallow in this area because of coincidence of uplift bringing the top of the Yates Formation to elevations of as high as 2,000 ft above sea level and incision by the Pecos valley. Permian changes across the southern Central Basin Platform have been crosscut and complicated by post-Permian salt dissolution. South of the Central Basin Platform was the Permian Sheffield Channel, an area that was topographically lower than the platform in the Guadalupian and may have been significant in basin circulation. This feature is filled with 600 to 800 ft of cyclic Salado salt and anhydrite. The log character of this sequence is fairly typical of the Midland Basin, suggesting that by Ochoan time the Sheffield Channel was topographically part of the shelf that extended over the Midland

Basin and Central Basin Platform. At the west end of the Sheffield Channel, log character changes and may preserve a transition between shelf and Delaware Basin facies.

Part of the north–south stratigraphic cross section across the Pecos valley and uplifted southern Central Basin Platform was selected in an area at the west end of the uplifted area where some salt is preserved and several useful caliper logs are available. A structural cross section of this area was prepared (fig. 31). Multiple changes in salt geometry are noted on this cross section. Salt has been completely dissolved on the crest of the structure at Pecos County well 10. Salt has been dissolved to depths between 700 and 800 ft beneath the Pecos valley alluvium, and here it forms a depression in the top Alibates structure on top of the more regional structural positive (fig. 14). Where salt occurs at greater depths away from the uplift, less salt has been dissolved.

Anhydrite beds thicken across the Central Basin Platform, probably in response to increased water depth and better circulation during deposition in this area of slightly greater subsidence. Thicker anhydrite beds begin at about the same place that dissolution cuts deeply into the section (fig. 12), compounding the problem of determining how much salt has been dissolved. Measured salt thickness in the interval where salt is preserved documents the relatively low percent salt, which is between 46 to 64 percent (fig. 17). Although percent salt could potentially be in error because of the salt dissolution, inspection of the logs and cross section supports the conclusion that the percent salt decrease is because of increased anhydrite bed thickness. Potential but discounted sources of error are: (1) sampling effects because a different stratigraphic interval is included in each calculation as the top salt varies stratigraphically across the dissolution zone, and (2) some effects of dissolution, if some salt has been removed interstratally within the salt section. Predictions of residue thickness based on stratigraphy of adjacent areas where salt is preserved yielded values similar to those observed. For example, Pecos 1 contains 215 ft of residue stratigraphically equivalent to 620 ft of salt section in Crane 11; this reduction could occur in a section containing 65 percent salt.

Interpretation of this cross section is complemented by maps and cross sections from the Yates Field area (Wessel, 1988a) that show structure of the Cretaceous in outcrop. In the Yates

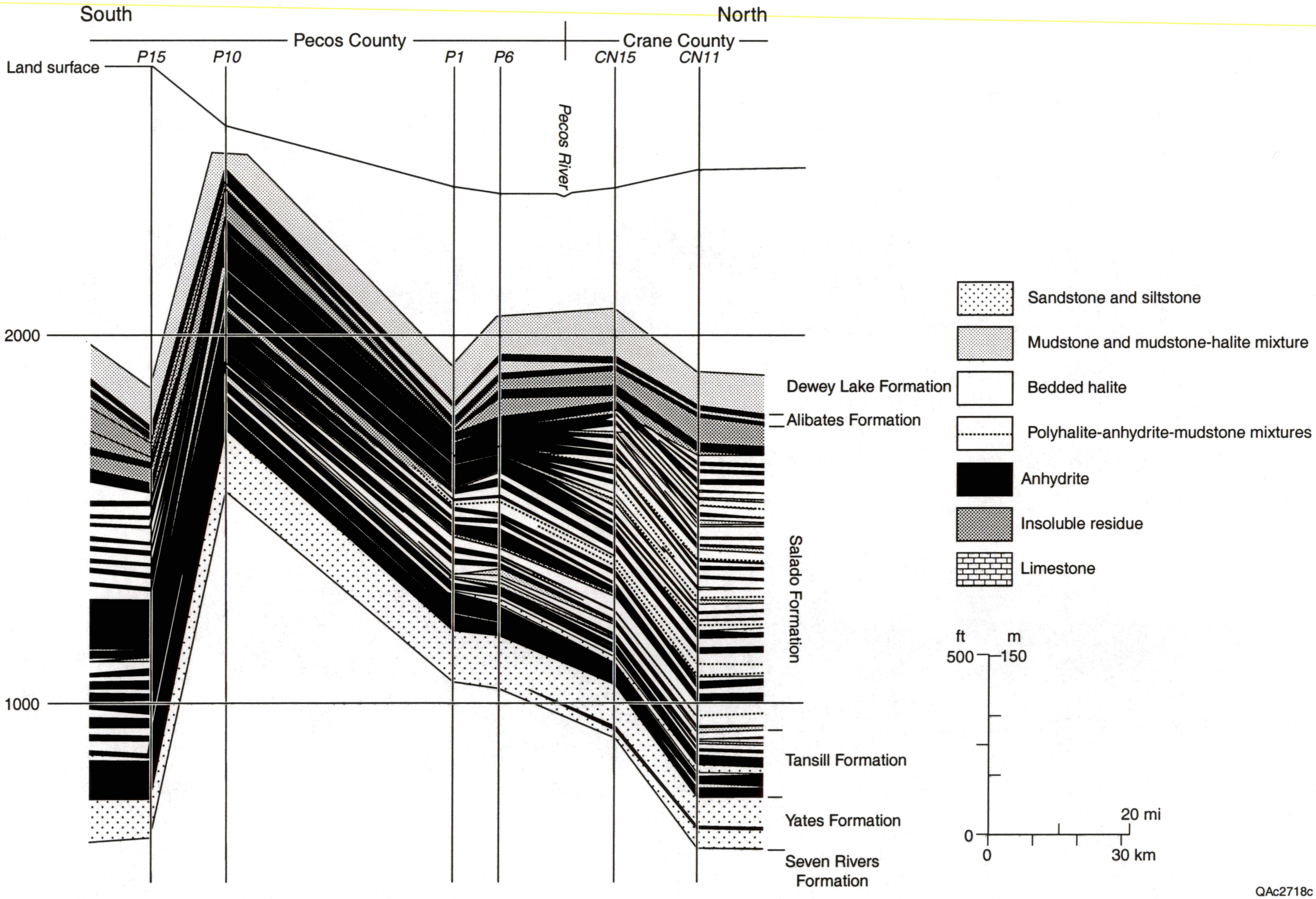

Figure 31. North–south structural cross section across the Pecos valley and uplifted southern Central Basin Platform showing changes in salt character controlled by post-Permian dissolution. Location shown on figure 2.

area, at the east end of the south part of the Central Basin Platform, the Cretaceous strata have been deformed on the north side of the structure in the Pecos valley, but have not been deformed across the top of the structure or on the south side. This supports the conclusions of Adams (1940), based on stratigraphic interpretation, that salt dissolution across much of the structure was pre-Cretaceous. Cenozoic and potentially ongoing dissolution has occurred in the Pecos valley. This is a common model for understanding salt dissolution; active dissolution may be found on the flanks of the structure where initial dissolution removed accessible salt from the crest of the structure. The surface mapping by Wessel (1988a) also emphasizes the role of faults and fractures formed by salt dissolution in focusing further dissolution.

This relationship between the structural high, topographic low, and area of salt dissolution is similar to the relationship localizing the Canadian River on the crest of the Amarillo Uplift because of dissolution of salt in that area (Gustavson, 1986). The Rolling Plains, where Permian rocks crop out at the surface, lie at lower elevations than the adjacent Edwards Plateau and Southern High Plains, indicating that the Permian rocks have been eroded more rapidly than the Cretaceous carbonates or the Ogallala Formation that overlie preserved salt (Gustavson and Simpkins, 1989).

Case Study 4: Post-Permian Dissolution over the Capitan Reef

The salt-dissolution feature in Ward and Winkler Counties is another significant variation from those described in cases 1, 2, and 3. A depression of as much as 1,500 feet in the top Alibates structure (fig. 14) is filled with post-Permian sediments to depths of as much as 2,000 ft below land surface. Net salt thins from 600 ft on the Central Basin Platform to a measured minimum of 128 ft in the depression. Net salt thickens again west of the depression to 1,000 ft as part of a regional thickening trend (fig. 17).

Cross-section relationships (fig. 32) show that: (1) the thin in the salt is the result of dissolution, not facies changes, and (2) salt has locally been dissolved from the bottom of the salt as well as from the top. The facies changes in this area are readily understood in the context of

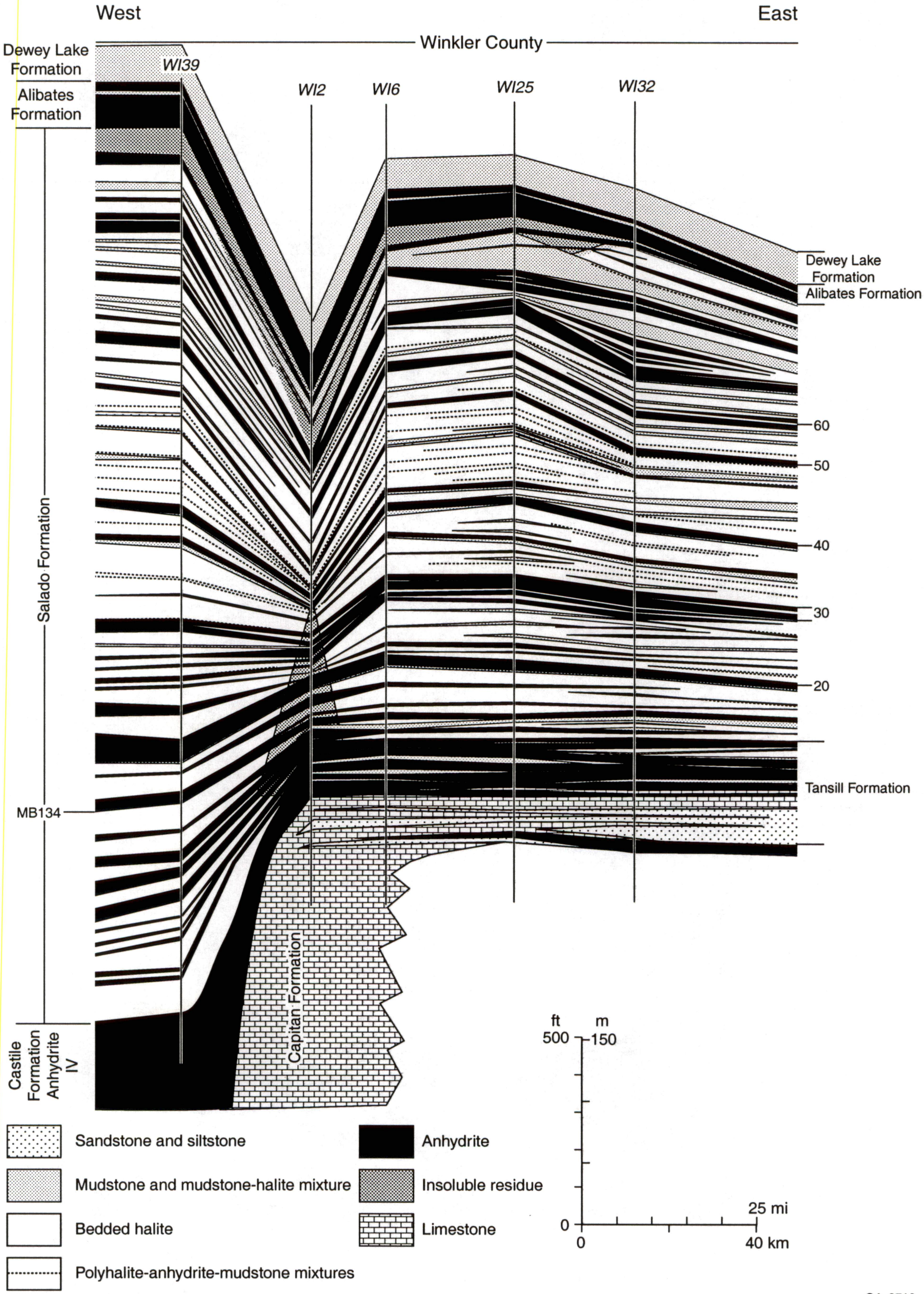

Figure 32. Detail of east–west stratigraphic cross section near the east edge of the Midland Basin showing salt-character changes controlled by post-Permian dissolution over the Capitan Reef trend. Location shown on figure 2.

cases 1 and 3, described above. Anhydrite beds start to thicken across the Central Basin Platform in western Ector County, east of the dissolution feature. Although individual bed correlations are tentative through the area of salt dissolution, caliper log character shows that salt is missing from the base of the Salado above a thick Tansill siliciclastic and anhydrite section. The salt-dissolution interval is condensed relative to adjacent areas, although some of the halite is represented by siliciclastic insoluble residue between anhydrite beds.

The Ward-Winkler salt-dissolution area lies along the trend of the Capitan Reef. Hiss (1975b, 1976, 1980) has proposed a genetic relationship based on a model where fresh ground water, moving through the highly transmissive Capitan aquifer from the Glass Mountains recharge area, has moved up through fractures into the salt. The Ward-Winkler salt dissolution is part of a larger system of depressions on the Alibates that follow the Capitan Reef trend into New Mexico toward its outcrop in the Guadalupe Mountains (Hiss, 1976). The geometry on top of the Guadalupian strata (top Yates, Capitan, and Bell Canyon) shows that beneath the dissolution area these units are dipping steeply to the west. Although the Capitan Reef or back reef may have been a relatively positive feature during deposition, Late Permian and post-Permian deformation has warped the western reef edge downward relative to the platform. The present structural high on both the Yates and the Alibates horizons (figs. 4 and 14) lies east of the main Capitan Reef (Hiss, 1975a) and east of the salt-dissolution zone. Therefore, the style of dissolution contrasts with that observed in case 3 on the southern Central Basin Platform, where dissolution was focused on the crest as well as the flanks of the structural uplift. The observations made in this study support the aquifer dissolution model of Hiss (1976).

The Ward-Winkler salt-dissolution feature is not related to a surface depression. The relationship between this feature and past drainage has been explored by Bachman (1984) and Hiss (1976). The timing of dissolution is not well constrained. Historic subsidence and recent formation of the collapse feature at the Wink Sink (Baumgardner and others, 1982; Johnson, 1987) and an area of subsidence on the east edge of the paleodissolution feature (Collins, 2000) indicates that salt dissolution may be ongoing in this area.

APPLICABILITY TO SITE EVALUATION

Geologic data can be applied to engineering needs, risk reduction, and assessing the future stability of the salt during site evaluation for solution-mined caverns. Geologic data include salt-bed thickness, salt quality, the type of salt dissolution, and the distribution of associated non-salt beds that may be of interest as horizons in which to set seals or as potential permeable beds to be avoided.

Regional trends and facies relationships are the basic tools to assess salt-bed thickness and quality. Facies models of the Permian depositional environment (Fracasso and Hovorka, 1986; Hovorka, 1994) suggest that salt beds have high continuity over the region. Mapping high-frequency cycles over the Midland Basin study area supports this model and provides confidence that experiences with salt quality in one part of the Midland Basin are likely to be reproduced in other areas. Measurement of individual salt-bed and interbedded non-salt units shows horizontal continuity of strata over wide areas and relatively minor variation in maximum salt-bed thickness and impurity content. Average net salt and percent salt show gradual regional variations from >75 percent salt in updip areas, where net-salt thickness is <400 ft, to <70 percent salt in areas where net salt is >600 ft. Throughout the study area, salt is interbedded with non-salt. Mudstone interbeds more than a few feet thick occur at intervals of 10 to 30 ft. Anhydrite beds 2 to 30 ft thick occur regularly through the salt at spacing of 50 to 150 ft. Some of the thickest and most pure salt beds are found near the top of the Salado Formation along the Midland Basin axis. These units, however, show the most complex facies relationships of any unit examined in the study. The complexity observed at a regional scale suggests that there may be variation over short distances in the character and thickness of the upper salt units. If these beds are a significant component of the cavern design, I suggest that site-specific data be acquired to address the heterogeneity of these units.

The observations made in this study support the validity of the common practice of assessing a solution-mined site based on examining logs of wells in the area. The exception to this rule is areas where complex facies variations are expected. In this study, most of the areas where complex facies variations are expected generally overlap areas where there is risk of salt dissolution described in the following paragraphs and shown in figure 33. The east and north margins of the Midland Basin are areas of depositional salt thinning. Across the Central Basin Platform, facies changes to more abundant and thicker anhydrite beds are observed, and the effect of these relatively high-strength, low-solubility units on salt-cavern design should be assessed. The area of most abrupt lateral changes corresponds approximately to the structural platform edge.

Salt dissolution may create risk factors to be assessed in salt-cavern design for three reasons. (1) Dissolution can cause the salt to thin over a short distance laterally into water-bearing, mechanically weak insoluble residue. The geometry of the salt-dissolution edge may be complex and difficult to map because of hidden hydrologic controls and the potential of feedback mechanisms to focus dissolution where previous dissolution has created fractures and breccia. (2) Drilling and other invasive activities have the potential to create fractures and conduits that might focus future dissolution around the facility. Therefore, in an area of active dissolution, a thick, preserved salt section might have risks of developing engineering problems. (3) In an area of salt dissolution, there is increased risk that some beds within the salt, particularly carbonates and sandstones, may have had halite cement dissolved and, as a result, allow leakage from the caverns. Overlying beds that are commonly used for setting casing and seals, such as the Alibates Formation, may also be of variable quality in areas of salt dissolution because of fracture permeability and hydration of anhydrite to gypsum.

The reality of these risk factors has not been tested in this study. I show the areas of interpreted salt dissolution in figure 33 and recommend that the potential risks associated with past or ongoing salt dissolution be assessed for sites developed near those areas. Other factors that might create potential for dissolution are also shown. High elevation contrast may create hydrologic gradients and favor active dissolution. Areas of focused structural deformation having the potential to create fractures are also mapped, although they have no correspondence to thin salt at the regional scale mapped. Large saline lakes and Pleistocene lake deposits are also shown

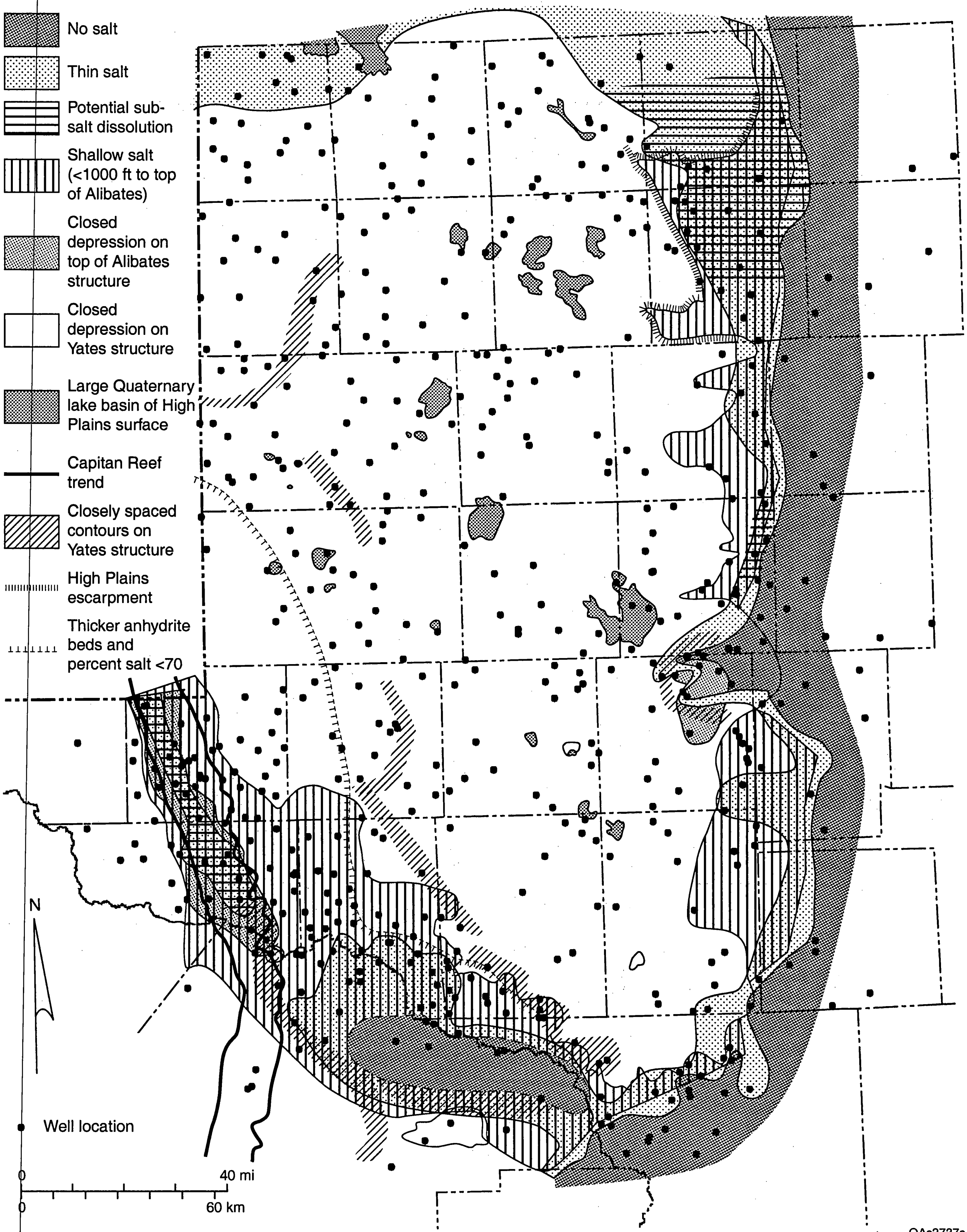

Figure 33. Areas where abrupt salt-thickness changes are noted or potentially exist.

(fig. 33) because of the unassessed potential risk that salt dissolution may have played a role in basin formation.

CONCLUSIONS

This report compiles basic descriptive information about the geometry of salt in the Midland Basin as well as guidance for site-specific evaluation of salt quality and geometry in the context of use of this salt for solution-mined caverns. Thick and laterally homogeneous bedded salt is found in the Salado Formation in the Midland Basin, Central Basin Platform, and associated areas. Regional and local variation in salt thickness, percent salt, structure on the top and bottom of the salt, and depth to salt are mapped throughout this region.

The geometry of salt is the product of interaction between depositional trends and postdepositional dissolution; reference to these two controls are used to aide both in describing the salt geometry and as a mechanism for interpreting relationships. Depositional geometry of the Salado Formation was fairly simple, with a gentle westward thickening from areas of little or no accumulation on the east to a maximum thickness in the Delaware Basin. The salt is divided into high-frequency genetic cycles composed of a basal anhydrite, overlain by halite, muddy halite, and mudstone. Many incomplete cycles containing only the halite, muddy halite, and mudstone facies are recognized within the master cycles defined by anhydrite beds at the base. Examination of the high-frequency cycles defining the stratigraphy within the Salado Formation shows that the observed westward thickening is an effect of greater accommodation (greater relative subsidence) during salt deposition, so that each individual salt bed thickens toward the west. The cycles in the upper part of the Salado Formation show a change from this pattern in that they are thickest along the present Midland Basin axis, contain thick but laterally discontinuous beds, and pinch out into mudstone toward the edges of the Midland Basin.

Depositional geometry of the salt has been modified by several episodes of postdepositional dissolution. The first postdepositional dissolution events probably occurred in terrestrial environments that preceded and followed Alibates deposition. A significant episode of dissolution occurred after significant warping of the Permian strata but prior to Cretaceous deposition. Dissolution occurred during the Cenozoic and continues today.

Substantial thicknesses of salt have been dissolved along the east margin of the basin, along the Central Basin Platform in the Pecos valley, and over the Capitan Reef margin in Ward and Winkler counties. Minimum postdepositional dissolution is seen in areas where the salt lies at depth below the most active near-surface hydrologic regime, typically at depths of more than 1,000 ft in the structural basin.

Thin salt generally corresponds to positive structural elements. Inspection of facies relationships in the Midland Basin and comparison with relationships seen in detailed studies in adjacent areas indicate that the salt thinned toward the basin margins because of reduced accommodation during deposition. The present-day structure on the top of the Alibates Formation/Rustler anhydrite (fig. 14) follows the long-lived structural pattern of the basin, so that positive areas during deposition have been uplifted more strongly than basinal areas. Postdepositional warping has therefore exposed thin marginal salt to more intense dissolution by placing it at higher elevations than basinal salts.

A change from this pattern is noted where salt has been dissolved in the Winkler-Ward County area. The general trend of thickening of the salt-bearing unit across the Central Basin Platform suggests that this area was subsiding during Salado deposition and is an area of subsidence west of the Central Basin Platform structural positive. In this area, a hydrologic model where salt dissolution is related to interstratal dissolution above the highly transmissive Capitan aquifer is accepted.

Modern landforms are overprinted on the structural elements. Areas where salt is present at shallow depths may influence landform development because salt has been dissolved, creating low areas, and overlying strata have collapsed, been brecciated, and are therefore easily eroded. The Pecos valley generally overlies an area of salt dissolution on the south end of the Central Basin

Platform. In this area, salt was probably relatively thick during deposition but has been removed over the uplift and at the hydrologically active areas along the valley.

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Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
AN1	ANDREWS	BRIGHT AND SCHIFF	J. E. PARKER -A- 1	SOUTH NIX	4	A-41	8501	9/30/61	003-00641
AN2	ANDREWS	CLIFFORD L. BROWN JR.	UNIVERSITY 1	W/C	21	4	4851	1/4/60	
AN3	ANDREWS	H. L. BROWN	CARMICHAEL 1	SHAFTER LAKE SAN ANDR	16	A-45	4763	8/21/60	003-00654
AN4	ANDREWS	BURDELL OIL CO.	SOUTHERN 1	LITTMAN	25	A-28	4320	6/28/59	003-00689
AN5	ANDREWS	BUFFALO OIL CO.	FASKEN -2C- 1	ANDREWS CO. W/C	30	43	4957	8/17/55	003-00673
AN6	ANDREWS	BUFFALO OIL CO.	UNIVERSITY -A- 1	ANDREWS CO. W/C	3	1	5014	9/26/56	003-00685
AN7	ANDREWS	B. B. CARTER DRILLING CO.	UNIVERSITY -48- 1	W/C	7	14	4434	4/27/58	
AN8	ANDREWS	CHAMBERS AND KENNEDY	SIMS 1	W/C	6	A-39	4436	1/27/60	003-00744
AN9	ANDREWS	CHAMBERS AND KENNEDY	MIDLAND FARMS 1	ANDREWS CO. W/C	1	40	4900	11/23/58	003-00743
AN10	ANDREWS	CHAMPLIN OIL AND REFG. CO.	UNIVERSITY -K- 1	W/C	11	5	12654	9/6/59	003-00791
AN11	ANDREWS	CHEYENNE OIL CORP.	GULF UNIVERSITY -36- 1	W/C	36	12	8232	10/11/61	003-01966
AN12	ANDREWS	CITIES SERVICE OIL CO.	UNIVERSITY -AZ- 3	EMMA	25	10	12752	11/4/59	003-00813
AN13	ANDREWS	CITIES SERVICE OIL CO.	REED -B- 1	SHAFTER LAKE	10	A-36	10999	10/21/59	003-00875
AN14	ANDREWS	CONTINENTAL OIL CO.	J. J. KEMPER 1	W/C	11	A-44	13434	5/1/63	003-00941
AN15	ANDREWS	CONTINENTAL OIL CO.	J. L. LINDLEY 1	W/C	16	A-47	4785	11/29/60	003-00954
AN16	ANDREWS	COSDEN PETROLEUM CORP.	PARMER COUNTY SL 1	W/C			7822	9/9/66	003-01033
AN17	ANDREWS	EDWIN L. COX	UNIVERSITY -A- 1	W/C	37	9	4812	4/13/60	003-00775
AN18	ANDREWS	THE DENVER COMPANY	MARSHALL 1	W/C	11	A-48	4550	10/28/61	003-00775
AN19	ANDREWS	ANDERSON PRITCHARD OIL CORP.	DAVID FASKIN -J5- 4	MIDLAND FARMS	5	42	4775	4/23/55	003-00074
AN20	ANDREWS	ASHMUN AND HILLARD	UNIVERSITY 3-10	FULLERTON	10	13	7040	12/31/63	003-00040
AN21	ANDREWS	ASHMUN AND HILLARD	LOWE-BITLER 3	FULLERTON	10	A-32	7140	6/14/62	003-00248
AN22	ANDREWS	ATLANTIC REFINING CO.	UNIVERSITY -9A- A	W/C	13	9	8950	9/3/57	003-00375
AN23	ANDREWS	ATLANTIC RICHFIELD CO.	MC FARLAND QUEEN UNIV 24	MC FARLAND QUEEN	3	4	4850	10/13/81	003-31579
BO1	BORDEN	AMBASSADOR OIL CORP	JESSIE B. JACKSON 1	W/C	520	97	8246	10/11/60	033-01085
BO2	BORDEN	FRED S. ALEXANDER	C. H. GARNER 1	W/C	80	20	4282	11/17/55	033-00003
BO3	BORDEN	AMERADA PETROLEUM CORP	J. R. CANNING -B- 1	W/C	142	25	7301	10/13/54	033-00019
BO4	BORDEN	BLANCO OIL CO. / NEWMAN BROS. DRLG. CO.	MILLER 1-11	JO MILL SPRAYBERRY	11	33	7338	2/22/59	033-00083
BO5	BORDEN	BRITISH AMERICAN OIL PRODUCING CO.	H. D. BEAL ETAL 1	W/C	4	30	8095	3/17/58	033-00157
BO6	BORDEN	HANLEY CO.	J. R. RUSSELL 1	W/C	7	27	7808	8/30/58	033-00553
BO7	BORDEN	MAGNOLIA PETROLEUM CO.	J. F. YORK 1	BORDEN COUNTY W/C	279	97	8310	3/27/59	033-00477
BO8	BORDEN	TEXAS CRUDE OIL CO.	R. C. MILLER 1-588	W/C	588	97	8751	4/9/63	033-01084
BO9	BORDEN	SAM D. ARES	DENNIS 1-A	W/C	4	30	5258	6/2/58	033-00072
BO10	BORDEN	STANDARD OIL CO. OF TEXAS	GRIFFIN A-1	W/C	35	25	6249	9/1/60	033-00908
BO11	BORDEN	SUNRAY MID-CONTINENT OIL CORP.	C. C. MILLER 1	W/C	365	97	8202	11/5/60	033-00949
BO12	BORDEN	THE TEXAS COMPANY	CLAYTON 5	GOOD	31	32	8236	12/9/55	033-01003
BO13	BORDEN	THE TEXAS COMPANY	PATTERSON 1	W/C	520	97	8376	12/16/57	033-01085
CC1	COCHRAN	AMERADA PETROLEUM CORP	ELMA SLAUGHTER 1	W/C	53	101	4694	7/31/62	079-00034
CC2	COCHRAN	ANDERSON PRITCHARD OIL CORP.	FROST 1-B	W/C	6	W	5080	1/15/62	
CC3	COCHRAN	ARD DRILLING CO.	D. S. WRIGHT -G- 3	LEVELLAND	12	95	4990	5/11/62	079-00142
CC4	COCHRAN	ATLANTIC RICHFIELD CO.	F. J. MASTEN 6	LEVELLAND	23	133	5093	12/25/81	079-30831
CC5	COCHRAN	ATLANTIC REFINING CO.	J. C. O'BRIAN 1	W/C	5	147	4800	5/14/68	079-10008
CC6	COCHRAN	J. D. BAKER	M. E. HANCOCK 1	W/C	22	119	5015	11/11/60	079-00209
CC7	COCHRAN	BIG CHIEF DRILLING CO.	SUPERIOR DEAN -B- 1	LEVELLAND			5015	3/1/54	
CC8	COCHRAN	BIG SPRING EXPLORATION CO.	LLOYD EVANS 1	W/C	10	124	4630	9/20/63	079-00256
CC9	COCHRAN	BIG SPRING EXPLORATION CO.	SLAUGHTER 1	W/C	37	83	5455	1/7/64	079-00257
CC10	COCHRAN	W. H. BLACK	J. Y. ROBB 1	BUCKSHOT	9	153	5063	4/25/61	079-00260
CC11	COCHRAN	BONANZA OIL CORP.	RJR RANCH 1	W/C	9	Y	5018	7/22/70	079-20013
CC12	COCHRAN	CAPITAL OIL CORP.	DEAN -B- 1	SLAUGHTER		57	5074	5/21/75	
CC13	COCHRAN	CASCADE PETROLEUM CO.	BARKER 1	W/C	3	V	4577	12/23/61	079-00304
CC14	COCHRAN	CHAMPLIN OIL AND REFG. CO.	GEORGE E. BENSON 1	W/C		136	5000	12/6/65	079-00319
CC15	COCHRAN	COLINE OIL CORP.	WEST LEVELLAND UNIT 186	LEVELLAND	6	61	5010	8/13/80	079-30420
CC16	COCHRAN	DAVID BROTHERS ET AL	MASTEN 1-U	W/C	21	163	4655	12/31/65	079-00512
CC17	COCHRAN	DELTA DRILLING CO.	STARNES 1	W/C	39		12082	4/2/56	079-00565
CC18	COCHRAN	EASTLAND DRILLING CO.	FRANCIS SILHAN 1	W/C	19	105	4480	5/1/64	079-00782

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Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
CN1	CRANE	GULF OIL CO. U. S.	W. N. WADDELL (TR A) W. I.	SANDHILLS (MCKNIGHT)	17	B-26	3584	1/23/75	103-30340
CN2	CRANE	GULF OIL CORP.	W. N. WADDELL ETAL 229	W/C	15	4	7989	2/8/59	103-05728
CN3	CRANE	GULF OIL CORP.	W. N WADDELL 239	WADDELL	2	B-25	3471	7/1/60	103-01096
CN4	CRANE	GULF OIL CORP.	W. N. WADDELL ETAL 357-I	W/C	14	B-27	7436	12/17/61	103-01825
CN5	CRANE	GULF OIL CORP.	W. N. WADDELL ETAL 514-	W/C	21	B-21	6957	8/2/61	103-01966
CN6	CRANE	GULF OIL CORP.	W. N. WADDELL ETAL 568	W/C	13	3	6043	12/19/61	103-02018
CN7	CRANE	GULF OIL CORP.	W. N. WADDELL 634	STATE TEST	7	3	6120	11/7/64	103-02083
CN8	CRANE	GULF OIL CORP.	W. N. WADDELL ETAL 950	W/C	14	B-21	4800	9/25/70	103-10966
CN9	CRANE	GULF OIL CORP.	W. N. WADDELL 1141	WADDELL	9	B-23	3570	1/22/85	103-32396
CN10	CRANE	R. B. HAMM & EDWIN L. COX	MARY LIEURANCE ET AL 1	WILDCAT (TUBB)	12	1	4009	8/21/67	103-10270
CN11	CRANE	HENDERSON & LYNN INC.	HUMBLE-COWDEN 1	W/C	65	X	4677	9/21/67	103-10213
CN12	CRANE	HILL & MEEKER	JAX M. COWDEN 54 1	W/C	54	X	6510	5/19/68	103-10428
CN13	CRANE	HILL & MEEKER	WIRT DAVIS 1	W/C	39	4	5702	12/11/67	103-10207
CN14	CRANE	HUBBARD, MONTGOMERY, & BELLOWS	DAWSON 1	W/C	2	6	3800	10/28/68	103-10429
CN15	CRANE	HUMBLE OIL AND REFINING CO.	JAX M. COWDEN -B- 43	WILDCAT (DEONIAN)	4	2	5659	5/16/68	103-10437
CN16	CRANE	HUMBLE OIL AND REFINING CO.	J. A. TUBBS 48	SANDHILLS	18	32	4446	4/3/56	
CN17	CRANE	MIDWEST OIL CORP.	HENDERSON 1	C-BAR WEST	17	B-22	4734	12/9/60	103-03811
CN18	CRANE	HUMBLE OIL AND REFINING CO.	YARBROROUGH & ALLEN 40	ARMER-GLOIETTA	6	B-17	4384	1/19/63	103-02737
CN19	CRANE	CURT INMAN OIL CO.	BILLY TOM COWDEN 1	CRANE COUNTY W/C	35	X	7385	1/31/62	103-04719
CN 20	CRANE	KENWANEE OIL CO.	WEEKLEY -C- 12	MCELROY	22	30	3175	7/16/53	103-03539
CN21	CRANE	PAUL PAGE	CARTER ESTATE 1	W/C (DEVONIAN)	21	6	5525	4/8/68	103-10475
CN22	CRANE	J. I. & P. D. MOORE	BARNSLEY 1	TUBB SANDHILLS	42	32	4561	10/18/59	103-03782
CN23	CRANE	MIDWEST OIL CORP.	DORA LANHAM 1	W/C	78	X	5700	7/2/70	103-10909
CN24	CRANE	MIDWEST OIL CORP.	LILLIE REED ET AL 1	W/C	2	4	6019	1/13/60	103-03807
CN25	CRANE	HUMBLE OIL AND REFINING CO.	J. B. TUBBS 105	W/C	22	B-27	6035	5/4/65	103-02869
CN26	CRANE	HUMBLE OIL AND REFINING CO.	JAX M. COWDEN B-4	W/C	16	2	5729	5/16/54	
CN27	CRANE	HILL AND MEEKER	T. A. S. 3-23	W/C	23	4	5785	3/5/65	103-05623
CN28	CRANE	T. M. EVANS	MCGEE 1	W/C	1	32	4959	12/31/59	103-04986
CN29	CRANE	DAVID FASKIN	ATLANTIC 1-31	W/C	31	35	3460	6/4/70	103-10910
CN30	CRANE	GEORGE ABELL	ADAMS 1	W/C	23	3	6770	11/9/59	103-03096
CN31	CRANE	TOM BROWN DRILLING CO.	COWDEN ET AL 1	W/C	5	X	8953	11/22/67	103-10300
CN32	CRANE	ATLANTIC REFINING CO.	H. T. FILLINGHAM 1	W/C	20	35	5349	9/16/65	103-03092
CO1	CROSBY	BOND OIL CORPERATION	ROBERTSON 1-C	FORBES	19	B9	3880	8/18/61	107-00015
CO2	CROSBY	HALLMARK PETROLEUM CORP.	HIMMEL 1	W/C	73	8	4590	4/30/71	107-10208
CO3	CROSBY	DAVE HARRIS DRILLING CO.	SHERROD 1	W/C	1051	1	4450	4/14/61	107-00037
CO4	CROSBY	HUMBLE OIL AND REFINING CO.	R. M. IRVIN 1	W/C	889	C3	9944	8/1/57	107-00043
CO5	CROSBY	HUMBLE OIL AND REFINING CO.	MORGAN JONES 2	W/C	8	D13	6033	12/23/65	107-00045
CO6	CROSBY	JORFORD CORP.	ENGLISH 3	HOOPLE	1066	O19	4600	7/2/89	107-30803
CO7	CROSBY	MCDANIAL & BEECHERL & ANDERSON BROS.	AMMONS	W/C	11	46	4516	11/30/51	107-00056
CO8	CROSBY	MAX PRAY	ALICE HUMBLE 1	W/C	74	8	4500	11/25/63	107-00070
CO9	CROSBY	ROY H. SMITH DRILLING CO.	W. D. COLLIER 1	W/C	7	2	4100	12/5/68	107-10005
CR1	CROCKETT	J. S. ABERCROMBIE	FELPS 1	W/C	15	31	6142	3/1/09	105-00005
CR2	CROCKETT	AMBASSADOR OIL CORP	W. T. NOELKE D-1	NOELKE	30	GG	1233	10/26/61	
CR3	CROCKETT	AMBASSADOR OIL CORP	J. M. SHANNON EST. 1	W/C	44	UV	1630	4/20/61	105-00043
CR4	CROCKETT	AMERICAN TRADING AND PRODUCTION	UNIVERSITY LANDS 1-D	W/C	7	13	3935	10/12/58	105-00102
CR5	CROCKETT	W. H. BLACK	SHANNON EST. 1	W/C	12	BB	2753	1/9/61	105-00230
CR6	CROCKETT	JOHN BLAKE	MEADOWS 1	W/C	48	GG	1707	9/29/69	105-10027
CR7	CROCKETT	M. D. BRYANT	UNIVERSITY 1	W/C	16	46	2450	8/3/59	105-00295
CR8	CROCKETT	CAL-MON OIL CO. & CHEMICAL EXPRESS	SHANNON 1-4	W/C	4	Q	2500	6/15/69	105-10034
CR9	CROCKETT	A. W. CHERRY	M. A. SHANNON 1	W/C	28	BB	2650	8/30/57	105-00521
CR10	CROCKETT	CITIES SERVICE OIL CO.	NOELKE -D- 1	CLARA COUGH CISCO	34	GG	6451	1/29/59	105-00522
CR11	CROCKETT	CITIES SERVICE OIL CO.	NOELKE -E- 2	W/C	32	GG	5699	12/8/59	105-00547
CR12	CROCKETT	S. T. CONSTANTINE	SHANNON 2	W/C	26	GG	2240	1/21/63	105-00495
CR13	CROCKETT	CRISTO REY PETROLEUM CO.	UNIVERSITY 1	W/C	7	51	2433	1/16/62	105-02427

Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
CR14	CROCKETT	ROBERT A. DEAN	HARRIS 1	CROCKETT	3	W	1548	5/23/72	
CR15	CROCKETT	DRILLING AND EXPLORATION INC.	UNIVERSITY LANDS 1-8	W/C	8	29	3015	1/26/66	105-00797
CR16	CROCKETT	DRILLING AND EXPLORATION INC.	UNIVERSITY -29- 2-4	W/C	4	29	2965	12/4/65	105-00799
CR 17	CROCKETT	EL CINCO PRODUCTION COMPANY LTD.	C. D. JOHNS 2	W/C	24	31	5589	5/15/35	105-00837
CR18	CROCKETT	EL PASO NATURAL GAS PRODUCTS CO.	MINTEL 1	W/C	13	HH	3209	4/29/61	105-00843
CR19	CROCKETT	RALPH E. FAIR & S. T. CONSTANTINE	NOELKE 1	W/C	54	GG	1901	5/2/64	105-00861
CR20	CROCKETT	FULLERTON OIL & GAS CO.	SHANNON 1	W/C	6	FF	8033	7/30/58	105-00903
CR21	CROCKETT	G. M. GRAHAM	SHANNON 1	W/C	9	A	1995	2/26/61	105-00947
CR22	CROCKETT	GULF OIL CORP.	STATE -IW- 1	W/C	5	46	2600	3/21/65	105-01226
CR 23	CROCKETT	GULF OIL CORP.	J. H. TIPPETT -G- (NCT-B) 7·	TIPPETT (WOLFCAMP)	42	31	6238	8/31/65	105-01177
CR24	CROCKETT	JAKE L. HAMON	MARY SUE HUNT 1	W/C	6	1	3399	11/30/61	105-01245
CR25	CROCKETT	H. C. HOOD	TODD 2	W/C	16	10	1812	3/27/68	105-10169
CR26	CROCKETT	HUMBLE OIL AND REFINING CO.	STATE UNIVERSTIY -CR- 1	BEAN AREA WILDCAT	30	30	7065	3/18/67	105-02629
CR27	CROCKETT	SHELL OIL CO.	C. D. JONES -24- 1	UNDESIGNATED	24	31	5598	7/16/65	105-02578
CR28	CROCKETT	RODMAN & TREBOL OIL	UNIVERSITY -E- 1	W/C	18	31	1655	1/4/60	105-02433
CR29	CROCKETT	G. E. KADANE & SONS, ET AL	MARGARET H. SMITH 1	W/C	4	HH	2990	3/23/62	105-01528
CR30	CROCKETT	C. L. NORSWORTHY	SHANNON 1	CROCKETT CO. W/C	2	10	2500	6/29/62	105-02031
CR32	CROCKETT	A. N. NORWOOD INC.	HUNT UNIVERSITY -30- 1	W/C	30	29	2509	8/12/69	105-10221
DA1	DAWSON	RAY A. ALBAUGH	J. T. MIDDLETON 1	W/C	69	8	5014	5/18/50	115-00006
DA2	DAWSON	AMERADA PETROLEUM CORP	F. J. BEAVER 1	W/C	18	33	8950	9/3/59	115-00013
DA3	DAWSON	AMERADA PETROLEUM CORP	T. B. MOORE 1	WEST LAMESA (MISS.)	14	36	11423	8/14/64	115-00019
DA 4	DAWSON	ARD DRILLING CO.	H. F. WELLS 1	WELLS (DEVONIAN)	30	4	12078	4/13/67	115-10025
DA 5	DAWSON	BLACKWOOD AND NICHOLS CO.	RICHARDS 1	W/C	66	278	4998	7/20/59	115-00056
DA 6	DAWSON	BROWN & SCARBER	RANDOLPH & FANBROUGH ·	DAWSON COUNTY W/C	20	M	5036	1/10/60	115-00085
DA7	DAWSON	BYERS & DIBERT	SOUTHEAST CEDAR LAKE UN	SOUTHEAST CEDAR LAKE	111	M	4975	9/19/68	115-10076
DA8	DAWSON	CAMP OIL CO. & JONES DRILLING CO.	EMMA BLUE 1	W/C	25	34	9171	9/16/60	115-00098
DA9	DAWSON	CHICAGO CORP.	HUDDLESTON 2	SMITH-SPRAYBERRY	35	C41	7966	7/10/55	115-00130
DA 10	DAWSON	CHICAGO CORP.	SHAPPELL 1	W/C	3	4	7738	4/9/57	115-00131
DA 11	DAWSON	CITIES SERVICE OIL CO.	MIERS -A- 1	W/C	2	3	8415	8/15/67	115-10079
DA 12	DAWSON	DAVISON & PEMBROOK	BURKETT 1	WELCH	14	C39	4943	10/5/60	115-00370
DA 13	DAWSON	HUSKEY OIL CO.	MURRELL 1	PATRICIA FUSS	20	262	12125	11/29/64	115-00528
DA14	DAWSON	F. KIRK JOHNSON	GRISSOM 1	W/C	25	34	7761	1/12/60	115-00531
DA15	DAWSON	J. E. JONES DRILLING CO.	MITCHELL 2	W/C	11	36	12039	2/6/63	115-01030
DA 16	DAWSON	KERR-MCGEE OIL INDUSTRIES INC	DELIA SEWART 1	W/C	7	M	5007	4/1/64	115-00552
DA17	DAWSON	J. W. KING DRILLING CO.	STANFORD 1	W/C	32	M	4975	9/21/67	115-10164
DA18	DAWSON	GORDON KNOX & ASSOCIATES	J. E. NEELY 1	W/C	28	35	11544	2/28/68	115-10170
DA19	DAWSON	NEVILLE G. PENROSE	O. H. SPIRES 1	W/C	24	C41	4992	9/9/62	115-00659
DA20	DAWSON	SHELL OIL COMPANY	WRIGHT 1	W/C	1	2	3745	6/29/66	115-00840
D1	DICKENS	SKELLEY OIL CO.	? AND SWENSON 2	GIRARD TANNHILL	162	1	4450	8/13/56	
D2	DICKENS	SKELLY OIL CO.	GEO.BEGS 1	W/C	246		6998	4/26/57	
EC1	ECTOR	ADA OIL COMPANY	WALTER COWDEN EST. 1	W/C	1	42		2/3/60	135-02615
EC2	ECTOR	ANDERSON PRITCHARD OIL CORP.	DAVID & INEZ FASKEN -E 32-	ECTOR COUNTY W/C	32	41	4950	10/8/54	135-04913
EC 3	ECTOR	SAM D. ARES	COWDEN 1	W/C	38	42	5503	1/26/59	135-02842
EC4	ECTOR	ASHMUN AND HILLARD	FRANK COWDEN 1	W/C	11	44	9503	2/29/64	135-00249
EC5	ECTOR	ATLANTIC RICHFIELD CO.	B. H. BLAKENEY -C- 5	NORTH COWDEN DEEP	22	43	5406	1/29/78	135-31298
EC6	ECTOR	ATLANTIC RICHFIELD CO.	GOLDSMITH-CUMMINS (S. A.)	GOLDSMITH	25	45	4346	3/12/82	135-32887
EC7	ECTOR	ATLANTIC RICHFIELD CO.	J. L. JOHNSON -O- 4	JOHNSON	42	42	4326	9/12/81	135-32742
EC8	ECTOR	ATLANTIC RICHFIELD CO.	J. L. JOHNSON -P- 5	JOHNSON GRAYBURG	43	42	4280	10/5/81	135-32771
EC9	ECTOR	ATLANTIC RICHFIELD CO.	JOHNSON DEEP UNIT 12	JOHNSON HOLT	34	43	5600	1/16/79	135-31483
EC10	ECTOR	ATLANTIC RICHFIELD CO.	JORDAN (SA) 7912	JORDAN SAN ANDRES	9	35	3679	12/31/81	135-32857
EC11	ECTOR	ATLANTIC RICHFIELD CO.	NORTH FOSTER UNIT 86	FOSTER	1	43	4650	4/17/79	135-31539
EC12	ECTOR	ATLANTIC RICHFIELD CO.	TXL -M- 1	LAWSON - SIMPSON	5	44	5800	2/18/54	135-05433
EC13	ECTOR	ATLANTIC RICHFIELD CO.	TXL -N- 1	GOLDSMITH	31	44	5763	4/5/54	135-05434
EC14	ECTOR	BIG SPRING EXPLORATION CO.	EDWARDS ESTATE 1	W/C	47	43	4952	2/7/61	135-08491

Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
EC15	ECTOR	BRITISH AMERICAN OIL PRODUCING CO.	MILLARD-EIDSON 1	W/C	26	45	8959	5/21/57	135-08506
EC16	ECTOR	BUFFALO OIL CO.	PAUL MOSS 1	W/C	46	44	4210	2/4/60	135-08508
EC17	ECTOR	CITIES SERVICE OIL CO.	COWDEN -T- 1	W/C	29	43	4255	8/11/61	135-03140
EC18	ECTOR	CONTINENTAL OIL CO.	TXL -13- 9	SOUTH COWDEN	13	43	9113	5/28/75	135-30574
GA1	GAINES	ADVANCE , REVILO AND SMITH	NICK ALLEY 1A	DEMPSEY CREEK SAN AND	23	A-27	4588	9/7/59	165-02626
GA2	GAINES	O. D. ALSABROOK	CARTER 2	ALSABROOK	424	G	11296	12/20/58	165-00325
GA3	GAINES	AMERADA HESS CORP.	A.S.A.U. 1606	ADAIR	16	C-31	4898	12/20/80	165-30592
GA4	GAINES	AMERADA PETROLEUM CORP	O'DANIEL HEIR'S 1	S. E. SEMINOLE	16	C-44	5315	4/3/69	165-10195
GA5	GAINES	ANDERSON PRITCHARD OIL CORP.	H. L. WEBB 1	W/C	20	C-35	13137	3/23/59	165-00139
GA6	GAINES	SAM D. ARES	LOMAX JOHNSON 1	GAINES CO. W/C	9		8905	1/21/59	165-00004
GA7	GAINES	ASHMUN AND HILLARD	G. D. NORMAN -A- 1	NORMAN	8	C-45	12250	10/27/65	165-00165
GA8	GAINES	ATLANTIC REFINING CO.	RITLEY -H- 1	GAINES CO. W/C	125	G	3550	12/22/53	165-00364
GA9	GAINES	ATLANTIC REFINING CO.	J. S. HOWLAND 1 DEEP	HOWLAND	46	H	11673	1/5/67	165-10027
GA10	GAINES	ATLANTIC REFINING CO.	ETHEL GARLAND 1	W/C			11364	9/21/67	165-10030
GA11	GAINES	DAN AULD & TOM BROWN DRILLING CO.	MOBIL AND ATLANTIC 1	W/C	101	H	11933	11/26/67	165-10048
GA12	GAINES	CALRTON BEAL & ASSC.	LINDSEY 1	W/C	327	G	7200	3/17/61	165-00438
GA13	GAINES	MURPHY H. BAXTER	MAYO 1	W/C	19	A-22	4227	1/29/60	165-00405
GA14	GAINES	CARLTON BEAL & ASSOCIATES	WASSON 1	WASSON	27	C-35	5040	12/21/61	165-00443
GA15	GAINES	KELLY BELL	CORNETT 1	NORMAN	63	G	3725	4/3/61	165-00444
GA16	GAINES	THE BLUE DANUBE OIL CO.	R. J. RILEY 1	W/C	357	G	5207	4/11/59	165-00479
GA17	GAINES	BRIGHT AND SCHIFF	SPARKS -A- 1	W/C	5	A-13	3356	5/27/60	165-00485
GA18	GAINES	BROSECO CORP.	R. C. BURLESON 1	W/C	112	G	3455	12/2/68	165-10210
GA19	GAINES	BROSECO CORP.	MARY HARDIN-BAYLOR 1	W/C	306	G	5580	11/5/68	165-10211
GA20	GAINES	JAMES G. BROWN & ASSOC.	JONES 1	JONES RANCH	10	A-7	11378	1/12/61	165-00489
GA21	GAINES	H. L. BROWN JR. & PENNZOIL CO.	NIEL PLATTER 1	W/C	Leage 311	track 8	12725	5/21/69	165-10381
GA22	GAINES	CHERRY BROTHERS	N. P. TATE 1	GAINES CO. W/C	7	C-32	3500	12/16/64	165-00603
GA23	GAINES	CHILES & LAWSON	WOOLSEY & DAVIS 1	GAINES CO. W/C			5118	12/28/53	165-01446
GA24	GAINES	COASTAL STATES GAS PRODUCING CO.	NOBLE 1	W/C	925	H	13136	7/6/69	165-10389
GA25	GAINES	PLYMOUTH OIL CO.	C. THOMPSON 1	W/C	1	A-22	4808	3/22/61	165-02173
GA26	GAINES	HUMBLE OIL AND REFINING CO.	METHODIST HOME B1	W/C	8	A-9	11949	3/27/60	165-01215
GA27	GAINES	HUMBLE OIL AND REFINING CO.	FEE EUBANKS -C- 7	ROBERTSON	7	AX	7200	3/13/62	165-01363
GA28	GAINES	JAKE L. HAMON	L.A. TEDFORD 1	W/C	12	A-11	11535	10/31/68	165-10239
GA29	GAINES	GROVER & MAC CURDY	SPENCE 1	NORTH ROBERTSON	2	AX	7222	10/4/65	165-01064
GA30	GAINES	GREAT WESTERN DRILLING CO.	GRANBERRY 1	W/C	6	A-9	11912	1/30/61	165-01032
GA31	GAINES	G. M. K. OIL COMPANY	R. E. COOK 1	W/C	20	A-11	4877	12/5/63	165-01010
GA31	GAINES	FOREST OIL CORP.	G. E. NEWTON 1	W/C	14	297	12830	9/13/67	165-10520
GA33	GAINES	FELMONT OIL CORPERATION	RUTH HUDSON 1	W/C	60	AX	6138	11/5/62	165-00983
GA34	GAINES	LELAND DAVIDSON	L. F. EVANS ESTATE 1	W/C	62	AX	5265	7/20/67	165-10045
GA35	GAINES	CONTINENTAL OIL CO.	WASSON 48 7D	WASSON	48	AX	7550	12/16/60	
GA36	GAINES	DALTON H. COBB	H. E. FORD 1	W/C	24	A-10	7254	7/2/63	165-00684
GL1	GLASSCOCK	ADVANCE PETROLEUM CO.	WM. HOWARD 1	LOWER SPRAYBERRY W/C	29	35	7392	8/17/60	173-00036
GL2	GLASSCOCK	AMERADA PETROLEUM CORP	OVERTON 1	W/C	25	33	2519	8/8/64	173-00059
GL3	GLASSCOCK	R. S. ANDERSON	EVA COLE 1	W/C	16	32	2936	5/31/69	173-00392
GL4	GLASSCOCK	AUSTRAL OIL CO.	ELEANDOR HOUSTON POE ET	W/C	5	35	9915	7/19/70	173-10278
GL5	GLASSCOCK	BRIGHT AND SCHIFF	J. C. BRYANS 1	W/C	26	35	6215	4/20/62	173-00157
GL6	GLASSCOCK	CHAMPLIN OIL AND REFG. CO.	F. I. HILLGER 1	W/C	18	34	3001	6/10/61	173-00177
GL7	GLASSCOCK	CONTINENTAL OIL CO.	W. P. EDWARDS 1	W/C	10	34	3506	5/14/59	173-00192
GL8	GLASSCOCK	S. C. CURRIE	GRIGSBY 1	W/C	10	32	3149	11/3/69	173-10111
GL9	GLASSCOCK	S. C. CURRIE AND R.R. MERRELL	REYNOLDS 1	W/C	38	32	2739	1/18/58	173-00262
GL11	GLASSCOCK	DUNCAN DRILLING CO.	CALVERLEY 1	W/C	1	34	2926	2/16/62	173-00301
GL12	GLASSCOCK	VAUGHN PETROLEUM INC.	TOM CURRIE 2	W/C	191	29	1615	6/8/65	173-01056
GL13	GLASSCOCK	FRANKLIN OIL CO./TEXAS AMERICAN OIL	COVERT 1	W/C	8	33	2705	11/19/61	173-00351
GL14	GLASSCOCK	A. K. GURTHRIE	GLASS 1	W/C	3	32	3034	9/8/69	173-10086
GL15	GLASSCOCK	A. K. GURTHRIE	REYNOLDS 2-A	W/C	34	32	4649	6/24/68	173-10025

Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
GL16	GLASSCOCK	C. W. GUTHRIE	CARTER 1	W/C	5	33	2746	12/25/61	173-00383
GL17	GLASSCOCK	HAMILTON BROS. LTD.	CLYDE C. REYNOLDS -A- 1-27	W/C	27	32	1841	1/30/64	173-00393
GL19	GLASSCOCK	PHILLIPS PETROLEUM CO.	JUDKINS 2	TEX HARVEY	43	36	6888	7/16/55	173-00642
GL20	GLASSCOCK	SINCLAIR OIL AND GAS CO.	L. C. CLARK 1	W/C	41	35	6333	3/29/56	173-00784
GL21	GLASSCOCK	SOUTHLAND ROYALTY CO.	MCDOWELL 1	W/C	22	34	2380	5/27/58	173-10060
GL22	GLASSCOCK	PHILLIPS PETROLEUM CO.	MCDOWELL C1	GLASSCOCK CO. W/C	31	33	2764	10/16/56	173-00653
GL23	GLASSCOCK	SEABOARD OIL CO. OF DELAWARE	BISHOP 1	W/C	31	32	6215	6/20/56	173-00713
GL24	GLASSCOCK	CONTINENTAL OIL CO.	OVERTON -A- 2	HOWARD-GLASSCOCK	8	32	2471	4/22/52	173-00201
GL25	GLASSCOCK	LION OIL CO.	LION COFFEE 4C	HOWARD-GLASSCOCK	15	33	2145	12/31/51	173-00722
GL26	GLASSCOCK	A. K. GURTHRIE	A. L. HOLLEY 1	W/C	222	29	3361	3/2/63	173-00386
GZ1	GARZA	ADA OIL COMPANY	MOLLY SAUNDERS 1	W/C	1304		4248	10/25/60	169-00002
GZ2	GARZA	ADVANCE DRILLING CO.	NELSON 1	W/C	1238		4415	6/4/59	169-00011
GZ3	GARZA	ALAMO CORPERATION	G. W. CONNELL -A- 1	W/C	55	5	2296	7/5/59	169-00033
GZ4	GARZA	R. S. ANDERSON	WALKER 1C	W/C	44	6	3830	10/7/59	169-00148
GZ5	GARZA	ANDERSON PRITCHARD OIL CORP.	CONNELL ESTATE F1	W/C	41	5	8357	8/30/63	169-00156
GZ6	GARZA	ASHMUN AND HILLARD	WELCH 1	GARZA COUNTY W/C	13	4	3805	6/5/60	169-00176
GZ7	GARZA	BROWN BROTHERS. ET AL	SHYTLES 1	GARZA COUNTY W/C	10	2	3226	5/13/60	169-00309
GZ8	GARZA	CONTINENTAL OIL CO.	BLAKE 1 -1204-	W/C	1204		4941	11/27/60	169-00565
GZ9	GARZA	CONTINENTAL OIL CO.	SWENSON L & C 2	W/C	43	2	8145	11/2/55	169-00646
GZ10	GARZA	CONTINENTAL OIL CO.	FUMAGALLI 1	W/C	14	8	8196	5/7/55	169-00623
GZ11	GARZA	EDWIN L. COX	J. T. SIMS 1	W/C	706		4294	3/11/60	169-00695
GZ12	GARZA	DORFMAN PROD CO & DELTA DRLG CO....	SPELLINGS 1	W/C			3800	4/4/64	165-00708
GZ13	GARZA	JOHN J. EISNER	PORTER 1A	W/C	6&5	97	3753	9/9/63	169-00810
GZ14	GARZA	FELMONT OIL CORPERATION	CONNELL 1-11	ROCKER A	11	5	8259	1/12/84	169-31376
GZ15	GARZA	FAIRWAY OIL AND GAS INC.	CARL RAINS 1	W/C	24	D19	8891	7/5/69	169-10057
GZ16	GARZA	BERT FIELDS JR.	C. EASON 1	W/C	1217		4003	10/19/70	169-10347
HC 1	HOCKLEY	ADOBE OIL COMPANY	ALTMAN 1	SMYER	15	2	6135	9/16/80	219-31790
HC2	HOCKLEY	AMBASSADOR OIL CORP	B. H. IVEY 1	HOCKLEY COUNTY W/C	21	703	4691	8/5/60	219-00009
HC 3	HOCKLEY	ARD DRILLING CO.	P. H. TULLIS 1	ANTON (LOWER CLEARFC	112	A	5578	9/27/67	219-00001
HC4	HOCKLEY	ASHLAND OIL AND REF. CO.	HARRIS 1	W/C	12	73	4903	5/12/58	219-00036
HC5	HOCKLEY	BANKLINE OIL CO. & MIDWEST OIL CORP.	MALLETT RANCH OWNERS 2-	HOCKLEY COUNTY W/C	2	34	8868	9/20/57	219-00063
HC6	HOCKLEY	JAMES G. BROWN & ASSOC.	SCHWAB 1	N. E. LEVELLAND	21	734	10098	4/11/69	219-10009
HC7	HOCKLEY	BRUNNER	ARMSTRONG 1	W/C	6	23	10486	9/19/63	219-00103
HC8	HOCKLEY	CACTUS-BROSECO	CACTUS-BROSECO 1 (D.T. B(	W/C	22	695	4554	8/10/68	219-10012
HC9	HOCKLEY	CACTUS DRILLING CORP.	MALLET 1	SLAUGHTER W/C	7	46	4960	7/1/56	219-00114
HC10	HOCKLEY	CAPITOL OIL CORPORATION	DEAN 1	DEAN			5066		
HC11	HOCKLEY	CITIES SERVICE OIL CO.	HARSHBARGER -A- 1	W/C	18	17	10850	11/7/83	219-32721
HC12	HOCKLEY	CITIES SERVICE OIL CO.	BATES -A- 1	W/C	15	19	10329	12/18/67	219-10013
HC13	HOCKLEY	COASTAL STATES GAS PRODUCING CO.	GLEN C. MASON 2	LEEPER	16	X	5987	8/10/67	219-10019
HC14	HOCKLEY	CONTINENTAL OIL CO.	SLAUGHTER ESTATE 1	W/C	43	35	8463	12/7/64	219-00130
HC 15	HOCKLEY	RALPH E. FAIR INC	T. F. JONES 1	W/C	21	5	10277	7/9/60	219-00391
HC 16	HOCKLEY	FELMONT OIL CORPERATION	D. C. REED ESTATE 1	W/C	6	728	10822	1/19/61	219-00403
HC17	HOCKLEY	FELMONT OIL CORPERATION	C. M. PHILLIPS 1	W/C	20	26	10164	11/8/61	
HC 18	HOCKLEY	FELMONT OIL CORPERATION	L. C. HEWITT 1	W/C	18	714	10817	3/29/62	219-00401
HO1	HOWARD	AMERADA PETROLEUM CORP	DORA ROBERTS 1	HOWARD-GLASSCOCK	137	B-29	2979.5	8/8/52	227-04240
HO2	HOWARD	AMERADA PETROLEUM CORP	DORA ROBERTS 4	HOWARD-GLASSCOCK	128	B-29	3012.5	9/12/52	227-00023
HO3	HOWARD	R. S. ANDERSON	MOLLIE ANDERSON 1	HOWARD CO. W/C	26	34	3503	6/30/59	227-00091
HO4	HOWARD	BLUE DANUBE OIL	DOUTHITT 1	W/C	116	29	3113	9/9/59	227-00288
HO5	HOWARD	EL PASO NATURAL GAS PRODUCTS CO.	BARNET 1	W/C	7	29	3679	4/12/62	227-01087
HO6	HOWARD	GREAT WESTERN DRILLING CO.	ECHOLS 1	W/C	2	31	6210	11/1/74	227-30187
HO7	HOWARD	HUMBLE OIL AND REFINING CO.	M. M. EDWARDS -B- 1	W/C	44	30	3194	5/5/66	227-01735
HO8	HOWARD	LION OIL CO.	T. W. LONGSHORE 2	HOWARD-GLASSCOCK	15	33	2486	7/31/52	227-01925
HO9	HOWARD	LARIO OIL AND GAS CO.	BARBER 1	W/C	11	31	6145	9/12/70	227-10717
HO10	HOWARD	LARIO OIL AND GAS CO.	BARBER 2	W/C	11	31	6140	10/17/70	227-10726

Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
HO11	HOWARD	LONE STAR PRODUCTION CO.	MINNIE WALTERS 1	MOORE	34	34	3200	6/4/58	227-01970
HO13	HOWARD	M. A. MACHRIS	J. E. BROWN 13-28	W/C	28	33	8998	4/25/58	227-02025
HO14	HOWARD	MAGNOLIA PETROLEUM CO.	GUY GUFFER -A- 1	W/C	58	20	8423	10/25/51	277-02116
HO15	HOWARD	RUSSELL MCGUIRE	FEYAR 2	W/C	4	33	3200	2/17/52	227-02183
HO16	HOWARD	MAGNOLIA PETROLEUM CO.	E. W. LOVE 2	VEALMOOR	34	32	7966	6/29/56	277-04340
HO17	HOWARD	JOHN I. AND P. D.	IDEN 2	OCEANIC PENN	26	33	8249	9/20/58	227-02458
HO18	HOWARD	MARATHON OIL CO.	KLOH 23	HOWARD-GLASSCOCK	5	32	3238	4/8/86	227-32450
HO19	HOWARD	PAN AMERICAN PETROLEUM CO.	H. R. CLAY -B- 5	HOWARD-GLASSCOCK	139	29	3256	6/28/61	227-02595
HO20	HOWARD	PHILLIPS PETROLEUM CO.	BELLNOLIA 2	ITIAN-HOWARD	12	30	2820	2/26/52	227-02635
HO21	HOWARD	J. B. HAWLEY, JR.	GOWDEN 1	W/C	18	33	3138		227-01595
HO22	HOWARD	THE SUN OIL CO.	COSDEN 1	HOWARD CO. W/C	38	31	8333	4/26/53	227-03497
HO23	HOWARD	COSDEN PETROLEUM CORP.	M. NOBLE READ 1	W/C	22	30	5265	9/14/56	227-00846
HO24	HOWARD	COSDEN PETROLEUM CORP.	N. O. PHILLIPS 1	W/C	42	34	4070	4/12/58	227-00845
HO25	HOWARD	BRUCE C. CLARDEY	BRUCE C. CLARDEY 1	W/C	4	33	3551	11/20/49	227-00361
HO26	HOWARD	COSDEN PETROLEUM CORP.	W. W. LAY 1	W/C	23	31	5053	10/16/55	227-00782
HO27	HOWARD	COSDEN PETROLEUM CORP.	WHITE 1	W/C	36	31	5573	9/8/55	227-00875
HO28	HOWARD	CONTINENTAL OIL CO.	W. B. CONNALLY 1	W/C	14	33	3250	5/16/59	227-00456
HO29	HOWARD	ATLANTIC RICHFIELD CO.	G.M. DODGE ESTATE 183	IATAN-EAST -HOWARD	3	30	2900	8/18/80	227-31041
HO31	HOWARD	TURNER DRILLING CO.	VERA WADE CHOATE 1	W/C	17	31	3565	8/19/66	277-03763
HO	HOWARD	TEXAS PACIFIC COAL & OIL CO. ET AL	VIRGIL LITTLE 1	SE LUTHER-SILURO DEV.	11	32	9994	11/25/57	227-03663
IR5	IRION	ATLANTIC RICHFIELD COMPANY	KETCHUM MOUNTAIN CLEARI	KETCHUM MOUNTAIN CLEA	50	14	4550	6/25/81	
IR4	IRION	MURPHY BAXTER	SUGGS 1	W/C	47	14	4901	12/27/68	
IR3	IRION	CHAMBERS AND KENNEDY	H. M. NOELKE 1	W/C			7598	12/28/67	
IR2	IRION	GULF ENERGY & MINERALS CO.-U.S.	J. D. GIBSON ET AL A-1	W/C	3		9125	3/2/80	
IR1	IRION	VANDEVER PETROLEUM COMPANY	ELLA C. SUGG 1-B	W/C	97	14	4759	1/1/67	
K1	KENT	JACK G. ELAM	HARRISON 1	W/C	56		3940	4/3/84	
K2	KENT	HUMBLE OIL 7 REFINING	LIDA VICK 1	POLAR W/C	45	5	7890	4/11/50	
K3	KENT	BRITISH AMERICAN PETROLEUM	L.R. SPIRES B 1	W/C	40	4	7185	2/19/58	
K4	KENT	F. A. CALLERY, INC	E. E. WALLACE 1	W/C	60	G	7640	6/26/56	
L1	LOVING	GULF RESEARCH	PDB 03						
LU1	LUBBOCK	DELFERN OIL CO.	LEFTWICH 1	LEE HARRISON	24	A	4878	9/26/60	303-00191
LU2	LUBBOCK	CONCHO PETROLEUM CO.	C. HAYES 1	W/C	50	5	4505	7/2/57	303-00033
LU3	LUBBOCK	CONCHO PET. CO. & J. PAUL KARCHER	HONEY 1	W/C	20	33	4572	3/9/63	303-00034
LU4	LUBBOCK	APACHE CORP.	BRYANT 1	W/C	18	JS	5941	3/8/70	303-10201
LU5	LUBBOCK	AMARADA PETROLEUM CORP.	BRADFORD 1	W/C	35	D7	3590	6/12/53	303-00005
LU6	LUBBOCK	HONOLULU OIL CORP.	MCELROY 1	BROADVIEW W. (CLFK)	26	JS	5604	6/11/64	303-00066
LU7	LUBBOCK	HUMBLE OIL AND REFINING CO.	C. L. PARR 1	W/C	72	C	10552	9/10/57	303-00078
LU8	LUBBOCK	HUMBLE OIL AND REFINING CO.	V. J. FARRIS 1	W/C	29	P	11775	2/12/55	303-00077
LU9	LUBBOCK	W. M. & A. P. FULLER	H. T. SWANNER 1	W/C	21	24	5016	8/14/60	303-30041
LU10	LUBBOCK	LELAND FIKES	F. H. MILLER 1	LEE HARRISON	43	1	4845	8/26/61	303-00218
LU11	LUBBOCK	WESTERN DRILLING CO.	J. W. JACKSON 1	LEE HARRISON	71	A	4874	12/4/60	303-00160
LU12	LUBBOCK	STANOLIND OIL & GAS CO.	G. G. FLINN 1	W/C	10	D	8500	8/9/51	303-00119
LU13	LUBBOCK	PLYMOUTH OIL CO.	W. E. SMART 1	W/C	61	S	5904	12/28/60	303-00112
LU14	LUBBOCK	PAN AMERICAN PETROLEUM CO.	THELMA SANDLIN 1	W/C	37	20	5829	10/31/64	303-00110
LU15	LUBBOCK	NORWALK CO.	MCMILLAN 1	W/C	12	D2	6300	3/13/49	303-00107
LU16	LUBBOCK	DIAMOND DRILLING CO.	GRIFFITH 1	W/C	71	S	5814	9/23/64	303-00195
LU17	LUBBOCK	MARATHON OIL CO.	E. B. SHIPP 1	W/C	32	JS	5900	11/6/67	303-10013
LU18	LUBBOCK	DOB OIL PROPERTIES INC	BOYD 2	SOUTHEAST STENNETT	4		4608	9/21/67	303-10009
LY1	LYNN	ALAMO CORPERATION	H. G. TAYLOR 1G	W/C	1251		4483	4/1/60	305-00004
LY2	LYNN	ALAMO CORPERATION	J. O. REED 1	W/C	1426	18	4645	2/14/61	305-00005
LY3	LYNN	ALAMO CORPERATION	MARCUS WILKE 1	W/C	1271		4575	11/9/61	305-00003
LY4	LYNN	AMBASSADOR OIL CORP	C. A. COLEMAN 1	LYNN COUNTY W/C	1	L	4805	4/18/60	305-00008
LY5	LYNN	HERMAN BROWN	W. P. MARTIN 1	W/C	422	21	5485	10/31/64	305-00030
LY7	LYNN	HANSON CORPORATION	HEATH ESTATE 1	W/C	28	20	10012	6/10/84	305-30222

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Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
LY8	LYNN	W. H. HUNT	C. D. YOUNG 1	W/C	1	M	4010	8/6/55	305-00095
LY9	LYNN	HAROLD D. JENKINS	ROBERTS 1	W/C	8	C41	5015	7/11/63	305-00098
LY10	LYNN	MAGNOLIA PETROLEUM CO.	P. CALLOWAY 1	W/C	6	10	6762	4/26/55	305-00122
LY 11	LYNN	MAGNOLIA PETROLEUM CO.	TIMMONS 1	W/C	142	12	4410	5/3/57	305-00125
LY12	LYNN	SANTANA PETROLEUM CORP.	GULLY 1	W/C	9	O	4810	2/9/65	305-00137
LY13	LYNN	W. A. STOCKARD	R. W. ALLEN 1	W/C	133	12	5750	3/13/62	305-00157
M1	MIDLAND	BLOUNT DRILLING CO.	POWELL 1	W/C	44	36	4257	10/24/57	329-00202
M 2	MIDLAND	CITIES SERVICE OIL CO.	DORA ROBERTS -D3- 1	W/C	42	41	9589	8/13/62	329-00309
M3	MIDLAND	CUMBERLAND & WEINER	FASKEN 1-6	W/C	8	36	7459	9/18/54	329-00259
M 4	MIDLAND	T. M. EVANS ET AL	INEZ FASKEN 1	W/C	17	40	5010	5/7/59	329-00380
M5	MIDLAND	EL CAPITAN OIL CO.	W. A. HUTCHINSON 1	W/C	36	37	7112	3/16/55	329-00365
M6	MIDLAND	DAVID FASKEN	O. P. BUCHANAN 1	AZALEA			11450	11/28/62	329-00540
M7	MIDLAND	FRYER & HANSON	FASKEN 1-6-13A	GERMANIA	13	37	4004	5/31/59	329-00488
M8	MIDLAND	ROY FURR	DRIVER G4	W/C	10	37	3780	9/26/59	
M9	MIDLAND	F. W. HOLBROOK & R. S. BRENNAND JR.	M. O. MCALISTER 1	W/C	28	37	4297	4/3/70	329-10329
M10	MIDLAND	SINCLAIR OIL AND GAS CO.	HERD-MIDKIFF A1	W/C	42	38	7400	4/5/56	
M 11	MIDLAND	MAGNOLIA PETROLEUM CO.	S. J. REED 1	PARKS	40	40	10581	9/18/57	
M12	MIDLAND	MAGNOLIA PETROLEUM CO.	ARCH BENGE -B- 1	PARKS-PENN	2	40	10647	4/22/61	
M 13	MIDLAND	MAGNOLIA PETROLEUM CO.	REYNOLDS-PARKS 5	VIREY	26	41	13223	5/7/59	329-01149
M 14	MIDLAND	STANOLIND OIL & GAS CO.	DAVID FASKIN -X- 1	W/C	1	40	4800	9/20/57	329-01527
M15	MIDLAND	TEXAS PACIFIC COAL &OIL CO./COSDEN PET.	PRICE 1	AZALEA	43	37	11580	5/20/65	329-01964
M16	MIDLAND	TXL OIL CORP.	MIDLAND -ST- 1	W/C	23	39	8503	11/24/63	329-01795
M17	MIDLAND	TXL OIL CORP.	WINDHAM 1	W/C	4	40	8004	4/14/62	
MA1	MARTIN	ASHLAND OIL AND REF. CO.	TANT LINDSLAY 1	W/C	17	38	7625	10/26/54	317-00006
MA2	MARTIN	W. H. BLACK DRILLING CO.	HOUSTON 1	W/C	3	37	5101	8/10/52	317-00014
MA 3	MARTIN	W. H. BLACK	KING 1	W/C	32	40	5513	10/17/57	317-00422
MA4	MARTIN	BLANCO, JONES, & STOLTZ	WILKINSON 1	W/C	2	34	7583	2/27/65	317-00164
MA5	MARTIN	BROWN & WHEELER	M. P. MORRISON 1	W/C	28	36	4035	5/3/57	317-00016
MA 6	MARTIN	HEALEY & LE BOND	MABKE 1	W/C	7	38	4575	6/9/69	317-10039
	MARTIN	JOSEPH I. ONEILL, JR.	TANT LINDSEY 1	GRAYBURG W/C	17	38	4400	1/3/67	317-10056
MA 8	MARTIN	PLYMOUTH OIL CO.	FLYNT 1	W/C	9	320		11/25/62	317-00260
MA9	MARTIN	PLYMOUTH OIL CO.	MILHOLLEN 2	W/C	7	35	6704	12/25/61	317-00262
MA10	MARTIN	R. K. PETROLEUM CORP.	TOM 2	R. K. DEVONIAN	3	37	11926	4/22/80	317-31528
MA 11	MARTIN	JAKE L. HAMON	TEXAS UNIV. -C- 1	W/C	13	7	13386	12/5/57	317-00142
MA12	MARTIN	NEVILLE G. PENROSE	MCKINNEY 1	W/C	37	37	4810	9/18/63	317-00252
ML4	MITCHELL	MRS. WILLIAM KECK, JR.	COLMEN RANCH 4	SHARON RIDGE	84	97	1895	4/5/90	
ML6	MITCHELL	RAY ALBAUGH (FORMERLY SHAMROCK O & G)	ELMWOOD EST. 1 (OWWC	W/C	19	17	6300	4/19/68	
ML5	MITCHELL	AMERICAN TRADING PRODUCTION CORP.	A. L. ELWOOD ESTATE 1	W/C	27		7560	6/3/81	
ML3	MITCHELL	MARATHON OIL COMPANY	NAIL OIL TRUST 1	NENA LUCIA WEST	19	12	7100	9/24/66	
ML2	MITCHELL	ROBINSON DRILLING COMPANY	J. D. BARBER 1	W/C	13	29	4300	11/19/68	
ML1	MITCHELL	YOUNG OIL CORPERATION	SNYDER ESTATE 1	W/C	43	29	5368	6/5/74	
P1	PECOS	GEORGE T. ABELL	MOTLEY 1	W/C	25	2	5133	6/23/70	371-10732
P2	PECOS	GEORGE T. ABELL	STATE-STARK 1	W/C	28	2	4829	3/10/69	371-10421
P3	PECOS	GEORGE T. ABELL	CORRIGAN -A- 1	W/C	14	3	6112	8/4/61	371-00079
P4	PECOS	GEORGE T. ABELL	STATE-HEIERMAN 3	W/C	12	3	5239	10/6/68	371-04223
P5	PECOS	GEORGE T. ABELL	MOBIL FEE 1	W/C	41	9	3925	11/7/67	371-10141
P6	PECOS	ADAMS EXPLORATION	ADAMS HAFNER 1	ABELL TUBE	13	2	4000	2/7/85	371-33217
P7	PECOS	ADMOR DRILLING CO INC.	H. J. EATON 1-25	W/C		203	2453	9/15/64	
P8	PECOS	CLAUDE E. AIKMAN	HOLLINGSWORTH 1	WENTZ-CLEARFORK	37	11	2620	1/10/58	371-00228
P9	PECOS	AMBASSADOR OIL CORP	ROY GIRVIN 1	W/C	120	11	4719	12/17/63	371-00231
P10	PECOS	AMERADA PETROLEUM CORP	R. MCDIVITT 1	W/C	14	105	2800	12/19/63	371-00247
P 11	PECOS	AMERICAN TRADING AND PRODUCTION	HARALSON 1	W/C	15	604	9600	7/31/80	371-31709
P12	PECOS	AMERICAN PUBLIC ENERGY CO.	MOBIL FEE 1	W/C	9	9	6000	3/18/84	371-32976
P13	PECOS	AMERICAN TRADING AND PRODUCTION	PECOS CO. WATER DIS.(3) WI	W/C	11	9	5940	11/10/61	371-01383

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Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
P14	PECOS	AMERICAN TRADING AND PRODUCTION	MAX D. SHAFFRATH ET AL	CHERRY CANYON W/C	26	C2	6374	5/18/66	371-00264
P15	PECOS	AMERICAN TRADING AND PRODUCTION	BOYS RANCH -B- 1	W/C	2	228	8350	2/6/67	371-10050
P16	PECOS	AMERICAN TRADING AND PRODUCTION	STATE NATIONAL BANK 1	W/C	11	140	5261	1/22/60	371-00265
P17	PECOS	JAMES K. ANDERSON	IOWA REALITY TRUST 1	W/C	31	10	5585	1/1/70	371-10609
P18	PECOS	ANDERSON PRITCHARD OIL CORP.	AERO 1	APCO WARNER	101	10	4717	5/23/53	
P19	PECOS	W. D. ANDERSON & SONS	ATLANTIC 1	W/C	17	11	3209	10/12/67	371-10083
P20	PECOS	L. H. ARMER/FOREST OIL CORP./HOUSTON OIL	JASPER CSL 1	W/C		104	8041	12/28/55	371-00325
P 21	PECOS	ANDREWS DRILLING CO.	SHERBINO 1A	PECOS COUNTY W/C	19	C41	3332	5/28/62	371-00316
P22	PECOS	ASHMUN AND HILLARD	DOUGLAS OI COMPANY 1	PECOS COUNTY W/C	15	194	1562	4/3/57	371-00346
P23	PECOS	ASHMUN & HILLARD & SHIRLEY MILLER DRLG	BAILEY 1	FORT STOCKTON	25	146	3051	8/4/57	371-00345
P 24	PECOS	ATLANTIC REFINING CO.	STATE 1	S. TIPPETT / UPPER WOLF(	24	12	6103	3/28/63	371-00366
P25	PECOS	ATLANTIC REFINING CO.	CORDZ & JUUL 1	PAYTON-DEVONIAN	101	8	6955	9/16/58	371-00355
P26	PECOS	MURPHEY H. BAXTER	MENDEL 1B	W/C	11	49	6979	8/21/68	371-10179
P27	PECOS	BAY PETROLEUM CO. & J. E. JONES DRLG.	WILLIAMS 1B	W/C	84	8	2266	5/16/59	371-01051
P28	PECOS	BLOUNT DRILLING CO.	CLEO RIGGS 1	FORT STOCKTON	10	146	2930	4/8/59	
P29	PECOS	BOND OIL CORPERATION	M. R. KENNEDY 1	W/C	168	3	5037	3/26/65	371-01140
P30	PECOS	BRITISH AMERICAN OIL PRODUCING CO.	MOORE & GILMORE 1	W/C	6	10	6025	3/1/63	371-01185
P31	PECOS	ATLANTIC REFINING CO.	ROSA MITCHELL ST. GAS UNI	PUCKETT	34	100	13344	11/14/62	371-00364
RE1	REAGAN	ADA OIL COMPANY	MERCHANT HEIRS 1	REAGAN COUNTY W/C	13	A	6412	12/8/58	383-00001
RE2	REAGAN	ADOBE OIL COMPANY	COPE 1	W/C	108	2	7980	5/22/70	383-10756
RE3	REAGAN	W. D. ANDERSON & SONS	UNIVERSITY 1	W/C	3	7	3186	1/12/60	383-00115
RE4	REAGAN	ASHMUN AND HILLARD	BARBEE -A- 2	BARBEE WICHITA ALBANY	3		6755	8/4/64	383-00149
RE5	REAGAN	BEAL, TROBAUGH & ASSOC.	CREWS 1	STILES ELLENBERGER	9		10232	6/28/63	383-00269
RE7	REAGAN	TOM BROWN INC.	SLAUGHTER 1	W/C	12	H	4047	2/19/80	383-30722
RE8	REAGAN	DAVID FASKEN	C. H. SUGG -A- 1	W/C	105	2	5500	10/3/63	383-00680
RE9	REAGAN	HONOLULU OIL CORP.	H. G. COPE -B- 2	COPE	34	A	5145	10/9/59	383-01037
RE10	REAGAN	HUMBLE OIL AND REFINING CO.	W. A. BLAKLEY 2	JOHN SCOTT	151	I	2709	1/27/61	
RE11	REAGAN	CARL ENOKL & JACK EDWARDS	BOOTHE 1	W/C	237	1	2258	10/30/59	383-00676
RE12	REAGAN	LENONIE OIL COMPANY	SCOTT 1B	PRICE NE GRAYBURG		176	2736	8/8/65	383-00961
RE13	REAGAN	LION OIL CO.	RUBY WRIGHT 1	W/C	21	C	6879	10/3/55	383-00977
RE14	REAGAN	LYNCH & GRIFFITH	UNIVERSITY -28- 1	W/C	28	8	3141	10/6/69	383-10173
RE15	REAGAN	MCELROY RANCH CO. ET. AL.	C. H. SUGG 1	W/C	53	2	5400	3/2/57	
RE17	REAGAN	JAMES H. SNOWDEN	GIDNEY 1-37	W/C	2	36	6495	7/29/55	
RE18	REAGAN	TRIPLE "L" OIL CO.	UNIVERSITY A1	REAGAN COUNTY W/C	12	48	2550	1/7/62	
RE19	REAGAN	A. J. VOGEL ET. AL.	FRIEND 1	REAGAN COUNTY W/C	50		2417	7/31/69	383-10670
RE20	REAGAN	WILBANKS & RASMUSSEN	UNIVERSITY -14- 1	W/C	14	12	2782	11/25/71	383-11257
ST2	STERLING	SUNSET INTERNATIONAL PETROLEUM CORP.	NICK AND JOHN REED 1	W/C	94	2	6855	10/11/70	
ST4	STERLING	SUN OIL COMPANY	J. F. ELLWOOD 1	W/C	10	2	5250	8/18/70	
ST5	STERLING	SOUTHERN MINERALS CORPERATION	SUGG 1	W/C	27	7	8744	9/24/70	
ST7	STERLING	CHAMPLIN PETROLEUM COMPANY	T. F. FOSTER 1	W/C	6	13	8525	5/5/70	
ST8	STERLING	CONTINENTAL OIL CO.	REED 1	W/C	13	30	7733	12/12/69	
SC1	SCURRY	W. A. & G. OIL AND GAS INC.	CARY 6	SHARON RIDGE	158	97	3200	10/15/84	
SC4	SCURRY	MCCANN CORPERATION	VOSS 1	N/A	73	97	7110	8/3/85	
SC3	SCURRY	MCGRATH & SMITH INC.	JOHN JONES 1	W/C	514	97	7845	3/8/73	
SC2	SCURRY	SAMEDAN OIL CORP.	HAMLETT 1	N. E. TONTO	266	2	5131	6/3/85	
TY1	TERRY	M. D. ABEL	FLEMING 1	W/C	69	DD	5520	3/24/71	445-10223
TY 2	TERRY	AMERADA PETROLEUM CORP.	A. M. BROWNFIELD -A- 1	W/C	7	K	5173	2/2/64	445-00014
TY4	TERRY	ANDERSON PRITCHARD OIL CORP.	OIL DEVELOPMENT CO. -F- 1	W/C	10	DD	12855	4/9/60	445-00079
TY 5	TERRY	CITIES SERVICE OIL CO.	LINDSLEY 4	MOUNDLAKE (FUSS)	45	E	11400	1/31/68	445-10012
TY6	TERRY	FRANKFORT OIL CO.	B. E. GIVAN 1	W/C	16	D11	6078	12/13/66	445-10018
TY7	TERRY	GREATHOUSE, PIERCE & DAVIS	ZEB A. MOORE JR. 1	W/C	19	C36	9864	3/18/65	445-00210
TY8	TERRY	JAKE L. HAMON	E. C. HOWARD 1	W/C	75	T	12013	12/9/68	445-10023
TY9	TERRY	HOUSTON OIL & MINERALS	AULD 1	W/C	28		4720	10/21/84	
TY10	TERRY	HONOLULU OIL CORP.	VERA V. WILMETH 1	W/C	44	K	13429	5/6/62	445-00358

Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
TY 11	TERRY	J. M. HUBER CORP.	CONTINENTAL-WILSON 1	W/C	5	M	11880	12/19/68	445-10024
TY12	TERRY	LIPAN OIL CO.	POOL 1	W/C	36	D11	7085	8/5/66	445-00401
TY13	TERRY	I. W. LOVELADY	GRIMES 1	W/C	92	D11	5612	4/10/68	445-10034
TY14	TERRY	MAC DONALD OIL CORP.	SMITH 1	W/C	47	DD	5590	4/29/70	445-10207
TY15	TERRY	MAYNARD OIL CO.	R. G. BEASLEY 1	W/C	1	DB	7100	10/2/84	445-30868
TY16	TERRY	MOBIL OIL CORP.	TEXAS TECH 1	W/C	124	D11	5869	9/8/83	445-30782
TY	TERRY	AMERADA PETROLEUM CORP.	A. W. BROWNFIELD 1	W/C	26	A1	10364	12/26/53	445-00013
U2	UPTON	ASHLAND OIL AND REF. CO.	SHERROD 1-43 B	W/C	43	37	6931	6/28/55	461-00394
U 3	UPTON	ATLANTIC REFINING CO.	J. W. ROBBINS 1	W/C	2		8735	12/6/63	461-00506
U4	UPTON	BOND OIL CORP. & BENWAR OIL CORP.	GOODE EST. 1	W/C	23	B	4203	11/1/56	461-00924
U 5	UPTON	ALBERT C. BRUCE	A. J. SABO 1	W/C	176	E	3978	5/10/63	461-01585
U6	UPTON	CHAMBERS & KENNEDY & EDWIN L. COX OIL	SANGER INVESTMENT CO.	W/C	24	35	5304	4/12/61	
U7	UPTON	CITIES SERVICE OIL CO.	UNIVERSITES AS 1	W/C	8	14	7168	2/20/57	461-02189
U8	UPTON	CONCHO PET. CO.	TIPPETT 1-23	W/C	23	38	7405	8/3/55	
U9	UPTON	W. R. GODDARD	AVERY 1	W/C	3	A	2354	2/1/62	461-00434
U10	UPTON	GULF OIL CORP.	ED. S. HUGHS CO. 7	W/C	4		7592	10/13/61	461-03936
U11	UPTON	GULF OIL CORP.	I. W. ROBBINS -H- 1	W/C	6		7434	1/9/63	461-00760
U 12	UPTON	GULF OIL CORP.	J. T. MCELROY CONS. 829	MCELROY	195	F	3043	7/13/79	461-30447
U13	UPTON	GULF OIL CORP.	RICHARD KING 1	W/C	11	3.5	6730	6/16/67	461-10119
U14	UPTON	HUMBLE OIL AND REFINING CO.	ELLA M. COREETT -B- 1	W/C	19	2	5861	2/18/58	461-03843
U 15	UPTON	KEWANEE OIL CO.	HOBBS 2	W/C	52	35	5910	5/17/59	461-02868
U16	UPTON	WILLIAM MOSS PROPERTIES INC.	LYONS 1	W/C	2		2900	1/17/70	461-10513
U17	UPTON	LARIO OIL & GAS CO.	WOOLSEY 1	W/C	3		3804	11/24/67	461-10123
U 18	UPTON	C. E. MARSH II	JOSIE FAY PECK 1	W/C	26	42	4452	8/1/64	461-00359
U19	UPTON	PURE OIL CO.	WANDA HANKS -A- 1	W/C	52	C	13264	3/27/57	461-03718
U20	UPTON	PHILLIPS PETROLEUM CO.	UNIVERSITY G. G. 1	W/C	5	58	6747	3/3/56	461-00868
U21	UPTON	COQUINA OIL CORP.	HALF 1	SPRABERRY TREND	2	Y	8400	11/15/83	461-31471
U22	UPTON	DURHAM INC.	JOHNSTON 1	HURDLE	20	1	2200	1/31/83	461-31403
U23	UPTON	HUMBLE OIL AND REFINING CO.	SHACKELFORD B10	N. PEMBROOK	16	38	7495	2/24/59	461-03217
U24	UPTON	SHELL OIL COMPANY	KING RANCH OIL & LIGNITE C	SHIRK AREA	26	2	3407	9/13/63	461-02608
U25	UPTON	SINCLAIR OIL AND GAS CO.	UNIVERSITY -6- 1	W/C	6	A5	5080	?/4/63	
U26	UPTON	SINCLAIR OIL AND GAS CO.	LILLIE MILKIFF -B- 2	W/C	13	38	7116	10/11/59	461-04031
U27	UPTON	R. B. STALLWORTH JR.	CONNEL -B- 1	SPRABERRY CLEARFORK	45	39	7127	9/9/61	461-01926
U 28	UPTON	THE TEXAS COMPANY	MINNIE S. HOBBES NCT-1	UPTON COUNTY W/C	60	35	5624	10/2/60	461-03877
U 29	UPTON	BEN W. WISEMAN JR.	UNION SHIRK 1	W/C	17	3	8240	6/11/80	461-30516
U99	UPTON	ROBERT A. DEAN	HARRIS 3	CROCKETT	3	W	1548	5/23/72	461-10603
WA1	WARD	ADOBE OIL AND R.S. BRENNAND JR.	RUESS FEE 90 1	W/C	90	34	6367	4/7/65	475-00445
WA2	WARD	ALDRIDGE AND CLARK OIL CO.	J. D. JONES 1	WARD CO. WC	21	B-29	4205	8/13/62	475-00040
WA3	WARD	AMERICAN TRADING AND PRODUCTION	UNIVERSITY "33A" 1	W/C	33	18	6693	3/23/68	475-10001
WA4	WARD	ATLANTIC REFINING CO.	UNIVERSITY WICKETT -A- 6	NORTH WARD ESTES	1	16			475-00207
WA5	WARD	BRITISH AMERICAN OIL PRODUCING CO.	J. B. TUBBS F 6	CRA-WAR	8	B-20	8295	8/4/59	475-00511
WA6	WARD	H. L. BROWN JR. AND W. J. HEATH	W. I. WINTER 1	W/C	14	B-20	6391	1/12/68	475-10015
WA7	WARD	H. L. BROWN JR. AND CLEM E. GEORGE	FRITZ 1	W/C	165	34	5189	5/7/66	475-00382
WA8	WARD	TOM BROWN DRLG. CO.	CYNTHIA MONROE 1	W/C	118	34	6405	1/29/65	475-00384
WA9	WARD	BOLIN DRILLING AND PRODUCTION CO.	S. R. ALLEN 2	W/C	30	34	2627	10/11/63	475-00314
WA10	WARD	CARE, HAEN, STAFFORD AND WATT	HALL 1	NETTERVILLE	14	32	2320	10/3/60	475-00609
WA11	WARD	CITIES SERVICE OIL CO.	LYNCH 1	PAYTON DEVONIAN	7	32	5015	8/7/58	475-00774
WA12	WARD	CONTINENTAL OIL CO.	W. D. BLACK 87 1	UNKNOWN	87	34	6193	8/10/94	475-00755
WA13	WARD	DIXILYN DRILLING CORP.	SEALY SMITH 1	W/C	19	A	5775	8/30/61	475-00831
WA14	WARD	FRED A. DAVIS	UNIVERSITY 1	W/C	16		5215	5/17/63	475-00819
WA15	WARD	GULF OIL EXPLORATION AND PRODUCTION COMI	HSA 1290	NORTH WARD EST.ATES	2	F	3341		
WA16	WARD	GULF OIL EXPLORATION PRODUCTION CO	HAS 1219	NORTH WARD ESTES	82	N	3384	9/13/87	475-32916
WA17	WARD	GULF OIL EXPLORATION PRODUCTION CO	HAS WI 121	NORTH WARD ESTES	8	O	2850	6/10/87	
WA18	WARD	GULF OIL CORP.	W. A. ESTES 50D	W. SANDHILLS (DEV)	5	B28	6427	11/16/65	475-01270

Appendix 1. Wireline logs used for this study.

Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
WA19	WARD	GULF OIL CORP.	J. H. EDWARDS ET AL -C-	W/C	18	B18	7350	2/27/67	475-10047
WA20	WARD	HARLAN PRODUCTION CO.	R. H. DORSEY 1	W/C	57	34	6510	9/16/66	475-02580
WA21	WARD	GULF OIL CORP.	WRISTEN BROS. 10	W/C	20	5	7532	1/25/57	475-01395
WA22	WARD	ARGO OIL CORP.	CYRUS MONROE 1A	QUITO	5	34	5188	1/6/58	475-00115
WA23	WARD	CONTINENTAL OIL CO.	MIZE & GASKILL 1	W/C	36	1	5001	10/10/62	475-00752
WA24	WARD	BRITISH AMERICAN OIL PRODUCING CO.	MARSTON 1B	W/C	15	B19	3184	9/30/65	475-00502
WA25	WARD	CARTER & MANDEL CO.	SEALY SMITH 1	WARD COUNTY W/C	80	A	3335	1/22/66	475-00621
WA26	WARD	BTA OIL PRODUCERS	708 JVS PYOTE 3-20	W/C	20	16	16400	11/29/75	475-30413
WA27	WARD	D. D. FELDMAN OIL & GAS	TREBOL 6	NORTH WARD ESTES	6	16	2875	4/18/60	
WA28	WARD	LIEDTKE '60 LTD.	OHIO UNIVERSITY 1	W/C	3	18	5159	6/25/64	475-03289
WI1	WINKLER	ASHMUN AND HILLARD	SEALY SMITH 1D	SEALY SMITH	45	A	8618	3/17/68	495-10003
WI2	WINKLER	ATLANTIC RICHFIELD CO.	IDA HENDRICK -M- 3	HENDRICK (YATES)	31	B-5	3054	9/23/71	495-10880
WI3	WINKLER	BAY-TEX OIL CO.	HENDRICK -G- 1	HENDRICK	39	26	3102	12/31/66	495-10033
WI4	WINKLER	BAKKE OIL COMPANY	WILD TURKEY 1	W/C	36	46	8796	8/28/63	495-00194
WI5	WINKLER	BASS BROTHERS ENTERPRISES INC	PERRY R. BASS ET AL FEE 1-5	G. P. M. (WADDELL)	5	B-10	7199	10/31/66	
WI6	WINKLER	J. C. BARNES OIL COMPANY	KERR -B- 1	EMPEROR-DEVONIAN	26	B-5	9170	5/22/64	495-00198
WI7	WINKLER	FELMONT OIL CORPERATION	ATLANTIC G-3-A	HENDRICK	46	26	3147	5/10/67	495-00358
WI8	WINKLER	FELMONT OIL CORPERATION	HENDRICKS -B7- 7	HENDRICK	29	26	3280	1/20/69	495-10108
WI9	WINKLER	GULF OIL CORP.	KEYSTONE CATTLE CO. 173-I	FLYING -W-	24	A-57	9709	9/18/59	495-01325
WI10	WINKLER	GULF OIL CORP.	STATE -GV- 1	W/C	43	21	5148	12/3/58	495-01878
WI11	WINKLER	GULF OIL CORP.	O. CLAPP 31	BROWN ALTMAN	37	26	3230	9/8/58	495-01770
WI12	WINKLER	JAKE L. HAMON	S. B. WIGHT 1	W/C	19	40	9520	12/2/60	495-01918
WI13	WINKLER	HNG OIL COMPANY	UNIVERSITY (21-10) 1	W/C	10	21	17098	12/24/78	495-30284
WI14	WINKLER	BETTIS AND SHEPERD	SETH CAMPBELL 1	W/C	2	5	4046	3/7/60	495-00300
WI15	WINKLER	GULF OIL EXPLORATION PRODUCTION CO	HAS 1290	NORTH WARD ESTES	2	F	3400	9/4/63 (?)	
WI16b	WINKLER	J. C. BARNES OIL COMPANY	KERR 1	W/C	26	B-5	11668	9/18/58	495-00197
WI17	WINKLER	GEORGE L. BUCKLES CO.	COLBY 16	KERMIT	38	26	3200	12/15/64	495-00364
WI18	WINKLER	E. P. CAMPBELL	TOBE MORTON 1-51	HENDRICK	8	B-12	2890	12/4/62	
WI19	WINKLER	CARTER FOUNDATION PROD. CO	PURE-WALTON -E- 3	KEYSTONE	1	B-3	9914	6/7/56	495-00414
WI20	WINKLER	BUFFALO PETROLEUM CORPORATION	SEALY-SMITH -B- 1-11	W/C	11	A	5765	11/14/63	495-00373
WI21	WINKLER	EXXON COMPANY U.S.A.	HALEY UNIT 19-1	EVETTS	19	27	18470	10/30/77	495-30226
WI22	WINKLER	J. C. BARNES OIL COMPANY	BROWN-ALTMAN -B- 1	EMPEROR DEEP	5	B-11	1140	4/9/61	495-00196
WI23	WINKLER	TOM BROWN DRLG. CO.	HOGG 1	W/C	9	B-11	6250	9/20/70	495-10793
WI24	WINKLER	E. P. CAMPBELL AND F. R. JACKSON	GEORGE SEALY 1-52	HENDRICKS	52	F	3052	8/6/62	495-00385
WI25	WINKLER	PERRY R. BASS	G. P. MITCHELL 7824 1	W/C	16	B-10	6140	1/25/66	
WI26	WINKLER	CHAMPLIN OIL AND REFG. CO.	E. W. COWDEN 12	EMPEROR	2	B-12	3802	7/23/60	495-00490
WI27	WINKLER	CITIES SERVICE OIL CO.	WILLIAMSON -C- 1	W/C	10	46	3404	7/2/63	495-00539
WI28	WINKLER	CITIES SERVICE OIL CO.	TUBB -B- 1	W/C	14	C-23	9809	7/6/62	495-00534
WI29	WINKLER	CITIES SERVICE OIL CO.	BUTTRAM 1	CHEYENNE-BONESPRINGS	17	C-23	9934	11/26/62	495-00521
WI30	WINKLER	CITIES SERVICE OIL CO.	WADDELL 1	N. W. WHEELER	5	B-7	10860	10/3/54	495-00536
WI31	WINKLER	BLACKWOOD AND NICHOLS CO.	AMBURGEY 1-7	W/C	7	B-9	6533	7/24/58	495-00305
WI32	WINKLER	HUMBLE OIL & REFINING CO.	YARBROUGH & ALLEN 62	SEALY SMITH	21	B9	8954	1/18/69	495-10195
WI33	WINKLER	GULF OIL CORPERATION	K. C. C. 258	S. KEYSTONE (TUBB)	1	B6	6800	1/25/68	495-10137
WI34	WINKLER	PAN AMERICAN PETROLEUM CORP.	RUTH M. BAKWIN 1	W/C	39	27	5161	2/18/68	495-10241
WI35	WINKLER	CITIES SERVICE OIL CO.	CAMPBELL -B- 1	SOUTH KERMIT DEV.	5	B6	8766	7/29/63	495-00522
WI36	WINKLER	MAGNOLIA PETROLEUM CO.	J. B. WALTON 242	KERMIT	36	74	3006	10/28/60	495-03134
WI37	WINKLER	MCGRATH & SMITH	SEALY SMITH ESTATE -88-	W/C	88	A	3314	12/31/67	495-10228
WI38	WINKLER	DIAMOND DRILLING CO.	JOHN HALEY 1	W/C	5	27	5309	1/16/63	495-00690
WI39	WINKLER	CACTUS DRILLING CO.	UNIVERSITY -D- 1	W/C	12	20	5354	7/20/69	495-10057
WI40	WINKLER	DOYLE HARTMAN	ARCO-CUMMINS -D- 1	HENDERSON	15	26	3135	12/23/80	495-30405
WI41	WINKLER	GREATHOUSE, PIERCE, & SMITH	SEALY-SMITH 1	W/C	75	A	9446	3/16/67	
WI42	WINKLER	BOBBY HOLT (GREATHOUSE, HOLT, MADDOX)	WHEELER 1	W/C	18	B7	4551	3/22/70	495-10742
WI43	WINKLER	DIVERSA INC.	AMBURGEY B1	W/C	22	B7	8260	3/6/64	495-00693
YO1	YOAKUM	J. S. ABERCROMBIE	A. L. CONE 1	W/C	332	D	5461	11/6/62	501-00015

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Well #	County	Driller	Lease and Well Number	Field	Section	Block	TD	Completion	API Number
YO2	YOAKUM	J. S. ABERCROMBIE	N. H. HORNER 1	W/C	750	D	5704	5/2/61	501-00016
YO3	YOAKUM	ADMOR DRILLING CO INC.	HARTGROVE 1	W/C	211	D	5317	12/13/62	501-00029
YO4	YOAKUM	AMERADA PETROLEUM CORP.	ANNIE ARMSTRONG 1	W/C	276	D	12501	12/12/68	501-10003
YO5	YOAKUM	AMERADA PETROLEUM CORP.	FITZGERALD 1	W/C	82	D	5170	11/16/63	501-00234
YO6	YOAKUM	ADA OIL COMPANY	J. C. POWELL 1	W/C	4	D	8024	6/18/59	501-00028
YO7	YOAKUM	AMERADA PETROLEUM CORP.	RANDALL 1	W/C	853	D	9018	9/3/58	501-00246
YO8	YOAKUM	ANDERSON PRITCHARD OIL CORP.	T. A. ELLISON 1	REEVES	876	D	5640	4/21/63	501-00280
YO9	YOAKUM	ARGO OIL CORP.	BERTIE BROWN 1	W/C	220	D	5337	7/9/64	501-00314
YO10	YOAKUM	BLACKWOOD AND NICHOLS CO.	CARTER 1	W/C	534	D	5348	8/21/59	501-00404
YO11	YOAKUM	F. T. BRAHANEY	D. B. THRASHER 1	W/C	343	D	5292	5/14/59	501-00428
YO12	YOAKUM	BRITISH AMERICAN OIL PRODUCING CO.	BROWNFIELD 1	W/C	563	D	8750	11/15/57	501-00445
YO15	YOAKUM	H. L. CAIN	CAIN-KELLER 1	YOAKUM COUNTY W/C	541	D	5305	4/1/59	501-00488
YO15	YOAKUM	CAL-MON OIL CO.	HUDSON 1	W/C	834	D	9111	8/13/67	501-10021
YO17	YOAKUM	CONTINENTAL OIL CO.	M. S. PIERSON 1	W/C	16	L	12325	7/26/55	501-00614
YO18	YOAKUM	CONTINENTAL OIL CO.	W. L. ROGERS 1	W/C	106	D	13012	9/10/55	501-00615