

SALT CAVERN STUDIES — REGIONAL MAP OF SALT THICKNESS  
IN THE MIDLAND BASIN

FINAL CONTRACT REPORT

Prepared by  
Susan Hovorka

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Bureau of Economic Geology  
Noel Tyler, Director  
The University of Texas at Austin  
Austin, Texas 78713-8924

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## EXECUTIVE SUMMARY

Regional variation in the thickness of the major bedded salt-bearing interval of West Texas, the Salado Formation, provides a screening criterion for separating areas where the salt is heterogeneous, complex, and potentially less stable from areas where salt is more homogeneous. Areas of reduced and variable salt thickness and relatively shallow depths to the top of the salt are identified on the eastern shelf of the Midland Basin in Garza, Borden, Howard, Glasscock, and Reagan counties; along the Pecos River in Crockett, Upton, Crane, and Pecos Counties; and along the western edge of the Central Basin Platform in Ward and Winkler Counties. Reconnaissance data suggest that salt may be locally or regionally actively dissolving from these areas.

Salt thinning in areas where the top of salt is relatively deep (>1500 ft) is noted south of the Matador Arch in Cochran, Hockley, and Lubbock counties, and locally along the eastern edge of the Central Basin Platform in Gaines, Andrews, and Ector Counties. The thinning in these areas is tentatively interpreted as dominantly the result of deposition of thin salt or Permian salt dissolution. In all the areas of thinning, sedimentary patterns suggest that facies changes may also change the quality of the salt (salt purity, water content, bed thickness) over short distances.

In other areas within the Midland and Delaware Basins, salt thickness changes are gradual. However, the potential for local areas of salt dissolution not identified in this regional study, for example those that may be beneath saline lakes, to impact the suitability for salt in these areas as host strata for cavern development was not investigated in this regional study.

## INTRODUCTION

Utilization of salt caverns in bedded salt for storage of product or disposal of wastes associated with oil and gas exploration and production activities is an attractive alternative to other storage and disposal options if there is assurance that products or wastes will remain

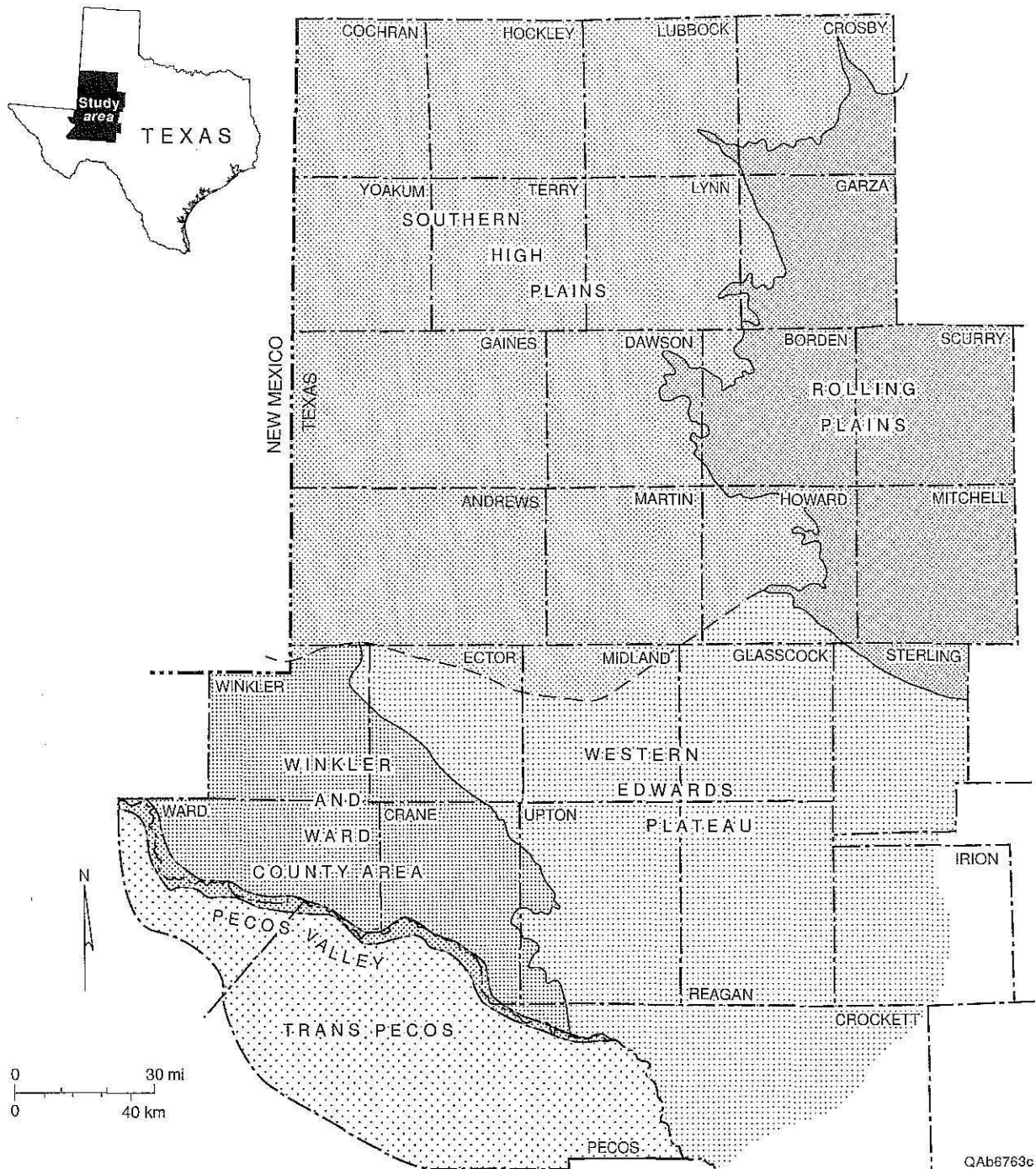


Figure 1. Location map showing study area and physiographic regions.



the upper salt-bearing unit in the study area. Throughout much of the study area, the thickest and most extensive salts occur in this interval. Documents from the Railroad Commission of Texas (1995) indicate that the Salado Formation is the stratigraphic interval targeted for underground storage facilities in this area. However, when the extent of the Salado salt was mapped, some of the storage facilities lie east of the salt pinch-out. These facilities may be in the older salt bearing units, the Seven Rivers, Queen, and Grayburg Formations (fig. 2); therefore a reconnaissance map showing the extent of salt in these older units was also prepared.

About 500 wireline logs were selected and photocopied from log files at the Bureau of Economic Geology. An effort was made to distribute well locations through the study area with a few additional logs in areas where the literature search suggested that heterogeneity was expected. Previous experience suggested that the most useful logs for West Texas bedded salt mapping are gamma-ray-caliper-sonic combinations. If these were not available in the log files, neutron or resistivity logs were used. The log data base assembled is not exhaustive; many thousands more logs through the salt interval are available but could not be analyzed in the time available.

The stratigraphic interval selected for mapping was based on prominent, areally extensive markers that bound the salt. The upper marker bed is the top of the Alibates Formation in the Midland Basin and equivalent top of upper Rustler anhydrite in the Delaware Basin (fig. 2). The lower marker beds are the top of the Yates Formation in the Midland Basin and Central Basin Platform and top of the Lamar limestone in the Delaware Basin (fig. 2). Selection of these markers includes some regional nonsalt bed units within the mapped interval; however, using well-defined markers reduced stratigraphic ambiguity and allowed completion of mapping within the available time frame. Below the Salado Formation but within the mapped interval is the Tansill Formation, a relatively thin (typically 100-ft) carbonate, anhydrite, and sandstone unit. In the Delaware Basin, a thick interval of the Castile Formation, containing anhydrite, salt, organic shale, and carbonate, underlies the Salado Formation above the Lamar marker. Above the Salado salt are the relatively thin (average 100-ft) carbonate, anhydrite, and sandstone units of the

review, documenting how these variables control salt character is provided in the following section.

The depositional setting for salt in the Permian Basin was controlled by paleogeography. 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). Sedimentary patterns show that by the Guadalupian, 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. 3) were expressed only by subtle contrasts in subsidence rates (Adams, 1940; Feldman, 1962; Machus and Jones, 1984; Fracasso and Hovorka, 1986). The Sheffield and Hovey channels were topographic features that served as conduits for marine water to move onto the shelf. Salt precipitation began in the Midland Basin during the Guadalupian; salt occurs in the Grayburg, Queen, and Seven Rivers Formations (Price, 1991). The thickest salts are generally observed on the parts of the shelf away from the Delaware Basin toward the east and north. Carbonate accumulation rimming the Delaware Basin is known as the Capitan reef (King, 1942; Garber and others, 1989). 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 is the basinal equivalent (Garber and others, 1989).

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 (Meissner, 1972; 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, which 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 crystals' size, shape, and interrelationship; 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 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). Stratigraphic nomenclature and relationships are complex in the Delaware Basin (Powers and Holt, 1990). However, genetic equivalence and correlation of the upper Rustler anhydrite 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 (Dewey Lake Formation or upper Rustler Formation) that represent the end of Permian deposition.

The post-Permian evolution of the area includes deposition of the Triassic Dockum Formation in fluvial and lacustrine environments (McGowen and others, 1979); erosion and truncation; deposition of Cretaceous sandstones and carbonates over most of the area; regional uplift and erosion during the Cenozoic; and deposition of gravels, sands, and finer grained clastics of the Miocene-Pliocene Ogallala Formation in fluvial and upland eolian settings (Seni, 1980; Gustavson, 1996). Other significant Cenozoic deposits include Pecos river gravels (Bachman, 1984) and surficial sand, terrace, and colluvial deposits (Barnes, 1992). Cenozoic uplift and tilting reactivated structural elements with the same sense of motion as they had during the Permian (McGookey, 1984), so that in the center of the Midland Basin the top of the Alibates

area), where the Permian units are overlain by Triassic, Cretaceous, and Cenozoic strata, dissolution has removed less salt than in the Permian outcrop (Gustavson and others, 1980; McGookey and others, 1988). 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).

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. This process is thought to have contributed to modern salt dissolution and collapse at the Wink Sink (Baumgardner and others, 1982; Johnson, 1987; 1989a), and modeling suggests that it might occur elsewhere in the Permian Basin (Anderson, 1981; Howard, 1987).

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). The relationships between surface depressions 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 (Richter and Kreitler, 1986; Dutton, 1987; 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 rates and processes of salt dissolution (Swenson, 1974; Gustavson and others, 1980; Gustavson and Simpkins 1989, Paine and others, 1994).

## SALT THICKNESS

Salt thickness (fig. 4) was mapped in an interval from the top of the Alibates Formation and equivalent top of upper Rustler anhydrite to the top of the Yates Formation in the Midland Basin and Central Basin Platform and top of the Lamar limestone in the Delaware Basin (fig. 2). The thickest interval (2000 to 4000 ft) is in the Delaware Basin in the southwest part of the study area

(western Pecos, Ward, and Winkler counties). This is the margin of the very thick and extensive salt of the Delaware Basin. The lower half of this interval is made up of anhydrite of the Castile Formation; complex facies in the upper part of the Castile Formation precluded separating the Salado from the Castile Formation during this study. The Castile and Salado salt in this area has been examined in the Gulf Research PDB-03 core from southeastern Loving county just west of the study area (Hovorka, 1990). The salt-bearing interval thins rapidly over the Capitan reef margin (fig. 3). This thinning is because of dramatic thinning or pinch out of the Castile Formation as well as thinning of the Salado Formation (Girard, 1952; Bachman, 1984; Garber and others, 1989). On the platform that makes up the rest of the study area, a generally gradual eastward and northward thinning trend is noted. Examination of logs shows that throughout much of the study area, this interval contains abundant, thick, and extensive salt beds.

A number of variations superimposed on the regional pattern can be identified at the scale mapped (fig. 4). A thick salt interval (greater than 1200 ft) occurs in the western part of the Midland Basin (Ector, Midland, and Upton Counties); another thick interval fills the Hovey channel (western Gaines County). A pronounced thinning trend is noted on the edge of the Central Basin Platform, starting in Winkler and Ward County and extending eastward along the Central Basin Platform trend to eastern Pecos and western Crockett counties. This corresponds to thin, absent and dissolved salt along the Capitan reef trend (Girard, 1952; Baumgardner and others, 1982; Johnson, 1987; 1989a) and in the Yates field area (Adams, 1940; Wessel 1988, 1992a, 1992b). This trend also continues northward along the reef trend into New Mexico (Bachman, 1984).

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, 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



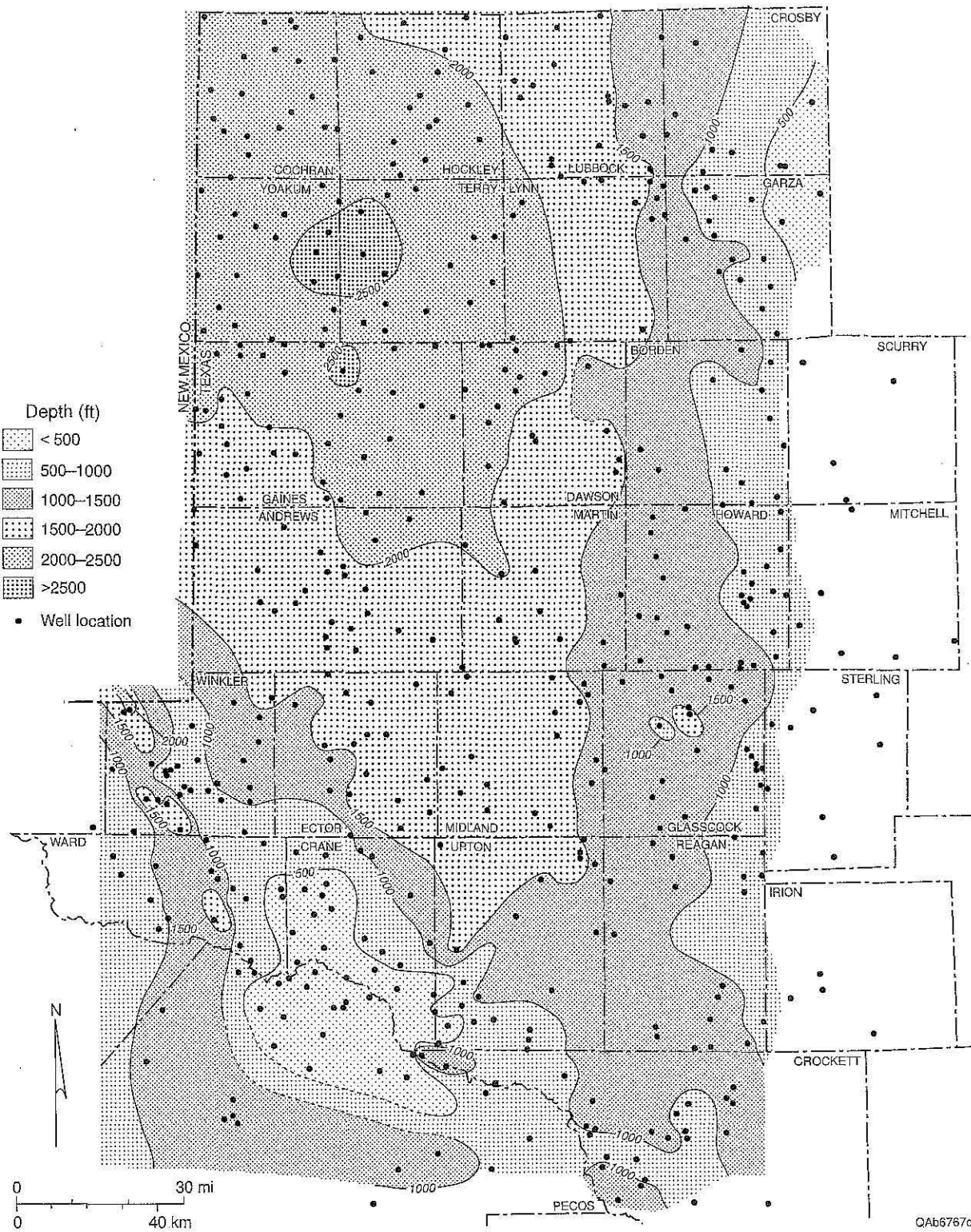


Figure 5. Depth to top of Salado salt-bearing interval from approximate land surface (log datum, typically kelly bushing) to top Alibates Formation and equivalent top of upper Rustler anhydrite.

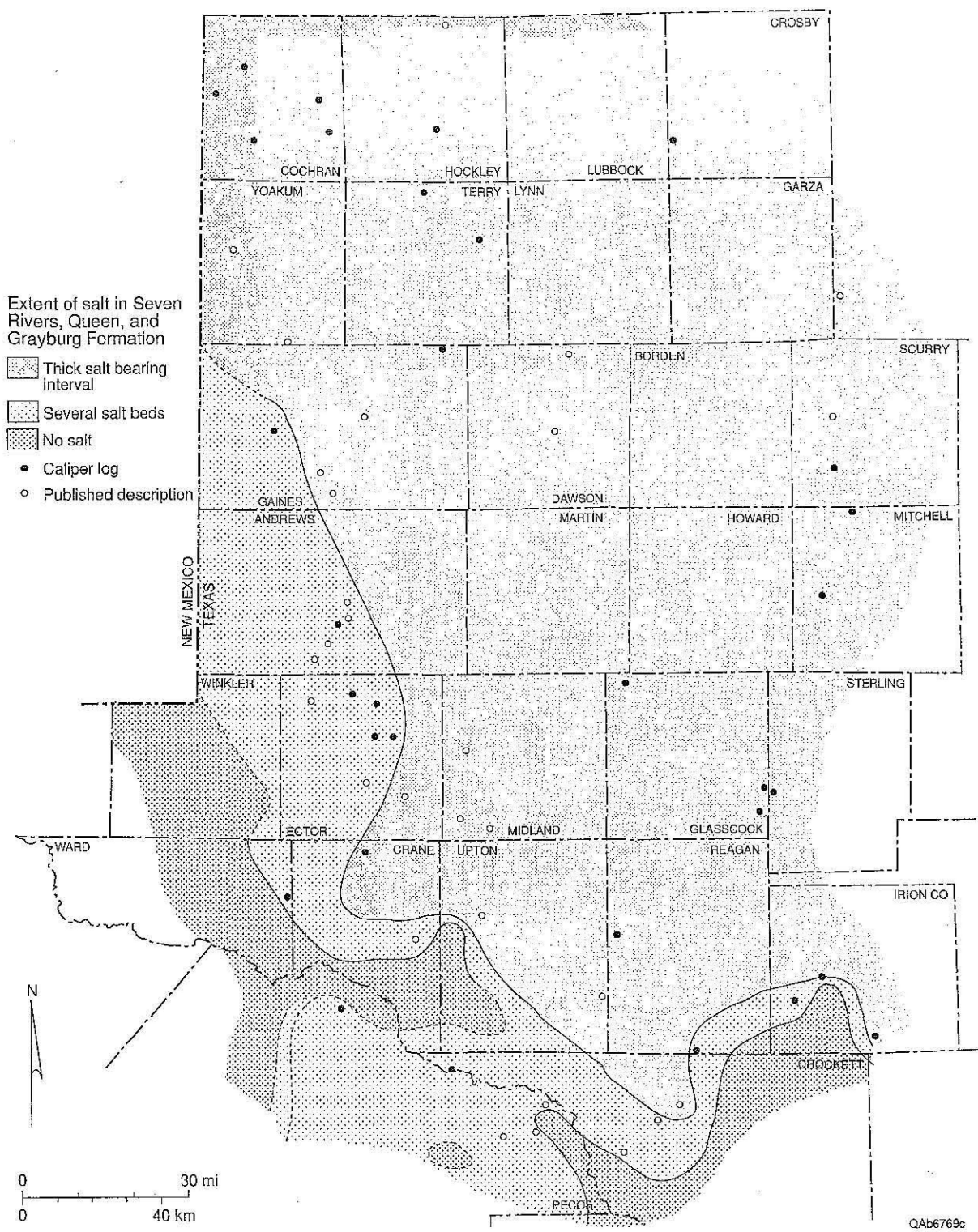


Figure 6. Extent of older salts in Seven Rivers, Queen, and Grayburg Formations. In many areas the salt in these intervals contains many mudstone, sandstone, and anhydrite interbeds; however, these formations comprise the major salt-bearing interval toward the east edge of the study area where the Salado is thin or absent because of dissolution.

increase in depth to salt in this area. Similar filled salt-dissolution features occur intermittently along the Capitan reef in New Mexico (Bachman, 1984) and have been interpreted as the result of salt dissolution related to the hydrology of the Capitan reef (Hiss, 1980), although the rates, timing, and processes of dissolution along this feature are not well constrained.

The areas of thin salt at shallow depth are identified as areas of probable recent and ongoing salt dissolution. On figure 7 these areas are highlighted; they include (1) the eastern shelf beneath the Rolling Plains, (2) the Ozona Platform beneath the western Edwards Plateau, and (3) the Central Basin Platform in the Pecos Valley area. The salt dissolution feature (4) along the Capitan reef trend in Ward and Winkler County is not related to a surface feature; however, the recent formation of the collapse feature at the Wink sink (Baumgardner and others, 1982; Johnson, 1987) on the eastern edge of the paleo-dissolution feature indicates that ongoing salt dissolution may be a risk in this area. A general thinning in the salt-bearing interval corresponding to the eastern edge of the Central Basin Platform in Crane and Ector Counties (5) occurs at shallow depths but has no surface expression; its cause and current status require additional work. Other areas of thin salt—the eastern edge of the Central Basin Platform (6), the north side of the Hovey Channel (7), the Matador Arch on the north edge of the Midland Basin (8)—are found at greater depth and have no surface expression; these may be entirely depositional or paleo-dissolution features.

Salt dissolution may occur in localized areas not identified on this regional study. Local areas where salt dissolution has occurred may be marked by geomorphic features. For example, some of the large saline lake basins on the Southern High Plains including some in the study area have been interpreted as having salt dissolution features beneath them (Reeves and Temple, 1986; Ateiga, 1990).

## CONCLUSIONS

Geologic mapping is a fast and economical method for characterizing regional and local variability in the quality of salt. This study identifies regional trends in decreased salt thickness.



Salt has been dissolved along the east margin of the basin, along the Pecos, and over the Capitan reef margin in Ward and Winkler counties. Depositional complexities in salt thickness are recognized in several areas, especially in areas of complex basin geometry such as Pecos County. Relationships among salt thickness, depositional trends, and structures are noted and can be used to further characterize salt.

#### FURTHER WORK

Additional work at a regional scale needed to complement the results of this study should include a map of percent salt. This would show the pinch-out of salt in areas of dissolution and variation in the quality of salt in stable areas. Hydrologic data for the Midland Basin documenting areas of highly saline ground water and high saline ground-water discharge complement geologic data by separating areas of current salt dissolution from areas of paleo dissolution. Areas where there are vertical hydrologic gradients across the salt may also be high risk because of the potential for boreholes to serve as conduits and allow salt dissolution, conduit, enlargement, contaminant movement or collapse, and loss of cavern integrity.

This study identified eight regions of complex salt geometry. Detailed studies of these areas could separate ancient from ongoing dissolution and refine mapping of areas having thin, complex, or rapidly dissolving salt.

Bedded salt is highly variable laterally and vertically and has different petrophysical and mechanical characteristics. Because the rheologic properties of salt are strongly dependent on water content, crystal size, and impurity distribution, a matrix of tests must be designed for each type of salt. Geologic data can extend the utility of costly geotechnical data by identifying areas where salt character is similar to the test sites.

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