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Beth M. Madsen and Omer B. Raup

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Characteristics of the boundary between the Castile and Salado Formations near the western edge of the Delaware Basin, southeastern New Mexico

by *Beth M. Madsen* and *Omer B. Raup*, U.S. Geological Survey, Box 25046, MS–939, Denver, CO 80225

Abstract

The contact between the Upper Permian Castile and Salado Formations throughout the Delaware Basin, southeast New Mexico and west Texas, has been difficult to define because of facies changes from the basin center to the western edge. Petrographic studies of core from a Phillips Petroleum Company well, drilled in the western Delaware Basin, indicate that there are major mineralogical and textural differences between the Castile and Salado Formations. The Castile is primarily laminated anhydrite with calcite and dolomite. The Salado Formation is also primarily anhydrite at the location of this core hole, but with abundant layers of magnesite. This magnesite indicates an increase of magnesium enrichment in the basin brines, which later resulted in the deposition of magnesium-rich potash deposits within the Salado Formation elsewhere in the basin. A breccia zone at the top of the Castile Formation shows evidence of massive recrystallization, which indicates a break in sedimentation and possible subaerial erosion. This breccia zone probably represents an unconformity along the western edge of the basin between the Castile and Salado Formations, which has been recognized by other workers.

Introduction

The contact between the Upper Permian Castile and Salado Formations in the center of the Delaware Basin of southeast New Mexico and west Texas has been defined by several authors on the basis of major lithologic differences between the two formations. In the center of the basin, where the Salado contains numerous beds of halite and significant potash deposits, the contact has been placed at the base of a prominent anhydrite bed that overlies the thick laminated anhydrite sequence of the Castile Formation. Toward the edge of the basin, however, both formations are primarily anhydrite, and the contact between the two formations is not obvious. This paper attempts to define the contact at the west edge of the basin on the basis of mineralogical and textural differences of the anhydrite beds in the two formations observed in one core hole.

In 1969 Phillips Petroleum Company drilled an exploratory hole for sulfur in southeastern New Mexico. The core hole, NM 3170–1, was located in the SW1/4SW1/4 sec. 21, T26S, R25E, (Fig. 1). Coring began at 108 ft below the surface in the Salado Formation, continued through the Castile Formation, and terminated in the underlying Lamar Limestone Member of the Bell Canyon Formation at a depth of 1,230 ft. This core provides a rare opportunity to examine the Castile–Salado contact, which is not seen in outcrop. A description of the upper part of the Castile Formation, the lower part of the Salado Formation, and the contact between the two formations is presented. Textural and mineralogical differences between the two formations indicate a significant change in the environments of deposition for the two formations.

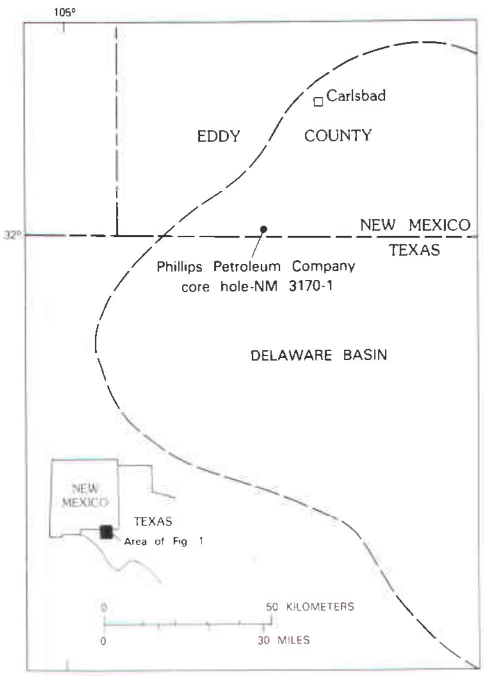

FIGURE 1—Index map showing location of the Phillips Petroleum Company core hole. Dashed line shows the western edge of the Delaware Basin.

Previous investigations

The Castile and Salado Formations are part of a marine evaporite sequence that was deposited in the Delaware Basin of southeast New Mexico and west Texas during Late Permian (Ochoan) time. In early investigations the Castile and Salado Formations were undifferentiated, and the two formations were called Castile by Richardson (1904). Cartwright (1930) divided the sequence into the upper and lower parts of the Castile on the basis of lithology and areal distribution. Lang (1935) introduced the name "Salado halite" for the upper part of the sequence, and he retained the term Castile for the lower part of the sequence. Lang placed the base of the Salado Formation at the base of potassium (polyhalite) mineralization. This proved to be an unreliable marker because the zone of mineralization occupies different stratigraphic positions in different areas. Lang (1939) then proposed that the boundary be- ☞

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Scanning electron microscope study of authigenic zeolites

Geomorphic development of City of Rocks, Grant County tween the Castile and Salado Formations should be at the base of a prominent anhydrite marker bed, which he later named the Fletcher Anhydrite Member of the Salado (Lang, 1942). The Fletcher, however, can not be traced throughout the basin and is not recognizable at the location of this Phillips drill core.

Geologic setting

The evaporites of the Castile and Salado Formations were deposited in a basin that was initially quite deep. Regional studies by Udden (1924), Lang (1935), Adams (1944), and King (1947) suggest that the water depth at the beginning of Castile deposition was about 500 m. Anderson and Kirkland (1966) and Anderson et al. (1972) showed that very thin laminations in the Castile, which are composed of distinct couplets of anhydrite and calcite (occasionally with minor dolomite), can be identified and correlated over wide areas throughout the Delaware Basin. Such well-preserved delicate laminations indicate that deposition was in fairly deep water, well below wave base. Detailed studies by Dean and Anderson (1978, 1982) indicate that the salinity of the water in the Delaware Basin increased during the deposition of the Castile Formation. This salinity increase is indicated by: 1) an increase in the amount of anhydrite in the anhydrite-calcite couplets from the base upward, and 2) an increase upward in the number of interbedded halite beds.

The Salado Formation, which overlies the Castile, is the result of evaporite deposition from brines that were generally of higher salinity than those of the Castile. The salinity changes were probably gradual as indicated by Bachman's (1984) evidence that the Castile and Salado lithologies interfinger in the center of the basin. The work of Lowenstein (1982) indicates that the Salado Formation was deposited from very saline brines, under shallow water conditions, with occasional periods of desiccation.

In summary, the Castile–Salado sequence in the center of the Delaware Basin represents the filling of a deep basin with chemical sediments of progressively higher salinity. The ratio of anhydrite to calcite (or dolomite) in laminated beds of the Castile increases upward, and halite, which is sparse in the lower Castile, becomes plentiful toward the top. The Salado Formation represents a continuation of the general increase in salinity of brines in the basin; it is primarily halite with significant amounts of sylvite, carnallite, and polyhalite and minor amounts of anhydrite.

The core hole described in this report was drilled along the western edge of the Delaware Basin where the evaporites are mostly anhydrite, with some calcite, dolomite, gypsum, and magnesite. Figure 2 shows the lithologies of the upper part of the Castile Formation and the lower part of the Salado Formation in the Phillips core hole. The breccia zone at the top of the Castile Formation is also shown.

Petrography

Petrographic examination of thin sections and polished core sections and scanning electron microscope studies were made of several samples collected through the Castile and Salado Formations. Mineral identification was by x-ray diffraction. A description of the rocks from these studies follows.

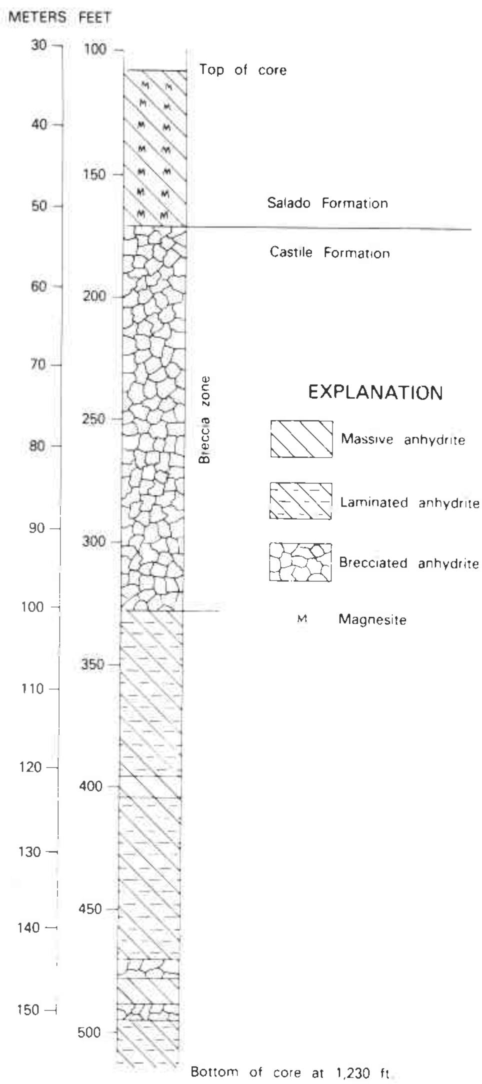

FIGURE 2—Lithologic column of the upper part of the Phillips Petroleum Company core hole (NM 3170–1), Eddy County, New Mexico.

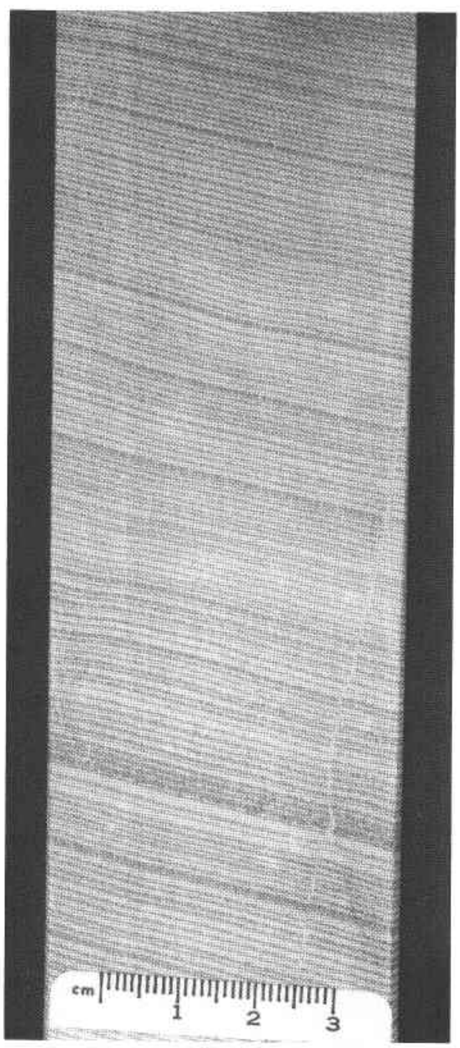

FIGURE 3—Core sample of typical interlaminated anhydrite and calcite of the Castile Formation. Lighter layers in photo are anhydrite. Depth—750 ft.

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Castile Formation

The Castile Formation, in this core, is composed predominantly of interlaminated light-gray anhydrite and light-brown, organic-rich calcite (Fig. 3). In the upper part of the section, the anhydrite is interlaminated with calcite and dolomite. Interspersed with the laminated section are beds of massive, light-gray anhydrite and beds of pale yellowish-brown limestone. Halite, which may have been present in this part of the section, has been leached out and is represented by collapse breccia cemented by clear selenite.

Laminated anhydrite-carbonate rock—Anhydrite in the laminated rock in the Castile Formation (Figs. 3 and 4) is interlaminated with both calcite and dolomite. Calcite is present throughout the Castile, whereas dolomite is present only in the upper third.

Anhydrite in the laminated rock is composed of blocky, subhedral to euhedral crystals from 0.01 to 0.15 mm. This is the so-called "pile-of-bricks" texture (Fig. 5A). Within the groundmass of fine-grained anhydrite are a few larger crystals of anhydrite (Fig. 5B).

Calcite crystals in the laminated anhydrite rock (Fig. 4) range widely in size from 0.005 to 0.05 mm and are anhedral to subhedral.

Dolomite crystals in this rock type (Fig. 6) are very uniform in size and range from 0.01 to 0.03 mm. The crystals are subhedral to rounded, and appear light brown in transmitted light.

Massive anhydrite rock—Anhydrite in unlaminated, massive anhydrite rock is almost identical to the anhydrite in the laminated parts of the section. It is light gray and composed of subhedral to euhedral crystals that range in size from 0.01 to 0.15 mm. This anhydrite characteristically also has the "pile-of-bricks" texture.

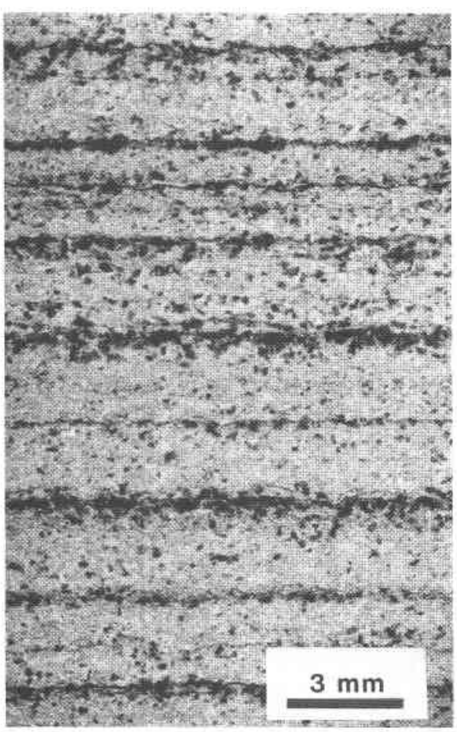

FIGURE 4—Photomicrograph of interlaminated anhydrite and calcite typical of the Castile Formation. Dark crystals are calcite. Plain light. Depth—750 ft.

Limestone—Calcite in the laminated brown limestone beds has an average grain size larger than calcite in the laminated anhydrite rock. Calcite occurs as an interlocking mosaic of anhedral crystals that range in size from 0.03 to 0.2 mm. The subtle lamination in some of the limestone is due to alternating layers of different crystal size (Fig. 7). In other parts of the limestone the lamination is due to organic-rich partings that separate crystal layers of fairly uniform grain size (Fig. 8).

Breccia zone—The breccia zone at the top of the Castile Formation consists of approximately 154 ft of brecciated massive anhydrite, which is bounded at the top by the lowest occurrence of magnesite of the Salado Formation and at the base by the last appearance of laminated anhydrite typical of the Castile. The anhydrite rock of the breccia interval is light gray and contains numerous veins of selenite and breccia zones cemented by clear selenite (Fig. 9). These rocks are mostly free of carbonate. Figure 10 shows the initial stage of multiple generations of recrystallization of the breccia zone anhydrite. In this section, fine-grained anhydrite (less than 0.1 mm) is being replaced by coarser, blocky material (0.5–5.0 mm). This blocky, medium-grained anhydrite is, in turn, replaced by very coarse, radial laths (Fig. 11). These laths, which form fans and spherulites, commonly include fine-grained impurities. In some areas the laths form a dense interlocking mat of coarse-grained anhydrite. The overall appearance of this zone is that of an interval of collapse breccia and massive recrystallization. There is no remaining evidence of original sedimentary layering.

The brecciation in this zone is probably the result of removal of halite that was interbedded with the anhydrite at the top of the Castile Formation. Anderson (1981) documented several breccia horizons within the Castile that he interpreted as resulting from the removal of halite. Solution breccias have been identified by Bachman (1984) between the Castile and Salado Formations in southern Eddy County, New Mexico, and the adjacent area of Texas. Bachman interpreted the solution breccias to be the result of dissolution of salt beds in the overlying lower Salado in either early Mesozoic or Cenozoic time. We believe that the dissolution of the halite occurred before the deposition of the Salado Formation. There is no evidence of collapse of Salado rocks into the breccia zone, which indicates that the brecciation was pre-Salado in age. This breccia zone is probably an unconformity, representing a period of subaerial erosion at the top of the Castile along the western edge of the basin. Both Adams

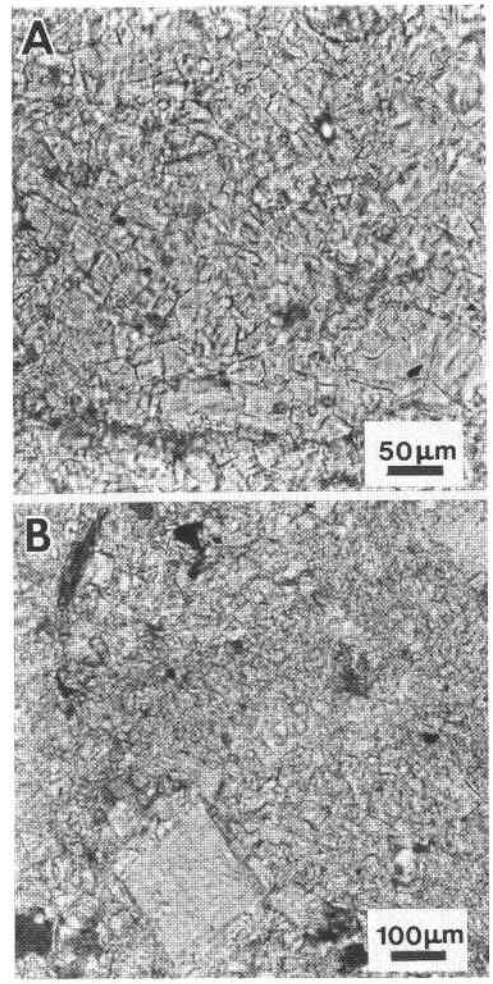

FIGURE 5—Photomicrographs of laminated anhydrite rock from the Castile Formation. **A**, Typical "pile-of-bricks" texture of anhydrite crystals. Plain light. Depth—750 ft. **B**, A few large crystals of anhydrite in a matrix of smaller anhydrite crystals. Crossed polarizers. Depth—1,130 ft.

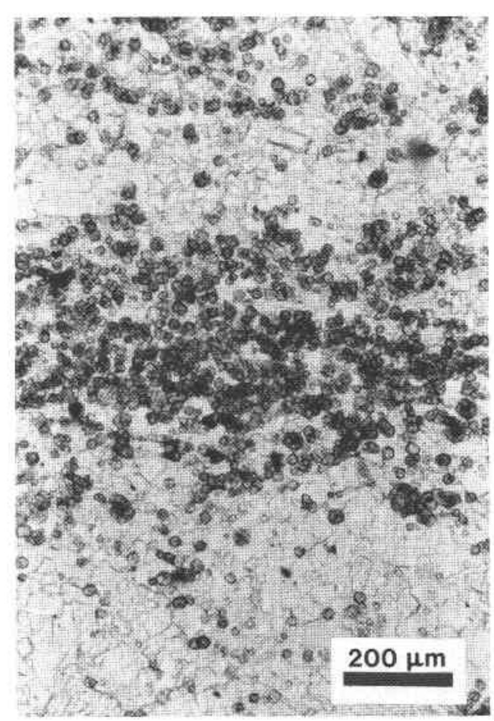

FIGURE 6—Photomicrograph of Castile anhydrite with a lamina of dolomite crystals. The dark crystals of dolomite are very uniform in size and subhedral to rounded. Plain light. Depth—667 ft.

(1944) and Anderson (1978, 1981) advocated an unconformity at this horizon.

Salado Formation

The Salado Formation consists of massive, very fine grained, light-gray anhydrite rock, mottled with streaks and wisps of white microcrystalline magnesite (Fig. 12). Thin section examination of the magnesitic anhydrite shows the anhydrite to be less than 0.01 mm, equigranular, and anhedral (Fig. 13). This xenotropic anhydrite matrix contains irregular patches of coarser anhydrite ranging in size from 0.02–0.05 mm (Fig. 14). The very fine grained magnesite appears in thin section as opaque streaks and swirls in the anhydrite matrix (Fig. 15). A scanning electron microscope (SEM) photograph shows that the magnesite occurs in small clusters surrounding larger, blocky crystals of anhydrite (Fig. 16A). Higher magnification of one of the clusters shows that they are formed of closely packed rhombohedral crystals (Fig. 16B).

Fractures and small breccia zones, which were formed after the consolidation of the anhydrite rock, are cemented and filled by clear selenite.

Summary and conclusions

The Castile and Salado Formations in the Delaware Basin represent sediments that were deposited in an evaporite environment of steadily increasing salinity. The boundary between the two formations, in general, represents a change from sulfate, carbonate, and some chloride deposition in the Castile, to deposition of chlorides and magnesium-rich potash minerals in the Salado Formation.

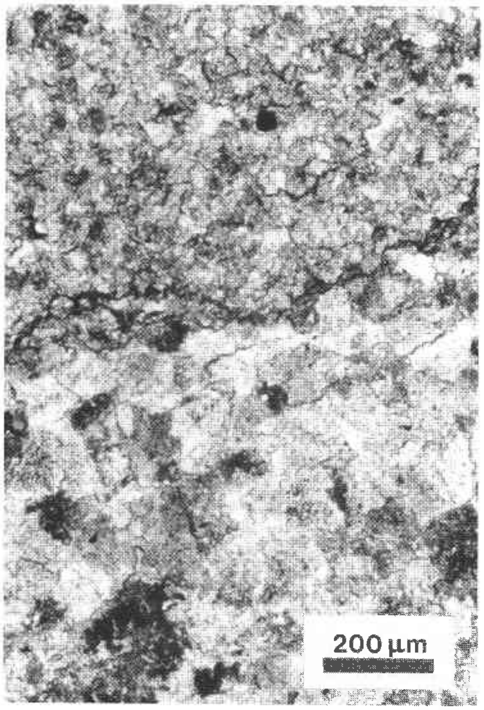

FIGURE 7—Photomicrograph of laminated Castile limestone. The subtle lamination is caused by alternating layers of calcite crystals of different size. Crossed polarizers. Depth—1,221 ft.

FIGURE 8—Photomicrograph of laminated Castile limestone. The lamination is caused by thin partings of organic material between the layers of calcite. Plain light. Depth—1,222 ft.

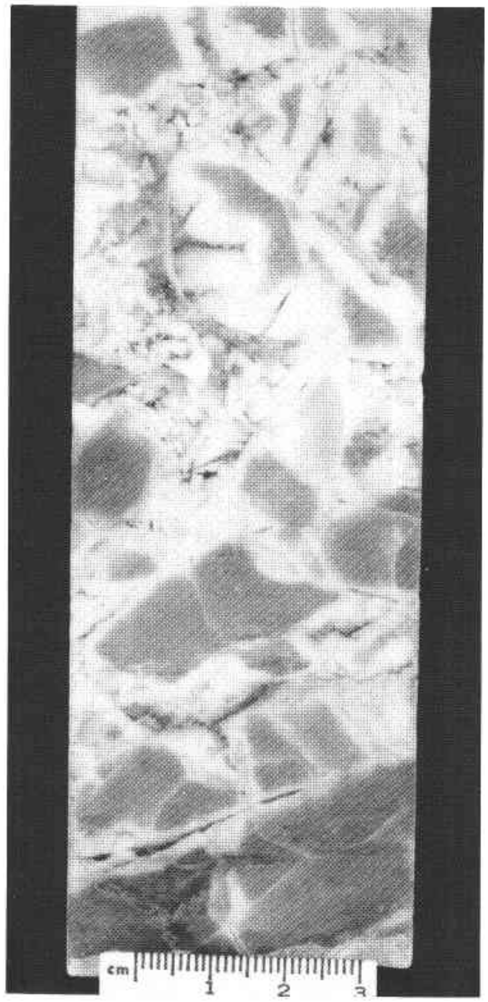

FIGURE 9—Core sample of a breccia zone cemented by selenite from the breccia zone at the top of the Castile Formation. Depth—291 ft.

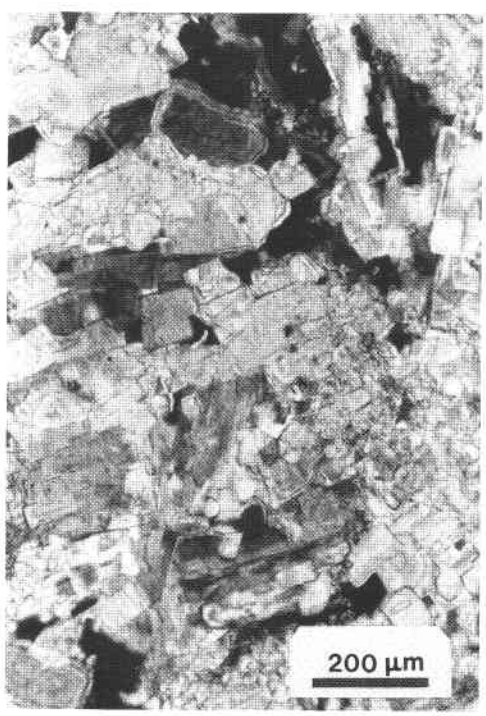

FIGURE 10—Photomicrograph of coarse, recrystallized anhydrite from the breccia zone at the top of the Castile Formation. Crossed polarizers. Depth—322 ft. →

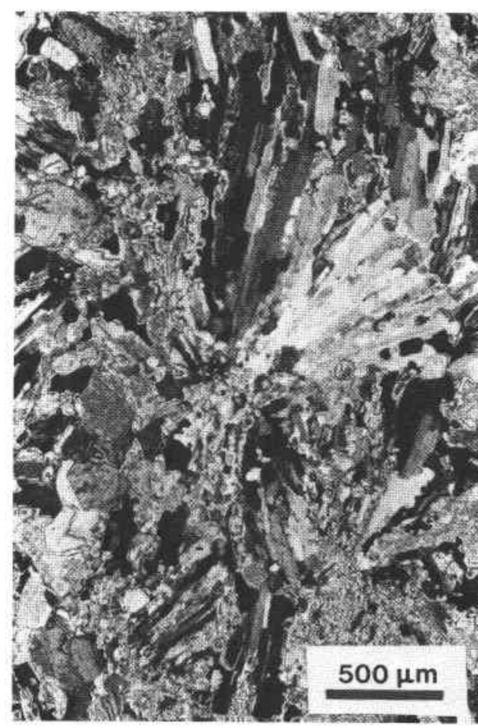

FIGURE 11—Photomicrograph of coarse, radiating crystals of anhydrite from the breccia zone at the top of the Castile Formation. Crossed polarizers. Depth—246 ft.

Adams (1944) recognized an unconformity between the Castile and Salado Formations in the northern part of the Delaware Basin. Correlations of acoustical logs and facies studies by Anderson (1978, 1981) support Adams' interpretation. Anderson (1978, p. 17) said that "there was an episode of non-deposition, angular unconformity, and even salt dissolution in the northern part of the basin following the deposition of the Halite III unit (upper halite) of the Castile Formation."

The Phillips core hole, on which this study is based, was drilled at the western edge of the Delaware Basin where both the Castile and Salado Formations are now primarily anhydrite with some layers of carbonate. The major difference between the Castile Formation in this core, as compared to core from farther into the basin, is the absence of halite that has been removed by dissolution. The Salado Formation in the core can be distinguished from the underlying Castile Formation on the basis of anhydrite characterized by major inclusions of magnesite. The magnesite in this basin-edge facies indicates an enrichment of magnesium in the basin brines that later resulted in the deposition of magnesium-rich potash deposits within the Salado Formation elsewhere in the basin.

The top of the breccia zone in the Phillips core probably represents the unconformity, and perhaps the period of subaerial erosion at the top of the Castile that was described by Adams (1944) and Anderson (1978, 1981). This breccia zone in the core represents dissolution of halite that resulted in brecciation and massive recrystallization of the anhydrite at the top of the Castile before deposition of the overlying magnesitic anhydrite of the Salado Formation along the western edge of the basin. Contortion of the magnesite layers, as described from this core hole, probably resulted from slumping and differential compaction of soft sediments that were deposited over the irregular breccia surface at the top of the Castile Formation.

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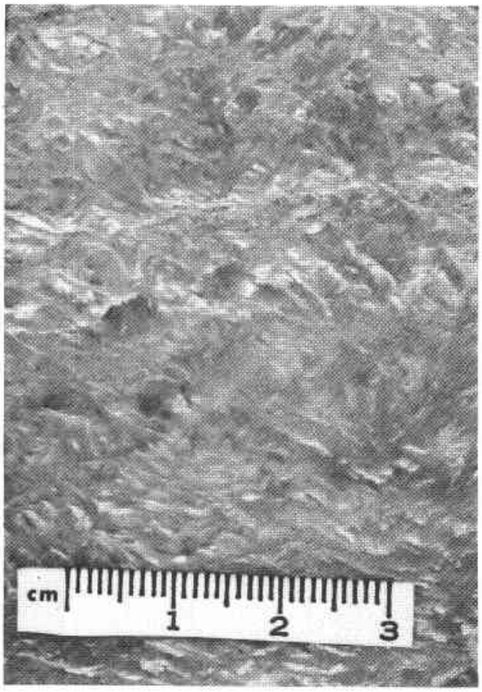

FIGURE 12—Core sample of anhydrite from the Salado Formation mottled with white, very fine grained magnesite. Depth—142 ft.

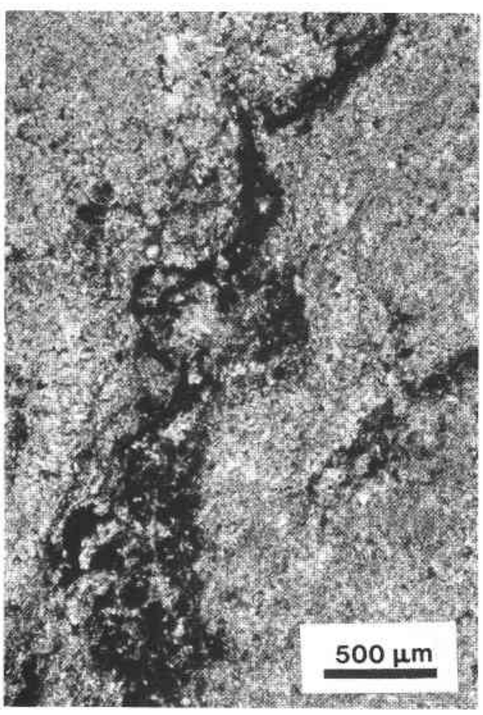

FIGURE 13—Photomicrograph of magnesitic anhydrite from the Salado Formation. Magnesite appears as opaque streaks. Crossed polarizers. Depth—109 ft.

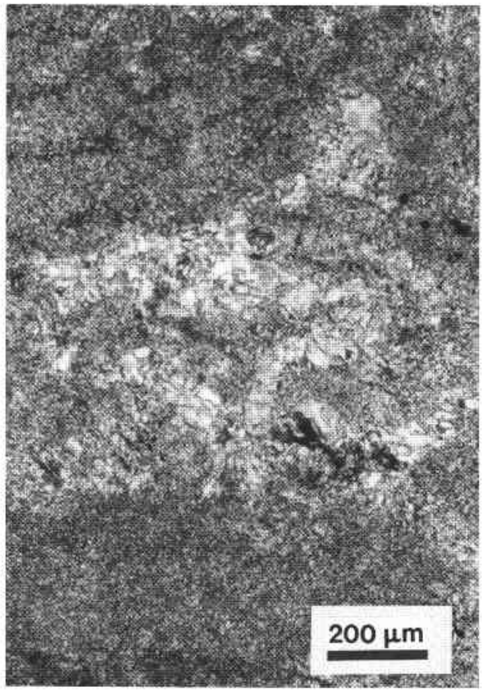

FIGURE 14—Photomicrograph of fine-grained anhydrite with irregular patches of coarser anhydrite from the Salado Formation. Partially crossed polarizers. Depth—153 ft.

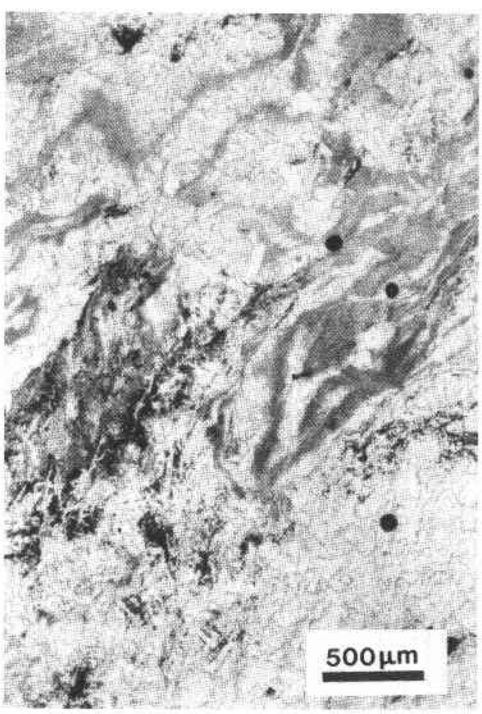

FIGURE 15—Photomicrograph of very fine-grained Salado anhydrite with dark-gray streaks and swirls of magnesite. Plain light. Depth—118 ft.

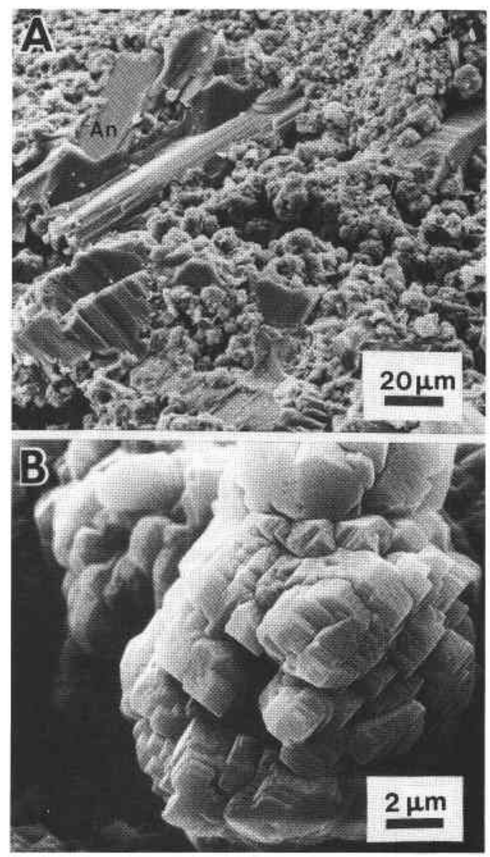

FIGURE 16—Scanning electron micrographs of magnesitic anhydrite of the Salado Formation. Depth—153 ft. **A**, Clusters of magnesite crystals surrounding larger blocky crystals of anhydrite (An). **B**, Closer view of a cluster of rhombohedral magnesite crystals.

terrane (Fig. 8). The valleys formed mostly before Ogallala deposition primarily by westward headward erosion across the southern High Plains (Seni, 1980).

Significantly, Lower Cretaceous reservoirs also discharge some ground water into bounding reservoir systems. In the Causey–Lingo area of Roosevelt County, New Mexico, basal Lower Cretaceous sand and gravel reservoirs are truncated in downdip areas by coarse-grained "valley fill" Ogallala deposits, permitting cross flow into the Ogallala system. Vertical leakage into the underlying Dockum Group (Late Triassic) also occurs at isolated locations, particularly where coarser-grained fluvial-deltaic facies exist in upper parts of the red bed sequence (Granata, 1981).

Wells completed in Lower Cretaceous reservoirs under the southern High Plains of New Mexico provide ground water for various surface uses. Widely spaced over much of the study area, wells drawing from the reservoirs are thus far noticeably concentrated only in the Causey–Lingo area of Roosevelt County, where they supply water for both crop irrigation and domestic use. Undeveloped parts of the reservoir systems showing potential for supplying additional surface water to the southern High Plains exist in northern Lea County, particularly where relatively thick basal Lower Cretaceous sands and sandstones occupy erosional scour channels that are cut into the underlying Dockum Group (Late Triassic).

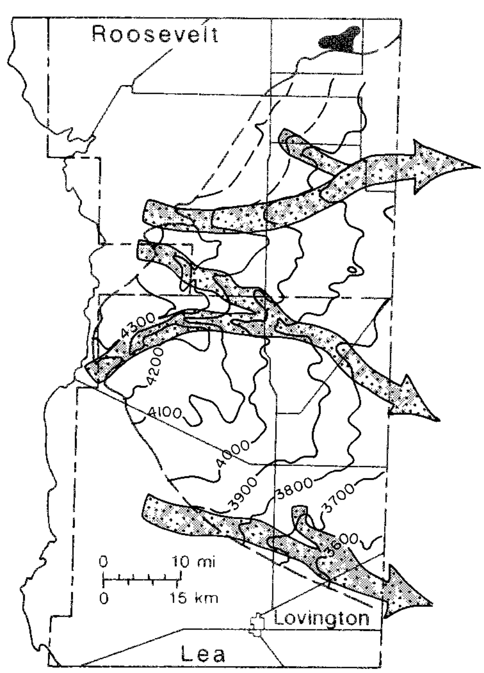

FIGURE 8—Structure contour map showing the altitude of the top of Lower Cretaceous strata under the southern High Plains of New Mexico.

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