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New Mexico Geology, v. 3, n. 4 pp. 49-53, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v3n4.49

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New Mexico GEOLOGY

• Science and Service

Volume 3, No. 4, November 1981

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Introduction

Laminae in evaporites, such as those observed in the Cañas Gypsum Member of the Yeso Formation, have been interpreted as basinal varves or cyclic yearly deposits formed by seasonal blooms of planktic organisms and/or seasonal changes in water chemistry (Dean and others, 1975). Deposits of laminar evaporites accumulate in arid climates in relatively still lagoons or bays with restricted marine inlets (Schmalz, 1969). A water depth greater than the maximum wave base is necessary for the preservation of laminae. The Cañas evaporites were deposited in a late Leonardian (Baars, 1962) hypersaline lagoon with an area of approximately 25,000 km^2 (fig. 1). East-central New Mexico was an arid coastal plain and shoreline in Leonardian time (Dott and Batten, 1981), and the Cañas lagoon may represent a relatively short-lived and shallow arm of the deep and persistent Permian seas to the south and east.

This paper relates the stratigraphy and petrology of the Cañas Gypsum Member to the overall paleoenvironmental and paleogeographic context of Leonardian deposits in central New Mexico. The lateral extent and facies boundaries of the Cañas were mapped on a 1:500,000 base (fig. 1), modified from Dane and Bachman (1965). Sources of information included field mapping (Hunter, 1980), information from Tenneco Oil Company (unpublished report, 1979), and other sources listed in fig. 1. Samples for petrographic analysis were collected from outcrops near Engle and Socorro.

Previous work

Lee and Girty (1909) first described and named the Yeso Formation in New Mexico. Needham and Bates (1943) redescribed the Permian System and located and measured type sections. Regional correlations of Permian deposits of the Colorado Plateau region have been compiled by Baars (1962), Dixon (1967), and Skinner (1946). Discussions of Permian stratigraphy in central New Mexico may be found in Anderson and others (1972), Bachman and Hayes (1958), Kottlowski and Stewart (1970), and Speed (1958).

The following works were used in correlating the stratigraphy of the Permian System in central New Mexico: Anderson (1970), Baars (1962), Bachman (1968), Bachman and Hayes (1958), Bachman and Myers (1969), Black (1973), Dane and Bachman (1965), Headley (1968), Johnson (1969), Kottlowski (1975), Kottlowski and Foster (1960), Kottlowski and Stewart (1970), Kottlowski and others (1956), and Lloyd (1949).

The geologic history and stratigraphy of the study area have been reconstructed with the aid of Cook and Bally (1975), Dott and Batten (1981), Hock (1970), Kottlowski and Foster (1960), Rocky Mountain Association of Geologists (1972), Stearn and others (1979), and Thompson (1961).

Laminated evaporites have been studied in great detail by Anderson and Koopmans (1963), Anderson and others (1972), Dean and others (1975), Schmalz (1969), and Sloss (1953). Of particular interest are papers by Dzens-Litovskiy (1967) and Dzens-Litovskiy and Vasil'yev (1962) describing the ongoing deposition of evaporites in a restricted bay of the Caspian Sea, known as Kara-Bogaz-Gol. This locality serves as an actualistic model for the depositional environment of the Cañas Gypsum Member.

Stratigraphy

The Yeso Formation has been divided into four members at the type section near Socorro: the basal Meseta Blanca Sandstone; the lower-middle Los Vallos or Torres carbonate, evaporite, and sandstone member; the upper-middle Cañas Gypsum Member, which includes some carbonates and sandstones; and the upper Joyita Member, which is composed primarily of sandstone with some carbonates to the north and west and predominantly of carbonates to the southeast (figs. 1 and 2).

Regional Yeso-lithofacies trends typically show gradations from silty and sandy continental red beds in the north and west into shallow-marine carbonates, evaporites, and sandstones in central New Mexico. These lithologies grade into a thick sequence of carbonates to the east and southeast, correlative with the Bone Springs Formation of eastern New Mexico and west Texas (Skinner, 1946).

MESETA BLANCA SANDSTONE MEMBER—The Meseta Blanca Sandstone (Wood and Northrop, 1946) has been correlated with the De Chelly Sandstone of the Fort Defiance, Arizona, area by Baars (1962). This medium-bedded, reddish-brown to light-tan, fine-grained sandstone with interbeds of calcareous and sandy mudrocks is the most widely recognizable and areally extensive member of the Yeso. Most of this member was deposited in fluvial, flood-plain, and marginal-marine environments (Baars, 1962).

LOS VALLOS OR TORRES MEMBER—The Los Vallos (Kelley and Wood, 1946) is characterized by relatively thin (0.1–3.0 m) beds of limestone, dolostone, sandy or muddy red beds, and gypsum. Complex facies changes occur on a scale of kilometers, but no distinct lithologic changes define the boundaries of this unit.

The Los Vallos appears to have been deposited on a low, flat coastal plain, which periodically was submerged by brief marine transgressions. The percentage of carbonates and evaporites increases upsection, indicating an overall trend of rising sea level, gradual subsidence, and/or lessening of detrital input. The culmination of this transgressive trend was a relatively stable highstand during which the Cañas Gypsum Member was deposited.

CAÑAS GYPSUM MEMBER—Within the study area, the Cañas Gypsum Member (Needham and Bates, 1943) is defined as the stratigraphically continuous, upper-middle gypsum and carbonate member of the Yeso and generally consists of a basal, laminated, dolomitic limestone which is fetid, carbonaceous, and locally fossiliferous; a lower laminated gypsum unit 10–20 m thick with some thin (0.1–0.5 m) carbonate beds; a continuous bed of thin-bedded to laminar, dolomitic limestone (2–5 m thick) with thin (0.1–0.5 m) gypsum beds; and an upper laminated gypsum unit (10–20 m thick). Sandstone beds commonly occur in the Cañas interval near its western margins.

Fig. 1 illustrates the lateral extent and facies ☞

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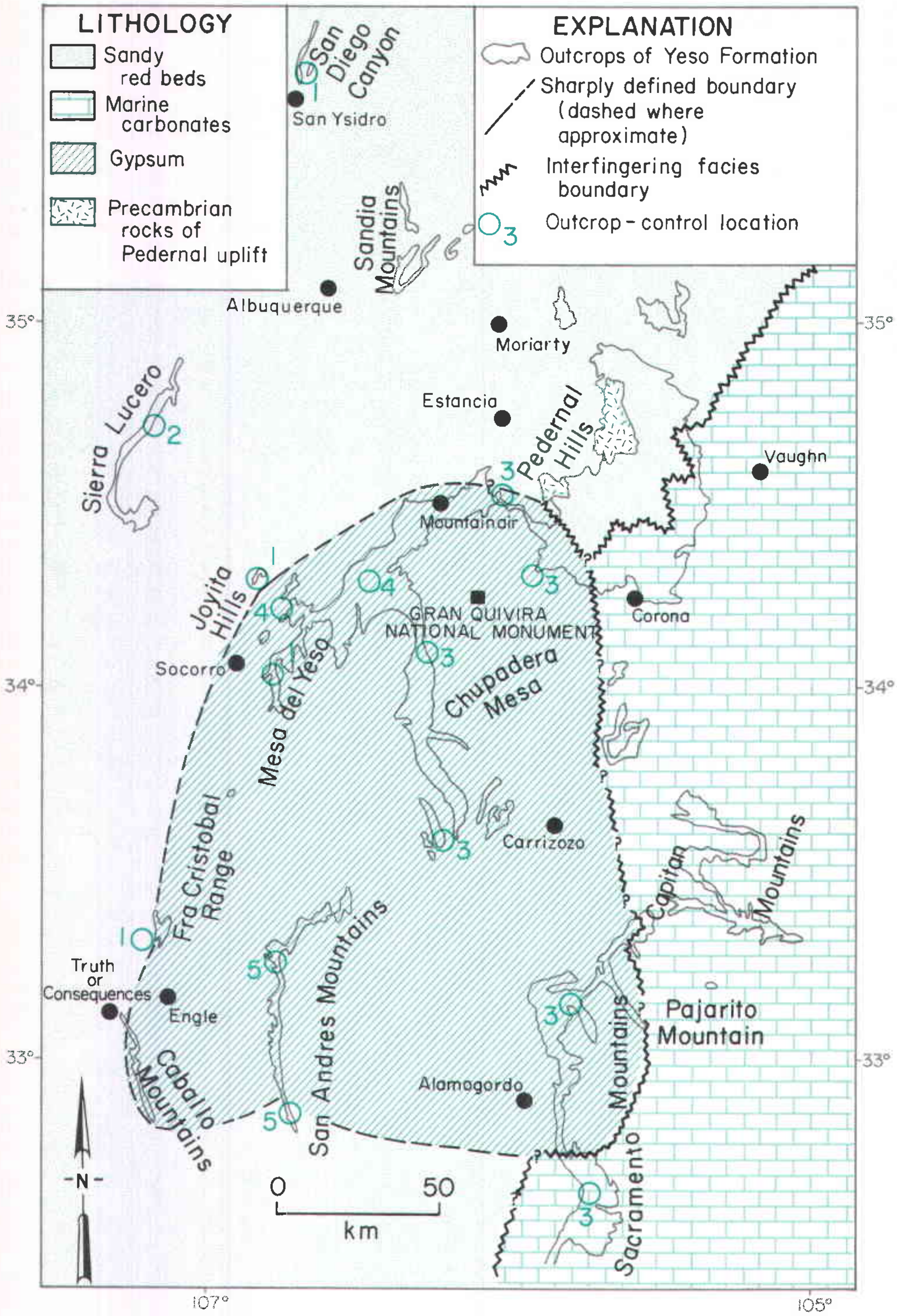

FIGURE 1—General extent and facies boundaries of Cañas Gypsum Member and correlative units; indicated lithologies were predominant during Cañas deposition. The Pedernal uplift formed a ridge along the east side of the Cañas Basin as far south as Pajarito Mountain (Kelley, 1968, 1971); by Cañas time, the ridge was being covered by marine environments. Yeso sandstones near the Pedernal uplift are arkosic due to their derivation from Precambrian basement (Kelley, 1968, 1971). Outcrop control at numbered locations based on the following references: 1) Hunter (1980), 2) Kelley and Wood (1946), 3) Lloyd (1949), 4) Needham and Bates (1943), and 5) Kottlowski (1975).

boundaries of the Cañas. The western edge is typically sharp and well defined and is characterized by gypsum grading into sandstone with carbonate interbeds over a distance of from less than 100 m to 1 km. This edge is exposed in the central Fra Cristobal Range, where the presence of brachiopods and fusulinids confirms marine conditions (S. Thompson III, personal communication, 1981). Near Socorro, the exact edge of the Cañas is covered, but no Cañas gypsum occurs in the Joyita Hills, 10 km northwest of the Mesa del Yeso type section (fig. 1). The western edge of the Cañas is obscured in many places by structures and strata of the Rio Grande rift (Neogene). To the east and southeast, the Cañas grades into marine carbonates that are mapped as Yeso (undivided) by Baars (1962).

Laminae in the Cañas have thicknesses of approximately 1–5 mm, and the entire evaporite deposit is about 50 m thick. On the assumption of yearly cyclic deposition, this thickness suggests that the evaporites were deposited over a period of 10,000–50,000 yrs.

Joyita Sandstone Member—The Joyita Sandstone Member was named by Needham and Bates (1943). This coastal and eolian(?) deposit consists of medium-bedded, tan to red, fine- to medium-grained sandstone with local interbeds of carbonate. It interfingers with the continental red beds of the San Ysidro Member of the Yeso north of Albuquerque and grades into carbonates near the Sacramento Mountains (fig. 1). The areal extent and geometry of this member closely parallel those of the underlying Cañas, suggesting that the Joyita is a progradational beach and dune facies associated with the withdrawal of the Cañas sea.

Petrology

Thin sections of evaporite, clastic, and carbonate rocks from all members of the Yeso Formation were prepared and examined according to methods summarized by Hunter (1980). Twelve clastic samples were point-counted to determine composition and provenance.

Sandstone—Point-counting results are summarized in table 1, and constituent ratios are illustrated in fig. 3. Techniques employed are those of Dickinson (1970), Ingersoll (1978), and Ingersoll and Suczek (1979). The 95-percent confidence intervals for QFL and LmLsLv (figs. 3a and 3b) overlap for the total Yeso Formation and for each of its members,

New Mexico GEOLOGY
• Science and Service
Volume 3, No. 4, November 1981

published quarterly by
New Mexico Bureau of Mines and Mineral Resources
a division of New Mexico Institute of Mining & Technology

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Circulation: 1,200

Printer: University of New Mexico Printing Plant

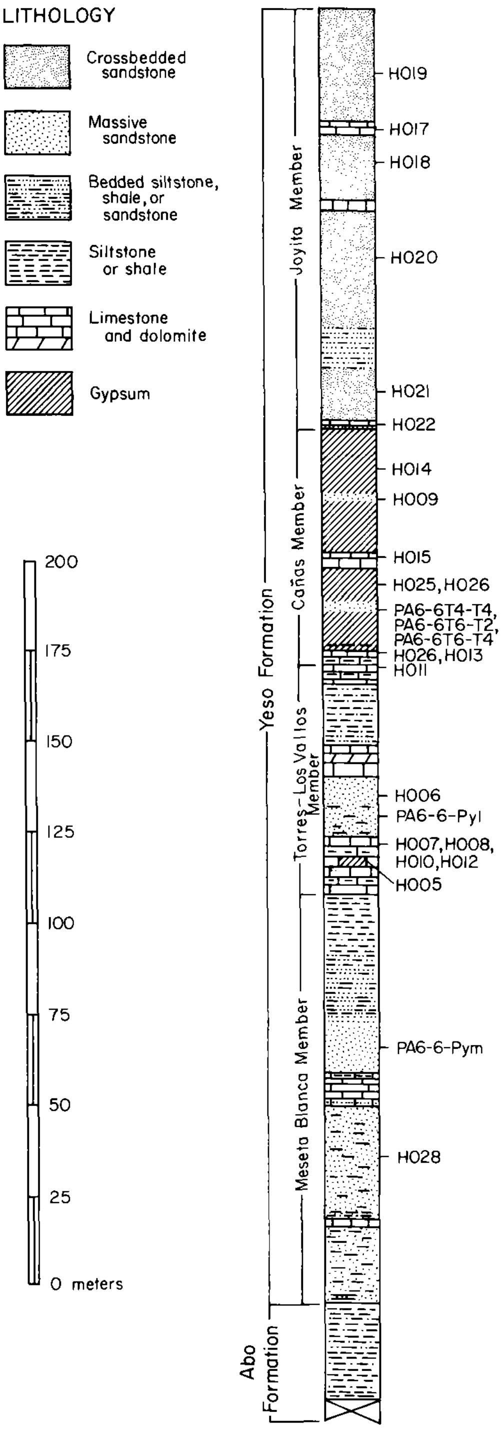

FIGURE 2—Composite stratigraphic column of the Yeso Formation (see Hunter [1980], for descriptions and locations of samples [numbers]).

thus supporting the hypothesis that all Yeso sandstones in the study area share a similar provenance and/or are of equal maturity.

The Pedernal uplift (fig. 1) appears to have been both the structural control and the source of clastic material for the northern and eastern margins of the Cañas Basin. This persistent structural high is composed of Precambrian metamorphic rocks and was a local source of clastic material during most of the Paleozoic (Hock, 1970). This land mass was a positive feature during Permian time before Cañas deposition, and Permian deposits pinch out and coarsen along its flanks (Kelley, 1968, 1971). By Cañas time, the subsiding land mass probably formed a submarine ridge, thus restricting circulation and promoting evaporite deposition in the Cañas lagoon.

The high percentage (79 ± 8 percent) of metamorphic lithic fragments (fig. 4 and table 1) within total unstable lithic fragments in all Yeso sandstones examined is consistent with the interpretation that the Pedernal uplift was a major supplier of clastic material for the Cañas Basin. Most sedimentary lithic fragments are likely intrabasinal in origin (Hunter, 1980). Volcanic lithic fragments are statistically negligible (fig. 3b).

All Yeso sandstones examined in this study exhibit a similar diagenetic history. An initial stage of quartz overgrowth was followed by the development of authigenic clay coatings (fig. 4). This was followed by compaction and pressolution of quartz grains with attendant squashing of monocrystalline phyllosilicate grains and some conversion of softer lithic fragments into pseudomatrix (Dickinson, 1970). Compaction features are overlain by a second stage of clay and/or other phyllosilicate coatings. The final diagenetic effect was the precipitation of sparry calcite and the formation of calcite veinlets. As a result of calcite precipitation, little or none of the original porosity is preserved in outcrop.

Gypsum—The gypsum found in surface exposures of the Cañas typically is recrystallized as a result of ground-water infiltration and at least one cycle of gypsum/anhydrite inversion. A secondary "chicken-wire" texture is common and may result from local segregation and concentration of dark, organic-rich carbonate material of the laminae during repeated episodes of recrystallization (Anderson and Kirkland, 1960). Microfolds result from both externally induced deformation and diagenetic effects.

Although gypsum is the only evaporite mineral observed in outcrop, anhydrite occurs at depths of less than 300 m. Drillers' logs from an oil test in the Jornada del Muerto near Engle indicate the presence of halite in the upper Yeso (Tenneco Oil Company, unpublished reports).

Depositional models

The Cañas Gypsum Member probably was deposited in a barred marine basin or lagoon, under conditions similar to those described by Schmalz (1969) for a salina-type model (fig. 5). Carbonate interbeds in the evaporites may represent brief periods of more normal salinity as a result of increased seawater influx. Clastic interbeds may be related to periods of progradational deposition of shoreline and eolian facies and/or storm-related deposits.

Cyclic sedimentation characterizes the Permian System in the study area. These cycles are related to changes in sea level, the balance between subsidence and deposition rates, and the nature and amount of sediment available. Cycles are visible on a wide range of scales. Laminae are cyclic on a scale of millimeters; sets of sandstone, carbonate, and shale beds are cyclic on a scale of meters to tens of

TABLE 1—Petrographic compositions of Yeso sandstones; original data from Hunter (1980); techniques and terminology from Dickinson (1970), Hunter (1980), Ingersoll (1978), and Ingersoll and Suczek (1979).

Component		Percent or fraction	Standard deviation	Number of samples
Polycrystalline quartz	(Qp)	2.8	1.3	12
Monocrystalline quartz	(Qm)	44.2	6.1	12
Total quartz	(Q)	(47.0)	6.3	12
Plagioclase feldspar	(P)	5.7	1.9	6
Potassium feldspar	(K)	10.0	3.1	6
Total feldspar	(F)	(15.7)	5.1	12
Metamorphic lithics	(Lm)	8.3	5.2	12
Sedimentary lithics	(Ls)	2.4	2.7	12
Volcanic lithics	(Lv)	0.1	0.2	12
Total unstable aphanitic lithics	(L)	(10.8)	7.1	12
Monocrystalline phyllosilicates	(M)	1.4	0.9	12
Miscellaneous framework	(MS)	1.2	0.8	12
Total interstitial (matrix, cement, voids, and secondary minerals)	(I)	23.9	4.5	12
		100.0%		
QFL% Q		64	7	12
QFL% F		21	7	12
QFL% L		15	10	12
		100%		
LmLvLs% Lm		79	12	11
LmLvLs% Lv		2	3	11
LmLvLs% Ls		19	13	11
		100%		
Qp/Q		0.06	0.03	12
P/F		0.37	0.16	6

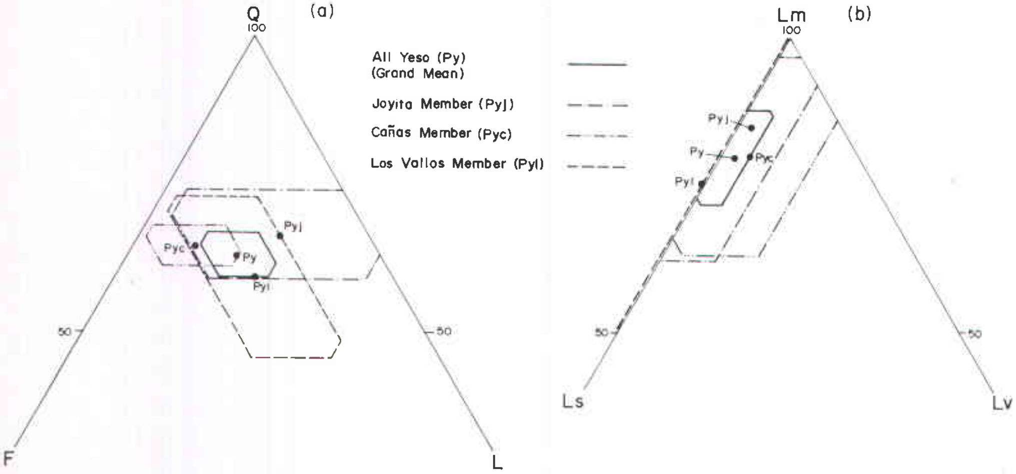

FIGURE 3—TRIANGULAR PLOTS SHOWING MEAN AND STANDARD DEVIATIONS (95-PERCENT CONFIDENCE INTERVALS) FOR YESO SANDSTONES. See table 1 for summary data and symbols; a) QFL triangle, b) LmLsLv triangle.

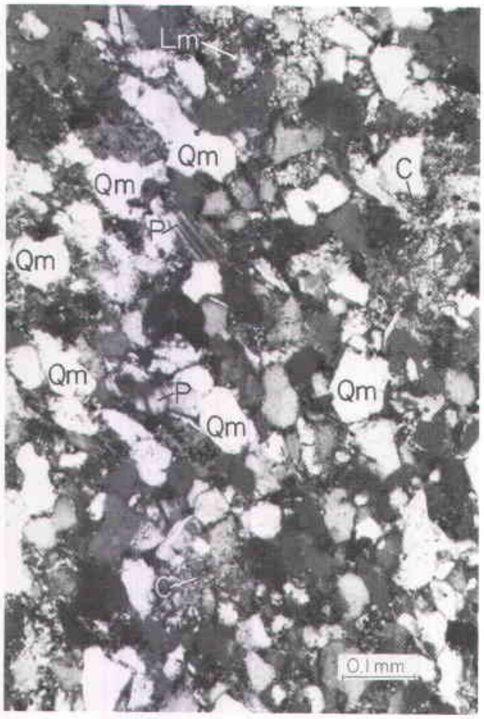

FIGURE 4—TYPICAL CAÑAS GYPSUM MEMBER SANDSTONE WITH MONOCRYSTALLINE QUARTZ (QM), METAMORPHIC LITHIC FRAGMENT (LM), PLAGIOCLASE FELDSPAR (P), AND CALCITE (C) (SECONDARY?). Note concavoconvex grain contacts, suturing of grains, pressolution, overgrowth on Qm grains, and phyllosilicate coatings; crossed nicols.

meters; lithologies of Yeso members are cyclic on a scale of tens to hundreds of meters; and the entire Permian System in the study area may represent a series of transgressions and regressions that deposited hundreds of meters of interbedded marine and continental deposits.

A similar modern environment is the Kara-Bogaz-Gol, a hypersaline bay (approximate area 18,000 km^2 and depth about 10 m) linked to the Caspian Sea by a narrow strait. This region has been studied and described by Dzens-Litovskiy (1967) and Dzens-Litovskiy and Vasil'yev (1962), who report active precipitation of marine salts. This basin is located in a temperate desert region and is surrounded by sandy shoreline and dune deposits.

In addition to being similar to the Cañas Basin in size, physiography, climate, and depositional environment, the Kara-Bogaz-Gol has a similar tectonic setting. The Kara-Bogaz-Gol and Caspian Sea are, in part, remnants of the once more extensive Tethys Sea that has closed during complex continental collisions in the Mesozoic and Cenozoic (Sengor, 1979). In an analogous situation, the Cañas Basin or lagoon was a small part of the Permian basins of southern and eastern New Mexico and west Texas, all of which represent the last vestiges of a once more extensive remnant ocean basin that was closed during continental collision in the late Paleozoic (Ouachita-Marathon orogeny) (Graham and others, 1975). The Pedernal uplift and related deformation may be responses to this continental collision (Coney, 1978; Kluth and Coney, 1981; Woodward and Ingersoll, 1979).

Economics

The Cañas Gypsum Member extends over an area of approximately 25,000 km^2 (fig. 1). If one assumes an average gypsum/anhydrite thickness of 30 m, this indicates a total sulphate tonnage of about 1.5×10^{12} metric tons. Gypsum is an important industrial mineral; New Mexico produced 4.1×10^5 metric tons with a value of \$$4.3 \times 10^6$ for the years 1977–1978 (Eveleth and Kottlowski, 1980). The United States consumed 3.7×10^7 metric tons (\$$2.4 \times 10^8$) in the same period, of which approximately 31 percent was imported (Pressler, 1979). The Cañas represents a significant gypsum resource, and further exploration of near-surface deposits is indicated.

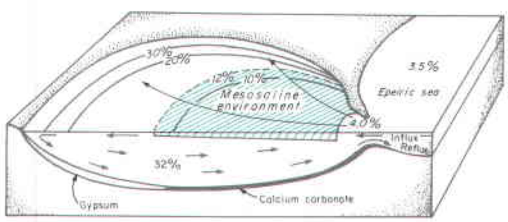

FIGURE 5—SIMPLIFIED SALINA-TYPE MODEL OF AN EVAPORITE BASIN (modified after Briggs and Pollack, 1967) showing: surface-water isosalinity lines (‰), direction of near-surface currents (arrows), and area of mesosaline environment (cross-hatched). (Kirkland and Evans, 1981.)

Conclusions

The Cañas Gypsum Member was deposited during a 10,000–50,000-yr interval of relative sea-level stability in a marine lagoon or basin connected across shallow shelves to the deeper Permian basins to the south and east. The location, geometry, and facies boundaries of this basin were controlled, in part, by the Pedernal uplift, which also was a source of clastic material. The restricted basinal conditions of all Permian basins of southeastern New Mexico and west Texas owe their origin to the Ouachita-Marathon orogeny caused by continental collision. The size and thickness of the Cañas evaporites make these deposits an important mineral resource for New Mexico.

ACKNOWLEDGMENTS—The authors thank Tenneco Oil Company, Minerals Exploration, for funding a Senior Honors Thesis (Hunter, 1980) on which much of this paper is based. Appreciation also is extended to J. L. Wilson and D. L. Emmons (Tenneco geologists) for their assistance and comments. J. F. Callender, V. C. Kelley, F. E. Kottlowski, and S. Thompson III also reviewed this paper and are gratefully acknowledged.

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Early Tertiary(?) strata penetrated in Jornada del Muerto

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Rocks that appear to be of early Tertiary age were penetrated by four wells drilled in the Jornada del Muerto near Engle, New Mexico, during 1979 and 1980.

Samples from SERA #1 and TAC #2 wells have been filed with the New Mexico Bureau of Mines and Mineral Resources in Socorro, New Mexico, where they may be examined by interested parties.

No other wells in this part of the Jornada del Muerto penetrate rocks of similar character or apparent age. All four wells penetrate strata that apparently represent post-Mesaverde but pre-Santa Fe deposition.

1) TAC #2 well is located 783,100 ft north, 746,500 ft east (New Mexico coordinate system, west zone); total depth is 500 ft; 60 ft are sediments and sedimentary rocks (presumably of the Santa Fe Group); lower 440 ft are grayish-red, brownish-gray, and grayish-brown rhyolite and latitic tuffs and breccias.
2) JDC #1 well is located 797,100 ft north, 744,900 ft east (New Mexico coordinate system, west zone); total depth is 500 ft, mostly in gray, red, and blue sedimentary rocks (some probably volcaniclastic); one very hard red "sandstone" may be a volcanic flow.
3) JDC #2 well is located 800,250 ft north, 745,000 ft east (New Mexico coordinate system, west zone); total depth is 300 ft, mostly in gray, red, and blue sedimentary rocks; lowest 75 ft are probably volcaniclastic or volcanic; lowermost 33 ft are probably rhyolite.
4) SERA #1 well is located 830,700 ft north, 737,600 ft east (New Mexico coordinate system, west zone); total depth is 345 ft, in sediments and sedimentary rocks; below uppermost 114 ft (Santa Fe Group), well penetrated red, brown, gray, and, occasionally, purple sediments and sedimentary rocks; few samples may include volcaniclastics.

Our cursory examination of the drill cuttings from SERA #1 and TAC #2 wells and the drillers' logs of JDC #1 and JDC #2 wells, in addition to discussions with others working in the area, indicate that all four wells may penetrate different atypical phases of the Palm Park Formation (Eocene).

These correlations are uncertain and more detailed study could show that all or part of the strata belong in the Thurman, Love Ranch, or McRae Formations instead of the Palm Park Formation. Of these formations, only the McRae Formation has been identified this far north in the Jornada del Muerto. It occurs as isolated outcrops near the railroad in T. 12 S., R. 2 W. as well as extensive outcrops along the east shore of Elephant Butte Reservoir; Sun-Victorio #2 well in sec. 27, T. 10 S., R. 1 W. penetrated 39 ft of McRae(?) Formation. Frank Kottlowski (personal communication, 1981) recalls cuttings of McRae Formation from a series of seismic shot holes along old NM-52 east of Engle.

Whatever the ultimate correlation, the rocks involved are atypical of the early Tertiary formations elsewhere in the basin. □