SALT IN THE OCHOA SERIES
NEW MEXICO AND TEXAS

By Philip T. Hayes

Trace Elements Investigations Report 709

UNITED STATES DEPARTMENT OF THE INTERIOR
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TEPCO, Washington	2
	87

CONTENTS

ILLUSTRATIONS

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ABSTRACT

The Permian Ochoa series of southeastern New Mexico and western Texas contains three salt-bearing formations which in ascending order are the Castile, Salado, and Rustler formations. The Castile formation is confined to the Delaware basin whereas the Salado and Rustler formations extend northward and eastward many tens of miles beyond the limits of the Delaware basin.

The Castile formation which ranges in thickness from about 1,500 feet to nearly 2,000 feet has an average composition of one-half anhydrite, one-third halite, and one-sixth calcite in the northwest part of the Delaware basin. The thickest known sequence of nearly pure halite is 350 feet.

The Salado formation underlies an area of 25,000 square miles but its thickest part coincides approximately with that of the Castile formation. In the potash area of southeastern New Mexico where the formation reaches a thickness of nearly 2,000 feet it consists of 84% halide, 12% sulfate, and 4% clastics.

The Rustler formation which is less than 400 feet in thickness consists predominantly of anhydrite, dolomite, and clastic beds, and only contains thin unimportant beds of halite.

INTRODUCTION

This report is a synopsis of readily available information on the mineralogy, thickness, and areal extent of soluble salt deposits in the Ochoa series of Permian age in southeastern New Mexico and western Texas. Any study of soluble salt deposits in an area of open drainage must be based almost entirely on knowledge obtained from subsurface data because nearly all evaporite deposits more soluble than gypsum or polyhalite are removed by solution at the outcrop even in arid regions. Fortunately, a large part of the area in southeastern New Mexico and western Texas underlain by salt deposits of the Ochoa series is underlain at greater depth by numerous oil pools with the result that many thousands of drill holes have penetrated the complete salt sequence. The great majority of these holes, however, were drilled by rotary tools with the result that the most soluble salts were generally dissolved in the drilling mud.

In addition to the oil wells and test holes, hundreds of core holes have been drilled through the salt in Eddy and Lea Counties, New Mexico, in exploration for minable deposits of potassium salts. In spite of the vast amount of information on the salt deposits resulting from these drill holes, there is a surprising paucity of published material on the subject. For the most part, this report synthesizes information that could be gleaned from the published literature and from the examination of about thirty oil-well sample logs. The samples from several of these wells have been personally examined by the writer. A more comprehensive study of the Ochoa salt deposits would naturally be based on the examination of hundreds of cores and well logs available at core and well-log libraries, and at oil and mining company offices.

This report is part of a more extensive investigation of salt being carried out by the U. S. Geological Survey in connection with its Investigations of Geologic Processes project on behalf of the Division of Research, U. S. Atomic Energy Commission.

STRATIGRAPHY

Saline deposits of Permian age are present over a large area from northern Kansas, through western Oklahoma, western Texas, and southeastern New Mexico. In general, these deposits are progressively younger in age from northeast to southwest. The great salt deposits of Kansas, Oklahoma, and the northern part of the Texas panhandle belong to the lower two series of the Permian whereas in southeastern New Mexico and southwestern Texas the great salt deposits belong to the upper two series. In this southern area the salt in the uppermost or Ochoa series is in much thicker and more extensive beds than that in the underlying Guadalupe series. This report is confined to a discussion of the salt deposits of Ochoa age in southeastern New Mexico and western Texas.

The Ochoa series contains three salt-bearing formations: the Castile formation at the base, the Salado formation, and the Rustler formation. The Castile formation is confined to the Delaware basin but the higher two formations extend northward and eastward over the northwest shelf area, the central basin platform, and the Midland basin (fig. 1).

Castile formation

The Castile formation contains the oldest Permian evaporite deposits of the Delaware basin although earlier Permian formations contain back-reef evaporite deposits on the shelf areas surrounding the Delaware basin and in the Midland basin. The Castile formation of present-day usage includes only the lower part of the original Castile formation as defined by Richardson (1904). Lang (1937) split the old Castile into the Castile and overlying Salado formations on the basis of distinct lithologic differences which had long been recognized. The arbitrary boundary between these units is described below.

The basal few feet of the Castile formation in most areas consists of thinly laminated non-fossiliferous brownish limestone which rests with apparent conformity on thinly bedded very fine-grained sandstone of the Bell Canyon formation. The basal limestone of the Castile grades upward into interlaminated white anhydrite and brownish limestone. This so-called "banded anhydrite" of the Castile is one of the most distinctive features of the formation. Interbedded with

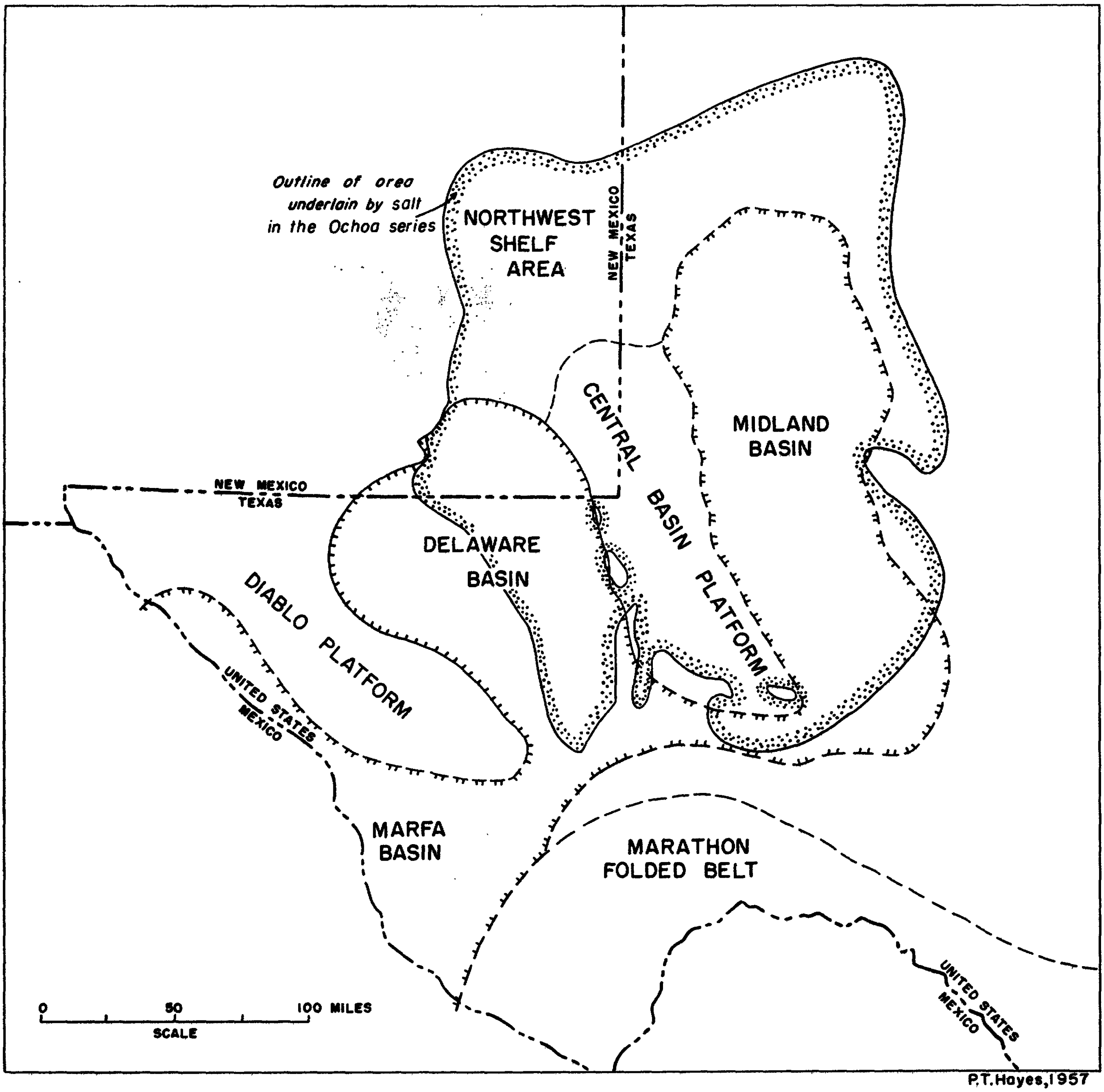

Fig. I. Index map showing outline of area underlain by salt in the Ochoa series in relation to late Permian basins and shelf areas. (Adapted from King, 1948).

the "banded anhydrite" are several sequences of relatively pure halite some of which are in places more than 350 feet thick but which are usually less than 250 feet in thickness. The thickest sequences of halite in the Castile are in the north and east parts of the Delaware basin, but everywhere the halite sequences are separated by 50 to 500 feet of anhydrite, and in no place does halite comprise more than about 40 percent of the formation. The total thickness of all the halite sequences in the Castile locally exceeds 600 feet (fig. 2). The approximate average composition of the Castile formation in the northwest part of the Delaware Basin in New Mexico on the basis of examination of cuttings from several wells drilled with cable tools is one-half anhydrite, one-third halite, and one-sixth calcite. On the southwest side of the Delaware basin there is little or no salt in the Castile formation, and on the southeast side south of the central part of Ward County, Texas, salt is present only in thin beds and makes up only a small fraction of the formation (fig. 2). Over most of its extent, the interlaminated anhydrite and limestone grade upward into pure white anhydrite, but in the extreme southeastern part of the Delaware basin in the eastern part of Reeves and the western part of Pecos Counties, Texas, it is immediately overlain by the basal halite bed of the Salado formation. In this part of the basin thin beds of the "banded anhydrite" are even present in the lower part of the Salado formation.

Northward and along the margins of the basin the top of the "banded anhydrite" is well below the top of the Castile formation.

The exact position of the arbitrary boundary between the Castile formation and the overlying Salado formation has been the subject of considerable debate. In general, the Castile, as is described above, consists predominantly of interlaminated anhydrite and limestone, several beds of relatively pure halite, and non-laminated anhydrite. Clastic beds and salts more soluble than halite are virtually nonexistent in the formation. The Salado formation, on the other hand, consists predominantly of halite but contains minor clastic beds and many of the rarer salts over much of its extent. Lang (1937) in his original definition of the Salado formation divided the two formations on the basis of potassium content. Later (1939) he revised his placement of the boundary downward to the base of the Fletcher anhydrite member, the lowest unit overlying the Capitan limestone of late Guadalupe age which forms the margin of the Delaware basin. This placement of the boundary between the Castile and Salado formations restricts the Castile to the Delaware basin and has been accepted by most workers.

The lateral relationships of the Castile formation with the surrounding Capitan limestone are still imperfectly understood. The generally accepted interpretation is that the Castile was deposited in a deep basin with the Capitan limestone reef forming the steep sides of the basin (Lang, 1937;

Kroenlein, 1939; Adams, 1944). The contact of the Castile with the underlying Bell Canyon formation is assumed to be conformable whereas the contact with the Capitan limestone which is generally believed to be entirely equivalent in age to the Bell Canyon is regarded as one of depositional onlap. This notion requires a hiatus in deposition between the top of the Capitan limestone and the overlying Salado formation outside the Delaware basin. Evidence for this hiatus has never been satisfactorily demonstrated, and Jones (1954) presents subsurface evidence to the effect that deposition was continuous from Capitan time into Salado time. Newell and others (1953) made the very reasonable suggestion that the basal limestone beds of the Castile were equivalent in age to the top of the Capitan limestone. If one accepts this correlation as correct, it might be suggested that the remainder of the Castile formation is equivalent in age to the much thinner Fletcher anhydrite member of the Salado formation and immediately overlying beds in the shelf area. Jones' (1954) cross section seems to suggest this. Perhaps the problem will be resolved in the future when some well placed core holes are drilled. It now appears hopeless to resolve the problem on the basis of the poor surface exposures.

The Castile formation is exposed on the surface over a broad area on the western side of the Delaware basin between exposures of the underlying Bell Canyon formation and the residual debris of the overlying Salado formation. No salt is present in surface exposures of the Castile, and the anhydrite has been hydrated to gypsum at the surface to depths ranging from nearly 100 feet to more than 500 feet. For these reasons no reasonable surface sections of the formation can be measured. In the subsurface, however, the Castile generally ranges in thickness from about 1,500 to nearly 2,000 feet except near the north and east margins of the Delaware basin where it thins to a wedge-edge in a distance of about one mile (fig. 3). One well in the central part of Loving County, Texas, penetrated nearly 2,500 feet of Castile where it is considered likely by the writer that the uppermost approximately 500 feet of white anhydrite in the Castile is a time equivalent of the basal part of the Salado halite in areas to the north and east.

The shallowest known occurrence of a thick halite sequence in the Castile formation is in the Hanson and Yates #1 Cordie King well in NW$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 22, T. 23 S., R. 26 E. Eddy County, New Mexico, where the top of a 353 foot thick sequence of nearly pure halite lies at a depth of 695 feet. Westward from this locality this salt thins to 35 feet within 3/4-mile and southeastward the top deepens at the rate of about 90 feet per mile.

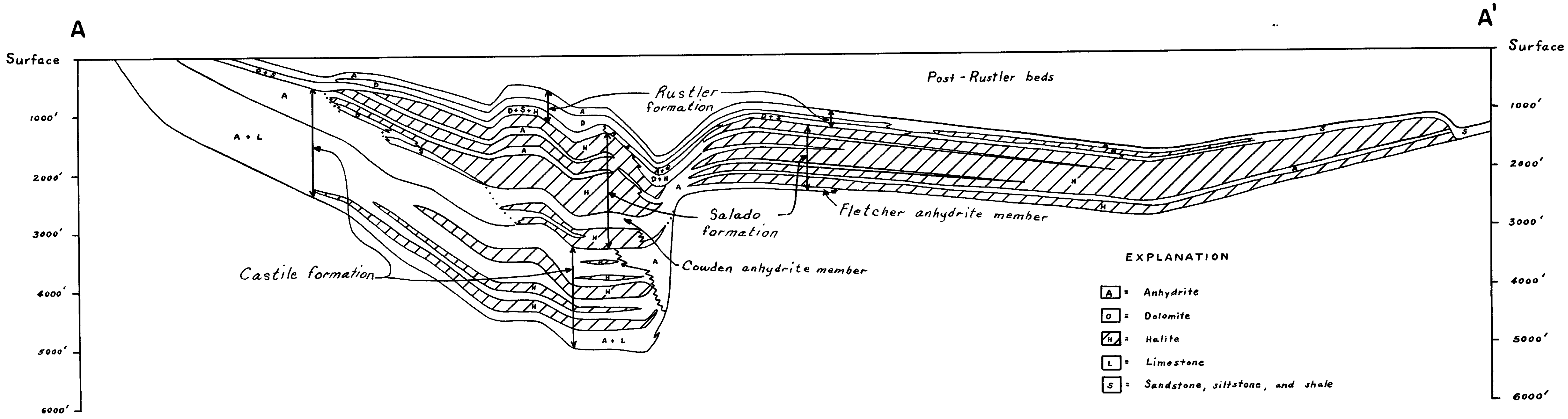

Fig. 3. Stratigraphic diagram A - A' of Ochoa series. (See figs. 2 and 4).

Salado formation

The Salado formation is one of the world's greatest deposits of soluble salts. Unlike the underlying Castile formation, the Salado is not confined to the Delaware basin but extends more than 100 miles to the north and to the east of the basin, underlying an area of about 25,000 square miles.

Halite comprises from about 75 percent to about 90 percent of the Salado formation except in areas where solution has removed much of the salt and toward the depositional edges of the formation where variegated muds are predominant (Maley and Huffington, 1953). The next most abundant constituent of the Salado is anhydrite. The remainder of the formation consists of sandstone, siltstone, shale, polyhalite, numerous less abundant potassium minerals, and dolomite. Some of the clastic, anhydrite, and polyhalite beds and potassium mineral zones are thick enough and extensive enough that they form important "marker beds" over wide areas. According to unpublished data of C. L. Jones the Salado formation in the potash area of New Mexico (fig. 4) averages 84% halide, 12% sulfate, and 4% clastic (Moore, 1957).

The halite of the Salado formation, with the exception of the basal beds in the Delaware basin area, is in general less pure than that in the Castile formation. Much of the Salado halite, especially in the area where soluble potassium salts are present (fig. 4), has a pinkish color probably caused by minor traces of iron oxide. Considerable grayish halite is also present throughout the extent of the formation. The gray color is usually imparted by admixed black mud and clay. Minor amounts of blue halite are occasionally found in close association with the more soluble potassium salts. Anhydrite in the form of very thin beds and blebs is also a common impurity in the halite of the Salado. The thickest accumulation of halite in the formation is on the north and east edge of the Delaware basin where more than 1,700 feet of total halite content is present in a narrow band more than 35 miles long (fig. 4). On the shelf area adjacent to the Delaware basin there is only a relatively small area where thickness of the halite in all beds of the Salado totals more than 1,000 feet, and the salt gradually thins to a wedge-edge to the north and east.

The most extensive clastic bed in the Salado formation is the Vaca Triste member of Adams (1944). At its type locality in a well in the southwestern part of Lea County, N. Mex., where the Salado formation is about 1,750 feet thick, the Vaca Triste consists of about 10 feet of reddish fine-grained sandstone about 475 feet below the top of the formation. This unit can be recognized from the southern part of Ward County, Texas, into southern part of Chaves County, N. Mex. The only other named clastic member is the thin "La Huerta silt" which occurs near the base of the Salado over a broad area north of the Delaware basin. Numerous other very thin beds of sandstone and variegated shale are present in the Salado formation and considerable silt and clay are present as impurities in the evaporite beds of the formation. Near the presumed depositional edges of the formation on the north and east, and in areas where considerable salt solution has taken place near the southwest edge of the formation and elsewhere the clastics assume a greater relative abundance. In most drill holes clastics comprise less than five percent of the formation.

Anhydrite is the second most abundant mineral in the Salado formation after halite. It occurs in numerous beds ranging from inches to more than 100 feet thick. One of these is the Fletcher anhydrite member which forms the basal bed of the Salado formation on the shelf to the north and east of the Delaware basin. The Fletcher anhydrite reaches a maximum thickness of nearly 80 feet but averages about 40 feet over most of its extent, then thins abruptly northward, and apparently has not been recognized as far north as Chaves County, N. Mex. A better known and more widely recognized anhydrite bed of the Salado formation is the Cowden anhydrite member. The Cowden lies immediately above the basal halite zone of the Salado near the edge of the Delaware basin and over the adjacent shelf area. Like the Fletcher, it thins northward and is not recognized far north of Eddy County, N. Mex. Basinward, the Cowden apparently grades into the upper part of the Castile formation as a result of the pinch-out of the basal

Salado halite bed within a few miles of the basin edge (fig. 3). The thickness of the Cowden anhydrite member does not exceed 40 feet and in most places is little more than 20 feet. Depending on the thickness of the basal halite of the Salado, the Cowden lies between about 100 and about 300 feet above the base of the formation. There are several other widespread anhydrite beds in the Salado formation that can be traced from the Delaware basin into the shelf area. Most of these have been given informal number designations. The most important of these from youngest to oldest are Nos. 4, 7, 12, 24, 39, and 44 (Kroenlein, 1939). According to Jones (1954) many of the anhydrite beds traced shelfward from the Delaware basin grade "laterally from anhydrite ($CaSO_4$) to polyhalite ($2CaSO_4 \cdot MgSO_4 \cdot K_2SO_4 \cdot 2H_2O$) and then to kieserite ($MgSO_4 \cdot H_2O$)" or from "anhydrite to glauberite ($CaSO_4 \cdot Na_2SO_4$) and then to polyhalite and kieserite."

Polyhalite is the second most abundant and widely distributed sulfate mineral in the Salado formation. It occurs in thin beds throughout the formation over the northwest shelf area, but within the Delaware basin it is not present below the Cowden anhydrite. Southward and eastward in Texas, polyhalite occurs only in the middle part of the formation and there only very sparingly.

The Salado formation is well known for its large reserves of potassium minerals. The most important of these are: sylvite (KCl), langbeinite ($2MgSO_4 \cdot K_2SO_4$), carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$), kainite ($MgSO_4 \cdot KCl \cdot 3H_2O$), and leonite

($K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$). These minerals occur as accessory minerals in halite beds, mixed halite and clastic beds, and in the anhydrite and other sulfate beds; as stratified deposits in the sulfate strata; as bedded deposits in the mixed halite and clastic strata; and as vein or lens deposits which have replaced or displaced the enclosing strata (Jones, 1954). These minerals are generally confined in occurrence to the north and east edges of the Delaware basin in Lea and Eddy Counties, N. Mex., and Loving and Winkler Counties, Texas, and to the adjacent shelf areas in Eddy, Lea, and Chaves Counties, N. Mex. In the Delaware basin area, the potassium minerals are found only in the upper part of the Salado formation whereas in the shelf area they are found throughout the formation. At the present time, seven mines in Eddy and Lea Counties, N. Mex., (fig. 4) are exploiting the potash in the form of sylvite from bed No. 28, and one mine is taking langbeinite from bed No. 22 (Smith, 1949).

Dolomite and magnesite are very minor constituents of the Salado formation in the northern part of the area where they occur as impurities in anhydrite beds, but southward in the southern part of the Delaware basin several thin dolomite beds are present. Near the south end of the area of present distribution of the Salado formation, dolomite makes up as much as 20 percent of the formation (Adams, 1944). Limestone is present as laminae in anhydrite beds in the lower part of the Salado formation in the southern end of the Delaware basin.

The isopachous map of soluble salt in the Salado formation (fig. 4) is only suggestive of the original thickness and extent of salt in the formation. This is particularly true of the south and west sides of the area of present distribution of the formation where much of the original salt has been removed by solution. To the south and southwest, however, the increasing proportion of dolomite, limestone, and anhydrite in the formation suggests that the soluble salts never extended far beyond the present limits. It is believed by King (1942) and Adams (1944) that the Salado grades southward into the Tessey formation of the Glass Mountain area. The original western extension of the Salado formation has been entirely removed by erosion and solution. It is considered probable that the Salado never was present many tens of miles west of the Delaware basin. Kroenlein (1939) believes the original limits on the west were not far different from the present limits. The more gradual wedging out of the salt and the increase in clastic components of the formation to the north and east are evidences that on these sides the present distribution very closely reflects the original depositional limits.

Subsurface solution has removed great amounts of salt from several areas. The largest area of salt removal is along the margin of the Delaware basin from Pecos County, Texas, to Eddy County, N. Mex. (figs. 3 and 4). Another linear area where solution has removed much salt lies in the southeastern part of Eddy County, N. Mex., and the western part of Loving County, Texas. Maley and Huffington (1953) attribute this solution to the action of downward percolating surface waters in late Tertiary time during an eastward tilting of the Delaware basin. Two other prominent areas of possible solution are indicated on the isopachous map. One of these is a southeasterly trending area extending from the southeastern part of Gaines County to the northwestern part of Sterling County, Texas, and the other is a small area in the eastern part of Crockett County, Texas. Adams (1944) believes there have been at least five periods of salt solution. These are: (1) pre-Salado solution of the upper Castile salt along the edge of the Delaware basin; (2) pre-Rustler solution of the upper part of the Salado formation along the west edge of the Salado distribution area; (3) early Triassic solution along the east edge of the Delaware basin evidenced by an over-thickened section of Triassic rocks over an abnormally thin salt section; (4) the Tertiary solution described above; and (5) solution taking place at the present time at the top of the Salado formation in the vicinity of the potash mines (fig. 4). It is considered likely by the writer that much of the solution on the west side attributed a pre-Rustler age by Adams may actually have taken place mostly during the Tertiary tilting of the Delaware basin.

The Salado formation is overlain by the Rustler formation. The contact is conformable and gradational, but there are areas where solution has removed and is removing the uppermost Salado. The exact position of the contact is usually arbitrary. Usually it is placed at the top of the highest thick halite bed in the Salado formation, but some workers prefer to place it at the base of the Culebra dolomite member of the Rustler formation thus including a few tens of feet of predominant anhydrite and clastic beds in the Salado. The latter contact is a more convenient contact for surface mapping (Hayes, 1957) where all salt has been removed, whereas the former is generally preferred by subsurface workers and is the contact used in this report.

The total overburden over soluble salt in the Salado formation varies from as little as 400 feet near the southwest corner of the area to more than 2,500 feet in the northern part. As a general rule the overburden in the Delaware basin area ranges from about 700 or 800 feet on the west and south sides to about 1,500 feet on the northeast side, whereas on the shelf area the overburden generally ranges from about 1,000 to 2,000 feet (West Texas Geological Society, 1949, 1951, 1953).

Rustler formation

The Rustler formation is the highest Permian salt-bearing unit in western Texas and southeastern New Mexico; but unlike the Castile and Salado formations, soluble salt comprises only a relatively small percentage of its total thickness. The following description of the Rustler is, therefore, very brief.

Anhydrite (or its hydrated counterpart gypsum) is the dominant rock type in the Rustler formation; but gray sandstone, reddish siltstone, and red and yellow shale are common; and conglomerate is locally present. Halite occurs in a few thin beds especially in the lower part of the formation. Polyhalite and the soluble potassium minerals also are locally present in the lower part overlying the area where potassium salts are present in the Salado formation (fig. 4). There are two prominent named dolomite members of the Rustler formation. The lower of those is the Culebra dolomite member, and the upper is the Magenta dolomite member. These average between 20 feet and 40 feet in thickness in Eddy and Lea Counties, N. Mex. Southward toward the Glass Mountains in Pecos and Brewster Counties, Texas, the dolomite units thicken and grade to limestone while the anhydrite members grade to dolomite. Conversely, the dolomite members thin northward and the anhydrite members grade to halite. Beds of soluble salt are nowhere of great thickness in the Rustler formation, and no isopachous or distribution map of Rustler salt is included in this report.

The total thickness of the Rustler formation averages between 300 and 400 feet over most of the Delaware basin and between 100 and 300 feet over the shelf areas.

DEPOSITIONAL HISTORY

The mechanics and chemistry of deposition of the Ochoa evaporite deposits were exceedingly complex, and detailed discussion of the subject is not warranted here. The following paragraphs merely outline the general depositional history and point out a few of the problems.

The Delaware basin was apparently cut off from the open sea at the beginning of Castile deposition. The few feet of non-fossiliferous limestone at the base of the Castile are believed to represent inorganic calcium carbonate deposits resulting from the initial evaporation of the trapped waters. Udden (1924) interpreted each pair of anhydrite and limestone laminae of the overlying "banded anhydrite" as annual layers resulting from seasonal variations in salinity. The warming of the surface waters in summertime would result in the loss of carbon dioxide and the consequent decrease in solubility of calcium carbonate. Thus the limestone laminae, which incidentally are high in organic content, are thought to represent warm-season deposition, whereas the intervening calcium sulfate laminae were deposited in the colder seasons. Whether the calcium sulfate was originally deposited as anhydrite or gypsum is unsettled, but the weight of modern opinion would favor gypsum. King (1947) explains the great thickness of anhydrite and relative paucity of halite in the Castile with a modification of Ochsenius' bar theory (Grabau, 1920). King (1947) suggests that "the water within the basin consisted of a body of brine lying below average wave base and a less dense surface layer lying above average wave base" and that the barrier which closed off free circulation between the Delaware basin and the open sea either had a top which "lay partly below wave base or the barrier was permeable." The relatively fresh surface waters of the basin were continually replenished from the open sea while the denser brines below drained out to the sea over or through the barrier. The few beds of halite in the Castile were deposited at times when this outflow was retarded or stopped.

By the close of Castile time, the Delaware basin was nearly filled with evaporite sediments, the saline waters spread far beyond the borders of the basin over the northern and eastern shelf areas during Salado deposition, and the outflow of the more saline brines ceased. The relative proportions of limestone, anhydrite, and halite in the Salado formation as a whole are much closer to the proportions in normal sea water than those in the Castile. That the replenishing waters of the open sea still came from the south is suggested by the greater preponderance of the least soluble salts such as calcium carbonate and calcium sulfate in the southern end of the Salado basin, whereas the extremely soluble salts such as sylvite and carnallite are generally confined to the northern part.

On the north and northeast edges of the Salado sea land-derived detrital material was deposited with the evaporite deposits. At times, great floods of terrestrial clastic material swept far into the sea leaving such beds as the "La Huerta silt" and Vaca Triste sandstone member. Toward the close of Salado time the influx of clastic material increased. The beginning of Rustler time is marked by a great increase in clastic deposition and a concurrent freshening of the waters as reflected in a marked decrease in the relative abundance of halite and an increase in the proportion of carbonate rock.

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