Ore Controls, Carlsbad Potash District, Southeast New Mexico

Samuel S. Adams
The Anaconda Company
1849 West North Temple
Salt Lake City, Utah

ABSTRACT

Regional studies covering approximately 2,500 square miles within and adjacent to the Carlsbad potash district, southeast New Mexico, have outlined the general distribution of potassium mineralization within the Permian Salado Formation. The potassium mineralization, exclusive of polyhalite beds, occurs principally in nine stratigraphically distinct ore zones and covers a cumulative area in excess of 3,000 square miles. The present distribution of potassium mineralization and specific minerals within the ore zones reflect the conditions of deposition and post-depositional metasomatism of the ore zones. South of the buried Permian Capitan Reef, within the Delaware basin, rising formation brines have locally altered the ore zones to secondary potassium sulfate-bearing assemblages or have replaced all potassium-bearing minerals. Extensive areas of mineralization south and east of the mining district have apparently been completely destroyed.

Clastic wedges within the Salado Formation southwest of the potash district suggest that potassium deposition occurred during periods of extreme dessication attended by basin restriction and peripheral mud flats. Structure on a horizon between the principal ore zones indicates prolonged subsidence of the basin of deposition. Minor subsidence structures on the shelf are related to potassium distribution. In the Delaware basin most relationships which may have existed between ore and structure have been obliterated by the metasomatism and dissolution of potassium mineralization within the ore zones. Potassium distribution within the Salado Formation is not obviously related to thickness variations of selected intervals within the Formation. The details of the present distribution, geometry and constitution of the potassium deposits seem, therefore, less related to depositional than to post-depositional processes.

INTRODUCTION

The Carlsbad Potash District of southeastern New Mexico includes some of the world's major potassium deposits. The mining district covers approximately 1200 square miles and since 1931 has produced various refined products valued at more than one billion dollars. The host rock for the deposits in the Upper Permian Salado Formation which is present over an area in excess of 25,000 square miles in southeast New Mexico and adjacent west Texas.

Many of the potassium deposits in the Salado Formation are mineralogically complex and irregular in outline and distribution. These features have complicated exploration for new deposits and the evaluation of known deposits, and have prevented a systematic appraisal of the potash potential of the district and adjacent areas. Published geologic studies are in general limited to broad lithologic and stratigraphic considerations or local mineralogical and structural problems. The absence of any reasonably inclusive description and interpretation of the potassium deposits reflects both the complexity of the problem and the large volume of available data. This paper, supported by earlier studies, attempts to briefly outline the general potassium distribution and identify the factors principally responsible for the present mineralogy and distribution of the potassium deposits.

Subsurface data presented in the accompanying maps were obtained from more than 600 core tests, principally within the potash district, and more than 900 gamma ray and electrical oil well logs. The data were collected and interpreted while the writer was employed by the International Minerals and Chemical Corporation and it is with gratitude that the writer acknowledges the permission of IMC to publish this material. In a large measure any exploration success or professional contribution resulting from this work is due to the commitment of IMC, and in particular the Chief Geologist, Dr. Donald L. Everhart, to comprehensive studies of ore deposits. In addition, Dr. Kurt O. Linn contributed substantially to parts of the program.

REGIONAL SETTING

The Upper Permian Salado Formation is one of the youngest sediments associated with the major Permian marine transgression in the southwest United States. Evaporite deposition, represented by the Castile, Salado and Rustler formations, was preceded by the more widespread deposition of marine shales, limestones and sandstones. In southeast New Mexico and adjacent west Texas several Permian sedimentary provinces have been identified and described in detail (King, 1942). The principal provinces are shown in Figure 1 together with the location of the Carlsbad potash district, the limits of the Salado Formation and the area considered in this paper. The sedimentary provinces include the Delaware and Midland basins, the Diablo and Central Basin platforms and the shelf areas to the north and east. During Lower and Middle Permian times these provinces profoundly influenced the types and distribution of sediments deposited. For example, the deposition of thin bedded limestone and black shale in the deep parts of the basins occurred contemporaneously with the formation of organic reefs around the edge of the basins and the deposition of limestones or blanket sands on the shelf. Whereas these physiographic provinces influenced the deposition and distribution of formations older than the Salado Formation, the writer does not believe the provinces were important in determining the distribution of the Salado Formation and younger evaporites nor the distribution of potassium within the Salado Formation.

The Salado Formation contains all known occurrences of bedded potassium evaporite minerals in west Texas and New Mexico. The western limit of the formation is, at least in part, erosional whereas

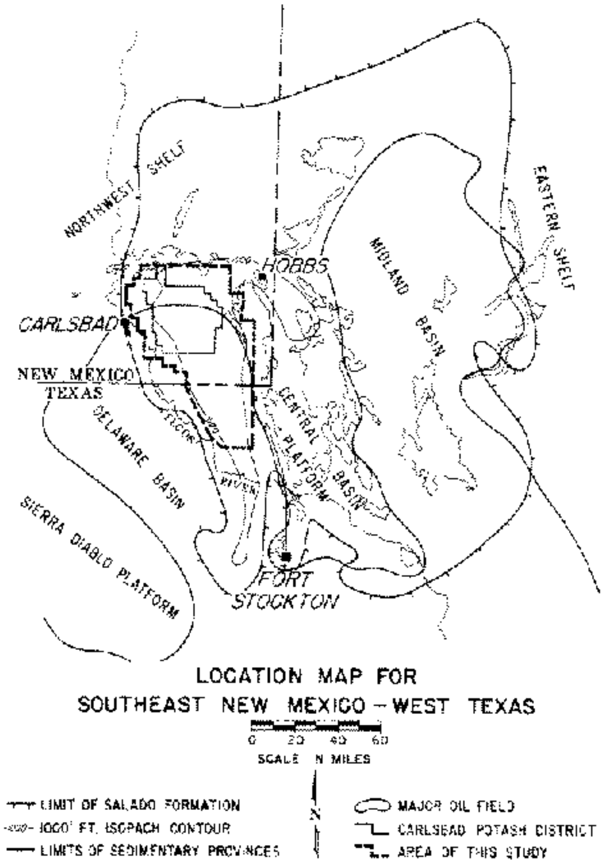

Figure 1. Location Map, Southeast New Mexico and West Texas.

elsewhere the salt of the formation interfingers with and gives way to shale beds. As indicated in Figure 1, the limits of the formation are not related to Permian sedimentary provinces.

Throughout this paper reference will be made to the Delaware basin, the basin margin area or reef zone and the shelf or back reef area. The boundary between the basin and shelf, as shown on the accompanying maps, is based on the distribution of the back reef Yates Sand as presented by Stipp and Haigler (1956). It must be remembered that these sedimentary provinces existed *prior* to the deposition of the Salado Formation. They exerted no obvious control on primary potassium deposition but profoundly influenced secondary changes.

SUBSURFACE GEOLOGY

Source of Subsurface Information.

Within the potash district abundant subsurface information is available through core tests and mine workings augmented locally by oil well logs. Within areas held by some of the mining companies, where drill results were not available for this study, details of potassium distribution could doubtless be improved. A recent U.S. Geological Survey Bulletin (Jones and Madsen, 1968), describing aspects of the fifth ore zone, draws on the drilling results of all companies and should, therefore, support more detailed investigations. For the scale, purposes and conclusions of this report the subsurface control within the potash district is considered adequate.

Outside the potash district subsurface information was obtained from oil well gamma ray and electrical logs and a few core tests. The stratigraphy of the Salado Formation is sufficiently uniform and consistent to permit the correlation of most beds throughout the area studied. In addition, the position of all polyhalite and anhydrite beds, locally referred to as marker beds, and all ore zones have been compiled and assigned numbers by C.L. Jones, C.G. Bowles and A.E. Disbrow of the U.S. Geological Survey. In this study preliminary correlations were made for the polyhalite and anhydrite beds based on their easy identification on the oil well logs. The positions of the ore zones were then determined with respect to the marker beds and the mineralogy and grade of potassium mineralization (if any) interpreted. Whereas the isopach and structure contour maps are based on the comparatively unambiguous correlation of logs, the interpretation of potassium mineralization within the ore zones is somewhat more involved and deserves some explanation.

All oil well logs used in this study contained a gamma ray log and either a neutron, sonic or acoustical log. The relative responses of these logs to the important minerals of the Salado Formation were determined by studying the electrical logs of core holes. The comparative responses of the logs to a portion of the Salado Formation are shown in Figure 2. The positions of the ore zones could

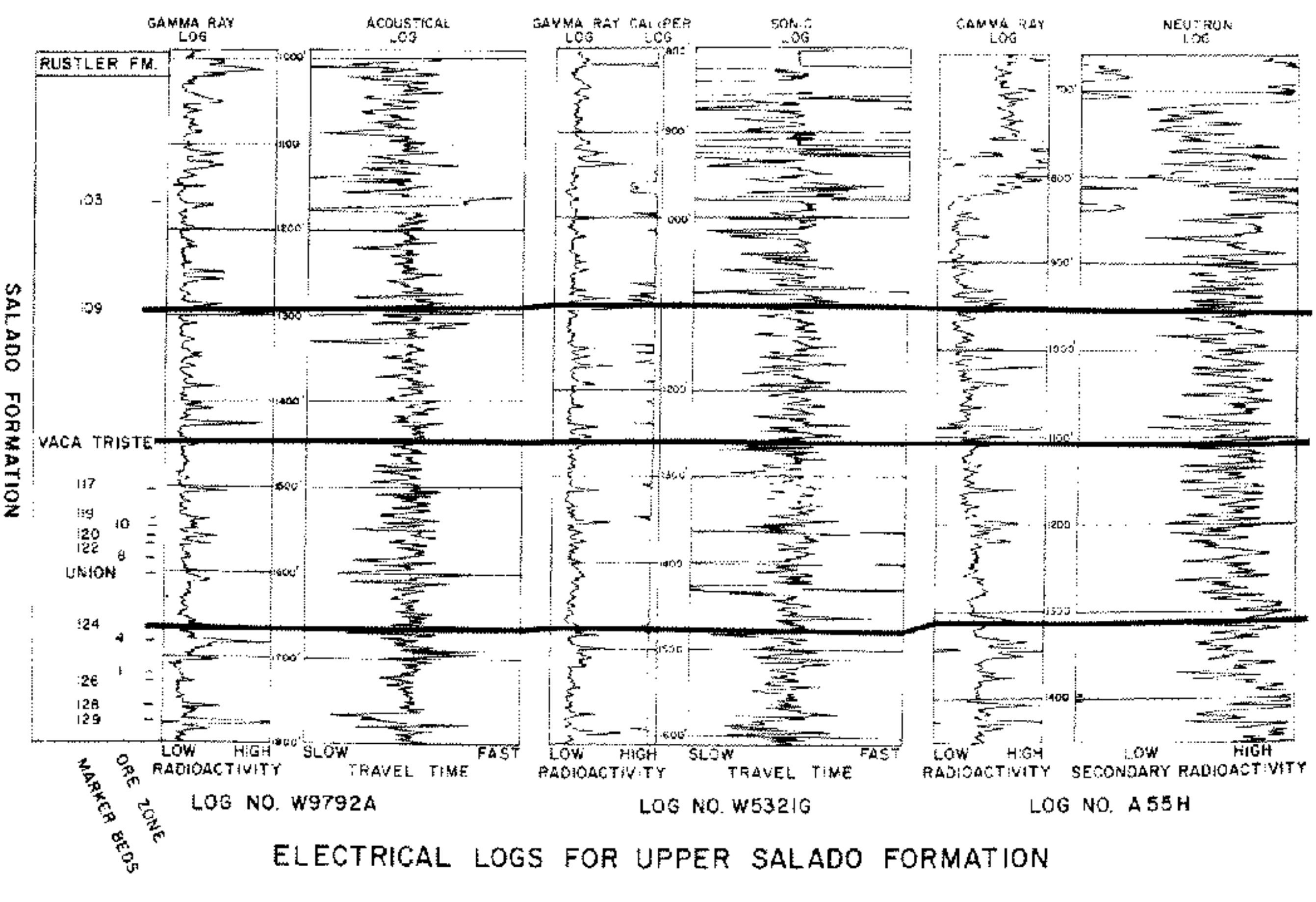

Figure 2. Comparative responses of electrical logs to a portion of the Salado Formation.

generally be located to within five feet and the presence or absence of anomalous potassium mineralization readily determined from the gamma ray log. The grade of each potassium anomaly was determined to within an estimated accuracy of 5 percent K_2O. Interpretation of the mineralogy of the anomaly was based on the different responses of the minerals to neutron, sonic and acoustical logs. Under favorable conditions carnallite can be differentiated from sylvite on a neutron log and sylvite from the potassium sulphate minerals on a sonic log. Whereas little confidence can be placed in the interpretation of an isolated log, most areas of the mineralizations outlined in the accompanying maps are based on corroborative information from several logs. The interpretation of the oil well logs, therefore, is believed to provide reasonably reliable definition of the distribution of carnallite, sylvite and potassium sulphate mineralization within the ore zones.

Distribution of Potassium Mineralization.

Of the twelve ore zones recognized in the Salado Formation, all but the ninth, eleventh and twelfth contain sufficient potassium minerals to be considered in the study. Figures 7 through 10 show the distribution of potassium mineralization in the principal economic ore zones and Figures 11 and 12 show the composite distribution within the lower and upper ore zones, respectively.

The boundaries of the mineralized areas were drawn to include reasonably continuous, potassium distribution. Widely scattered or isolated potassium occurrences were not included and scattered barren holes were not excluded from the areas. From underground mapping(Linn and Adams, 1966), it is known that even minable ore bodies contain numerous barren areas, called salt horses, particularly around the fringes of the deposits. The limits of most areas, therefore, can only be approximately located with the control and scale used in this study.

Potassium mineralization, as outlined in these maps, includes all measurable indications of potassium at the stratigraphic positions of the respective ore zones. In core holes the thickness, mineralogy, and grade are known. From the oil well logs, the minimum detectable potassium concentrations are in the rage of, or equivalent to, two feet as 3 percent K_2O. At these small thicknesses and grades, one can say little more than that an anomaly exists.

The maps for the first, fourth, fifth and tenth ore zones show the distribution of mineralogical ore types within the limits of control and scale. It must be emphasized that, as with the limits of mineralization, the boundaries of the ore types are more irregular and complex than can be shown.

Distribution of Clastic Sediments.

The majority of clastic or nonchemical sedimentary material in the Salado Formation is clay occurring (1) disseminated or as thin, discontinuous seams in the halite rock, (2) as disconformable residual accumulations from halite dissolution and (3) as half- to one-foot beds underlying polyhalite and anhydrite marker beds. Potassium ore zones are characterized by higher average concentrations of clastic material than are typical of halite sections. In addition to these occurrences, clay and silt are concentrated at three horizons within the formation throughout most of the area studied; at the top of the Salado salt, between 128 and 129 polyhalite marker beds and between the 116 marker and the eleventh ore zone (Vaca Triste Sand Member of Adams, 1944). The latter two accumulations reflect the influx of appreciable clastic material into the basin. The occurrence at the top of the salt is probably in part residual and in part depositional reflecting the transition from evaporite to clastic sedimentation. South of the potash district an area has been partly outlined within which the lower half of the Salado Formation consists of interbedded clastic and evaporite beds. In this area, shown in Figure 3 together with an area on the flank of the Central basin platform, clastic intervals coalesce and irregularly increase toward the west. Up to 400 feet of upper Salado salt overlies this clastic salt section throughout most of the area. As high clastic concentration generally reflects a change in the basin regime occasioned by dessication, basin shrinking and the influx of extraneous clastic-bearing solutions, this clastic area may represent the primary sediments and residium which accumulated in a basin margin zone. This zone may once have extended northwest along the west flank of the potash district but has since been destroyed by the extensive subsurface dissolution of the Salado Formation.

Structure.

The 124 anhydrite marker bed is a persistent unit above the first and fourth and below the fifth and tenth ore zones and is, therefore, a suitable horizon on which to study the structure in the area of study. Relief on this horizon, exceeding 2400 feet, is expressed in the back reef or shelf area as gentle anticlines and synclines whose trends are

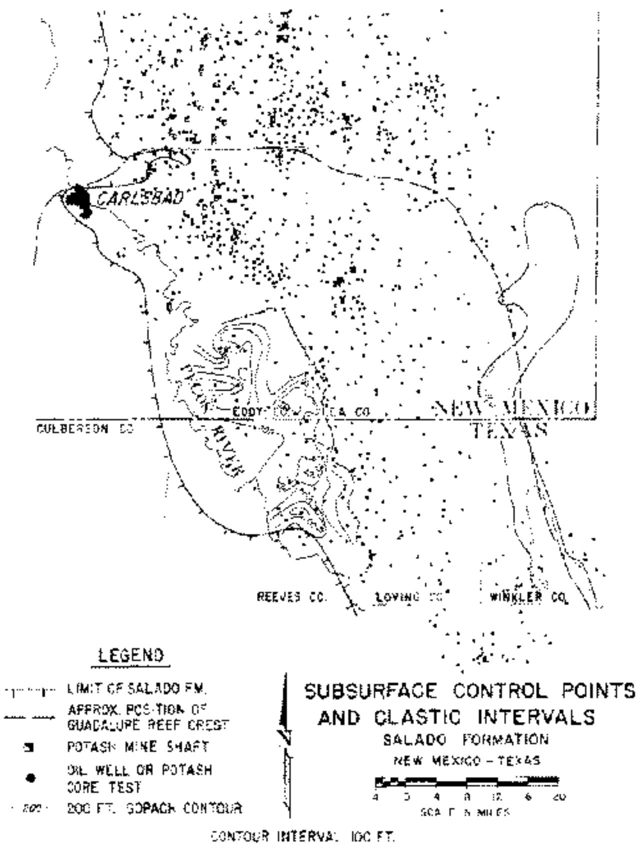

Figure 3. Major clastic intervals of the Salado Formation and subsurface control points.

subparallel to the basin margin or reef zones. Within the Delaware basin the dominant eastward dip is interrupted by a pronounced pro reef anticline, the amplitude of which increases toward the southeast, and a zone of deranged structure immediately north of the Texas-New Mexico state line.

The structural relief thus indicated within the Salado Formation is considered for a sequence of broadly continuous, shallow water, chemical precipitates. This, together with the coincidence of orientation between the fold axes and the regional tectonic framework, indicates that subsidence continued, during, and perhaps after, Salado time. This interpretation is important to the discussion of ore distribution in a later section and is incompatible with the view that evaporites "fill up" preformed basins of deposition.

Thickness Variations.

Two sedimentary intervals, containing the economic ore zones, were selected for isopach maps. The lower interval (Fig. 5) extends from the 124 marker down to the 126 marker and includes the first and fourth ore zones. The second (Fig. 6) extends from the 124 up to the 118 marker and includes the fifth and tenth ore zones. The thickness of the salt increases from the shelf and platform areas into the Delaware basin reflecting the more rapid and persistent subsidence of the latter. The shifting areas of thick sedimentation in the vicinity of the Texas-New Mexico state line may be related to the deranged structure in the same area. Beyond these broad correlations between sedimentation and structure only the coincidence of a thickened east-west salt section (Fig. 5) and a structural trough in the northern part of the potash district appears to be worthy of note.

DEPOSITIONAL ORE CONTROLS

The present distribution of potassium in the Salado Formation has resulted from depositional and post-depositional processes. As the effects of the secondary processes have been superimposed on primary featrues they are more pronounced, easier to study and interpret and, therefore, perhaps receive more attention in the following paragraphs than they deserve.

The Salado Formation covers an area exceeding 25,000 square miles within which significant occurrences of potassium evaporite minerals (other than polyhalite) are limited to an area of 2,500 square miles. This area of potassium deposits coincides with thicker Salado Formation, occurring essentially within the 1000-foot isopach contour. One might infer, therefore, that some relationship exists between potassium precipitation and the deeper parts of the basin. It appears, however (Adams, 1969), that the precipitation of the potassium-bearing portions of the Salado Formation occurred in shallow depths of brine. The coexistence of thick evaporite deposits and evidence of shallow-water precipitation suggest that basin subsidence continued during Late Permiantime. These subsiding areas received potassium deposits, then, because they experienced rapid and persistent subsidence and under conditions of extreme desiccation and basin restrictions, were the sumps for super-saline brine accumulation. The brine depth during the precipitation of halite rock and potash ore zones is not known and is difficult to estimate. Suffice it to say that during the precipitation of the upper half to two-thirds of the Salado Formation the brine was sufficiently shallow to permit influx solutions to dilute the *entire* brine volume to the point that evaporite rock was repeatedly dissolved on the basin floor. Considering the efficiency of density stratification and the slow rate of mixing, the brine depth was probably in the range of 2 to 10 meters during most of Salado time. Total solution depths likely exceeded this range following the influxes which produced the thicker sulfate beds. At the other extreme, evaporation to near or complete dryness may have occurred intermittently but the mineral assemblages formed would have been dissolved by the subsequent influx of solutions.

The shallow water environment of potassium deposition, as indicated by disconformities and clastic-bearing intervals within the evaporite stratigraphy and possibly the clastic area peripheral to the potash district (Fig. 3), should be an important criteria in the assessment of the potash potential of some evaporite deposits. In the absence of potassium mineralization, the type, amount and distribution of clastic material may indicate the general favorability of the evaporite deposits and those portions of the stratigraphy most likely to contain potassium deposit. The mineralogy and composition of the clastic material, principally clays, deserve far more study because they are, in part at least, authigenic and may augment lithology and bromine geochemistry in defining the conditions of evaporite sedimentation.

Within the general framework of basin restriction during potassium deposition and extension during halite deposition, evaporite precipitation is influenced by several factors which constitute the hydrologic regime of the basin. These factors include (1) the volume, source, frequency and composition of influx solutions, (2) the meteorology of the basin area, and (3) the size, shape, and bottom configurations of the basin. Data collected during this study provides information on some of these factors and others have been discussed more fully elsewhere (Adams, 1969).

The stratigraphy and lithology of the Salado Formation indicate that the basin received repeated solution influxes resulting in crude cyclic sedimentation. The compositions of these influxes were sufficiently different to yield different primary mineral assemblages. The third and fourth ore zones, for example, contain sulfate assemblages throughout their area of occurrence indicating that the primary mineral assemblages were sulfate-bearing. Sulfate assemblages in the other ore zones are more common within the Delaware basin and are the product of post-depositional processes.

It may be inferred from Figures 7 through 12 that the original distribution of potassium mineralization was not the same in all ore zones. The area of distribution seems to increase in size from the most valuable deposits (first, fourth and fifth ore zones) to the locally and potentially minable deposits (tenth, seventh and eighth ore zones) and the uneconomic deposits (second, third and sixth ore zones). The effectiveness of basin restriction during periods of extreme desiccation and potassium deposition was, therefore, important in formation of valuable potassium deposits.

On the shelf, an association exists between east-west subsidence structures and ore, particularly in the third and fourth ore zones (Figs. 4, 11). This relationship may indicate that at the time of deposition the configuration of the basin floor exerted some influence on the distribution of precipitating mineral assemblages. The relationship may be a simple reflection of brine depth but probably

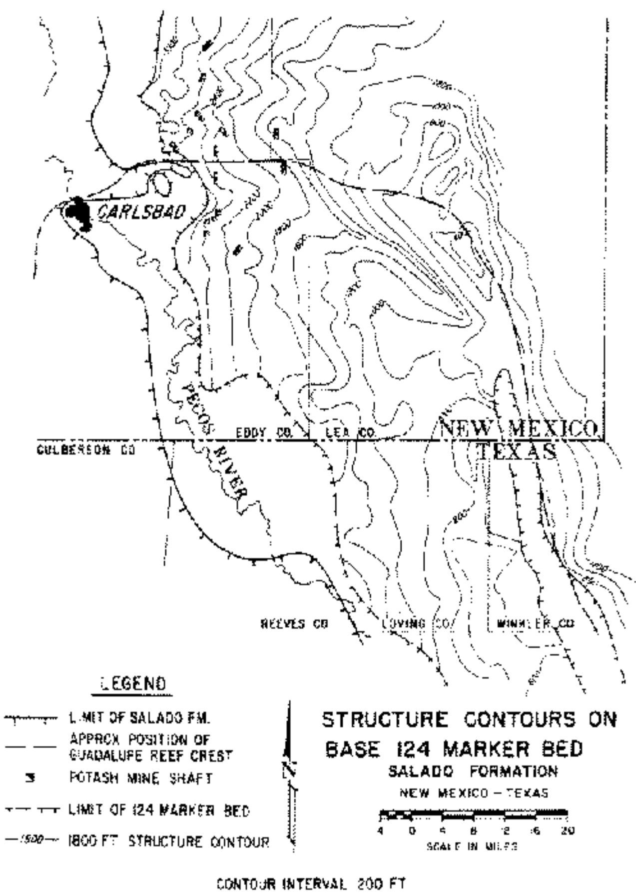

Figure 4. Structure contour map for the base of the 124 marker bed.

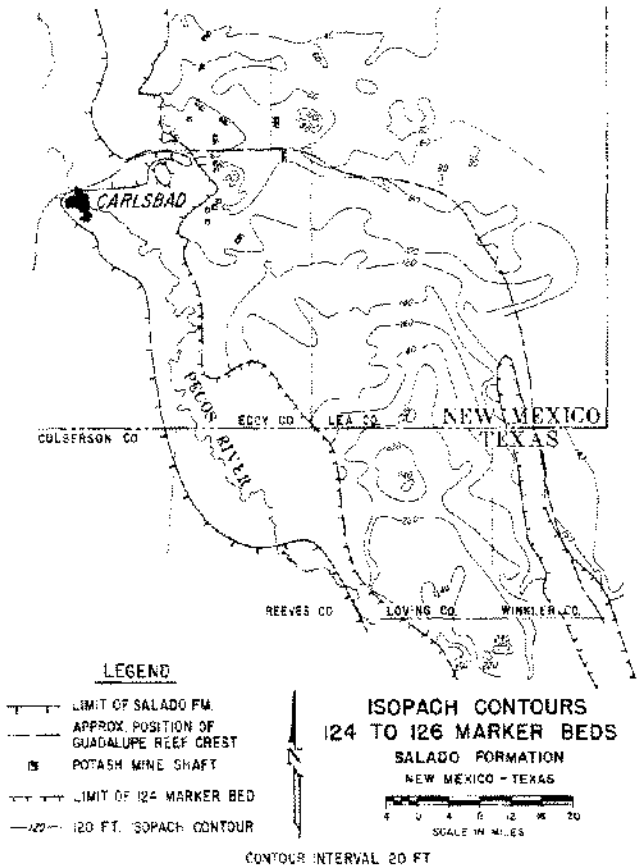

Figure 5. Isopach map for the interval between the base of the 124 marker bed and the base of the 126 marker bed.

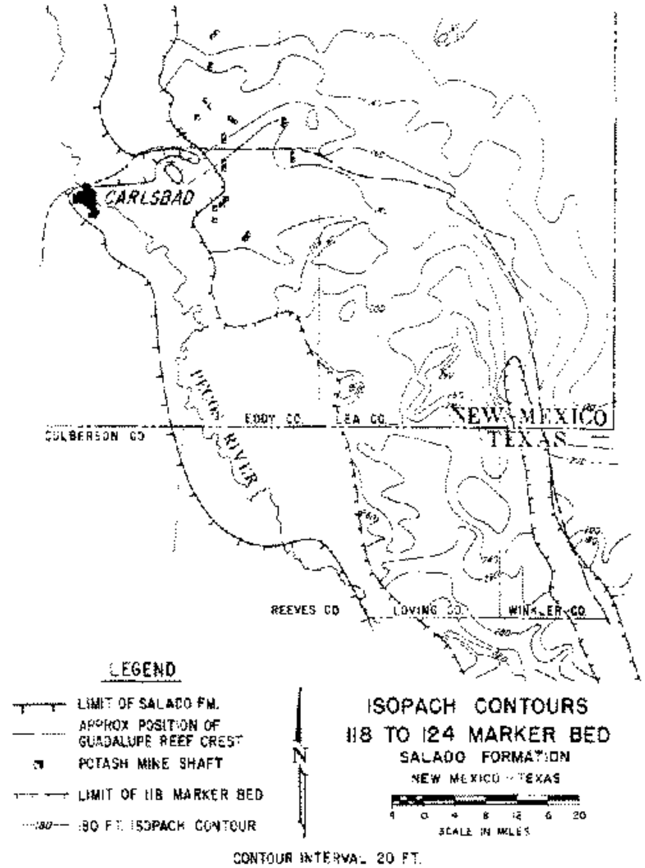

Figure 6. Isopach map for the interval between the base of the 118 marker bed and the base of the 124 marker bed.

involves such factors as temperature and salinity variations and surface and bottom currents. The isopach maps of intervals including the first through fourth, and fifth through tenth, ore zones show remarkably poor correlation with potassium distribution. A vague relationship exists between potassium mineralization and thicker sections on the shelf but it does not deserve further comment.

The dominant depositional ore control is the restriction of potassium mineralization to specific stratigraphic intervals, herein referred to as ore zones. The precipitation of potassium within these intervals was controlled by the general hydrologic regime of the basin and solution equilibria in the system Ca_2-Mg_2-K_2-Na_2-Cl_2-SO_4-H_2O. Study of certain deposits in the context of this system (Adams, 1969) leaves little doubt that these primary controls account for the presence of potassium in the ore zones and that post-depositional processes have only altered or removed the original potassium-bearing minerals.

POST-DEPOSITIONAL ORE CONTROLS

Certain aspects of the potassium mineralogy and distribution are not characteristic of primary chemical sedimentation and have been interpreted as reflecting metasomatism and dissolution of the ore zones. Post-depositional processes destroy or reconstitute potassium mineralization but do not form potassium deposits where none existed. The interpretation of these secondary effects and processes (Linn and Adams, 1966) was based on mine mapping and a general consideration of the chemistry of the systems involved. Subsequently, the solution compositions, temperature of alteration and other conditions of metasomatism were considered by Adams (1969). The information collected in this study has been interpreted in the context of these earlier studies and has, in turn, extended the concept of post-depositional metasomatism and dissolution to a broader area of the Salado Formation. A brief resume of the

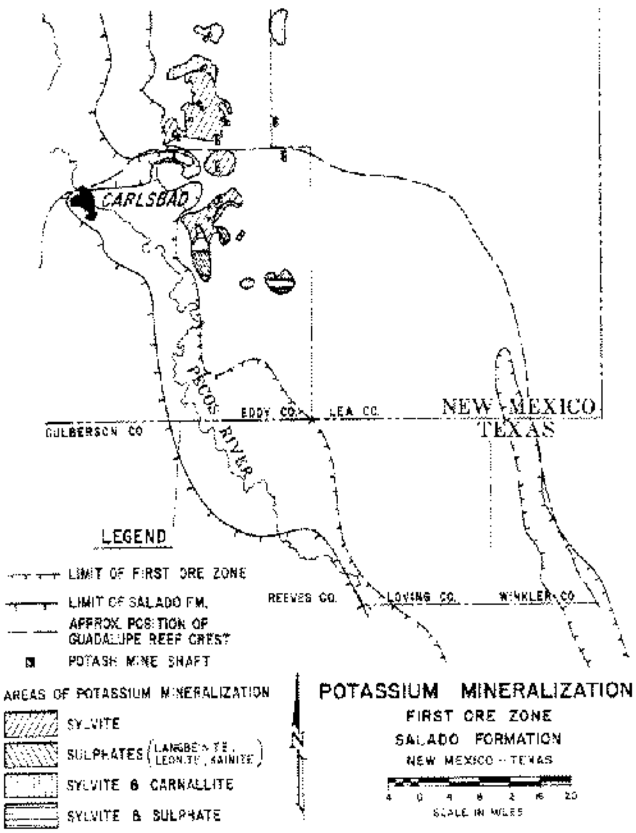

Figure 7. Potassium mineralization in the first ore zone.

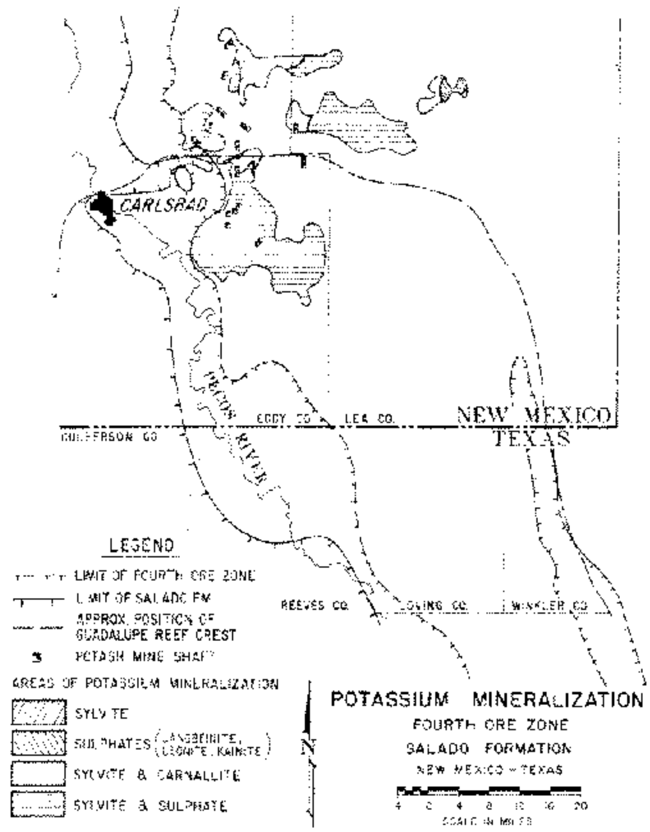

Figure 8. Potassium mineralization in the fourth ore zone.

conclusion of the earlier investigations will facilitate the interpretation of the data presented in this paper.

(1) Subsequent to deposition of the potash ore zones, interstitial brines, expelled from the underlying chemical sediments, and saturated with respect to halite and polyhalite, passed through parts of the deposits. The primary or early diagenetic sylvite and carnallite of the ore zones were dissolved by these brines with the precipitation of halite and, locally, potassium, magnesium and sodium sulfate-bearing minerals. In the Delaware basin a portion of the altering brine may have been derived from the underlying Castile Formation through the alteration of gypsum to anhydrite.

(2) The dissolution of the potassium deposits began with the formation of small leached areas, referred to as salt horses, which coalesced to form large barren areas as the brine flow continued.

(3) The passage of brine through the ore zones began shortly after deposition and probably continued intermittently through Salado time.

The studies supporting these conclusions were conducted almost exclusively within one mine in the Delaware basin and are, therefore, both more thorough and restricted than the present study. Features of potassium mineralogy and distribution interpreted as originating from post-depositional processes are shown in Figures 7 through 12 and discussed below.

Distribution of Mineralization.

Discontinuities occur in the mineralization of most ore zones along the northern edge of the Delaware basin. The coincidence of the southern limit of mineralization with the edge of the basin is apparent in Figure 12, particularly for the fifth, sixth and eighth ore zones. The same relationship for the deeper ore zones is apparent in Figure 11 with two important differences. First, the dissolution extends farther north in the lower ore zones and only small isolated areas of mineralization remain over the reef zone. The more extensive dissolution at depth probably reflects longer exposure to larger volumes of unsaturated brine. Second, larger areas of mineralization remain with the basin, particularly in the third and fourth ore zones. These two ore zones were probably less susceptible to leaching because the primary assemblages contained appreciable amounts of less soluble sulfate minerals.

The discontinuities in mineralization, particularly along the northern edge of the basin, were apparently produced by the dissolution of potassium chloride mineralization by brines, expelled from the underlying sediments, percolating through the poorly consolidated evaporite sediments. Near the northern edge of the basin, brine flow was deflected up dip within the sediments toward the reef crest. This convergent brine flow produced the more continuous dissolution indicated over and immediately south of the reef zone. The preservation of abundant mineralization within the basin on the western edge of the potash district is perplexing. There is no obvious reason why this mineralization was not leached. The broad areas of mineralization in Texas are known only from drilling and speculation on the origin of their limits is not attempted.

Superposition of Limits of Mineralization.

Commonly the limits of mineralization in two or more ore zones essentially coincide, suggesting that the distributions of their mineralization are not independent. The superposition of limits of mineralization over and slightly displaced from the margin of the Delaware basin was noted in the preceding paragraph. It was suggested that these relationships were the result of dissolution limited and locally enhanced by the particular rocks and structure of the basin, reef and shelf provinces. The superposition of limits of mineralization occur in other areas where they cannot be related to any structures or changes in lithology. Note, for example, the coincidence of the southern and eastern limits of mineralization south and, to a lesser extent, north of the basin margin in the western part of the district (Figs. 11, 12). The nine ore zones shown in Figures 11 and 12 are distributed vertically, through more than 150 feet of evaporites and the lithologic equivalent to the ore zones, as with most stratigraphic units within the Salado Formation, are remarkable for their lateral

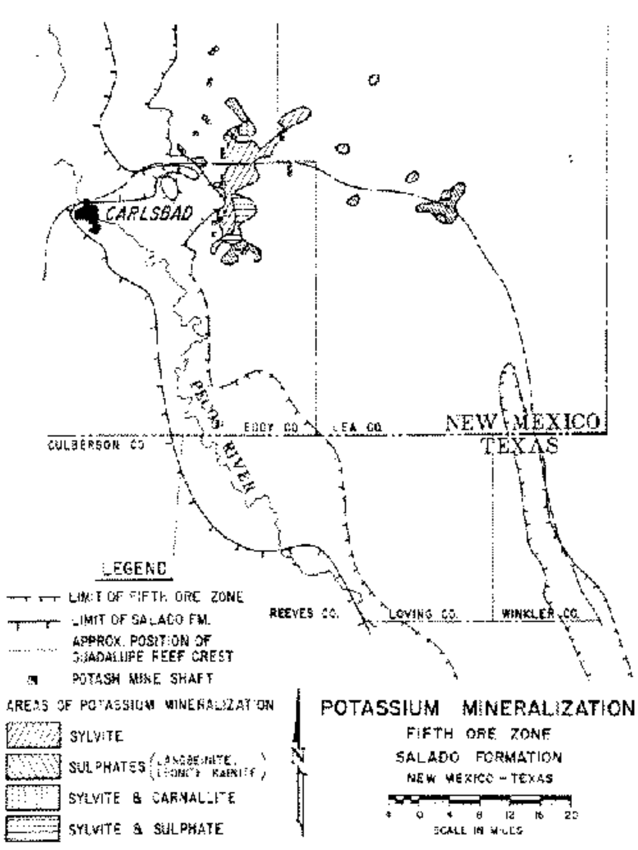

Figure 9. Potassium mineralization in the fifth ore zone.

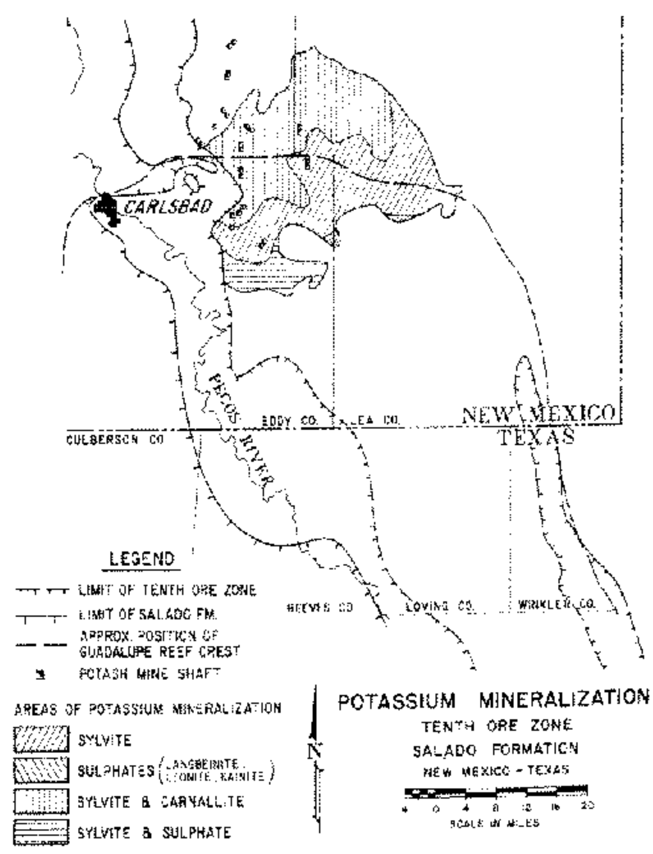

Figure 10. Potassium mineralization in the tenth ore zone.

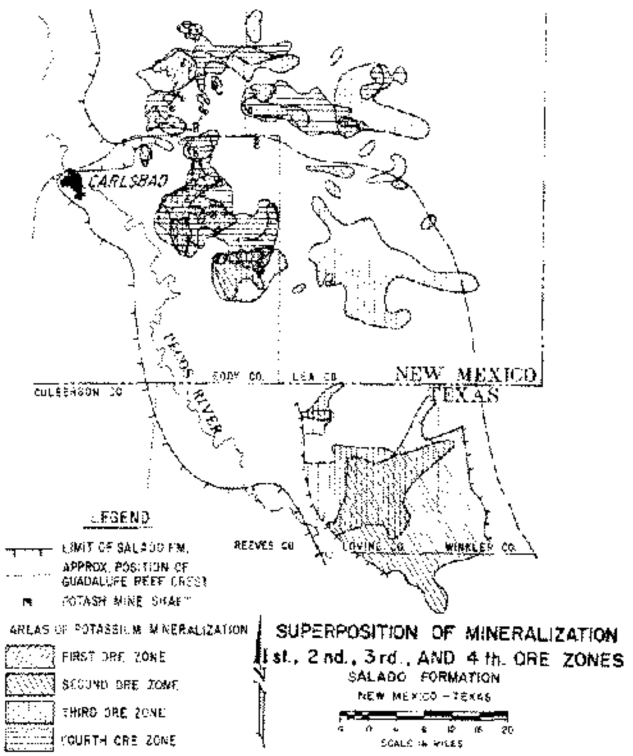

Figure 11. Superposition of mineralization in the first, second, third and fourth ore zones.

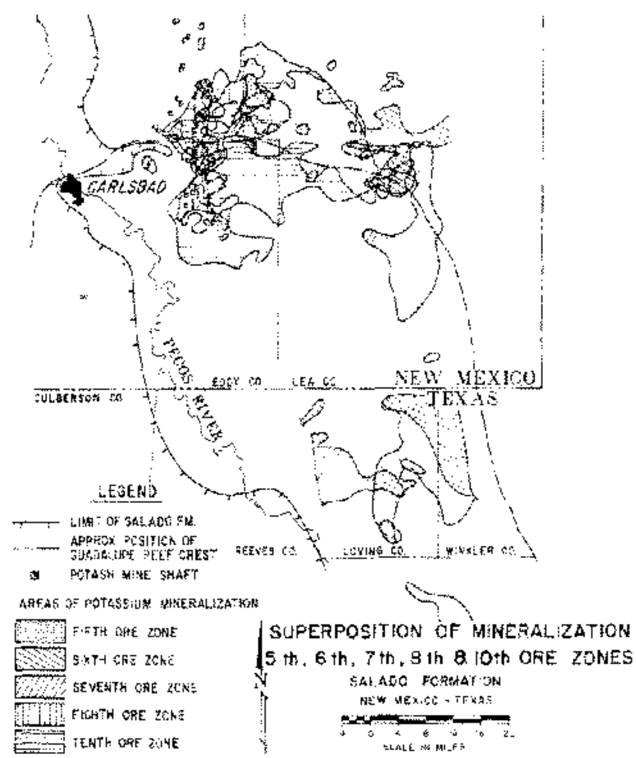

Figure 12. Superposition of mineralization in the fifth, sixth, seventh, eighth and tenth ore zones.

continuity. Whereas changes in thickness are common, broad lithologic discontinuities are rare. It is unlikely, therefore, that the superpositions of limits of mineralization within the different ore zones are the result of primary deposition. Were such the case there would be some indication in the structure and stratigraphy of the formation. Underground mapping in the first and fifth ore zones in the IMC mine has demonstrated the secondary origin of ore limits, and it appears reasonable that similar limits elsewhere in the Salado Formation developed in the same way.

The coincidence of the western limits of mineralization are equally impressive and also are the result of post-depositional leaching. In this case the leaching has been effected by ground water which is progressively dissolving the Salado Formation in the subsurface. It is likely that the potash deposits once extended farther west but it is not possible to evaluate how much ore has been destroyed.

Continuity of Mineralization.

Potassium mineral distributions in the ore zones appear to be related in another way. Referring to Figure 11, it will be noted that in the western part of the potash district within the Delaware basin, the area of mineralization increases irregularly from the first to the fourth ore zones. This possibly reflects the more extensive dissolution of the lower ore zones and the progressive saturation of the brines as they moved up through the salts. The absence of potassium minerals in an ore zone above mineralization in a lower ore zone may indicate non-deposition of potassium minerals in the former. It is also probable that the alteration of some ore zones began soon after deposition so that an ore zone may have been extensively altered before the next was deposited. The distribution of mineralization in the fifth, sixth, seventh and eighth ore zones (Fig. 12) in this same area is restricted and does not continue the trend of increased distribution. The tenth ore zone, however, extends beyond the limits of mineralization in most lower ore zones. On the shelf this relationship is less pronounced, reflecting possibly greater irregularity in the distribution of primary potash deposition and less post-depositional dissolution of the ore zones.

Distribution of Potassium Minerals.

The important potassium-bearing mineral assemblages of the ore zones include langbeinite ($K_2SO_4 \cdot 2MgSO_4$)-halite (NaCl), langbeinite-sylvite (KCl)-halite, sylvite-halite, sylvite-carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$)-halite and carnallite-halite. These assemblages are arranged approximately in the order they would precipitate from sea water or a similar brine with one notable exception. Sylvite generally does not precipitate as a primary mineral but forms through the alteration of carnallite. If, on the other hand, one were to pass sea water, or a halite-calcium sulfate saturated brine, through a deposit containing carnallite or sylvite, the reverse of this sequence of assemblages would approximately describe a sequence of retrograde metasomatism. To be sure, the mineralogy resulting from metasomatism of a potassium chloride deposit would be more complicated and, depending on the temperature, in addition, would produce with progressive alteration such minerals as kainite, leonite, kieserite, loewite and bloedite.

The ore zones of the Salado Formation generally contain more than one mineral assemblage and some contain several. In general, the assemblages do not occur as successive beds within an ore zone, as would be the case if the assemblages were produced by primary precipitation, but rather as broad areas or fringes of one assemblage peripheral to another. Sulfate assemblages in most of the ore zones are more abundant within the Delaware basin (Figs. 7-10). Underground mapping in the first, fifth and tenth ore zones has demonstrated that the majority of these sulfate assemblages have resulted from the alteration of potassium chloride assemblages by brines entering the ore zones from below. Commonly, these secondary sulfate assemblages form intermittent or continuous zones between unaltered sylvite-halite rock and barren ground (Linn and Adams, 1969). This pattern and the abundant sulfate assemblages of the basin suggest these assemblages were formed by the same processes which produced widespread dissolution of the ore zones.

Carnallite-bearing mineralization is present in the first, fifth, sixth, seventh, eighth, and tenth ore zones, particularly north of the basin. The carnallite may be, in part, primary but at least part formed after the beds were deposited. The majority of the sylvite in these ore zones was deposited as carnallite which was subsequently altered by formation brines. Whereas salt horses are present in the ore zones on the shelf, they are not as numerous as in the basin and generally have no associated secondary sulfate assemblage. Mineralization in the fourth and third ore zones departs somewhat from the preceding generalization. Whereas the sylvite content of the beds increased from south to north, apparently at the expense of potassium sulfate minerals, north of the basin there appears to be more sulfate and less carnallite than in the other ore zones suggesting that the primary assemblages were sulfate bearing.

CONCLUSIONS

The distribution of the potassium deposits of the Carlsbad potash district was controlled by the progressive subsiding of a shallow evaporite basin. Potassium-rich assemblages were deposited during periods of advanced desiccation and basin restriction. The original mineralogy and reoccurrences of these potassium assemblages were controlled by the source and composition of the brines which intermittently flowed into the basin.

Subsequent to deposition the primary mineralogy of the ore zones was progressively altered from principally carnallite-rich assemblages to sulfate-bearing assemblages and locally to barren halite rock. The brines responsible for these alterations were more profuse in the basin than on the shelf and were derived from underlying sediments through compaction and perhaps alteration. Depositional and post-depositional processes have combined, therefore, to first produce and then in part destroy the extensive potassium deposits of the district.

REFERENCES

Adams, J.E., 1944, Upper Permian Ochoa series of Delaware basin, west Texas and southeastern New Mexico: Am. Assoc. Petrol. Geol. Bull., v. 28, p. 1596-1625.

Adams, S.S., 1969, Bromine in the Salado Formation, Carlsbad Potash District, New Mexico: New Mexico State Bur. Mines and Min. Res., Bull. 93, 122 p.

Jones, C.L., and Madsen, Beth M., 1968, Evaporite geology of the fifth ore zone, Carlsbad district, southeastern New Mexico: U.S. Geol. Survey Bull. 1252-B, 21 p.

King, P.B.,1942, Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 26, p. 535-763.

Linn, K.O., and Adams, S.S., 1966, Barren halite zones in potash deposits, Carlsbad, New Mexico, *in* Second symposium on salt: Northern Ohio Geol. Soc., v. 1, p. 59-69.

Stipp, T.F., and Haigler, L.B., 1956 (1957), Preliminary structure contour map of a part of southeastern New Mexico showing oil and gas development: U.S. Geol. Survey OM-177.