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THE GEOLOGY OF THE LISBON VALLEY POTASH DEPOSITS, SAN JUAN COUNTY, UTAH

by

Robert J. Hite

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards

PREFACE

This report is composed of material excerpted from an administrative report written by the author in 1963. Since that time, considerable more subsurface data has become available as the result of development drilling in the Lisbon Valley oil and gas field. However, this additional data has not required modification of the original geologic interpretations.

Originally the information from potash drilling in the Lisbon Valley area was proprietary. Presently, however, this information, which is stored in the files of the U.S. Geological Survey in Salt Lake City, Utah, is available for public inspection because the company involved has relinquished all of its potash leases in the area.

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INTRODUCTION

The Lisbon Valley potash deposits are located in the southeast corner of Utah about 50 km (31 mi) southeast of Moab and about the same distance southeast of the Texasgulf, Inc., potash mine at Cane Creek (fig. 1). The nearest railhead is the Denver and Rio Grande Western spur to the potash mine at Cane Creek. Geologically the deposits are located within a structural and sedimentary basin of Pennsylvanian age which is called the Paradox basin (Baker and others, 1933, fig. 1, p. 964). The boundaries of the basin are generally determined by the wedge edge of the evaporites of the Paradox Member of the Hermosa Formation.

GENERAL STATEMENT

Deposits of potash were unknown at Lisbon Valley until 1958 when the Superior Oil Co. drilled a potash test (table 1, no. 1) near the crest of the Lisbon Valley anticline. The test was drilled to a depth of 1,111 meters (3,644 ft) and gamma ray-neutron logs were run. Although no conventional coring was done, the gamma ray-neutron log indicated two significant deposits of potash between the depths of 732 and 745 m (2,400 and 2,455 ft) and 968 and 980 m (3,175 and 3,215 ft). Later, sidewall cores, analyses of which yielded a high K_2O content, were taken from these two deposits. Following this initial success, the Superior Oil Co. began a series of potash tests and by January 1960 had completed four test holes, all of which had penetrated potash deposits. During this same month the Pure Oil Co. successfully completed the discovery well in the Lisbon oil and gas field immediately to the west of the potash area. At the time of this writing, development drilling in the oil and gas field plus additional potash tests had provided a total of 46 wells which supplied information about the potash deposits.

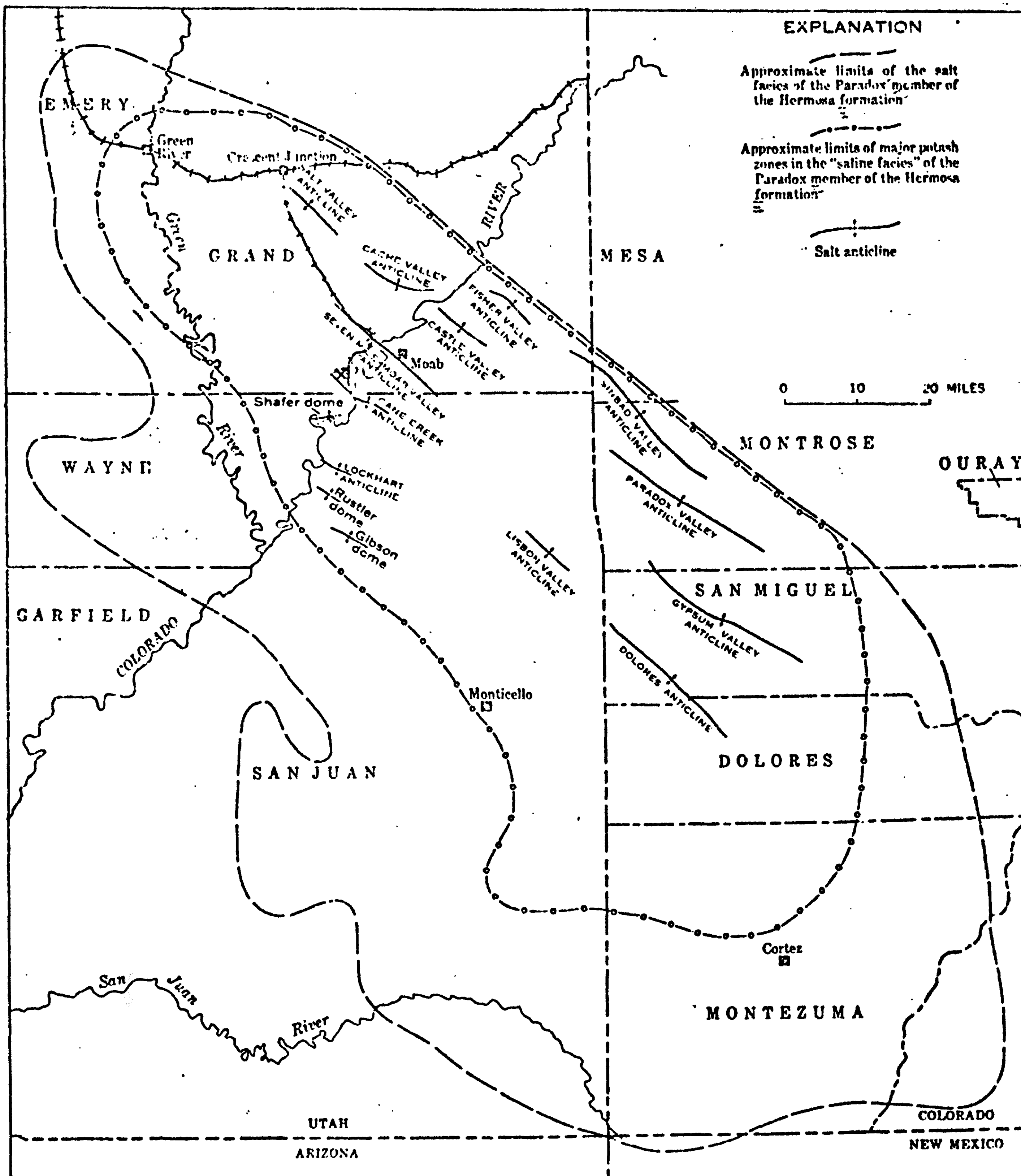

Figure 1--Index map Paradox basin

STRATIGRAPHY

Rocks exposed in the Lisbon Valley area range in age from Lower Cretaceous to Pennsylvanian. The oldest rocks, limestones of the Hermosa Formation, are exposed on the crest of the Lisbon Valley anticline and successively younger rocks crop out downdip to the southeast. In the subsurface, rocks of the Jurassic, Triassic, Permian, Pennsylvanian, Mississippian, Devonian, and Cambrian Systems have been penetrated by wells in the Lisbon Valley oil and gas field. For the purpose of this report the Hermosa Formation of Middle and Late Pennsylvanian age is divided into three members, which include the upper member, which is primarily a carbonate facies; the Paradox Member, which is an evaporite facies and includes the potash deposits; and the lower member, which is mostly a carbonate facies.

The upper member of the Hermosa Formation crops out in an area of about 28.5 km^2 (11 sq. mi) along the crest of the Lisbon Valley anticline. The formation is in fault contact to the northeast with the Dakota Sandstone (Late Cretaceous age) and Morrison Formation (Late Jurassic age). The resistant limestones of the upper member form a hogback on the west limb of the anticline and dip under the less resistant shales and siltstones of the Cutler Formation (Early Permian age) which have been eroded to form the valley referred to as Big Indian Wash.

The upper member of the Hermosa Formation in the Lisbon Valley area consists of interbedded sandstone, gray and green shale, and fossiliferous limestone in its upper one third, and interbedded limestone, dark-gray and black shale with thin beds of anhydrite in its lower two thirds. About 122 m (400 ft) of the upper part of the member are exposed on the Lisbon Valley anticline. Where penetrated by wells, the member has an average thickness of about 609.6 m (2,000 ft). The contact between the upper member and Paradox Member is subject to a wide range of interpretation by various workers. Some have used a datum plane or time line, usually a black shale; others have indicated that any anhydrite-black shale facies belongs in the Paradox Member. For the purposes of this report the base of the upper member in the Lisbon Valley area is placed at the top of a thick black shale bed overlying the first halite bed.

The Lisbon Valley potash deposits are in the Paradox Member of the Hermosa Formation. The member has been divided into 29 evaporite cycles (Hite, 1960). At Lisbon Valley the uppermost evaporite cycle containing halite is "cycle 4." The younger cycles (cycles 1, 2, and 3), which contain halite in the deeper northwest part of the Paradox basin, consist of an anhydrite-carbonate facies at Lisbon Valley. The total halite-bearing sequence, which includes cycles 4 through 28, has a maximum thickness of at least 2,100 m (6,888 ft) in the core of Lisbon Valley anticline.

SURFACE STRUCTURE

The surface structure in the area consists of the asymmetrical Lisbon Valley anticline which is cut near its axis on the northeast or steep limb by the Lisbon fault. Both the axis of the anticline and the fault trend about N. 45°W. The dip of the fault plane is 58°NE at the Big Indian mine (Lekas and Dahl, 1956, p. 162). The Lisbon fault zone can be traced northwest and southeast for a distance of 66 km (41 mi). The Lisbon fault and others like it can be explained either as tectonic features, or collapse structures resulting from the removal of salt. Most of the literature concerning the salt anticlines touches lightly on these faults, or ignores them altogether even though they are among the most conspicuous structural features in the area. Shoemaker and others (1958, p. 5) suggested that the Moab fault, located northwest of Lisbon Valley anticline, probably continues into and offsets older Paleozoic and basement rocks. There is no evidence which indicates the Lisbon fault passes through the Paradox Member and is directly connected with a basement fault. There is some evidence that the fault could possibly be related to a thrust fault which the writer has mapped in the beds of the Paradox Member (see fig. 5). The latter case would call for a curving fault with reversal in dip from northeast on the surface to southwest in the evaporite core of the anticline. In explaining the Lisbon fault as a collapse structure it is possible that such a structure can be due to collapse following removal of salt by dissolution or by flowage. On the upthrown side of the fault, halite beds in the Paradox Member have been removed through dissolution. Isopach maps of the potash deposits in salt beds 5 and 9 (figs. 3 and 4) show the dissolution surface affecting these deposits is

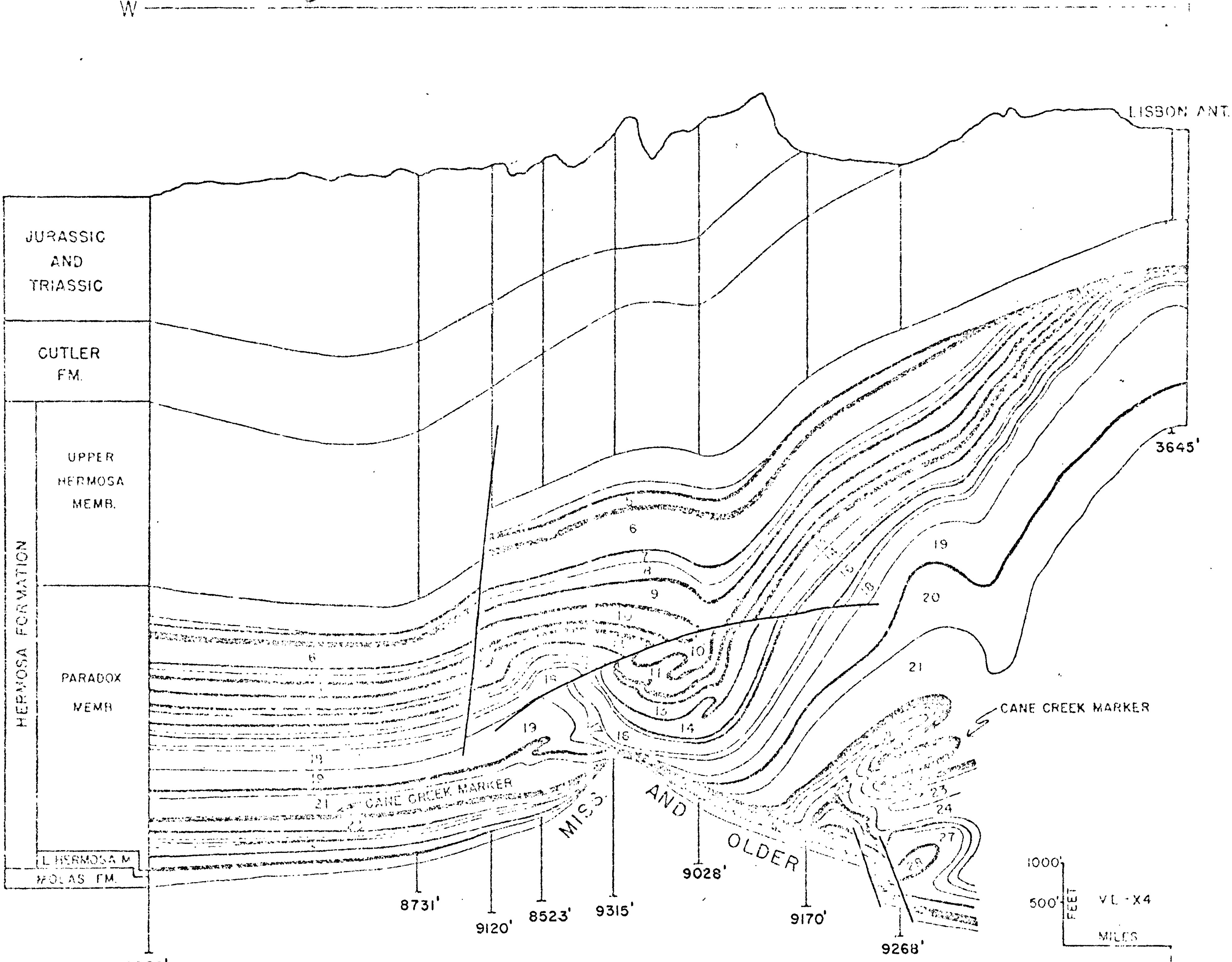

FIGURE 5.-- CROSS SECTION THROUGH LISBON FIELD

roughly a function of structural position in the anticline. Three potash tests drilled by the Superior Oil Co. near the crest of the anticline penetrated a section of the Paradox Member in which a great number of halite beds are missing. In well 17-8P (table 1, no. 11) all of the halite beds above salt 20, as well as the intervening marker beds, are missing. The missing section might normally represent a thickness of about 825 m (2,700 ft). In the other two wells (table 1, nos. 1 and 14), most of these same halite beds are missing; however, a residual cap composed of the intervening marker beds is present. Most of the clastic units in this residual cap show evidence of internal thinning. This would indicate that the thinning and removal of units in the Paradox Member took place during and perhaps shortly after deposition. This timing of removal would eliminate the possibility of collapse structures (faulting) forming in the overlying rocks due to dissolution of salt. The transfer of salt by flow from the area of the downthrown block to the upthrown side of the Lisbon fault could have caused the faulting. Since the fault cuts rocks of Early Cretaceous age, differential loading seems unlikely as the cause of salt removal. Differential loading during deposition of the Cutler Formation has been used by Jones (1959) as the mechanism of forcing the evaporites into the salt anticlines. Other workers (Elston and others, 1962) suggest tectonism in conjunction with differential loading. At the time this report was written there was no information available concerning the thickness of the Cutler on the downthrown side of the fault. If differential loading triggered flow of salt into the anticline, causing faulting by collapse, then the Cutler should show considerable thickening. It is assumed that flow of salt into the anticline would not be so rapid as to cause immediate collapse but would produce an anticlinal bulge of salt with similar dips on opposite flanks. The actual failure (faulting) of rocks overlying the Paradox Member may not have occurred until after the Lisbon Valley anticline and other salt anticlines were covered by a thick layer of Cretaceous sediments. At that time the greater weight pressing down on the flanks of the salt anticline, and forcing more salt into the anticline, may have created sufficient tension to cause faulting instead of folding, provided that a sufficient thickness of salt was left on the flanks.

SUBSURFACE STRUCTURE

The Paradox Member within the Lisbon Valley salt anticline is much thicker than on the flanks of the structure. This is due both to a greater original depositional thickness within the salt anticline, and to salt flowage. The maximum thickness of the Paradox Member penetrated at Lisbon Valley was 2,058 m (6,750 ft) in well 55 (see table 1). On the flank of the anticline within the Lisbon Valley oil and gas field the Paradox Member thins to 897 m (2,943 ft) in well 38 (see table 1). This thinning is due to the wedgeout of basal units of the Paradox Member against a fault block of older Paleozoic rocks. This fault block, which has a maximum structural relief of 732 m (2,400 ft) on Mississippian rocks, forms the hydrocarbon trap for the Lisbon Valley oil and gas field.

Intraformational Folding in the Paradox Member

Intraformational folding within the Paradox Member is commonplace at Lisbon Valley. The writer first observed and interpreted this type of folding in 1958 in Superior Oil Co. potash test 47-17P (table 1, no. 2). Folding in this well involved salt 9, its potash deposit, and the overlying clastic. Since that time, folding has been encountered in many wells drilled at Lisbon Valley. As a rule these structures are tight isoclinal recumbent folds. The folds are most evident where marker beds are involved; however, they are also discernible where potash deposits are affected. The typical fold is a simple "S" turn in which a marker bed is encountered in normal position, then overturned, and then back in normal position. Folding of considerable more complexity has been encountered in several wells such as Pure Oil Co.'s State-Spiller Canyon 1 (table 1, no. 55), where the "C" marker was repeated seven times. Intraformational folds may sometimes involve several units in the Paradox Member; however, many times only a single unit is involved and the fold is not expressed in underlying or overlying units. Folding where potash deposits are involved may have a pronounced effect on the distribution of the potash minerals. The potash minerals, particularly carnallite, are relatively unstable and more susceptible to flowage than halite; consequently it is not uncommon to find a potash deposit of abnormal thickness or grade squeezed into the apex of a fold. Halite rock involved in folding usually has a schistose or gneissic texture (Hite, 1960, p. 87). The individual halite crystals show a preferred orientation, or elongation parallel to bedding, and the rock may be extremely friable. Halite rock of this type is believed by the writer to have higher than normal permeabilities. Occasionally cores of schistose halite are saturated with oil, and it is suggested that some of the flush production encountered in the Paradox Member may come from this type of reservoir.

Intraformational folding in the Paradox Member occurs most commonly in the innermost core of the salt anticlines. This perhaps is expected since this part of the anticline is most affected by tectonic crustal shortening, and also appears to be the point where material may be added by flowage from flanking areas.

Faulting in the Paradox Member

Rock salt, with its tendency to behave in plastic-like fashion when subjected to stress, is not normally expected to rupture. Many variable factors such as the sudden application of stress, depth of overburden, and presence of nonsaline interbeds which add strength, may provide conditions which allow faulting of salt beds to take place. Interpretation of well logs and cores indicate that considerable faulting must be present in the Paradox Member. This faulting occurs as normal, high-angle reverse, and overthrust movements. One of the major structural features in the Paradox Member at Lisbon Valley is a large thrust fault which has its roots in the Lisbon Valley oil and gas field. The fault plane, which dips southwest at about 95 m per km (500 ft per mi), steepens to the northeast, and if projected to the surface its intersection would be near the surface trace of the Lisbon fault. The Pure Oil Co. completed an oil well in the Paradox Member (table 1, well 51) from an interval roughly coinciding with intersection of the plane of the thrust fault and salt 16. This well, which produced about 2,965 metric tons (22,000 bbls) of oil before abandonment, occasionally "blew out" large quantities of shale and salt fragments. This material probably came from a breccia developed along the fault plane.

Of the 58 wells listed in table 1 at least 11 penetrated one or more faults. Generally these are reverse faults although several normal faults were also penetrated. Faulting probably plays an important role in explaining certain anomalies in the distribution of the potash deposits. Perhaps a good example of this is the Pure Oil Co. N. W. Lisbon well B-1 (table 1, no. 44) which encountered only a trace of potash in salt 9. Isopach maps of the potash deposit in salt 9 (fig. 7) show that a thick trend of potash should pass through the area of this well location. The anomalous absence of the deposit in this well suggests that it may have been faulted out. In other wells faulting is suspected where a potash deposit is unusually thick and low in grade, suggesting that the deposit may have been smeared along a fault plane.

HISTORY OF STRUCTURAL DEVELOPMENT

The inception of the Lisbon Valley salt anticline, as well as the other salt anticlines of the Paradox basin, was probably during Molas time (Early Pennsylvanian). During this time positive elements with a predominate northwest trend exposed rocks of Mississippian age to an environment which favored the development of a karst surface and the regolith which makes up the Molas Formation. Locally the effects of this environment were severe and resulted in complete removal of Mississippian rocks over structural highs. The Molas Formation filled in the low areas between these highs and locally covered structure with a thin mantle of red shale and silt and reworked limestone. Later subsidence and invasion by marine waters gave rise to deposition of the normal marine carbonate rocks of the lower member of the Hermosa Formation. Further subsidence provided a framework for restricted circulation of sea water and deposition of the evaporites of the Paradox Member began. The northwest-trending positive elements continued to be active during deposition of the evaporites and locally may have been emergent features. The rapid deposition of thick salt beds such as 19, 20, and 21, caught up with most of the positive elements and began to mask the structurally formed submarine topography of the basin. Still later, an active compressional force over the evaporite basin is believed by the writer to have started the first upwellings of salt along previous low areas where greater thicknesses of the Paradox Member had been accumulating. This compressional force was probably related to a pulse of uplift in the ancestral Uncompahgre highland which bordered the evaporite basin on the northeast (Elston and others, 1962, p. 1874). The reversal of structural elevation from the buried pre-salt features to the belts of thick salt was due to the inherent structural weakness of the thick salt trends. Compression would most logically cause upward bulging at weak points in the crust which were provided by the thick salt trends. At Lisbon Valley the first upward bulge of salt probably began during the deposition of salt 16. The evidence for this is based largely on the loss of several salt beds and the thinning of marker beds still present which normally were interbedded with the missing salt units. The salt beds could have been removed by downward percolating ground water even after being covered by beds of the upper member of the Hermosa or younger rocks, but the clastic marker beds could only have been thinned during or shortly after deposition.

The synclinal structure (fig. 5) on the west flank of the Lisbon Valley anticline is probably a compressional feature which may have begun to form during the deposition of salt 10. Units in the Paradox Member younger than salt 10 thicken in the syncline and the distribution of salt 4 in this area was probably controlled by this structure. Structure contour maps of salt beds 5 and 9 (figs. 3 and 4) show this folding is less evident at the salt 5 level. The thrust fault depicted on figure 5 probably formed as a result of tightening of the syncline to its breaking point with the upper plate moving northeast. The relative dating of thrusting similar to this has been established at the Cane Creek anticline. A well recently drilled on this structure encountered a thrust fault which repeated salt 5 and the units above. On the upper plate of the thrust salt beds 2, 3, and 4 had been removed by dissolution. On the lower plate these salt beds were unaffected, thus dating the faulting as sometime before the area was covered by rocks of the upper part of the Hermosa. Similar dating may also apply to the faulting at Lisbon Valley.

Thinning of the upper member of the Hermosa and the Cutler Formation over the Lisbon Valley anticline indicates continued growth of the structure during the remainder of Pennsylvanian time and the duration of Permian time. The Triassic(?) and Triassic Meonkopi Formation is missing over the crest of the anticline and the Mossback Member of the Upper Triassic Chinle Formation rests directly on the Cutler (Lekas and Dahl, 1956, p. 162). There is no evidence of any appreciable growth during the remainder of Triassic and Jurassic time. As pointed out in the previous discussion on the Lisbon fault, structural activity in the area was rejuvenated during Cretaceous time, probably by Laramide tectonism.

POTASH DEPOSITS

As previously stated, the Lisbon Valley potash deposits occur in the evaporites of the Paradox Member. The deposits at Lisbon Valley are in areal extent only a small portion of a larger area in the Paradox basin which contains potash salts (fig. 1). Many of the deposits present at Lisbon Valley can be correlated with those found elsewhere in the basin. Most of the deposits show remarkable lateral continuity, particularly in a northwest to southeast direction. Regional studies of the potash deposits indicate their distribution was determined in part by the same factors controlling salt deposition.

In 18 of the 29 evaporite cycles of the Paradox Member, potash deposits of variable thickness and grade are present (Hite, 1961, p. 135). Most of these are present at Lisbon Valley; however, only those in salt beds 5, 6, 9, 19, 20, and 21 appear attractive for present or possible future exploitation.

One of the most widespread and extensively explored potash deposits in the Paradox basin occurs in cycle 5. It can be correlated over an area of about 2,500 km^2 (965 mi^2) from Dolores anticline on the south, to Lisbon Valley, and on north to the Cane Creek and Seven Mile localities. This deposit has been the prime target of exploration at Seven Mile and Cane Creek, and is the source of ore at the Texasgulf mine at Cane Creek (see location of mine, fig. 1).

At Lisbon Valley the cycle 5 potash deposit consists entirely of sylvite with possibly minor amounts of carnallite or kieserite near its base. It is missing over an area of about 31 km^2 (12 mi^2) along the crest of the Lisbon Valley anticline (fig. 6) where it has been removed by dissolution.

The mineralized interval is well represented in the Pure Oil Co. N. W. Lisbon D-1 well (table 1, no. 33). This well is located in an area where the the deposit reached its maximum development (see fig. 5). In this well the deposit is separated from the overlying marker bed by about 6.1 m (20 ft) of unmineralized halite. Locally this barren interval of halite attains a thickness of 10.7 m (35 ft). The thickness of this halite is important for two reasons. First, it is important to any conventional underground mining because it will afford a strong mine back separating the potash from the weaker gas-bearing shales above. In this sense, the deposit is superior to that at Cane Creek where only about 0.5 m (1.6 ft) of halite separate the potash from roof problems. Secondly, as previously mentioned, the contact between this halite unit and the overlying anhydrite-clastic unit probably represents a dissolution surface from which a few centimeters to several meters of halite have been removed. If the protective layer of halite overlying the potash deposit is extremely thin or missing, then the likelihood of damage to the deposit by solution is enhanced. The highest concentration of sylvite is generally at the top of the deposit, and its contact with the overlying barren halite is abrupt. The base of the high-grade material is somewhat transitional with an underlying weakly mineralized interval which may extend downward another 10 m (33 ft). Including this weakly mineralized interval, the whole deposit may be as much as 18 m (60 ft) thick. Thicknesses reported in table 3 and on figure 6 represent only the high-grade interval.

Out of the 12 potash deposits present at Lisbon Valley the mineralized interval in salt 9 appears most favorable for conventional underground mine development. Regionally it is not as widespread as the one in salt 5, underlying a smaller area of about 900 km^2 (350 mi^2). In an area of about 11.7 km^2 (4.5 mi^2) over the crest of the Lisbon Valley anticline it has been removed by dissolution.

The deposit at Lisbon Valley consists mostly of sylvite although locally a high percentage of carnallite is present. In the second potash test drilled on Lisbon Valley anticline (table 1, well no. 2) a mineralized interval about 6.4 m (21 ft) in thickness was penetrated. The upper 2.4 m (8 ft) of this interval is an unusual looking rock consisting of fine-grained (crystal size <2 mm) halite with laminae of reddish-orange sylvite about 3 to 12.5 mm in thickness, and anhydrite laminae which are about 1 mm in thickness. The succession in a couplet proceeding upward is anhydrite-halite-sylvite-anhydrite. Most of the anhydrite laminae are highly contorted by flowage. Beneath the laminated halite, and in abrupt contact, is about 3 m (10 ft) of high-grade, milky white, fine grained sylvite. This sylvite unit is in sharp contact with an underlying unit of carnallite which is about 6.7 m (22 ft) thick. The carnallite is very pure, colorless, transparent, and completely devoid of any bedding features. This carnallite unit has not been penetrated in other drill holes at Lisbon Valley.

The areal distribution of the evaporite cycle 9 potash deposit at Lisbon Valley presents an unusual pattern. Maximum development of the deposit is in two separate belts, each trending northwest, parallel to the axis of the anticline. When the isopach pattern of this deposit is compared to the deposit in evaporite cycle 5, it is evident that trends of thick potash in one cycle overlie trends of thin potash in the other cycle. The explanation for this relationship is not known. The thick potash trend in evaporite cycle 9, located in secs. 10, 11, 13, and 14, T. 30 S., R. 24 E., is centered over the pre-salt structure of the Lisbon oil and gas field (fig. 7). This relationship may be only coincidental. The present-day structural attitude of evaporite cycle 9, consisting of two small anticlinal folds superimposed on the west limb of the salt anticline does not suggest a relationship affecting the contained potash deposit (fig. 4). The average dip in the deposit is about 16° southeast. Near the southeast corner of the anticline the dip steepens to about 22° southeast.

Other Potash Deposits

The combination of structural elevation and dissolution of salt beds at Lisbon Valley presents a unique situation where multiple deposits of potash are brought within the depth range of present-day mining techniques. Besides the deposits already described, those in evaporite cycles 6, 19, 20, and 21, although somewhat less significant, do deserve mention.

Evaporite cycle 6 contains a potash deposit that in regional distribution compares with the overlying deposit in evaporite cycle 5. Its best development is in the Seven Mile area where it has been cored in numerous wells. It is also present in the Cane Creek anticline where its average K_2O content and thickness are similar to those at Lisbon Valley. The deposit has been cored in one well at Lisbon Valley (see table 1, well no. 5) and it consisted of about 7.6 m (25 ft) of medium-grade sylvite. The grade of this deposit probably would not exceed 18 percent K_2O in any of the wells in which it has been penetrated at Lisbon Valley.

Evaporite cycle 19 contains one of the thickest potash deposits in the Paradox basin. In the Seven Mile area one drill hole penetrated 131 m (430 ft) of potash in this deposit. A thickness of 49.7 m (163 ft) was penetrated in this deposit in well 46 (table 1) at Lisbon Valley. A potash deposit of such unusual thickness may often be the result of the bit penetrating steeply dipping beds. However, if the overlying and underlying anhydrite-clastic marker beds have a normal thickness then the thickness of the potash deposit is probably reliable, and this seems to be the case at Lisbon Valley. In most of the Lisbon Valley area the deposit probably does not exceed 18 percent K_2O for any interval of significant thickness. Characteristically the deposit gradually increases in grade from top to base. It consists, in most of the wells which have penetrated it, of a mixture of carnallite and sylvite although in a few wells it is mostly sylvite. This deposit could probably be reached at depths of less than 1,000 m (3,280 ft) over about 8 km^2 (3 mi^2) in the crestal portion of the Lisbon Valley anticline.

A mineralized interval occurs in evaporite cycle 20 over a small portion of the Paradox basin. At Lisbon Valley the deposit ranges in thickness from 2.1 to 14.6 m (7 to 48 ft). In three wells, which penetrated evaporite cycle 20 (see table 1, well nos. 1, 14, and 31), the mineralized interval would probably average more than 18 percent K_2O. The deposit in the Lisbon Valley area generally consists of a mixture of carnallite and sylvite. No core data are available on this interval except in the Superior Oil Co. well 47-16P (table 1, well no. 1), where the deposit was sidewall cored. This deposit occurs at depths of less than 1,000 m (3,280 ft) in a small area near the crest of the Lisbon anticline.

Another thick interval of potash occurs in evaporite cycle 21. At Lisbon Valley this deposit attains a maximum thickness of 73.2 m (240 ft) in the Pure Oil Co. N. W. Lisbon D-2 well (table 1, well no. 46). The percent K_2O potash in this interval is relatively low at Lisbon Valley except in the Superior Oil Co. well 71-1P (table 1, well no. 10). Both carnallite and sylvite occur in this deposit. Like the deposits in salt 19 and 20, it occurs at favorable depths over a small portion of the crestal area of the Lisbon anticline.

In summary, the potash deposits in a low stratigraphic position in the Paradox Member at Lisbon Valley are generally thick but show great variation in K_2O content. The area in which these deposits could be exploited is confined to a small portion of the Lisbon anticline where upwelling of the Paradox Member plus removal of salt beds places them at depths within the range of conventional mining. Exploitation of these deposits in any other part of the area could only be by solution mining.

BRINES

High-density calcium-magnesium-rich brines are frequently found in the Paradox Member. The brine is in both clastic interbeds and salt beds. These brines probably represent mother liquor trapped within an originally porous halite bed. Where it is found in a clastic unit it has probably been squeezed upward into fractures following compaction of the underlying halite bed. This is commonly indicated by vertical veins of halite and carnallite which pass upward from a salt bed into a highly fractured shale-anhydrite marker bed above. These brines are mobile at the temperatures and pressures of the reservoir; however, when these brines are brought to the surface the sudden change in temperature and pressure causes precipitation of carnallite and other salts, which often plugs producing facilities. These brines may run as high as 366,000 ppm dissolved solids with a density of 1.33. Characteristically, these brines have a high calcium content, as much as 53,000 ppm, and almost no sulfate.

The main value of the typical Paradox brine is in its potassium and magnesium content. The average potassium content is about 20,000 ppm, and magnesium is about 40,000 ppm. This compares favorably with brines elsewhere which are commercially exploited. Other constituents in the brine which would be valuable byproducts are bromine, boron, calcium chloride, and lithium salts. The main problem in developing this resource is finding a reservoir capable of supplying large volumes of brine. As yet most of the brine flows, encountered in the Paradox Member by drilling wells, were depleted in a short time and gave little indication of being capable of sustaining production. The one known occurrence of brine at Lisbon Valley was in the Superior Oil Co. well 88-21P (table 1, well no. 3). This brine flowed to the surface for 3 or 4 days during coring operations. An analysis of this brine is given in table 2. The stratigraphic position of the brine source could never be established even though the company cored continuously through the evaporites.

GAMMA RAY LOGS

The presence of the radioactive potassium isotope K^{40} in all potash minerals has made the detection of potash deposits by the gamma ray log a simple matter. Detection is particularly facilitated when this log is run in conjunction with other geophysical logs such as the neutron, laterolog, and sonic or acoustic log. Besides establishing the presence of a potash deposit the gamma ray log gives a precise measurement of the thickness of the deposit penetrated. Estimates of the percent K_2O for a deposit can also be made. Gamma ray emission and percent K_2O do not follow a straight line relationship. One of the leading commercial logging companies has charted a curve of this relationship. In deriving the K_2O content from a gamma log by using this chart, it is first necessary to correct for borehole conditions. This includes such parameters as density of mud or fluid in the hole, diameter of the hole, and so forth. Table 3 shows a comparison of the actual chemical analyses of potash intervals from core holes at Lisbon Valley, and the estimate arrived at from evaluation of the gamma log of the same intervals. Estimates of thickness of potash deposits in the 10 wells used in table 3 were extremely accurate. The estimation of grade of the deposits was reasonably accurate in all wells except C, D, and G. It should be noted that in each well the estimated K_2O content was less than the actual chemical analysis. The average correction factor for the radiometric analyses was 1.27. This figure was used as a correction factor in radiometric analyses of K_2O content in several wells in the Lisbon Valley area (table 4).

In summary, it can be stated that the gamma ray log can unquestionably establish the presence of potash deposits in areas where the stratigraphy of the host formation is known. It can also be used with a high degree of accuracy in establishing the thickness of a deposit. When used to derive the grade, or K_2O content, for a specific interval it is subject to greater error. Fortunately the error in every case observed gives a radiometric estimate less than the actual value. In the writer's judgment this log can be used to provide data of sufficient accuracy to be used for land classification determinations where core material is not available.

Table 2.--Analysis of brine sample collected at Lisbon Valley from the Superior Oil Co. well 88-21P

(Analyses by K. P. Moore, U.S. Geological Survey, Casper, Wyoming)

	In percent		In percent
Na_2O (calc.)	9.24	SO_3	0.021
K_2O	2.91	B_2O_3	0.84
Li_2O	0.073	P_2O_5	0.0009
CaO	1.30	Cl	19.44
MgO	7.44	Br	0.32
CO_2	0.056	I	0.003

Spec. Grav. 60/60°F.................1.261

pH..................................5.5

Table 3. - - Comparison of chemical analyses from cored potash deposits at Lisbon Valley and radiometric calculations of the same intervals using the gamma ray log.

Map No.	Name, Lease No., and Location of Well	Deposit	Chemical Analyses: Thickness In feet 2/	Chemical Analyses: % K_2O	Radiometric Analyses: Thickness in feet 2/	Radiometric Analyses: % K_2O	Correction Factor 1/
2	Superior Oil Co., 47-17P, (U-07129) NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 17, T. 30 S., R. 25 E.	salt 9	10'	33.4	9'	28.0	1.11
3	Superior Oil Co., 88-21P, (U-012942) C E$\frac{1}{2}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21, T. 30 S., R. 25 E.	salt 9	4'	28.0	4'	20.5	1.37
4	Superior Oil Co., 73-19P, (U-018443) C S$\frac{1}{2}$NE$\frac{1}{4}$ sec. 19, T. 30 S., R. 25 E.	salt 9	3'	13.3	4'	10.5	1.27
5	Superior Oil Co., 75-12P, (U-018444) C W$\frac{1}{2}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 12, T. 30 S., R. 24 E.	salt 5 salt 9	10' 6'	22.5 23.7	10' 6'	19.0 20.5	1.18 1.16
7	Superior Oil Co., 63-29P, (U-016348) NE$\frac{1}{4}$SW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 29, T. 30 S., R. 25 E.	salt 5	4.4'	15.9	4.5'	13.0	1.22
8	Superior Oil Co., 37-1P (U-018409) C SW$\frac{1}{4}$ sec. 1, T. 30 S., R. 24 E.	salt 5	6.8'	24.5	7'	15.0	1.63
9	Superior Oil Co., 77-35P, (U-018749) NW$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 35, T. 29$\frac{1}{2}$ S., R. 24 E.	salt 5 salt 9	- - - 19.4'	- - - 31.09	6.5' 18'	20.5 28.0	- - - 1.11
10	Superior Oil Co., 71-1P, (U-016349) C N$\frac{1}{2}$NE$\frac{1}{4}$ sec. 1, T. 30 S., R. 24 E.	salt 9	3.86'	29.6	4'	19.0	1.56
12	Superior Oil Co., 36-29P, (U-018407) SW$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 29, T. 30 S., R. 25 E.	salt 5	3.94'	14.18	4'	12.5	1.13
17	Superior Oil Co., 41-7P (U-16349) NE$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 7, T. 30 S., R. 25 E.	salt 9	4.78'	33.06	6'	28.0	1.18
					Average Correction Factor =		1.27

1/ The correction factor is the chemical K_2O divided by the radiometric K_2O.

2/ To convert feet to meters, multiply by 0.3048.

Table 4. - - Depth, thickness and grade of potash deposits inselected drill holes at Lisbon Valley as interpreted from gamma ray logs.

Map No.	Name and Location of Well	Depths to Potash Deposits in feet 3/	1/	Thick-ness in feet 3/	Calculated K_2O in %	Corrected K_2O in % 2/
31	Pure Oil Co., Big Indian U.S.A.-1	4323'-31'	(salt 5)	8'	12.5	15.9
	SE¼NE¼ sec. 33, T. 29 S., R. 24 E.	4968'-78'	(salt 9)	10'	14.0	18.0
33	Pure Oil Co., State A-1	3599'-3612'	(salt 5)	13'	14.2	18.0
	NE¼SW¼SE¼ sec. 2, T. 30 S., R. 24 E.	- - - -	(salt 9)	0'	- - - -	- - - -
34	Pure Oil Co., N.W. Lisbon C-3	4466'-73'	(salt 5)	7'	6.5	8.3
	SW¼SE¼ sec. 3, T. 30 S., R. 24 E.	5151'-61'	(salt 9)	10'	15.5	19.7
39	Pure Oil Co., N.W. Lisbon A-2	5544'-62'	(salt 9)	18'	17	21.6
	NE¼SE¼ sec. 10, T. 30 S., R. 24 E.					
44	Pure Oil Co., N.W. Lisbon B-1	4634'-37'	(salt 5)	3'	5	6.4
	NW¼NW¼, sec. 14, T. 30 S., R. 24 E.	5790'-5865'	(salt 9)	75'	trace	
45	Pure Oil Co., N.W. Lisbon B-2	4571'-80'	(salt 5)	9'	17.5	22.2
	C SE¼, sec. 14, T. 30 S., R. 24 E.		(salt 9)	16'		
46	Pure Oil Co., N.W. Lisbon D-2	3550.5'-57'	(salt 5)	6.5'	13.2	16.7
	SW¼NE¼NW¼ sec. 13, T. 30 S., R. 24 E.	4357'-74'	(salt 9)	17'	15.1	19.2
47	Pure Oil Co., N.W. Lisbon D-1	3887'-3895'	(salt 5)	8'	13.5	17.1
	NW¼NE¼NW¼ sec. 24, T. 30 S., R. 24 E.	- - - -	(salt 9)	- -	None	
51	Pure Oil Co., N.W. Lisbon C-2	- - - -	(salt 5)	- -	None	
	NE¼NW¼ sec. 3, T. 30 S., R. 24 E.	5520'-25'	(salt 9)	5'	17	21.6
57	Pure Oil Co., N.W. Lisbon A-814	4514'-17'	(salt 5)	3'	9.0	11.4
	NE¼SW¼ sec. 14, T. 30 S., R. 24 E.	5260'-73'	(salt 9)	13'	22	27.9

1/ Depths from ground level.

2/ Corrected by multiplying the calculated K_2O by the average correction factor (1.27) derived from table 3.

3/ To convert feet to meters, multiply by 0.3048.

REFERENCES CITED

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1933, Paradox Formation of eastern Utah and western Colorado: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 963-980.

Bass, N. W., 1944, Paleozoic stratigraphy as revealed by deep wells in parts of southwestern Colorado, northwestern New Mexico, northeastern Arizona, and southeastern Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 7, with accompanying text.

Elston, D. P., Shoemaker, E. M., and Landis, E. R., 1962, Uncompahgre front and salt anticline region of Paradox basin, Colorado and Utah: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 10, p. 1857-1878.

Gard, L. M., 1963, Nuclear explosions: Some geologic effects of the Gnome shot: Science, v. 139, no. 3558, p. 911-914.

Hite, R. J., 1960, Stratigraphy of the saline facies of the Paradox Member of the Hermosa Formation of southeastern Utah and southwestern Colorado, in Four Corners Geol. Soc., Geology of the Paradox basin fold and fault belt, 1960: p. 86-89.

______1961, Potash-bearing evaporite cycles in the salt anticlines of the Paradox basin, Colorado and Utah, in Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 424-D, art. 337, p. D-135-D-137.

Hite, R. J., and Gere, W. C., 1958, Potash deposits of the Paradox basin, in Intermountain Assoc. Petroleum Geologists Guidebook, 9th Ann. Field Conf.: p. 221-225.

Jones, R. W., 1959, Origin of salt anticlines of Paradox basin: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 8, p. 1869-1895.

Lekas, M. A., and Dahl, H. M., 1956, The geology and uranium deposits of the Lisbon Valley anticline, San Juan County, Utah, in Intermountain Assoc. Petroleum Geologists Guidebook, 7th Ann. Field Conf.: p. 161-168.

Shoemaker, E. M., Case, J. E., and Elston, D. P., 1958, Salt anticlines of the Paradox basin, in Intermountain Assoc. Petroleum Geologists Guidebook, 9th Ann. Field Conf. 1958: p. 39-59.

Stewart, F. H., 1963, Marine evaporites, in Data of geochemistry, 6th ed., Chapt. Y: U.S. Geol. Survey Prof. Paper 440-Y, p. 52.

Wengerd, S. A., and Strickland, J. W., 1954, Pennsylvanian stratigraphy of Paradox salt basin, Four Corners region, Colorado and Utah: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2157-2199.

Wengerd, S. A., and Matheny, M. L., 1958, Pennsylvanian system of Four Corners region: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 9, p. 2048-2106.