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MINERAL SOURCES OF WATER IN EVAPORITE SEQUENCES (SALADO SALT AND ADJACENT BEDS AT THE PROPOSED WASTE DISPOSAL FACILITY NEAR CARLSBAD IN LEA AND EDDY COUNTIES, NEW MEXICO)

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FINAL RESEARCH REPORT FOR SUBCONTRACT NO. 3670,

SUPPLEMENTS NOS. 3 AND 4

OAK RIDGE NATIONAL LABORATORY

Mineral Sources of Water in Evaporite Sequences (Salado Salt and Adjacent Beds at the Proposed Waste Disposal Facility Near Carlsbad in Lea and Eddy Counties, New Mexico)

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INTRODUCTION

The purpose of this project was to determine the mineralogy and petrologic characteristics of samples taken from two cores of the Salado Salt in Lea and Eddy Counties, near Carlsbad, New Mexico, and the degree to which the evaporite rocks present would dehydrate if subjected to the heat generated by containers of radioactive wastes (radwaste). In a previous study (Kopp and Fallis, 1973; Fallis, 1973) the general characteristics of evaporite deposits and their minerals were described and a detailed mineralogic and petrologic study of two cores from the Hutchinson Salt near Lyons, Kansas, was made. The results at that time indicated that water losses ranging from 0.4 to 19.0 weight % might be anticipated if the surrounding rocks were heated to 100°C. (The reader is referred to copies of those earlier works for details of those analyses).

The Lyons site was later abandoned and a new potential site in the vicinity of Carlsbad, New Mexico was chosen for study by several groups, including the U. S. Geological Survey, the Massachusetts Institute of Technology, the Oak Ridge National Laboratory, Los Alamos Scientific Laboratory and the New Mexico Institute of Mining and Technology. Drs. Richard Beane and Carl Popp received sample splits corresponding to the ones used in this study. A comparison of their results and ours is presented in this Final Report.

SUMMARY AND CONCLUSIONS

The results of this study indicate that the Salado Salt in the samples received is composed primarily of fine to coarse-grained halite with polyhalite, anhydrite, and clay minerals. Other minerals detected in

small amounts include gypsum, magnesite, quartz, feldspar, sylvite, carnallite, celestite(?), glauconite, and kainite(?). It should be noted that the samples received for analysis were selected from halite-rich zones in most cases; hence, some of the rarer evaporite minerals such as kieserite, langbeinite, leonite, bischofite, etc., noted by Schaller and Henderson (1932) were not detected either because they were absent from the specimens analyzed or present in amounts too small (or too fine grained) to identify.

There is much petrographic evidence that the Salado Salt was deposited in rather shallow water and may have been exposed subaerially at times. This evidence includes the presence of numerous hopper crystals (which can develop at the air-water interface of quiet, shallow seas) and the intergrowth of euhedral grains of halite with clay and silt-sized minerals, anhydrite, and polyhalite. The latter texture can develop in an exposed, mud-flat type environment. Previous workers, such as Anderson, et al (1972), have concluded that the underlying, Castile Formation was deposited in deep water, perhaps as much as 2100' (650mm) deep. Hence, there must have been a major change in environmental conditions between the deposition of the Castile and that of the Salado.

Petrographic evidence also suggests that fluids have been able to move through the Salado Salt along beds and seams of clay and silt, and to a lesser degree along fractures. These paths are now marked by entrapped fluid inclusions, zones of altered minerals and zones along which new minerals have been deposited.

Water loss determinations for over eighty samples from cores #7 and #8, indicate a range of water loss (upon heating to 102±5°C) from 0.0 to 3.5%, which is considerably below the water losses for samples from Lyons, Kansas. It should be noted that the samples from the Lyons site came from much shallower depths than those from the Carlsbad area. In a later

section (WEIGHT LOSSES), the ranges of dehydration to be anticipated with respect to depth are shown graphically. It appears that the ranges determined for the relatively shallow Lyons site merge with the ranges determined for the deeper Carlsbad site. It is not known whether this is fortuitous..

Most of the dehydration water at relatively low temperatures (near 100°C) appears to come from clay minerals, although gypsum may make a contribution for samples taken at shallow depths. At higher temperatures, polyhalite will start to contribute to the dehydration water. This dehydration takes place somewhere between 170° and 300°C. Pure polyhalite rock can lose up to 6% water. In general, the purer halite beds have weight losses below 0.3 to 0.5%.

As far as we can determine from the samples available for study, the rock units present in the Salado Salt seem to release much less water when dehydrated than do the rocks of the Hutchinson Salt at Lyons. Hence, the site near Carlsbad would seem to be much more favorable (in so far as dehydration water goes) than Lyons. Even so, it must be remembered that these rocks are not totally without water. Most units will lose from 0.0 to 0.3% water when heated and some units may lose up to 3.5% water.

Finally, it was noted during the preparation of some of the samples that H_2S (and possibly some natural gas) was released when the samples were crushed. Whether this will pose a health hazard is not known, but workers in the repository should be prepared if they should encounter such noxious and/or flammable gases.

SAMPLING AND SAMPLE PREPARATION

Samples for this study were selected by members of the U. S. Geological Survey and shipped to us in the Fall of 1974. Segments of the original 4 inch (10.2 cm) cores were split in half, lengthwise, and one half of

each sample was sent us and the other half to Dr. Richard Beane, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM, for chemical analysis and weight loss determination by thermogravimetric analysis. Eighty-three samples (coded by core number and depth) arrived wrapped in plastic to reduce the possibility of adsorption of moisture during shipping and handling. Core AEC-7 was drilled in Lea County and core AEC-8 in Eddy County, New Mexico, 30 miles east of Carlsbad. Hereafter, these sample will be referred to as the Carlsbad Samples.

Throughout the sample preparation care was taken to not expose any of the samples to water; however, since it was necessary to cut, grind and sieve various portions of the samples, it was not possible to completely protect them from exposure to moisture in the air. During those periods when samples were not actively being worked upon they were kept in plastic bags, tightly-stoppered bottles, etc.

Since several different analyses were to be made, it was necessary to obtain representative sample splits which would correspond to each other as closely as possible. A more complete discussion of sample preparation will be given in the thesis by Combs. However, for convenience, a brief summary of the methods used in sample preparation is given below:

1. A representative segment of each core sample was chosen and removed by sawing the original core (normal to the axis of the core) with a dry blade, masonary-type saw. This new segment was typically about three inches (8 cm) long.

2. Next, a slice was cut from each core segment (parallel to the axis of the core) with the approximate dimensions 3 x 2 x ½ inches (8 x 5 x 1 cm) for use in preparing the thin sections. The sections were prepared by Fred Roberts Petrographic Section Service, Monterey Park, California.

They were cut using oil rather than water and mounted with an expoxy cement which was not heated.

3. About one-half of the remainder of each core segment was crushed and sieved, and representative portions selected to be analyzed by X-ray diffraction, X-ray spectroscopy and by static heating methods for water loss determinations. (Later, some additional separations were made and portions of the samples selected for bromine analysis using X-ray spectroscopy. These procedures will be described briefly in the following section and in detail in the thesis by Combs).

ANALYTICAL METHODS USED IN THIS STUDY

Several different kinds of analyses were performed on the samples received. The methods used include static weight loss determinations (water loss), mineralogical and petrological analysis, and some chemical analyses using X-ray spectroscopy.

The weight loss determinations were made in essentially the same manner as for samples studied from Lyons, Kansas, and which were reported in the Final Report for that work (Kopp and Fallis, 1973). Splits of the several samples (sample size generally ranged from 1.5 to 2.0 gms and in the 60 to 120 mesh size fraction) were heated to 102±5°C for periods ranging from 2 to 42 days. The results of repeated analyses indicated that the precision of weight loss determinations was generally ± 0.1 to 0.2%. When new sample splits were used, the "precision" dropped to approximately ± 0.2 to 0.3%. Some data concerning precision are presented in Appendix A.

In addition to the weight loss determinations performed near 100°C, weight loss determinations were also made for several samples which had been heated to 170±5° (for 2 days) and 300±10°C (for 2 to 3 days). The results of the weight loss analyses are reported in Appendix B and discussed

in the section on WEIGHT LOSSES.

Mineralogical and petrological analyses were made using X-ray diffraction and standard petrological techniques. A summary of important mineralogical and petrological data is given in Appendix C and discussed in the section on MINERALOGY AND PETROLOGY. Details of these analyses will be given in the thesis by Combs. The chemical analyses were made using two variants of the X-ray spectrographic method, X-ray fluorescence analysis (wave length dispersive) and X-ray emission spectroscopy (non-dispersive). The methods used will be described in some detail in the thesis by Combs and hence will not be described further here. The chemical analyses were made primarily for bromine, which can be used to aid in the interpretation of the origin of evaporite deposits, and semi-quantitative analyses were made for chlorine, sulfur and iron.

WEIGHT LOSSES FOR CORES NO. 7 AND 8

Weight loss data for the samples studies are tabulated in Appendix B and illustrated in Figure 1. In general, the weight losses are much less than those found for samples from the site at Lyons, Kansas. (The range of weight loss values at 102±5°C for the Carlsbad samples (Salado Salt), Cores #7 and 8 was from 0.0 to 3.5% with the majority of samples showing losses less than 0.5%, while the Hutchinson Salt, Cores No. 1 and 2 was from 0.4 to 19.0%, and most of the samples showed weight losses from 1 to 5%. A plot of approximate range of water loss at 102±5°C to be expected at various depths is shown in Figure 2. This is based on data from both the Lyons, Kansas and Carlsbad, New Mexico sites Three potential repository horizons in the Salado Salt show the following ranges of weight loss in weight % (note that most of the values in all three horizons were less than 0.3%):

Potential Horizon	Core #7	Core #8
1	0.0-0.2	0.0-0.6
2	0.0	0.0-0.3
3	0.1-3.5	0.0-2.4

A number of samples were also heated to 170±5°C and 300±10°C. The results of these heat treatments (weight losses) are summarized in Appendix B, part 3. Based on the results of the various heat treatments, the following conclusions can be drawn concerning the behavior of the samples from Carlsbad:

1. Samples consisting almost entirely of halite and/or anhydrite show weight losses (up to 300°C) which are typically less than 0.5% and probably less than 0.3%. The final total loss will depend on the amounts of clay minerals and minor hydrated evaporite minerals, such as polyhalite, which are present.

2. Larger water losses (> 1%) at 102±5°C are generally associated with the presence of clay minerals (and/or gypsum) in more than trace amounts. The exact losses will depend on the kinds and amounts of clays present, the temperatures to which they are heated and the length of time for which they are heated.

3. At some temperature between 170° and 300°C, polyhalite, which is an important mineral constitutent in the Salado Salt, will start to break down. It can contribute water to the extent of about 6% of its weight in the rock being heated.

4. Although present in only minor amounts (or absent) in the samples we analyzed, there are other evaporite minerals such as carnallite, kainite, leonite, etc., in and near the potash ore zones (the Mc Nutt potash zone at approximately 1600' to 1800') which contain water of crystallization. Potential repository horizon 3 lies just below the Mc Nutt

potash zone. If it were to be used for radwaste disposal, it might be important to evaluate the potential dewatering of this potash zone.

The final report from Richard Beane and Carl Popp (June, 1975) was received shortly before preparations for this final report were begun. The weight losses determined in their study are compared with ours in Appendix B. It should be noted that Beane and Popp's data were determined by thermogravimetric analysis; hence, weight losses were not determined at any fixed temperatures but at the actual temperatures at which the decompositions were detected. In order to make the data more comparable, Beane and Popp's data were rearranged and weight losses taking place within certain temperature ranges were combined. The reader is referred to Beane and Popp's report for the specific temperatures at which weight losses occured. It should also be noted that the two sets of data are not directly comparable, since our weight losses were accomplished by heating under static heating conditions for periods of 2 or more days, while Beane and Popp's data were obtained under dynamic conditions (much more rapid heating). As a general rule, the decomposition temperature of any given mineral will be higher under the conditions of dynamic heating rather than under static heating.

Even so, there is general good agreement between the two sets of data which were obtained by different investigators using different techniques. Most minor discrepancies can be explained on the basis of differences in the methods of analysis. Only a few real discrepancies seem to exist (such as for sample at 1697 in Core #7). This is to be expected since each group received different halves of the core and since Beane and Popp took a sample split of the entire core segment while we analyzed only a sample split corresponding to the portion of the core used in preparing

the thin section. Since there are both vertical and lateral variations in mineral content within the cores, we might occasionally have analyzed samples which were mineralogically different.

All things considered, the rocks being considered for radwaste disposal near Carlsbad, New Mexico, appear to be much more favorable than those from Lyons, Kansas. Even so, some mineral water is still present and is apt to be released during the period when the rocks are heated by the waste containers. It will be important to determine the maximum temperatures to be reached, the volume of rock which will be heated, and the probable maximum volume of water which will be released.

MINERALOGY AND PETROLOGY OF CORES NO. 7 AND 8

In some respects the mineralogy and petrology of the core samples from Carlsbad are similar to those of the core samples from Lyons. Both cores were taken through evaporite sequences and hence encountered sedimentary sequences containing typical saline minerals such as halite, anhydrite, etc.

The major minerals found in the Carlsbad samples were halite, anhydrite and polyhalite. In addition, clay minerals, magnesite, gypsum quartz, feldspar, carnallite, celestite(?) glauconite and kainite(?), were detected in smaller amounts. The presence of any of the other less common evaporite minerals in the samples studied is uncertain. In general, they only occur in such small amounts and/or such fine grain sizes that positive identification was not possible using the diffractometer and petrographic microscope. In the final report of Beane and Popp (1975) several of these less common minerals are said to be present in many of the samples analyzed. Readers of this report and that of Beane and Popp should be aware that our analyses are based on the actual minerals observed (modal analysis) in thin section as supplemented by X-ray diffraction while the analyses

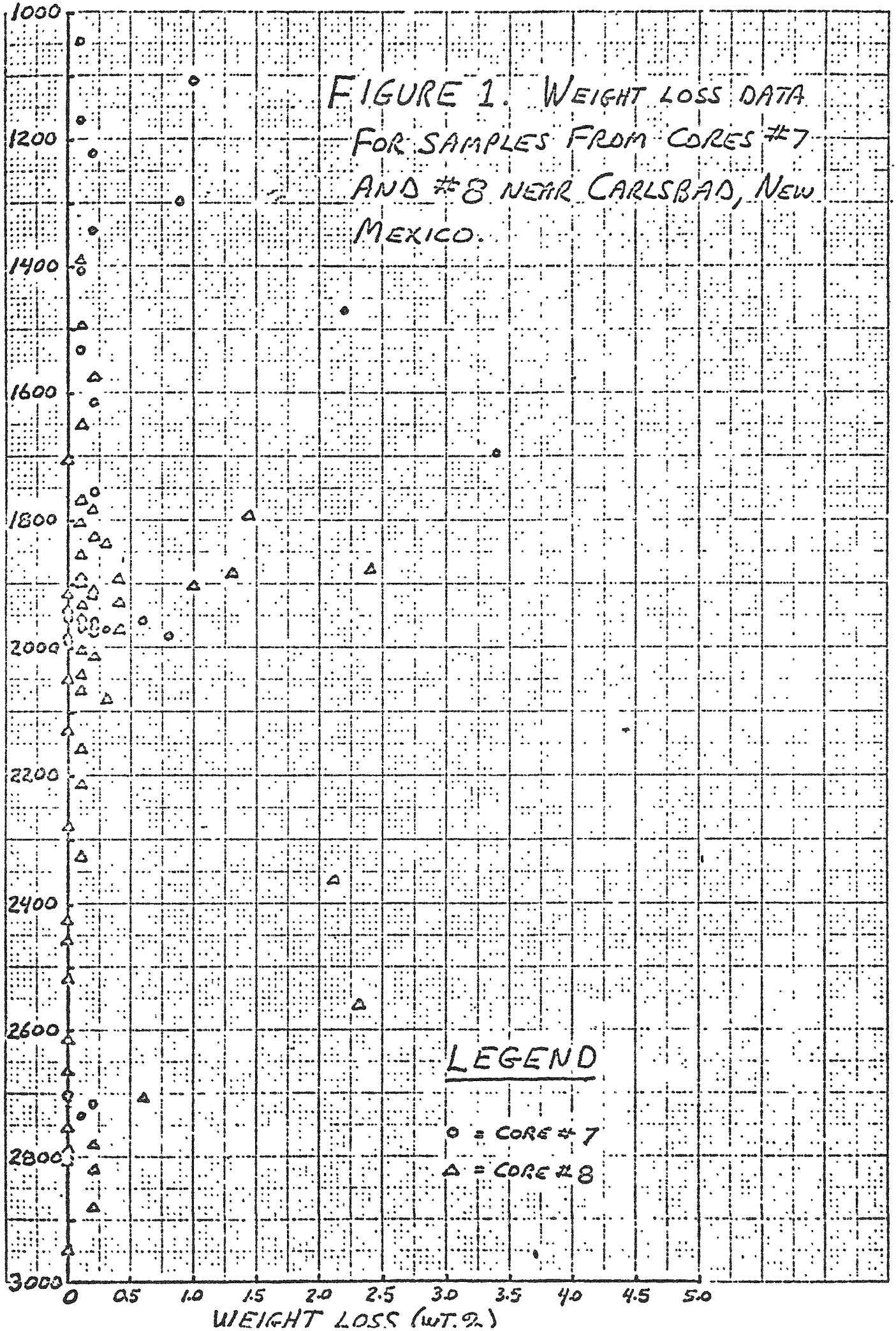
FIGURE 1. WEIGHT LOSS DATA FOR SAMPLES FROM CORES #7 AND #8 NEAR CARLSBAD, NEW MEXICO.
SAMPLE DEPTH (feet)
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
WEIGHT LOSS (WT. %)
LEGEND
○ = CORE #7
△ = CORE #8

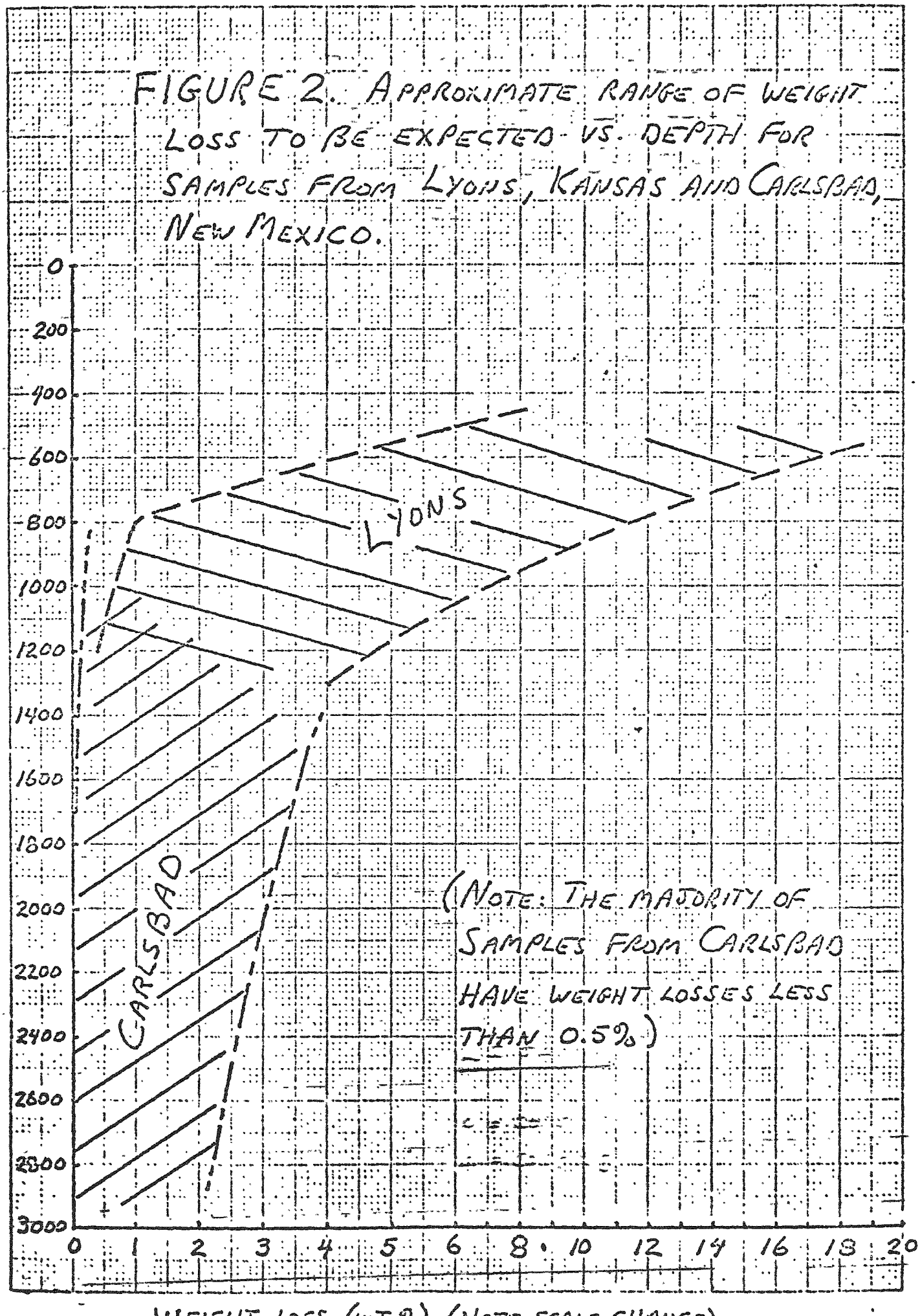

FIGURE 2. APPROXIMATE RANGE OF WEIGHT LOSS TO BE EXPECTED VS. DEPTH FOR SAMPLES FROM LYONS, KANSAS AND CARLSBAD, NEW MEXICO.

presented by Beane and Popp were done by computer manipulation of the chemical analyses determined for each sample (normative analysis). Such normative analyses can be quite useful, especially when working with very fine grained or glassy materials. However, it should be noted that normative analyses may generate mineral assemblages which do not agree with the actual minerals present.

Summaries of the mineralogic and petrologic features of the individual samples studies are presented in Appendix C. For the reader's convenience, some general comments about the mineralogy and petrology of these samples are presented below. More detailed descriptions will be presented in the thesis by Combs. An excellent (if somewhat dated) study of the mineralogy and petrology of the rocks in this regions is given by Schaller and Henderson, 1932. Brief descriptions of the major minerals noted in the Carlsbad samples follow.

Halite

Most of the halite is colorless and shows excellent cubic cleavage. These features, coupled with its low relief and isotropic optical character, make its identification easy. Sometimes the halite is colored red or orange by minute inclusions of hematite (or other iron oxides) or other minerals such as polyhalite. The grain size showed a wide range, from less than 1 mm (fine grained), to greater than 1 cm (coarse grained). Grains between 1 mm and 1 cm were considered to be medium grained.

Because halite fractures and cleaves so readily, it is difficult to determine whether the numerous breaks observed in thin section were already present at depth or whether they developed during the coring operation or later during shipping, handling, thin section preparation, etc. More fractures, etc., are noted at the outer margins of each of the

thin sections. However, some of them must have occurred prior to the taking of the core because they are filled (at least in part) with other minerals, petroliferous material, etc. In several cases fracture zones could be traced across the entire width of a thin section.

Inclusions (liquid, solid and gas) are common in the halite. During the preparation of some samples hydrogen sulfide (gas) was released. Whether the amounts contained (presumably in the inclusions) is large enough to pose a health hazard to workers is not known. In many cases the inclusions are oriented with respect to the cubic crystal planes. These oriented inclusions appear to represent hoppered crystals which grew at the water surface in times of quiet water and are inferred to represent deposition from shallow water.

Intergrowths of relatively well-formed, cubic crystals of halite with clay and silt-sized minerals are likewise inferred to represent very shallow conditions, perhaps even subaerial exposure for brief periods.

"Patches" (regular to irregular, more or less equidimensional areas) and "stringers" (regular to irregular areas which are generally elongated in one direction) of anhydrite, polyhalite, clay and silt-sized minerals are common in the halite. Sometimes these patches and stringers follow grain boundaries, but often they cut across grains. Where they follow grain boundaries, they may represent (nearly) simultaneous growth of the halite crystals and smaller amounts of the other mineral phase(s). Where they cut across grains, they presumably represent deposition of the minerals along zones of weakness or along which solutions passed. Enough of this latter material is present to demonstrate that there were opportunities for solutions to migrate through these relatively impermeable rocks, even though it is not possible to determine just how far the solutions actually traveled.

Anhydrite

Anhydrite was recognized on the basis of its relatively high birefringence, differences in relief upon rotation and cleavages at right angles. Normally, anhydrite shows parallel extinction, too, but because to twinning, replacement phenomena, etc., this characteristic was not always useful.

Anhydrite occurs in three major types. "Primary" anhydrite, which is commonly bedded, is very fine grained (much less than 1 mm) and somewhat fibrous in character. It also occurs in coarser-grained crystals and twinned crystals (sometimes over 1 cm long). At least some of these large crystals appear to be pseudomorphs (replacement) after previously-existing gypsum crystals. Sometimes, very small amounts of questionable gypsum are noted nearby, perhaps as a result of partial rehydration of the anhydrite. Finally, there are more or less isolated crystals and crystal clusters of anhydrite which occur in patches and stringers within the halite or are intergranular with halite. These may be associated with polyhalite and/or clay and silt-sized minerals. This type of anhydrite is thought to be authigenic (formed in placed from fluids contained in the pores of the rock or passing through the rock).

Anhydrite can be replaced by polyhalite if fluids containing potassium, magnesium and additional sulfate ions are present. Many examples of this replacement were observed.

A few of examples of bedded, nodular anhydrite were observed. The nodules may have originally been composed of gypsum which was later replaced by anhydrite. The origin of such bedded nodules is thought by some workers to represent deposition in very shallow water which was periodically exposed (Sahbka facies).

Polyhalite

Polyhalite was recognized on the basis of its relatively low birefringence, inclined extinction and complex twinning. (Unfortunately in some fine-grained material and/or mixtures, polyhalite and anhydrite can be confused because their optical properties of relief and birefringence are almost the same in certain orientations).

Much of the polyhalite observed is rather fine grained (much less than 1 mm in size for the individual crystallites) and often fibrous. However, some larger crystals and numerous, isolated crystals and crystal clusters were observed. Polyhalite is often reddish due to iron oxide inclusions, but this is not universally true.

Some of the polyhalite appeared to be in bedded form associated primarily with halite and lesser anhydrite. This polyhalite may be primary in origin. Polyhalite also is found replacing anhydrite and associated with nearby patches and stringers of clay and silt-sized minerals. Whether the clay, etc., provided some of the ions necessary for the formation of polyhalite or just acted as a pathway for solutions passing through the rock cannot be determined.

Minor minerals

Minor minerals were identified on the basis of their optical properties and X-ray diffraction analyses, which were occasionally aided by information contained in the well logs for the cores. Just a few brief comments for each mineral are given here.

Clay minerals. Overall, much less clay is present in the samples from Carlsbad than was present in the Lyons samples. X-ray diffraction peaks attributed to clay minerals were noted in nine samples from Core #7 and in fourteen samples from Core #8. Based on the X-ray patterns and

peaks noted at approximately 7, 10, 11.5, 14 and 15 Å, we believe that the major clay minerals present include illite, chlorite, mixed-layer clays and possibly some kaolinite.

However, because the amount of clay present in most sample is less than 10% (often only a few per cent or less) no additional analyses using chemical or heat treatments are planned to determine the specific clay minerals present in each sample. Although not detected in these samples, Bailey (1949) has detected talc in some samples from this region.

Magnesite. Although well-crystallized magnesite was not detected in thin sections, some very fine-grained, relatively high birefringent phase was noted in some thin sections and magnesite peaks were detected in a number of X-ray patterns. Schaller and Henderson (1932) stated that many of the clays in the samples they studied were magnesitic. The common association of polyhalite with clay and silt-sized minerals may be due in part to the magnesium ions in the magnesitic shales and clays.

Gypsum. Gypsum is monoclinic and in thin section, has low birefringence and low, negative relief. Twins ("swallowtail") are fairly common. Well-crystallized gypsum was detected in only one thin section among the samples studied. In addition, several of the sections contained small amounts of questionable gypsum in association with anhydrite and/or polyhalite. However, the amounts present were much less than 1% and could not be confirmed by X-ray diffraction.

Quartz and feldspar. These minerals are present in two forms, as detrital (silt and very fine, sand-sized) material deposited along with the clays, and also as authigenic minerals which formed in or near patches and stringers of clay and silt-sized minerals.

Sylvite. A few thin sections contain small amounts of sylvite which was recognized on the basis of its distinctive reddish purple color (due

to iron oxide inclusions) and lower relief than halite. Most of the sylvite observed was associated with polyhalite as well as with halite. We did not have any samples from the sylvinite (mixed halite and sylvite) zones. Adams (1967) reported that not all sylvite is colored; however, in the thin sections studied, the distinctive color was useful in locating the small amounts present.

Carnallite. Only one section contains detectable carnallite. This mineral was suspected on the basis of nearby carnallite as noted in the well log. Its high negative relief and "metallic" luster due to inclusions were used to confirm its presence.

Celestite(?). In two or three thin sections some isolated spear-shaped crystals and cluster of crystals with relatively high relief were noted. Although no positive identification could be made, it is suspected that these are celestite, which is the most common strontium mineral present in evaporite deposits.

Glauconite. A few greenish, rounded grains of glauconite were noted, generally associated with the clay and silt-sized minerals. Not enough of this material was present to attempt to determine its origin or source.

Kainite(?). Kainite(?) was observed in only one thin section. It is a monoclinic mineral with moderate birefringence and negative relief.

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APPENDICES

A. Analytical Precision.

1. General statement concerning sample sizes, weighing errors, etc.

2. Results of triplicate analyses on selected samples.

B. Weight Loss Data for Cores #7 and #8, Carlsbad, New Mexico, Including Comparisons with the Data of Beane and Popp (1975).

1. Core #7
2. Core #8
3. Weight losses determined at higher temperatures for selected samples from Core #8

C. Mineralogy and Petrology of Samples from Cores #7 and #8.

1. Abbreviations and notes.
2. Core #7.
3. Core #8.

APPENDIX A. Analytical Precision.

1. General statement concerning sample sizes, weighing errors, etc.

The sample weights used in this study ranged from approximately 0.5 to 2.5 grams, but typically were from 1.5 to 2.0 grams. The sample bottles were weighed before each new batch of samples was prepared, and both the sample bottles and the combined sample bottle and sample were weighed two times or more. Replicate weighings fell within ±0.001 gram of the mean. For most samples, weighing errors should result in a precision of no worse than ±0.1 to 0.2 weight %.

2. Results of triplicate analyses on selected samples.

Triplicate analyses were performed on separate splits taken from the sample vial using different initial sample weights each time. The results are tabulated below:

Sample	Weight Losses Determined (Wt. %)			Mean To Nearest 0.1%
7-1044	0.1	0.1	0.3	0.2
7-1296	1.3	0.9	1.3	1.2
8-1794	1.2	1.4	1.2	1.3
8-1986	0.0	0.0	0.1	0.0
8-2563	2.0	2.3	1.9	2.1
8-2616	0.0	0.0	0.0	0.0

The results of these analyses indicate that most weight losses determined from replicate samples (taken from the same sample bottle) fall within ±0.2 to 0.3 of the mean value. Because of vertical and lateral variations in mineral content typical of sedimentary rocks the range anticipated for different samples of the same core would be larger, but it is not possible

to estimate the precision under such non-reproducible conditions. In the case of relatively uniform samples (such as some halite or anhydrite beds) the precision might be anticipated to remain fairly good. On the other hand, samples which contain varying amounts of clays or other hydrous minerals might be expected to show much larger variations in their weight losses upon heating.

APPENDIX B. Weight Loss Data for Cores #7 and #8, Carlsbad, New Mexico, Including Comparisons with the Data of Beane and Popp (1975).

1. Core #7.

Sample (ft)	Depth (m)	Weight Losses at 102±5°C (Wt.%)	Data From Beane and Popp (1975) @70°C	To 200°C	To Above 400°C
1044	318.2	0.1	0.10	0.10	0.10
1107	337.4	1.0	0.12	0.22	1.99
1171	356.9	0.1	0.14	0.14	0.80
1221	372.2	0.2	0.30	0.44	0.51
*1296	395.0	0.9	-	-	-
1342	409.0	0.2	0.27	0.27	0.43
1402	427.3	0.1	0.19	0.19	0.31
1468	447.4	2.2	1.27	1.73	2.59
1533	467.3	0.1	0.22	0.23	0.47
1615	492.3	0.2	0.34	0.43	0.80
1697	517.2	3.4	0.82	0.82	0.85
1755	534.9	0.2	0.19	0.23	0.28
1952	595.0	0.0	0.14	0.14	0.58
1954	595.6	0.6	0.32	0.32	0.41
1958	596.8	0.2	0.20	0.20	0.32
1960	597.4	0.1	0.07	0.39	0.39
1967	599.5	0.1	0.20	0.20	1.13
1969	600.2	0.2	0.43	0.51	0.71
1973	601.4	0.3	0.19	0.26	0.40
1975	602.0	0.2	0.17	0.17	0.24
1978	602.9	0.8	0.36	0.40	1.67
1983	604.4	0.0	0.29	0.32	0.51
1986	605.3	0.0	0.10	0.10	0.10
1993	607.5	0.0	0.19	0.24	1.04
*2537	773.3	-	0.47	0.56	9.24
2702	823.6	0.0	0.24	0.27	0.39
2716	827.8	0.2	0.22	0.22	0.26
2736	833.9	0.1	0.08	0.08	0.11

*Apparently Beane and Popp and we received one part each of these two samples without the other group receiving the corresponding half.

APPENDIX B. Weight Loss Data, Continued.

2. Core #8.

Sample (ft)	Depth (m)	Weight Losses at 102±5°C (Wt.%)	Data From Beane and Popp (1975) @70°C	To 200°C	To Above 400°C
1391	424.0	0.1	0.04	0.07	0.26
1495	455.7	0.1	0.05	0.08	0.08
1573	479.5	0.2	0.04	0.33	1.18
1652	503.5	0.1	0.09	0.09	4.52
1705	519.7	0.0	0.15	0.17	0.32
1769	539.2	0.1	0.09	0.15	0.35
1787	544.7	0.2	0.32	0.36	0.59
1794	546.8	1.4	0.44	0.71	5.41
1804	549.9	0.0	0.02	0.07	0.07
1829	557.5	0.1	0.16	0.39	0.39
1838	560.2	0.3	0.39	0.39	0.39
1857	566.0	0.1	0.07	0.07	0.10
1875	571.5	1.2	0.22	0.64	0.64
1884	574.2	0.9	0.36	0.36	0.80
1890	576.1	0.1	0.05	0.05	0.13
1894	577.3	0.4	0.30	0.30	0.30
1899	578.8	0.1	0.16	0.16	0.16
1900	579.1	0.1	0.17	0.17	0.81
1905	580.6	1.0	0.36	0.36	0.62
1911	582.5	0.2	0.06	0.06	0.10
1913	583.1	0.2	0.11	0.14	0.21
1916	584.0	0.0	0.13	0.13	0.25
1923	586.1	0.1	0.19	0.19	0.49
1930	588.3	0.4	0.05	0.05	0.47
1933	589.2	0.1	0.19	0.28	0.28
1938	590.7	0.0	0.13	0.27	0.49
1953	595.3	0.1	0.05	0.10	0.42
1967	599.5	0.5	0.28	0.32	0.52
1986	605.3	0.0	0.07	0.07	5.81
2006	611.4	0.1	0.20	0.20	0.66
2017	614.8	0.2	0.22	0.24	0.41
2039	621.5	0.1	0.21	0.26	1.02
2050	624.8	0.0	0.11	0.11	0.79
2068	630.3	0.1	0.04	0.04	0.14
2084	635.2	0.3	0.17	0.22	0.71
2130	649.2	0.0	0.11	0.18	0.28
2162	659.0	0.1	0.14	0.14	0.62
2217	675.7	0.1	0.04	0.04	0.44
2280	694.9	0.0	0.19	0.19	0.27
2326	709.0	0.1	0.11	0.14	0.70
2366	721.2	1.9	0.43	0.43	6.84
2427	739.7	0.0	0.03	0.03	0.43
2460	749.8	0.0	0.17	0.22	0.37
2519	767.8	0.0	0.08	0.08	0.14
2563	781.2	2.3	1.87	2.13	2.24

APPENDIX B. 2. Weight Loss Data, Continued.

2. Core #8, continued.

Sample (ft)	Depth (m)	Weight Losses at 102±5°C (Wt.%)	Data From Beane and Popp (1975) @70°C	To 200°C	To Above 400°C
2616	797.4	0.0	0.21	0.21	0.27
2666	812.6	0.0	0.25	0.25	0.73
2707	825.1	0.6	0.16	0.16	1.66
2758	840.6	0.0	0.11	0.11	0.16
2779	847.0	0.2	0.21	0.21	0.21
2793	851.3	0.0	0.18	0.18	0.18
2803	854.4	0.0	0.10	0.12	0.14
2809	856.2	0.0	0.15	0.24	0.48
2821	859.8	0.2	0.18	0.18	0.36
2879	877.5	0.2	0.06	0.06	3.37
2948	898.6	0.1	0.20	0.22	0.26

APPENDIX B. Weight Loss Data, Continued.

3. Weight losses determined at higher temperatures for selected samples from Core #8.

Sample (ft)	Depth (m)	Weight Losses (± 0.1 to 0.2 Weight %) 102±5°C	170±5°C	300±10°C
1804	549.9	0.0	0.0	0.2
1829	557.5	0.1	0.2	0.4
1875	571.5	1.2	1.8	2.2
1884	574.2	0.9	1.0	1.5
1923	586.1	0.1	0.1	0.2
1967	599.5	0.5	0.5	1.4
2050	624.8	0.0	0.0	0.7
2366	721.2	1.9	2.0	7.4
2948	898.6	0.1	0.0	0.2

Note: In this set of weight loss determinations, one split from each sample selected was heated to successively higher temperatures.

APPENDIX C. Mineralogy and Petrology of Cores #7 and #8.

1. Abbreviations used.

Minerals In the summaries which follow the approximate amounts of the minerals present are indicated by upper and lower case letters. AN = MAJOR (>25%); An = Minor (5 to 25%); an = trace (<5%. Often less than 1%)

AN	=	Anhydrite	HA	=	Halite
CAR	=	Carnallite	KAIN	=	Kainite
CEL	=	Celestite	PH	=	Polyhalite
CSSM	=	Clay and silt-sized minerals (often magnesitic)			
FELD	=	Feldspar(s)	QTZ	=	Quartz
GLAU	=	Glauconite	SYL	=	Sylvite
GYP	=	Gypsum			

Grain Sizes

fg = fine grained (<1 mm)

mg = medium grained (1 mm to 1 mm)

cg = coarse grained (>1 cm)

With the exception of halite, which shows a wide range of grain sizes, most of the minerals observed are fine grained.

APPENDIX C. Mineralogy and Petrology, Continued.

2. Core #7.

Depth (ft)	Description
1044	cg HA with An and cssm in patches and stringers. An also in isolated crystals and crystal clusters.
1107	fg to mg Ha with mg gyp which is partially replaced by An. fg to mg ph in patches and stringers along with cssm.
1171	Appears macroscopically bedded. Primarily vuggy AN. Voids filled with radial ("starbursts") of ph and also with ha and cssm.
1221	cg HA. Patches and stringers filled with ph (radial in part) and an. Some evidence of ph replacing an.
1296	mg to cg HA with Cssm, ph and possibly some an in patches and stringers. Some of the Cssm appears intergranular among HA crystals. May represent subaerial deposition.
1342	mg to cg HA with ph and cssm in patches and stringers.
1402	mg HA. ph (radial in part) and an in patches and stringers and as crystal clusters.
1468	mg HA with much intergranular Cssm. Possibly represents subaerial deposition. Trace an and ph as isolated crystals and crystal clusters. Some authigenic quartz and feldspar.
1533	mg to cg HA with poorly preserved hoppers. Ph in patches and stringers, some possibly intergranular with HA. Trace Cssm associated with the Ph.
1615	mg to cg HA with hoppers. fg to mg An and ph in patches and stringers. ph appears to be replacing An, some of which may be psuedomorphic after gypsum.
1697	Appears to be macroscopically bedded. Large, nodular masses of AN (possibly pseudomorphic after gypsum nodules) with voids filled with Cssm, Ph, ha and syl. Ph associated with Cssm; syl associated with Ph.
1755	mg to cg Ha with poorly preserved hoppers. ph and an in patches and stringers. ph replaces an in part. Perhaps a little syl is present.
1952	Appears macroscopically bedded. mg to cg HA with hoppers. Ph and an in patches, stringers and as isolated crystals and clusters. Ph replacing an in part.

APPENDIX C. Mineralogy and Petrology, Continued.

2. Core #7, continued.

Depth (ft)	Description
1954	mg to cg HA with Cssm in patches and stringers. Some Cssm is intergranular with HA. May represent subaerial deposition. Some isolated crystals and clusters of ph associated with Cssm.
1958	mg to cg HA. cssm in patches and stringers. (Some cssm may be intergranular). ph and possible an in patches and stringers associated with cssm and also in isolated crystals and clusters.
1960	Possibly macroscopically bedded. fg to cg HA with hoppers. Intergranular Cssm with associated authigenic qtz and feld. May represent suberial deposition. Some isolated crystals and clusters of ph and an.
1967	mg to cg HA with poorly preserved hoppers. ph in patches and stringers shows some evidence of flow of deformation. A few isolated crystals and clusters of an.
1969	fg to cg HA with poorly preserved hoppers. Intergranular Cssm with associated authigenic qtz and feld. Isolated crystals and clusters of an and lesser ph.
1973	cg HA with very few patches and stringers of cssm, ph and even some ha crystals.
1975	cg HA with ph, cssm and an in patches and stringers. ph appears to be replacing an. ph associated with cssm.
1978	mg to cg HA with intergranular Cssm and ph. May represent subaerial deposition. Some ph in patches and stringers and as isolated crystals and clusters. Some ph is mg. Isolated crystals of an are associated with the ph.
1983	mg to cg HA with hoppers. Ph and an in patches and stringers Ph replacing an.
1986	mg to cg HA with small amounts of ph, an and cssm in patches and stringers.
1993	cg HA with hoppers. Ph and an in patches and stringers. (Some Ph and an may be intergranular). Ph appears to replace an.
2702	mg to cg HA with An and cssm in patches and stringers.

APPENDIX C. Mineralogy and Petrology, Continued.

2. Core #7, continued.

Depth (ft)	Description
2716	mg to cg HA with hoppers. an and cssm in patches and stringers, some possibly intergranular with HA. May represent subaerial deposition.
2736	mg to cg HA with hoppers. An and cssm in patches and stringers, some possibly intergranular with HA. May represent subaerial deposition.

APPENDIX C. Mineralogy and Petrology, Continued.

3. Core #8

Depth (ft)	Description
1391	cg HA with ph and possibly some an in patches and stringers.
1495	mg to cg HA with hoppers. Ph associated with cssm in patches and stringers. Some may be intergranular. Ph shows evidence of flowage or deformation.
1573	Appears macroscopically bedded. mg to cg HA with Ph and fg to mg An in large patches. Ph appears to be replacing An.
1652	Appears macroscopically bedded. fg to mg AN with Ph. mg Ha in patches or voids. Some syl associated with Ph. Algal laminations may be present in the AN.
1705	fg to cg HA with hoppers. Ph in patches and stringers; some may be intergranular. Small amount of an associated with Ph.
1769	mg to cg HA with poorly preserved hoppers. fg to mg Ph in patches and stringers and intergranular with HA. In part, Ph appears to be replacing HA. Some gyp (?) may be present in very small amounts. There also may be trace amounts of cel (?).
1787	mg to cg HA with hoppers. Ph in patches and stringers and some intergranular with HA. Some mg, acicular an crystals and mg, acicular cel (?) crystals noted. There may be a small amount of gyp (?) present in this slide.
1794	Appears macroscopically bedded. fg to mg HA with hoppers. CSSM is intergranular with HA. May represent subaerial deposition. Also noted: a few isolated ph crystals, some authigenic qtz and feld, and a trace of glau (?).
1804	fg to cg HA with poorly preserved hoppers. CSSM is intergranular with HA. May represent subaerial deposition. ph in isolated crystals and clusters.
1829	cg HA with hoppers. Cssm in patches and stringers and some intergranular. Possible subaerial deposition. Trace of ph.
1838	fg to mg HA with poorly preserved hoppers. Cssm intergranular with HA. Ph and An in patches and stringers and associated with the Cssm. May represent subaerial deposition.
1857	cg HA with poorly preserved hoppers. ph along stringers.

APPENDIX C. Mineralogy and Petrology, Continued.

3. Core #8, continued.

Depth (ft)	Description
1875	Appears macroscopically bedded. fg to mg HA intergranular with CSSM. May represent subaerial deposition. Isolated crystals and clusters of ph and fg to mg an. Traces of authigenic qtz and feld.
1884	fg to mg HA with hoppers, intergranular with CSSM. May represent subaerial deposition. Some isloated crystals and clusters of fg to mg an (some may be pseudomorphic after gyp). Possible trace of syl.
1890	mg to cg HA with hoppers. ph and an in patches and stringers.
1894	mg to cg HA with poorly preserved hoppers. ph and an in patches and stringers. cssm in patches and stringers with authigenic qtz and feld.
1899	fg to cg HA with hoppers and some intergranular Cssm. (May represent subaerial deposition). Authigenic qtz and feld associated with Cssm. Some isolated crystals of an and ph.
1900	fg to cg HA with hoppers. Ph, An and cssm in patches and stringers and some intergranular with HA. May represent subaerial deposition. Some Ph appears to be deformed or to have flowed.
1905	mg to cg HA with patches and stringers and some intergranular Cssm. (May represent subaerial deposition). Scattered, isolated crystals of ph and an.
1910	mg to cg HA with poorly preserved hoppers. Ph, an and cssm intergranular with HA and in patches and stringers. Ph appears to be replacing an.
1911	mg to cg HA with hoppers. Ph, An and cssm in patches and stringers, some intergranular with HA. (May represent subaerial deposition). Ph appears to be replacing an.
1913	fg to cg HA with intergranular Cssm. Inclusions of ha in Cssm. May represent subaerial deposition. Isolated crystals of ph. A few authigenic grains of qtz and feldspar.
1916	cg HA with poorly preserved hoppers. ph and an in patches and stringers.

APPENDIX C. Mineralogy and Petrology, Continued.

3. Core #8, continued.

Depth (ft)	Description
1923	fg to cg HA with intergranular Cssm. May represent subaerial deposition. ph and an in patches and stringers and as isolated crystals. Trace authigenic feld.
1930	mg to cg HA with poorly preserved hoppers. Ph and an in patches and stringers, some as isolated crystals. cssm in patches and stringers. Possible trace gyp (?).
1933	cg HA with hoppers. cssm, ph and an in patches and stringers. Small amounts of authigenic qtz and feld (?).
1938	cg HA with poorly preserved hoppers. Ph and an in patches and stringers.
1953	fg to mg HA with hoppers, some of them quite large. An in patches and stringers often surrounding ph.
1967	fg to cg HA with hoppers. Cssm intergranular with HA and in patches and stringers. May represent subaerial deposition. Isolated crystals and clusters of ph and an.
1986	Appears cross-bedded. PH with mg AN. Ph appears to be replacing AN. Some fine laminations may be algal laminations or traces of cssm seams. ha in patches or filling void places.
2006	fg to cg HA with hoppers. Ph and an in patches and stringers. Trace of syl associated with Ph.
2017	mg to cg HA with hoppers. Ph and an in patches and stringers. Ph appears to be replacing an. cssm in patches.
2039	mg to cg HA with hoppers. Ph and an with cssm in patches and stringers. Much of the Ph is radial. Ph appears to be replacing an.
2050	mg AN with numerous inclusions. AN appears to be replacing ha with former cubic crystal outlines preserved.
2068	fg to cg HA. Patches and stringers and intergranular An, cssm and possible ph (?). May represent subaerial deposition.
2084	fg to cg HA with much intergranular Cssm, ph and possible an (?). May represent subaerial deposition. Some Ha crystals appear to be growing in the Cssm.

APPENDIX C. Mineralogy and Petrology, Continued

3. Core #8, continued.

Depth (ft)	Description
2130	fg to mg HA with intergranular An and minor cssm. Some ph (?) may be replacing An.
2162	cg HA with intergranular Cssm and Ph. May represent subaerial deposition. Trace of an associated with Ph. Trace of syl associated with Ph.
2217	cg HA with patches and stringers of Ph and an. Some Ph radial and replacing an. Possible syl associated with Pn.
2280	fg to cg HA with patches and stringers of Ph and an. Possible trace of kain (?).
2326	fg to cg HA with poorly preserved hoppers. Cssm intergranular with HA. May represent subaerial deposition. Isolated crystals and clusters of ph and an. Trace authigenic feld (?).
2366	Possibly macroscopically bedded. fg, radial PH with minor an. cssm scattered throughout.
2427	fg to cg HA with poorly preserved hoppers. An and cssm in patches, stringers, and intergranular with HA. May represent subaerial deposition, in part. Possible fossil (bryozoan) fragment.
2460	mg to cg HA with hoppers. Patches, stringers, and intergranular An and cssm. mg an in isolated crystals and clusters along the margins of the patches and stringers.
2519	mg to cg HA with poorly preserved hoppers. Patches, stringers and intergranular an often associated with cssm. May represent subaerial deposition.
2563	Possibly macroscopically bedded. Nodular AN with patches of Cssm. Possible mudcrack or burrow along one edge of slide normal to the bedding.
2616	fg to mg HA with poorly preserved hoppers. An intergranular with HA and as patches and stringers. May represent subaerial deposition.
2666	fg to cg HA with poorly preserved hoppers. Patches, stringers, and intergranular Cssm and an. May represent subaerial deposition.

APPENDIX C. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2707	cg HA with hoppers. Patches and stringers of Cssm and an.
2758	fg to mg HA with poorly preserved hoppers. An associated with cssm in patches, stringers (some intergranular). May represent subaerial deposition. Some An in isolated crystals.
2779	fg to cg HA with hoppers. An and cssm in patches, stringers and intergranular with HA. May represent subaerial deposition.
2793	fg to cg HA with trace evidence of hoppers. Intergranular An and cssm. May represent subaerial deposition. Patches and stringers of An. Traces of ph and authigenic qtz (?).
2803	fg to cg HA with hoppers. Intergranular An and cssm. Some An in patches with possible ph (?). A few large, isolated crystals of An. May represent subaerial deposition.
2809	fg to mg HA with trace evidence of hoppers. An and cssm in patches, stringers and as intergranular material. May represent subaerial deposition.
2821	mg to cg HA with hoppers. Intergranular An and cssm. Some An in patches and stringers. May represent subaerial deposition.
2879	Possible macroscopic evidence of bedding. fg to mg HA with hoppers. Patches and stringers of An and cssm. Possible trace of ph (?). An unknown mineral with low birefringence and positive relief was observed. Also present are some large, isolated crystals of An.
2948	Possible macroscopic evidence of bedding. mg to cg HA with hoppers. Some patches and stringers of An present. Some may be nodular (?) (possibly pseudomorphic after gyp). a few isolated crystals of ph (?) were noted.