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Petrology and Bromine Geochemistry of the Hutchinson Salt Member of the Wellington Formation in Ellsworth County, Kansas: A Paleoenvironmental Analysis

by

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PETROLOGY AND BROMINE GEOCHEMISTRY OF THE HUTCHINSON SALT MEMBER OF THE WELLINGTON FORMATION IN ELLSWORTH COUNTY, KANSAS: A PALEOENVIRONMENTAL ANALYSIS

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ABSTRACT

The Permian Hutchinson Salt Member of the Wellington Formation is a regularly laminated unit composed predominantly of halite interbedded with anhydrite and dark gray laminated shale. This unit underlies much of central and western Kansas, northwestern Oklahoma, and the northeast corner of the Texas panhandle.

A complete section of the Hutchinson Salt (73.8 m) from a core in Ellsworth Co., Kansas, contains many thin units of well preserved primary halite as well as recrystallized and partially recrystallized halite. Textural evidence of the halite and bromine profiles of three sections of primary halite suggest that halite precipitation occured somewhat rapidly in a shallow but stable basin. A well balanced influx - evaporation - reflux system was operative for much of the time. However, intermittent drops in sea level severely restricted the basin and produced many of the lithologic, stratigraphic, textural, and geochemical features that characterize the Hutchinson Salt.

INTRODUCTION - PURPOSE AND METHODS OF STUDY

The principal objective of this investigation is to improve the understanding of the depositional environment in which the Permian Hutchinson Salt Member accumulated. The conclusions of this report are based on detailed bromine analyses and petrographic studies from a core of the entire Hutchinson Member. The core site is located in Ellsworth Co., Kansas, T17S R9W sec. 32 NW1/4 NW1/4.

The Hutchinson Salt Member consists of anhydritic and argillaceous halite interstratified with beds of shale and anhydrite. Dolomite and magnesite also have been found in the sequence (Jones, 1965). The Hutchinson Salt is known to underlie much of central Kansas, northeastern Oklahoma, and the northeast corner of the Texas panhandle (Bass, 1926; Kulstad, 2959; Watney _et_ _al_., 1980 - figure 1).

The Hutchinson Salt Member is the middle member of the Wellington Formation, a formation that conformably overlies the marine shale and limestone of the Lower Permian Chase Group (figure 2). The Wellington Formation is, in turn, overlain unconformably by shales, evaporites and redbeds that constitute the Ninnescah Shale.

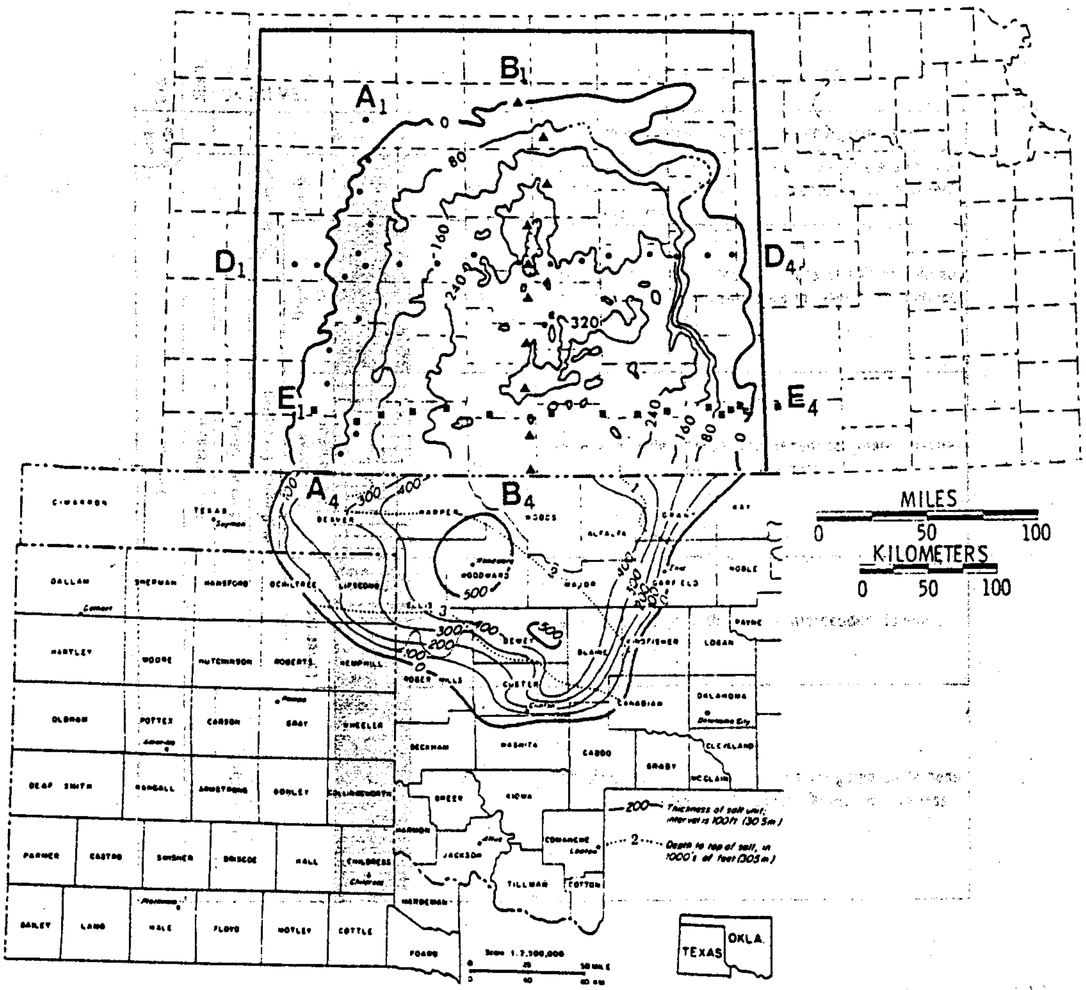
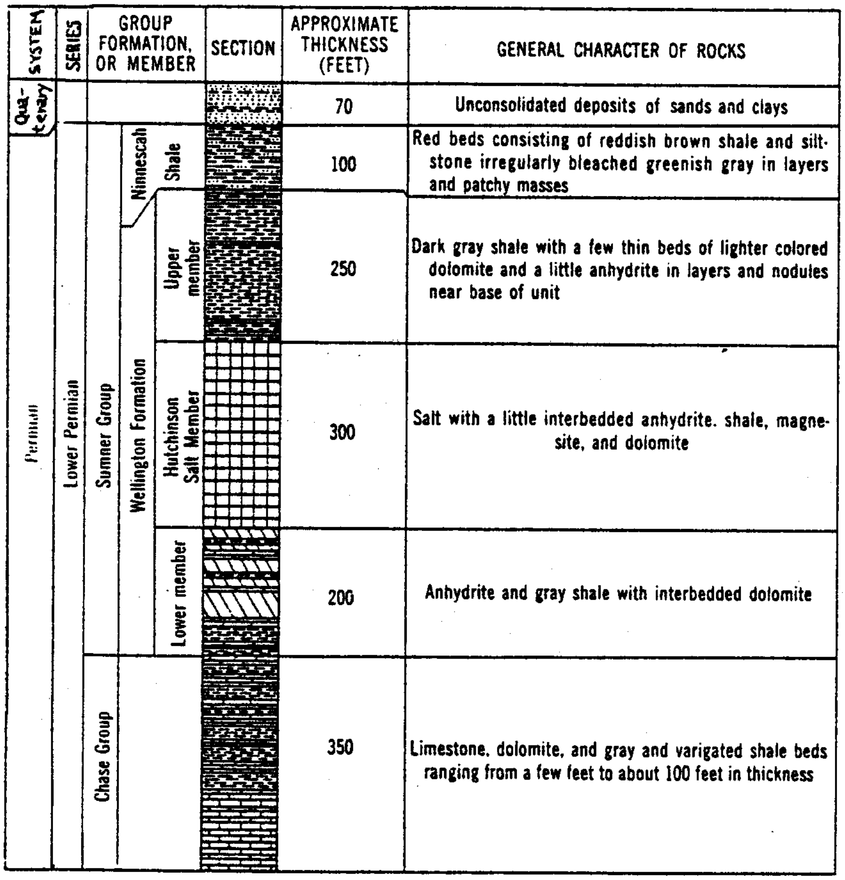


Figure 1.

Kansas: Net salt isopach of Hutchinson Salt, 80 foot contour interval, annotated with cross section index lines. Study area is outlined by heavy lines and the southern border of Kansas.

Oklahoma and Texas: Thickness and depth to the top of salt-bearing strata in Hutchinson Salt Member of Wellington Formation (from Johnson, 1976, Figure 7). (From Watney, 1980, Figure 1.)



SYSTEM	SERIES	GROUP FORMATION, OR MEMBER			SECTION	APPROXIMATE THICKNESS (FEET)	GENERAL CHARACTER OF ROCKS
Quaternary						70	Unconsolidated deposits of sands and clays
Permian	Lower Permian	Sumner Group	Ninnescah Shale			100	Red beds consisting of reddish brown shale and siltstone irregularly bleached greenish gray in layers and patchy masses
			Wellington Formation	Upper member		250	Dark gray shale with a few thin beds of lighter colored dolomite and a little anhydrite in layers and nodules near base of unit
				Hutchinson Salt Member		300	Salt with a little interbedded anhydrite. shale, magnesite, and dolomite
				Lower member		200	Anhydrite and gray shale with interbedded dolomite
		Chase Group				350	Limestone, dolomite, and gray and varigated shale beds ranging from a few feet to about 100 feet in thickness

Figure 2 Generalized section of rocks penetrated by drill holes in the general region of the Hutchinson Naval Air station (from Jones, 1965, figure 2, p.7)

PREVIOUS INVESTIGATIONS

Hay (1891) and Haworth and Kirk (1899) provide the earliest references to the salt beds of the Wellington Formation. Bass (1926) produced the first isopach map based on limited sample log data. A more detailed account of the distribution, thickness and percentage of salt in the Hutchinson Member was published by Kulstad (1959).

The Wellington Formation was first subdivided by Ver Wiebe (1937) into five units based on lithologic changes. Further descriptions of salt beds in the Wellington Formation, together with correlated stratigraphic sections and maps showing the distribution and thickness of the salt, were included in a study of the stratigraphy and structural development of the Salina Basin by Lee (1956). The latest and most detailed set of stratigraphic sections and maps are given in Watney *et al*. (1980).

Mineralogic and petrologic descriptions of evaporitic rocks from the salt mines of central Kansas were first published by Rogers (1910). Traces of polyhalite were reported by Smith (1938) and later confirmed by x-ray diffraction analysis (Swineford and Runnels, 1953). Swineford (1955) described some of the dolomite and halite rock units of the Wellington Formation.

The problem of the origin of the Hutchinson Salt was first addressed by Kulstad and others (1956) who concentrated on the association of gypsum with halite and anhydrite. Dellwig (1963) identified most of the significant sedimentary features of the Hutchinson Salt from Kansas salt mines and proposed a comprehensive depositional model involving the influxing of seawater and refluxing brines in a shallow basin. Jones (1965) studied a cored section of Hutchinson Salt taken near Hutchinson, Kansas. He described the relationships of the halite to associated sulfates, carbonates, argillaceous materials and other minor constituents. Bromine geochemistry of brine inclusions in the Hutchinson Salt (Holser, 1963) and of the halite (Holser, 1966) have also been used as a line of evidence in the determination of a depositional model. Analyses for other trace elements, notably K, Ca, Sr, Fe, and Cu, have been conducted only to a limited extent (Runnels _et al_., 1962).

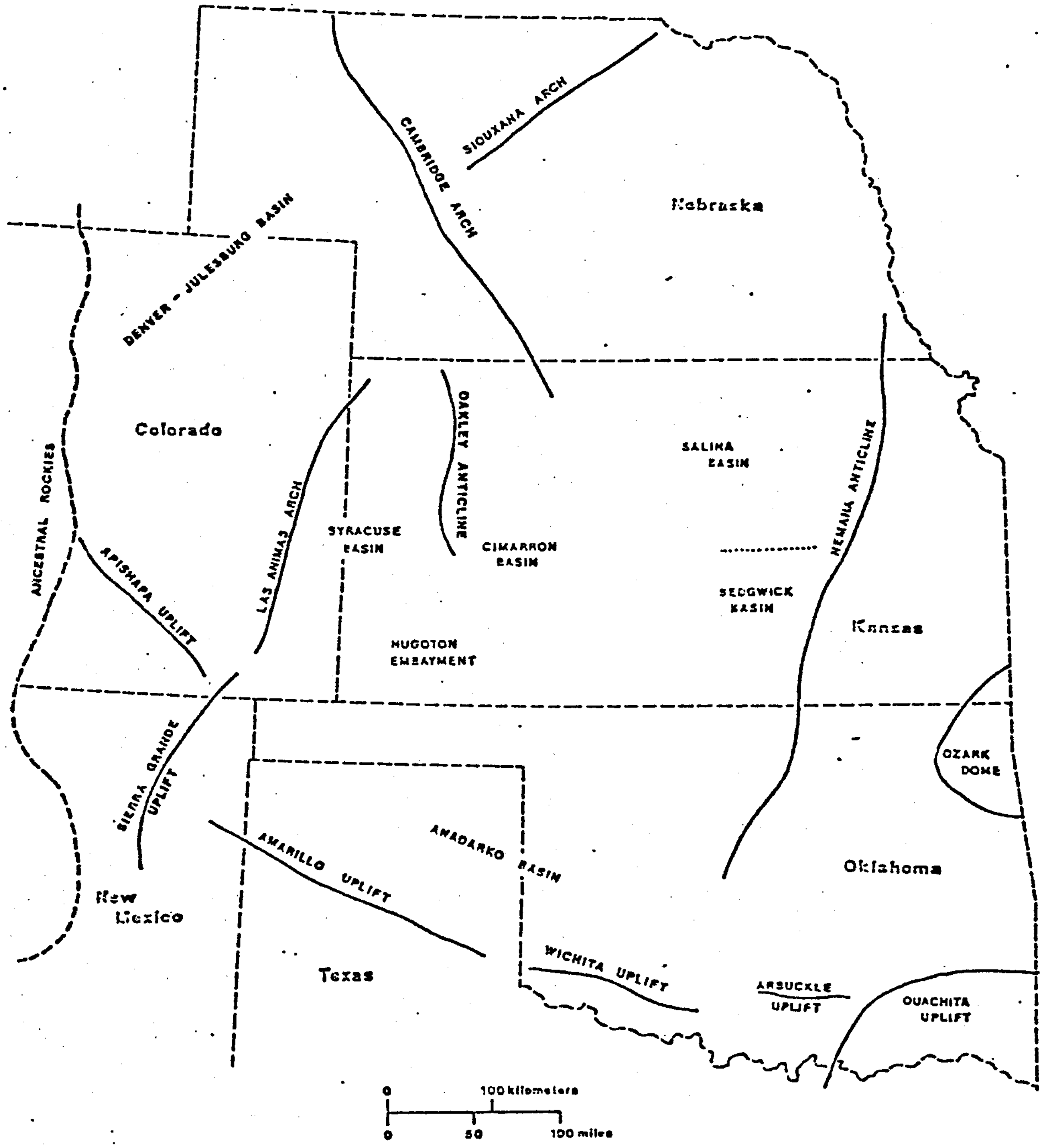
Paleontological studies of the Wellington Formation began with Dunbar (1924) who studied the insects found in outcrops east of, and updip from the salt beds. Stratigraphic distributions of insects, pelecypods, and conchostracans have been noted from outcrops of the Wellington Formation (Tasch and Zimmerman, 1961; and Tasch, 1962). Tilden (1930) identified a commonly occurring orange-red colored filamentous material in the Hutchinson Salt as a blue-green algae associated with minor microscopic iron oxide particles. An investigation of salt mine exposures has revealed the presence of abundant spores and pollen in the halite (Schaffer, 1962).

Other aspects of the geology of the Wellington Formation include the evaluation of the suitability of the Hutchinson Salt for radioactive waste storage (Angino et al., 1971, 1972; Bayne, 1972; Bayne et al., 1972; Johnson, 1976), land subsidence due to salt dissolution (Faden, 1975; Walters, 1977, 1980) and the Permian salt as a source of natural water pollution in Kansas (Gogel, 1979).

PALEOGEOGRAPHY

The deposition of the Hutchinson Salt occurred within the northern part of a broad, gently downwarped basin that extended across the midcontinent area of Kansas, Oklahoma, and west Texas (figure 1). The Kansas basin has been described as a northern shelf extension of the deeper Anadarko Basin of Oklahoma (McKee, 1967; Rascoe, 1962, 1968). By Permian time tectonic activity throughout the United States had decreased and the major positive features which controlled sedimentation in the midcontinent area were for the most part inherited from the late Pennsylvanian (McKee, 1967 - figure 3).

Figure 3. Structural elements controlling Leonardian deposition in the Midcontinent (after McKee, Oriel *et al*., 1967).



GENERAL STRATIGRAPHY

The Lower Leonardian Stage, which includes the Hutchinson Salt Member is a thin layered sequence of sedimentary rocks representing a transitional zone from normal marine limestones and shales of the underlying Chase Group to the restricted marine evaporites and continental red clastics which overlie the Wellington Formation (Swineford, 1955; Holdoway, 1978).

The Chase Group consists of about 350 ft. (107 m) of shales and carbonate rocks which grade into dolomite and associated shales of the Wellington Formation. The Wellington averages 750 ft (229 m) of thickness and is divided into three lithologic units. Norton (1939) and most later workers defined them as the lower anhydrite member, the Hutchinson Salt Member, and the upper shale member.

The lower anhydrite member is composed mainly of anhydrite and shale although dolomite is present in significant amounts. The lithologies alternate with one another in thin to moderately thick beds which grade into the shale and evaporites of the Hutchinson Salt Member (Jones, 1965). The lower member averages 200 ft (61 m) of thickness throughout Kansas, thickening only slightly toward the basin center (Watney et al., 1980, cross section B).

The upper shale member is a regularly laminated gray shale that resembles the shale beds in the salt member and the lower anhydrite member. This upper member of the Wellington is about 250 ft (76 m) thick. It is anhydritic in the lower part and includes a few thin beds of dolomite at widely spaced intervals (Jones, 1965).

CORED SECTION OF THE WELLINGTON FORMATION

Well No. 85 was cored for the Hydrocarbon Transportation Company which is currently operating a hydrocarbon storage facility near Bushton Terminal, Kansas. The core was originally examined by L. F. Dellwig for the purpose of determining the suitability of solution mining of the Hutchinson Salt in this area.

The cored section as measured at the well site includes 242 ft (73.8 m) of strata, of which 225 ft (68.6 m) is the Hutchinson Salt. The depths below ground level of the top and the base of the salt members are 931 ft (283.8 m) and 1156 ft (352.4 m), respectively. Measurement of the salt member for the purposes of this study revealed a thickness of 215.3 ft (65.6 m).

ROCKS BELOW THE SALT

The rock from a depth of 352.4 m to 357.6 m are part of the lower member of the Wellington Formation. The sequence is composed predominantly of alternating light and dark gray contorted and breciated laminations of clay shale and clayey siltstone and dolomite. X-ray diffraction analysis shows that a minor amount of finely dispersed anhydrite exists in the clastic rock. Anhydrite also occurs as small (0.5-2 cm) light-medium gray nodules dispersed throughout the sequences. A few beds with thicknesses of 7-10 cm were also noted (figure 4). A massive dark brown 1.4 m thick dolomite dominates the middle portion of the upper part of the lower member (figure 4). The dolomite unit has gradational upper and lower contacts. The beds of siltstone and dolomite are randomly crosscut by veins of orange-red halite. This occurrenace of orange-red halite is a very common feature of the shales in the overlying Hutchinson Salt.

The laminated sediments surrounding the anhydrite nodules have clearly been displaced during the growth of the nodules within the detrital host sediments.

HUTCHINSON SALT MEMBER

The predominant rock type in the salt member is halite, which accounts for 86 per cent of its thickness. Shale and anhydrite beds account for 13 per cent and less than 1 per cent, respectively. No predominantly carbonate units were found in the salt member. The overall mineral proportions are slightly different as anhydrite composes some 5-10 per cent of the halite units.

Figure 4 Core log of the Hutchinson Salt Member and an upper section of the lower member of the Wellington Formation - well no. 85, Schroeder ethane storage, Bushton Terminal, Kansas. From left to right the columns represent presence of red salt and polyhalte, relative abundance of chevrons, lithology, and bromine concentrations of some of the chevron halite.

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A systematic x-ray diffraction analysis of the insoluble residues was not performed as a part of this study. However, the x-ray patterns of two shale layers in the upper and lower parts of the core show that a minor amount of magnesite is present. Jones (1965) reports 4 per cent dolomite and magnesite in the salt member of the Hutchinson Naval Air Station core. These beds are present as thin homogenous beds, commonly 0.6 cm, and rarely up to 300 cm thick. It is likely that minor amounts of dolomite and magnesite occur within some of the shale beds of the core from Well No. 85.

THE ORIGINS OF SOME HALITE

The occurrence and distribution of a rather distinctive looking type of halite crystal called a chevron was studied in detail and forms the basis for much of this investigation. These crystals are upwardly elongated with a chevron appearance that can be seen in hand specimen and thin section. This form is due to the parallel alignment of fluid inclusions along the crystal faces. Thin bedded sequences of these chevrons have been found in modern environments and in ancient salt deposits including the Hutchinson Salt.

The chevron form is a result of competitive upward growth from small euhedral halite crystals on the floor of a brine body. During uniform growth, the edges of the cubes will advance more rapidly than the faces (Shearman, 1978). Valyashko (1952) observed that in a freshly precipitated layer of euhedral halite crystals the cubes that were oriented with an edge or a corner pointing upward continued to grow upwards and produce elongate crystals that are separated by compromise boundaries. Zones with a high density of minute fluid inclusions form parallel to the cube faces and the repetition of these zones within the crystal produces the chevron appearance (figure 5).

The best described example of chevron halite in ancient layered halite is from the Prairie Evaporite Formation (Devonian) of Saskatchewan (Wardlaw and Schwerdtner, 1966). Layers of halite from 1-10 cm thick consist partially of zoned halite and partially of clear inclusion-free halite. The authors write, "Textural observations suggest that perfectly transparent grains of halite associated with the chevron grains locally replace the chevron grains and therefore are younger and secondary to the rock." (p. 335). Individual crystals are abruptly truncated, the boundaries between zoned and clear areas are commonly arcuate and the clear areas often cut deep embayments into the zoned halite. Similar textural relationships have been found in bedded chevrons from the marginal basin areas of the Lower Salina Group (Nurmi and Friedman, 1977).

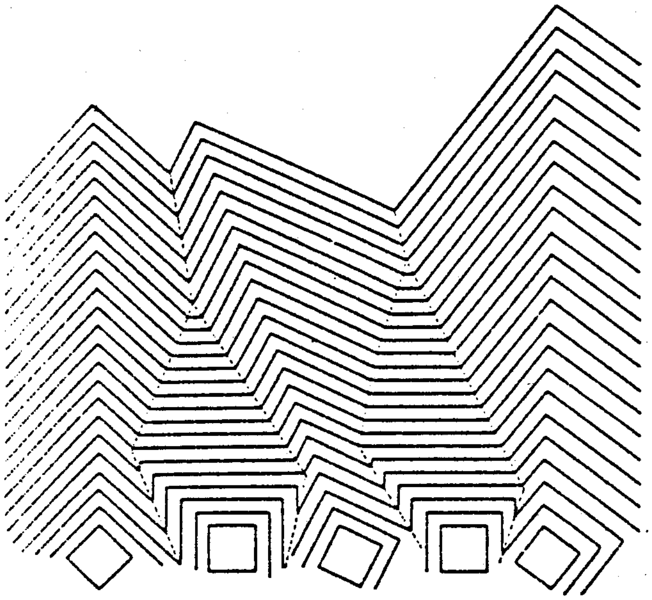


Figure 5 Nearly vertical elongate halite crystals with comprimise boundaries. Note how the crystals which are initiated with an edge or a corner directed away from the surface have overriden those that have a cube face parallel to the surface (from Shearman, 1970, figure 5a, p.158)

Recent examples of this rock type have been found in the supratidal depression - Salina Ometepec, along the eastern coast of Baja California, Mexico (Shearman, 1970). Thin sections of the Baja salt reveal chevrons that are truncated and embayed by dissolution cavities. Shearman concludes that if these voids were to be subsequently filled with a clear diagenetic halite, the rock would look very much like the halite of the Prairie Evaporite Formation.

Sorby (1858, p. 460) made observations of fluid inclusions in artificially grown crystals and reported that, "In general the size of the cavities varies inversely as their number, for when the crystals are slowly formed, they are larger and less numerous." Therefore, if Sorby was right, the zones of the chevrons which contain a high density of minuscule fluid inclusions were formed during periods of relatively rapid halite precipitation. Shearman (1970, p. 161) writes that "...the multiplicity of zones in any one crystal testify to repeated eqisodes of rapid crystal growth, these characteristics would argue against the halite crystals having grown beneath a deep body of brine. In such an environment one would expect physio-chemical conditions to have remained relatively uniform, and that those changes which did occur were gradual ones." The Hutchinson Salt contains many units that contain halite chevrons. A shallow water origin is therefore suggested.

HALITE OF THE HUTCHINSON SALT

Most of the Hutchinson Salt contains laminations that are composed primarily of clay with lesser amounts of anhydrite. The laminations are commonly 2-10 mm thick and occur at a spacing of 0.5-4 cm. They have previously been described by Jones (1965) and Dellwig (1963). Dellwig noted the similarities to the Jahresringe of the German Zechstein deposits and the laminations of the Silurian Salina Salt of the Michigan Basin. Layered halite of this scale is also known to characterize other salt deposits, notably the Prairie Evaporite of Saskatchewan and recent brine pan deposits of the Baja California, Mexico.

RECRYSTALLIZED HALITE

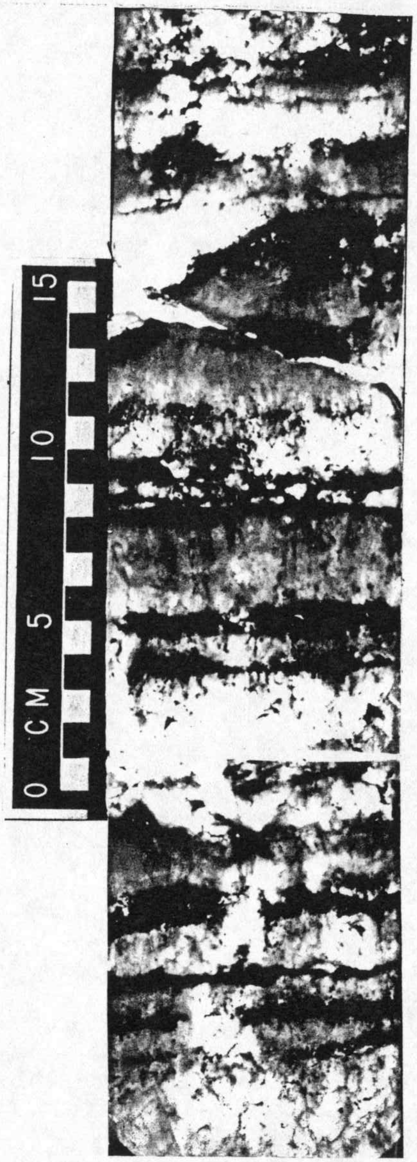
Poorly bedded to massive, clear, moderately coarse - coarse crystalline halite is the predominant rock type of the Hutchinson Salt Member. The unit ordinarily occurs as fairly even-grained aggregates of anhedral crystals with interlocking margins. Fluid inclusions are relatively scarce in this type of halite but they are typically many times larger than those that occur in chevrons and the are inevitably cubic in form.

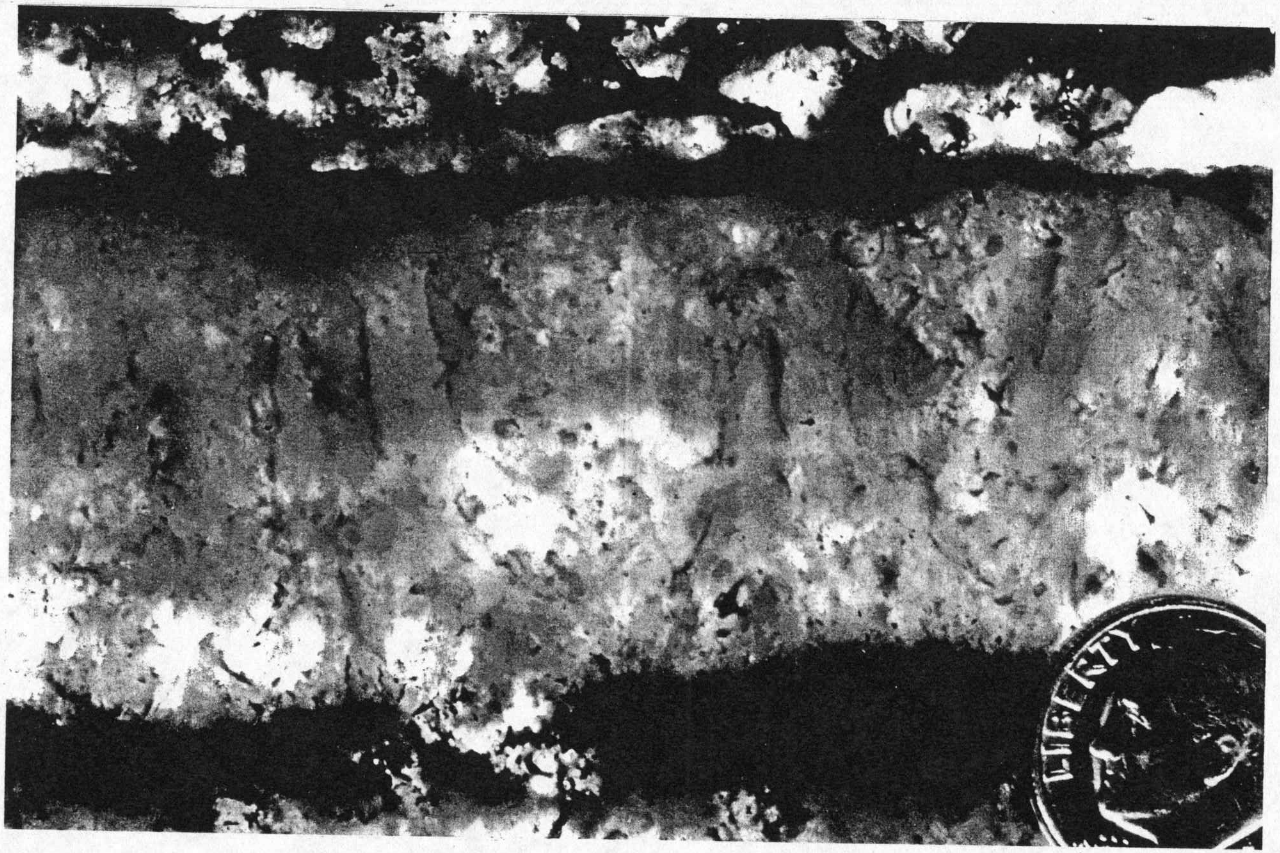
Irregularly shaped clods and specks of clay and anhydrite are unevenly distributed through the intervals of predominantly coarse halite. This material is usually interstitial but less commonly is found as disturbed irregularly spaced laminations which closely resemble those found in the primary halite.

An orange to red coloration often characterizes this type of rock. The redness is due to the presence of minute iron oxide granules that are associated with extremely slender filaments of blue-green algae (Tilden, 1930). The precipitation of iron has been attributed to bacterial action as the remains of these organisms have been found in the water insoluble residue of the halite (Dellwig, 1968). This red tinted halite is more common in the upper part of the member than in the lower (figure 4).

This type of halite is widely regarded as having been recrystallized (Holser, 1963). According to this theory the interstitial clay and anhydrite were expelled from the halite during recrystallization. The larger, more perfectly formed fluid inclusions presumably formed from the coalescence of many smaller ones.

Partially recrystallized layered chevron beds are present locally in the Well No. 85 core. Clay-anhydrite laminations (plate 1) have been truncated by a cross-cutting vein of moderately coarse clear halite. Recrystallization was accomplished with little or no slumping or collapsing of the laminations. It is likely, therefore, that the recrystallization process occurred slowly in a





(951.5 FT)

Plate 1 Samples 940 1-3, 290.2 m. Left photo; Partially recrystallized halite, vien of medium - coarse clear halite cross - cutting beds of chevron halite and clay - anhydrite laminations. Right photo; Chevron halite bed with small portions of intimately associated clear halite. The thin dark vertical lines are "walls " of clay and anhydrite which outline the chevrons. Coin is 0.68 IN in. diameter.

layer by layer fashion. The brine must have been only slightly undersaturated with respect to sodium chloride.

Collapse structures do exist in the Winnipegosis Salt of the Middle Devonian Upper Elk Point in central Alberta (Fuller and Porter, 1969), and have been attributed to the effects of contemporaneous recrystallization of exposed salt. A feature similar to the collapse structure in the Winnipegosis salt (Fuller and Porter, 1969; figure 16A) was found in Well No. 85 core (plate 2). However, the apparently recrystallized halite crystals are just as fine-grained and full of impurities as the original halite, whereas the recrystallized halite in the Winnipegosis salt is coarse and clear. This textural relationship suggests that this structure is the result of slumping of unconsolidated halite crystals which might have been caused by the addition of slightly undersaturated brine to the depositional site.

Recrystallized halite is found interstratified with banded primary halite in the Hutchinson Salt and it is therefore likely that intermittent periods of recrystallization interrupted the deposition of primary halite. Richter-Bernburg (1953) observed a similar interstratification in the Muschelkalk Salt and proposed the following sequence of events:

Plate 2 Samples 3-18-5 and 3-18-6, 335.3 m. Collapse structure, dark areas are composed of small specks of clay and anhydrite. Note the truncated and downward turned clay - anhydrite laminations.

PHOTOGRAPH MISSING

Plate 2 Samples 3-18-5 and 3-18-6, 335.3 m. Collapse structure, dark areas are composed of small specks of clay and anhydrite. Note the truncated and downward turned clay - anhydrite laminations.

1) Recrystallization of halite sediment over a wide area
2) Formation of an extensive dissolution surface by a temporarily diluted basin water
3) Deposition of new rocksalt after the restoration of saturation

A similar sequence is proposed to have resulted in the interstratification of the Hutchinson Salt with one variation. Most of the upper recrystallized halite-shale contacts can be generally described as gradational. However, the increased detrital content in the upper portions of the recrystallized units is almost always accompanied by clasts of lithified shale, presumably from the overlying shale layer. An exact mechanism is difficult to envisage solely on the basis of observational evidence but it appears that a sequence of events can be established whereby the deposition of the shale units occurred before the recrystallization of the underlying halite.

PRIMARY HALITE

The most important criterion used to distinguish beds of primary halite was the presence of bedded chevron crystals. Samples 940-2 (plate 1) and 3-19-5 (plate 3) are typical of most of the primary halite deposits. The chevron structure may or may not be readily apparent in hand specimen. However, photomicrographs of cloudy halite beds that apparently

PHOTOGRAPH MISSING

Plate 3 Sample 3-19-5, 336.3 m. Chevron halite band with overlying and underlying clay - anhydrite rich zones.

Plate 3 Sample 3-19-5, 336.3 m. Chevron halite band with overlying and underlying clay - anhydrite rich zones.

lack any chevron structure show that the cloudiness is, in fact, due to the presence of regularly spaced zones of fluid inclusions that characterize a chevron.

In all of the beds there is at least a small amount of clear halite intimately associated with the chevrons. Similar clear and cloudy halite associations in the Prairie Evaporite Formation (Wardlaw and Schwerdtner, 1969) and in sections of the Silurian Salina Salt of the Michigan Basin (Nurmi and Friedman, 1977) have been interpreted as having resulted from deposition in a supratidal environment. Therefore an interpretation of the origin of the clear halite that is associated with the chevrons is critical to a paleoenvironmental analysis of the Hutchinson Salt.

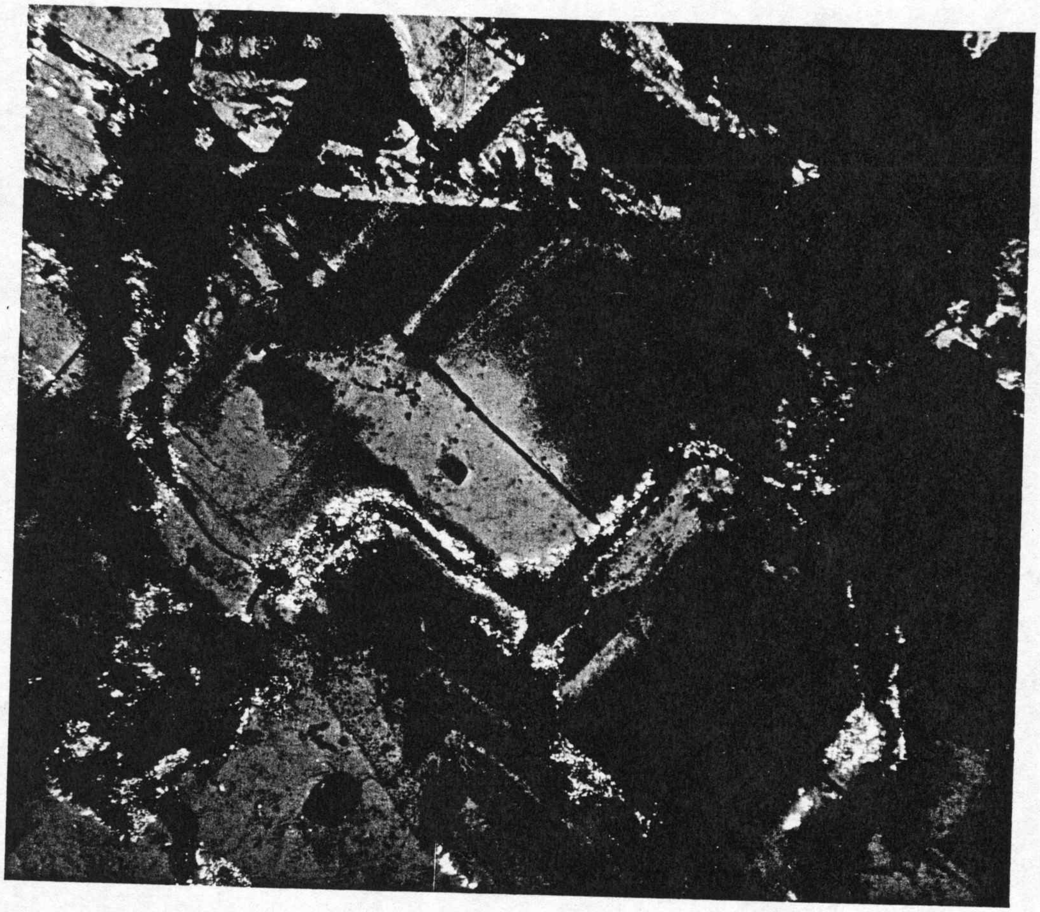
Photomicrographs of the Baja and Prairie Evaporite chevron halite and those from this study of the Hutchinson Salt, show that two general types of boundary relationships exist between the clear and chevron halite. The first type is arcuate, abrupt and consertal. The clear salt often forms deep embayments into the fluid inclusion zones of the chevrons. Wardlaw and Schwerdtner (1969) and Shearman (1979) agree that the clear halite with these boundary relationships is undoubtedly of a secondary origin. The evidence from modern environments suggests that these abrupt boundaries are the result of penecontemporaneous dissolution of the halite (Shearman, 1970).

The origin of a second boundary type is more Problematic. This boundary type is gradual, sometimes arcuate, but it is more commonly a ragged surface (plate 4). Experiments by Arthurton (1973) show that slowly grown halite crystals (2-3 mm/month) are only cloudy at the centers. No mechanism is offered as an explanation for this phenomenon, but it is entirely possible that chevrons that grade into a surrounding mass of clear halite are characteristic of slow crystallization.

The boundaries between the clear and chevron halite considered in this study are predominantly of the gradational type. Furthermore the chevrons are rarely truncated by the overlying anhydrite-clay laminations. Instead, the clay and anhydrite seem to have settled on the pointed or rounded tops of the crystals and partially filled the depressions between the points (plate 5 and 6). The same relationship has been described by Jones (1965, p. 25, figure 7). Commonly, thin walls of clay and anhydrite separate the vertical crystal boundaries. They are most common in the upper portions of the band and generally thicken upward. A continuous and increasing supply of detritus to the interpoint depressions during upward crystal growth probably produced the elongated clay-anhydrite masses that separate the halite crystals. The fact that the points of the halite crystals remained rounded or pointed after the influx of detrital sediments suggests that the water that transported the

Plate 4 Sample 4-1-5, 338.0 m. (1108.2 FT) Gradational clear - chevron halite boundary. Dark speckled areas are fluid inclusion rich zones that give the chevron its cloudy appearance. ~~40~~X 26 partially crossed polars.

Plate 5 Sample 3-18-1, 336.1 m (1102.0 FT). Two generations of chevron halite. The first generation retains it~~'~~s points which are covered with a thin layer of anhydrite. The second generation is truncated at a clay - anhydrite laminae. ~~10X~~ 5 partially crossed polars.



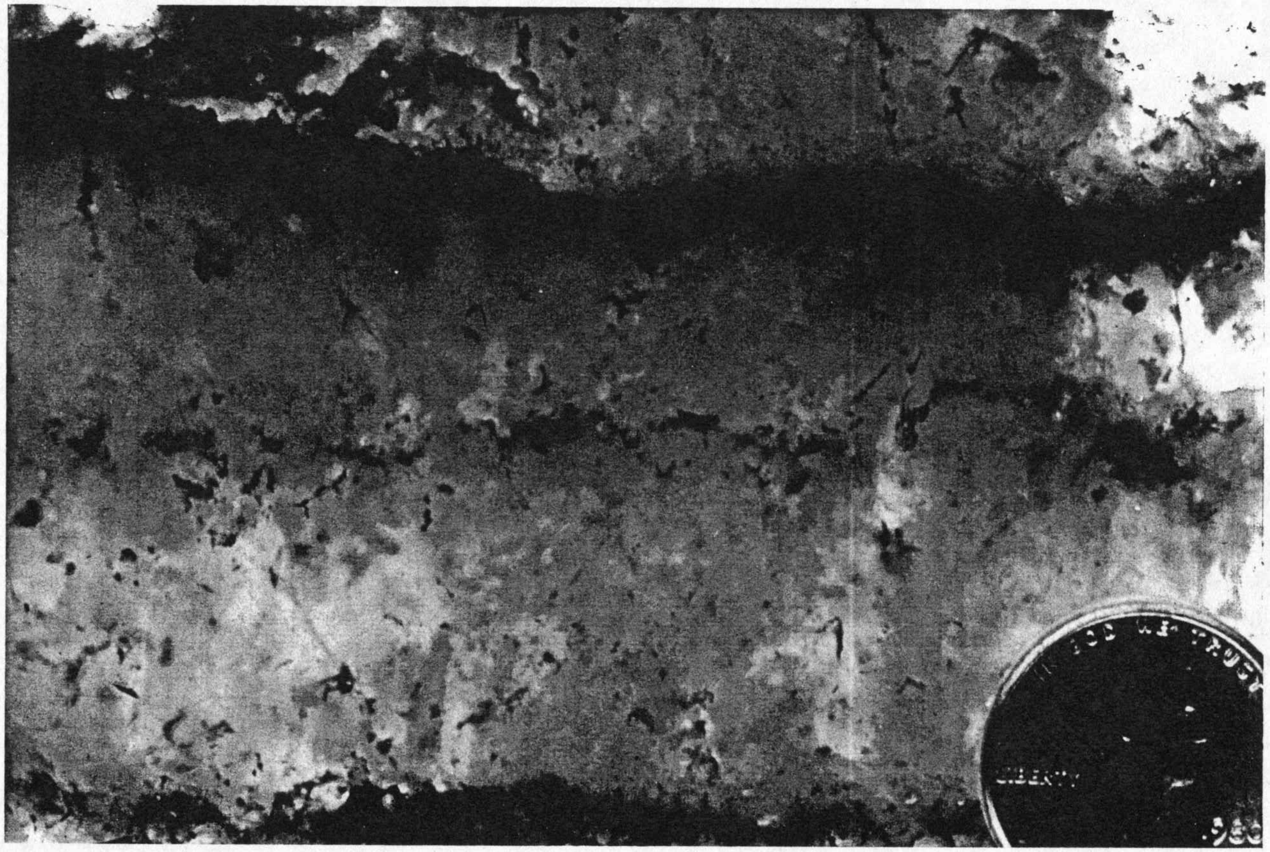


Plate 6 Sample 3-11-1b, 329.9 m. Conformable clay - anhydrite laminae overlying a band of chevron halite with patches of clear halite. Also note the thin dark vertical "walls" of clay and anhydrite near the contact with the overlying laminae.

detritus was saturated or nearly saturated with respect to sodium chloride by the time it reached the depositional site or the transporting water was less saline than the basinal brine and floated on top of the water body during the deposition of the detritus.

Only one primary halite band in the entire core appears to have been significantly affected by penecontemporaneous dissolution (plate 5). These chevrons have been truncated at the contact of the anhydrite-clay lamination.

In conclusion, petrographic evidence of the primary halite indicates that the halite crystals grew upward from the floor of what was probably a well established shallow brine body. The thicknesses of the individual halite bands vary over only a small range. This suggests that the alternating periods of halite and clay-anhydrite deposition were regularly episodic, if not seasonally controlled events. Furthermore, the primary halite is believed to have crystallized at a rate of a few millimeters per month as suggested by the petrograhic similarities with experimentally crystallized halite (Arthurton, 1973). This is also consistent with an interpretation that each band represents a yearly layer (Jahresringe).

The clear halite-chevron boundaries within individual bands are more gradational and less consertal than those described from Recent halite in Baja California and the Devonian Prairie Evaporite formation. The clear halite is believed not to have formed in relict dissolution cavities and thus it is unlikely that any of the examined halite rock was deposited in a supratidal environment. Much of the clear halite that is associated with bedded chevrons in the Hutchinson Salt may be cogenetic; however, a certain amount of uncertainty remains due to a general lack of halite crystallization experiments.

The interstratification of recrystallized and primary halite suggests that the basin brines intermittently became undersaturated with respect to sodium chloride throughout the time of Hutchinson salt deposition. Inclusions of shale clasts in underlying recrystallized halite suggests that undersaturation often developed after shale deposition.

SHALE

Clayey shale is the second most commonly occurring rock type in the salt member. Shale beds are irregularly spaced throughout the sequence in thicknesses ranging from 0.5 cm-1.21 m. The shale is relatively soft, fairly cohesive, and non-fissile. Most beds consist of light and dark gray 1-5 mm thick laminations. The laminations thicken and thin laterally within the small area exposed in the core (plate 7). A one cm thick ripple laminated shale occurs just below the base of the salt. Otherwise the lack of cross-bedding in the salt member suggests that the shale was deposited below the wave base.

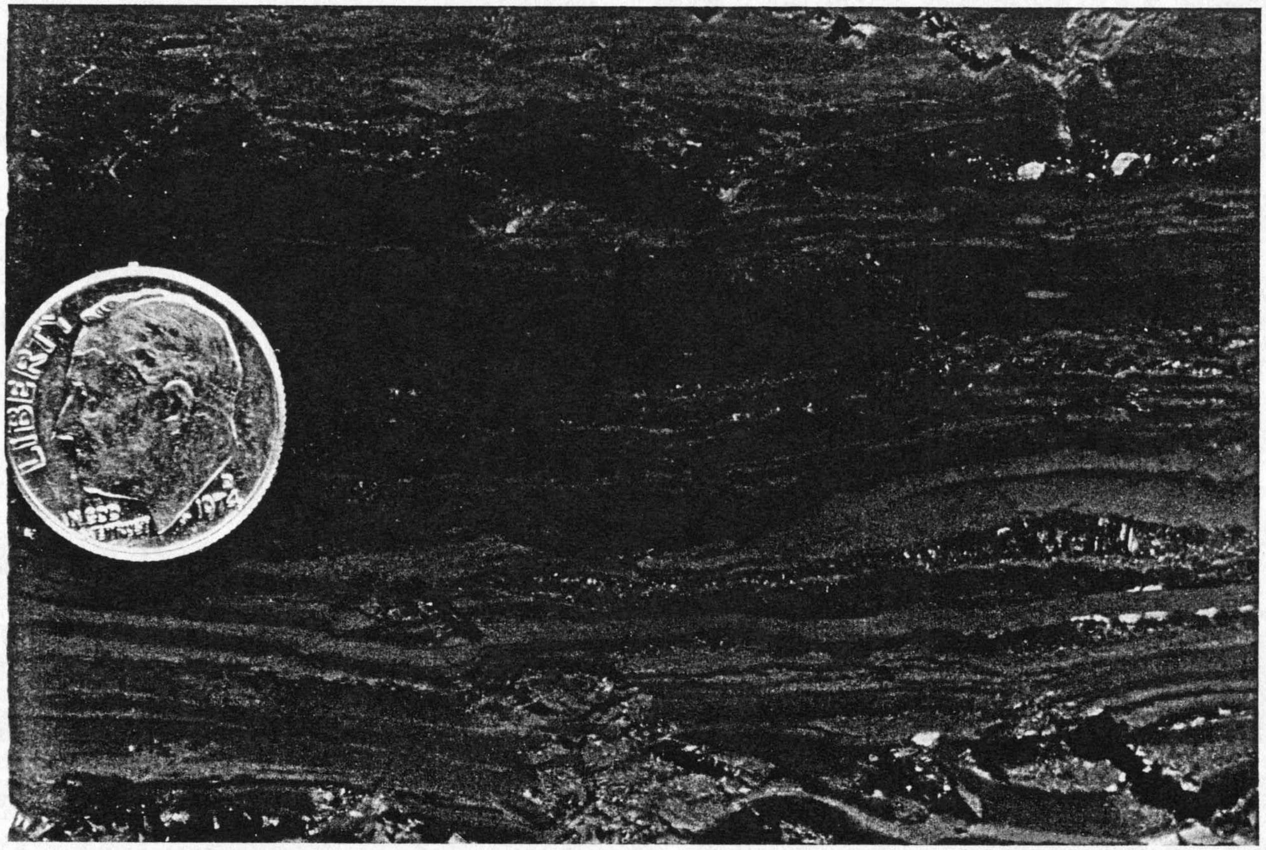


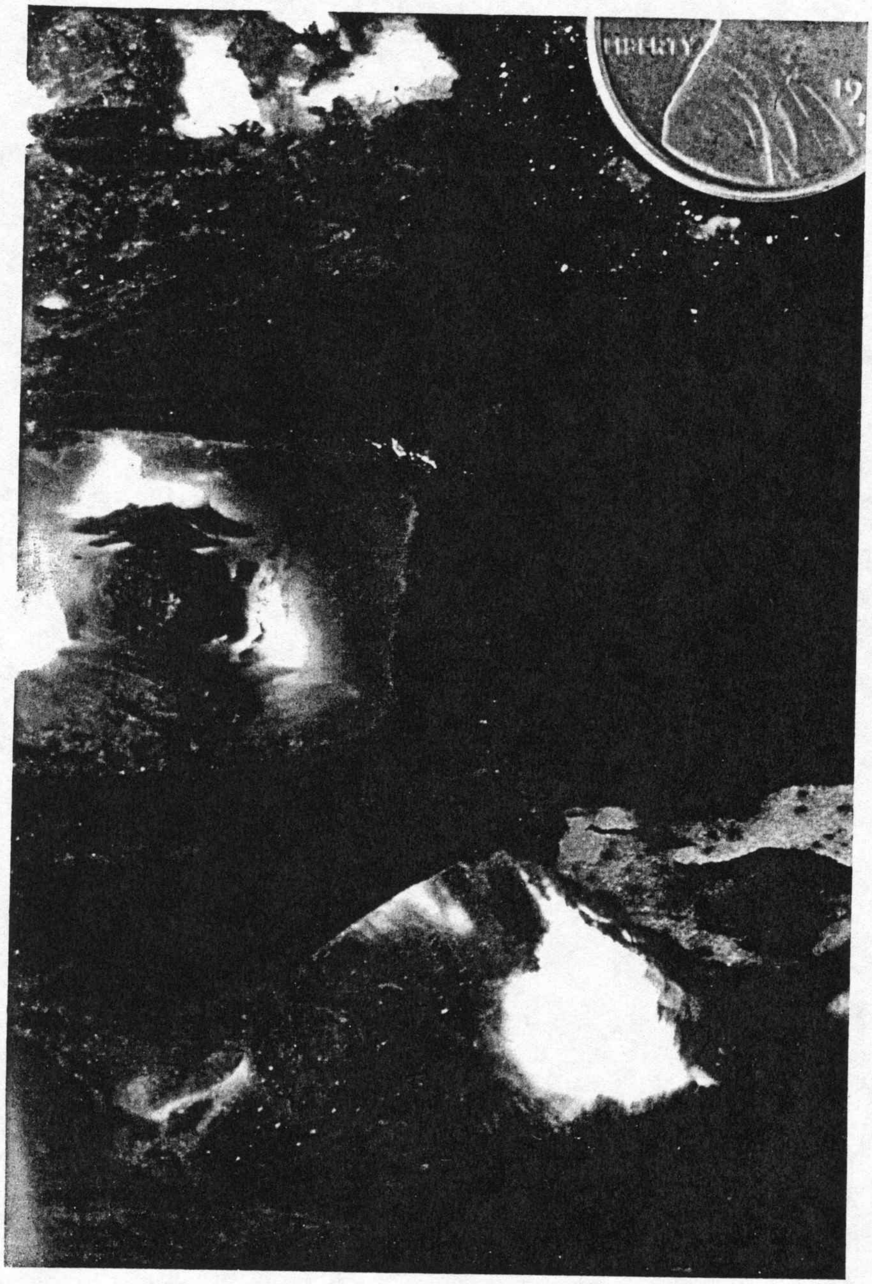
Plate 7 Sample 2-19-2, 319.4 m. Clay shale with alternating light and dark gray laminations, conformable lenses of fine grained halite and halite filled cracks.

Secondary structures are common within these beds. Post-depositional compaction of the original sediment probably accounts for the occasional microfaults and slumps that occur in these beds.

Red salt in cross-cutting veins or cracks is very nearly ubiquitous and has also been noted by previous investigations (Dellwig, 1963; Jones, 1965). The veins of halite typically are cross fibrous in structure. The red color is from interstitial films of reserved blue-green algae and associated hematite (Tilden, 1930). The veins are commonly only millimeters thick but can be as thick as 1 cm. Dellwig (1968) reported that these cracks form non-polygonal shapes on bedding surfaces and are commonly associated with slickensides. They are therefore thought to have formed subaqueously as a result of volume decrease through water loss of flocculated clay sediment.

Large (approximately 1 cm) clear euhedral halite crystals were also found locally in the shale but are relatively scarce (plate 8). These crystals commonly contain inclusions of clay anhydrite and polyhalite but lack the very finely dispersed granules of hematite that are so common in the other types of shale-associated halite. Zoned layers of the enclosing mud may form cube faces in the crystals (plate 8).

Plate 8 Sample 973-2, 300.0 m. Argillaceous euhedral halite crystals in laminated and breciated shale.



Similar occurrences of randomly oriented euhedral halite in a shale matrix have been reported from modern environments (Gornitz, 1965, reported by Shearman, 1978; Neev and Emery, 1967) and ancient evaporite deposits (Smith, 1972; Holdoway, 1975). The presence of halite with zoned mud inclusions and the disruption of the shale laminations is considered strong evidence that these crystals grew within brine saturated mud that was pushed aside by the force of crystallization of the growing halite. Holdoway (1975) speculated that the growth of large euhedral crystals is favored by slow growth in the sort of stable environment that would exist beneath a brine cover. In contrast, displacive lenses and pods of anhedral halite that also occur locally in the shale are probably a product of rapid crystallization (plate 7).

Small (0.5-3.0 cm) light gray, mottled anhydrite nodules occur within some of the shale layers (plate 9). This is the predominant shale-anhydrite association in the salt member. The limitations of interpreting sedimentary structures from a core become important in determining the origin of these nodule-like masses. Dellwig (1968) noted a well-developed polygonal pattern of anhydrite in shale from surfaces exposed in mine roofs. The development of a polygonal pattern of depressions in the shale was attributed to the effects of subaerial exposure due to regression and the anhydrite was presumed to be the initial precipitate of a

Plate 9 Sample 4-1-4, 338.1 m. Nodular - like anhydrite in contorted and breciated light and dark gray shale. Nodule truncates a near vertical red halite filled crack.

PHOTOGRAPH MISSING

Plate 9 Sample 4-1-4, 338.1 m. Nodular - like anhydrite in contorted and breciated light and dark gray shale. Nodule truncates a near vertical red halite filled crack.

subsequent inundation. The infilling anhydrite has a somewhat nodular form and can be as much as 7 inches (18 cm) wide and 2 inches (5 cm) thick. It is entirely possible that the nodular-like anhydrite in the Well No. 85 core is part of a larger polygonal structure that cannot be identified from a 4 inch core.

POLYHALITE

Polyhalite is present locally as a minor constituent between 294.2-293.1 m, 296.6-297.7 m, and 304.5-305.8 m (figure 4). This is approximately the medial portion of the upper part of the member. It has previously been described from mine exposures by Smith (1938), Runnels and others (1952), Swineford and Runnels (1953), and Swineford (1955). Jones (1965) noted the occurrence of this mineral in the medial portion of the salt member from the H.N.A.S. core. Detailed descriptions supplied by Runnels (1952) and Jones (1965) on the habit and mode of occurrence of the polyhalite fit the characteristics of the polyhalite found in the Well No. 85 core.

The polyhalite is commonly in microcrystalline blebs that reach a maximum dimension of about 5-10 mm. These masses are almost invariably red from the enclosed hematite and are composed of much smaller polyhalite spherulites. The spherulites commonly surround or are associated with masses of anhydrite or anhydrite-clay laminations and are found along intercrystalline halite boundaries. The polyhalite in core No. 85 is always found in recrystallized or partially-recrystallized halite. In the latter occurrence, individual needles invade and replace some zoned primary halite. Together, these relationships suggest that the polyhalite crystallized after the primary halite and anhydrite during diagenesis. Polyhalite pseudomorphs after gypsum and anhydrite are common in both modern and ancient evaporites (Holser, 1966), and the formation of polyhalite at the expense of anhydrite is predicted by equilibrium relationships in a theoretical six component system of Na - K - Mg - Ca - SO_4 - Cl - H_2O at a seawater concentration factor of approximately 45X (Eugster, 1980). It is therefore likely that diagenetic waters with a high concentration of potassium circulated through the salt and altered the anhydrite or gypsum to polyhalite.

BROMINE GEOCHEMISTRY

The interpretation of the origin and diagenesis of halite and potash deposits has been greatly facilitated by investigations on the behavior of bromine during the crystallization of these minerals. Bromine is normally not very reactive and ordinarily follows chloride through the geochemical cycle. Boecke (1908) discovered that bromine minerals do not form during the crystallization of salts from seawater. A fractionation occurs where chloride is removed from solution in preference to bromide. The bromine occurs only in solid solution as a replacement of chlorine in chloride minerals. Bromine determinations have been used to correlate chlorides within salt basins (Raup, 1970), as a tool in prospecting for potash minerals (Valyashko, 1956; Adams, 1969), and as a means for estimating the brine depth during the precipitation of evaporites (Kuhn and Hsu, 1974). Bromine concentrations can also be used to distinguish between primary and recrystallized marine salts inasmuch as the original precipitates lose substantial amounts of bromine through repeated dissolution and reprecipitation by continental waters (Holser _et_ _al_., 1972; Holdoway, 1975). The emphasis of this study is on the vertical concentration changes measured within selected beds represented in the core from Well No. 85, and their implications with respect to the depositional environment of the Hutchinson Salt Member.

BEHAVIOR OF BROMINE DURING HALITE DEPOSITION

Halite is the only chloride mineral occurring in the Hutchinson Salt and therefore the emphasis of the following summary will be on the behavior of bromine with respect to sodium chloride. Experimental studies of evaporating brines and precipitates have been discussed by Valyashko (1956), Holser (1966), and Braitsch (1971), and in the evaporation of seawater in artificial salt pans by Herrmann _et_ _al_. (1973).

The amount of bromide from a solution that will substitute for chlorine in the salt depends on the partition coefficient which is expressed as a ratio of concentrations in the solid and liquid phases.

From Braitsch (1971):

$$\text{the partition coefficient } b = \frac{\text{weight \% Br (mineral)}}{\text{weight \% Br (solution)}}$$

A value of 0.14 ± 0.01 has been obtained from concentrated seawater brine at the beginning of the halite precipitation stage (Holser, 1966). The coefficient decreases from this value at eleven times (11X) the concentration of normal seawater to 0.07 at a concentration factor of 65X at the beginning of the sylvite precipitation stage (Holser, 1966). This decreasing coefficient is accompanied by an inrease in $MgCl_2$ in progressively concentrated seawater. Presumably in $MgCl_2$ rich solutions, bromine is bound up in hydrated $MgCl_2$ complexes and is not available for incorporation into halite. Conversely, this effect is negligible in solutions with low $MgCl_2$ concentrations (Herrmann, 1973). However, the effect of this rather small decrease in the partition coefficient through the halite precipitation stage is more than counteracted by an increase in the bromine concentration of evaporating seawater which ranges from 500 ppm to about 2300 ppm over the same concentration range (11X-65X) (Valyashko, 1956). Therefore the absolute amount of bromine in a given halite sequence that precipitates from a restricted body of seawater will increase with each successive layer.

The theoretical minimum bromine concentration of the initial halite precipitate from concentrated seawater is 75 ppm. However, the observed minimum bromine content in halite ranges from 20-75 ppm (Holser, 1966). This discrepancy has yet remained unexplained.

Theoretical bromine profiles have been constructed using two types of sedimentary models (Holser, 1966). In figure 6, the vertical axis represents that fraction to which an original hypothetical depth of brine will be filled by a solid layer of salt at any point during the halite precipitation stage of that brine. The line labeled zero inflow shows the shape of a bromine profile that would be derived from a halite sequence that had precipitated from a totally isolated body of evaporating seawater. The upper profile, labeled constant volume, would be expected from salt precipitated in a body of brine where an equilibrium is maintained between loss of seawater through evaporation, and replenishment of the brine by inflow of normal seawater. The latter scenario is essentially the barred basin model proposed by King (1947), later refined by Scrutton (1953). This same profile form has been found to characterize halite sequences such as the 700 m thick Strassfurt Series of the German Zechstein (Kuhn, 1968) and the 55 m and 30 m thick

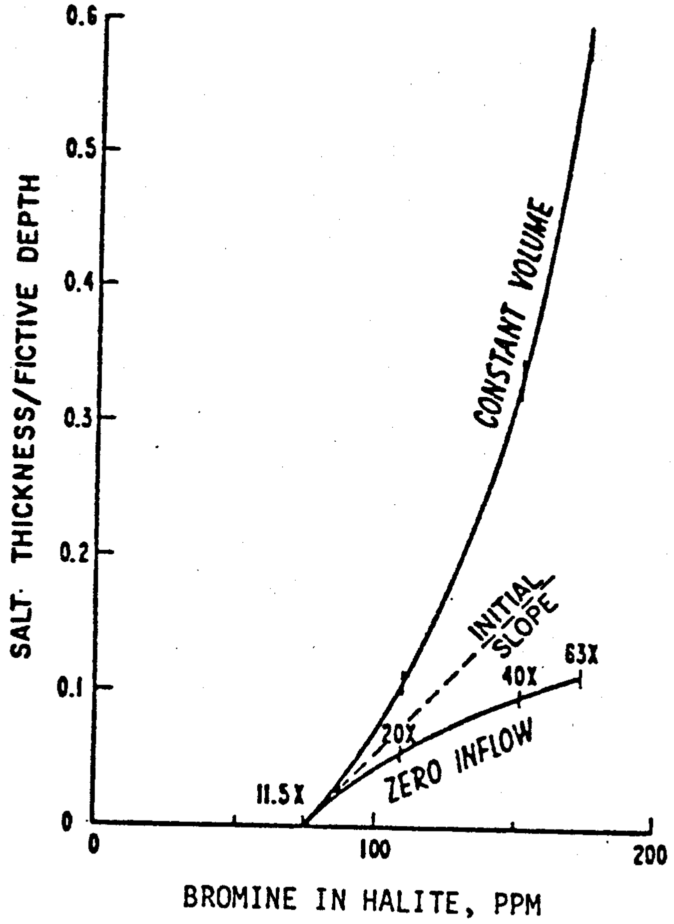


Figure 6 Theoretical bromine profiles in halite, corrected for the variation in distribution coefficient with brine concentration. The ordinate represents the fraction to which an original fictive depth of brine has been filled by solid salt at any point during the sequence of salt crystallization. (from Holser, 1966, p. 254.).

salt beds 4 and 5 in the Paradox Member of the Hermosa Formation (Raup and Hite, 1978 - figure 7).

Commonly bromine profiles through sections of about 50-150 m fail to resemble the constant volume or isolated basin theoretical profiles and tend to be very irregular. The bromine concentrations in these types of deposits tend to rise and fall significantly over vertical intervals of less than a meter to several meters. The Hutchinson Salt, Salina Formation (Michigan), Ochoan Series (Texas-New Mexico), and the Prairie Evaporite Formation (Saskatchewan) are all characterized by irregular vertical distributions of bromine which typically range from 30-80 ppm and occasionally show increases to 150 ppm (figure 8). The irregularity has been attributed to the cumulative effects of repeated seawater incursions to the respective basins during halite precipitation. Dissolution and reprecipitation in bromine deficient water is perhaps another cause as the bromine concentrations of much of this halite are below the theoretical minimum expected for the initial halite precipitated from normal seawater (Holser, 1966).

BROMINE GEOCHEMISTRY OF THE HUTCHINSON SALT

Any genetic model of the Hutchinson Salt must account for the irregularity of the bromine profile and the narrow range of bromine concentrations. Two hypotheses were considered at the beginning of this investigation. One possi-

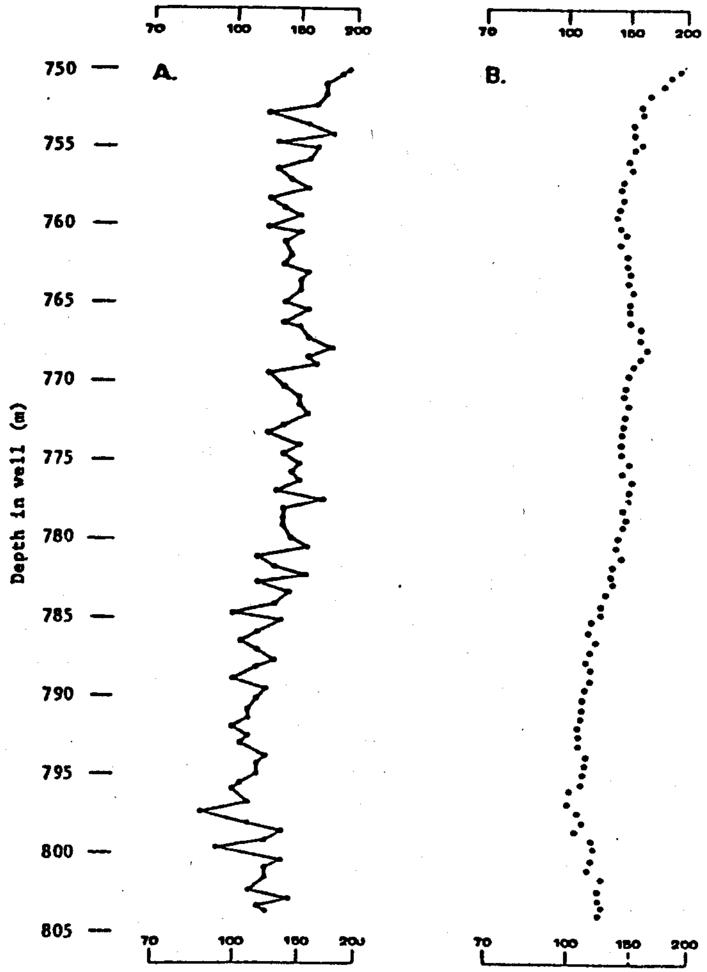


Figure 7. Bromine profile of salt bed 4, Paradox Member, Hermosa Formation. A. Analysis values; smoothed profile in parts per million.

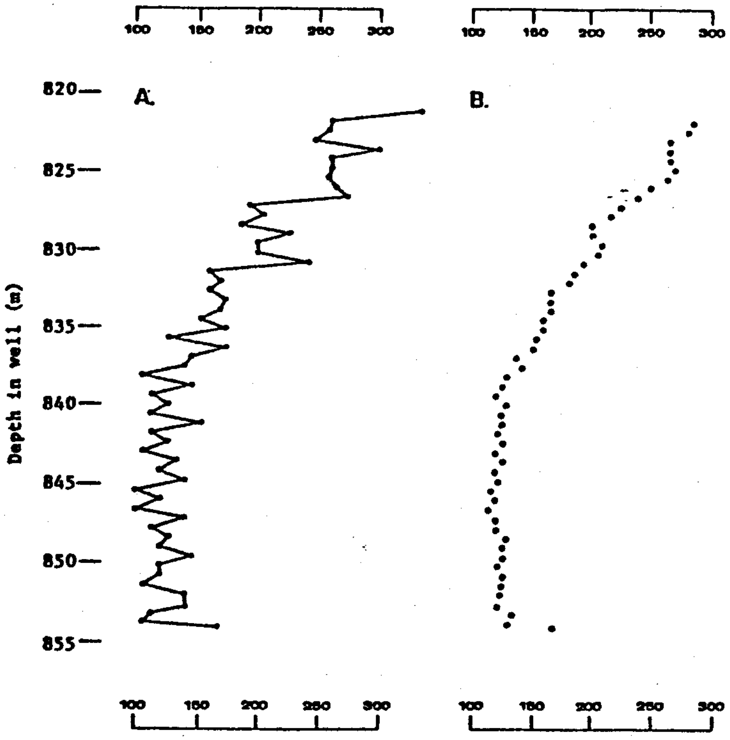


Figure 7. Bromine profile of salt bed 5, Paradox Member, Hermosa Formation. A. Analysis values; smoothed profile in parts per million. (Figures from Raup et al, 1978.)

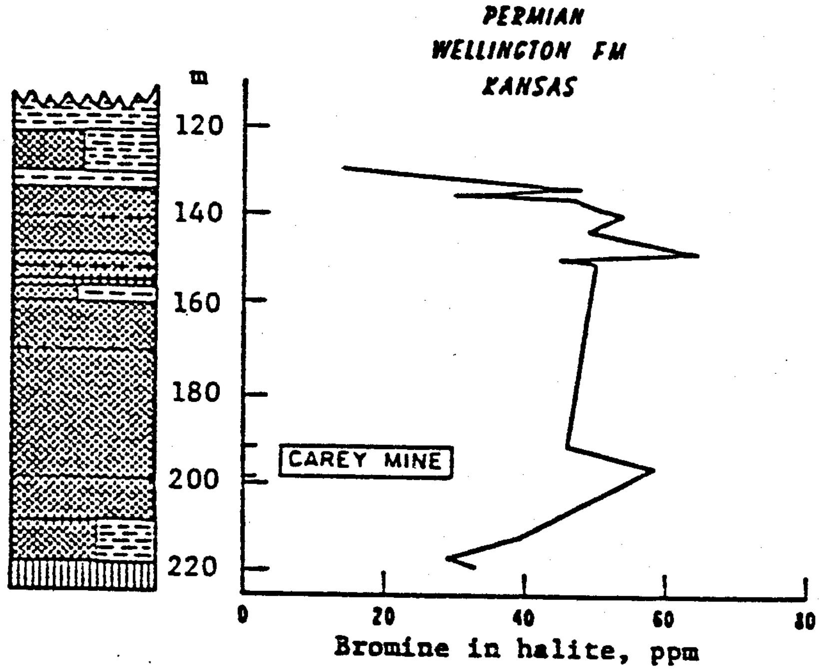


Figure 8. Bromine profile through the Hutchinson Salt Member of the Permian Wellington Formation, Kansas. Crosshatching is mainly salt, vertical lines are anhydrite, and dashed lines are shale, all highly generalized. (after Holser, 1966, p.257.).

bility is that the entire sequence is actually a composite of many successive cycles of crystallization. The suggestion here is that the gradually increasing concentrations that characterize the theoretical constant volume model should be apparent at some scale smaller than the total thickness of the salt member. Halite precipitation in a supratidal brine-pan setting similar to the brine pans of Baja California has been rejected on the basis of petrographic evidence. The second hypothesis is that the bromide concentrations are truly irregular on any scale. This could be due to the fact that in a shallow basin the brine concentration would be subject to frequent fluctuations because of the small volume of brine. The halite precipitated from such a brine would reflect the same irregularities in bromine concentration.

It was the author's original contention that the irregular bromine profile of the Hutchinson Salt could be deciphered by analyzing thin sequences of halite that occur between significant lithologic breaks such as shale or anhydrite-rich intervals. Only those halite intervals containing chevrons were sampled for bromine analysis, as there is a chance that some of the recrystallized salt has undergone bromine redistribution which might have obscured the original bromine profile.

METHOD OF ANALYSIS

The separation of the chevron from the clear halite was a difficult and time-consuming procedure and some beds contained only a small amount of chevron halite. Therefore, an analytical technique for the determination of bromine concentrations was chosen that did not require a large sample size. Analysis for bromine in sodium chloride was accomplished by a spectrophotometric measurement of the sample solutions in which phenol red had been brominated by oxidized bromide (Taras and others, 1971).

PREPARATION OF SAMPLES

Samples were taken throughout the salt member wherever the chevrons were large enough and abundant enough so that a sample of approximately one-half gram could be extracted. Three particularly well-preserved sequences were found within the core with thicknesses of 0.5-3 meters. The sample spacing within these units was approximately 5-30 cm (figures 9, 10).

The salt samples were extracted from core slabs with the aid of a small hand held hobby saw. Care was taken not to include any clear halite with the chevron halite or vice versa. Anhydritic or argillaceous halite was avoided. The halite was then ground and washed in absolute alcohol in an effort to remove the brine from the fluid inclusions. This

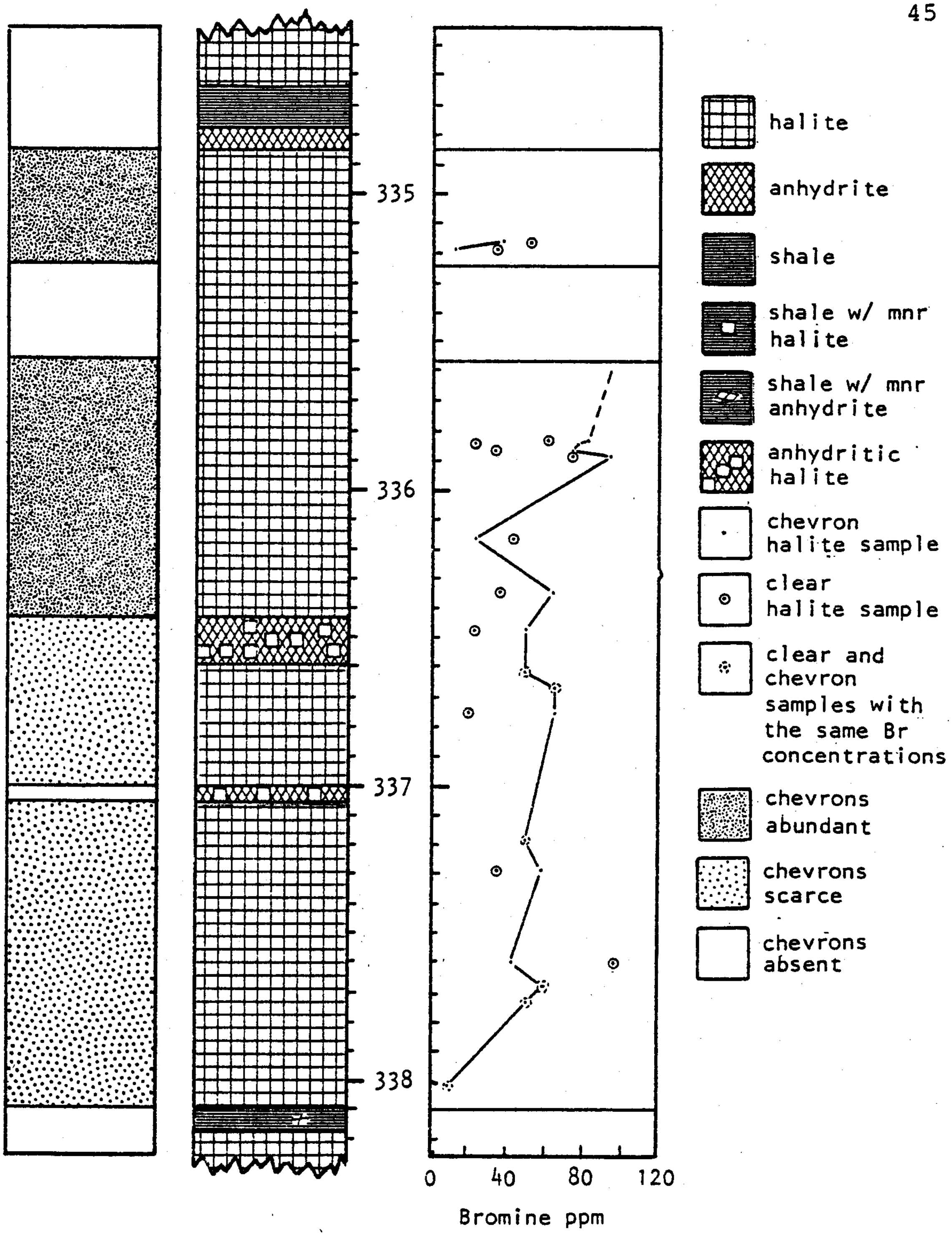


Figure 9. Bromine profile through bed 1 of the Hutchinson Salt. Relative chevron abundances shown in the left column.

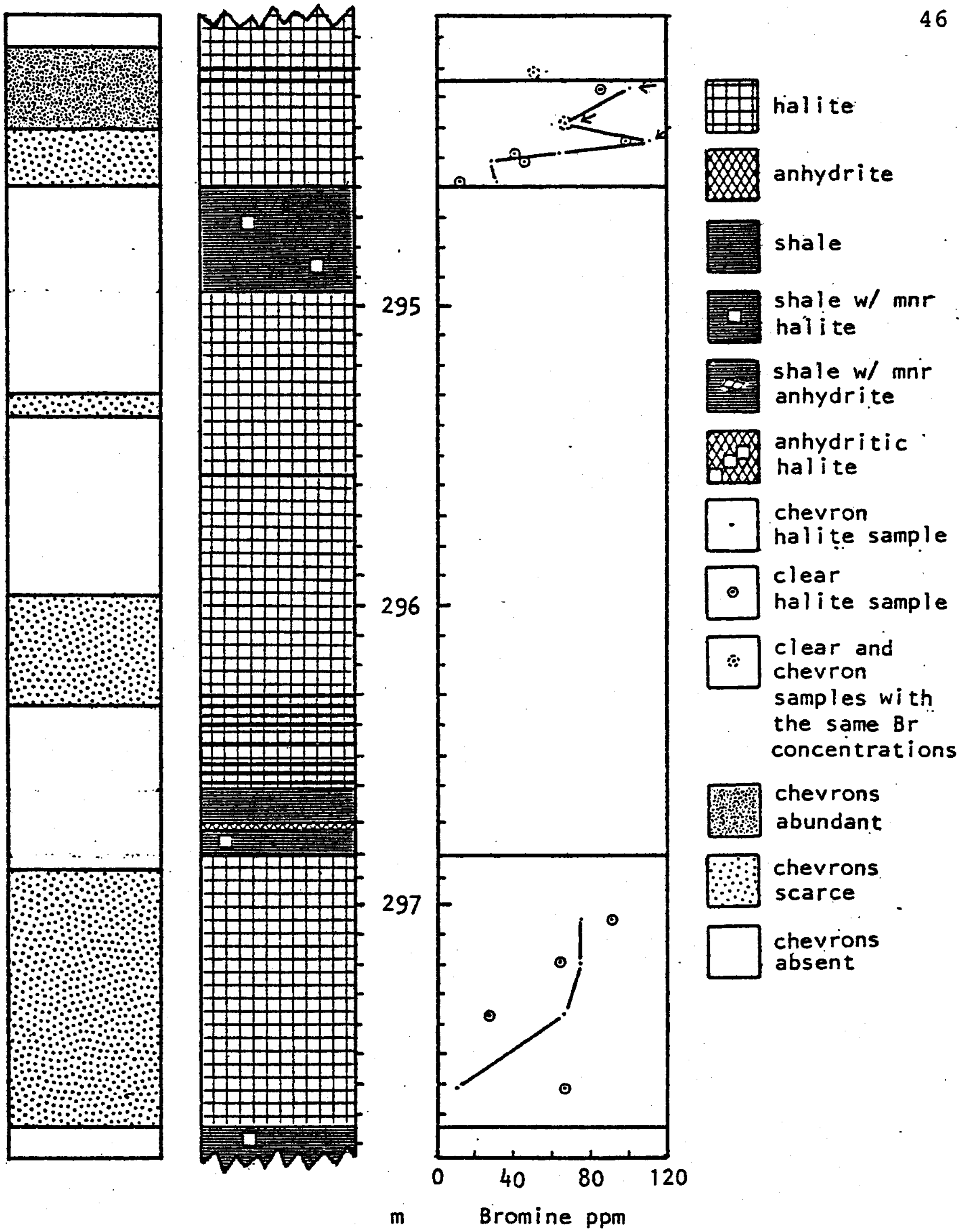


Figure 10. Bromine profiles of bed 2 at the bottom, and bed 3 at the top of the figure. Relative chevron abundances shown in the left column. Arrows denote data points with a precision of ± 30 ppm at one sigma.

was done so the bromine conentration data would represent the bromine concentrations in the halite itself and not some cumulative concentration from the halite and the highly concentrated brine in the inclusions. The solutions for analysis were then made by dissolving 0.15-0.16 g sodium chloride in 100 ml H_2O to yield a concentration of 1.5-1.6 g/l.

PREPARATION OF STANDARDS

Whittemore et al. (1979) found that although there was no mention of interferences in the description of the procedure by Taras and others (1971), higher concentrations of chloride were found to appreciably increase the absorbence of the phenol red at 590 mμ. Thus the uncorrected bromide concentrations determined by this procedure would tend to be higher than the actual bromide concentrations. The effect of sulfate concentrations up to 5660 mg/l in Whittemore's study were within the margin of experimental error for this technique.

The standards were made with approximately the same chloride concentrations as the samples so that the effect of the chloride interference on the bromine concentration computations could be neglected. A pure Ultrex sodium chloride with a Br concentration of less than 0.5 ppm was used for this purpose.

Standards at Br concentrations of 25, 38, 64, 128, and 255 parts per million (ppm) of chloride were analyzed regularly along with the samples. A precision of ±12 ppm at two sigma was estimated for most samples (Tables 1 and 2); however, duplicate analyses of samples containing minor amounts of an unidentified white insoluble material revealed a precision of only ±30 ppm at one sigma (Table 2).

BROMINE PROFILES FROM CHEVRON HALITE

The three continuous halite sequences, 334.85-338.11 m, 296.83-287.74 m, and 294.20-294.60 m will be referred to as Beds 1-3, respectively (figure 9 and 10). Each bed is situated stratigraphically between shale beds of various thicknesses. These beds are fairly representative of other halite beds within their respective parts of the sequence as it is not uncommon for continuous halite beds to reach thicknesses of 2-3.5 m in the lower part of the member, whereas 1.0-1.5 m is typically the maximum in the upper part.

The basal halite from Bed 1 has a bromide content less than 12 ppm. (Table 3). The overall trend within the bed (figure 9) is a gradual increase from the base followed by fairly constant values throughout most of the interval with a small increase at the top. The 20 cm thick section at 335.5 m has clearly undergone some sort of solution related slumping which is suggestive of introduction of

Table 1. Deviation of standard solution bromine concentrations from calibration lines.

	Bromine concentrations of standards (mg/l)			
Set No.	0.040	0.060	0.100	0.200
10/19	-.025 +.005	.000 .000	.000 +.005	.000 .000
10/22	.000 .000	+.005 -.010	+.005 -.005 -.010	.000 .000
10/23	+.010 -.010	+.010 -.010	-.005 -.015	-.010
10/27	.000 +.005	.000 -.010	-.005 -.020	+.015
10/29	.000 .000	.000 .000 .000	.000 -.005	.000 .000
10/31	.000 +.005	.000 -.010 -.020	+.005 +.025	+.020
Two sigma -	0.018 or 11 ppm Cl	0.016 or 11 ppm Cl	0.022 or 14 ppm Cl	0.018 or 11 ppm Cl

Table 2. Reproduceability test for bromine analysis of halite samples.

Sample No.	Br concentration (ppm) Set 1	Set 2	
31	3	25	
32	65	70	
33	74	69	
34	74	74	
35	30	25	Two sigma 16 ppm
36	26	29	

Halite samples with minor amounts of insoluble residue.

Sample No.	Br concentration (ppm) Set 1	Set 2	
38	111	87	
39	99	64	
40	65	29	One sigma 30 ppm
41	49	25	

Table 3. Bromine concentrations of halite samples in Bed 1.

Sample No.	Core box location	Elevation above salt base (m)	Depth to top of bed (m)	Br concentrations (ppm) Chevron halite	Br concentrations (ppm) Clear halite
1	4-16-3	1.07	351.29	--	28
2	4-1-5	14.34	338.01	9	9
3	3-20-2	14.62	337.73	51	52
4	3-20-3	14.75	337.60	42	96
5	3-20-5a	15.07	337.29	58	34
6	3-20-5b	15.17	337.18	48	50
7	3-19-3a	15.60	336.75	65	20
8	3-19-3b	15.69	336.66	65	67
9	3-19-4a	15.75	336.61	49	53
10	3-19-4b	15.88	336.47	50	23
11	3-19-5	16.01	336.34	64	36
12	3-18-1	16.19	336.16	23	43
13	3-18-3a	16.47	335.88	95	74*
14	3-18-3b	16.49	335.87	74	33*
15	3-18-3c	16.51	335.84	77	23
16	3-17-1a	17.18	335.18	12	34
17	3-17-1b	17.19	335.17	37	52
18	3-12-4	22.12	330.24	63	--
19	3-11-1a	22.45	329.90	42	25
20	3-11-1b	22.50	329.85	70*	17
21	3-11-2	22.54	329.82	41	10
22	3-11-4	22.93	329.43	65	54
23	3-2-2	30.34	322.02	29	39
24	2-17-1	34.46	317.89	57	71
25	2-16-1	35.30	317.05	53	59
26	2-16-6	35.87	316.48	85	93
27	2-10-1	40.71	311.65	35	67
28	2-4-4	46.36	305.99	63	93
29	976-3	51.49	300.87	70	52

Fig. 9 bed 1

Table 3 (continued)

Sample No.	Core box location	Elevation above salt base (m)	Depth to top of bed (m)	Br concentrations (ppm) Chevron halite	Br concentrations (ppm) Clear halite
30	973-3	52.41	299.94	19	34
31	964-1	54.74	297.61	3	64
32	964-2	55.01	297.34	65	26
33	964-4	55.16	297.19	74	63
34	964-5	55.30	297.05	74	89
35	949-2a	57.76	294.59	30	11
36	949-2b	57.83	294.52	26	44
37	949-2c	57.86	294.49	62	38
38	949-2d	57.90	294.45	111*	97*
39	949-3a	57.95	294.40	65*	58*
40	949-3b	58.07	294.28	99*	84*
41	949-4	58.14	294.21	49	56

* Sample contained minor amounts of water insoluble material which reduced precision to approximately ±30 ppm at one sigma

undersaturated brine and should therefore be considered the top of this sequence rather than the shale bed at 334.8 m. The low bromine concentrations in samples immediately overlying this unit (335.5 m) support this contention.

The bromine content is nearly the same throughout the bed, indicating very little change in the salinity of the brine during deposition. Brines must have been refluxing out of the basin while seawater was flowing in because without the loss of brines, bromine would have accumulated, reflecting a total increase in salinity. The bromine profile of Bed 1 shows that the influx-evaporation-reflux system must have been very nearly balanced except in the early stages of deposition where the profile more resembles that of a closed basin.

The bromine profile of Bed 2 (figure 10) shares most of essential characteristics of the Bed 1 bromine profile. It begins with a very low concentration value. The curve gradually rises and maintains an almost vertical profile through much of the interval with concentration values in a range of 65-75 ppm. Similarly, a well balanced influx-evaporation-reflux system must have been operative during the deposition of Bed 2.

As in Beds 1 and 2 the basal halite of Bed 3 has a low bromine concentration value of 30 ppm. Thereafter the profile is somewhat irregular with a rapid vertical increase of bromine concentration to 111 ppm followed by a drop to

NO PAGE 54

65 ppm and again a rise to 99 ppm at the top of the bed. However, the overall trend is one of rapidly increasing bromine concentrations. The first 0.5 cm thick shale at the top of the bed appears to have marked the beginning of the decreased salinities as the overlying salt has a relatively low bromine concentration value of 49 ppm.

It appears the influxing and refluxing of seawater and brines came to an equilibrium that existed for a long time during the deposition of Bed 1 and a shorter time for Bed 2. This somewhat typical development of an equilibrated influx-reflux system in the lower intervals of the Hutchinson Salt must have been operative for progressively shorter periods of time as the sea slowly regressed and water depths became progressively shallower. Presuming a barrier existed between the basin and the larger Permian sea to the south, sea level might have dropped to a point where the Kansas basin became isolated thus halting brine reflux. This scenario would account for the steep positive slope of Bed 3.

DISCUSSION

The deposition and diagenesis of the Hutchinson Salt must have been a rather complicated series of events controlled by a unique balance of geology and climate. However, a model involving minor transgressions and regressions in a barred basin can account for much of the stratigraphic, lithologic, and geochemical features that characterize the Hutchinson Salt. The importance of fresh water influxes as a factor controlling paleosalinity variations is largely unknown as its effects can perhaps only be realized in an investigation that explores the geochemical nature of the deposit in more than one dimension.

The existence of a topographically high barrier or shelf that might have isolated or restricted the Kansas basin has neither been proven nor disproven. The circulation of oceanic water across a long shallow continental shelf that is not restricted by a barrier may result in the saturation of seawater and subsequent precipitation of evaporites (Richter-Bernburg, 1955). However, it is difficult to account for the positive slope of the Bed 3 bromine profile and those of the basal portions of Beds 1 and 2 without proposing a severe restriction of refluxing brine from the basin during the deposition of these units. The bromine profile that would be expected from the non-barred shelf model or so called saturation shelf model would be nearly vertical as seawater influx would continually be accompanied by a brine reflux. The saturation shelf model therefore does not adequately account for the steep positive bromine profile segments of halite units from the Well No. 85 core.

Perhaps the most significant result of this study is the demonstration of a correlation between paleosalinity changes and shale deposition. Bromine concentrations in the halite tend to be highest just below shale layers and lowest just above them. It appears that increases in brine salinity during the deposition of halite frequently culminated with the deposition of layer of shale.

The entrapment of basin brine is probably the mechanism that caused the observed paleosalinity increases. The same mechanism may have resulted in the deposition of the culminating shale layers. Much of the clay and fine silt-sized particles that were supplied from basin margins may have been held in suspension or even flushed from the basin by tidal and reflux currents while the basin was only partially restricted from the southern ocean. Severe restriction or complete isolation of the basin would result in stagnation and deposition of the very fine detrital material.

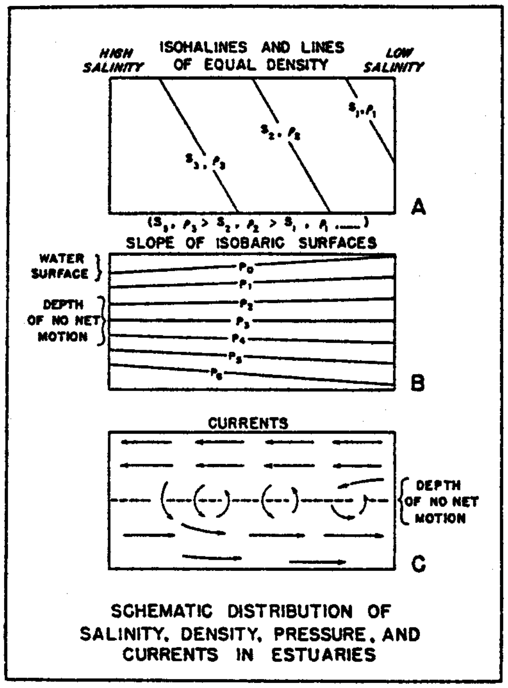
Minor sea level transgressions and regressions could have caused these alternating periods of increased and decreased communication with the open sea. Sea level changes have previously been proposed to have caused the formation of polygonal anhydrite filled cracks in some shale in the Hutchinson Salt (Dellwig, 1963). The periodicity of faunal occurrences in the upper and lower members of the Wellington Formation from outcrops along the basin margin have also been attributed to sea level fluctuations (Tasch, 1964). These fluctuations, if this hypothesis is correct, may have been the result of repeated continental glaciations that are known to have occurred in early Permian time (Silver, 1969).

The importance of fresh water input as a controlling factor of the observed paleosalinity trends is difficult to assess with the existing bromine data. If a brine were created by a mix of surface runoff and basin brine, the degree of dilution and therefore the degree of bromide deficiency should be greater in the near-shore halite than in the halite deposited at a central location in the basin. Bromide values in stratigraphically equivalent laminations in the Upper Silurian evaporites (Michigan) show just such a relationship (Kunasz, 1966). The range and mean of bromine concentrations in the Carey Salt Mine from Hutchinson, Kansas (Holser, 1966) are very close to those of the Well No. 85 core. This is, however, not surprising as both sample suites are from approximately the same part of the basin and thus no clues as to the significance of fresh water influx in the depositional environment are gained from such a comparison.

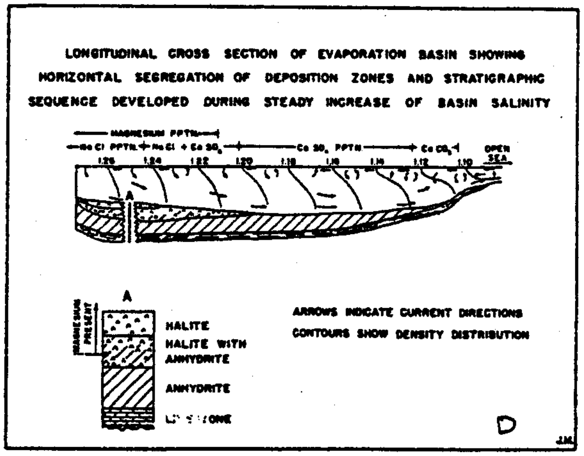
DEPOSITIONAL MODEL

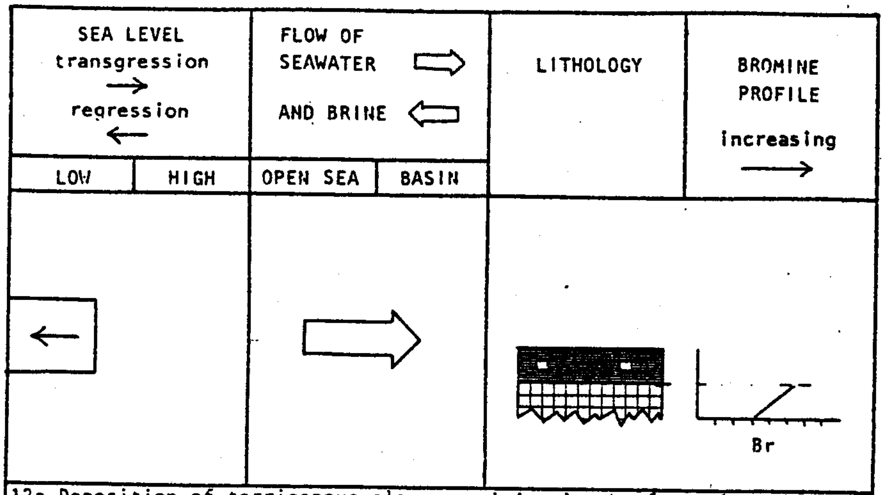
The bromine profiles from this study suggest that a sequence of halite between two shale units constitutes one cycle of deposition. The ideal development of an evaporite-shale sequence that might result from transgressions and regressions in a barred basin is outlined in figure 12. The circulation of influxing seawater and refluxing brine are patterned after a model proposed by Scruton (1953). An excessive rate of evaporation removes water from the restricted basin, thus causing a slope of the sea surface to develop. A continuous flow of additional water from the ocean is initiated in response to this surface slope (figure 11D). A horizontal salinity-density gradient is established across the basin (figure 11A) which in turn creates sloping pressure surfaces at depth (figure 11B). A reflux current will be established if the potential for flow exceeds the hydrostatic head, the topographic restraint posed by the barrier, bottom friction and the frictional forces due to oppositely directed currents (figure 11C). The reflux current will of course stop if the basin brine drops below that of the barrier.

Figure 11. The development of an influx - reflux circulation pattern in a restricted basin due to a horizontal salinity gradient (from Scruton, 1953).

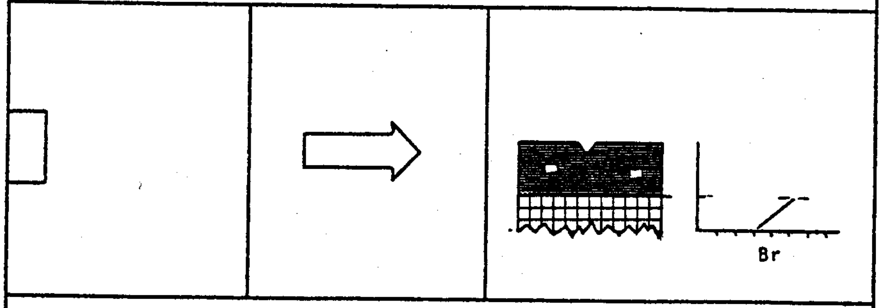


SCHEMATIC DISTRIBUTION OF SALINITY, DENSITY, PRESSURE, AND CURRENTS IN ESTUARIES

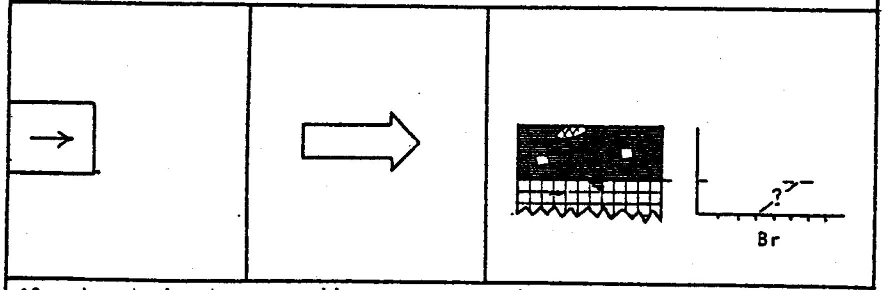

LONGITUDINAL CROSS SECTION OF EVAPORATION BASIN SHOWING HORIZONTAL SEGREGATION OF DEPOSITION ZONES AND STRATIGRAPHIC SEQUENCE DEVELOPED DURING STEADY INCREASE OF BASIN SALINITY



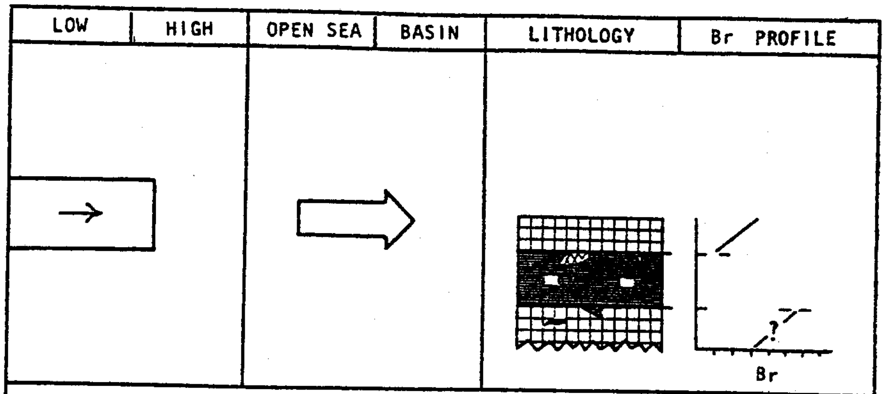
12a Deposition of terrigenous clay, resulting in the formation of shale w/ mnr amounts of ingrown halite. Upper segment of Br profile from previously deposited halite shown in right column.



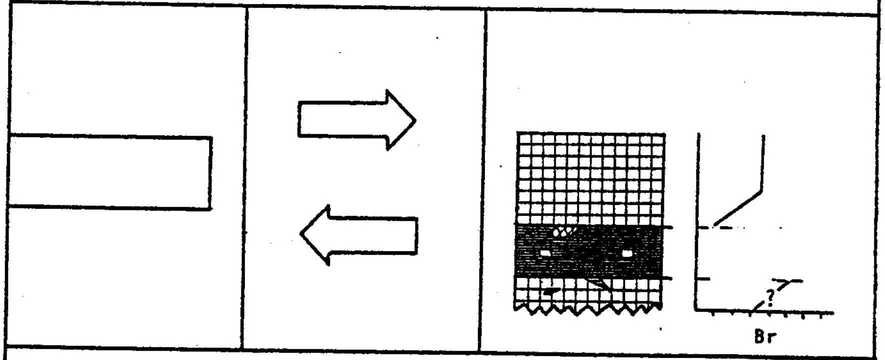
12b Continued regression, exposure of basin margins and development of polygonal mud cracks.



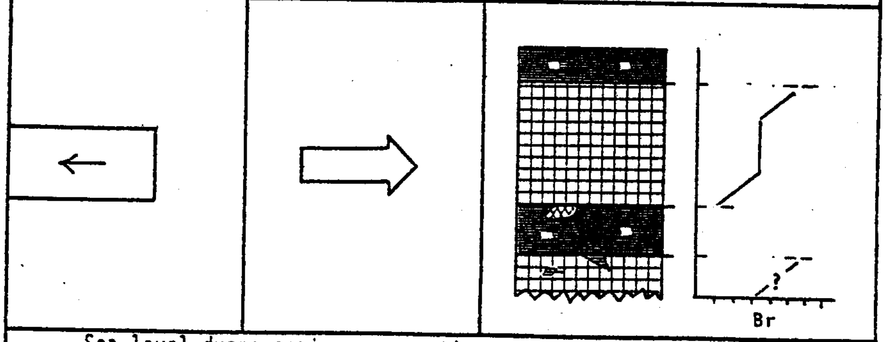
12c Inundation by penesaline seawater, subsequent recrystallization of underlying halite, degeneration of lower shale contact, dilution of basin brine and precipitation of anhydrite in shale.



12d Continued influx and evaporation without reflux and accumulation of a halite sequence with a steep positive bromine profile.



12e A density - salinity gradient is established and a backflow of dense brine is initiated which stabilizes salinity.



12f Sea level drops again, evaporation exceeds influx, basin brine level drops below that of the barrier and the reflux current stops A halite sequence is deposited with a positive bromine profile.

The lithologic column on the right side of figures 12a-f shows the type of rocks and sedimentary structures that might form at each successive stage. All the features and relationships shown are characteristic of a typical 0.5-3 m cycle in the Hutchinson Salt.

The development of a coinciding bromine profile in the far right column is according to the theoretical behavior of bromine in a constant volume situation (figure 6) and that of a zero inflow or inhibited reflux situation. The development of this profile also reflects the tendencies found in the bromine profiles of Beds 1-3; however, a certain amount of ambiguity exists in exactly what shape the profile assumes in upper segments of Beds 1 and 2. More data need to be collected in these portions.

The deposition of shale with minor amounts of anhydrite and halite occur during the regressive phase as the detritus is trapped in the basin (figure 12a). Continued regression lowers the brine level and exposes the marginal portions of the basin resulting in the formation of large polygonal mud cracks (figure 12b). At the beginning of the transgressive phase, the inundation of penesaline seawater results in the slow recrystallization of underlying halite to a limited depth, degeneration of the lower shale contact, dilution of the hypersaline basin brine to a penesaline concentration, and precipitation of anhydrite in the polygonal mud cracks (figure 12c). The combination of influxing penesaline seawater and subsequent evaporation in a closed basin without any refluxing of brine produces a halite sequence with a steep positive bromine profile (figure 12d). Once a strong density-salinity gradient is established a backflow of dense brine to the sea is initiated which stabilizes brine salinity and flushes appreciable amounts of terrigenous clay out of the basin (figure 12e). Sea level drops again, which decreases the inflow of seawater to the basin. Evaporation soon begins to exceed inflow and the brine elevation in the basin falls below that of the barrier, thus stopping the reflux of brine. A halite sequence with a steep positive slope accumulates which is followed by the deposition of a shale layer as the basin stagnates (figure 12f).

SUMMARY AND CONCLUSION

The boundary relationships of chevron halite and intimately associated clear halite along with the lack of dissolution structures suggest a subaqueous origin for the halite of the Hutchinson Salt Member. Chevron halite is thought to form during rapid crystallization of brine with accumulations rates perhaps as much as centimeters per month. However, observations of experimentally grown halite have shown that some clear halite will form around cloudy halite if the process is slowed to a rate of centimeters per year. Primary halite in the Hutchinson Salt is believed to have formed at approximately the same rate. Since the average thickness of halite between clay-anhydrite laminations is on the order of a few centimeters, it is not unreasonable to consider them yearly layers (Jahresringe).

Recrystallized halite is the predominant form of halite in the Hutchinson Salt Member. The scarcity of collapse structures indicates that recrystallization was a slow layer-by-layer process. The interstratification of primary and recrystallized halite suggests that basinal brines intermittently became undersaturated with respect to sodium chloride.

Nodular-like anhydrite masses in some laminated shales of the salt member may be part of anhydrite-filed polygons that have been observed in Kansas salt mines. Shale beds also commonly contain lenses and pods of anhedral halite and rarely euhedral halite crystals that grew displacively in soft unconsolidated sediment beneath a well-established brine cover.

A small amount of polyhalite was found in the medial part of the upper part of the member. It commonly replaces anhydrite and can be seen to invade primary chevron crystals and is therefore thought to have formed diagenetically.

The bromine profile in the middle portions of two of the sampled units is nearly vertical and it is therefore suggested that a balanced influx-evaporation-reflux system was operative in the basin that kept the salinities fairly constant throughout the time of deposition of the Hutchinson Salt. However, bromine concentrations tend to be high just below shale layers and low just above them. The equilibrium that was established between influx and reflux was probably destroyed intermittently by sea level changes. Sea level lowering decreased the rate of seawater inflow to the basin to the point where evaporation exceeded inflow. The basin brine level then dropped below that of the barrier, cutting off the reflux of brine to the ocean, which resulted in the deposition of a layer of halite with a positive bromine profile. At the lowest sea level stand stagnation of the basin brine may have resulted in the deposition of substantial amounts of previously suspended clay. A subsequent transgression would result in the inundation of the basin with normal seawater and dilution of the concentrated basin brine.

The effect that fresh water input may have had on the observed paleosalinity trends is largely unknown and probably impossible to evaluate with existing data.

In conclusion, paleosalinity changes and shale deposition were somehow linked during the lower Leonardian in Kansas. Perhaps small-scale lithologic correlations exist in other evaporite units that exhibit so-called irregular bromine profiles. The discovery of these relationships may represent an important step toward an understanding of their apparent large scale irregularity and the unique balance of the controlling geologic and climatic influences.

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CORE LOG

Well No. 85, Schroeder ethane storage, Bushton Terminal, Kansas

Location: Ellsworth Co., T17S R9W, sec. 32, NW1/4 NW1/4.
Top of salt: 286.42 m (939.74 ft) below ground level.
Total depth: 357.61 m (1173.32 ft).
Date drilling: 8/5/79

Depth		Thickness		Description
m	ft	m	ft	
286.42	939.74			Top of core.
286.72	940.73	.30	.99	Clay shale, disturbed light and dark gray laminations, bedded light gray microcrystalline anhydrite in lower 6 cm., a few red halite filled cracks.
287.16	942.17	.44	1.44	Clear halite slightly argillaceous and anhydritic (5%), fine - moderately coarse, coarse - very coarse in lower 9 cm., top of Hutchinson Salt.
288.19	945.55	.53	1.74	Clay shale, brecciated, microfaulted, and contorted light and dark gray laminations, a few thin laminations of brown mottled medium grained sandstone, contains small patches of ingrown halite and a few red halite filled cracks.
288.57	946.57	.38	1.25	Halite locally mixed clear and cloudy argillaceous and anhydritic (15-20%), orange tint, fine - medium grained.
289.02	948.27	.45	1.47	Halite, interbedded clear and cloudy fine grained halite separated by diffused bands of clay and anhydrite, also contains a vertically oriented concentration of clay and anhydrite from 20-30 cm above base of unit.

Depth		Thickness		Description
m	ft	m	ft	
290.33	952.57	1.31	3.77	Clear halite, irregularly distributed argillaceous and anhydritic patches (5-10%), medium - coarse grained.
290.46	953.00	.13	.43	Clear halite, orange tint, contains a few small clods of shale, fine grained.
290.58	953.39	.12	.39	Clear halite, contains abundant small shale clasts (50%), orange tint, upper contact is unconformable with 7 cm of relief, very fine grained.
291.73	957.17	1.15	3.77	Clear halite, contains thin (less than 0.5 cm thick) disrupted dark gray anhydritic shale laminations from 10-15 cm apart in lower 55 cm, transitional to evenly distributed small argillaceous - anhydritic patches (10%), medium - coarse grained.
292.07	958.28	.34	1.12	Halite, bands of clear and chevron halite from 1-4 cm thick separated by 1-3 cm thick disrupted dark gray anhydritic shale laminations, fine - medium grained.
293.01	961.37	.94	3.08	Clear halite, 1-2 cm thick disrupted dark gray anhydritic shale laminations from 4-16 cm apart, medium - coarse grained.
293.60	963.30	.59	1.94	Clear halite, contains finely dispersed argillaceous - anhydritic patches (15-20%), also 0.5-1 cm thick light and dark gray laminated shales from 7-30 cm apart, medium - moderately coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
294.20	965.27	.60	1.97	Halite, mostly clear except for a few small (less than 1 cm) wispy chevrons in the lower 4 cm, contains disrupted dark gray anhydritic shale laminations 1-2 cm thick, 2-12 cm apart, medium - coarse grained.
294.60	966.58	.40	1.31	Halite, bands of clear and chevron halite separated by 0.5-2 cm thick disrupted dark gray anhydritic shale laminations from 1-15 cm apart, small - large chevrons (0.5-2 cm), some small blebs of orange polyhalite, two thin (less than 0.5 cm) laminated shale layers in upper 5 cm, fine - moderately coarse grained.
294.95	967.73	.35	1.15	Clay shale, contorted and brecciated light and dark gray laminations, contains fine - moderately coarse polyhalitic euhedral halite crystals and halite in cracks (total halite 15%).
295.30	968.88	.35	1.15	Clear halite, contains irregularly distributed shale clods (10%), local orange tint, medium - moderately coarse, locally fine grained.
295.38	969.08	.08	.26	Halite, clear with a few small wispy chevrons, contains less than 1% clay or anhydrite, fine - medium grained, locally moderately coarse.
295.56	969.67	.18	.59	Clear halite, contains evenly distributed patches of anhydritic shale (10%), medium - coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
296.61	971.34	1.05	3.45	Halite, clear with a few small (0.5 cm) and medium (1 cm) in the middle 1/3 of the unit, contains laminated light and dark gray 0.5-1 cm thick anhydritic shale layers in lower 30 cm which grade into disrupted shale layers which in turn grade in to irregularly distributed argillaceous - anhydritic patches in upper 1/3, laminations from 1-2 cm apart, minor specks of orange polyhalite throughout, fine - moderate coarse grained.
296.83	972.07	.91	2.99	Halite, mostly clear with a few large (2-3 cm) isolated wispy chevrons, thin (less than 1 cm thick) disrupted dark gray anhydritic shale laminations from 3-20 cm apart, small orange polyhalite masses thoughout, medium - coarse grained.
297.89	977.32	.15	.50	Clay shale, light and dark gray laminations, minor amount of salt in small (2-3 mm) ingrown nodules and orangish salt filled cracks, non-laminated and mottled in lower 4 cm.
298.11	978.40	.22	1.08	Clay shale, highly contorted light and dark gray laminations with small ingrown nodules of salt and orange salt filled cracks, upper half has secondary red coloration.

Depth		Thickness		Description
m	ft	m	ft	
298.74	980.11	.63	1.71	Clay shale, light and dark gray laminations, locally mottled, interlaminated halite in lower 9 cm, mixed and contorted reddish and dark gray laminations in upper 20 cm, small red salt filled cracks and anhydrite nodules throughout.
299.10	981.29	.36	1.81	Clay shale, dark gray - mottled, with clear small ingrown salt nodules and salt filled cracks, some small (2-3 mm) anhydrite nodules throughout.
299.22	981.68	.12	.39	Clear halite, with interstitial orange coloration, clay - anhydrite less than 1%, moderately coarse - very coarse grained.
299.42	982.34	.20	.66	Clear halite, with irregular argillaceous anhydritic patches (10%), 1 cm shale at top, moderately coarse - coarse grained.
300.05	984.40	.63	2.06	Halite, with a few medium - large chevrons (1-2 cm) in the lower 20 cm, thin (2-3 mm) disrupted anhydritic shale partings from 5-15 cm apart, medium - moderately coarse grained.
300.36	985.42	.31	1.02	Clay shale, light and dark gray laminations, with small ingrown salt nodules throughout, lower 8 cm mottled and has 1 cm pods of red clay and red salt filled cracks, 8-20 cm - brecciated and contorted, contains bedded and cross-cutting masses of red clay (bioturbation?).

Depth		Thickness		Description
m	ft	m	ft	
300.74	986.67	.38	1.25	Clear halite, argillaceous and anhydritic patches associated with locally fine - medium grained halite, otherwise halite is medium - moderately coarse grained, orange coloration in upper 7 cm, total clay-anhydrite 10%.
300.80	986.86	.06	.19	Halite, clear and cloudy, with finely dispersed specks of clay and anhydrite, 1 cm thick shale at top with red salt filled cracks, fine - medium grained.
300.95	987.36	.15	.50	Halite, bands (1-3 cm thick) of clear and chevron halite separated by partings of clay and anhydrite, finely dispersed specks of clay and anhydrite throughout (less than 5%), abundant small - medium chevrons (0.5-1 cm), fine - medium grained.
301.15	988.01	.20	.65	Halite, bands of clear and chevron halite separated mostly by 0.5-1 cm thick layers of finely dispersed specks of clay and anhydrite (20%), orange tint, small (0.5 cm) wispy chevrons fine - moderately coarse grained.
301.33	988.60	.18	.59	Halite, fine - medium grained clear halite in matrix of dark gray shale (30%) saltess shale laminations at base, 10 cm, and top.
301.61	989.52	.28	.92	Halite, clear and cloudy with finely dispersed specks of clay and anhydrite (<5%), localized faint orange-brown coloration mostly in upper 1/2 of unit, fine - medium grained, locally moderately coarse.

Depth		Thickness		Description
m	ft	m	ft	
302.71	993.13	1.10	3.61	Halite, clear with a few medium wispy chevrons in upper 1/3 of unit, disturbed anhydritic shale partings from 10-30 cm apart, some scattered white anhydritic and dark gray anhydritic - argillaceous patches (5-10%), medium - moderately coarse grained.
302.75	993.26	.04	.13	Clay shale, dark gray, brecciated, with small ingrown salt and anhydrite nodules and red salt filled cracks.
302.94	993.89	.19	.62	Halite, clear and cloudy with small argillaceous - anhydritic patches and dark gray shale clods (30%), grades into overlying shale, fine - medium grained.
304.15	997.86	1.21	3.97	Clear halite, contains irregularly distributed clasts of anhydritic dark gray shale (5-10%), medium - coarse grained.
304.51	999.04	.36	1.18	Halite, mostly clear with yellowish cloudy intervals (2-3 cm thick), a few thin (0.5 cm) disrupted clay-anhydrite partings, a few small dark gray shale clasts in upper 10 cm which grades into 2 cm thick dark gray shale at the top, fine-medium grained, moderately coarse in lower 5 cm.

Depth		Thickness		Description
m	ft	m	ft	
305.57	1002.51	1.06	3.47	Halite, clear and cloudy bands 3-10 cm thick, separated by 0.5-2 cm thick bands of finely dispersed clay and anhydrite, a few medium (1 cm) chevrons throughout, 36-75 cm - contains small masses of orange polyhalite, 1 cm thick dark gray shale at top, total clay-anhydrite 10-15%, fine - moderately coarse grained.
305.82	1003.34	.25	.83	Clear halite, finely dispersed clay and anhydrite, a few disturbed anhydritic shale partings in lower 1/2, total clay-anhydrite less than 5%, 5-10% wispy orange polyhalite masses, medium - moderately coarse grained.
306.18	1004.52	.36	1.18	Halite, clear and cloudy bands (0.5-3 cm) separated by disrupted dark gray anhydritic shale partings and bands of finely dispersed clay and anhydrite, some small wispy chevrons in lower 1/2, total clay-anhydrite 5-10%, fine - moderately coarse grained, coarsens upward.
306.31	1004.94	.13	.42	Clay shale, light and dark slightly contorted laminations contains fine - medium grained clear salt lenses with radiating red salt filled cracks, one small orangish anhydrite nodule.
306.42	1005.30	.11	.36	Clear halite, 10% anhydritic shale clasts and anhydrite, orangish color, fine - medium.
306.50	1005.57	.08	.27	Clay shale, dark gray, interlaminated with fine - medium grained clear halite, also contains small red salt filled cracks.

Depth		Thickness		Description
m	ft	m	ft	
306.87	1006.78	.37	1.21	Clear halite, clods of dark gray anhydritic shale at upper contact (5%), medium - moderately coarse grained.
307.03	1007.31	.16	.53	Clay shale, light and dark gray laminations with layers clear white halite and orangish 1 cm thick anhydrite nodules (40%), salt and anhydrite content decreases upward.
307.34	1008.32	.31	1.01	Clay shale, brecciated light and dark gray laminations with some red salt filled cracks, 1 cm thick orangish nodular anhydrite at 22 cm.
307.65	1009.34	.31	1.02	Clear halite, contains 5-10% finely distributed specks of clay and anhydrite, orangish tint throughout, fine - medium grained.
307.68	1009.44	.03	.10	Clay shale, dark gray, laminated, with small red salt filled cracks.
308.56	1012.33	.88	2.89	Clear halite, up to 0.5 cm thick disrupted anhydritic shale layers from 5-10 cm apart (10%) faint orangish color throughout - most intense in upper 30 cm, fine - medium grained, locally moderately coarse.
308.62	1012.52	.06	.19	Clay shale, slightly contorted laminations of light and dark gray shale with small red salt filled cracks.
308.86	1013.31	.24	.79	Halite, mostly clear with a few small chevrons, contains widely spaced (10-12 cm) anhydritic shale partings (5-10%), medium - moderately coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
308.90	1013.44	.04	.13	Clay shale, disrupted light and dark gray laminations with 30% fine - medium grained clear halite.
309.11	1014.13	.21	.69	Halite, 1-3 cm thick clear and cloudy bands, separated by 2-20 mm thick disrupted anhydritic shale laminations, small - medium (0.5-1 cm) chevrons with minor interstitial clay and anhydrite specks, fine - medium grained.
309.39	1015.05	.28	.92	Clay shale, light and dark gray laminations, interval from 7-12 cm contains 2-4 mm light gray and orangish anhydrite nodules, red salt filled cracks throughout except for the interval 7-12 cm.
311.31	1021.35	1.92	6.30	Clear halite, contains a few scattered anhydritic shale clasts (5%), medium - moderately coarse grained, locally coarse.
311.60	1022.30	.29	.95	Clay shale, even and irregular light and dark gray laminations with 15% fine - moderately coarse clear red ingrown halite.
311.96	1022.59	.09	.29	Halite, a few large (2-3 cm) in upper 1/2 of unit, a few thin (2 mm) anhydritic laminations, moderately coarse - very coarse grained.
311.96	1023.38	.24	.79	Halite, mostly clear with a few small - medium (0.5-1 cm) wispy chevrons, contains disrupted anhydritic shale partings from 1-4 cm apart, orangish anhydrite nodule in upper 10 cm, 1 cm thick dark gray shale at top, medium grained.

Depth		Thickness		Description
m	ft	m	ft	
312.07	1023.84	.14	.46	Clay shale, light and dark gray laminations, contains some small (2-3 mm) red salt nodules.
312.18	1025.88	.51	1.68	Halite, clear and cloudy with 1-5 mm thick anhydritic shale layers from 2-8 cm apart (10%), medium - moderately coarse grained, 1 cm thick shale at upper contact.
313.86	1029.71	1.17	3.83	Clear halite, contains irregularly distributed clods of anhydritic dark gray shale associated with minor amounts of orange algae (?), grades into 0.5 cm thick light and dark gray laminated shale at top of unit, some small anhydritic patches throughout, total clay - anhydrite 15%, medium - moderately coarse grained.
315.22	1034.18	1.36	4.47	Clear halite, contains disrupted dark gray anhydritic shale partings from 4-10 cm apart - spacing decreases upward, minor dispersed clay - anhydrite in lower 2/3 or unit, 1 cm thick dark gray shale layer with small red salt filled cracks at top of unit, medium - moderately coarse grained, total clay - anhydrite 5-10%.
315.62	1035.49	.40	1.31	Halite, clear and cloudy bands separated by 2-6 mm layers of finely dispersed specks of clay and anhydrite from 1-2 cm apart, small (0.5 cm) wispy chevrons throughout, upper contact at 1 cm thick dark gray shale with small red salt filled cracks, total clay - anhydrite 5%, fine - medium grained, locally moderately coarse.

Depth		Thickness		Description
m	ft	m	ft	
316.15	1037.23	.53	1.74	Halite, clear and cloudy bands separated by 3-5 mm thick disrupted anhydritic shale partings from 5-10 cm apart, some light and dark gray 0.5-1.5 cm thick shale layers in lower 1/2 of unit, total clay-anhydrite - 15%, a few small wispy chevrons throughout, fine - moderately coarse grained.
316.71	1039.07	.56	1.84	Halite, clear and chevron halite in bands, with fairly regularly spaced (1-4) dark gray disrupted anhydritic shale partings in lower 1/2 which become thicker, more widely spaced, and more disrupted upward, total clay - anhydrite 5-10%, some small - large (0.5-3 cm) chevrons throughout, medium - moderately coarse grained.
318.34	1044.41	1.63	5.34	Halite, mostly clear with a few small - medium wispy chevrons, with widely spaced (8-25 cm) anhydritic and argillaceous layers, total clay - anhydrite 5%, medium - moderately coarse grained, locally coarse.
318.45	1044.77	.11	.36	Clay shale, light and dark gray laminations with clear colorless salt vein cross-cutting the entire unit.
319.12	1046.97	.67	2.20	Clear halite, with dark gray anhydritic clods of shale (10%), medium - coarse grained, locally very coarse.
320.33	1050.94	1.21	3.97	Clay shale, light and dark gray laminations, red halite ingrown in cracks and along bedding planes, bedded and nodular anhydrite from 0-34 cm, 47-67 cm - laminations disrupted almost to the point of homogeneity.

Depth		Thickness		Description
m	ft	m	ft	
320.58	1051.76	.25	.82	Clear halite, with clods of dark gray anhydritic shale (10%), orange color throughout but most intense around shale clods, medium - coarse grained.
320.74	1052.29	.16	.53	Clear halite, orangish color, contains fine dispersed specks of clay and anhydrite (less than 5%), upper contact at 2-4 mm thick dark gray anhydritic shale parting, medium grained in lower 10 cm, fine - medium in upper 6 cm.
320.90	1052.81	.16	.52	Clear halite, orange, small, argillaceous and anhydritic patches throughout (15-20%), 3 cm disrupted dark gray shale at top with small (less than 1 cm) anhydrite and salt nodules, medium - moderately coarse grained.
321.68	1055.37	.78	2.56	Halite, clear and cloudy bands with 0.5-2 cm thick layers of fine dispersed specks of clay and anydrite from 4-6 cm apart, a few small wispy chevrons throughout, upper contact at 1 cm thick light and dark gray disrupted anhydritic shale, total clay-anhydrite 10%, fine - medium grained, locally moderately coarse.
322.38	1057.67	.70	2.30	Halite, a few medium sized wispy chevrons, relatively clean banded interval from 0-50 cm, with thin (1-2 mm) dark gray disrupted anhydritic partings, grades into faintly banded interval with 40% fine dispersed clay and anhydrite, upper contact at 2 cm thick light and dark gray lamination with small clear colorless salt nodules and red salt filled cracks, medium - moderately coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
323.12	1060.10	.74	2.43	Clear halite, with finely dispersed specks of clay and anhydrite (1%), medium - moderately coarse grained.
323.84	1062.46	.72	2.36	Clear halite, with 10% irregularly distributed dark gray anhydritic shale clods upper contact at 0.5 cm thick dark gray shale layer with small red salt filled cracks, medium - moderately coarse grained.
325.27	1067.15	1.43	4.69	Clear halite, irregularly distributed argillaceous and anhydritic patches (25%), content increasing upward, upper contact at 0.5 cm dark gray anhydritic shale with red salt filled cracks, medium - coarse grained.
326.24	1070.33	.97	3.18	Clear halite, contains irregularly distributed clods of dark gray anhydritic shale (40%), coarse - very coarse grained.
326.44	1070.99	.20	.66	Clear halite, orange, contains irregularly distributed anhydrite nodules mixed with dark gray shale (30%), medium - moderately coarse grained.
326.48	1071.12	.04	.13	Clay shale, dark gray.
327.01	1072.86	.53	1.74	Halite, clear and cloudy with a few small (0.5 cm) wispy chevrons in the upper 13 cm, contains disrupted layers of dark gray anhydritic shale (30%), fine - medium grained.

Depth		Thickness		Description
m	ft	m	ft	
327.45	1074.30	.44	1.44	Clear halite, contains irregularly distributed argillaceous and anhydritic patches, also clods of dark gray anhydritic shale, clay-anhydrite content increases upward, total 20%, upper contact at 0.5 cm dark gray anhydritic shale, moderately coarse - coarse grained.
327.76	1075.32	.31	1.02	Clear halite, contains finely dispersed specks of clay and anhydrite (5-10%), medium - moderately coarse grained.
328.00	1076.11	.24	.79	Clear halite, thin (0.5 cm) dark gray shale at 9 cm with anhydrite nodule, dark gray anhydritic shale clods (10%), medium - moderately coarse grained.
328.04	1076.24	.04	.13	Clay shale, disturbed light and dark gray laminations, contains small light gray anhydrite nodules (40%) and small nodules of orange halite (10%).
328.14	1076.57	.10	.33	Clear halite, with small anhydritic patches and clods of light and dark gray laminated shale (30%), moderately coarse grained.
328.36	1077.29	.22	.72	Clay shale, disturbed and brecciated light and dark gray laminations, contains orange argillaceous and anhydritic halite between fragments and laminations.
328.48	1077.68	.12	.39	Clear halite, contains clods of light and dark gray laminated shale (5%), medium - moderately coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
329.53	1081.13	1.05	3.45	Halite, mostly clear with a few medium (0.5-1 cm) chevrons in lower 1/2, contains irregularly spaced (3-15 cm) 2-4 cm thick layers of disrupted dark gray anhydritic shale, grades into 1 cm light and dark gray anhydritic shale at upper contact, medium - moderately coarse grained.
329.98	1082.60	.45	1.47	Halite, clear and cloudy bands, abundant small - large chevrons in l ower 1/2 of unit becoming less abundant upward, contains disrupted dark gray anhydritic layers (1-3 cm thick), from 1-6 cm apart, medium - moderately coarse grained.
330.44	1084.11	.46	1.51	Halite, mostly clear with a few small wispy chevrons throughout, contains disrupted dark gray anhydritic shale layers from 4-15 cm apart, medium - moderately coarse grained, locally coarse.
330.62	1084.70	.18	.76	Clear halite, light and dark gray anhydritic shale laminations (0.5-1 cm thick) interbedded with fine - moderately coarse grained halite layers, from 0.5-3 cm thick increasing upward, orange halite just below top shale layer.
330.85	1085.46	.23	.76	Clear halite, with widely spaced disrupted dark gray anhydritic shale (5-10%), medium grained.
331.03	1086.05	.18	.59	Clear halite, contains argillaceous and anhydritic patches (5%), which grade into 1.5 cm dark gray shale at top of unit, medium grained locally coarse.

Depth		Thickness		Description
m	ft	m	ft	
331.24	1086.74	.21	.69	Clear halite, contains disrupted dark gray anhydritic shale layers (10%) from 4-6 cm thick which grade into 2 cm thick light and dark gray laminated shale at top of unit, medium - moderately coarse grained.
331.71	1088.28	.47	1.54	Clear halite, contains irregularly distributed dark gray anhydritic shale clods in lower 1/2, interstitial clay and anhydrite in upper 1/2, 1 cm dark gray shale at top of unit, medium - moderately coarse grained.
332.90	1092.18	1.19	3.90	Halite, clear and cloudy bands from 4-15 cm thick separated by disrupted dark gray anhydritic shale layers (15-20%), bands in lower middle and upper portions of the unit contain small - medium chevrons, abundant anhydrite nodules in upper 15 cm, fine - moderately coarse grained.
333.03	1092.61	.13	.43	Clear halite, contains closely spaced (1-1.5 cm) disrupted dark gray anhydritic shale partings (30-35%), medium grained.
333.83	1095.24	.80	2.63	Clear halite, contains disrupted dark gray anhydritic shale partings from 1-15 cm apart (15%), medium - moderately coarse grained.
334.43	1097.20	.60	1.96	Clear halite, disrupted dark gray anhydritic partings from 10-15% cm apart (5%), medium - very coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
334.64	1097.89	.21	.69	Clear halite, contains dark gray anhydritic shale clods (50%), medium - moderately coarse grained.
334.78	1098.35	.14	.46	Clay shale, disturbed light and dark gray laminations with 20% clear halite in middle 1/3 of unit with shale matrix, a few orangish anhydrite nodules in upper 1 cm.
334.85	1098.58	.07	.23	Anhydrite, nodular with 5% interbedded clay.
335.34	1100.19	.49	1.61	Halite, clear and chevron bands 1-3 cm thick with disrupted dark gray anhydritic shale partings between bands, distinct and wispy small - medium chevrons throughout, fine - moderately coarse grained.
335.53	1101.17	.20	.98	Halite, contains disrupted dark gray anhydritic shale partings 30-40%, medium grained.
336.44	1103.80	.91	2.63	Halite, clear and cloudy bands 3-8 cm thick separated by disrupted dark gray anhydritic partings, small - medium chevrons in lower 2/3 of unit, fine - moderately coarse grained.
337.06	1105.81	.62	2.01	Halite, clear and cloudy, anhydritic lower 5.5 cm (70%), anhydrite in small masses and a few disturbed partings throughout, abundant small indistinct chevrons from 30-38 cm, medium - moderately coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
338.11	1109.28	1.05	3.47	Halite, contains disrupted argillaceous anhydrite partings from 2-15 cm apart, abundant large (2-3 cm) chevrons in lower 13 cm, a few scattered chevrons throughout the rest of the unit, clay-anhydrite less than 5%, moderately coarse grained.
338.18	1109.51	.07	.23	Clay shale, dark gray, brecciated with a few small anhydrite nodules, and fine - medium grained ingrown halite, a few red salt filled cracks.
339.04	1112.33	.86	2.82	Clear halite, with finely dispersed specks of clay and anhydrite - locally banded, anhydrite nodules (1-5 cm) rimmed or associated with clay, fine - medium grained locally moderately coarse.
339.17	1112.76	.13	.43	Clay shale, mixed clear halite and anhydrite in a dark gray clay matrix.
339.59	1114.13	.35	1.14	Halite, mostly clear with some small cloudy patches in the lower 9 cm, clods of laminated dark gray anhydritic shale throughout (15%), interstitial red color, moderately coarse grained.
339.77	1114.73	.18	.60	Clay shale, disrupted and brecciated light and dark gray laminations, 0.5 cm - 1 cm wide red salt filled crack crosscutting entire unit.
340.03	1115.58	.26	.85	Clear halite, 5-10% clods of dark gray anhydritic shale, medium - moderately coarse.

Depth		Thickness		Description
m	ft	m	ft	
340.15	1115.97	.12	.39	Clay shale, disturbed and microfaulted light and dark gray laminations, with a few small dark gray anhydrite nodules, one large (10 cm long) red salt filled crack.
340.70	1117.78	.55	1.81	Halite, mostly clear with a few medium chevrons at 28-30 cm above base of unit, contains widely spaced yellowish anhydrite partings (10%), minor clay, medium - moderately coarse grained.
340.74	1117.91	.04	.13	Clay shale, mottled and irregular light and dark gray laminations.
340.95	1118.60	.21	.69	Clear halite, with dark gray anhydritic and argillaceous patches (20%), moderately coarse grained.
341.10	1119.09	.15	.49	Clay shale, disturbed and irregular light and dark gray laminations with 50% moderately coarse grained ingrown halite, small white anhydrite blebs in lower 1 cm.
341.22	1119.48	.12	.39	Halite, mostly clear with a few small chevrons, contains finely dispersed specks of clay and anhydrite and small dark gray anhydritic shale clods, fine - medium grained.
341.31	1119.78	.09	.30	Clay shale, irregular and disrupted light and dark gray laminations.
341.47	1120.30	.16	.52	Clear halite, contains dark gray anhydritic shale clods and finely dispersed dark gray specks of clay and anhydrite (20%), grades into overlying shale, medium - moderately coarse grained.

Depth		Thickness		Description
m	ft	m	ft	
341.93	1121.81	.46	1.51	Clear halite, with argillaceous and anhydritic patches (10%), fine - medium grained, locally moderately coarse.
342.75	1124.51	.82	2.70	Clear halite, with argillaceous and anhydritic patches (5-10%), moderately coarse - coarse grained.
343.61	1127.32	.86	2.81	Clear halite, irregularly distributed argillaceous and anhydritic patches (5%), coarse - very coarse grained.
344.23	1129.36	.62	2.04	Clear halite, with argillaceous and anhydritic patches (10%), moderately coarse grained locally very coarse.
344.40	1129.92	.17	.56	Halite, clear and cloudy (no visible chevrons), with finely dispersed dark gray specks of clay and anhydrite (less than 5%), medium - moderately coarse grained.
344.51	1130.34	.11	.36	Clay shale, dark gray with 10% ingrown clear halite.
344.72	1131.03	.21	.69	Halite, clear, locally cloudy in lower 10 cm, contains disrupted dark gray anhydritic shale laminations which grade into argillaceous-anhydritic patches, which in turn grade into the overlying shale, orangish algal patches in upper 10 cm, very finely dispersed specks of dark gray clay and anhydrite throughout, fine - medium grained.
344.80	1131.23	.08	.26	Clay shale, disrupted and irregular light and dark gray laminations, contains 35% fine - medium grained ingrown clear halite, a few small red salt filled cracks.

Depth		Thickness		Description
m	ft	m	ft	
344.85	1131.39	.05	.16	Halite, mostly clear with a few small chevrons, contains disrupted dark gray anhydritic shale partings from 1-2 cm apart, fine - medium grained.
345.00	1131.88	.15	.49	Clear halite, contains vertically oriented band of clay and anhydrite and irregularly distributed clods of dark gray anhydritic shale (10%), moderately coarse grained.
345.94	1134.97	.94	3.09	Clear halite, contains dark gray argillaceous and anhydritic patches (20%), thin 0.5-1 cm thick light and dark gray laminated shale beds in lower 20 cm, medium - coarse grained.
347.86	1137.99	.92	3.02	Halite, contains dark gray argillaceous and white anhydritic patches, total clay - anhydrite 20%, a few medium chevrons in middle portion of unit, moderately coarse grained, locally very coarse.
347.73	1140.84	.87	2.85	Clear halite, contains dark gray argillaceous and white anhydritic patches, total clay-anhydrite 30%, moderately coarse grained, locally very coarse grained.
348.01	1141.76	.28	.92	Clear halite, less than 5% finely dispersed specks of clay and anhydrite, very coarse grained.
348.45	1143.24	.45	1.48	Clear halite, contains dark gray argillaceous and anhydritic patches - 15%, moderately coarse grained, locally very coarse.

Depth		Thickness		Description
m	ft	m	ft	
349.02	1145.07	.56	1.83	Clear halite, contains dark gray argillaceous and white anhydritic patches, total anhydrite-clay 10-15%, moderately coarse grained.
349.12	1145.40	.10	.33	Clay shale, large anhydrite nodules (1-3 cm) in matrix of mixed light and dark gray shale, matrix contains small (3 mm) orange pods and specks of halite, anhydrite - 40%.
349.22	1145.73	.10	.33	Clay shale, dark gray, with small orangish halite pods and specks of anhydrite.
349.43	1146.42	.21	.69	Clay shale, disrupted light and dark gray laminations, desiccation cracks, red salt filled cracks in lower 13 cm.
349.64	1147.11	.21	.69	Halite, contains light and dark gray shale laminations which have been separated and distorted by ingrown halite, 1-3 cm light gray anhydrite nodules (orangish around edges) in lower 6 cm.
349.97	1148.19	.33	1.08	Clay shale, dark gray with shrinkage cracks(?) filled with light gray clay, a few specks of red halite throughout.
350.40	1149.60	.43	1.41	Clay shale, light and dark gray laminations, contains pods and specks of red halite decreasing upward, desiccation cracks and small slumps throughout, mottled upper 10 cm, 2 cm enterolithic anhydrite at top of unit.

Depth		Thickness		Description
m	ft	m	ft	
350.90	1151.24	.50	1.64	Halite, contains finely dispersed specks of clay and anhydrite in lower 1/2 of unit (less than 5%), disrupted dark gray shale partings in upper 1/2 of unit from 3-10 cm apart, some indistinct chevrons throughout, becoming more abundant and distinct upward, orangish tinge around anhydrite in upper 6 cm, medium - coarse grained, very coarse in lower 6 cm.
351.28	1152.49	.38	1.25	Halite, mostly clear with a few medium (1 cm) chevrons in upper 1/2 of the unit, contains disrupted dark gray anhydritic shale partings from 10-13 cm apart, medium - coarse grained.
351.38	1152.82	.10	.33	Halite, contains disrupted dark gray anhydritic shale partings from 2-4 cm apart, a few small chevrons throughout, medium grained.
351.42	1152.95	.04	.13	Clay shale, dark gray with small red salt filled.
351.58	1153.47	.16	.52	Clear halite, contains dark gray anhydritic shale clods (40%), moderately coarse grained.
351.75	1154.30	.17	.83	Anhydrite, yellowish, with 40% ingrown euhedral fine - medium grained clear halite.
352.27	1155.74	.52	1.65	Clear halite, contains a few disrupted light gray argillaceous anhydrite partings, anhydrite most abundant in upper 4 cm, moderately coarse - coarse grained.
352.35	1156.00	.08	.26	Clear halite, contains dark gray anhydritic shale clods and finely dispersed specks of clay and anhydrite (50%), fine - medium grained, base of Hutchinson Salt Member.

Depth		Thickness		Description
m	ft	m	ft	
353.29	1159.14	.94	3.14	Clay shale, contorted and brecciated light and dark gray laminations, upper 12 cm contains 0.5 cm thick interbedded light gray anhydrite layers and 20% small ingrown halite nodules, small (less than 0.5 cm) anhydrite nodules scattered throughout.
353.37	1159.40	.08	.26	Anhydrite, nodular, light gray.
353.57	1160.06	.20	.66	Clay shale, dark gray, light and dark gray laminations in upper 3 cm.
353.64	1160.29	.07	.23	Anhydrite, nodular, mottled light and dark gray.
353.86	1161.01	.22	.72	Clay shale, contorted and brecciated light and dark gray laminations.
354.24	1162.26	.38	1.25	Dolomite, argillaceous, light brown, earthy, microcrystalline, regularly interbedded with 2-3 cm dark gray silty shale layers, small (less than 0.5 cm) light gray anhydrite nodules, 2 cm medium gray penemosaic anhydrite at top of unit.
355.24	1165.54	1.00	3.28	Dolomite, argillaceous, light brown, earthy, microcrystalline, wispy laminations in upper and lower 1/3 of unit, a few red salt filled cracks throughout.
355.35	1167.90	.11	.36	Clay shale, dolomitic, light and dark gray laminations, grades into above unit.
355.70	1167.05	.35	1.15	Clay shale, silty, light and dark gray laminations, 2 cm light gray anhydrite nodule at 22 cm.

Depth		Thickness		Description
m	ft	m	ft	
355.80	1167.37	.10	.32	Siltstone, clayey, contorted light and dark gray laminations with abundant small (less than 0.5 cm) light gray anhydrite nodules.
356.06	1168.23	.26	.86	Siltstone, clayey, contorted and microfaulted light and dark gray laminations.
356.64	1170.14	.58	1.91	Anhydrite, 1-1.5 cm medium gray nodules in a matrix of light and dark gray contorted laminations of clayey siltstone, 4 cm thick beds of non-anhydritic dark gray siltstone at 20 and 32 cm above base of unit, lower 10 cm is all light gray nodular anhydrite.
356.95	1171.15	.31	1.01	Siltstone, clayey, contorted light and dark gray, some small (0.2-1 cm) anhydrite nodules throughout, 1 cm thick light gray enterolithic anhydrite bed at base of unit.
357.25	1172.14	.30	.99	Siltstone, light and dark gray laminations, lower 10 cm is slumped, upper 5 cm - microfaulted, long narrow red salt filled cracks throughout.
357.61	1173.32	.36	1.18	Siltstone, contorted and brecciated light and dark gray lamiantions, small (less than 0.5 cm) light gray anhydrite nodules throughout.

BASE OF CORE