Petrography of Evaporites From the Wellington Formation Near Hutchinson, Kansas

GEOLOGICAL SURVEY BULLETIN 1201-A

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By C. L. JONES

CONTRIBUTIONS TO GENERAL GEOLOGY

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A study of halite, anhydrite, and carbonate rocks in a part of the lower Permian sequence of central Kansas

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library card for this publication appears on page after index.

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PETROGRAPHY OF EVAPORITES FROM THE WELLINGTON FORMATION NEAR HUTCHINSON, KANSAS

By C. L. Jones

ABSTRACT

Evaporite rocks belonging to an extensive salt deposit in the Wellington basin of Kansas are described in this petrographic report on the Hutchinson Salt Member of the Wellington Formation. The descriptions are derived chiefly from detailed study of drill core from a depth of 423–734 feet in a boring near Hutchinson, Kans. Included written and graphic logs of this core present new data on the lithology of the Hutchinson Salt Member within a region in which the unit is characteristically developed.

The Hutchinson Salt Member consists of anhydritic and argillaceous halite rocks interstratified with beds of shale, anhydrite, and carbonate rock. Most of the rocks constituting the unit are in laminae and layers a few inches thick and occur in systematic alternation of one upon another or as part of a regular succession of shale, carbonate, anhydrite, and halite layers. Matted filamentous remains of the blue-green algae *Phormidium antiquum* Tilden are found in many of the halite layers and also in crosscutting veins of halite in shale and carbonate layers. Occurrence of other types of fossils is restricted to small *Permophorus*-like pelecypods and associated sessile foraminifers, *Serpulopsis* sp., found in anhydrite and magnesite near the base of the unit. These fossils indicate a shallow-water-marine or possibly brackish-water environment during carbonate deposition.

The halite rock is coarsely crystalline and essentially equigranular, and it consists dominantly of a colorless limpid halite. Enclosed in much of this halite are small islanded and embayed remnants of a white translucent halite. Anhydrite and detrital argillaceous materials are the main accessory constituents of the rock and commonly form angular interstitial patches and irregular veinlike masses. Other minor constituents—such as polyhalite, dolomite, magnesite, hematite, celestite, marcasite, and pyrite—occur as single crystals or as groups of crystals which project into halite from the edges of argillaceous patches and from small lenticular or veinlike masses of anhydrite. Small pseudomorphs after gypsum, outlined by crystals and fine-grained masses of anhydrite, are scattered irregularly through the rock.

The anhydrite rock is compact and microcrystalline and either is banded by carbonate-rich laminae or has a mottled appearance as a result of the laminae being broken into irregular strips and patches. Most of the rock is even grained

and has a granular texture distinguished by stubby, almost cubic grains of anhydrite. Isolated grains and angular aggregates of carbonate (dolomite and magnesite) are commonly present in the mesh of stubby anhydrite crystals, and anhydrite pseudomophs after gypsum are scattered through the matrix of anhydrite and associated carbonate. Halite is found in the interstices between the mineral grains, in small irregular masses, and in pseudomorphs after gypsum. Some of the pseudomorphs containing halite are in a narrow row along the contact between the anhydrite and the overlying halite rock; others are concentrated in bands parallel to the bedding.

Two types of carbonate rock—dolomite and magnesite—are associated with anhydrite and other rocks of the Hutchinson Salt Member, but they are set apart stratigraphically so that dolomite dominates in the lower part of the member and magnesite dominates in the middle and higher parts. The two rocks are relatively soft and earthy, like silty shale; and they are composed of clay- and silt-size particles of carbonate and other minerals which produce a granular texture. Dolomite and magnesite are the predominant carbonate minerals; calcite is a scarce constituent that is restricted to magnesite rock. Other constituents of the two carbonate rocks include detrital quartz, feldspar, mica, and clay minerals, as well as one or more authigenic minerals—such as anhydrite, quartz, chalcedony, pyrite, and halite.

The evaporites of the Hutchinson Salt Member are believed to be products of chemical processes involving (1) sequential deposition of calcite, gypsum, and halite; and(2) subsequent reorganization of crystalline materials in an exchange of major salt ions and other substances between marine salts and the waters associated with them. The textures and structures of the rocks and the presence of relict minerals and pseudomorphous structures suggest that the reorganization of crystalline materials involved (1) the conversion of carbonate from calcium-rich to magnesium-rich materials, either dolomite or magnesite; (2) the formation of anhydrite, in part from calcium sulfate given up by gypsum and in part from calcium released on the destruction of calcite and from sulfate obtained from brines and residual solutions; (3) the recrystallization of halite; and (4) the transport of materials to new sites of crystallization in the carbonate, anhydrite, and halite rocks, in veins and lenticles cutting these rocks, and in mineral grains scattered through them.

INTRODUCTION

PURPOSE AND METHODS OF STUDY

Central Kansas and a part of the Panhandle sections of Oklahoma and Texas are underlain by saliferous evaporites of the Wellington Formation of Early Permian (Leonard) age (fig. 1). The evaporites include rocks ranging in composition from dolomite and magnesite through anhydrite to halite, and they contain numerous intercalations of clay shale and associated siltstone. This assemblage of rocks forms the oldest and northernmost salt deposit in a broad region of Permian evaporites which reaches to the trans-Pecos area of western Texas. The deposit has been exploited more than 70 years for the extraction of salt and has been used a much shorter period for the seasonal storage of liquefied petroleum gases.

Many features of this Lower Permian salt deposit have been examined and reported on by geologists; and much information has been published concerning the composition, structure, and distribution of salt in the Wellington Formation. Nevertheless, the salt and the evaporites associated with it are still an intriguing subject, and much work remains to be done to understand the interrelations and history of the rocks and the circumstances of their formation. One useful contribution to the solution of problems involving the origin and history of the evaporites is a petrographic study of the rocks themselves. This report presents the results of such a study made by the U.S. Geological Survey and deals primarily with a systematic description of the evaporites and the interpretation of their megascopic and microscopic features.

The descriptions and interpretations presented here are based on core from a boring (H.N.A.S. core hole) drilled in May 1958 at the Hutchinson Naval Air Station, a few miles south of Hutchinson, in central Reno County, Kans. (fig. 1). The drilling was done by a private contractor for the Geotechnical Corp., which in turn was act-

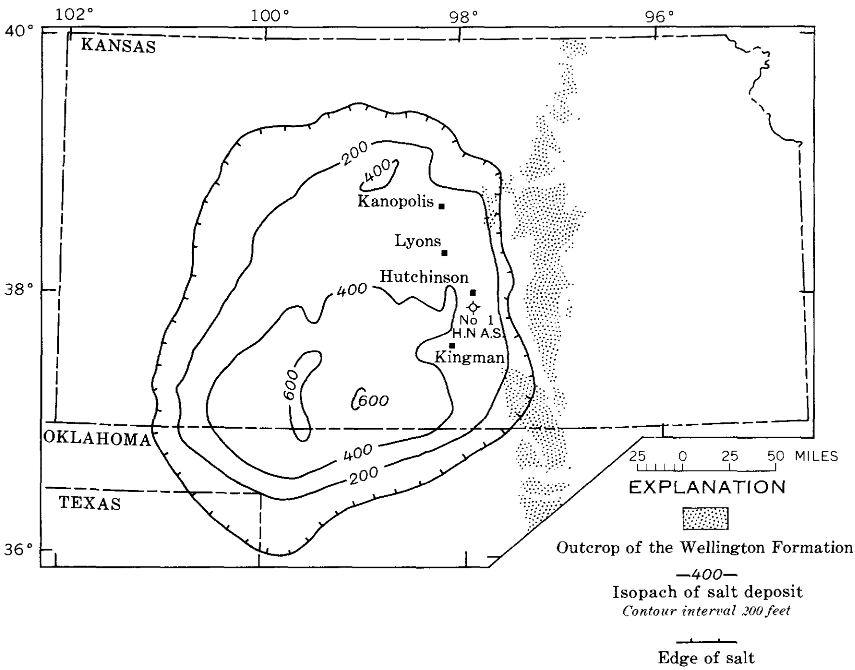

FIGURE 1.—Wellington salt basin showing location of H.N.A.S. core hole 1 and outcrop of the Wellington Formation. Adapted from maps by Norton (1939), Lee and others (1948), Miser (1954), Kulstad and others (1956), Kulstad (1959), and Pierce and Rich (1962).

ing on behalf of the Union Carbide Nuclear Corp. The Geotechnical Corp. had consecutive cores taken through the sequence of beds known to be salt bearing from previous drilling in the vicinity of the air station. Dr. W. B. Heroy, Jr., and other members of the corporation prepared a detailed log of the core hole which shows formation tops and the lithology of the rock units. A radioactivity log (gamma ray; neutron) was taken the full length of the hole, and an electric log (S.P.; resistivity) was made of a shorter length of hole (293 ft.), one ending a few feet above the depth at which coring was started. The core was quartered longitudinally: one quarter was retained by the Geotechnical Corp., Dallas, Tex., and the others were distributed to the core-and-sample library of the State Geological Survey of Kansas, Lawrence, Kans.; the Union Carbide Nuclear Corp., Oak Ridge, Tenn.; and the U.S. Geological Survey, Washington, D.C., for study and for storing as a matter of public record.

The present petrographic study of the salt and other evaporites of the Wellington Formation was begun in 1959 to obtain information on their composition, texture, and structure, and on the stratigraphic details of their occurrence in the sequence. The complete section of core received in Washington was examined, and a detailed log was prepared. The core log with some abridgment and modification of descriptive material is presented here in both written and graphic form along with the radioactivity log of the section of hole from which the core was taken. The written log (p. A55–A65) is left as nearly in its original form as conformity to one style and subsequent findings allow, and the graphic log is combined with the radioactivity log in a single illustration (pl. 1) as this best shows the relations between lithology and radioactivity.

The written log deals chiefly with features that are readily discernible on megascopic examination. Individual rock units or layers are designated by a descriptive name, such as halite rock, which indicates the dominant mineral constituent; and other materials that occur as minor constituents are designated by such descriptive terms as anhydritic, polyhalitic, or argillaceous. No units or rock layers less than 1 inch thick are described, though such units are present. They form an integral part of an orderly succession of contrasting laminae and thin layers that are described in the text of this report. Color names given in the log are approximate. All colors refer to the color of the rock when it is wet and is viewed in indirect sunlight. Textures are described only briefly in the log but are treated in more detail in the text of the report. The sedimentary structures are necessarily small-scale features, limited by the size of the core. However, studies by the Geological Survey in the potash district of southeastern New Mexico have shown that small-scale features seen in drill cores are representative of structures visible in large exposures in the mine workings. Consequently, in this respect, it seems relevant to note that varvelike bedding structures, like those in the core, are very characteristic of the rocks exposed in the mine workings at Hutchinson and elsewhere in central Kansas.

The observations based on core logging have been supplemented by study of polished sections of rock specimens and by petrographic studies of 66 thin sections. Of these thin sections, 36 were from halite layers, 8 from carbonate layers, and 9 from clay shale and siltstone layers. In these studies, emphasis was focused on the description of the evaporites, their minerology, and their gross paragenetic relations. Minerals were identified chiefly from crushed fragments in immersion oils under a petrographic microscope. The identifications were verified as occasion demanded by X-ray-diffraction studies. The diffraction patterns were compared with those of previously studied specimens of minerals and rocks from Permian salt beds in southeastern New Mexico.

PREVIOUS WORK

The evaporites in the Lower Permian sequence of central Kansas have interested geologists since reports by Hay (1891) and by Haworth and Kirk (1899) first directed attention to the salt beds in the Wellington Formation. Studies by Cragin (1896), Prosser (1897), Perrine (1918), Elias (1937), Ver Weibe (1937), and Norton (1939) have added to the knowledge of the geology of the Wellington Formation and its widespread beds of salt. Bass (1926) described the structure, thickness, and limits of the salt beds in western Kansas; and Taft (1946) published a review of salt deposits in Kansas. Further descriptions of salt beds in the Wellington Formation, together with correlated stratigraphic sections and maps showing the distribution and thickness of salt, were included in studies of the stratigraphy and structural development of the Salina basin by Lee and others (1948) and by Lee (1956). A more detailed account of the distribution, thickness, and percentage of salt in the saliferous part the Wellington Formation was published by Kulstad (1959).

Other aspects of the geology of the Wellington Formation were dealt with by Dunbar (1924) in his paleontological study of insects found in outcrops east of, and updip from, the salt beds. The occurrence of insects in clam-and-shrimp-bearing beds of the Wellington was noted by Tasch and Zimmerman (1961) in connection with their study of fossil and living conchostracans in Kansas, and subsequently the distribution of insect-bearing beds in the sequence of exposed strata was investigated by Tasch (1962). Tilden (1930) described algae and noted the presence of possible iron-secreting microbes in red halite

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from central Kansas and northwestern Oklahoma, and Schaffer (1962) described the microfloral successions in saliferous sequences of beds in underground workings of salt mines in Rice and Reno Counties, Kans.

The earliest observations of a purely mineralogical or petrographic nature were made by Rogers (1910); he described anhydrite and other minerals from salt mines in central Kansas. Swineford and Runnels (1953) worked on chemical and X-ray-diffraction analyses of polyhalite, and Swineford (1955) described some dolomite and halite rock of the Wellington Formation in connection with her petrographic study of red beds in the Permian sequence of southern Kansas. The origin of gypsum and its relation to halite and anhydrite in Kansas was discussed by Kulstad and others (1956). Dellwig (1958) dealt casually with bedding structures in the evaporite sequence in his investigation of pillar failure and bucklings of floors in underground workings in salt beds at Lyons, Kans. Liquid inclusions in halite from the Lyons area were described by Dreyer and others (1949) in connection with their study of geologic thermometry, and the chemistry of red halite from the same area was investigated by Kleihege (1948). Runnels and others (1952) published a report on the minor elements found in Kansas salt, together with spectrographic analyses of rock salt.

The geology of salt deposits in Kansas was summarized by Pierce and Rich (1962) in their review of salt deposits that may be suitable sites for disposal of radioactive waste in the United States

ACKNOWLEDGMENTS

The present study has involved the contributions of several individuals whose assistance, advice, and useful services are gratefully acknowledged. Beth M. Madsen did X-ray-diffraction and fluorescence analyses on many samples of minerals and on the water-soluble and insoluble constituents of the rocks. E. L. Yochelson and L. G. Henbest examined and identified megascopic fossils, and Marie L. Lindberg and C. S. Ross carried out electron-microscope and other studies that confirmed the organic nature and the identity of algal remains. E. C. Morris and N. F. Prime took the photomicrographs which illustrate this report. The salt cores were made available through the courtesy of the Health Physics Division of the Oak Ridge National Laboratory. W. B. Heroy, Sr., president of the Geotechnical Corp., furnished a copy of the radioactivity log of the core hole; and he generously provided much information concerning the coring operations and the results of drilling. His interest in the geology and the possible utilization of Kansas salt beds for storage of radioactive waste furnished a great impetus to the present study. The report

was critically reviewed by J. J. Norton, to whom special acknowledgment is due for his many valuable comments and suggestions concerning its content and organization.

STRATIGRAPHY AND LITHOLOGY

GENERAL STRATIGRAPHIC SEQUENCE

The salt and other evaporites, with which this report is concerned, are part of a thin-layered sequence of marine sedimentary rocks of the Lower Permian Series. These rocks include the Chase Group (limestone and shale) and the overlying Sumner Group (an evaporite and shale sequence), of which the Wellington Formation forms a large part (fig. 2). The two groups have an aggregate thickness of about

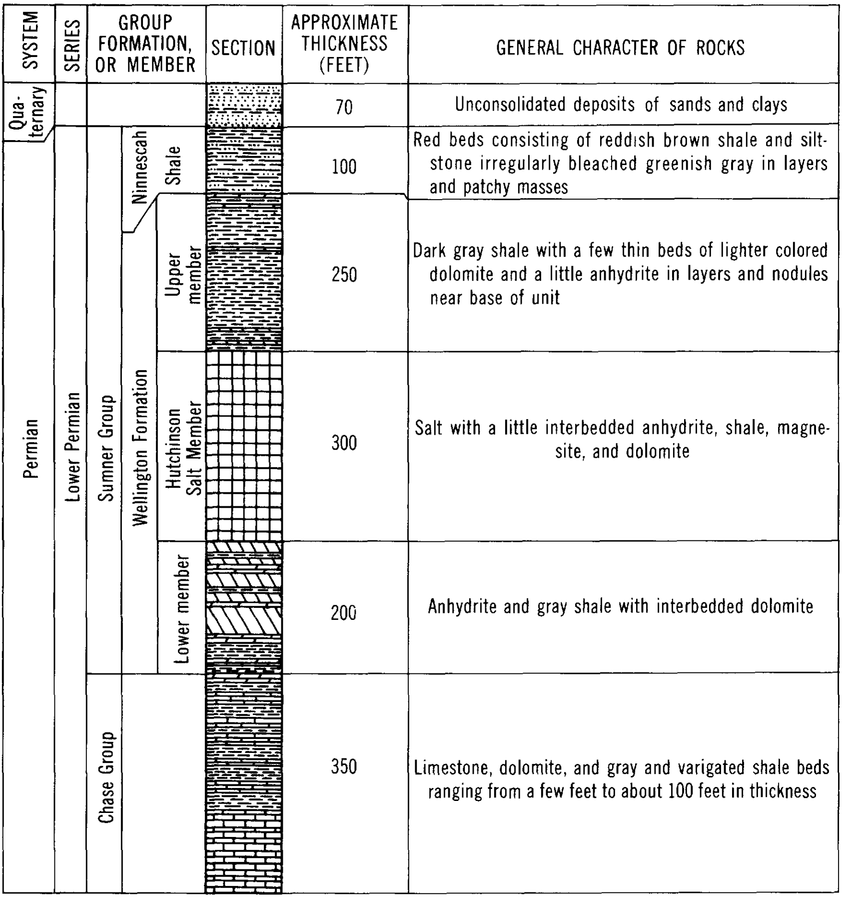

FIGURE 2.—Generalized section of rocks penetrated by drill holes in the general region of the Hutchinson Naval Air Station. Adapted from published sections by Norton (1939), Lee (1949), and Swineford (1955).

1,200 feet near the Hutchinson Naval Air Station; but the original thickness must have been somewhat greater, because the Sumner Group has been partially eroded. The Sumner Group forms the bedrock of the area and is mantled by different thicknesses of unconsolidated surficial deposits of Quaternary age.

The rocks of the Chase and Sumner Groups have been described in so many publications since the early studies of Cragin (1896) that only a general outline of the stratigraphic sequence seems warranted here. The summary is based largely on published descriptions and cross sections by Elias (1937), Norton (1939), Lee (1949), and Swineford (1955); and it is concerned mainly with the general character of the stratigraphic sequence to which the salt and other evaporites belong. In general the sequence is a succession of carbonates, evaporites, and clastic rocks that can be conveniently subdivided into five lithologic units, of nearly equal thicknesses, to illustrate a crude vertical gradation from limestone and dolomite, through evaporites and shale, to red beds. The lowermost of these five lithologic units consists of the Chase Group and all of its carbonate and shale formations. The second, third, and fourth units are parts of the Wellington Formation; and the fifth and uppermost is the Ninnescah Shale. All these units are within the Sumner Group.

The Chase Group, about 350 feet thick, consists of carbonate rocks and shales deposited under both normal and restricted marine conditions on fairly stable shallow shelf areas (Elias, 1937). The carbonate rock is nearly all limestone in the lower part of the group and dolomite in the upper part, and much of it is cherty. It is interbedded with dark-gray and variegated green and brown shales. Upward the carbonate rock grades into dolomite and associated evaporites and shales of the Wellington Formation of the Sumner Group.

The Wellington Formation is about 750 feet thick and represents a transitional zone from normal marine limestone and shale to red beds deposited under restricted marine conditions (Swineford,1955). It is divided into three lithologic members that have been described by Norton (1939) and most later workers as a lower anhydrite member, the Hutchinson Salt Member, and an upper shale member. The basal member accounts for almost one-third of the thickness of the formation and is composed mainly of anhydrite and shale, but dolomite is present in appreciable amounts. These rocks alternate with one another in thin to moderately thick beds. They grade upward into the other evaporites and the shale of the Hutchinson Salt Member, on which attention is mainly focused in the present study. This middle member of the Wellington Formation is largely a deposit of salt—almost 300 feet thick—but it has sparse thin beds of dolomite, magnesite, anhydrite, and shale scattered through it. The salt member is overlain by a somewhat monotonous succession of gray shale beds resembling those in the Hutchinson and in the lower member of the formation. This shale succession forms the upper member of the Wellington and is about 250 feet thick. It includes some anhydrite in its lower part, and a few thin beds of dolomite at wide intervals.

Above the gray shale member of the Wellington Formation are red beds of the Ninnescah Shale. The Ninnescah is only about 100 feet thick at the air station, but it is much thicker to the west where the red beds were not eroded during the period of erosion that followed Permian deposition (Lee, 1949). It is composed almost entirely of reddish-brown shale and siltstone that are irregularly bleached greenish gray in splotchy masses and layers; it includes some beds of dolomite.

CORED SECTION OF THE WELLINGTON FORMATION IN THE H.N.A.S. BORING

The core from the H.N.A.S. (Hutchinson Naval Air Station) boring includes 311 feet of strata between a depth of 423 feet and the bottom of the boring at 734 feet. This thickness represents a complete section of the Hutchinson Salt Member of the Wellington Formation, together with small sections of beds immediately below and above this member (pl. 1). The beds below the Hutchinson are composed of gray shale and anhydrite interbedded with gray to brownish-gray dolomite. Presumably they are the uppermost part of the rock unit described by Norton (1939, p. 1758) as the lower anhydrite member of the Wellington Formation. The beds above the Hutchinson consist of dark-gray shale resembling that scattered through the salt, but they form part of an unbroken succession of shale that extends to the top of the Wellington Formation. Accordingly, they were referred to as the upper shale member by Norton (1939).

ROCKS BELOW THE SALT

Rocks from a depth of 712 feet to the bottom of the drill hole at 734 feet are somewhat arbitrarily assigned to the lower member of the Wellington Formation. The sequence consists of thin layers of anhydrite, shale, and dolomite and is similar in nearly every respect to parts of the Hutchinson Salt Member; but the halite layers that are diagnostic of the salt member are lacking. Anhydrite and shale layers of almost equal thicknesses make up a little more than three-fourths of the sequence (pl. 1; table 1). Both the anhydrite and shale are dolomitic and contain a little halite and very small amounts of pyrite and bituminous matter. The layers of anhydrite are dominantly gray, microcrystalline in texture, and lamellar to massive in structure.

All carry laminae or streaky and patchy masses of dolomite. Less commonly they contain halite in large grains having scalloped margins embayed by anhydrite. The shale is light to moderately dark gray and has a generally bluish cast; much of it has a lamellar structure, caused by an irregular to fairly even interlamination of light gray siltstone and brownish-gray dolomite. The dolomite in both the thin laminae and the thicker layers is entirely microgranular in texture and earthy in appearance, so that it resembles a siltstone or silty shale. It is very sparingly pyritic and bituminous and contains lenticles and veins of halite and anhydrite similar to those in the Hutchinson Salt Member.

TABLE 1.—*Summary of lithology of the cored section of the H.N.A.S. boring*

	Thickness (ft)	Halite rock (percent)	Anhydrite rock (percent)	Carbonate rock (percent)	Shale and siltstone (percent)
Rocks above the salt	3				100
Hutchinson Salt Member	286	82	3	4	11
Rocks below the salt	22		40	23	37
Complete core	311	75	7	5	13

HUTCHINSON SALT MEMBER

The Hutchinson Salt Member is a distinctly saliferous sequence of evaporites and shales 286 feet thick that extends from a depth of 426 feet to 712 feet in the drill hole. The sequence consists of an irregular alternation of relatively thick salt beds and thinner beds of clayey and silty shales, dolomite, magnesite, and anhydrite. The alternation of salt beds and shale, carbonate, and anhydrite beds, such as that shown in plate 1, is repeated on a much smaller scale within the beds. As a consequence, virtually all the beds are lithologically complex and have different combinations of contrasting laminae or layers, such as shale and magnesite, magnesite and anhydrite, or other rocks as listed in figure 3. The layering is rhythmic in character, and there is a regular order of succession. In general, a basal shale or siltstone gives place upward to carbonate rock (dolomite or magnesite), anhydrite, and halite rock. The carbonate and the anhydrite are ordinarily no more than a fraction of an inch thick, but the halite rock is almost everywhere several times as thick—often as much as 8 or 10 times as thick. The difference in thickness together with repetition of sequence give rise to a great but not an anomalously large ratio of halite to carbonate and anhydrite. As it is, the ratio is only about 12 to 1, and this ratio is smaller by about one-half than the ratio to be expected on complete evaporation of sea water.

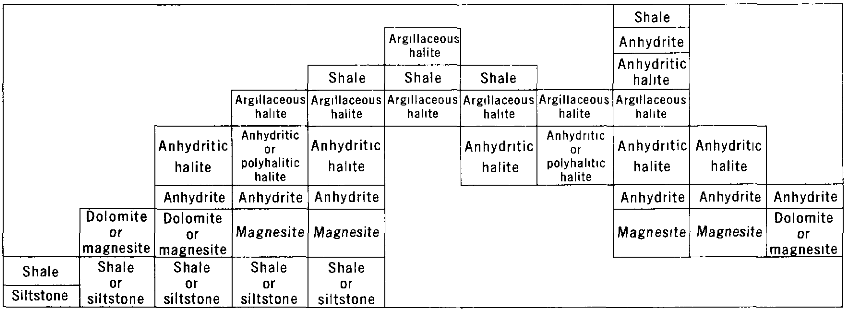

FIGURE 3.—Couplets and other combinations of contrasting rock laminae found in the evaporite and shale beds of the Hutchinson salt Member. The order of lithologic succession is from the base upward, and the uppermost rock lamina is listed at the top.

HALITE ROCK

Layers of halite rock occur fairly regularly throughout the entire sequence, and their thickness ranges from a few inches to 14 feet. The rock is semitransparent to translucent and dominantly grayish white; but the color varies from almost pure white through reddish orange, amber, buff, brown, and various shades of gray, to almost black. Most of the rock consists of 95 percent or more of the mineral halite in compact, megacrystalline, and essentially equiangular form; all the rock contains one or more accessory minerals. The most common accessory minerals are anhydrite, quartz, feldspar, mica, and clay minerals (illite, chlorite, and montmorillonite); but polyhalite, dolomite, magnesite, hematite, celestite, and marcasite are present locally. Other impurities include interstitial traces of organic matter and small amounts of brine and gas in a few small cubic and rectangular cavities or in countless tiny negative-crystal cavities which mark growth lines in the halite.

The halite rock in practically all parts of the sequence is of two or more compositional types distinguished by a particular accessory mineral or group of minerals. The least distinctive but by far the most abundant type is a light-colored, grayish or whitish anhydritic halite rock that ordinarily contains 3 or 4 percent anhydrite in the form of small stellated groups of tiny crystals and in compact microcrystalline nodules and veinlets. In a less common type, anhydrite is absent or is present in very negligible amounts; its place is taken by polyhalite. The presence of polyhalite distingushes a typically and often intensely reddish-orange polyhalitic halite rock that resembles in every respect the so-called blebby salt described by Schaller and Henderson (1932, p. 58, 67) from the potash field of southeastern New Mexico. Both the anhydritic and the polyhalitic halite rocks usually are underlain by anhydrite rock, with a sharp break between, whereas they merge upward into an argillaceous halite rock without perceptible break. This third argillaceous type of halite rock contains mica and clay minerals together with angular detrital grains of quartz and feldspar. This rock occurs characteristically as dark-colored layers—often gray or grayish black—as much as one inch thick that are in sharp contrast to the thicker and lighter colored layers of anhydritic halite rock or to the more vividly colored layers of polyhalitic halite rock. The rock may gradually give place upward to shale, or abruptly to carbonate rock; but in many parts of the sequence it is overlain by anhydritic halite rock.

ANHYDRITE ROCK

Anhydrite rock forms a much smaller part of the sequence than does halite rock, yet it occurs almost as regularly and as widely as the halite rock and is in distinct layers ranging from about one-tenth of an inch to 4 feet in thickness. The rock is compact, microcrystalline, and light gray to bluish gray; `much of it is streaked and mottled in dark and lighter shades of gray owing to differences of texture, to impurities such as dolmite and magnesite, or to the presence of halite and anhydrite pseudomorphs after gypsum. Practically all the rock is composed of 90 percent or more of the mineral anhydrite in a compact microcrystalline form; and it almost invaribly contains, as accessory minerals, a carbonate (dolomite or magnesite) and (or) halite, together with traces of bituminous matter and a little authigenic quartz, chalcedony, and pyrite. Most of these accessory constituents ordinarily are associated with the halite or with the carbonate mineral, and in places they are accompanied by clay minerals and angular detrital grains of quartz and feldspar.

The anhydrite rock in much of the sequence is in layers no more than one-eighth of an inch thick. Many of these layers lie between layers of carbonate rock (dolomite or magnesite), most of which have an abrupt lithologic break at their base but pass gradually upward into the layers of anhydrite rock. Other layers of anhydrite rock have halite rock on both sides, or halite rock below and shale above; many of them contain small isolated patches of carbonate rock in their lower part, if overlain by halite rock, or in their upper part, if overlain by shale. Still other layers of anhydrite rock are bounded below by carbonate rock and above by halite rock, so that the anhydrite apparently forms an integral part of a tripartite succession of rocks of different lithologic types. In many such successions, the anhydrite rock and the accompanying carbonate and halite rocks are separated by irregular, interpenetrating contacts, from which sinuous veinlets and narrow lenticular and veinlike masses of anhydrite project into both the carbonate rock and the halite rock and there send out apophyses which come together irregularly, and enclose detached and embayed patches of the carbonate and the halite rock.

CARBONATE ROCK

Carbonate rock makes up only a small part of the sequence, yet it is scattered throughout as homogeneous layers which seldom are more than one-quarter of an inch thick and only rarely are a foot or more thick. It occurs as two main compositional varieties, dolomite and magnesite, but these two varieties are so similar that they ordinarily are indistinguishable except by mineralogical or chemical tests. Both the dolomite and the magnesite carbonate rocks are distinctly fine grained and nearly everywhere are relatively soft and earthy; they have a general appearance and microgranular texture much like that of a silty shale or siltstone. Both are dominantly brownish gray, in shades ranging from very light to moderately dark; and both are sparingly halitic, pyritic, bituminous, and cherty. In addition, these two varieties of carbonate rock may contain silty and argillaceous materials and (or) anhydrite, and there are nearly all degrees of gradation from essentially pure carbonate rock (dolomite or magnesite) to silty shale or siltstone in some places and to anhydrite rock in other places. Moreover, both varieties of carbonate rock occur almost as often with the fine-grained clastic rocks as they do with the anhydrite rock. One or the other of the two types of carbonate rock almost invariably separates the clastic rocks from the anhydrite rocks, so that layers of anhydrite rarely rest directly upon layers composed of silty and argillaceous materials.

Despite the similarity of physical properties, minor constituents, and lithologic associations, the two varieties of carbonate rock differ in one major respect besides their carbonate mineralogy. They are set apart stratigraphically—the magnesite is widespread, but the dolomite is restricted in distribution to a small section of beds, about 60 feet thick, at the base of the sequence. This basal section contains both dolomite and magnesite. These varieties do not pass vertically into one another but occur separately and in irregular alternation as the dolomite dies out upward, giving way entirely to magnesite in the middle and higher parts of the sequence.

SHALE

Fine-grained clastic rocks, here collectively referred to as shale, are of three main lithologic types: clay shale, silty shale, and siltstone. The shale is irregularly scattered throughout almost the entire sequence as beds ranging from less than 1 inch to about 4 feet in thickness. It is not nearly so abundant as the halite rock, but its total thickness exceeds that of all the anhydrite and carbonate rocks combined. It is relatively soft and waxy or earthy and has good

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cohesion, a blocky to conchoidal fracture, and little or no fissility. Many beds have horizontal laminations consisting of dark and light layers of fine and coarse particles; these laminations commonly are crenulated and broken by small faults, as if disturbed by subaqueous slumping or gliding. Most of the shale is light to moderately dark gray, but the color ranges from bluish gray to brownish gray as the carbonate content of the rock increases. The beds of lightest shade almost invariably are silty, and those of darkest bluish gray carry sparse pyrite and occasionally bituminous matter.

Nearly all the shale layers contain magnesite, but below a depth of 675 feet the carbonate mineral ordinarily contains enough calcium to be called dolomite. The carbonate mineral may occur as discrete laminae, about one-tenth of an inch thick; but more commonly it is disseminated through the rock. Nearly all degrees of gradation from shale to magnesite or to dolomite rock are present; and much of the material described here as shale could be called marl, though the carbonate is magnesite or dolomite rather than calcite.

HALITE AND ANHYDRITE VEINS

Nearly all layers of shale, dolomite, and magnesite contain halite and anhydrite in the form of narrow nearly vertical veinlets, broader nearly horizontal lenticles and seamlike veins, or single crystals.

The veins of halite typically are cross fibrous in texture; they generally are colored red by interstitial films of organic matter and associated hematite; and they invariably have sharp contacts with the host rock (fig. 4). Most of them are no thicker than about one-eighth of an inch, but some are as much as one-half of an inch thick. They bifurcate and come together here and there, thickening and thinning irregularly. Many of them die out upward, either against a bedding plane or by fraying out into stringers.

The veins and lenticles of anhydrite resemble the layers of anhydrite both in texture and color; and like these layers they commonly are irregularly streaked and mottled with magnesite or dolomite, as if coalescing masses of anhydrite had merged but failed to assimilate all the magnesite or dolomite. They may be cross fibrous and nearly vertical like the veins of halite; but more commonly they are even grained and nearly horizontal, so that they are practically parallel with the bedding. However, some of them extend across bedding planes in sequences of different rocks. Others cut into veins of halite and spread upward or downward, enclosing in places small halite relicts, some of which retain their fibrous texture and some of which are recrystallized into an even-grained mass. Still other veins of anhydrite are cut by cross-fibrous veins of halite; and the detached

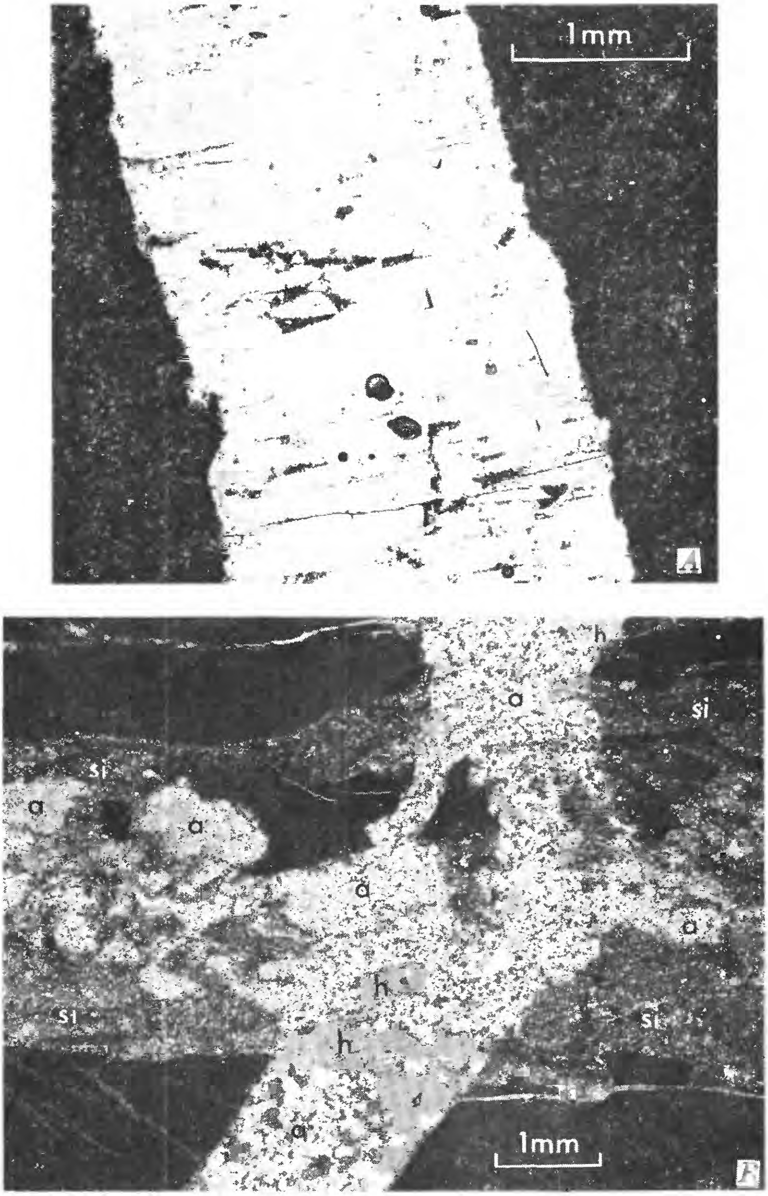

FIGURE 4.—Veins and lenticles of halite and anhydrite. *A*, Cross-fibrous halite in dolomitic shale. Hematite associated with algae darkens the margins of the elongate halite grains. Other inclusions are iron-magnesium carbonate crystals and patches of shale. Depth, 651 feet 7 inches. *B*, Anhydrite (a) in siltstone (si) cut by transverse vein of halite (h) into which the anhydrite has spread. Dark material above and below the siltstone is magnesite. Nicols inclined. Depth, 530 feet 9 inches.

parts of these anhydrite veins are offset, as if the halite had been injected along minor fractures or faults.

FOSSILS

Like most deposits of its kind, the Hutchinson Salt Member contains few fossils except for the widely scattered remains of algae.

This drill core is thus notable in that a thin layer of magnesite at the depth of 698 feet contains many small shells. The shells are both so numerous and so closely packed that the upper 2 inches of the layer forms a coquinalike deposit resembling the gypsiferous coquinas described by Clifton (1944, p. 1020, 1028–1029) from marina strata in the Lower Permian sequence of Kansas, Oklahoma, and Texas. Unlike the gypsiferous coquinas, however, there are no fragments of broken shells; specimens in the lower part of the coquinalike deposit are entirely enclosed in magnesite, and those in the upper part are enclosed in anhydrite. The shells retain very little of their original calcareous material, and their mode of preservation is as unusual as is the mineralogical character of the matrix. The shells embedded in anhydrite now consist almost entirely of halite, and those in magnesite now consist dominantly of anhydrite. As far as has been determined from perusal of geological literature, these fossil shells constitute the only known example of the replacement of originally calcareous shell material by halite. Anhydritic fossils are also rare, though these specimens are not unique. Their mode of preservation is somewhat similar to that of the anhydritic and gypsiferous fossils found in Tertiary rocks of Egypt (Dabell, 1931), in Cretaceous rocks of Russia (Chirvinski, 1928), and in Upper Permian rocks of England (Dunham, 1948) and of Texas (Adams, 1932, and Walter, 1953).

The fossils were examined by E. L. Yochelson and L. G. Henbest of the U.S. Geological Survey, who found a populous but very simple pelecypod and foraminifer fauna. According to Yochelson (written commun., 1959), the fauna is dominated by a small *Permophorus*-like pelecypod, though there may be more than one genus present. Some of the specimens retain both valves; and even though the rest are single valves, the right and left valves are about equally abundant. Nearly all the specimens for which the outer shell surface is preserved carry one or more encrusting foraminifers. These were identified by Henbest (written commun., 1959) as *Serpulopsis* sp., a sessile foraminifer having an agglutinated siliceous test. According to Henbest, they are shallow-water marine, or possibly brackish-water, species living in or near the zone of light.

As interpreted by Yochelson (written commun., 1959), the presence of the fossils indicates a temporary freshening of the water between periods of evaporite deposition. The degree of freshening is uncertain, however, inasmuch as typically marine fossils such as brachiopods, bryozoans, and enchinoderms are absent; and the fauna is limited in variety. In modern environments, according to Yochelson, such an occurrence of abundant specimens of a limited variety is taken to mean that living conditions are far from ideal. If this general principle is applied to the present example, the living conditions were almost certainly rigorous and possibly were adversely affected by inflow of brackish water.

The only other fossils are algae that are widely scattered through the drill core in layers of halite containing silt and clay; in veins of halite; and in crystals of halite embedded in shale, magnesite, and dolomite. They have the same mode of occurrence, appearance, and morphology as the species of blue-green algae, *Phormidium antiquum* Tilden, figured and described by Tilden (1930) from saliferous rocks of the Wellington Formation; their reference to this species of algae seems reasonable. The algae occur as inclusions and interstitial films in granular and fibrous masses of halite. On dissolving the halite in water, the remains of the algae are liberated; they expand to a gelatinous mass and float to the surface of the water. Under the microscope the gelatinous material is found to be a matted flexible mass of colorless exceedingly slender and branching hairlike filaments carrying countless minute red particles on their outer surface. The red particles have optical properties and an X-ray-diffraction pattern indicating that they are hematite. Some of the particles resemble coccus and bacillus forms of bacteria in shape, as was previously noted by Tilden (1930, p. 299), but others are tabular plates having a hexagonal outline like euhedral crystals of hematite.

ROCKS ABOVE THE SALT

Only 2 feet 7 inches of the core, starting at the depth of 423 feet, represents the part of the Wellington Formation that overlies the Hutchinson Salt Member. The rocks consist mainly of moderately dark bluish gray clay shale and small amounts of siltstone, magnesite, and anhydrite. The shale carries magnesite, accessory pyrite, and bituminous matter. It is cut by veinlets of halite and by many small lenticular and veinlike masses of microcrystalline anhydrite, which are ordinarily arranged in narrow rows a fraction of an inch thick and nearly parallel with the bedding. Much of the shale is interlaminated with siltstone in layers a fraction of an inch thick; the remainder has laminae of magnesite containing small nodular masses of anhydrite. The contact with underlying rocks is sharp, yet somewhat sinuous.

MINERALOGY AND PETROGRAPHY

The halite, anhydrite, and carbonate rocks in the drill core, like nearly all such rocks in marine evaporites, are practically monomineralic in composition. Consequently, the mineralogy and petrography of these evaporites are closely allied topics that can be combined in describing the halite and other evaporite minerals found in the rocks. These minerals are authigenic: they formed in place by chemical processes involving direct precipitation from crystallizing solutions and by subsequent recrystallization and reaction of early formed sediments with interstitial waters or percolating brines. The authigenic minerals are associated with allogenic ones that form fine-grained clastic rocks which are apparently similar in texture, structure, and composition to the shales and siltstones described by Swineford (1955) from various parts of the Permian sequence in south-central Kansas. The clastic rocks, however, are grayish shales and siltstones and not red beds as were most of the rocks studied by Swineford.

Only the authigenic minerals will be described in detail in this report. These minerals and their theoretical compositions are shown as follows:

- Chlorides:
  - Halite [$NaCl$]
- Sulfates:
  - Anhydrite [$CaSO_4$]
  - Celestite [$SrSO_4$]
  - Polyhalite [$2CaSO_4 \cdot K_2SO_4 \cdot MgSO_4 \cdot 2H_2O$]
- Carbonates:
  - Calcite [$CaCO_3$]
  - Dolomite [$MgCO_3 \cdot CaCO_3$]
  - Magnesite [$MgCO_3$]
- Oxides:
  - Hematite [Fe_2O_3]
  - Quartz [SiO_2]
  - Chalcedony [SiO_2]
- Sulfides:
  - Marcasite [FeS_2]
  - Pyrite [FeS_2]

The chief allogenic minerals are quartz and clay minerals; but small amounts of orthoclase, plagioclase, muscovite, and heavy accessory minerals of both opaque and translucent varieties are present. The clay minerals have not been studied in detail; but they can provisionally be called illite, montmorillonite, and chlorite. Some of them are undoubtedly detrital in origin; but most of the argillaceous material apparently has been recrystallized in place, because the clay minerals are found arranged as paralled elongate flakes that extinguish together under crossed nicols. The accessory heavy minerals include ilmenite, magnetite, hornblende, rutile, zircon, and possibly garnet.

The halite is by far the most abundant mineral, making up about 69 percent of the drill core. Next in abundance are the clay and associated allogenic minerals, forming about 14 percent of the materials present. Next comes anhydrite, accounting for nearly 10 percent. Magnesite and dolomite each forms about 3 percent of the core materials. All the other minerals together account for less than 1 percent of the core.

Halite, shale minerals, and anhydrite are distributed throughout almost the entire cored section of the H.N.A.S. boring (fig. 5). Magnesite, pyrite, quartz, and hematite are the next most widespread; these occur at irregular intervals in nearly all parts of the section. Locally, marcasite takes the place of pyrite, especially near the middle of the cored section, which also is the part richest in halite. Polyhalite has been found only in the middle part of the section, where it occurs at irregular intervals in a few layers of halite. A short distance below these layers, dolomite makes its appearance and gradually takes the place of magnesite in the basal, more anhydritic part of the section. The change from one carbonate mineral to another takes place in an interval of about 60 feet and involves a somewhat erratic alternation and overlap. The change is accompanied by the appearance of calcite locally and by the disappearance of marcasite a short distance above the base of the salt.

Some of the minerals, especially quartz, celestite, and chalcedony, may be more widely distributed than is shown in figure 5, because they are present in very minute quantities and may easily have escaped detection.

The authigenic minerals described here are widely distributed in almost all marine evaporites. Thus the authigenic minerals found by core drilling in central Reno County may reasonably be expected to be present over large parts of the region underlain by salt (fig. 1). This is corroborated by the mineralogy of salt beds at other localities. The salt beds exposed in mine workings and shafts at Kanopolis, Kans., were found by Rogers (1910) to carry discrete crystals of anhydrite, celestite, dolomite, pyrite, and quartz; and those at Hutchinson, Kans., according to Swineford and Runnels (1953, p. 368) and Swineford (1955, p. 102–103, 150), contain anhydrite, celestite, glauberite, polyhalite, and calcite. Red halite described from Kanopolis, Kans., and from Woodward County, Okla., by Tilden (1930) is similar to, if not identical with, the red halite exposed in the core from Reno County. Furthermore, magnesite, dolomite, hematite, marcasite, pyrite, quartz, and anhydrite, together with veins of red halite and

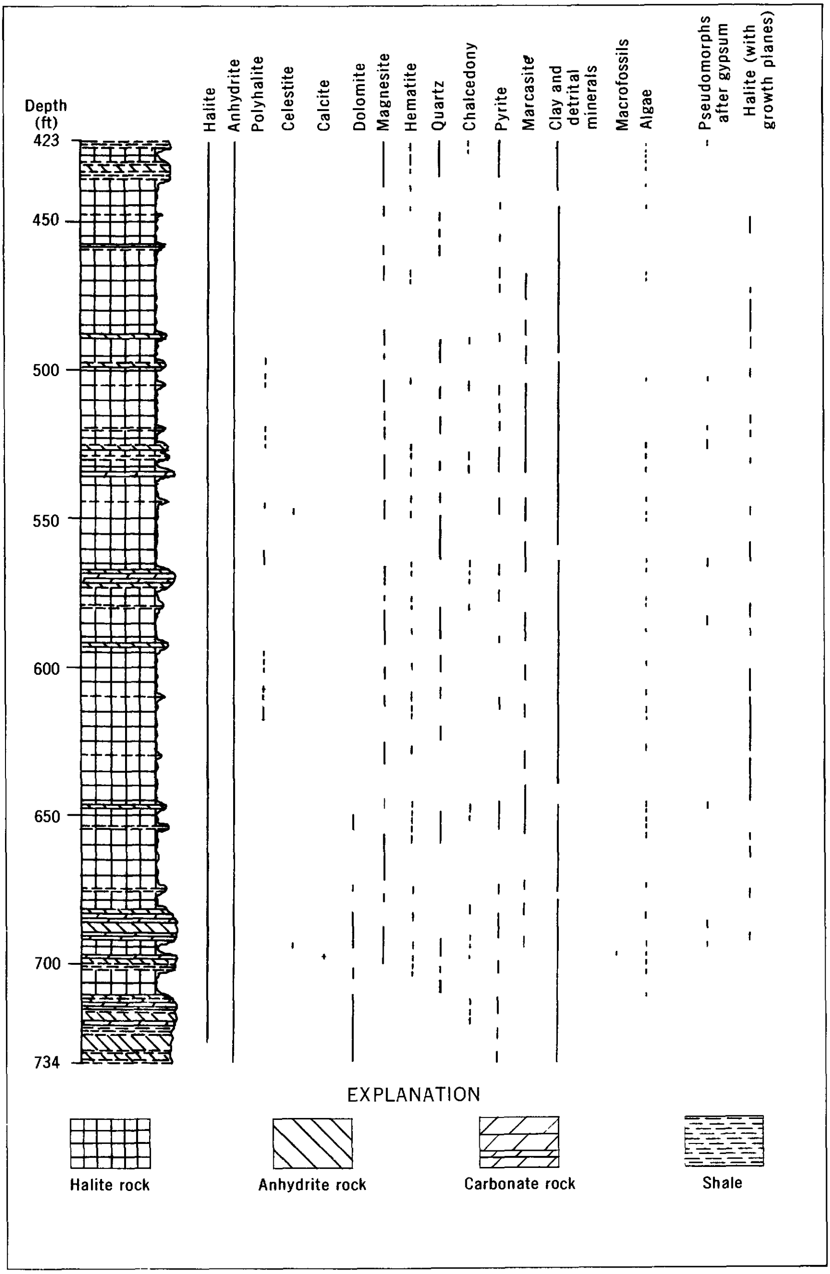

FIGURE 5.—Distribution of minerals, fossils, and relicts in middle part of Wellington Formation, H.N.A.S. core hole 1.

several varieties of halite and anhydrite pseudomorphs after gypsum, were found during the present investigation in a core from an underground core hole at the Carey mine, Hutchinson, Kans. This hole cuts the part of the section shown in figure 5 and plate 1 between the depths of 646 and 658 feet.

HALITE

Halite has several distinct modes of occurrence, its most common one being rock salt. It is found in layers as much as 14 feet thick that contain 95 percent or more halite. These layers are interstratified with shale and anhydrite, and nearly all of them contain crystals and particles of anhydrite and (or) clay and silt. Halite is generally present as irregular crystals and crystalline masses in the shale and anhydrite and also in the dolomite or magnesite associated with them. Narrow nearly vertical veins of virtually pure halite cut these rocks. Halite is also scattered through anhydrite in prismatic and spear-shaped pseudomorphs after gypsum, similar to those described by Schaller and Henderson (1932, p. 32–33, fig. 7, and pls. 8, 9) from southeastern New Mexico. Least in abundance, yet notable in other ways, is the halite that preserves fossils in magnesite rock at the depth of 698 feet.

Nearly all the halite is massive and lacks regular crystal outlines; it has no unusual mineralogical characteristics. Ordinarily it occurs as fairly even-grained aggregates of anhedral crystals having well-interlocked margins, but in veins it nearly always forms columnar aggregates of markedly elongated crystals. The crystals of halite are noticeably larger than those of other minerals; they range from 3 to 12 mm (roughly ⅛–½ in.) in diameter, but larger anhedral crystals, as much as 30 mm across, are occasionally found in a matrix of finer grained halite. The finer grained halite ordinarily has inclusions of mineral grains or liquid and gas in minute cubic cavities, so that it is somewhat translucent rather than perfectly transparent and is colored rather than white or colorless. It is generally grayish white but ranges from almost pure white through various shades of gray to almost black; it may also be buff, reddish orange, amber, or brownish gray. In contrast, the large crystals are almost everywhere perfectly transparent and free of color and mineral inclusions. Tiny particles of clay, silt, and other materials are especially abundant around the large crystals, as if such particles were expelled when the large grains recrystallized.

The rock salt in many parts of the cored section is made up of two separate kinds of halite of contrasting transparency (fig. 6). These may be described as translucent and limpid halite.

The translucent halite is the more conspicuous of the two, owing in part to its translucence and general frosted appearance and in part to

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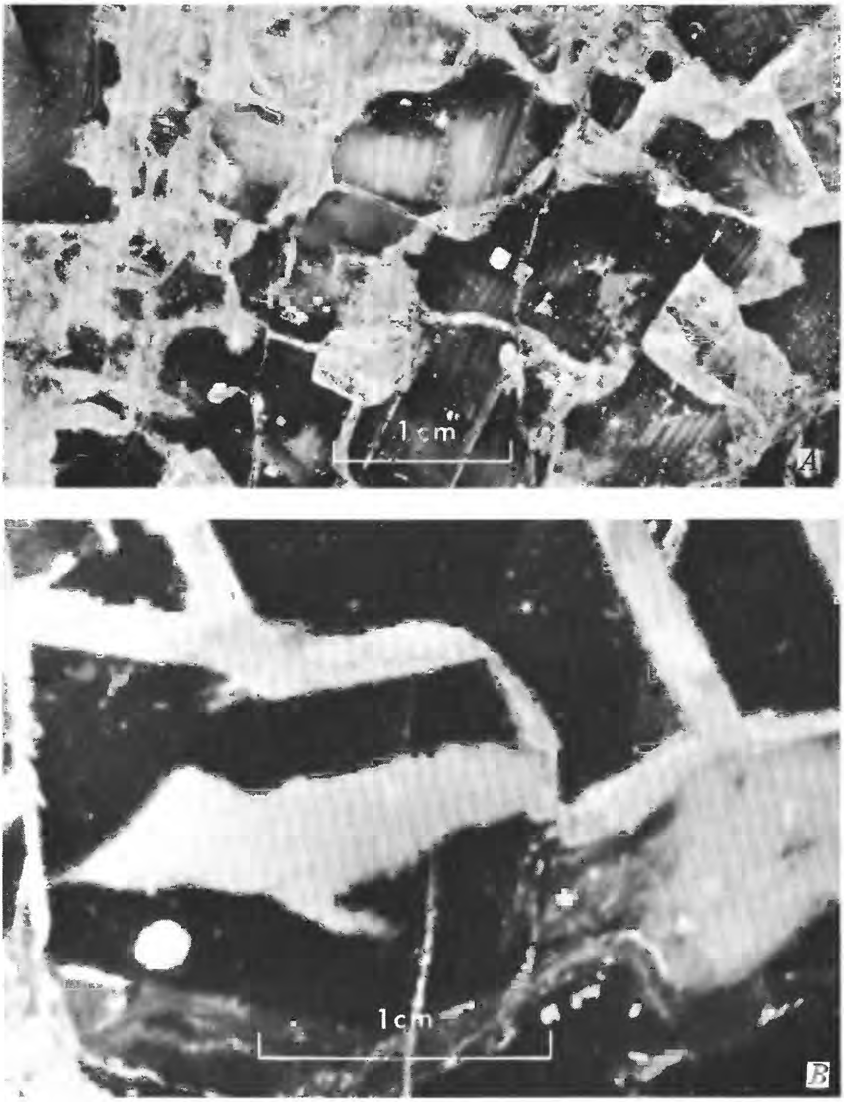

FIGURE 6.—Translucent and limpid halite. *A*, Patchy and streaky masses of translucent halite (grayish white) in limpid halite (black). Depth, 491 feet 1 inch. *B*, Residual translucent halite (grayish white) in limpid halite (black). Note sharp embayed margins of the translucent halite. Depth, 640 feet 9 inches.

the presence of growth planes. These planes are marked by three mutually perpendicular sets of narrow bands alternately rich and deficient in tiny cubic cavities 0.1 mm or less in diameter and invariably filled with brine and a tiny bubble of gas. The bands are arranged parallel to the margins of the cubes and extend to the edge of the translucent halite. No halite of this kind occurs as single grains or crystals. It is either entirely or partly enclosed by limpid halite and has sharp borders that may be straight, sinuous, jagged, or even scalloped and embayed. It very rarely contains inclusions of other minerals, though elongated crystals of some minerals, especially anhydrite, may project into it and cut the bands of fluid inclusions.

The limpid halite is much more abundant and widely distributed than is the translucent halite found scattered throughout the cored section. Also, unlike this earlier formed halite, much of the limpid halite is colored by inclusions of other minerals or of organic matter. Nevertheless, nearly all the limpid halite is transparent enough so that ordinarily the inclusions can readily be seen and identified even though they may lie a grain width or more below the surface of the drill core or hand specimen. The limpid halite is generally anhedral and commonly forms a coarse-grained matrix in which associated minerals occur as small single crystals, rarely exceeding 1 mm in diameter, or as noticeably finer grained aggregates of anhedral to subhedral crystals showing well-formed crystal faces. Along some of the contacts with the limpid halite, the adjacent minerals show a tendency to form fairly large crystals. Single crystals of such minerals as dolomite and quartz are disseminated throughout the halite or are molded to the edges of clayey, silty, or anhydritic patches. Crystalline aggregates of other authigenic minerals—especially polyhalite, marcasite, and celestite—consist of spherulitic or stellate groups of fibrous and elongate crystals that are completely enclosed by halite or project into halite from the edges of other mineral grains or crystalline aggregates. Other groups of crystals, especially those of anhydrite, have a veinlike form; they split and come together irregularly, enclosing isolated patches of limpid halite into which crystals having sharply defined crystal faces project from the edges of an otherwise interlocking mass of anhedral crystals.

Though much of the limpid halite contains fluid inclusions, these are secondary and are readily distinguished by their mode of occurrence and size. They are either irregularly scattered throughout recrystallized halite or are lined up in short en echelon rows that follow some crystallographic feature, such as cleavage or glide planes. Moreover, these fluid inclusions fill relatively large cubic to rectangular cavities—1 mm or more in diameter—and almost invariably contain a gas bubble of a proportionately large size. The gas bubble itself may be 0.5 mm or more in diameter, like the bubbles measured by Dreyer and others (1949, figs. 2–9) in their study of fluid inclusions in Kansas salt. It seems reasonable to suppose that these secondary fluid inclusions are of the same type as those described by Dreyer and others in their experimental studies. Consequently, Dreyer and others (1949, p. 33–34) were justified in their reluctance to consider that the filling temperatures of 70°–100° C, determined from their experiments are in any way related to temperatures prevailing in bodies of water from which the halite was precipitated as an original sediment. It is possible that their results give an indication of temperatures that prevailed during diagenesis, when recrystallization of halite may have taken place under higher temperatures than those prevailing during sedimentation.

Most of the halite in the shale is anhedral like the limpid halite, but some of it is in subhedral to euhedral crystals as much as 20 mm across. These crystals may be completely colorless and transparent and may have no visible impurities, but more commonly they are colored red or amber by algal remains and contain tiny particles of clay and silt and larger subhedral to euhedral crystals of quartz. The halite crystals are most abundant in bands parallel to bedding, but they are also irregularly scattered throughout the rocks. Other subhedral crystals of halite are occasionally found grouped compactly in a narrow row, no wider than a single grain, along the top of a halite layer overlain by shale. These crystals have irregular lower margins, but their sharply defined crystal faces project upward into the shale, as overgrowth formed on older crystals.

Subhedral crystals in argillaceous rocks, such as the halite in many parts of the cored section, are composite crystals that contain clay and silt between individual crystal units of similar crystallographic orientation. The clay and silt is spread as thin sheets and discontinuous films along the upper surfaces of the individual units, and it so coats these surfaces that the composite crystals have a chevron structure reminiscent of the zonal structure made by growth planes in other types of halite crystals (fig. 7). The sheets and films of clay and silt become thinner, and sometimes die out, over ridges formed by prominent crystal faces or corners. The sheets become noticeably thicker in the intervening troughs, as if marking stages in the growth of composite crystals along the sea floor, where clay and silt settled on the angular and inclined surfaces. Moreover, these sheets extend to the edges of the composite crystals, where they merge without perceptible break with the clay and silt present around the margins of these crystals.

Virtually all the halite in the anhydrite rock is limpid and forms grains containing small crystals and aggregates of essentially the same kinds of authigenic mineral as those found in the halite rock. This limpid halite rarely, if ever, assumes a cubic form or any regular shape other than that of simple and twinned crystals pseudomorphous after gypsum. It is also present as isolated detached remnants in pseudo-

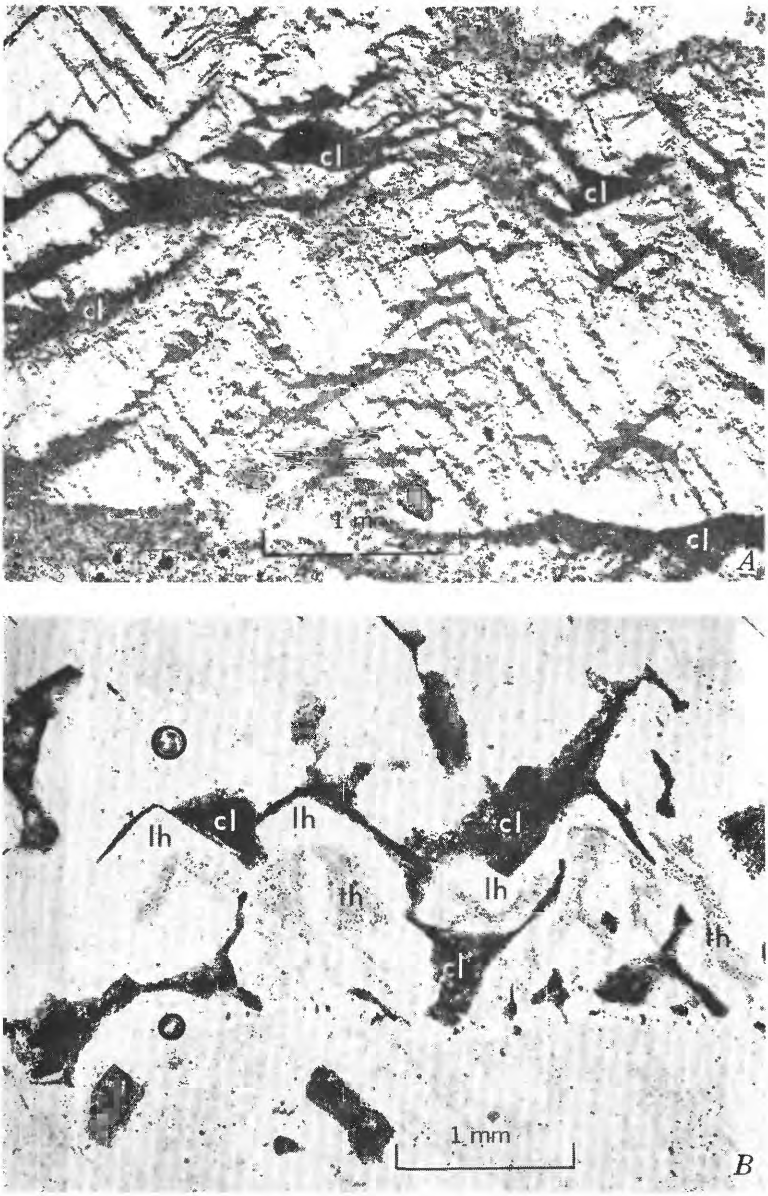

FIGURE 7.—Composite crystals of halite in argillaceous halite rock. *A*, Groups of superposed crystals containing similarly oriented sheets and wedges of settled clay and silt (cl). Depth, 710 feet 9 inches. *B*, Interior of crystal, showing limpid halite (lh) sandwiched between translucent halite (th) and settled clay (cl). Depth, 631 feet 10 inches.

morphs consisting largely of anhydrite (fig. 8). These halite remnants usually are largest and most numerous at the centers of the anhydrite

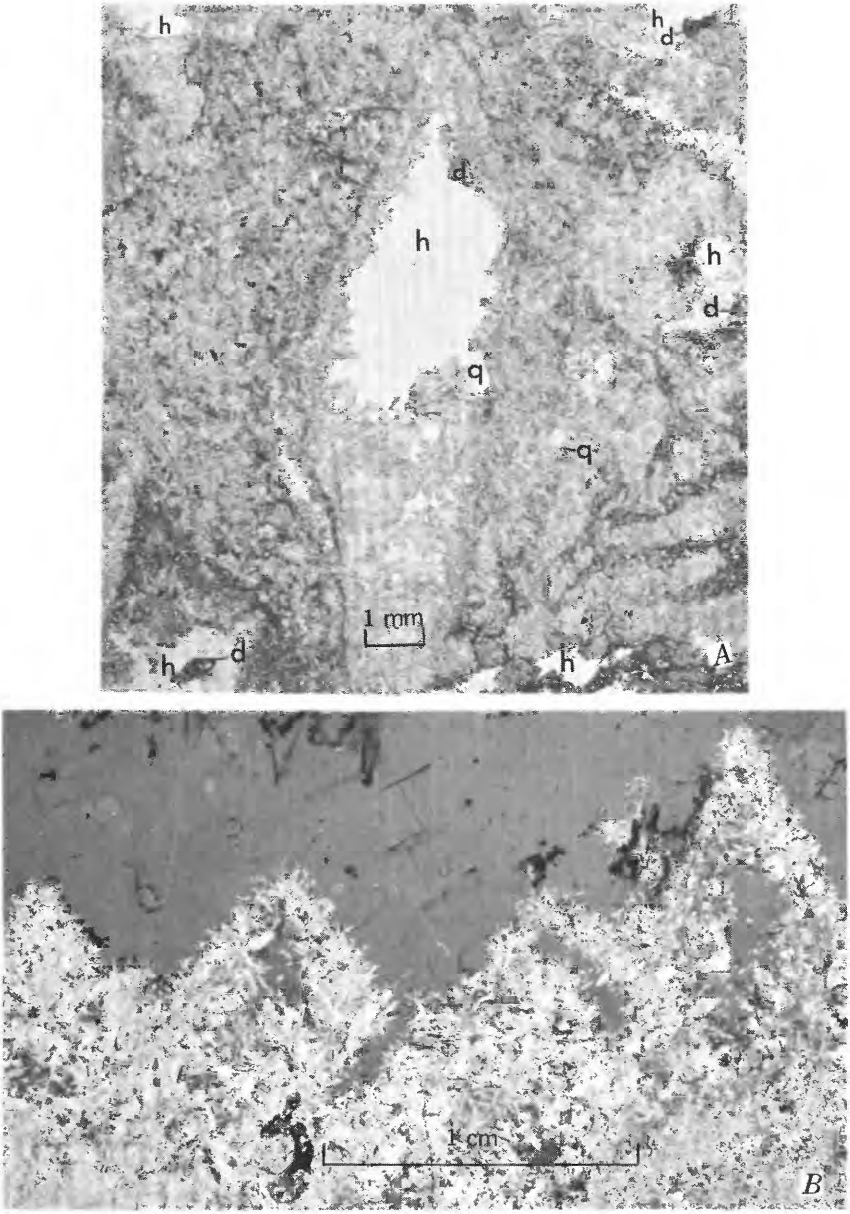

FIGURE 8.—Anhydritic halite pseudomorphs after gypsum. *A*, Pseudomorph set in a matrix of fine-grained anhydrite containing dark angular magnesite relicts. Note that both the pseudomorph and the matrix contain halite (h), dolomite (d), and quartz (q). Depth, 694 feet 2 inches. *B*, Pseudomorphs at contact between anhydrite and overlying halite. Core specimen from underground drill hole at Carey mine, Hutchinson, Kans., at the anhydrite-halite contact shown in figure 5 and plate 1 at a depth of 647 feet. Nicols inclined.

pseudomorphs, and their margins are cut by anhydrite crystals and aggregates which project into the halite as elongate crystals and knotty masses. Euhedral crystals and spherulitic clusters of elongate anhydrite crystals in the halite remnants also are present, and tiny angular halite relicts occur interstitially in the mesh of anhydrite crystals. Other halite relicts are in the anhydrite rims surrounding the halite centers of the pseudomorphs and also in the anhydrite in the interstices between pseudomorphs. Still other relicts are irregularly scattered throughout anhydrite rocks which are entirely free of pseudomorphs and throughout most, if not all, of the halitic anhydrite rocks.

ANHYDRITE

Anhydrite is next in abundance to halite and the detrital materials and is by far the most abundant sulfate mineral in the drill core. It makes up 3 percent of the drill core from the Hutchinson Salt Member and 40 percent of the 22 feet of drill core from beneath the Hutchinson. Practically all anhydrite occurs with halite alone, with dolomite or magnesite, or with halite and one or more of the carbonates. Layers of finely crystalline anhydrite lie between carbonate layers or halite layers or have halite on one side and carbonate or shale on the other. Most, if not all, of the anhydrite is banded or mottled to different degrees by laminae and small irregular masses of fine-grained carbonate and contains halite in scattered small masses in the interstices between mineral grains or in pseudomorphs after gypsum (figs. 8, 9, 10). Anhydrite crystals, singly or in groups, are scattered through layers and masses of fine-grained carbonate and coarsely crystalline halite; and many small lenticles and narrow veinlike tongues of anhydrite are also found. Small anhydrite pseudomorphs after gypsum occur in granular masses of fine-grained carbonate or are outlined by granular anhydrite containing fine-grained carbonate. Anhydrite also forms casts and molds of small fossil shells in finely crystalline magnesite rock at a depth of 698 feet in the drill hole, and some of the anhydrite fills the interstices between fossils replaced by halite.

A little anhydrite is present in the shale and siltstone. Much of it occurs as lenticles and as other small nodular or veinlike masses (fig. 4), but it is also present as single crystals and as small clusters of crystals. Still other anhydrite forms clusters of crystals and crystalline aggregates in nodules of chert in the carbonate and other rocks (fig. 17*B*).

The customary form of the anhydrite is a compact aggregate of small rectangular grains, 0.5 mm or less in length, having irregular well-interlocked margins. A few larger subhedral and still fewer euhedral crystals, as much as 6.5 mm across, occur as isolated grains in polyhalitic halite rock. Some of the anhydrite grains are stubby and

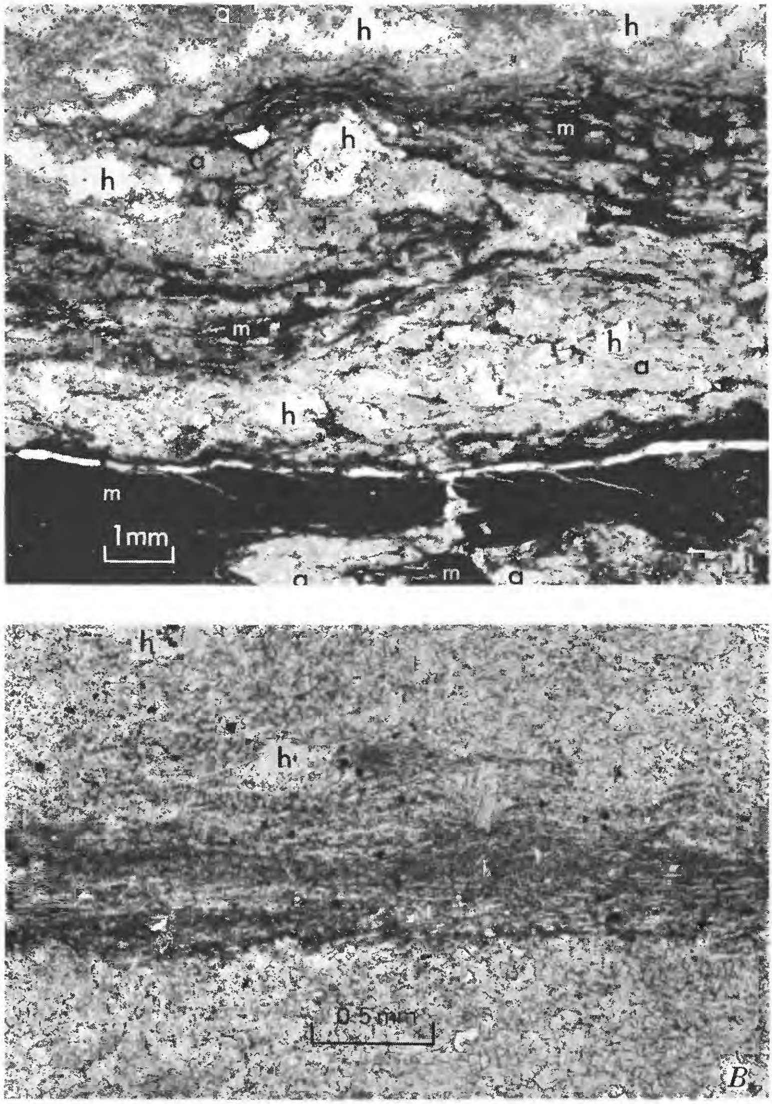

FIGURE 9.—Anhydrite rock containing magnesite and halite. *A*, Nodular anhydrite in gradation zone between anhydritic magnesite and halitic anhydrite. Constituents are anhydrite (a), magnesite (m), and halite (h). Light-colored seam below main body of anhydrite is a break in the thin section. Depth, 527 feet 1 inch. *B*, Foliated anhydrite in dark-colored magnesite layer in granular anhydrite rock containing inclusions of halite (h). Black grains are pyrite crystals. Depth, 489 feet 8 inches.

almost equidimensional; but most have an elongate, lathlike form. They may be randomly oriented and irregularly scattered throughout

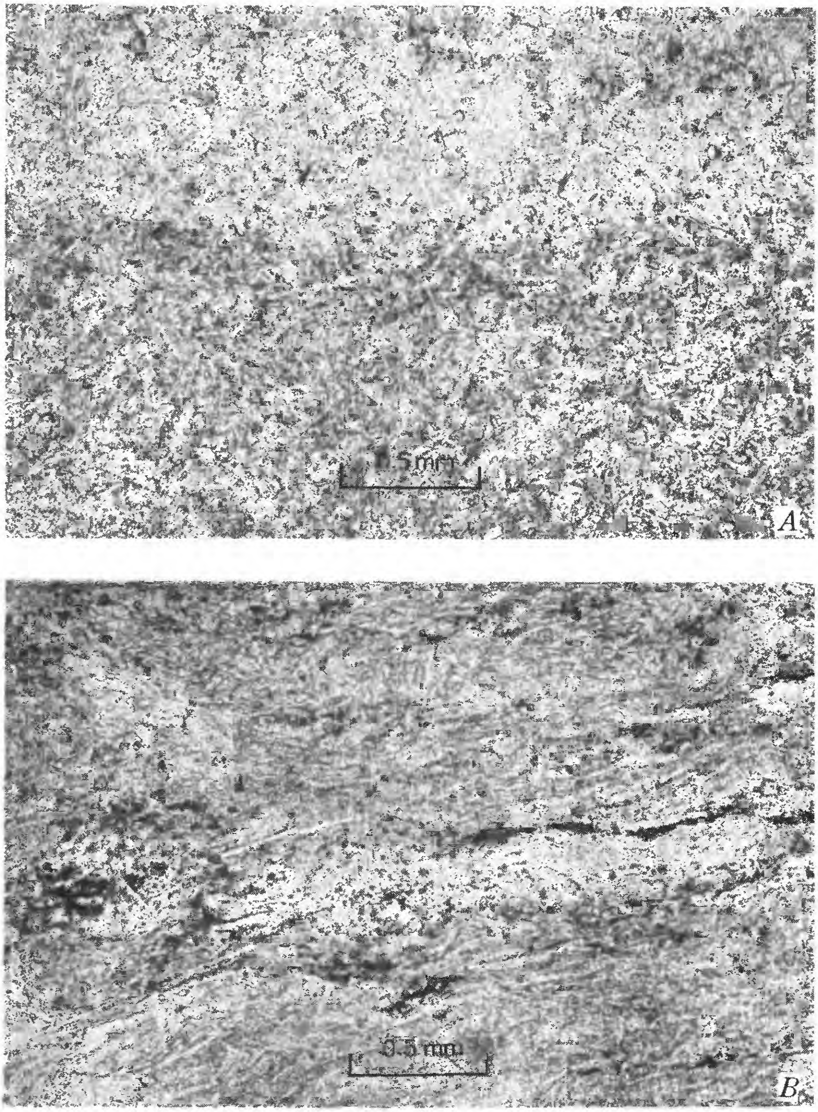

FIGURE 10.—Magnesitic and dolomitic anhydrite rocks. *A*, Felty magnesitic anhydrite rock overlain by granular anhydrite rock. Gray interstitial material in both rocks is fine-grained magnesite. Black grains are pyrite crystals. Depth, 431 feet 10 inches. *B*, Foliated dolomitic anhydrite rock. Black material is dolomite. Depth, 730 feet 8 inches.

the rock, or they may be grouped in stellate groups or radial fan-shaped clusters along intergranular boundaries in the halite. Still other elongate crystals occur as narrow bands, tabular masses, or streaky aggregates in fine-grained carbonate and have their longest

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dimension about parallel to the bedding. Some of the larger elongate crystals having well-defined pinacoidal faces project from a core of finer grained anhydrite into enclosing halite, dolomite, magnesite, or clay. A few of the crystals cut sharply through the chalcedony and microcrystalline quartz in chert nodules.

In the anhydrite layers the crystal forms of the mineral give rise to different textures, which can be described as granular, foliated, and felty. The granular type is a compact even-grained mosaic of stubby grains having interlocked margins and generally rectangular outlines (fig. 9*B*). It constitutes much of the material in the anhydrite layers and practically all of that in the veins and lenticles of anhydrite and in the anhydrite pseudomorphs after gypsum. The foliated anhydrite is characterized by an almost parallel arrangement of elongate grains having a regular lathlike form or a somewhat irregular spindle shape. Commonly there is a small to moderately large amount of carbonate between the similarly oriented grains of anhydrite and small groups of these grains (figs. 9*B*,10*B*). The felty anhydrite is made up of stubby and elongate grains that are irregularly entwined and intergrown in a tangled mass (fig. 10*A*), and much of it contains carbonate in the interstices between the anhydrite grains. The three different types of anhydrite may be complexly intermingled in a single layer; but more commonly they either follow one another in successive layers of contrasting textures, or one of them encloses lenticular or tabular masses of the other.

Aside from the difference in texture, there are virtually no features that set off one type of anhydrite from another. For the most part the three types are light to moderately dark gray and have a decidedly bluish tinge. These colors are characteristic of the anhydrite associated with carbonate and argillaceous materials rather than any particular form of anhydrite crystal or grain, and they contrast markedly with the whiteness of the anhydrite associated with halite. In general, all the types of anhydrite crystals and grains are vitreous, colorless, and fairly free of inclusions. The few inclusions that are present consist chiefly of smaller anhydrite grains, though occasionally they consist of tiny euhedral crystals of polyhalite, pyrite, and possibly marcasite, as well as rounded grains or anhedral crystals of halite, quartz, and one of the carbonate minerals. As far as can be determined, the carbonate is magnesite in the anhydrite above the depth of 568 feet; dolomite in the anhydrite below 710 feet; and magnesite, dolomite, or some other carbonate in the anhydrite between those depths. Practically everywhere, though, the anhydrite has well-defined crystal faces which cut the carbonate, and there are many sharply bounded and often elongate prisms of anhydrite which project into or through ragged streaks and patches of fine-grained carbonate in the layers or other compact masses of anhydrite.

With halite, anhydrite has virtually the same type of relationship as it has with the carbonate minerals. The anhydrite generally forms euhedral embayments in halite and commonly occurs as well-formed crystals in halite layers and veins and also in halite inclusions in anhydrite rock. Sharply bounded, and often elongate, prisms of anhydrite project into halite from the lower and upper edges of anhydrite layers; and similar anhydrite prisms cut sharply into or through halite inclusions in the anhydrite (figs. 8, 9A). Other anhydrite prisms are strung out in short streaks along grain boundaries in coarsely crystalline halite or form inclusions in halite, where they are commonly arranged in nearly parallel streaks and small poikilitic patches. Some of these streaks and patches enclose halite occurring pseudomorphously after gypsum, and others have angular outlines resembling the edges and corners on halite pseudomorphs after gypsum (fig. 11). Still other streaks and patches of anhydrite are lenticular or veinlike in general form. They spread through halite and bifurcate and coalesce at irregular intervals, like the narrow veinlike tongues of anhydrite in the carbonate and fine-grained clastic rocks. Other anhydrite invades veins of halite and spreads through them enclosing halite relicts Anhydrite also has replaced halite that is pseudomorphous after gypsum.

A little anhydrite in polyhalitic halite rock from the middle part of the evaporite section is in relatively large tabular crystals, averaging about 4 mm in diameter. These are similar to the anhydrite porphyroblasts described by Schaller and Henderson (1932, p. 16–17) from potassium-bearing evaporites of southeastern New Mexico and attributed to recrystallization of anhydrite in the presence of potassium salts. They are invariably associated with spherulites or matted crystals of polyhalite. Most, if not all, of them have been replaced to different degrees by polyhalite. They are also somewhat corroded by halite, which here and there encloses small detached anhydrite relicts, showing common optical orientation.

Although anhydrite occurs in many different forms, pseudomorphs of anhydrite after gypsum are scarce. However, these pseudomorphs are notable in several ways. The anhydrite in most of them resembles a mosaic of cubic or other rectangular grains and is very similar in practically all respects to the granular anhydrite which forms many of the anhydrite layers, veins, and lenticles. In addition, most, if not all, of the pseudomorphs are restricted in distribution to carbonate-bearing rocks; and their margins are outlined by fine-grained carbonate, by narrow rows or strings of carbonate grains, or by granular anhydrite containing a small but fairly evenly distributed amount of

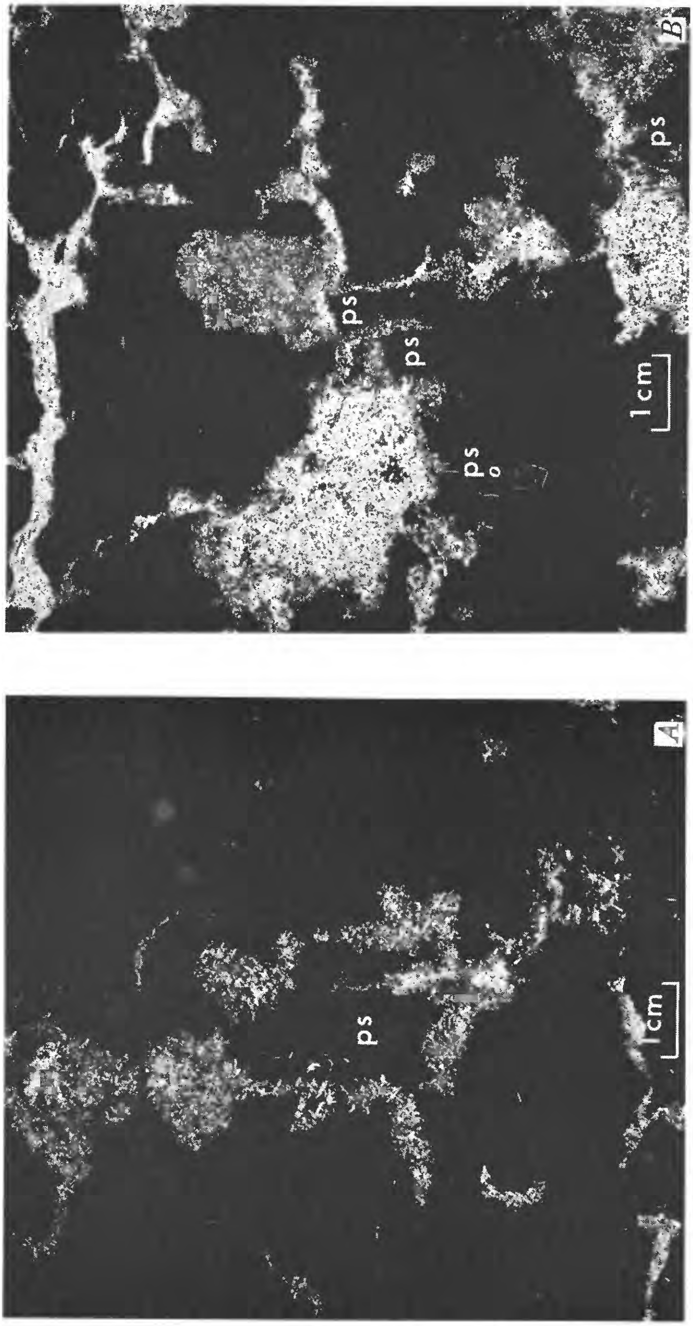

FIGURE 11.—Streaks and patches of anhydrite associated with pseudomorphous structures in halite rock. *A*, Polygonal patches and nearly parallel streaks of anhydrite enclosing halite pseudomorphs after gypsum (ps). Nicols crossed. Depth, 601 feet 5 inches. *B*, Rectilinear bands and polygonal masses of anhydrite formed along the sides and upper edges of halite pseudomorphs after gypsum (ps). Note sharp angular outlines of the masses of anhydrite and the number of straight-walled reentrants, wedge-shaped indentations, and swallow-tailed notches. Nicols crossed. Depth, 584 feet 5 inches.

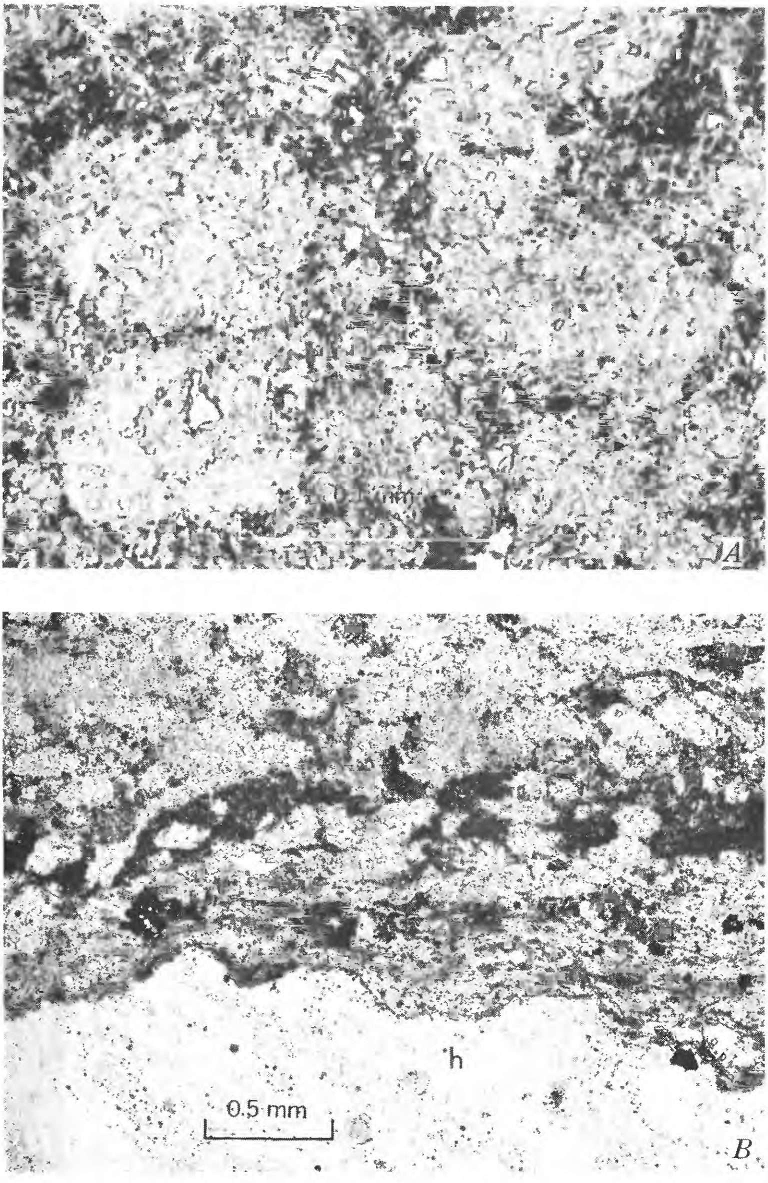

FIGURE 12.—Anhydrite pseudomorphs after gypsum. *A*, Small group of pseudomorphs in a matrix of anhydrite containing both magnesite (dark gray to black) and halite (white to light gray). Depth, 694 feet 2 inches. *B*, Pseudomorphs (ps) associated with magnesite remnants in anhydrite rock. Note the short distance from the lowermost pseudomorph to the base of the anhydrite rock and the truncation of the discontinuous rows of negative-crystal cavities in halite (h). Black grains are pyrite crystals. Depth, 647 feet 6 inches.

carbonate (fig. 12). Generally these pseudomorphs are stubby prisms having either a rectangular or a six-sided cross section, and they are considerably smaller than most of the halitic pseudomorphs after gypsum; few of them attain 5 mm in length. Many are randomly oriented like the single crystals of gypsum that form in unconsolidated muds or on the floor of salt pans and playa lakes. The pseudomorphs normally are most numerous and best formed in the lower and medial parts of anhydrite layers; locally they give way upward to halite pseudomorphs, such as those shown in figure 8.

CARBONATE MINERALS

Magnesite and dolomite are the predominant carbonate minerals and together form about 7 percent of all the materials in the drill core. Calcite occurs only as a minor constituent of magnesite rock at a depth of 698 feet in the drill hole. Still another carbonate, here not named but known to be rich in iron and to carry magnesium and manganese, is a minor constituent of saliferous rocks between the depths of 648 and 660 feet.

MAGNESITE

Magnesite is the main carbonate of the upper, halite-rich part of the drill core, but it gives way to dolomite near the base of that section (fig. 5). The transition takes place through a 60-foot section in which there is an erratic alternation and overlap in the distribution of magnesite and dolomite. The variable nature of the carbonate in this part of the section contrasts markedly with the persistence of magnesite in higher parts of the section, where rocks show nearly all stages of gradation from essentially pure magnesite to shale. Ordinarily the magnesite occurs in rocks showing a sequential layering of magnesite, anhydrite, and halite; or it is in laminae in rocks showing a regular alternation of magnesite and anhydrite or of magnesite and shale. Magnesite is present as streaky and patchy masses in much of the anhydrite rock and also in many lenticular and veinlike masses of anhydrite. Magnesite grains and granular aggregates are irregularly scattered through clayey and silty areas in halite rock. Still other magnesite—perhaps the most notable occurrence of all—forms part of the matrix in the coquinalike mass of marine, or possibly brackish-water, fossils in the magnesite layer at a depth of 698 feet in the drill hole.

The magnesite has normal properties and a simple crystallographic habit. Refractive-index measurements show no significant variations from the value $\omega = 1.70$, and X-ray-diffraction patterns are identical with those of magnesite from the Carlsbad potash field. Also, like much of that from the Carlsbad area, the magnesite is in small particles; it occurs as single crystals or as groups of crystals, as irregular patches, streaks, and ragged bands, and as compact fairly homogeneous layers. The individual particles and crystals are nearly spherical granules, 0. 02 mm or less in diameter, which present curved and irregular faces to one another or to grains of other minerals. These particles and crystals are commonly so small and so compactly arranged in layers and bunches that the magnesite appears almost opaque in thin section. The mineral, however, is transparent, vitreous, and colorless to light brown. It is also generally free of inclusions, though some of it contains grains of calcite.

The magnesite occurring as layers and bands is very fine grained and, for the most part, shows little variation in grain size from one layer or band to the next or within the individual layers and bands. It is usually brownish gray; yet it is also white to buff in the layers and bands which are largely free of clayey, silty, and bituminous matter. Regardless of its color, though, virtually all the magnesite is associated with one or more authigenic minerals. Among the most common of these are chalcedony and microcrystalline quartz, which form small chert nodules in many of the magnesite layers. Other authigenic minerals,—such as pyrite, quartz, and anhydrite,—occur as subhedral to euhedral crystals which sharply cut the magnesite, or they form crystalline masses bordered by one or more layers of subhedral to euhedral crystals which form embayments in the magnesite. In contrast to these minerals, halite seldom forms subhedral to euhedral crystals and mainly fills narrow fissures, small cavities, or the interstices between mineral grains.

Although magnesite occurs mainly as layers of fairly pure material, it is widespread as small microgranular aggregates and as ragged streaks and patches distributed through anhydrite. Most of the anhydrite above the depth of 710 feet in the drill hole either encloses small clusters and short irregular rows of magnesite granules or it contains streaky and patchy remnants of fine-grained magnesite. Ordinarily the magnesite remnants are largest and most numerous at or near the base of anhydrite layers, as is shown in the photomicrograph in figure 12, but they may be present in any part of the anhydrite layers or in anhydrite lenticles and veins. Tiny angular magnesite relicts occur throughout the layers of felty anhydrite, and tabular magnesite relicts are scattered irregularly through layers of foliated anhydrite. Veins and lenticles of anhydrite enclose angular and streaky magnesite remnants whose margins are sharply cut by small anhydrite prisms projecting from the main mass of anhydrite. Still other anhydrite contains magnesite that occurs pseudomorphously after gypsum (fig. 13), and small anhydrite prisms project into the

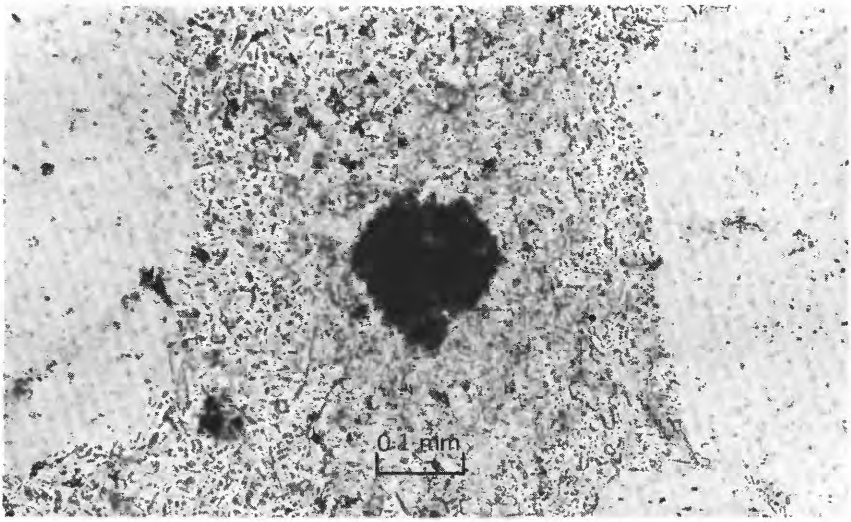

FIGURE 13.—Magnesite pseudomorph (black) after gypsum in anhydritic halite rock. Indentations in margins of the pseudomorph are due to small anhydrite prisms which project into magnesite from enclosing anhydrite. From a lower and different part of the same thin section as that shown in the photomicrograph in figure 11*B*.

magnesite in much the same way as do those cutting the margins of magnesite relicts in anhydrite layers, veins, and lenticles.

DOLOMITE

Dolomite is scattered through much of the section from a depth of 648 feet to the base of the drill hole (fig. 5). Beneath the Hutchinson Salt Member, in the lower 22 feet of the drill hole, it forms almost 25 percent of the rock; but it is not nearly so abundant in higher parts of the sequence. Most of the dolomite occurs as fairly homogeneous layers as much as 3.5 feet thick, but it also occurs as thin laminae in rocks showing a regular alternation of dolomite and other materials in couplets about one-tenth of an inch thick. It occurs almost as often with anhydrite as with shale; and in many places it separates the two so that layers of anhydrite rarely, if ever, rest directly on layers composed of silty and argillaceous materials. Dolomite also occurs as discrete grains or crystals and granular patches and streaks in shale and siltstone, in anhydrite rock, and in silty and argillaceous halite rock in which the dolomite is associated mainly with the allogenic materials. Crystals of dolomite are scattered through halite veins in magnesite and shale and also through halite pseudomorphs after gypsum in anhydrite layers.

The dolomite ordinarily is in tiny granules, 0.02 mm or less in diameter, which are nearly spherical or rounded rhombic in form.

Most of these granules are transparent, vitreous, colorless to light brown, and free of inclusions, though some with limpid margins have centers darkened by tiny opaque particles. The granules are grouped compactly in small irregular bunches or patches, in short sinuous streaks and discontinuous bands, and in distinct layers and laminae. In the outer parts of anhydrite bands and lenticles are a few isolated grains that tend to be slightly larger and more nearly euhedral than are most grains; these form small rhombohedral crystals as much as 0.05 mm across. A few larger euhedral crystals, as much as 1.5 mm in diameter, are found in the halite layers and veins and in anhydrite rocks exposed between the depths of 690 and 712 feet. These crystals are vitreous, limpid, and colorless to light yellowish amber. They are generally free of inclusions; but some contain euhedral to subhedral crystals of quartz and pyrite, together with angular and rounded grains of anhydrite, halite, and magnesite.

Both the granule and crystal varieties of dolomite have normal optical, X-ray, and chemical properties. There are no significant variations from the value $\omega=1.68$ (± 0.005). X-ray-diffraction examination yielded reflections identical in position and in relative intensities with those of the dolomite associated with anhydrite and halite in the Permian evaporites of southeastern New Mexico. X-ray-fluorescence analyses showed traces of iron and zinc. Manganese and strontium are not sufficiently abundant to have been detected.

Virtually all the dolomite occurring as layers and laminae is very fine grained and resembles a mosaic of minute irregular fragments. It also resembles fine-grained magnesite in color, in shape and size of individual grains, and in mineral associations and relationships. Much of the dolomite is somewhat stained by brownish bituminous matter, and particles and grains of silty and clayey materials are scattered through it. Halite, filling small cavities and narrow fissures, rarely forms cubic crystals against dolomite. Other authigenic minerals, such as pyrite and quartz, generally form euhedral embayments in dolomite; and some—like anhydrite, chalcedony, and microcrystalline quartz—commonly form nodular, lenticular, and veinlike masses in dolomite. Some of the anhydrite masses have smooth convex surfaces toward the enclosing dolomite, and others have jagged margins from which crystals and tongues of anhydrite project into the dolomite. A few small crystals of dolomite are found in the anhydrite aggregates, but not in the surrounding dolomite; many of them are well formed and are sharply bounded by crystal faces.

The dolomite associated with anhydrite rock is similar in nearly every respect to that in the carbonate layers. Its average grain size is perhaps slightly larger than in the typical carbonate rock, some granules of dolomite being as much as 0.02 mm in diameter and rhombohedral crystals, as much as 0.05 mm across. Ordinarily the dolomite is in tiny granules which present irregular or somewhat rounded surfaces toward contiguous grains. The granules commonly occur as small ragged clusters scattered through a mesh of anhydrite crystals, and less commonly they occur as thin residual strips or small irregular remnants of fine-grained dolomite (figs. 10*B*, 14).

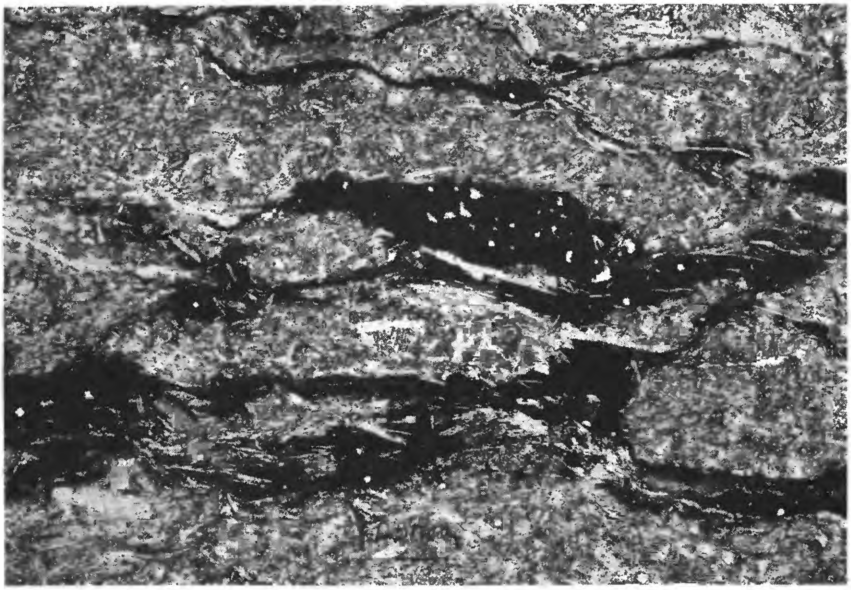

FIGURE 14.—Fine-grained dolomite in anhydrite rock. The dolomite (black) is split into a series of partially detached patches and narrow strips by crystals, lenticles, and veinlike tongues of anhydrite. All of the dolomite is extremely fine grained and, as a consequence, appears black in the photomicrograph. Depth of core, 683 feet 2 inches.

The margins of these dolomite remnants are jagged and embayed by anhydrite crystals and aggregates that project into the dolomite either as elongate crystals and narrow veinlike tongues or as aggregates having scalloped margins convex toward dolomite. The anhydrite contains small patches of fine-grained dolomite and sparse euhedral dolomite rhombohedra. These rhombohedra usually are larger than the granules in nearby dolomite remnants.

Besides the dolomite rhombohedra in anhydrite, there are other, generally larger and somewhat better formed rhombohedra of dolomite associated with halite in some of the rocks between the depths of 690 and 712 feet. These dolomite crystals are as much as 1.5 mm across and are notable not only for their unusual size but also for their general association with halite, both in layers and in narrow veins cutting rocks that are otherwise free of dolomite. Some of the crystals occur as isolated subhedral to euhedral inclusions in argillaceous and anhydritic halite rocks. Others form sharp, well-formed crystal faces against halite on one side, yet on another side are molded on fine-grained masses of anhydrite, silt and clay, or on small clusters of celestite crystals. Some of these crystals are in halite pseudomorphs after gypsum or in other halite-rich parts of anhydrite rock (fig. 8*A*). A few are largely enclosed by fine-grained magnesite occurring as a minor constituent of anhydrite rock, and their margins are indented and convexly scalloped by the magnesite (fig. 15). Still

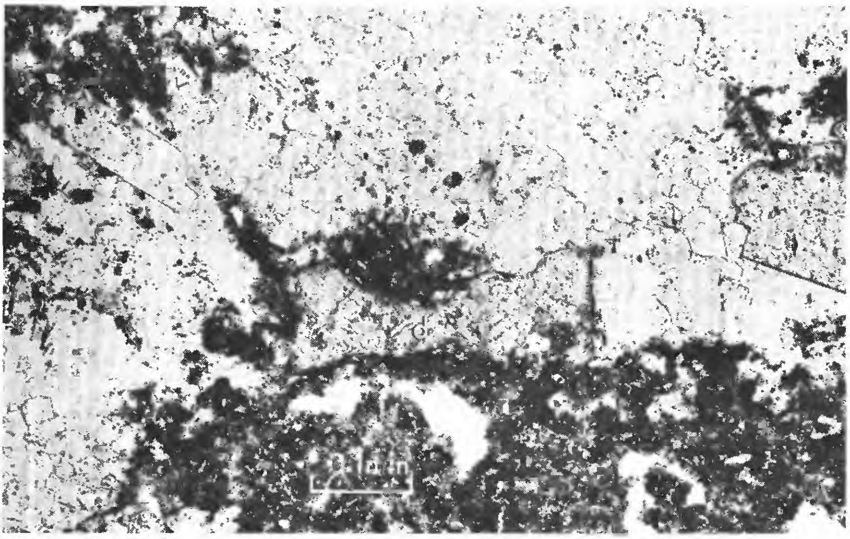

FIGURE 15.—Crystal of dolomite partly replaced by magnesite. The boundary of the dolomite crystal (d) is ragged and indented, and the embayments have been filled by fine-grained magnesite. The matrix is halitic anhydrite rock. From the same thin section as that shown in the photomicrograph in figure 8*A*.

others have their margins sharply cut by subhedral crystals of quartz, and tiny detached and corroded remnants of dolomite are in the quartz.

CALCITE

Calcite has been detected only as an accessory mineral in microgranular magnesite rock at a depth of 698 feet. It is scattered rather sporadically through the rock in small patchy areas of tiny granules 0.01 mm or less in diameter. These granules are transparent, colorless to light brown, and apparently free of inclusions. An estimated 20 percent of the rock is calcite, and 70 percent is magnesite. The remainder is chiefly halite and quartz, but there also are small amounts of clay minerals, feldspar, and pyrite. The halite occurs interstitially and as a nearly vertical vein in which relatively large single crystals of dolomite, as much as 0.25 mm across, are attached to the finer grained carbonate rock. The pyrite forms euhedral crystals.

In thin section the calcite is similar in every respect to the magnesite, and no distinctive features set off one carbonate mineral from another. Staining techniques involving Fairbank's solution and solutions of copper nitrate and of potassium ferricyanide also proved ineffectual for differentiating calcite from magnesite. As a consequence, the mode of occurrence of calcite and its relationship with magnesite is not evident on examination of either thin or polished sections but must be inferred from other types of observations.

On X-ray-diffraction analysis, calcite yields reflections distinct from those of magnesite, and this feature may be used in conjunction with acid leaching to obtain an indication of whether calcite occurs as discrete mineral grains. Untreated samples produced reflections corresponding to mixtures of calcite and magnesite, the principal calcite reflection of 3.04 A (29.4°2θ) occasionally having nearly one-third the intensity of the principal magnesite reflection at 2.74 A (32.7° 2θ). Treatment with dilute (1 : 1) hydrochloric acid for periods as long as 48 hours at room temperature did not cause any measurable reduction in intensity of either the 3.04 A or the 2.74 A reflection, and hence no detectable change in the amount of calcite or magnesite. On treatment with hot acid, however, both the reflection at 3.04 A and the one at 2.74 A were destroyed, indicating that calcite and magnesite had been removed. These results not only show that destruction of magnesite is necessary to affect removal of calcite, but they also indicate that calcite is shielded by a shell of magnesite; otherwise, removal of much, if not all, calcite could have been accomplished without recourse to hot acid. Thus, it can be concluded with confidence that calcite, rather than occurring as discrete mineral grains, forms the nucleus in carbonate granules having a peripheral shell of magnesite.

IRON-MAGNESIUM CARBONATE

Still another carbonate mineral, which is not well enough known to be named, occurs as rhombohedral crystals in halite at depths of 648 to 660 feet in the drill hole. The crystals are irregularly scattered through halite layers and veins but are not found in any of the materials intruded by the veins.

The mineral forms excellent simple and twinned rhombohedral crystals which attain a maximum diameter of about 0.3 mm. These crystals commonly have basal pinacoids, and some of them are so modified by a combination of positive and negative rhombohedral forms that they have a fair hexagonal outline. They are transparent, vitreous, and colorless. Many of them are free of inclusions, yet others contain tiny grains of anhydrite, dolomite or magnesite, and pyrite or possibly marcasite.

X-ray-fluorescence analysis of limpid crystals having no visible impurities shows that this mineral carries iron as a major cation, manganese as a subordinate cation, and zinc, strontium, and calcium in trace amounts. A chemical test shows that it also contains magnesium. Reflections from X-ray-diffraction analysis are similar in position and intensity to those of magnesite. The refraction indices, $\epsilon=1.54$ and $\omega=1.74$ (±0.005), are near those of mangesite. These data, taken together, suggest an iron-rich form of magnesite. They clearly exclude dolomite, despite a similarity in crystal habit. They also exclude ankerite, though the mineral is similar in optical properties and habit to the ankerite described by Taylor (1937, p. 1285–1286) from water-insoluble residues of rock salt in Louisiana salt domes.

Euhedral crystals of the mineral are disseminated somewhat sporadically through halite. They may be arranged in small clusters enclosing detached halite areas but inclosed in turn by halite; or, like beads, they may be strung out in short lines along grain boundaries in coarsely crystalline halite. Some crystals are molded to silty and argillaceous materials on one side, but on another side they have sharply bounded crystal faces next to halite (fig. 16*B*). Other crystals are scattered through cross-fibrous veins of halite, and many of them cut sharply through the films of organic material and associated hematite that commonly separate the elongate grains of halite (fig. 4*A*).

POLYHALITE

The complex sulfate polyhalite is the only water-soluble potassium mineral in the drill core, and it is restricted in distribution to the medial, most halite-rich part of the sequence (fig. 5). Virtually all the polyhalite occurs in halite rock as a minor constituent that apparently is widely distributed. It has previously been reported in halite rock from other localities in central Kansas by Smith (1938, p. 860), Swineford (1955, p. 103), and Swineford and Runnels (1953, p. 364) and is similar in both habit and mode of occurrence to the polyhalite found by Runnels and others (1952, p. 195, pl. 1) in rock salt from the Carey mine, Hutchinson, Kans. It is also similar in habit, general appearance, and mode of occurrence to the polyhalite found in much of the reddish-orange halite rock in southeastern New Mexico.

The polyhalite ordinarily is in microcrystalline blebs, reaching 5 mm in width. Most of these are red, from enclosed hematite, and are made up of coalescing spherulites or matted aggregates of tiny crystals.

A few crystals are tabular plates; but most are acicular, as much as 0.3 mm in length, and are arranged in columnar bundles, radiating aggregates, or stellate groups. The crystals are transparent, vitreous, and colorless and commonly show the various simple and complex forms of twinning illustrated by Schaller and Henderson (1932, p. 53).

Optically the polyhalite has normal properties, and its refractive indices are the same as those of the polyhalite described from New Mexico by Schaller and Henderson (1932, p. 72). X-ray-diffraction results, showing reflections at 28.1°, 30.8°, 14.8°, and 26.2° 2θ, are in accord with those cited by Swineford and Runnels (1953, p. 365–367).

Polyhalite is one of the more distinctive minor constituents of halite rock and almost invariably forms euhedral embayments in halite, as well as in anhydrite. Small fibrous wisps and bunches of polyhalite crystals are scattered throughout coarsely crystalline halite, or they project into halite from centers at the margins of contiguous halite grains. Polyhalite has entered halite along its cubic cleavages or formed as spherulites in halite (fig. 16*A*). Fibrous aggregates of polyhalite crystals attached to the edges of anhydrite porphyroblasts project into halite; elsewhere embayed anhydrite relicts, showing common optical orientation, are surrounded by a mesh of fibrous polyhalite crystals.

CELESTITE

Celestite has been observed in only two specimens: one is anhydritic halite rock from a depth of 547 feet, and the other is magnesitic anhydrite rock from a depth of 694 feet. Since celestite is somewhat similar to anhydrite in both habit and general appearance, it may have been overlooked elsewhere.

The celestite occurs as small groups of tiny elongate crystals as much as 0.05 mm in length that are arranged in sheaflike bundles or in stellate and spherulitic groups, but it is present also as single crystals in halite. The crystal groups are ordinarily enclosed in halite, but a few are found molded to the edges of finely crystalline anhydrite. Some of the crystal groups surround small grains of anhydrite, pyrite, and magnesite; in these aggregates the individual crystals of celestite may be so arranged that their long axis is perpendicular to the enclosed mineral grains (fig. 16*C*). In other crystal groups, relatively large crystals of dolomite and quartz are attached to their edges.

PYRITE AND MARCASITE

Pyrite and marcasite are present in small amounts in many parts of the evaporite sequence (fig. 5). Pyrite is the main sulfide in shale,

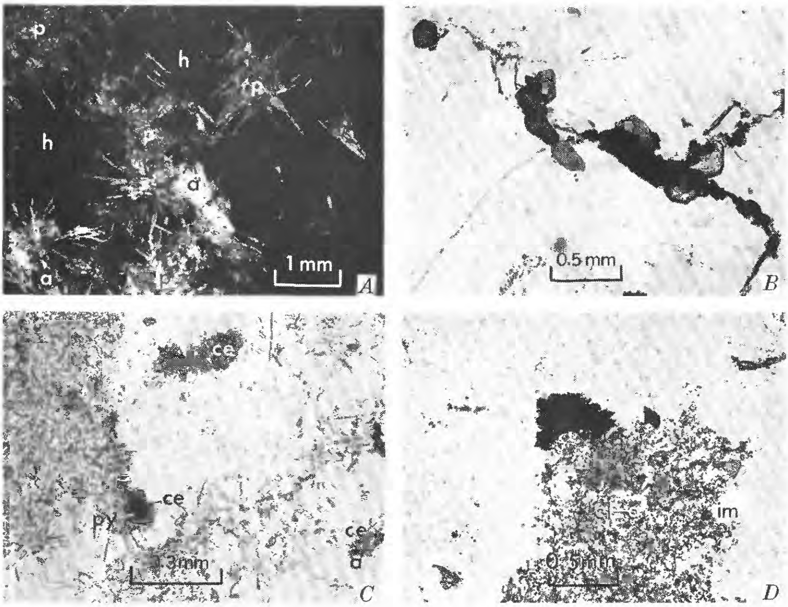

FIGURE 16.—Polyhalite and other authigenic minerals associated mainly with halite. *A*, Small wisps and fibrous masses of polyhalite (p) in halite (h). Note wisps and crystals of polyhalite that have grown in rectangular cleavage cracks of halite and also those that are attached to the edges of crystals of anhydrite (a). Nicols crossed. Depth, 560 feet 11 inches. *B*, Crystals of iron-magnesium carbonate in argillaceous halite rock. Note crystals molded on interstitial clay at center of photomicrograph. Depth, 654 feet 2 inches. *C*, Radial aggregate and other crystal groups of celestite (ce) in anhydritic halite rock. Note grains of anhydrite (a) and pyrite (py) surrounded by celestite. Depth, 547 feet 4 inches. *D*, Aggregate of marcasite molded on clay and anhydrite (cl-a) in argillaceous halite rock. Crystals below and to the right of marcasite are iron-magnesium carbonate (im). Nicols inclined. Depth, 648 feet 4 inches.

carbonate rock, and anhydrite rock; but it ordinarily gives way to marcasite in halite rock. However, minute quantities of pyrite have been found in some of the argillaceous halite rock from near the bottom of the drill hole.

The pyrite occurs in two varieties. In some of the rocks it forms tiny simple or twinned single crystals as much as 0.04 mm in diameter. These show cubic, octahedral, or pyritohedral forms and are either disseminated through the rock or arranged in lines like beads on a string. In other rocks, pyrite forms irregular grains and groups of euhedral crystals as much as 0.4 mm in width. These are especially common in rocks showing evidence that anhydrite has replaced carbonate, but they are also found in some of the shale and at the contact between shale and carbonate rock.

Marcasite ordinarily forms radial aggregates, attaining about 0.5 mm in diameter, that are either at the edges of or in anhydritic and argillaceous patches and layers in halite (fig. 16*D*). The individual crystals are acicular and are commonly twinned; their boundaries with halite are sharp, cockscomb, or spear shaped. Some of the marcasite encloses angular halite relicts and grains of anhydrite, quartz, and magnesite.

HEMATITE

Hematite is widely distributed as particles that range from submicroscopic size to about 0.5 μ in diameter and that are similar to those described by Schaller and Henderson (1932, p. 37). They are ordinarily found on the surfaces of threadlike remains of the algae *Phormidium antiquum* Tilden, but they also are disseminated through polyhalite aggregates. Some particles have a hexagonal outline, others are spherical or oval, and still others are rodlike. They can be recognized by their habit, pleochroism, and birefringence; and their identification was confirmed by X-ray examination.

Hematite and the remains of the algae form an exceedingly thin brittle red film in small veins of fibrous halite and in beds of essentially equigranular halite. They provide the coloring matter for the red halite, and particles of hematite are found disseminated through the polyhalite that is enclosed in halite. Here and there the films are cut by veinlets of anhydrite and halite and by well-formed single crystals of dolomite, anhydrite, quartz, and the iron-magnesium carbonate.

QUARTZ AND CHALCEDONY

Authigenic quartz and chalcedony are moderately widespread in the drill core (fig. 5), yet the total quantity of each is small. They have dissimilar modes of occurrence and rarely, if ever, are associated with one another.

Quartz has the more spectacular mode of occurrence and also the widest distribution in halite, anhydrite, and carbonate rocks. In many of these rocks it is present as excellent doubly terminated prismatic crystals, but it also occurs as somewhat imperfect crystals which are either surrounded by fine-grained anhydrite or carbonate or are molded on fine-grained anhydrite or argillaceous materials (fig. 17*A*). It is also present in the veins and lenticles of halite and anhydrite that cut these same rocks and, in minor amounts, in pseudomorphs of anhydrite after gypsum (fig. 8*A*). Quartz is generally euhedral, and much of it contains tiny remnants of dolomite, magnesite, anhydrite, and halite.

In contrast to quartz, chalcedony is almost entirely restricted to carbonate rocks. It is present as small lenticular and nodular masses

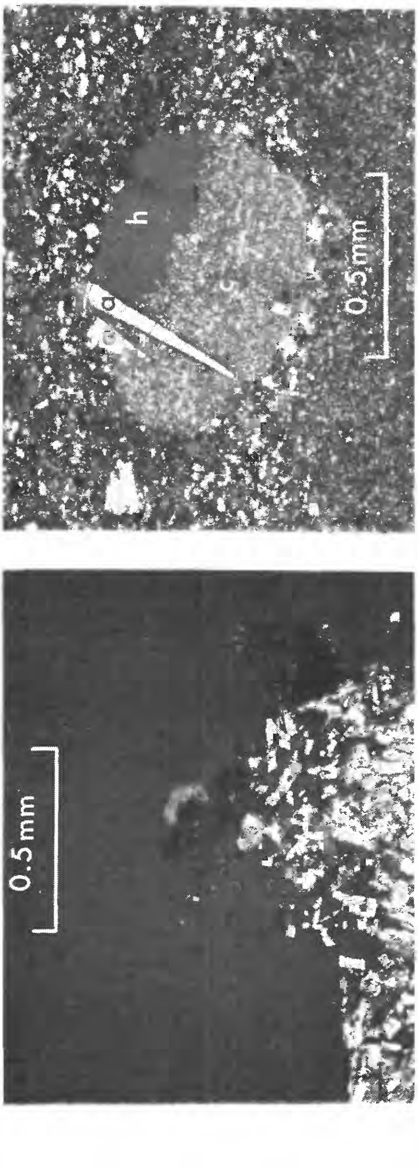

FIGURE 17.—Quartz and chalcedony. *A* (left), Subhedral crystal of quartz molded on clay in halite. Bright rectangular crystals are anhydrite. Nicols crossed. Depth, 459 feet 4 inches. *B* (right), Remnant of chalcedony (c) in chert nodule in silty magnesite. The chalcedony has been attacked and partly replaced first by halite (h) and, subsequently, by anhydrite (a). Nicols inclined. Depth, 529 feet one inch.

of chert, and much of it is split into small detached relicts by crystals and crystalline aggregates of anhydrite. Chalcedony also forms relicts in halite, and elongate anhydrite crystals sharply cut irregular contacts between the chalcedony and the encroaching halite (fig. 17*B*).

ORIGIN OF THE SALTS AND CARBONATE ROCKS

There has never been much doubt that the evaporites of the Hutchinson Salt Member and associated stratigraphic units in Kansas and nearby areas are made up of chemically formed marine salts and carbonates. They consist of a regular sequence of salts and carbonates which is repeated in a cyclic fashion; and their salts and carbonates are in anhedral to euhedral crystals, not in fragmental grains. Moreover, they belong to an unbroken sequence of sedimentary rocks showing a transition from normal marine limestone and shale to red beds deposited under restricted marine conditions; and they contain a small assemblage of marine, or possibly brackish-water, fossils. Accordingly, a review of the evidence for the origin of the halite, anhydrite, and carbonate rocks in the drill core can start from the premise of a marine origin.

It is not necessary, however, to rely solely on stratigraphy to establish the premise. The distribution of major salt ions in the Hutchinson Salt Member, as estimated from the drill core, is so close to their distribution in sea water that a marine origin can scarcely be doubted. The actual figures, in percent, are shown below, recalculated to total 100:

	Entire drill core	*Hutchinson Salt Member*	*Sea water*
Na	31. 6	33 7	31. 0
Ca	4. 2	2. 9	1. 2
Mg	1. 7	1. 4	3. 8
Cl	48. 7	52. 0	55. 8
SO_4	7. 9	5. 9	7. 8
CO_3	5. 9	4. 1	0. 4
	100. 0	100. 0	100. 0

The origin of the evaporites, however, can be only partly explained as a process of chemical sedimentation from sea water. Extensive petrographic evidence for recrystallization and replacement demonstrates notable changes in the structure, texture, and composition of the rocks after deposition. To account for these changes, diagenetic rather than sedimentary processes must be considered. Surely the sediments carried abundant water for a long time after deposition, and it can scarcely be a surprise that extensive reorganization of crystalline material played a major part in the formation of the rocks. This reorganization belongs to a period of diagenesis, involving exchange of major salt ions and other substances between crystalline materials and the water associated with them. Clearly it does not require a mineralization stage involving the influx or outgo of substances that were carried a long distance; for if it did, the parallelism between the chemistry of the drill core and the chemistry of sea water would probably have been destroyed.

The conclusion that the evaporites were formed in two major stages is drawn from present observations of the megascopic and microscopic features of rocks in the drill core. This conclusion is in accord with the structural and textural evidence of the sequential deposition of chemical sediments and subsequent reorganization of crystalline materials, as well as with the general paragenetic sequence of authigenic minerals. The sequential layering of the various lithologic types of evaporite rock is easily explained only as a product of chemical sedimentation involving fractional crystallization of marine salts; but the even-grained mosaiclike texture of the rocks and the changes of composition indicated by the presence of relict minerals and pseudomorphous structures can be clearly explained only by assuming a period of reorganization. It should be noted, however, that the two stages may well overlap in time and that deposition of halite, for example, may have taken place concurrently with recrystallization and replacement in layers of sulfate and carbonate minerals that had been formed earlier. In general the carbonate, sulfate, and other compositional varieties of authigenic minerals follow one another in regular succession, and in practically the same order in halite rock as in sulfate and carbonate rocks. The age relations of the minerals, as summarized in figure 18, are either shown by the megascopic structure and the microscopic detail or inferred from indirect geologic evidence, such as the occurrence of halite fossils in anhydrite.

SEDIMENTATION STAGE

Ideally, the sequence in which the primary chemical sediments were deposited should be, first, calcium carbonate; next, calcium sulfate; and then sodium chloride. Under actual conditions, of course, there will be many variations from the ideal; new supplies of water may be brought to the site of crystallization, thus changing the salinity, or conditions may be disturbed in other ways. Nevertheless, there is a definite tendency for the halite to be in the upper, younger beds, and for the sulfate and carbonate to be in lower beds. At nearly all places where anhydrite and shale are associated, there is at least a thin layer of carbonate rock between them. Furthermore, carbonate and anhydrite rocks are commonly found together, and so also are anhydrite and halite rocks, but carbonate and halite rocks tend to be separated from each other.

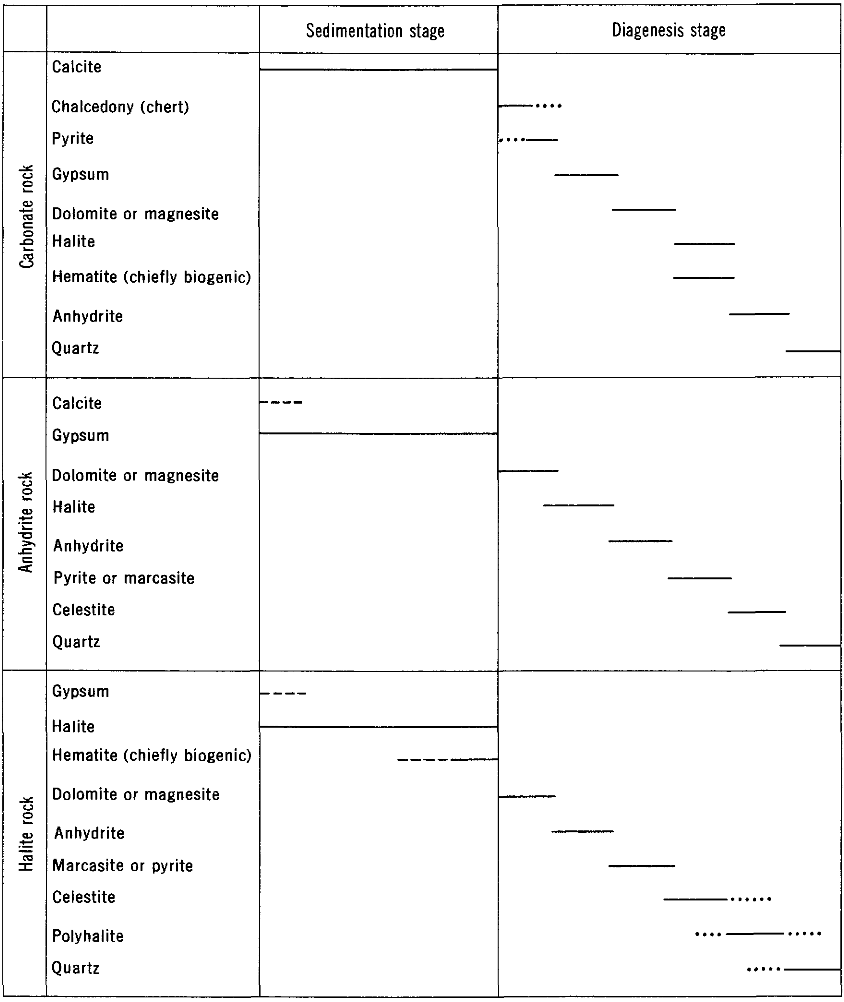

FIGURE 18.—Simplified paragenetic diagram for authigenic minerals in the Hutchinson Salt Member and part of the lower and upper members of the Wellington Formation.

The carbonate rocks in the drill core consist almost entirely of magnesite and dolomite. Calcite has been detected only in magnesite rock at the 698-foot depth, where it apparently forms the core of magnesite granules. There are reasons to believe that some, if not all, of the magnesite and dolomite is secondary, as the discussion of diagenesis will show. This fact opens up the possibility that the primary carbonate sediment was either entirely or very largely calcite. Irrefutable proof of this point cannot be assembled, however, for not enough evidence can be gathered from a single drill core or from samples from only one or two localities in an extensive salt basin.

There is, however, clear evidence that calcium carbonate was abundant in the original sediments. The calcite in the center of magnesite granules is easily explained only if it is considered to be remnants of granules that originally were entirely calcite and that subsequently were replaced by magnesite. Another clue to the history of calcium carbonate in the rocks is provided by the fossils found in magnesite rock. These fossils are clearly indigenous. Preservation in place is indicated by the presence of articulated specimens and of sessile foraminifera on outer shell surfaces of a small *Permophorus*-like pelecypod, as well as by the absence of sorting or of the broken and water-worn specimens that would be expected in reworked fossil material. The shells are preserved as anhydrite in a matrix of fine-grained magnesite or as halite in a matrix of fine-grained anhydrite. Yet the pelecypods presumably lived in marine or brackish waters and presumably could not have tolerated the hypersalinity of brines from which magnesite or anhydrite might have been precipitated. It thus seems evident that the calcium carbonate of the shells and any calcium carbonate in the surrounding muds were broken down at a later stage by reaction with interstitial solutions; the calcium went into anhydrite, and the carbonate went into magnesite.

The question of whether or not dolomite was a primary constituent of the sediments is an exceedingly difficult one, for not only is there no direct evidence that it was, but also, there is no firm reason to conclude that it replaced calcite. Whatever calcite there may have been in the dolomite beds has been entirely destroyed, so that none of the dolomite contains calcite remnants like those found in the fine-grained magnesite; yet the dolomite is similar to the magnesite. Both of them carry magnesium and carbonate; both are associated with anhydrite and halite, as well as with pyrite, chert, bituminous matter, clay, and silt; and both occur as discrete layers in rocks made up of an ascending series of carbonate, anhydrite, and halite or of a regular alternation of carbonate and anhydrite. The conclusion here offered—to be tested as further evidence becomes available—is that the primary precipitate was entirely calcite, stable in brackish or normal marine waters. Later, after prolonged evaporation, these waters changed in composition, becoming brines rich in magnesium, so that calcite was no longer inert to them, but reacted to form secondary magnesite and dolomite.

The nature of the primary calcium sulfate sediment is somewhat problematical because the evidence that it was gypsum is mostly indirect, yet evidence that anhydrite is mainly secondary is abundant. The literature on gypsum and anhydrite deposits in the Wellington and other evaporite formations in the Permian sequence of Kansas suggests that in places either gypsum or anhydrite may be a primary mineral (Kulstad and others, 1956, p. 22, 43–45, 65–66, 98). This idea is in accord with experimental results obtained by Posnjak (1940) as well as with thermodynamic calculations carried out by MacDonald (1953). The anhydrite of the rocks described in the current study, however, was largely, if not entirely, formed by secondary processes, as the discussion of its behavior during diagenesis will show. The former presence of gypsum is indicated by the presence of pseudomorphs resembling in every detail the pseudomorphs of simple and twinned crystals described by Schaller and Henderson (1932, p. 17–19, 32–37). The pseudomorphs have a marked tendency to be elongate vertically, and they commonly form parallel or radiating groups extending upward from centers in or at the upper edges of carbonate layers and anhydrite layers. (See fig. 8*B*.) Many of the pseudomorphs are composed mainly of halite, but others show various stages of replacement of halite by anhydrite; usually they are enclosed by anhydrite containing residual patches of fine-grained dolomite or magnesite. Other pseudomorphs consist entirely of anhydrite, and their edges are outlined either by fine-grained carbonate or by short rows of carbonate grains. Clearly the gypsum formed before at least some of the halite in these rocks, and it also preceded the diagenetic anhydrite. Thus it may be assumed that gypsum was a primary mineral of these deposits. That the anhydrite is entirely diagenetic cannot be firmly proved. However, the widespread textural and structural evidence of a secondary origin clearly places the burden of proof on the shoulders of anyone who cares to argue for a primary origin.

Unlike the carbonates and sulfates, no doubt exists that most of the halite is a primary sediment that has been changed mainly by recrystallization and only slightly by other diagenetic processes. Halite is the only chloride, and it is also the only sodium mineral. This circumstance makes the halite's history easier to decipher than that of minerals containing such ubiquitous constituents as calcium or carbonate because it means that halite was substantially in equilibrium with its environment at all times after it first began to precipitate. There was, of course, some solution, transport, and redeposition of halite; but not enough to destroy or significantly change the texture, structure, or composition of the rock. The layers of halite rock constitute about four-fifths of the material in the drill core. This point should be emphasized, because it brings out the fact that the predominant rock is a sediment not greatly altered since deposition and that the extensive diagenetic changes involving other rocks are not as important quantitatively as may seem to be implied by the extended discussion of their petrography.

Much of the halite that has escaped recrystallization is translucent, has a whitish appearance like that of frosted glass, and is readily distinguished by closely spaced rows of negative-crystal cavities, which mark growth planes. It closely resembles the cloudy halite described by Dellwig (1955, p. 88–92) as a primary constituent of Silurian evaporites in the Michigan basin. It is very similar also to the whitish translucent halite which crystallizes as hollow-faced cubes and other types of skeleton crystals during evaporation of sea water in the artificial salt pans in the San Francisco Bay region of California. Furthermore, like the halite described by Dellwig and also like much of that from the artificial salt pans, it is enclosed by colorless limpid halite, and its negative-crystal cavities are filled with brine containing a tiny bubble of gas. The resemblance in appearance, structure, and mode of occurrence may indicate similar, if not identical, modes of origin and certainly indicates the possibility that the whitish translucent halite is a primary constituent of the Hutchinson Salt. That it was at least one of the early minerals to form is indicated by its occurrence as remnants in grains of limpid halite. (See fig. 6.)

Besides the whitish translucent halite there is other halite that is an early, if not an original, constituent of the evaporites. This halite is restricted in distribution to layers of argillaceous halite rock. Most, if not all, of it is present as subhedral to euhedral crystals which are similarly oriented and have their crystal faces tilted at an angle to the horizontal. These crystals of halite contain sheets or films of argillaceous material that are parallel to crystal faces. The films extend to the edge of the crystals and merge with no perceptible break into the argillaceous material around the margins of the crystals (fig. 7*A*). From this arrangement it can be concluded that the growth of halite crystals forming on the sea floor was briefly interrupted from time to time by deposition of argillaceous sediments. Furthermore, it can be inferred that an influx of detrital sediments was effected without a noticeable reduction in the salinity of the crystallizing solution, because otherwise the argillaceous material would rest on a smooth surface, beveled by solution, and not on the sharp edges and well-formed faces of subhedral crystals of halite.

For the most part, halite either lies between the layers of anhydrite or it follows anhydrite in vertical sequences of rocks of different lithologic types. Much of the halite in contact with the anhydrite rock is cut by veinlets or narrow tongues of anhydrite which extend outward from the anhydrite. Commonly there also are crystals of anhydrite which project into halite from the lower and upper surfaces of the anhydrite layers. Halite occurring in stratigraphic sequence with anhydrite covers the upper surfaces of sharp, well-preserved anhydritic pseudomorphs after gypsum which extend upward from centers in the anhydrite rock (fig. 8*B*). It is thus evident not only that halite formed before some, if not all, of the anhydrite associated with it in vertical sequences of rocks but also that halite deposition followed gypsum deposition without an intervening stage of solution of gypsum or of anhydrite deposition.

DIAGENESIS STAGE

The diagenesis stage in the history of the evaporites in the drill core includes all events that took place during the conversion of primary precipitates and other materials from sediments to rocks. The events no doubt were many and involved all the major salt ions and most, if not all, of the authigenic minerals, yet apparently only a few events had appreciable effects on the composition and texture of the rocks. The main events that can be inferred from the available evidence are (1) the conversion of carbonate from originally calcium-rich to magnesium-rich materials, either dolomite or magnesite; (2) the formation of anhydrite, in part from calcium sulfate given up by gypsum and in part from calcium released on destruction of calcite and from sulfate obtained from the brines and residual solutions; (3) the recrystallization of halite; and (4) the transport of many materials to new sites of crystallization in carbonate, anhydrite, and halite rocks and in veins and lenticles cutting these rocks and in grains of minerals scattered through them.

The conclusion that the carbonate minerals now in the rocks are a product of diagenesis is drawn partly from textural evidence showing that at least some of the dolomite, magnesite, and iron-magnesium carbonate formed late in the paragenesis. Examples of such evidence are the euhedral crystals of dolomite formed in halite and anhydrite and the dolomite grains that on one side have crystal faces against halite and on the other are molded to the edge of fine-grained anhydrite or argillaceous materials. Some of these dolomite grains are present in both the matrix and the pseudomorphs after gypsum, and others are in halite veins which cut sharply through magnesitic shale and calcitic magnesite. The magnesite rims surrounding calcite cores, the pseudomorphic replacement of gypsum, and the invasion of dolomite crystals by magnesite all suggest a late age for the magnesite. Similarly, the euhedral rhombs of iron-magnesium carbonate that are in halite veins and the grains of this carbonate that are molded on argillaceous materials, yet have crystal faces against halite, must have formed at a late stage.

The textural evidence proves that part but not necessarily all of the dolomite and magnesite formed late in the paragenesis; it is also in accord with the inference that the carbonates were originally deposited as calcite and that all of the dolomite and magnesite arose from reactions that enriched the carbonate with magnesium and depleted the carbonate of calcium.

Furthermore, the diagenetic origin of dolomite and magnesite is in accord with the abundant evidence that anhydrite formed at a late stage, because the calcium entering anhydrite could have been obtained in part from the breakdown of calcite. Veins and lenticles of anhydrite cut shale, dolomite, magnesite, and halite; and elongate crystals of anhydrite project into these rocks. Ragged and embayed relicts of magnesite and dolomite are surrounded by a network of anhydrite or are included in anhydrite crystals. Carbonate and argillaceous rocks that are cut by halite veins contain anhydrite that invades the veins and spreads through them, enclosing detached remnants of halite. Anhydrite also invades chert nodules in carbonate rocks, and some of it forms elongate crystals which sharply cut halite as well as chalcedony that has been partially replaced by halite. Still another type of anhydrite occurs pseudomorphously after gypsum in fine-grained carbonate as well as in fine-grained anhydrite containing tiny carbonate relicts. There also are halite pseudomorphs after gypsum which have one or more layers of anhydrite attached to their edges.

Both veins of halite cutting shale, dolomite, and magnesite and the replacement of fossils by halite indicate that even sodium chloride was in part transported from one place to another or was precipitated from interstitial brines during diagenesis. For the most part, however, the textural evidence suggests that recrystallization in place was the chief process affecting halite. Grains of halite having crystal faces formed by overgrowths that project into shale belong to this recrystallization stage. Large clear anhedral grains of halite in a matrix of finer grained halite have rims of silt and clay that apparently were expelled from the large grains during recrystallization. The abundant limpid halite, surrounding halite that is apparently primary, probably formed entirely by recrystallization during the period of diagenesis. Dreyer and others (1949) obtained fluid-inclusion-temperature measurements of 70°–100°C from halite that may be of this type. The results justify the skepticism that the authors expressed, but such results may indicate that the temperature during recrystallization was higher than that prevailing during the precipitation of sodium chloride.

Besides halite, anhydrite, and carbonate minerals, most, if not all, of the other authigenic minerals have been involved to different degrees in the transport and recrystallization of materials at a late stage. Polyhalite, for example, commonly forms spherulites in halite or is associated with halite and anhydrite in ways that suggest it obtained some, if not all, of its sulfate from the breakdown of anhydrite. Quartz that formed as prismatic crystals in anhydrite pseudomorphs after gypsum and now encloses anhydrite remnants certainly is a product of transport and recrystallization. Such quartz may have obtained its silica either by solution of argillaceous materials or by replacement of chalcedony by anhydrite and halite. Still other examples of late-stage involvement include crystals and crystalline aggregates of marcasite and celestite that on one side are molded on anhydrite aggregates and on the other project into halite.

CORE LOG

The Geotechnical Corporation, H.N.A.S. core hole 1 Reno County, Kansas

Location: 40 ft north of south line and 275 ft west of east line of the SE¼NE¼ sec. 29, T. 24 S., R. 5 W.
Altitude: 1,588 ft (ground level)
Top of salt: 426 ft
Total depth: 734 ft
Date of drilling: May 1958
Type of drilling fluid: 30°-gravity crude oil
Casing record: 100 ft of 7 in. OD surface casing set with 6 sacks of cement; 150 ft of 5 in. ID casing set with 10 sacks of cement.

Depth		*Thickness*		
Ft	*in*	*Ft*	*in*	*Description*
423	1			Top of core.
425	8	2	7	Clay shale, magnesitic, medium-gray; has lighter gray laminae of siltstone and magnesite; contains small nodules and narrow seamlike veins of medium-light-gray microcrystalline anhydrite.
426	0		4	Halite rock, argillaceous, very light gray, moderately coarse-grained (¼ in.). *Top of Hutchinson Salt Member.*
426	3		3	Clay shale, magnesitic, medium-gray; has medium-light-gray laminae of siltstone and a scattering of small podlike lenses of halite.
426	10		7	Halite rock, argillaceous, very light gray, medium-grained (⅛–¼ in.).
427	1		3	Clay shale, magnesitic, medium-gray; has laminae of medium light-gray siltstone and a scattering of small nodules and veinlets of microcrystalline anhydrite and rare veinlets of halite.
428	6	1	5	Halite rock, anhydritic and argillaceous, very light gray, medium-grained (⅛–¼ in.).
428	11		5	Clay shale, magnesitic, medium-light-gray; contains small nodules of gray microcrystalline anhydrite and scattered veinlets of halite.
429	6		7	Halite rock, argillaceous, very light gray, medium-grained (⅛–¼ in.); has laminae of medium-gray clay shale.
429	9		3	Clay shale, magnesitic, medium-light-gray, laminated; evenly bedded at top but becomes irregular downward with the appearance of small nodules of medium light-gray microcrystalline anhydrite.
430	0		3	Halite rock, argillaceous, very light gray, medium-grained (⅛–¼ in.); has laminae of medium-light-gray clay shale.
431	11	1	11	Clay shale, magnesitic, medium-gray; has medium-light-gray laminae of siltstone. Lamination is generally fairly even and nearly straight, but locally disrupted by minor slump folds and minute faults. Veinlets of halite cut through the slumped and faulted material.
433	2	1	3	Anhydrite rock, magnesitic, medium-light-gray, microcrystalline; contains small patches and veinlike masses of very light gray halite.
433	9		7	Halite rock, very light gray, medium-grained (⅛–¼ in.).

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
433	10		1	Anhydrite rock, microcrystalline, amber-colored; very light gray mottling; contains a little halite at top and tiny patches of microgranular magnesite at base.
438	0	4	2	Clay shale, magnesitic, dark-bluish-gray; contains euhedral crystals of halite and small nodules of anhydrite. (Halite, 20 percent ±; anhydrite, 3–5 percent.)
439	0	1	0	Halite rock, argillaceous, very light gray, moderately coarse grained (¼–½ in.). (Halite, 95 percent ±.)
446	0	7	0	Halite rock, anhydritic, light-gray and amber-colored; in layers ranging from 2 to 10 in. in thickness; moderately coarse grained (¼–½ in.); contains a layer of medium-gray clay shale one-half inch thick, 6 in. below top of unit. (Halite, 95–96 percent.)
447	3	1	3	Clay shale, magnesitic, light-gray, darkening to medium-gray at base of unit, laminated; contains nodules and veinlike seams of light-gray microcrystalline anhydrite rock, in lower 5 in., and a few veins of halite.
454	5	7	2	Halite rock, argillaceous and anhydritic, very light gray; has grayish-black bands 3–6 in. thick of dark-gray clay; medium grained (⅛–¼ in.) but contains scattered patches of recrystallized halite in grains as much as three-fourths inch in diameter. (Halite, 95–97 percent.)
454	7		2	Magnesite, medium-gray; has bluish-gray laminae of microcrystalline anhydrite; bounded above and below by thin band of anhydrite by which it is separated from adjoining halite units.
457	4	2	9	Halite rock, anhydritic and argillaceous, very light gray to amber-colored; marked by grayish-black bands about an inch thick and 2–4 in. apart that contain dark gray clay. (Halite, 97 percent ±.)
457	6		2	Anhydrite rock, medium-light-gray, microcrystalline, laminated.
457	9		3	Clay shale, magnesitic, medium-light-gray and medium-dark-gray, laminated. Lamination is fairly even and relatively flat in upper 1 in. but is crenulated in remainder of unit.
459	5	1	8	Halite rock, argillaceous, medium-light-gray, moderately coarse grained (¼–½ in.). (Halite, 97 percent ±.).
468	2	8	9	Halite rock, anhydritic and argillaceous, moderately coarse-grained (¼–½ in.), markedly banded very light gray to amber-colored and grayish-black; light-colored bands contain anhydrite, and darker colored bands contain clay. Thickness of bands ranges from 2 to 6 in. (Halite, 97 percent ±.)
468	8		6	Clay shale, magnesitic, medium-light- to medium-dark-gray; contains veinlets of halite and a few nodules of medium-bluish-gray, microcrystalline anhydrite.
470	3	1	7	Halite rock, argillaceous and anhydritic, medium-coarse-grained to moderately coarse grained (⅛–½ in.), light-gray; marked by light-amber-colored bands, about 2 in. thick and from 4 to 6 in. apart. (Halite, 97 percent ±.)
470	10		7	Clay shale, magnesitic, medium-dark-gray.

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
474	5	3	7	Halite rock, argillaceous and anhydritic, medium-grained (⅛–¼ in., light-gray; marked by numerous grayish-black bands as much as one-fourth inch thick and from ¼ to 3 in. apart. The anhydrite is concentrated mainly in light-colored bands, and the clay, in darker bands. (Halite, 97 percent ±.)
474	7		2	Clay shale, magnesitic, medium-gray; contains nodules and veinlike seams of bluish-gray microcrystalline anhydrite.
475	0		5	Halite rock, argillaceous, medium-light-gray, medium-grained (⅛–¼ in.; contains a few thin partings of medium- to brownish-gray clay. (Halite, 95 percent ±.)
475	2		2	Clay shale, magnesitic, medium-dark-gray; contains small nodules of medium-bluish-gray microcrystalline anhydrite.
475	5		3	Halite rock, anhydritic, medium-light-gray, medium-grained (⅛–¼ in.). The anhydrite forms small nodules, veinlets, and a ⅛-in.-thick layer at base of unit. (Halite, 90 percent ±.)
487	9	12	4	Halite rock, anhydritic and argillaceous, moderately coarse grained (¼–½ in.); dominantly light gray, changing to light amber in places and marked by poorly defined grayish-black bands. (Halite, 97 percent ±.)
489	8	1	11	Anhydrite rock, microcrystalline, medium-bluish-gray, interlayered with brownish-gray magnesite rock and medium-grained light-amber-colored halite rock in the upper two-thirds of unit. Lower one-third of unit is made up largely of many small elliptical nodules of microcrystalline anhydrite embedded in a matrix of dark-bluish-gray slightly pyritic magnesite rock. (Anhydrite, 85 percent ±; halite, 5 percent ±; magnesite, 10 percent ±.)
492	11	3	3	Halite rock, polyhalitic and anhydritic, white, moderately coarse grained (¼–½ in.); has light-amber-colored patches containing blebs and veinlets of red microcrystalline polyhalite. (Halite, 98 percent ±.)
493	3		4	Clay shale, magnesitic, medium-dark-gray, interlayered with light-amber-colored halite rock and medium-gray microcrystalline anhydrite.
493	5		2	Clay shale, magnesitic, moderately dark bluish-gray; contains elliptical nodules and veinlets of bluish-gray microcrystalline anhydrite.
496	10	3	5	Halite rock, anhydritic, argillaceous, and polyhalitic; moderately coarse grained (¼–½ in.); mottled and poorly banded white, light-amber, and grayish black. (Halite, 97 percent ±.)
497	4		6	Clay shale, magnesitic, medium-dark-gray; has moderately dark bluish-gray laminae; contains small nodules of medium-bluish-gray microcrystalline anhydrite in upper one-half inch of unit and lower 1 in.
497	8		4	Anhydrite rock, microcrystalline, medium-dark-bluish-gray to moderately dark-bluish-gray; has medium-dark-gray laminae of magnesite.

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
501	0	3	4	Halite rock, argillaceous and sparingly anhydritic, light-gray; has numerous grayish-black bands as much as 4 in. thick containing clay and a little anhydrite. (Halite, 97 percent ±.)
501	1		1	Clay shale, magnesitic, medium-bluish-gray; contains small nodules of bluish-gray microcrystalline anhydrite.
504	2	3	1	Halite rock, argillaceous, anhydritic, and sparingly polyhalitic; moderately coarse grained (¼–½ in.); light gray, amber colored, and orange with numerous grayish-black bands ranging from ⅛ to 2 in. in thickness. (Halite, 97 percent ±.)
505	0		10	Clay shale, magnesitic, moderately dark bluish-gray; contains small patches and veinlets of halite.
505	3		3	Halite rock, argillaceous, moderately coarse grained (¼–½ in.), light-amber-colored. (Halite, 98 percent ±.)
505	4		1	Anhydrite rock, medium-bluish-gray, microcrystalline; contains patches of bluish-gray magnesite rock against which the anhydrite has rounded convex boundaries.
510	8	5	4	Halite rock, argillaceous and anhydritic, moderately coarse grained (¼–½ in.), light-gray; has numerous grayish-black bands ranging from 1 to 5 in. in thickness and as much as 1–4 in. apart. (Halite, 95 percent ±.)
512	4	1	8	Halite rock, argillaceous and sparingly anhydritic, medium-grained (⅛–¼ in.), light-amber-colored; has numerous grayish-black bands ranging from ⅛ to ¼ in. in thickness and containing dark-gray clay. Some of these are capped by filmlike partings of dark-gray clay shale. (Halite, 97 percent ±.)
517	9	5	5	Halite rock, argillaceous and sparingly anhydritic, medium-coarse-grained to moderately coarse grained (⅛–½ in.), light-gray and amber-colored; has numerous grayish-black bands ranging from 1 to 6 in. in thickness and from 2 to 4 in. apart. (Halite, 97 percent ±.)
518	2		5	Anhydrite rock, microcrystalline, medium-bluish-gray; has patches of brownish-gray magnesite and amber-colored halite.
519	1		11	Halite rock, argillaceous and anhydritic; medium grained (⅛–¼ in.) but contains patches of recrystallized halite in which grains are as much as one-half inch in diameter; light amber colored with poorly defined grayish-black bands as much as one-half inch thick containing dark- to medium-gray clay. (Halite, 97 percent ±.)
520	2	1	1	Clay shale, magnesitic and halitic, light- and medium-gray; contains small nodules of microcrystalline anhydrite arranged in narrow veinlike seams generally parallel to bedding; has laminated structure in upper part and is massive lower part. Much on the lamination disrupted by small slip folds and faults.
525	7	5	5	Halite rock, argillaceous and polyhalitic, moderately coarse grained (¼–½ in.) but contains patches of recrystallized halite grains as much as 1 in. across; very light gray to light red with a few poorly defined medium-gray bands. (Halite, 97 percent ±.)

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
532	0	1	0	Halite rock, argillaceous and sparingly anhydritic, medium-grained (⅛–¼ in.), light-amber colored; has grayish-black bands as much as one-fourth inch thick and spaced from ½ to 1 in. apart containing dark-gray clay. (Halite, 97 percent ±.)
534	2	2	2	Halite rock, argillaceous, medium-grained (⅛–¼ in.), very light gray; contains numerous partings of medium-gray clay shale as much as one-fourth inch thick and from ½ to 3 in. apart. (Halite, 95 percent ±.)
536	2	2	0	Magnesite rock, silty, medium-brownish-gray to moderately dark bluish-gray, laminated; contains small nodules of bluish-gray microcrystalline anhydrite. Laminae are fairly even and relatively flat in upper 7 in. of unit, but they are crenulated and faulted in remainder of unit.
537	8	1	6	Halite rock, argillaceous and anhydritic, moderately coarse-grained (¼–½ in.), grayish-black. (Halite, 95 percent ±.)
543	8	6	0	Halite rock, argillaceous and sparingly anhydritic, dominantly coarse-grained (¼–½ in.), white and very light gray; has grayish-black bands ranging from 2 to 4 in. in thickness and spaced from 6 to 8 in. apart. (Halite, 97 percent ±.)
544	8	1	0	Clay shale, magnesitic, moderately dark bluish-gray; contains thin nodular layers of bluish-gray microcrystalline anhydrite rock.
545	0		4	Halite rock, coarse-grained (¾–1 in.), white; contains fairly large blocky patches of dark-gray clay.
545	1		1	Clay shale, magnesitic, moderately dark bluish-gray; contains small nodules of bluish-gray microcrystalline anhydrite.
546	2	1	1	Halite rock, polyhalitic, anhydritic, and argillaceous; mottled medium-light-gray and amber-colored; moderately coarse grained (¼–½ in.) but has patches of recrystallized halite in which anhedral grains are as much as 1 in. in diameter. (Halite, 97 percent ±.)
548	11	2	9	Halite rock, argillaceous and sparingly anhydritic, coarse-grained (½–1 in.), medium-light-gray. (Halite, 95 percent ±.)
549	1		2	Clay shale, magnesitic, moderately dark bluish-gray.
549	3		2	Halite rock, argillaceous, medium-grained (⅛–¼ in.), amber-colored; has a medial black band one-half inch thick. (Halite, 98 percent ±.)
549	5		2	Clay shale, magnesitic, medium- to dark-gray; contains small nodules of gray microcrystalline anhydrite and patches of gray halite.
559	0	9	7	Halite rock, argillaceous and sparingly anhydritic; moderately coarse grained (¼–½ in.), but has patches of recrystallized halite in which anhedral grains are as much as 1 in. in diameter; white to very gray. (Halite, 97 percent ±.)
559	2		2	Clay shale, magnesitic, moderately dark bluish-gray; contains thin nodular layers of medium-bluish-gray microcrystalline anhydrite rock.

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
566	9	7	7	Halite rock, polyhalitic and sparingly argillaceous; medium grained (1/8–1/4 in.), but has patches of recrystallized halite in which anhedral grains reach 1½ in. in diameter; white and light reddish orange with grayish-black bands as much as one-fourth inch thick. (Halite, 97 percent ±.)
567	0		3	Clay shale, magnesitic, moderately dark bluish-gray; contains small nodules and laminae of bluish-gray microcrystalline anhydrite.
567	3		3	Halite rock, anhydritic and argillaceous, medium-grained (1/16–1/8 in.), amber-colored; contains veinlike seams of gray anhydrite and partings of gray clay shale. (Anhydrite, 10–15 percent; clay, 10–15 percent.)
567	9		6	Anhydrite rock, medium-bluish-gray, microcrystalline; contains patches of dark-gray microgranular magnesite and grains of halite.
568	0		3	Clay shale, magnesitic, moderately dark bluish-gray; has brownish-gray laminae.
570	8	2	8	Magnesite rock, silty, microgranular, brownish-gray; contains some fairly large nodules and thin veinlike seams of bluish-gray microcrystalline anhydrite.
571	0		4	Anhydrite rock, microcrystalline, bluish-gray; has brownish-gray laminae of microgranular magnesite rock.
571	5		5	Clay shale, magnesitic, moderately dark bluish-gray; has brownish-gray laminae; contains small nodules of bluish-gray microcrystalline anhydrite.
577	8	6	3	Halite rock, argillaceous and sparingly anhydritic, moderately course grained (1/4–1/2 in.), very light gray; has sharply defined grayish-black bands ranging from 2 to 6 in. in thickness and 4–8 in. apart. (Halite, 95–97 percent.)
578	11	1	3	Clay shale, magnesitic, moderately dark bluish-gray; has brownish-gray laminae and a few small bluish-gray nodules of microcrystalline anhydrite.
581	6	2	7	Halite rock, argillaceous and sparingly anhydritic, medium-coarse-grained to moderately coarse grained (1/8–1/2 in.), very light gray to amber-colored; has distinct grayish-black bands as much as 1 in. thick. (Halite, 97 percent ±.)
581	8		2	Clay shale, magnesitic, moderately dark bluish-gray.
589	1	7	5	Halite rock, argillaceous; medium grained (1/8–1/4 in.), but has patches of recrystallized halite in which anhedral grains reach a diameter of about 1 in.; very light gray to amber colored, with poorly defined grayish-black bands and a few widely separated medium gray partings. (Halite, 97 percent ±.)
589	4		3	Clay shale, magnesitic, moderately dark bluish-gray; has light-brownish-gray laminae; contains small nodular and thin veinlike seams of bluish-gray microcrystalline anhydrite at top and base of unit.
589	10		6	Halite rock, anhydritic and argillaceous; medium grained (1/8–1/4 in.), but has patches of recrystallized halite; very light gray to amber colored, with grayish-black bands ranging from 1/4 to 1/2 in. in thickness. (Halite, 95 percent ±.)

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
589	11		1	Clay shale, magnesitic, moderately dark bluish-gray; has light-brownish-gray laminae.
592	0	2	1	Halite rock, argillaceous and sparingly anhydritic, moderately coarse grained (¼–¾ in.), medium-dark- to light-gray. (Halite, 95–97 percent ±.)
592	7		7	Anhydrite rock, halitic, microcrystalline, medium-bluish-gray. (Anhydrite, 95–97 percent ±.)
600	1	7	6	Halite rock, polyhalitic, anhydritic, and argillaceous; moderately coarse to very coarse grained (¼–1½ in.) and extensively recrystallized; white to very light gray, with patches of very light red. (Halite, 95–97 percent.)
600	4		3	Clay shale, magnesitic, moderately dark bluish-gray.
601	10	1	6	Halite rock, argillaceous and sparingly anhydritic, medium-grained (⅛–¼ in.); has patches of recrystallized halite in which anhedral grains are as much as one-half inch in diameter; amber-colored, with grayish-black bands. (Halite, 95–97 percent.)
601	11		1	Clay shale, magnesitic, moderately dark bluish-gray; has light-brownish-gray laminae.
609	10	7	11	Halite rock, argillaceous, anhydritic, and polyhalitic; medium- to coarse-grained (⅛–1 in.); medium gray with patches of red; contains filmlike partings of clay shale. (Halite, 95–97 percent.)
610	4		6	Clay shale, magnesitic, moderately dark bluish-gray; has brownish-gray laminae.
611	9	1	5	Halite rock, anhydritic and argillaceous; medium-grained (⅛–¼ in.); has a few patches of recrystallized halite in which anhedral grains are as much as one-half inch in diameter; light amber to buff colored, with patches of grayish-black. (Halite, 95–97 percent.)
616	4	4	7	Halite rock, anhydritic, polyhalitic, and sparingly argillaceous; moderately coarse grained to coarse grained (½—1½ in.), with isolated patches of finer grained halite; white, with patches of red and grayish black. (Halite, 97 percent ±.)
619	3	2	11	Halite rock, argillaceous and sparingly anhydritic, medium-grained (⅛–¼ in.); has patches of recrystallized halite in which anhedral grains are as much as 1 in. in diameter; light gray to amber colored, with grayish-black bands ranging from 2 to 4 in. in thickness and from 1 to 3 in. apart; contains a few partings of medium- to dark-gray clay shale as much as one-half inch in thickness. (Halite, 95 percent ±.)
619	4		1	Clay shale, magnesitic, moderately dark bluish-gray; contains a few veins of anhydrite which extend downward into underlying halite rock.
622	6	3	2	Halite rock, anhydritic and argillaceous, moderately coarse grained to coarse-grained (¼–1½ in.); has isolated patches of finer grained halite; white to light gray, with grayish-black bands. (Halite, 97 percent ±.)

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
622	8		2	Anhydrite rock, microcrystalline; contains bluish-gray nodules embedded in a matrix of moderately dark bluish-gray magnesitic clay shale. (Anhydrite, 80 percent ±.)
629	1	6	5	Halite rock, argillaceous and anhydritic, medium-grained (1/8–1/4 in.); has isolated patches of recrystallized halite in which anhedral grains are as much as 1 in. in diameter; light gray to amber colored, with medium-gray bands. Halite, 95 percent ±.)
629	3		2	Clay shale, magnesitic, moderately dark bluish-gray; contains small nodules of gray microcrystalline anhydrite.
629	7		4	Halite rock, anhydritic and slightly argillaceous, moderately coarse grained (1/4–1/2 in.); amber-colored, with patches of gray. (Halite, 97 percent ±.)
630	1		6	Clay shale, magnesitic, moderately dark bluish-gray.
639	10	9	9	Halite rock, argillaceous and anhydritic, medium-coarse-grained to moderately coarse grained (1/8–1/2 in.), white, light-gray, and buff-colored; has grayish-black bands averaging one-fourth inch thick and from 1/2 to 4 in. apart. (Halite, 95–97 percent.)
644	2	4	4	Halite rock, anhydritic, coarse-grained (1/2–1 1/2 in.), white and buff-colored. (Halite, 98 percent ±.)
646	11	2	9	Halite rock, anhydritic, medium-grained (1/16–1/8 in.), buff-colored to white. (Halite, 98 percent ±.)
647	6		7	Anhydrite rock, very light gray to bluish-gray, microcrystalline; compact and massive in upper one-half and lower 1 in. of unit; remainder of unit contains fairly large halite pseudomorphs after gypsum, as much as 3 in. in length.
648	5		11	Halite rock, argillaceous and anhydritic, medium-coarse-grained to moderately coarse grained (1/8–1/2 in.), buff-colored and light-gray; has isolated darker gray patches; contains a few thin partings of dolomitic clay shale as much as one-eighth inch in thickness. (Halite, 95 percent ±.)
648	6		1	Clay shale, dolomitic, moderately dark bluish-gray.
651	6	3	0	Halite rock, anhydritic and argillaceous, coarse-grained (1/2–1 in.), white and medium-gray. (Halite, 95–97 percent.)
651	7		1	Shale, dolomitic, silty, moderately dark gray.
651	9		2	Halite rock, argillaceous, medium-grained (1/8–1/4 in.), amber-colored and brownish-gray. (Halite, 95 percent ±.)
651	11		2	Clay shale, dolomitic, moderately dark gray, laminated.
652	2		3	Halite rock, argillaceous and anhydritic, moderately coarse grained (1/4–1/2 in.), amber-colored to brownish-gray. (Halite, 92–95 percent.)
652	8		6	Clay shale, dolomitic, moderately dark bluish-gray; has laminae of lighter gray siltstone; contains small nodules of gray microcrystalline anhydrite grouped in a poorly defined layer at top of unit.
652	10		2	Halite rock, argillaceous, moderately coarse grained (1/4–1/2 in.), amber-colored; has patches of gray; contains thin partings of gray dolomitic clay shale. (Halite, 95 percent ±.)

Depth Ft	Depth in	Thickness Ft	Thickness in	Description
654	2	1	4	Clay shale, dolomitic, moderately dark bluish-gray; has medium-gray laminae; contains small nodules of bluish-gray microcrystalline anhydrite.
655	0		10	Halite rock, argillaceous, moderately coarse grained (¼–½ in.), medium- to light-gray. (Halite, 95 percent ±.)
655	3		3	Anhydrite rock, microcrystalline, bluish-gray; in nodular and lenticular masses embedded in a matrix of moderately dark bluish-gray magnesitic clay shale. (Anhydrite, 90 percent ±.)
655	6		3	Clay shale, magnesitic, moderately dark bluish-gray; contains small nodules of bluish-gray microcrystalline anhydrite.
659	7	4	1	Halite rock, argillaceous and sparingly anhydritic, moderately coarse grained (¼–½ in.), light-gray; has narrow grayish-black bands. (Halite, 95 percent ±.)
659	8		1	Clay shale, magnesitic, moderately dark bluish-gray.
665	9	6	1	Halite rock, argillaceous and sparingly anhydritic, moderately coarse grained (¼–½ in.), white to very light gray; has narrow grayish-black bands ranging from 1 to 2 in. in thickness and from 4 to 10 in. apart. (Halite, 95–97 percent ±.)
674	8	8	11	Halite rock, anhydritic and argillaceous, coarse-grained (½–1½ in.) and for the most part recrystallized, white to very light gray; has a few narrow, widely separated grayish-black bands. (Halite, 97 percent ±.)
675	7		11	Clay shale, dolomitic, moderately dark bluish-gray; contains small gray nodules of microcrystalline anhydrite. Some of these extend from the shale into the adjoining halite rock.
680	8	5	1	Halite rock, anhydritic and sparingly argillaceous, moderately coarse grained (¼–¾ in.), white; has light-gray mottling in places. (Halite, 95–97 percent.)
683	2	2	6	Halite rock, anhydritic, moderately coarse grained (¼–1 in.), buff-colored to light-gray; contains abundant small veinlets and nodular patches of gray microcrystalline anhydrite. (Halite, 85–90 percent.)
683	6		4	Anhydrite rock, microcrystalline, bluish-gray; has laminae and small inclusions of bluish- to brownish-gray dolomite rock. (Anhydrite, 95 percent ±.)
685	7	2	1	Dolomite rock, moderately dark brownish-gray, generally massive and earthy; contains inclusions and veinlets of halite.
686	0		5	Clay shale, dolomitic, bluish-gray; contains small nodular masses of microcrystalline anhydrite.
688	11	2	11	Anhydrite rock, microcrystalline, bluish-gray; has darker gray laminae of microgranular magnesite; contains variously shaped patches of halite and narrow rows of vertically elongated halite pseudomorphs after gypsum showing both the simple and swallowtail twinned forms. (Anhydrite, 95 percent ±.)

Depth		Thickness		
Ft	*in*	*Ft*	*in*	*Description*
690	3	1	4	Dolomite rock, microgranular, moderate-brownish-gray; has dark-gray laminae which are crenulated and offset by tiny faults; contains small bluish-gray nodules of microcrystalline anhydrite.
690	9		6	Anhydrite rock, microcrystalline, bluish-gray; contains small patches of gray to amber-colored halite. (Anhydrite, 95 percent ±.)
691	7		10	Dolomite rock, microgranular, moderate-dark-gray; contains small nodules and narrow veinlike seams of bluish-gray microcrystalline anhydrite.
694	0	2	5	Halite rock, anhydritic and argillaceous, medium-grained (⅛–¼ in.); has patches of recrystallized halite in anhedral crystals as much as one-half inch across; light gray with grayish-black bands from ½ to 3 in. thick and from ½ to 4 in. apart. (Halite, 95–97 percent.)
694	4		4	Anhydrite rock, microcrystalline, bluish-gray; contains patches of light-gray halite and streaky masses of brownish-gray magnesite.
697	7	3	3	Halite rock, anhydritic and sparingly argillaceous, medium-coarse-grained to moderately coarse grained (⅛–¾ in.), light-gray to amber-colored; has small patches of grayish black. (Halite, 95–97 percent.)
697	9		2	Magnesite rock, anhydritic, fossiliferous, microcrystalline to microgranular, buff-colored to light-brownish-gray; contains abundant specimens of a small *Permophorus*-like pelecypod. Some of these are preserved as halite casts embedded in microcrystalline anhydrite, and others, as anhydrite casts embedded in microcrystalline magnesite. Microcrystalline anhydrite forms a thin layer at top of unit, and it encloses isolated patches of fine-grained magnesite and presents a convex-curved surface against the main mass of magnesite rock.
698	5		8	Magnesite rock, microgranular, light-brownish-gray, soft, earthy.
699	0		7	Anhydrite rock, microcrystalline, medium-bluish-gray; has sinuous laminae of dark-gray magnesite rock.
701	11	2	11	Clay shale, magnesitic, moderately dark bluish-gray; contains small nodules of bluish-gray microcrystalline anhydrite which account for about one-third of the lower 6 in. of the unit.
703	6	1	7	Halite rock, argillaceous and sparingly anhydritic, moderately coarse grained (¼–¾ in.), light-gray; has medium-gray patches. (Halite, 95 percent ±.)
704	8	1	2	Clay shale, dolomitic, moderately dark bluish-gray; contains small nodules of bluish-gray microcrystalline anhydrite.
704	10		2	Anhydrite rock, bluish-gray, microcrystalline; in large nodular masses embedded in gray argillaceous halite rock. (Anhydrite, 80–85 percent.)

Depth		Thickness		
Ft	*in*	*Ft*	*in*	*Description*
710	0	5	2	Halite rock, argillaceous and sparingly anhydritic, moderately coarse grained (¼–¾ in.), light-gray; has narrow grayish-black bands. (Halite, 95–97 percent.)
710	4		4	Anhydrite rock, microcrystalline, bluish-gray; has sinuous laminae of dark-gray dolomite rock.
710	6		2	Clay shale, dolomitic, moderately dark bluish-gray and brownish-gray.
711	6	1	0	Halite rock, argillaceous, brownish-gray; shows a network of intersecting chevrons formed by thin films of clayey material coating upper surfaces of partly euhedral grains of halite. (Halite, 60–70 percent.) Base of Hutchinson Salt Member.
712	0		6	Anhydrite rock, microcrystalline, bluish-gray to buff; in nodular masses embedded in a matrix of dark-gray dolomite. (Anhydrite, 80 percent ±.)
712	5		5	Clay shale, dolomitic, medium-gray; contains small patches and euhedral crystals of halite.
715	11	3	6	Dolomite rock, silty, microgranular, soft, earthy, medium-light-gray; contains small patches of halite and lenticles of anhydrite.
719	3	2	1	Anhydrite rock, microcrystalline, light-gray; contains numerous patches of moderately coarse grained halite toward which the anhydrite presents sinuous convex boundaries. (Anhydrite, 50–60 percent.)
719	9		6	Anhydrite rock, microcrystalline, light-gray; has sinuous laminae of dark-gray dolomite.
721	4	1	7	Dolomite rock, silty, microgranular, medium-gray to brownish-gray contains small nodules and veinlike seams of bluish-gray microcrystalline anhydrite.
724	0	2	8	Clay shale, silty, medium-gray; has laminae of brownish-gray dolomite rock; contains veinlike seams of bluish-gray microcrystalline anhydrite.
728	0	4	0	Anhydrite rock, microcrystalline, light-gray; has sinuous laminae of dark-gray dolomite rock; at a depth of 726 ft. contains a 6-in. layer in which anhydrite occurs as small nodules in a matrix of soft, earthy dolomite rock.
729	10	1	10	Clay shale, dolomitic, dark-gray has medium gray laminae; contains thin, waferlike nodules of gray microcrystalline anhydrite.
731	3	1	5	Anhydrite rock, microcrystalline, gray; has laminae of dark-gray dolomite rock.
731	11		8	Clay shale, dolomitic, dark-gray; contains small nodules and veinlike seams of bluish-gray microcrystalline anhydrite.
732	6		7	Anhydrite rock, microcrystalline, bluish-gray; contains small patches of dark-gray dolomite rock.
733	11	1	5	Clay shale, dolomitic, dark-gray; has brownish-gray laminae; contains small nodules of gray microcrystalline anhydrite.
				End of core.

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The U.S. Geological Survey Library has cataloged this publication as follows:

Jones, Charles Leslie, 1922–
Petrography of evaporites from the Wellington Formation near Hutchinson, Kansas. Washington, U.S. Govt. Print. Off., 1965.

iv, 69 p. illus., map, diagrs. (1 in pocket) table. 24 cm. (U.S. Geological Survey. Bulletin 1201–A)
Contributions to general geology.
Bibliography: p. 66–67.

(Continued on next card)

Jones, Charles Leslie, 1922– Petrography of evaporites from the Wellington Formation near Hutchinson, Kansas. 1965. (Card 2)

1. Petrology—Kansas. 2. Geology, Stratigraphic—Permian. 3. Sedimentation and deposition. 4. Borings—Kansas. I. Title. II. Title: Evaporites from the Wellington Formation near Hutchinson, Kansas. (Series)