STRATIGRAPHY OF THE SALINE FACIES
OF THE PARADOX MEMBER OF THE HERMOSA FORMATION
OF SOUTHEASTERN UTAH AND SOUTHWESTERN COLORADO

By

Robert J. Hite

U. S. Geological Survey

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U. S. Geological Survey, Salt Lake City, Utah

INTRODUCTION

Problems related to the search for potash and petroleum in the Paradox member of the Hermosa formation of Pennsylvanian age have prompted a subsurface study of the "saline facies" of that member. The main purpose of this report is to present an informal type section with an accompanying scheme of nomenclature for the "saline facies". The study is confined to the restricted part of the Paradox basin in southeastern Utah and southwestern Colorado, commonly referred to as the Paradox salt basin. The results of this study should prove useful in gaining a better understanding of Paradox member stratigraphy and related problems.

The first descriptions of the Paradox member were based on incomplete surface exposures in diapiric salt anticlines and on information from a few widely separated exploration wells. Refinement of this early work progressed with petroleum exploration along the southwestern and southern basin margins. Recent petroleum discoveries in the eastern half of the basin have generated considerable drilling activity in areas where stratigraphic information is lacking or notably incomplete. In addition much detailed information has been provided by various companies engaged in potash exploration permitting the present study of the Paradox member from its maximum development, outward to the margin of the facies.

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METHODS OF INVESTIGATION

Radioactivity, electric, sonic, and lithologic logs of more than 75 wells, penetrating all or part of the "saline facies", were correlated and studied in this investigation, and about 8,000 feet of core, taken in various potash test holes, was examined. Isopachous maps were constructed for each salt bed and for several of the intervening shale-anhydrite marker beds.

The proposed type section of the "saline facies" of the Paradox member is a composite derived from the Delhi-Taylor Oil Corporation No. 2 Utah well, located in sec. 18, T. 25 S., R. 21 E., Grand County, Utah, and the Reynolds Mining Corporation No. 1 Egnar well, sec. 14, T. 43 N., R. 19 W., San Miguel County, Colorado (see fig. 1). The Utah No. 2 well, located on the northern extension of the Moab Valley anticline (locally referred to as the Seven Mile structure), penetrated the most complete section of the "saline facies" known at the time of this investigation. The basal part of the Egnar No. 1 well was added to the illustration to clarify recumbent folding found in the Utah No. 2 well. This folding, which occurs between the depths of 8,100 to 8,950 feet, affects salt beds 26 and 27. The Egnar No. 1 well also shows the relation of the "saline facies" to the underlying formations, which were not penetrated in the Utah No. 2 well.

The salt beds are numbered in sequence from youngest to oldest. It is unlikely that younger or stray beds within the depicted section will be found. A possibility exists, however, that beds older than salt bed 29 may be found in the salt basin. If and when such beds are found they can be added to the system of nomenclature without a renumbering of units. Satisfactory correlation of the stratigraphic units of the "saline facies" was aided by the recognition of several significant marker beds. Four of the shale-anhydrite interbeds were titled "A", "B", "C", and "D". These beds, although similar in most respects to the other marker beds, are as a rule markedly higher in radioactivity. Another clastic-sulfate marker bed, occurring between the depths of 7,550-7,730 feet in the Utah No. 2 well, is informally referred to in this report as the "Cane Creek" marker. This lithologic unit, named from the "Cane Creek" anticline in Grand County, Utah, where it is petroliferous, is one of the thickest marker beds in the "saline facies". Another important stratigraphic guide is an unusually widespread interval of argillaceous carnallite in salt bed 6.

Correlation within the "saline facies", with the exception of certain diapiric salt anticlines, is excellent throughout the salt basin. Correlation within the eastern half of the salt basin depends, however, on the recognition of certain carnallite-bearing units which are indistinguishable from shale-anhydrite marker beds on radioactivity logs. A correlation of the "saline facies" beds from the extreme northern end to the southern part of the salt basin is shown in figure 2.

STRATIGRAPHY

The Pennsylvanian rocks in the Paradox basin include a "saline facies" containing a tremendous volume of halite rock. This deposit of marine evaporites probably contains the greatest aggregate thickness of rock salt in any single formation on the North American continent. Sloss (1958) has classified this deposit as "basin center evaporites slightly modified by externally derived coarse clastics." The halite is confined to a structural and sedimentary basin referred to by Baker, and others, (1933, fig. 1, p. 964) as the Paradox basin. The "saline facies" is quite extensive, covering more than 11,000 square miles in southeastern Utah and southwestern Colorado.

The "saline facies" occurs in the Paradox member of the Hermosa formation of Bass (1944), originally defined as the Paradox formation by Baker, and others, (1933). In recent years the member has been restudied by several workers, notably Wengerd and Strickland (1954), Herman and Sharps (1956), Herman and Barkell (1957), Clair (1958), Wengerd (1958), and Wengerd and Matheny (1958). Wengerd and Matheny's study includes an excellent summary of the history of development of the present day terminology (1958, p. 2051-2056).

On the southern margins of the salt basin certain limestone equivalents of the "saline facies" have been given zone names, derived from the fields in which they yield oil and gas. These zones and their salt bed equivalents are shown in table 1.

Table 1.--Oil and gas producing zones and their saline equivalents, southwestern shelf of the Paradox salt basin.

Zone	Salt bed
Ismay	2 and 3
Desert Creek	4 and 5
Akah	6, 7, 8, 9, and 10
Barker Creek	11, 12, 13, 14, 15, 16, 17, 18, and 19

The latest scheme of classification has merit and will probably achieve formal acceptance. For this report, however, the terms Hermosa formation and Paradox member of Bass are used in conjunction with the zonal definement of Malin (1958).

A group of rocks in northwestern Colorado, which are age equivalent to the Paradox member and exhibit a similar lithologic character, have been designated the Paradox formation by Bass (1958, p. 92) and by Hallgarth (1960). Since a "saline facies" is apparently not present in the Colorado section, this discussion is restricted to the Paradox salt basin.

Paradox member of the Hermosa formation

The Paradox member of the Hermosa formation within the salt basin can be divided into three distinct units on the basis of lithologies. This tripartite division includes an upper and lower unit separated by a middle unit of salt, which in this report is referred to as the "saline facies". Previous workers have assigned the Paradox member a Pennsylvanian (Des Moines) age (Wengerd, 1958).

Upper unit

The upper unit of the Paradox member constitutes a penesaline facies over much of the salt basin and grades laterally into normal marine limestones on the southern and western margins of the basin. It consists of interbedded limestone, dolomite, anhydrite, black shale, and siltstone, and ranges from 150 to 500 feet in thickness. The contact between this unit and the overlying upper member of the Hermosa formation is generally picked at the first black shale or anhydrite (Wengerd 1954, p. 2173). Locally, residual material, resulting from the leaching of the salt along the crests of salt anticlines, may be included in this unit. The upper unit is overlain by normal marine limestones of the upper member of the Hermosa for which Wengerd and Matheny (1958, p. 2075) have proposed the name, Honaker Trail formation.

Middle unit ("saline facies")

The boundaries of the middle unit or "saline facies" are the first and last salt beds found. These boundaries laterally transcend time surfaces and, as shown in figure 2, move stratigraphically higher and lower in the section on approaching the deepest part of the basin.

The true depositional thickness of the "saline facies" ranges from zero on the margins of the salt basin to an estimated maximum of 7,000 feet in the basin deep. Within the diapiric salt anticlines, however, structurally thickened cores of salt in excess of 13,000 feet have been penetrated.

The "saline facies" contains 29 known beds of halite, separated by clastic and penesaline interbeds. Each salt bed represents a stage in a partial or complete evaporite cyclothem and grades laterally through anhydrite, dolomite, and limestone facies. Depending on its position in the basin, the bed may show a similar vertical transition. In 18 of the 29 salt beds, concentration of the brine is known to have reached the stage of potash salt precipitation. As a rule, the limestone and dolomite facies is not part of the cyclothem in the deeper part of the salt basin. The operation of a strong horizontal salinity gradient within the evaporite basin brought about peripheral precipitation of the less soluble carbonate salts. By the time each surge of fresher waters initiating a new cycle had reached the deeper part of the basin they were depleted in nearly all salts but the chlorides and sulfates. The normal marine limestone facies of several of the cyclothems have been described as reefoid in several of the oil fields on the southwestern shelf of the salt basin (Carter, 1958). There is, however, no direct evidence that for each cyclothem an extensive organic barrier restricting basin circulation was present. Herman and Barkell (1957, p. 868-869) suggest that restriction was more likely due to a dynamic barrier such as postulated by Scruton (1953).

The halite rock of the "saline facies" is equigranular with anhedral grains of halite ranging from 1/16 to 1/2 inch in diameter. Occasionally larger grains occur in a finer-grained matrix, giving the rock a texture described by Greensmith (1957) as evapo-porphyrocrystic. Commonly, the halite exhibits a schistose structure in the salt anticlines. Colors most commonly observed are smoky gray, amber, pale orange, or white. Color is usually a measure of anhydrite, clay, shale, or potash content. Irregular blebs and individual grains of carnallite and sylvite may be present and these, when pigmented, may be blood red, salmon pink, or light orange. As in most marine evaporites, the halite is marked at regular intervals by thin laminations (jahresringe) consisting either of black shale, gray clay, anhydrite, or more rarely, potash salts. In one core 1/16-inch thick laminae of pyrite were observed at the contact of a salt bed and the overlying anhydrite layer. Spacing between individual jahresringe ranges from 1/4 inch to 1-1/2 feet, but the average is about 2-1/2 inches. The jahresringe probably represent seasonal fluctuations in salinity, temperature and clastic supply. Where wells are closely spaced and core available, correlation of some of these laminae is possible.

The clastic-sulfate marker beds consist of interbedded black- to dark-gray carbonaceous shales and mudstones, light- to dark-gray calcareous siltstone which locally is very micaceous, minor sandstone, and dark- to light-gray laminated and blebby anhydrite. Small amounts of pyrite have been observed along with occasional small blebs of polyhalite and gypsum. Some of the organic-rich shales have a coal-like appearance and, like many rocks of this type, are more radioactive than other shales. As a rule many vertical to near-vertical fractures are present, ranging from hairline to 3 inches in width, and filled with halite and more rarely carnallite. Flowing zones of high density magnesium-rich brines, oil and gas, or combinations of these, are commonly found in these beds. Herman and Barkell (1957, p. 869) have stated that the black shales grade into dark gray-green shales and siltstones and red beds in approaching the Uncompahgre uplift on the eastern margin of the basin.

The "saline facies" contains individual salt beds of diverse thickness and geographic distribution, indicating that basin sedimentation was clearly influenced by bottom topography. Depositional patterns indicate the presence of numerous presalt highs, some of which were positive during only certain intervals and others positive throughout the period of salt deposition.

The great thicknesses of salt found in the cores of the salt anticlines of the region have commonly been ascribed to a large-scale transfer of salt by plastic flow from adjacent synclines. That some flow has occurred is evident in cores showing coarsely recrystallized halite, highly contorted bedding features (Hite and Gere, 1958, p. 223), and a structural fabric of halite crystals showing a preferred orientation. These recorded abnormal thicknesses, however, are more likely the result of original sedimentary thickening, tight recumbent folding of individual salt beds, and because wells have penetrated steeply dipping beds. The surficial ridgelike form of the salt anticlines, as Kelley has postulated (1958, p. 35), become synclinal structures at depth. These structures were in fact depositional troughs throughout most of the time of salt deposition. Many of the basal salt beds and intervening shale-anhydrite marker beds are found only in these troughs and wedge out against adjacent subsurface pre-salt highs. Each new bed added to the trough was downfolded making room for succeeding beds. Original thicknesses of salt beds deposited in these troughs range from 15 to 990 feet. Further evidence that structurally formed topography along the sea floor influenced deposition in the salt basin is found in certain potash-bearing units. These units show a change of mineralogy or disappear entirely as the enveloping salt bed thins over the underlying positive structure.

A study of the areal distribution of individual salt beds within the "saline facies" shows that the greatest expansion of the evaporite basin occurred during deposition of beds 6 to 19 inclusive. Of these salt bed 6 is the most widespread. The southernmost extension of the "saline facies" is represented by salt bed 6, which, as Wengerd and Matheny (1958, fig. 15) have suggested, may extend into the San Juan basin of northwestern New Mexico. In a northerly direction salt bed 2 is probably the most widespread. To the west, maximum spread of the "saline facies" occurred during salt bed 15 time.

A study of the distribution of salt beds 13, 15, and 18 indicates a marked westward shift of the center of chemical sedimentation during the time of their deposition. This is verified by isopach data on the above mentioned salt beds and by a high concentration of potash within these beds along their western limits. This is contrary to the commonly accepted belief that subsidence and accumulation of evaporites was greatest along the eastern margin of the basin.

Lower unit

The lower unit of the Paradox member constitutes a penesaline facies similar to that of the upper unit. It consists of thin, intercalated beds of anhydrite or gypsum, dolomite, siltstone and radioactive black shale. Within the salt basin the thickness of this unit ranges from 100 to 450 feet. As a rule, this lower unit thins basinward as additional salt beds are found. The lower unit is underlain by a series of fossiliferous limestones and interbedded gray shales belonging to the lower member of the Hermosa formation. This member has been redefined by Wengerd and Strickland (1954) as the Pinkerton Trail formation.

OIL AND GAS POSSIBILITIES

The hypersaline environment of the Paradox salt basin was highly conducive to the preservation of organic matter. During the operation of the Paradox evaporation pan, large quantities of organic matter were swept in from the open sea and terrestrial sources, and preserved in the high-density brine. This is well shown by the black, carbonaceous shale beds and black shale laminations in the salt. Much of the original organic debris has been converted to hydrocarbons, and few wells have been drilled through the "saline facies" without finding some oil and gas. Numerous spectacular but short-lived "blowouts" of oil and gas have been discovered in both salt and clastic-sulfate beds. In the Big Flat field in Grand County, Utah, several wells have experienced "blowouts" of oil and gas from a thin shale-anhydrite marker bed separating salt beds 15 and 16. This bed has been referred to locally as the "Black Oil" zone. Only recently an oil company is reportedly completing a well for oil production in this field from an interval within a salt bed. Another clastic-sulfate marker bed, to which the name "Cane Creek" marker is applied in this report, has shown some promise of oil production both in the Moab Valley and Cane Creek anticlines. This bed is one of the thickest clastic beds within the "saline facies". The "Cane Creek" marker has only been tested in the salt anticlines where downfolding has placed it at a low structural elevation. These and other marker beds of the "saline facies", although exhibiting some promise, have very low permeability. This permeability may be related to fracturing during formation of the salt anticlines. If so, permeabilities necessary for sustained production of oil or gas may only be found in the salt anticlines.

Much has been written concerning the oil producing limestone equivalents of the "saline facies" on the southwest shelf of the salt basin. It has been found that these productive rocks are peripheral facies of specific salt beds (see table 1). The trends of the peripheral limestone facies can be shown by mapping the areal distribution of the 29 known cyclothems. Within each of these trends limestone reefs similar to those in the Aneth area may exist. Most favorable areas would be where the limestone units of several cycles overlap. The thickness of a specific salt bed may be an indication of the degree of development of the limestone facies. A tremendously thick salt bed, such as salt bed 19, indicates a longer lived dynamic or physical barrier to circulation than a thin salt bed. Thus, opportune conditions for accumulation of greater thickness of deposit in the adjacent limestone facies should occur.

SUMMARY

The "saline facies" of the Paradox member is made up of a stratigraphic sequence of at least 29 evaporite cyclothems, containing thin beds of black shale. The sequence is readily amenable to a system of nomenclature which can be used over most of the Paradox salt basin.

Mapping of individual salt beds within the "saline facies" has shown that surface features within the Paradox salt basin, described as salt anticlines, were actually sedimentary troughs during most of the time of salt deposition. Many of the oldest salt beds deposited in these troughs thin out over adjacent highs.

Isopachous maps of several of the salt beds within the "saline facies" illustrate that for certain periods of chemical sedimentation the basin axis radically shifted from east to west.

Numerous occurrences of oil and gas have been discovered by wells in the "saline facies". These occurrences, which often cause high pressure "blowouts", have been found in both the salt beds and in the intervening clastic-sulphate units. Structural conditions may have been a determinant in developing favorable permeabilities in otherwise very tight reservoir rocks. The areal distribution of each evaporite cyclothem is directly significant to petroleum exploration. The limestone facies of each cyclothem may contain organic buildups similar to those in the oil and gas fields on the southwest shelf of the evaporite basin.

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