NORTH DAKOTA GEOLOGICAL SURVEY WILSON M. LAIRD, STATE GEOLOGIST

HALITE DEPOSITS IN NORTH DAKOTA

S. B. ANDERSON D. E. HANSEN

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ABSTRACT

Mappable halite beds are found in North Dakota in the Devonian Prairie Evaporite formation, the Mississippian Charles formation, the Permian Opeche formation and the Triassic Spearfish formation. Salt occurrences, their lithologic associations in the various formations, and their tectonic significance are discussed.

Isopach maps showing the thickness and extent of these salts; portions of typical electrical, radioactivity, and micrologs of the salt sections are included along with a composite section of the entire salt sequence.

INTRODUCTION

Extensive drilling has proved that there are widespread deposits of halite in North Dakota. Eleven separate mappable beds have been found. One is found in the Devonian Prairie Evaporite formation, seven in the Mississippian Charles formation, one in the Permian Opeche formation, and two in the Triassic Spearfish formation. Rough calculations show that these eleven beds represent a total volume of 1703 cubic miles of salt.

Recently there has been considerable interest shown in these salt beds, because of the possibility of commercial production of salt, the effect these salt beds have on the search for petroleum, and in estimating drilling and production costs in areas where salt sections may be encountered.

The Triassic Spearfish formation as used in this report refers to the red bed sequence of shales, siltstones, sandstones and salt lying between the base of the Jurassic Piper formation and the top of the Permian Minnekahta formation.

The Piper formation as referred to in this report includes the Gypsum Springs formation.

PURPOSE OF THE REPORT

The primary purpose of this report is to outline and define the salts occurring in the Devonian, Mississippian, Permian, and Triassic Systems in North Dakota.

LOCATION and STRATIGRAPHIC POSITION

Most of the halite beds in North Dakota are located in the western third of the state in the deeper portion of the Williston Basin, (Figures 1-9 and 11). The one exception is a salt that occurs near the base of the Mississippian Charles formation in the north central part of the state, (Figure 10). A composite section which shows the approximate stratigraphic position of the various salt beds is shown in Figure 16.

METHOD OF STUDY

The thicknesses of the various salt beds were determined from radioactivity logs, electrical logs, micrologs, microlaterologs, and caliper surveys. The almost exclusive use of mechanical logs was necessary because many of the wells were drilled with gypsum base mud which absorbs the salt cuttings which salt base mud does not do. The samples from a few wells that contained salt cuttings were spot-checked to establish the accuracy of the mechanical log correlations.

The data from the mechanical logs were tabulated and isopach maps of the various salts were drawn. The literature was searched for theory of salt deposition and sedimentation that would explain the data compiled by the authors.

DEPOSITION OF SALT

Twenhofel (1932, pp. 462-464) states that "the evaporation of sea or other salt water precipitates the substances in solution in reverse order to solubility and extent of saturation, with various modifications arising from interactions of the various substances in solution to temperature, sunlight, and probably other factors."

According to Twenhofel in a complete evaporite cycle, salts are precipitated in the following sequence. Calcium carbonate containing iron oxide forms the base followed by calcium sulphate in the form of gypsum or anhydrite which is succeeded by sodium chloride, followed by the salts of the last bitterms, which contain potassium chloride, (Twenhofel, 1932, p. 470)). In nature this cycle may fail to be brought to completion by a number of events, such as a change in climate or a greater influx of: sea water, which may stop the cycle at any phase in the sequence of deposition.

Sloss (1953, p. 153) describes a major evaporite cycle that can occur during carbonate rock deposition. The sequence begins with a basal light-colored, fossiliferous limestone (normal marine) followed by anhydritic dolomite and anhydrite (penesaline). The beds immediately above the penesaline are halite and anhydrite (saline). The saline beds are overlain by penesaline beds and these, in turn, are followed by normal marine limestones and shales.

During Mississippian salt deposition in North Dakota repeated evaporite cycles consist of fragmental to dense limestones, anhydrite with red and gray shales, and salt.

Grabau (1920, pp. 116-154) placed salts of marine origin in the following four classes, marginal salt pans, marine salinas, lagoonal deposits and relict seas.

Marginal salt pans are shallow depressions along the sea coast, where at periods of high tide and during storms sea water is washed in and later evaporated. These salt pans may be large in areal extent, but they are not very deep. They are usually

Grabau describes marine salinas as lakes mear the sea that obtain their water from the sea by percolation through some permiable media with subsequent evaporation forming a supersaline brine and eventual precipitation of salt.

Lagoonal deposits are formed when a barrier such as a bar with openings cuts off a part of the sea but still permits a steady influx of water equal to the evaporation, thereby forming a supersaline brine with a resulting precipitation of salt. The Gulf of Karabugas in the Caspian Sea is an example of this type of deposit, although gypsum and sodium sulphate are the only salts precipitated (Grabau, 1920, pp. 136-137).

Relict sea type deposits are formed when a portion of the ocean in an arid area is isolated from the main body. With evaporation the water becomes supersaturated and the precipitation of

The salt of lake deposits is probably derived from marine sediments from which it has been leached and redeposited (Gra-

Sloss (1953, pp. 155-160) has set up a classification of evaporite occurrences in intracratonic basins according to the position in which they occur in the basin. The two major groups are then subdivided on the basis of the restricting agency.

The first major group Sloss describes as intra-basin evaporites. The intra-basin evaporites develop because of restriction by tectonism or by reefs and possible combinations of the two. The Devonian Prairie Evaporite salt and the Mississippian "A" through "F" salts appear to be of this type.

The second major category of evaporitic occurrences are basin margin evaporites formed on the landward side of barriers. The Mississippian "X" salt located in the Bottineau County area appears to be of this type (Figure 10).

STRATIGRAPHY

Devonian Stratigraphy

The basal Middle Devonian beds are the red shales and light colored dolomites of the Ashern. The Elm Point and the Winnipegosis (unseparated in North Dakota) overlie the Ashern and consist of light-colored carbonate rocks on the basin margin or shelf area. In Manitoba the Winnipegosis contains biohermal reefs. In the basin deep area of northwestern North Dakota the equivalents of the basal Winnipegosis are dark colored limestones with shale partings. The beds above the basal dark limestones are the dense dolomites, anhydrites and salt of the Prairie Evaporite formation. The formation overlying the Winnipegosis and Prairie Evaporite, where found, is the Dawson Bay. The Dawson Bay is a series of red and green shales, argillaceous and fragmental limestones, and local anhydrite beds.

Thus, in ascending order above the Prairie Evaporite, the Dawson Bay, Souris River, Duperow, and Nisku formations are carbonates, with some minor shales, that contain repeated cycles of anhydrite but no salt. The uppermost Devonian formation, the Lyleton, is a red, shaly, silty, anrydritic sequence with some limestone and dolomite and is the closing phase of an evaporitic cycle.

Prairie Evaporite Formation

Baillie (1953, p. 10) proposed the name Prairie Evaporite for the evaporite section that forms the upper unit of the Devonian Elk Point group.

In North Dakota this section attains a thickness of over 350 feet (Figure 11) in the Amerada Petroleum Corporation H. O. Bakken well. (1) It thickens to the north as shown by a thickness of 650 feet in the Imperial Davidson well in Saskatchewan (Baillie, 1953, p. 95).

The lack of a salt section in the California Company Blanche Thompson well suggests removal of salt by solution followed by collapse of the overlying beds. This theory is supported by the fact that the Cardinal Drilling Company Keeler well located less than two miles from the Blanche Thompson contains 160 feet of salt in the Prairie Evaporite Section.

Solution of the salt with the resulting collapse of the overlying formations could provide excellent traps for the accumulation of oil. This condition is very likely not restricted to this one area in North Dakota but may be quite prevalent along the outer margin of the salt. Due to insufficient subsurface control this possibility can not be established at the present time.

A similar situation seems to occur in southwestern Saskatchewan. Apparent solution of the Devonian salt and collapse of the overlying sediments has created traps such as the Venn structure which contains gas. (Bishop, 1952, pp. 474-485).

Mechanical logs from the H. O. Bakken well illustrate a typical Prairie Evaporite section (Figure 12).

MISSISSIPPIAN STRATIGRAPHY

General Statement

The Mississippian in the area of the Williston Basin began with deposits of dark gray shale of the Englewood formation. A similar environment prevailed during deposition of the Lodgepole and part of the Mission Canyon formations in the deeper part of the basin. The sediments are chiefly dense, thinly bedded, gray limestones, and gray shales. In the shallower parts or the margins of the basin the Lodgepole consists of light colored fragmental to sublithographic limestones, partly shaly and cherty.

The overlying Mission Canyon formation consists of strata that vary from the argillaceous brownish gray, fragmental limestones to dense, thinly bedded, gray limestones, and gray shales in the deeper part of the basin grading to light colored, yellowish gray, slightly anhydritic fragmental limestones that represent shelf or basin margin deposits.

The base of the Charles formation consists of brownish and yellowish gray fragmental limestones in the deeper parts of the basin while the lateral equivalents on the basin margin are anhydrites, limestones, and dolomites. The Charles, however, is chiefly an evaporite sequence and contains repetitions of salts, anhydrites, thin shales, and dense to fragmental limestones.

Overlying the Charles formation are the reddish sandstones and silts of the Kibbey formation. The Kibbey apparently is the closing phase of an evaporite cycle.

Mississippian-Charles Formation

The Mississippian Charles formation contains seven separate salt beds in North Dakota, as shown in Figures 4 through 10. For purposes of discussion in this paper they have been termed in descending order the "A" through "F" Mississippian salts and the seventh salt (Figure 10) has been termed the "X" salt from the higher of two salt beds occurring near the base of the Charles formation in the Hunt Oil Company Shoemaker well. The Sohio Petroleum Company J. Nelson is the only other well in the area that has two salts near the base of the Charles, therefore an isopach map was drawn on the upper salt only. Mechanical logs of the "X" and "XY" salt sections from the Shoemaker well are shown in Figure 13.

The Mississippian salts "A" through "F" are located in the deepest part of the Williston Basin, in the western one-third of North Dakota and the eastern part of Montana with the "D" and "F" salts extending into Canada. Figure 14 illustrates typical mechanical log characteristics of the Mississippian salts "A" through "F" in the Gulf Oil Corporation Bennie Pierre well. This section is equivalent to the Poplar beds as defined by the Saskatchewan Geological Society (Saskatchewan Geol. Soc., 1956). The Mississippian "X" salt is confined to a relatively small area in the north central part of North Dakota and is apparently equivalent to the Alida-Frobisher beds as defined by the Saskatchewan Geological Society (Saskatchewan Geol. Soc., 1956). While this salt occupies less area than the others, and is among the thinnest herein discussed, it is found at shallower depths. Since is lies at an approximate depth of 3600' it might be the

most attractive for commercial salt production. The thickest of the Mississippian salts is termed the Mississippian "A" salt, which attains a thickness of 150 feet. This entire interval was cored in the Amerada Petroleum Corporation Lars Kvam well and a description of this core is provided in Table 2. The Mississippian "D" and "F" salts are greatest in areal extent, and attain a thickness of 60 feet and 90 feet respec-

Permian-Triassic-Jurassic Stratigraphy

The salt deposited during the Permian-Triassic-Jurassic time is associated with "red-bed" lithology. It is this similarity of lithology and lack of fossil evidence that has made the recognition of age and the correlation of these formations so difficult.

The Permian Opeche formation is generally a reddish sandstone, siltstone and red shale sequence, which in North Dakota contains a sequence of salt that has been referred to in this report as the Permian "A" salt (Figure 3). Due to the many associated impurities, this salt section is difficult to pick.

The Opeche formation is overlain conformably by the Permian Minnekahta formation and appears to overlie unconformably the Pennsylvanian Minnelusa formation.

The Permian "A" salt occurs in approximately the same area as the Mississippian salts in North Dakota and extends into (1) Wells are referred to by farm name. See Table 1 for their locations.

Montana, however, it does not extend so far north as the Mississippian salts. The Permian "A" salt reaches a maximum known thickness of 181 feet a few miles north of Dickinson, North Dakota in the Socony Vacuum Oil Company Dvorak well.

There is another salt in the Permian below the Permian "A" salt in the Dvorak well and a few other wells. This has been termed in this report the Permian "B" salt; however, it does not seem to be very extensive and not enough information is available now to make an isopach map of it. Figure 15 shows typical mechanical logs in the Permian and Triassic salt sections of the Carter Oil Company Lockwood well.

At the present time very little information is available on the Permian salts other than that furnished by mechanical logs as many of the wells penetrating the salts were drilled with gypsum-

Spearfish Stratigraphy The rocks called Spearfish in North Dakota are a sequence of brick red to brown sandstones, siltstones, and shales with two major salt sections. Table 3 provides a description of two cored Spearfish sections from the Amerada Petroleum Corporation Dena Svor well. These cored intervals represent part of the section referred to as the Spearfish "B" salt in this report.

Spearfish Salts

There are two salts in the Spearfish in North Dakota. In this report they have been termed in descending order the Triassic "A" and the Triassic "B". (Figures 1 and 2). Mechanical log sections of these salts as they appear in the Lockwood well are shown in

The "A" salt is 142 feet thick in the Wm. H. Hunt W. & D. Dunham well and the "B" salt is 199 feet thick in the Stanolind Oil and Gas Company J. Brusich well. These are the thickest known North Dakota sections of the Spearfish salts.

The Spearfish "A" salt thins over the Nesson anticline, thereby roughly showing the outline of the structure on the iso-

The "B" salt shows what appears to be salt solution with resulting collapse of the overlying formations in eastern Slope County. The Brusich well contains nearly 200 feet of salt while none is found in the Worley & Harrel Inc. Jack Benz well, two miles away. As mentioned previously in regard to the Devonian salt, this situation could create good traps for the accumulation of

oil. Zeiglar (1955, pp. 49-55) has presented evidence for placing of Triassic-Jurassic boundaries in North Dakota. Instead of calling the "red-bed" sequence between the top of the Minnekahta and the base of the Piper, Triassic Spearfish, Zeiglar has broken this sequence into the following units, which are in ascending order Triassic Spearfish, Pine salt, Jurassic Saude and Dunham salt. This, according to Zeiglar, limits the occurrence of the Spearfish largely to the western one-third of the state. Zeiglar's Dunham salt and Pine salt are termed respectively Triassic "A" and Triassic "B" in this report, since the authors have not been able to their satisfaction to separate the Spearfish into units.

PALEOGEOGRAPHY

General

In the North Dakota portion of the Williston Basin the various salts appear to outline the more negative areas of rock deposition. These areas appear to have been generally tectonically negative from Devonian through Triassic time.

During Devonian time the center of deposition was apparently located in northwestern North Dakota and southeastern Saskatchewan, while during Mississippian, Permian, and Triassic times the centers were located farther south in western North Dakota and eastern Montana.

Devonian

The deposition of the carbonates and evaporites of the Elk Point group in North Dakota was directly controlled by an area of downsinking that extended into the state from the northwest which Baillie (1953, p. 16) termed the Elk Point Basin. The Elk Point Basin was bounded on the northeast by the Manitoba shelf, on the east and south by the Dakota shelf, on the southwest by the Wyoming shield and Little Beaver positive axis, and on the west by the central Montana axis and Alberta arch. The Swift Current Platform was an extension into Saskatchewan of the

During deposition of the Elk Point group normal marine carbonates were deposited upon the shelf areas. Evaporite deposition in the Elk Point Basin was probably tectonically controlled in conjunction with biohermal barriers. After deposition of the Elk Point group the center of evaporitic deposition shifted northwest and never returned to North Dakota during Devonian time. Normal marine carbonates, intercalated with some anhydrites were then deposited in North Dakota until the Devonian sea regressed. The Lyleton clastics were laid down during the closing phases of the Devonian in North Dakota.

Mississippian

Mississippian sedimentation in the Williston Basin was initiated by an eastward advance of the Mississippian seas from the Idaho geosyncline through the Central Montana trough (Andrichuk, 1955, p. 2189). The sedimentation was influenced by several shelf areas. These were the Wyoming shelf on the south and west, the Alberta shelf to the northwest, the shelf area in Manitoba and eastern North and South Dakota on the east. The thickness of the sediments indicates that deposition was slow in the shelf areas in comparison to the sedimentation in the deeper areas of the Williston Basin.

According to Andrichuk (1955), shoals were developed during Mississippian time, extending from the Black Hills to part of eastern Montana and along the Wyoming shelf. With a lowering of the sea level during the deposition of the Charles formation these shoals restricted the sea and evaporites were deposited. With an increase in sea level the deposition of evaporites ceased. Fluctuations in the sea level such as these plus the effect of the shoals probably accounted for the salts in the Mississippian

Permian-Triassic-Jurassic

At present there is no definite hypothesis that adequately describes the occurrences of salts associated with red-beds. The occurrence of salt in red-beds is thought to be associated with

Possibly the deposition of the Opeche and Spearfish took place upon an area that was slowly and repeatedly invaded by seas from the south and southwest. The seas could have supplied the salt necessary for deposition in the more negative areas. This repeated transgression and regression at a slow rate, appears to be a satisfactory explanation of the salt occurrences.

USES OF SALT

The uses of salt have been outlined by Dr. Wilson M. Laird, State Geologist, in a speech prepared for presentation at the Second Annual Meeting of the Greater North Dakota Association. Excerpts from that address are given here.

Today more salt is used in the manufacturing of chemicals than any other single basic raw material. It is the chief raw material for practically all compounds containing sodium and chlorine. It is said that North Dakota and its bordering states consume more than 300,000 tons of salt per year for all purposes.

The greatest use for salt is soda ash. In 1951, for example, 8,303,000 tons of salt was used to make soda ash for use in the manufacture of textiles, soap, paper and in other processes. The second major use of salt is in the manufacture of chlorine, bleaches, and chlorides. In 1951, for example, 4,709,000 tons of salt was used for this purpose.

Other major uses of salt include dyes; inorganic chemicals; soap; textile processing; curing of hides and leather; meat packing; fish curing; dairy products; canning and preserving and other food processing; refrigeration; livestock, agriculture and general farm use; highways and railroads for dust control and ice control; table and other household uses; water treatment; metallurgy; and many other uses too numerous to mention.

In view of the nature of the occurrence of salt in North Dakota, there may be a question in the minds of some as to how it could be utilized. As can be seen from the maps, the salts are all relatively deep, most being more than 5,000 feet in depth. However, one salt (the Mississippian X salt, Figure 10) is a little over 3600 feet deep north of Minot. Apparently, the only economical way in which these could be used would be to drill wells to them and introduce water into the formation causing the salt to dissolve. When the salt was dissolved it would then be pumped to the surface as a brine and then evaporated. This would give a relatively pure type of salt, but, of course, the depth of the salt beds would make the salt more expensive. Therefore, it may be some time before our salts are utilized.

It could be, however, that if a well were drilled and the cost of it were borne by some other operation such as the operations for oil, that the well could be later taken over and used economically for the production of brine.

Along this line it might also be mentioned that the salt cavities so excavated have one other potential use and that is for storage of liquid petroleum gases. Such cavities for the storage of LPG are being widely used, particularly in Texas.

Growth of the oil and gas industry may well make our salt industry more possible. Well drilling in western North Dakota and eastern Montana requires 20,000 tons of salt a year for use in drilling mud. The mud companies also use caustic soda a derivative of salt and the acid companies use hydrochloric acid, another derivative of salt. With more and more gas being found and produced in North Dakota, the need for storage becomes even more apparent. Montana-Dakota Utilities Company presently stores North Dakota gas in Montana fields but it may someday be necessary for them to develop additional storage, and salt cavaties might conceivably be the answer. Likewise the Signal Oil and Gas Company of Tioga might find that salt cavaties can -provide needed storage for their LPG products.

1-Amerada Petroleum Corp., H. O. Bakken No. 1,

Sec. 12-T157N-R95W, Williams County. 2—California Co., Blanche Thompson No. 1,

Sec. 31-T160N-R81W, Bottineau County.

3-Cardinal Drilling Co., Keeler No. 1, Sec. 1-T159N-R82W, Bottineau County.

4—Hunt Oil Co., Shoemaker No. 1,

Sec. 3-T157N-R78W, McHenry County. 5—Sohio Petroleum Co., J. Nelson No. 1,

Sec. 34-T158N-R81W, Renville County. 6—Socony-Vacuum Oil Co., Dvorak No. F-43-6-P,

Sec. 6-T141N-R94W, Dunn County. 7-Wm. H. Hunt, W. & D. Dunham No. 1,

Sec. 24-T155N-R90W, Mountrail County. 8-Stanolind Oil & Gas Co., J. Brusich No. 1,

Sec. 8-T135N-R98W, Slope County.

9-Worley & Harrel Inc., Jack Benz No. 1, Sec. 20-T135N-R98W, Slope County.

10—Gulf Oil Corp., Bennie Pierre Federal Unit No. 1,

Sec. 28-T148N-R104W, McKenzie County.

11-Carter Oil Co., E. Lockwood No. 1, Sec. 5-T147N-R93W, Dunn County.

12—Imperial Oil Co., Davidson No. 1, 1sd. 16 Sec. 8-T27 R1-W3, Saskatchewan.

13—Amerada Petroleum Corp., Lars Kvam No. 2, Tract 1, Sec. 19-T156N-R95W, Williams County.

14—Amerada Petroleum Corp., Dena Svor No. 2, Tract 2, Sec. 18-T156N-R95W, Williams County.

TABLE II

Mississippian "A" salt as cored in the Lars Kvam well.

Depth in Feet 7587.5–7590 Salt with red shale partings.

7590–7628.5 7628.5-7636.5 Salt, red shale and traces of anhydrite.

7636.5-7651.5 Salt with red shale partings.

7651.5–7654 Salt, red shale, trace anhydrite. 7654–7656.5 Salt, dark gray calcareous shale.

7656.5–7664 Salt with traces of red shale. 7664–7669 Salt with gray anhydritic shale and anhydrite

7669–7671.5

7671.5–7674 Salt with traces of gray shale and anhydrite. 7674–7710.5

Salt with red shale and anhydrite partings. 7710.5–7713

7713–7718.5 7718.5-7720.5 Salt with trace of red and gray shale and anhy-

7720.5–7723 Medium dark gray hard shale and salt.

7723–7728

7728–7730.5 Gray anhydrite with small partings of shale and

7733–7735.5

*77*35.5–*77*38

7730.5–7733 Thin bedded gray shale and limestone.

Thin bedded calcareous gray shale. Thin bedded gray shale and anhydrite with a

trace of salt. TABLE III

Triassic "B" salt sections as cored in the

Amerada Petroleum Corp., Dena Svor well.

Depth in Feet 6316-6356

6356-6369 Dark, reddish, hard shale and mudstone with variable amounts of salt inclusions.

6369-6373 Halite, large crystals. 6373-6380 Reddish shale, hard, with scattered salt inclusions.

End of Core. 6447–6452 Very hard red shale with salt inclusions.

6452-6457 Salt and hard red shale. 6457–6465 Red shale with salt filling vertical fracture.

End of Core. REFERENCES Anrichuk, J. M., (1955) "Mississippian Madison Group Stratigraphy & Sedimentation in Wyoming and Southern Montana": Bull. Amer.

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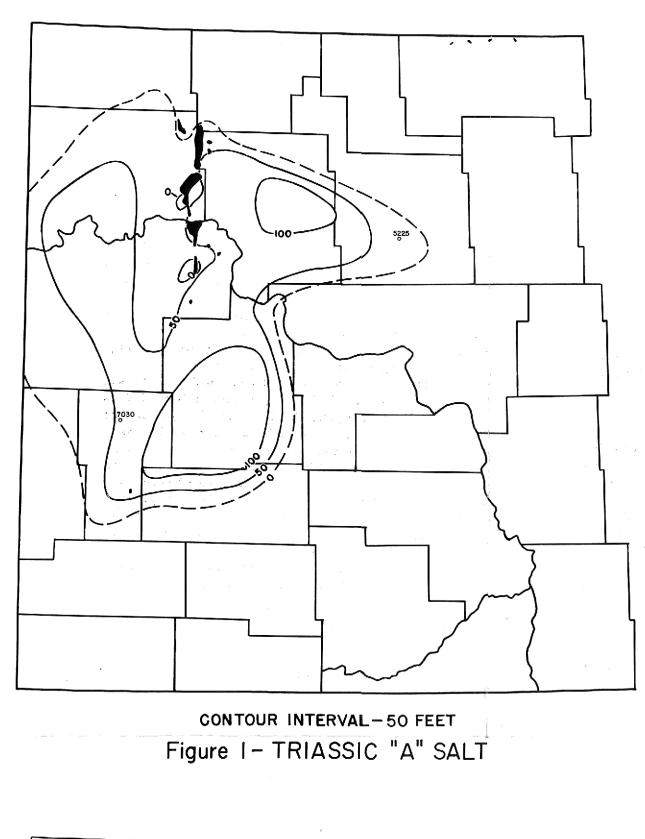
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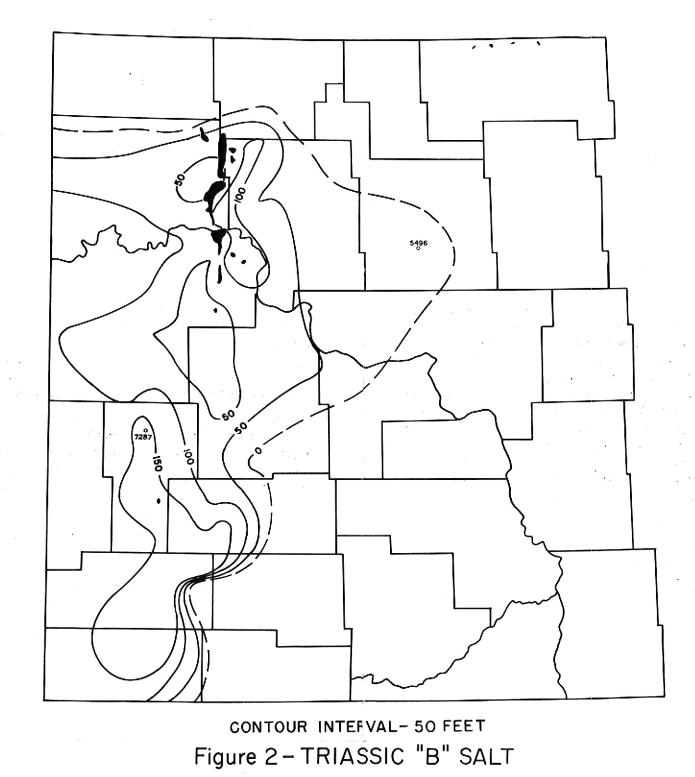
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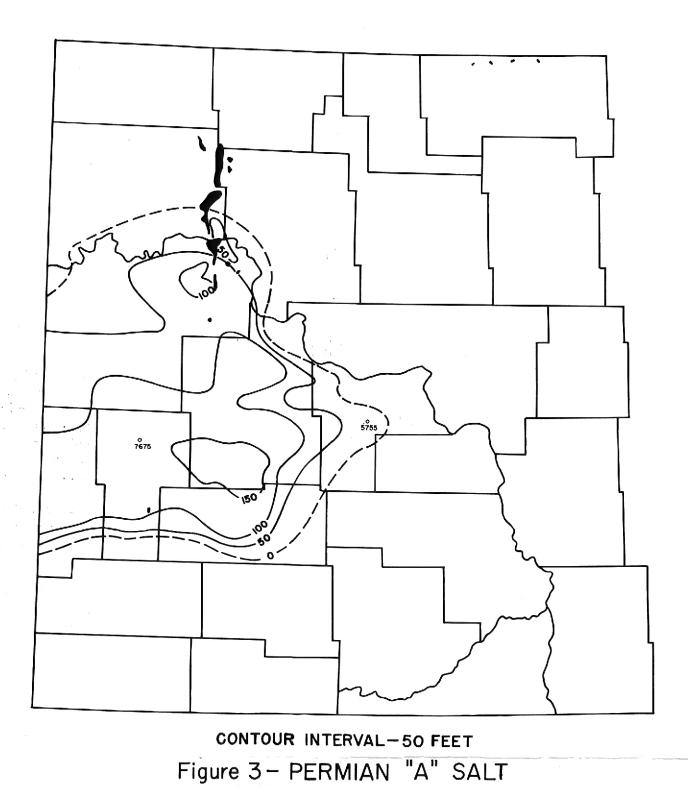
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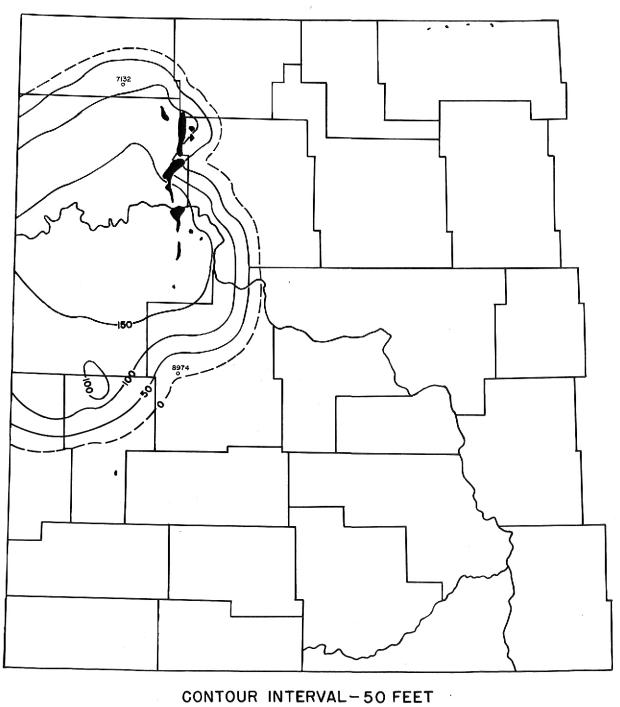
Williams and Wilkins Co., Baltimore.

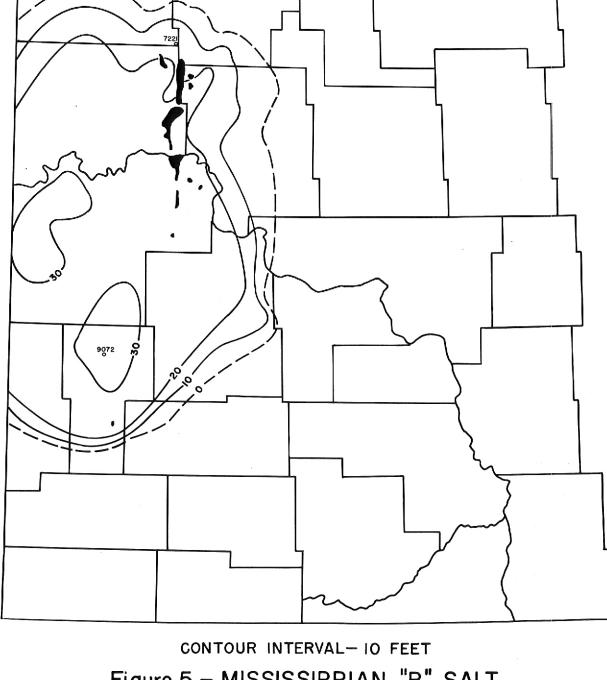
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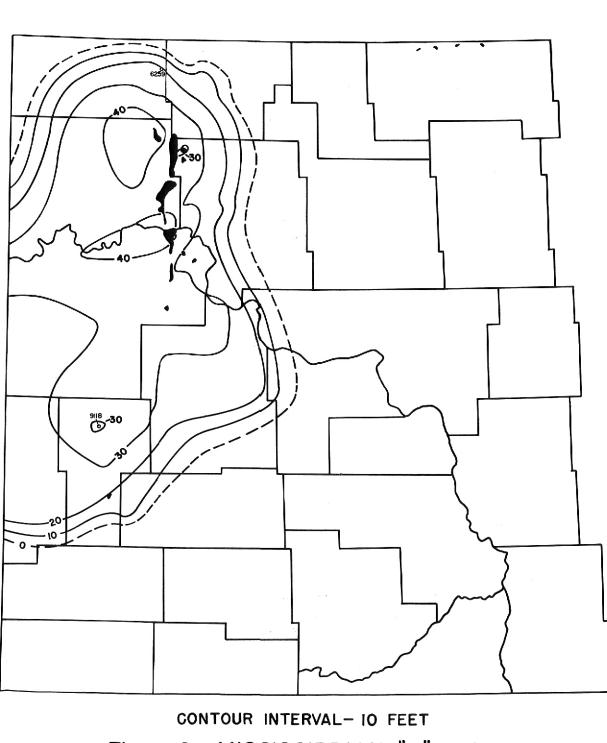
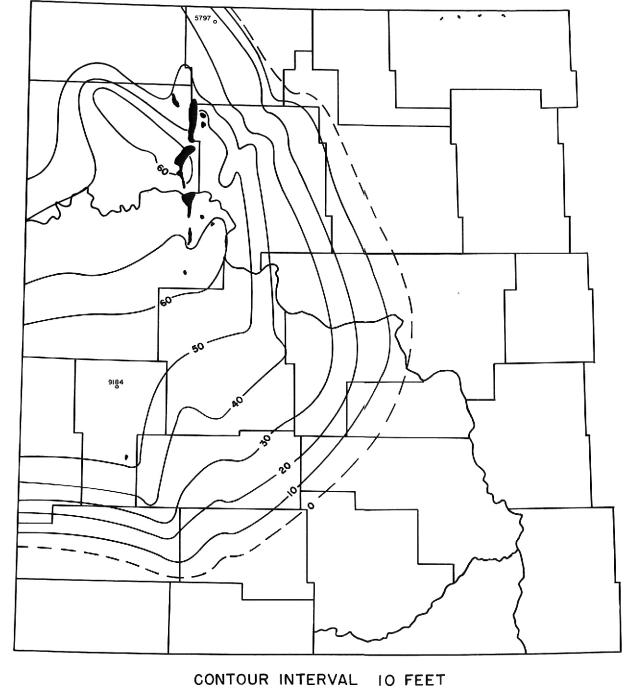
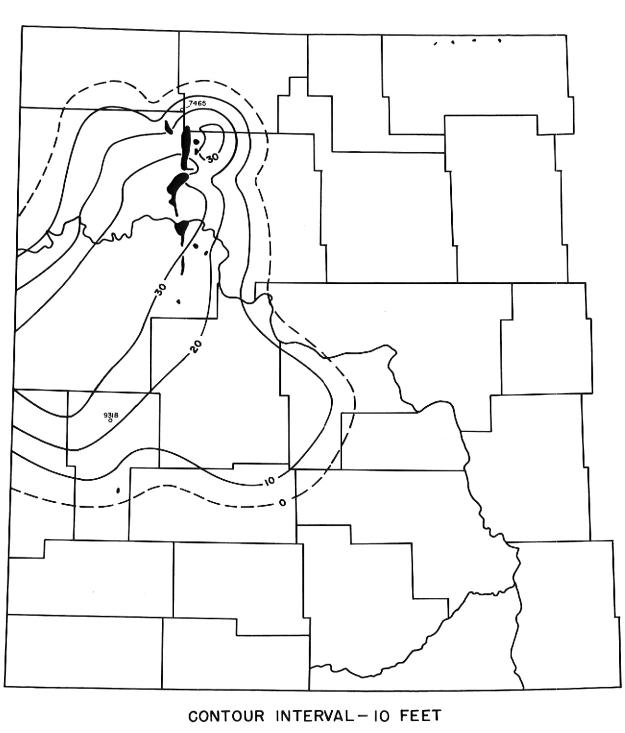


Figure 4 - MISSISSIPPIAN "A" SALT

Figure 5 - MISSISSIPPIAN "B" SALT

Figure 6 - MISSISSIPPIAN "C" SALT





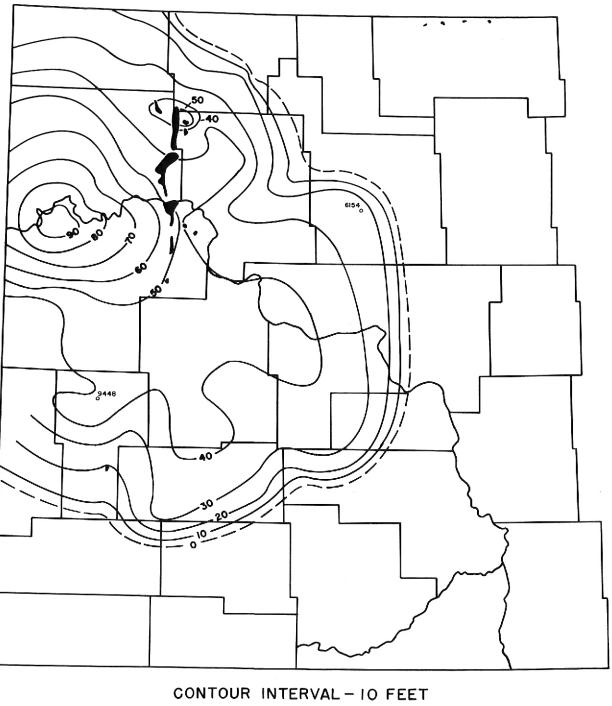
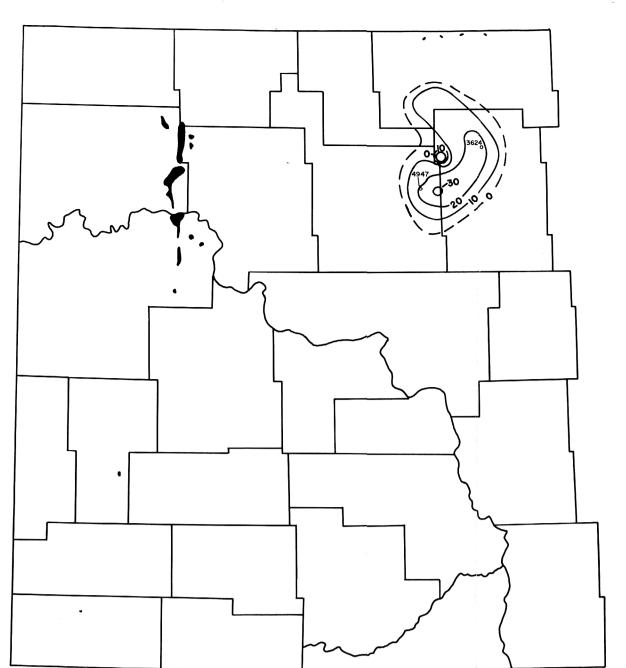


Figure 7- MISSISSIPPIAN "D" SALT

Figure 8 - MISSISSIPPIAN "E" SALT

Figure 9- MISSISSIPPIAN "F" SALT

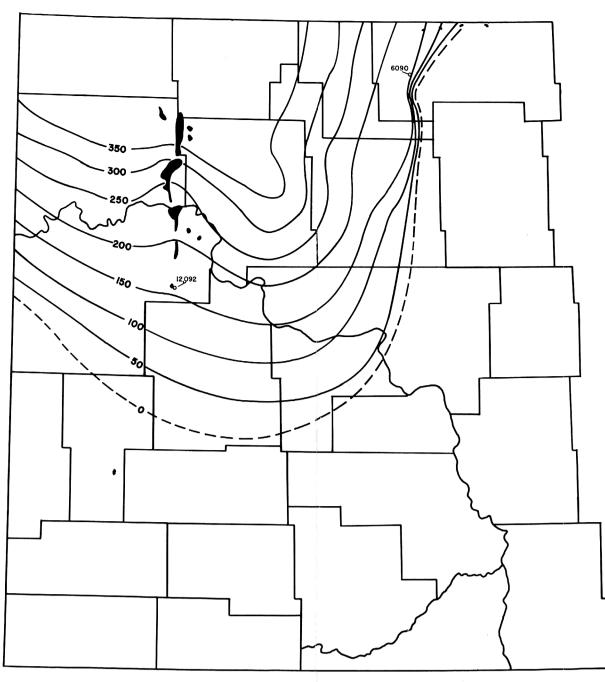
NORTH DAKOTA GEOLOGICAL SURVEY



CONTOUR INTERVAL- NO FEET

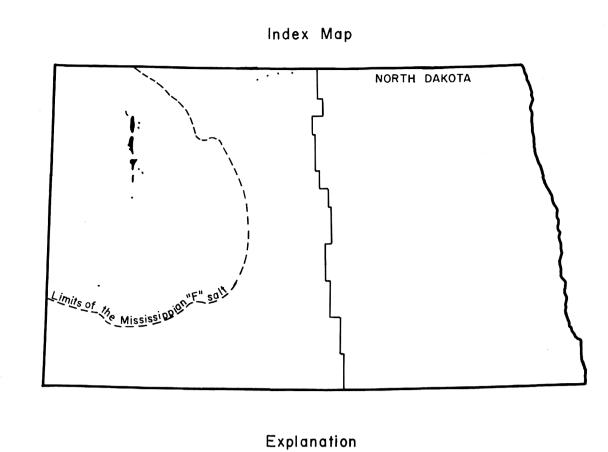
Figure IO- MISSISSIPPIAN "X" SALT

WILSON M. LAIRD, State Geologist



CONTOUR INTERVAL - 50 FEET
Figure II - DEVONIAN PRAIRIE EVAPORITE

REPORT OF INVESTIGATION 28, PLATE III LEGEND



The maps represented on plates I and 2 are thickness maps of eleven separate mappable deposits of salt found in North Dakota. The maximum and minimum depths from the surface to the top of the salt are located on the maps. The shaded areas represent the oil fields.

THICKNESS MAPS OF SALTS IN NORTH DAKOTA

