NORTH DAKOTA GEOLGICAL SURVEY

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Subsurface Correlations of the Cretaceous Greenhorn-Lakota Interval in North Dakota

by

DAN E. HANSEN

GRAND FORKS, NORTH DAKOTA, 1955

pach and sand-shale ratio map of the Greenhorn to Jurassic interval are not correct in this northeast area for the entire Cretaceous interval. In any event, the presence of lower Cretaceous continental deposition has not been proven at this writing, but awaits more study.

Economic Possibilities

In North Dakota the lower Cretaceous sandstones are probably best known as producers of artesian water. The only occurrence of hydrocarbons, to the writer's knowledge, is methane gas found in the artesian wells in southern Dickey County, North Dakota. The wells that contain methane produce from depths of 1100 to 1200 feet.[53] This means the water and gas producing sandstone is the Newcastle, as illustrated by the cross-section showing the correlation of the Greenhorn-Lakota interval in southeastern North Dakota (figure 2).

The absence of authenticated reports of oil or gas from the Dakota group of sandstones should not condemn the strata as nonproductive of hydrocarbons. There are many areas in North Dakota that have not been penetrated by the drill, and furthermore in other areas the density of wildcats drilled is not so great as to exclude possible lower Cretaceous sandstone production. The writer believes the best best possibilities of commercial hydrocarbon production are in the Fall River sandstones in northeastern North Dakota, the Fall River and Lakota sandstones around the Nesson anticline, and the Newcastle sandstone in southwestern North Dakota.

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53 Hard, H. A., "Geology and Water Resources of the Edgely and LaMoure Quadrangles North Dakota," **United States Geological Survey, Bulletin 801,** pp. 76-78, plates 1, 2, 3, 4, 1929.

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SUBSURFACE CORRELATIONS OF THE CRETACEOUS GREENHORN-LAKOTA INTERVAL IN NORTH DAKOTA

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DAN E. HANSEN

INTRODUCTION

ABSTRACT

The purpose of this research was to correlate the sandstones and shales of the Cretaceous Greenhorn-Lakota interval in North Dakota.

Rock samples and mechanical logs from forty-six petroleum exploration wells were studied and combination mechanical and lithologic logs were plotted on cross-sections to show the correlations. An additional one-hundred mechanical logs from petroleum exploration wells were studied and the data obtained were used to prepare several isopach, sandstone percentage, sand-shale ratio, and sandstone thickness maps.

The stratigraphic interval studied consists, in ascending order, of the Lakota, Fuson, Fall River, Skull Creek, Newcastle, Mowry, Belle Fourche, and Greenhorn formations. The formation nomenclature used is that of the Black Hills, South Dakota, where the previously mentioned formations crop out. The term Dakota is proposed for a group consisting of the Lakota, Fuson, Fall River, Skull Creek, Newcastle, and Mowry formations.

The Lakota quartzose sandstone was deposited as a sheet sand by a transgressing Cretaceous sea. The Cretaceous sea transgressed the area of North Dakota from west to east. The overlying gray shales of the Fuson were deposited as a result of sand and clay sorting and are the shale facies, at least in part, of the Lakota sandstone. The Fall River quartzose sandstones were deposited during a pause or slight regression of the Cretaceous sea. During Fall River time, and perhaps Lakota, continental deltaic sediments were probably being deposited in the area of northeastern North Dakota and possibly in the extreme eastern area of North Dakota. The last phase of Fall River deposition is one of complete transgression, by the Cretaceous sea, to the east beyond North Dakota. The gray Skull Creek shale is, in part, the shale facies of the Fall River sandstone. The Newcastle quartzose sandstones are discontinuous and occur in the areas of southwestern, northwestern, and eastern North Dakota. The gray shales of the Newcastle were deposited as shale facies of the sandstones. The Mowry shale is a thin, silty, gray shale in North Dakota and, with the exception of greater thickness in extreme southwestern North Dakota, has the same shale facies relationship, in part, to the Newcastle sandstones. The gray to dark-

gray Belle Fourche shale was deposited in the Cretaceous sea with the supply of volcanic ash material for the bentonites probably coming from the west. The calcareous nature of the gray to dark-gray Greenhorn shale was probably due to a rise in temperature of the Cretaceous sea. The Greenhorn is marked by the occurrence of **Globigerina** and **Inoceramus** calcite prisms.

Economic possibilities are the occurrence of oil or gas in the Newcastle sandstone of southwestern North Dakota and the Fall River-Lakota sandstones of northern North Dakota. For the purpose of finding ground water, the study shows the Newcastle sandstone in southeastern North Dakota has supplied the larger amount of artesian water for this area.

Acknowledgments

The writing of this report would not have been possible without the financial aid, office space, and use of instruments from the North Dakota Geological Survey. Dr. Wilson M. Laird, Head of the Geology Department and State Geologist made this study possible and also made many valuable suggestions and criticisms. Mr. F. D. Holland, Jr., Assistant Professor, Department of Geology helped the writer greatly by his objective criticisms and corrections and by his many suggestions, especially his explanation of K. E. Caster's magnafacies-parvafacies concepts. Thanks are also due to Dr. Gorden L. Bell. Assistant Professor of Geology, Mr. Miller Hansen, Assistant State Geologist, and Mr. Sidney Anderson, Geologist with the State Survey, who were consulted frequently.

Purpose of the Study

Investigation of the subsurface Cretaceous Greenhorn-Lakota sedimentary rock interval was suggested by Dr. Donald F. Towse, former Assistant Professor of the Geology Department, and Dr. Wilson M. Laird, Head of the Geology Department and State Geologist of North Dakota.

The study was undertaken to clarify the correlation of the basal Cretaceous sandstones that occur throughout the state of North Dakota, and to determine the relationship of the basal sandstones with the overlying and underlying strata.

The Greenhorn formation was chosen as a datum because it is easily recognized in the oil exploration wells of North Dakota by lithologic characteristics and by the definite pattern on the electric logs.

A stratigraphic sequence was worked out and suggestions are made for correlation with equivalent strata beyond the state boundaries.

The possible correlation of the Greenhorn-Lakota interval is shown by cross-sections of the formations involved in the study.

It would have been desirable to use fossils for correlation and for time equivalence study. However, few fossils were found in the samples and this type of study was not made.

To be an ideal study, geologic information from a sufficient number of exploratory wells spaced to cover the same amount of area was desirable. This equality of spacing was not possible, however, for the exploratory wells are not evenly distributed throughout the state. The formations did prove to be continuous, and where wells were drilled the sample and mechanical log study showed that correlation of the formations is possible.

The final result of the Greenhorn-Lakota interval study is the aid given to other geologists concerned with correlation problems within the state of North Dakota, and the suggestion of areas where probable stratigraphic traps for oil and gas could occur and which could contain commercial quantities of hydrocarbons.

Methods of Study

The recent drilling of many exploratory wells for petroleum made data for this study possible. The oil exploration companies operating within the state of North Dakota are required to furnish to the State a set of rock samples and mechanical logs from the wells they drill. This information is deposited with the State Geological Survey at Grand Forks. The amount of this geological information deposited with the State Survey is continually increasing. For example, during 1954 approximately 125 exploratory wells were drilled in eastern and central North Dakota. Because of the increases in short periods of time it is impossible for any individual to study all this very latest available information.

The study was undertaken during the period between June 1, 1953, and September 1, 1953, when the writer was employed by the North Dakota Geological Survey. The work was continued independently by the writer during the period of June 1 to August 1, 1954. From August 1, 1954, to the present the writer has continued this study while employed by the State Geological Survey.

The work of correlating the Greenhorn -Lakota interval began by choosing wells from which rock samples and mechanical logs were available. In North Dakota the relatively soft sands and shales of the Cretaceous are swiftly drilled and, as a consequence, the quality of the rock samples is generally very poor. It was important that the electrical and radioactivity logs were available to aid in the interpretation of the sedimentary interval studied. The number of wells with rock samples and mechanical logs available was sufficient in all but the extreme east part, where positive correlations could not be made with the formations of the Greenhorn-Lakota interval further west.

The examination of the rock samples was done with a binocular microscope using 9 power magnification. The color of the rock samples was determined by aid of the Rock-Color Chart prepared by the National Research Council. The booklet, "Examination of Well Cuttings," by Low[1] was used as the guide in methods of rock sample examination and the usage of descriptive terms.

To describe the size limits of the sandstone grains studied, the Wentworth grade scale[2] and the size classification was used as a guide. The grain size was obtained by comparing, under the binocular microscope, a mounted set of sand grains separated into the Wentworth grade scale with the sand grains observed in the well samples.

TABLE I

Wentworth Size Classification

Grade limits (diameters)	Name
2 - 4 mm.	Granules
1 - 2 mm.	Very coarse sand
½ - 1 mm.	Coarse sand
¼ - ½ mm.	Medium sand
⅛ - ¼ mm.	Fine sand
1/16 - 1/8 mm.	Very fine sand
1/256 - 1/16	Silt
Below 1/256 mm.	Clay

The description of a sandstone as consisting predominantly of a certain grain size was based on a visual estimation of the percentage of that grain size in the total volume occupied by the sand grains. The roundness of the sand grains was obtained by comparison with the chart of roundness given by Pettijohn.[3]

The combination of the sample descriptions, and the electrical and/or radioactivity logs were used to make up the final interpretive logs that were plotted to form the subsurface cross sections (Plate I and Plate II). Lithologic and mechanical logs from forty-six (46) wells were studied and plotted as the cross sections. A map showing the locations of these wells was prepared (Figure I). An additional one-hundred electrical and radioactivity logs from petroleum exploration wells were studied to get information to be used for the preparation of isopach, sand-shale ratio, sandstone percentage, structure, and paleogeological maps.

A list of wells referring to the location and cross-section numbers used in the text and to complement Figure I follows:

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[1] Low, J. W.: "Examination of Well Cuttings," **Colorado School of Mines Quarterly**, Vol. 46, No. 4, October, 1951.

[2] Wentworth, C. K., A scale of grade and class terms for clastic sediments, Jour. Geology, Vol. 30 pp. 377-392, 1922.

[3] Pettijohn, F. J.; **Sedimentary Rocks**, Harper and Brothers, New York, p. 52, 1949.

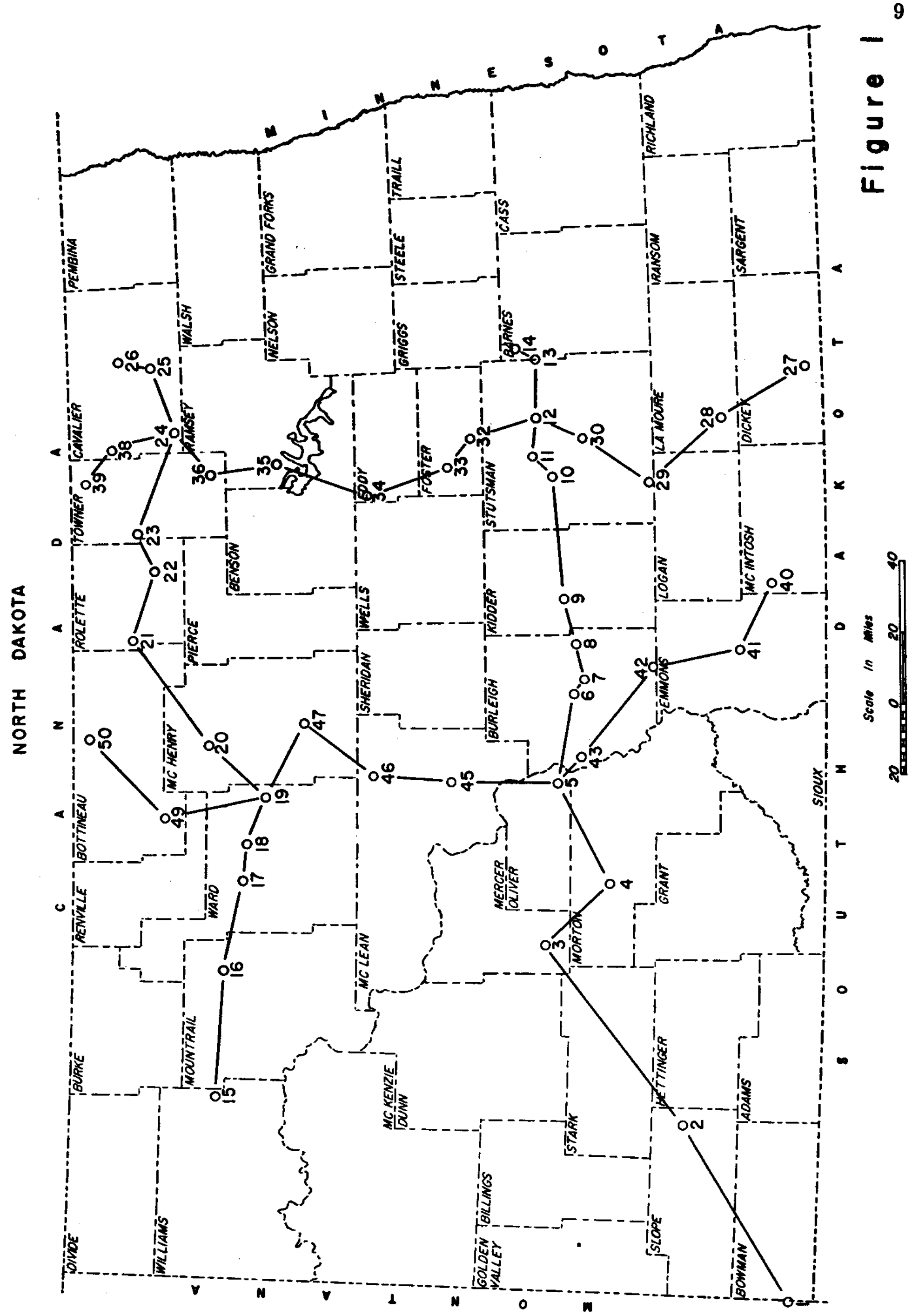

Figure I

LIST OF LOCATIONS

1. Carter Oil Company N. P. R. R. No. 1, SW., SE., Sec. 19, T., 4N., R. 62 E., Fallon County, Montana.
2. Stanolind Oil and Gas Company-Deep Rock James Brusich No. 1, SE., SE., Sec. 8, T. 135 N., R. 98 W., Slope County.
3. Kelly-Plymouth Fritz Leutz No. 1, NW., NE., Sec. 28, T. 142 N., R. 98 W., Mercer County.
4. Deep Rock Oil Corp. H. Johnson "A" No. 1, SW., SW., Sec. 30, T. 142 N., R. 98 W., Morton County.
5. Carter Oil Company E. L. Semling No. 1, SE., SE., Sec. 18, T. 141 N., R. 81 W., Oliver County.
6. Continenal-Pure Davidson No. 1, SW., SW., Sec. 6, T. 140 N., R. 77 W., Burleigh County.
7. Continental Oil Company Duemeland No. 1, NW., NW., Sec. 3, T. 140 N., R. 77 W., Burleigh County.
8. Continental Oil Company Dronen No. 1, NE., NE., Sec. 9, T. 140 N., R. 75 W., Burleigh County.
9. Magnolia Petroleum Company Dakota A., NE., Sec. 36, T. 141 N., R. 73 W., Kidder County.
10. Barnett Drilling Incorporated Gaier No. 1, NW., NW., Sec. 11, T. 141 N., R. 67 W., Stutsman County.
11. General Atlas Carbon Co. Floyd Barthel No. 1, SW., NE., Sec. 15, T. 142 N., R. 65 W., Stutsman County.
12. General Atlas Carbon Co. A. Peplinski No. 1 ,SE., NW., Sec. 21, T. 142 N., R. 63 W., Stutsman County.
13. Pollard and Davis Duane Guscette No. 1, NW., NW., Sec. 20, T. 142 N., R. 61 W., Barnes County.
14. Pollard and Davis Gregory No. 1, SE., SW., Sec. 23, T. 143 N., R. 61 W., Barnes County.
15. Amerada Petroleum Corporation Henry O. Bakken No. 1, SW., NW., Sec. 12, T. 157 N., R. 95 W., Williams County.
16. William Herbert Hunt L. C. Anderson No. 1, NW., NE., Sec. 25, T. 157 N., R. 89 W., Mountrail County.
17. Wanete Oil Company M. O. Lee, et al No. 1, NE., NE., Sec. 24, T. 156 N., R. 85 W., Ward County.
18. Quintana Production Company C. W. Linnertz No. 1, SW., SE., Sec. 33, T. 156 N., R. 83 W., Ward County.
19. William Herbert Hunt Wald No. 1, SE., SW., Sec. 23, T. 155 N., R. 81 W., Ward County.
20. Hunt Oil Company Shoemaker No. 1, NE., SW., Sec. 3, T. 155 N., R. 81 W., McHenry County.
21. Lion Oil Company Sebelius No. 1, SE., NW., Sec. 23, T. 161 N., R. 73 W., Rollete County.
22. T. M. Evans Production Corp., A. L. Johnson No. 1, NW., SW., Sec. 23, T. 160 N., R. 70 W., Rolette County.

23. Union Oil Co. of California Saari No. 1, SW., Sec. 35, T. 161 N., R. 68 W., Towner County.
24. Union Oil Co. of California Skjervheim No. 1, NW., NE., Sec. 28, T. 159 N., R. 63 W., Cavalier County.
25. Union Oil Co. of California Lillian Wohletz No. 1, NW., SW., Sec. 32, T. 160 N., R. 60 W. Cavalier County.
26. Union Oil Co. of California-Los Neitos Union Central Life Insurance Co. Ellis No. 1, NW., NE., Sec. 12, T. 161 N., R. 60 W., Cavalier County.
27. Herman Hanson Oil Syndicate H. Billey No. 1, SE., NW., Sec. 11, T. 129 N., R. 63 W., Dickey County.
28. Champlin Refining Co. Elmer Heim No. 1, NE., NW., Sec. 12, T. 133 N., R. 65 W., LaMoure County.
29. S. D. Johnson Company John Rath No. 1, NE., NE., Sec. 30, T. 137 N., R. 67 W., Stutsman County.
30. Herman Hanson Oil Syndicate Mueller No. 2, NE., NE., Sec. 20, T. 140 N., R. 65 W., Stutsman County.
31. (See well No. 12)
32. T. M. Evans Christian Erickson No. 1, NE., NE., Sec. 24, T. 145 N., R. 64 W., Foster County.
33. Pure Oil Company J. M. Carr No. 1, NE., NE., Sec. 15, T. 146 N., R. 66 W., Foster County.
34. Calvert Exploration Co. North Dakota State No. 1, NW., NW., Sec. 16, T. 150 N., R. 67 W., Eddy County.
35. Carter Oil Company Allyn MacDairmid No. 1, NE., NE., Sec. 16, T. 154 N., R. 65 W., Ramsey County.
36. R. H. Rhodes R. R. Gibbens No. 1, SW., SE., Sec. 17, T. 157 N., R. 65 W., Towner County.
37. (See well No. 24)
38. Union Oil Co. of California-Los Neitos U-C-L-I Restad No. 1, SW., NW., Sec. 26, T. 162 N., R. 64 W., Cavalier County.
39. F. H. Rhodes-Langenfeld Murphy No. 1, NW., NE., Sec. 18, T. 163 N., R. 65 W., Towner County.
40. General Atlas Carbon Co. A. Ketterling No. 1, NE., NE., Sec. 15, T. 131 N., R. 73 W., McIntosh County.
41. Roeser-Pendleton J. J. Weber No. 1, SE. Sec. 35, T. 133 N., R. 76 W., Emmons County.
42. Continental Oil Company Paul McCay No. 1, NW., NW., Sec. 12, T. 137 N., R. 76 W., Burleigh County.
43. Hunt Oil Company Emma Klevin No. 1, SW., SW., Sec. 18, T. 140 N., R. 80 W., Burleigh County.
44. (See well No. 5).
45. Samedan Oil Corp. Vaughn Hanson No. 1, NE., Sec. 10, T. 146 N., R. 81 W., McLean County.
49. The California Company Blanche Thompson No. 1, SW., SE., Sec. 28, T. 150 N., R. 80 W., McLean County.

47. Hunt Oil Company Peter Lennertz No. 1, NW., SE., Sec. 17, T. 153 N., R. 77 W., McHenry County.
48. (See well No. 19)
49. The California Company Blanche Thompson No. 1, SW., SE., Sec. 31, T. 160 N., R. 81 W., Bottineau County.
50. Hunt Oil Company Oliver Olson No. 1, SW., NW., Sec. 18, T. 163 N., R. 77 W., Bottineau County.

Previous Work

Previous articles describing sediments in the Williston Basin and in North Dakota have been very general in the treatment of the Greenhorn-Lakota interval. A moderately detailed study was not possible until recently for it was not until the years 1953-1954 that the number of wells drilled became sufficient to supply the information needed to show the correlation of the Greenhorn-Lakota interval that could be done.

A description of sediments equivalent to the formations studied in North Dakota was published by Seager,[4] in his article concerning the Carter, N. P. R. R. well in Fallon County, Montana. Kline[5] discusses the Greenhorn-Lakota formations in her general description of North Dakota stratigraphy. Laird and Towse[6] describe the sediments that occur in North Dakota and present formation nomenclature used by the North Dakota Geological Survey. The North Dakota Geological Society[7] published an electric log correlation of sedimentary rocks in North Dakota and nearby states. The Ground Water Reports of the United States Geological Survey for eastern North Dakota contain descriptions of sands found in the deeper wells. This basal sandstone is generally called the Dakota. Gries[8] describes and illustrates a correlation of the Cretaceous formations in the Williston Basin. The correlation by Gries of the basal sandstones from southeastern South Dakota to the Black Hills region is comparable to the correlation that can be done with the lower Cretaceous sandstones in North Dakota from east to west. During 1954 the North Dakota Geological Society[9] published descriptions of the formations found in the Williston Basin.

Nomenclature

The type area of the Dakota group is located in northeastern

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[4] Seager, O. H. "Test on Cedar Creek Anticline, Southeastern Montana," **Bulletin American Association Petroleum Geologists,** Vol. 26, No. 5, p. 863, 1942.
[5] Kline, V. H.; "Stratigraphy of North Dakota," **Bulletin American Association Petroleum Geologists,** Vol. 26, No. 3, pp. 350-352, 1942.
[6] Laird, W. M., and Towse, D. F.; "Stratigraphy of North Dakota with Reference to Oil Possibilities," **North Dakota Geological Survey Report of Investigations No. 2, Revised 1953,** 1953.
[7] "Correlated Schlumberger Cross Section, North and South Dakota and Eastern Montana," **North Dakota Geological Society,** 1953.
[8] Gries, J. P.; "Cretaceous Rocks of Williston Basin," **Bulletin American Association Petroleum Geologists,** Vol. 38, No. 4, p. 447, 1954.
[9] "Stratigraphy of the Williston Basin," **North Dakota Geological Society,** 1954.

Nebraska. Meek and Hayden[10] took the geographical name from outcrops in the "Hills back of the town of Dakota; also extensively developed in the surrounding country in North County (Nebraska) below the mouth of the Big Sioux River." These sandstones are the basal Cretaceous sediments in this area described by Meek and Hayden. Meek and Hayden[11] defined the Fort Benton (Benton) shales as lying between the Niobrara and Dakota. White[12] proposed the term Colorado Group for the Niobrara and Fort Benton shales. By 1909 Darton and O'Harra[13] had applied names to several formations of the Benton shale. The formations in ascending order are the Graneros (with Mowry member), Greenhorn, and Carlile. The lower Cretaceous sandstone, shale, and sandstone sequence was named the Lakota, Fuson, Dakota, respectively in ascending order. Hancock[14] introduced the term Newcastle for the sandstone member of the Graneros shale. The Belle Fourche and Skull Creek were names applied by Collier[15] to the extreme upper and lower members, respectively, of the Graneros shale. For the Black Hills area Russell[16] proposed the term Fall River be applied to the sandstone previously known as the Dakota formation. Ruby[17] placed the Fall River, Fuson, and Lakota formations in the Inyan Kara Group.

In North Dakota the lack of subsurface control retarded the study of the sediments until recently. Kline[18] divided the Niobrara-Lakota interval into three parts; Niobrara, Benton, and a group consisting of the Dakota, Fuson, and Lakota. Cobban and Reeside[19] divided the Niobrara-Lakota interval into the Niobrara, Benton, and Dakota. The Dakota and other sands of Cobban and Reeside are approximate time equivalents of the Newcastle sandstone and the underlying Skull Creek shale of the northern Black Hills. Laird and Towse[20] use the term Greenhorn and "Muddy Sandstone" for members of the Benton shale that have approximately the same stratigraphic position

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[10] Meek, F. B. and Hayden, F. V.; "Descriptions of New Lower Silurian (primordial), Jurassic, Cretaceous, and Tertiary Fossils, collected in Nebraska Territory, with some remarks on the rocks from which they were obtained," **Proceedings Philadelphia Academy Natural Science,** Vol. 13, pp. 419-420. 1861.
[11] Meek, F. B. and Hayden, F. V.; **Op. Cit. pp. 417.**
[12] White, C. S.; "Report on the Geology of a Portion of Northwestern Colorado," **United States Geological and Geographical Survey Tenth Annual Report,** pp. 21, 22, 30, 1887.
[13] Darton, N. H., and O'Harra, C. C.; "Description of the Belle Fourche Quadrangle, South Dakota," **United States Geological Survey Geological Atlas, Belle Fourche Folio,** p. 4, 1909.
[14] Hancock, E. T.; "The Mule Creek Oil Field Wyoming," **United States Geological Survey Bulletin 716,** p. 39, 1920.
[15] Collier, H. J.; "The Osage Oil Field Weston County, Wyoming," **United States Geological Survey Bulletin 736,** p. 76, 1922.
[16] Russell, W. L.; "Origin of Artesian Pressure," **Economic Geology,** Vol. 23, No. 2, pp. 136-137, 1927.
[17] Ruby, W. W.; "Lithologic Studies of Fine-grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region," **United States Geological Survey Professional Paper 165-A,** pp. 3-5, 1930.
[18] Kline, V. H. **op. cit.** p. 339, 1942.
[19] Cobban, W. A. and Reeside, J. B. Jr., "Correlation of the Cretaceous Formations of the Western Interior of the United States," **Bulletin Geological Society America,** Vol. 63. p. 1044, 1952.
[20] Laird, W. M. and Towse, D. F.; **op. cit.,** 1953.

Table II. Development and Application of Nomenclature used for the Greenhorn-Lakota Interval in North Dakota

<table>
<tr><th>Northern Great Plains 1861 [1]</th><th colspan="2">Northern Great Plains 1878 [2]</th><th colspan="3">Northern Black Hills 1909 [3]</th><th colspan="3">Northeastern Wyoming 1920 [4]</th><th colspan="3">Northeastern Wyoming 1922 [5]</th><th>Black Hills, South Dakota 1927 [6]</th></tr>
<tr><td>Niobrara</td><td rowspan="8">Colorado Group</td><td>Niobrara</td><td colspan="3">Niobrara</td><td rowspan="8">Colorado Group</td><td colspan="2">Niobrara</td><td rowspan="8">Colorado Group</td><td colspan="2">Niobrara</td><td rowspan="8">Not described</td></tr>
<tr><td rowspan="7">Fort Benton</td><td rowspan="7">Fort Benton</td><td rowspan="7">Benton Group</td><td colspan="2">Carlile</td><td colspan="2">Carlile</td><td colspan="2">Carlile</td></tr>
<tr><td colspan="2">Greenhorn</td><td colspan="2">Greenhorn</td><td colspan="2">Greenhorn</td></tr>
<tr><td rowspan="5">Graneros shale</td><td></td><td rowspan="5">Graneros shale</td><td>Dark shale</td><td rowspan="5">Graneros shale</td><td>Belle Fourche mem.</td></tr>
<tr><td rowspan="2">Mowry mem.</td><td rowspan="2">Mowry mem.</td><td>Mowry mem.</td></tr>
<tr><td>Nefsy mem.</td></tr>
<tr><td rowspan="2"></td><td>Newcastle ss. mem.</td><td>Newcastle ss. mem.</td></tr>
<tr><td>Dark shale</td><td>Skull Creek</td></tr>
<tr><td rowspan="3">Dakota</td><td colspan="2" rowspan="3">Dakota</td><td colspan="3">Dakota</td><td colspan="3">Dakota</td><td colspan="3">Dakota</td><td>Fall River</td></tr>
<tr><td colspan="3">Fuson</td><td colspan="3">Fuson</td><td colspan="3">Fuson</td><td>Fuson</td></tr>
<tr><td colspan="3">Lakota</td><td colspan="3">Lakota</td><td colspan="3">Lakota</td><td>Lakota</td></tr>
</table>

1 Meek, F.B., and Hayden, F.V.: 1861
2 White, C.A.: 1878
3 Darton, N.H., and O'Harra, C.C.: 1909
4 Hancock, E.T.: 1920
5 Collier, A.J.: 1922
6 Russell, W.L.: 1927

Table II. (Continued)

<table>
<tr><th colspan="3">Western Black Hills 1930 [7]</th><th>North Dakota 1942 [8]</th><th>North Dakota 1952 [9]</th><th colspan="3">North Dakota 1953 [10]</th><th colspan="2">North Dakota This paper</th></tr>
<tr><td rowspan="7">Colorado Group</td><td colspan="2">Niobrara</td><td>Niobrara</td><td>Niobrara</td><td rowspan="7">Colorado Group</td><td colspan="2">Niobrara</td><td rowspan="4">Colorado</td><td>Niobrara</td></tr>
<tr><td colspan="2">Carlile</td><td rowspan="6">Benton</td><td rowspan="4">Benton</td><td rowspan="6">Benton shale</td><td></td><td>Carlile</td></tr>
<tr><td colspan="2">Greenhorn</td><td>Greenhorn</td><td>Greenhorn</td></tr>
<tr><td rowspan="4">Graneros shale</td><td>Belle Fourche mem.</td><td rowspan="2"></td><td>Belle Fourche</td></tr>
<tr><td>Mowry mem.</td><td rowspan="6">Dakota and other sandstones not clearly distinguished.</td><td rowspan="6">Dakota Group</td><td>Mowry</td></tr>
<tr><td>Newcastle ss. mem.</td><td>"Muddy" ss. mem.</td><td>Newcastle "Muddy" ss.</td></tr>
<tr><td>Skull Creek</td><td></td><td>Skull Creek</td></tr>
<tr><td rowspan="3">Inyan Kara</td><td colspan="2">Fall River*</td><td>Dakota</td><td colspan="2" rowspan="3">Cloverly Dakota</td><td>Dakota</td><td>Fall River</td></tr>
<tr><td colspan="2">Fuson</td><td>Fuson</td><td>Fuson</td><td>Fuson</td></tr>
<tr><td colspan="2">Lakota</td><td>Lakota</td><td>Lakota</td><td>Lakota</td></tr>
</table>

7 Ruby, W.W.: 1930
8 Kline, V.H.: 1942
9 Cobban, W.A., and Reeside, J.B., Jr.: 1952
10 Laird, W.M., and Towse, D.F.: 1953

Table III. Formation Correlations, North Dakota and Immediate Vicinity

Northern and eastern Black Hills* (group)	Northern and eastern Black Hills*	Eastern Montana* (group)	Eastern Montana*	North Dakota (group)	North Dakota	Southern Saskatchewan and southwestern Manitoba
	Greenhorn	Colorado group	Greenhorn	Colorado group	Greenhorn	Second specks
Graneros shale	Belle Fourche	Colorado group; Graneros shale	Belle Fourche	Colorado group	Belle Fourche	shale; Fish scales
Graneros shale	Mowry	Colorado group; Graneros shale	Mowry	Dakota group	Mowry	shale
Graneros shale	Newcastle ss.	Colorado group; Graneros shale	Newcastle	Dakota group	Newcastle	Viking ss.
Graneros shale	Skull Creek	Colorado group; Graneros shale	Skull Creek	Dakota group	Skull Creek	shale
Inyan Kara grp.	Fall River	Inyan Kara grp.	Fall River	Dakota group	Fall River	"Blairmore"
Inyan Kara grp.	Fuson	Inyan Kara grp.	Fuson	Dakota group	Fuson	"Blairmore"
Inyan Kara grp.	Lakota	Inyan Kara grp.	Lakota	Dakota group	Lakota	"Blairmore"

* **Modified after** Cobban, W.A., and Reeside, J.B., Jr.; 1952

as equivalent members to the west and south of North Dakota, and have grouped the Dakota, Fuson, and Lakota into the Cloverly or "Dakota."

The formations in North Dakota, of the interval studied, are in ascending order the Lakota, Fuson, Fall River, Skull Creek, Newcastle ("Muddy"), Mowry, Belle Fourche, and Greenhorn. The Skull Creek, Newcastle, Mowry, and Belle Fourche are terms used for members of the Graneros shale in the northern Black Hills. The Colorado shale is used as a group term that includes the Belle Fourche, Greenhorn, Carlile, and Niobrara formations. The term "Muddy" is used by the petroleum industry in North Dakota, Montana and Wyoming and is a driller's term that originated in Wyoming.[21]

The term Dakota is herein proposed as a group name that includes the following formations; Lakota, Fuson, Fall River, Skull Creek, Newcastle, and Mowry. The use of the term Dakota is controversial. Gries[22] illustrates the applicability of the Dakota as a group term. However, Gries has used the term to designate a separate sandstone which he calls "true Dakota." In North Dakota the equivalent of the "true Dakota" occurs at a depth of 1853 to 2077 feet in the Calvert Exploration Company Bender No. 1, Sec. 19, T. 130 N., R. 69 W., McIntosh County and is identified by the writer as the Newcastle sandstone (see Figure 2). Gries also calls the widespread grit or "detrital zone" that occurs in northeastern South Dakota the Fall River. Bolin and Petsch[23] refer to this "detrital zone" as questionable upper Pennsylvanian. The writer believes it may be possible to correlate the Fall River and Lakota sandstones in southeastern North Dakota with the "detrital zone" in northeastern South Dakota after further study; thus giving impetus to the use of the Dakota as a group term in both North and South Dakota.

STRATIGRAPHY

Lakota Formation

The Lakota formation, named and described by Darton in 1899,[24] is a massive, buff, coarse, cross-bedded sandstone with some intercalated shale and local coal beds. The thickness is 200 to 300 feet. The formation underlies the Fuson shale and overlies the Jurassic Morrison formation. The type locality as given by Darton and

21 Hintz, F. F., Jr.; "The Basin and Greybull Oil and Gas Fields," Wyoming State Geological Bulletin 10. pp. 20-21, 1915.
22 Gries. J. P.; op. cit., p. 447, 1954.
23 Bolin, E. J. and Petsch, B. C.; "Well Logs in South Dakota East of Missouri River," South Dakota Geological Survey Report of Investigations No. 75, p. ii, 1954.
24 Darton, N. H.; "Geology and Water Resources of the Southern half of the Black Hills and Adjoining Regions in Wyoming." United States Geological Survey Annual Report, 21, part 4. p. 526, 1901.

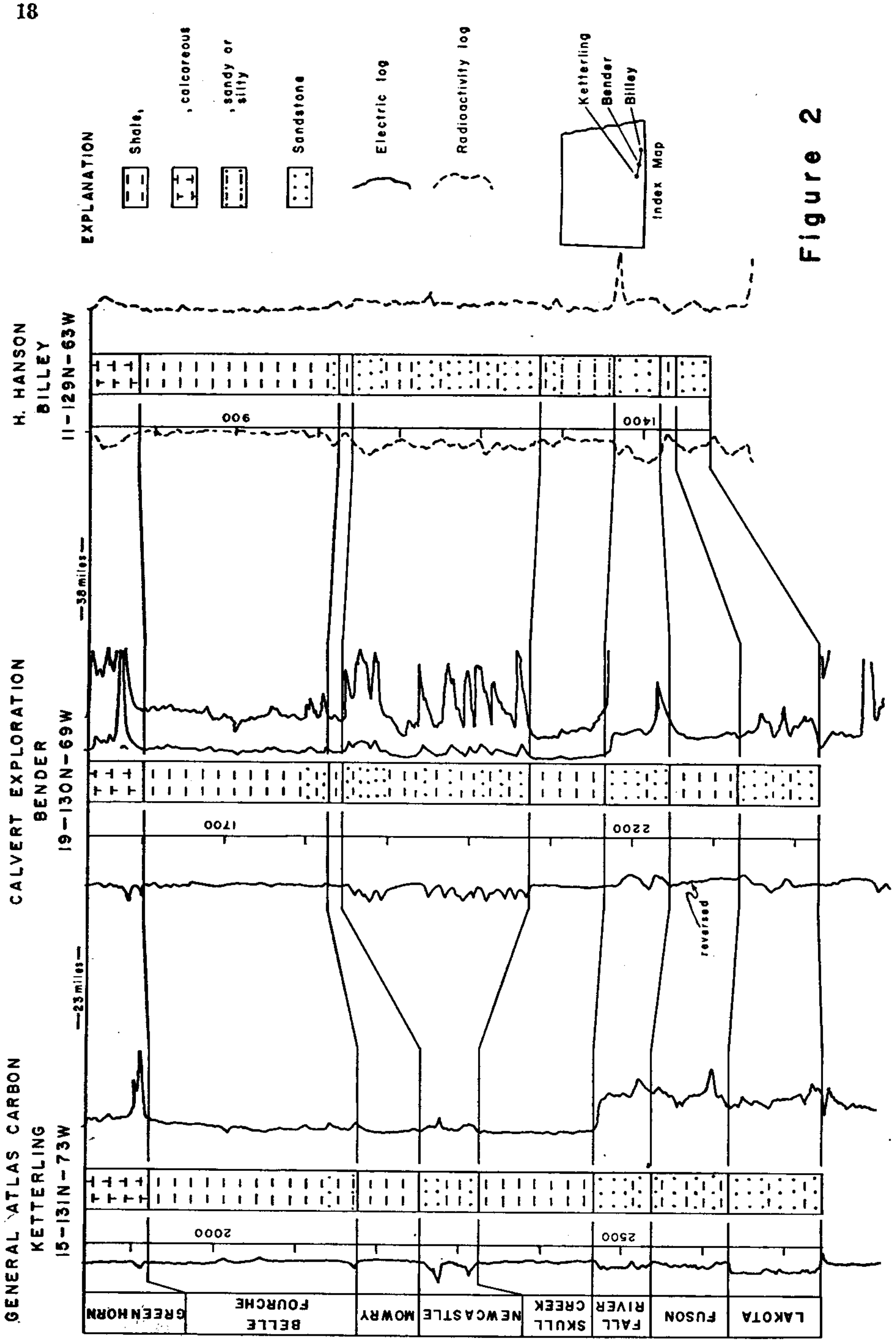


Figure 2

CORRELATION OF THE GREENHORN-LAKOTA INTERVAL, SOUTHEASTERN NORTH DAKOTA

O'Harra[25] is at Lakota Peak, a summit on Hogback Range, four miles northwest of Hermosa, South Dakota.

In North Dakota the subsurface equivalent of the Lakota consists of white and light-gray, medium-to coarse-grained, quartzose sandstone with gray shale streaks. The maximum thickness is generally 110 feet. The formation is absent in the northeastern part of the state.

Following is the Lakota section in the Amerada Petroleum Corporation H. O. Bakken No. 1, well No. 15.

Depth (feet)	Description
5120 - 5130	Sandstone, white, fine-grained, clear, angular quartz grains with dark gray shale and a few light brown concretions (pellets) of iron carbonate and silt.
5130 - 5220	Sandstone, pink, clear, white, angular to subrounded, medium-to coarse-grained, loose quartz grains with dark gray shale. The interval from 5190 to 5220 contains a small amount of pyrite, light brown concretions, and a few fragments of calcareously cemented fine-to medium-grained white quartz sandstone.

The basal sandstone that occurs in the California Company Thompson No. 1, well No. 49 is identified to be the Lakota equivalent. The description follows:

Depth (feet)	Description
2790 - 2800	Samples missing.
2800 - 2860	Sandstone, white, pink, clear, medium-to coarse-grained, angular to subrounded, vitreous. The samples contain small amounts of pyrite, light-brown iron carbonate-siltstone concretions (pellets) and much dark-gray shale.

The basal Lakota sandstone in southeastern North Dakota consists of very coarse sandstone of angular to subrounded white, pink, and clear quartz grains; polished grains of gray chert; and rounded, polished pale-brown dolomitic limestone granules. In areal extent the very coarse sandstone is found in the General Atlas Carbon Corporation Peplinski No. 1, well No. 12, the Pollard and Davis Gregory No. 1, well No. 14, and in the Herman Hanson Oil Syndicate Billey No. 1, well No. 27. The thickest section of this very coarse sandstone is found in the Billey well. The very coarse sandstone is strongly

[25] Darton, N. H. and O'Harra; op. cit., p. 4., 1909.

suggestive of a nearby source area to the east and south. In other areas of the state the sandstone consists of quartz grains, medium-to coarse-grained, and subangular to subrounded. Other source areas were at some distance to the southwest, east, and northeast. Another characteristic of the Lakota sandstone is the apparent general vertical sorting of the sand grains in any specific locale. Generally this sorting is from very coarse-grained sandstone at the base to coarse-or medium-grained near the top of the formation. The Lakota sandstone also contains small amounts of shale that are the result of minor fluctuations of the depositing agent.

In summary, the sandstone at the base of the Dakota group is identified as the Lakota. With the exception of the northeastern part of the state, the Lakota forms the basal transgressive sandstone facies. Where isolated highs on the Jurassic surface occur, the basal sandstone may be younger than the basal sandstone of the surrounding area. As an example, this may be true in the vicinity of the Continental Oil Company Dronen No. 1, well No. 8. The Lakota in North Dakota overlies sediments ranging in age from the Jurassic to the Pre-Cambrian in southeastern North Dakota. The thickness and sandstone content of the Lakota varies, but if correlated as the lower sandstone of the tripartite division, Fall River, Fuson, and Lakota, the formation is almost continuous throughout the state.

Fuson Formation

The Fuson formation was named by Darton[26] from exposures in Fuson Canyon on the eastern side of the Black Hills. The Fuson in the type area is described by Darton as consisting of very fine-grained sandstone and massive shales and clays that are white, gray, buff, purple and maroon. In the subsurface of North Dakota the Fuson equivalent is a medium-dark-gray to gray-black, flaky, soft shale with some development of a very fine-grained quartzose sandstone. The Fuson shale forms the interval between the basal Lower Cretaceous Lakota sandstone and the overlying Fall River sandstone.

The following is a section of Fuson formation in the Amerada Petroleum Corporation Henry O. Bakken No. 1, well No. 15.

Depth (feet)	Description
5030 - 5040	Shale, dark-gray, micaceous, flaky with very fine-grained, white, angular, quartz sandstone.
5040 - 5080	Shale, dark-gray, soft, micaceous, flaky. The sample from 5060 - 5070 contains a small amount of fine, greenish-gray, glauconitic, quartz sandstone.
5080 - 5115	Shale, dark-gray, medium-gray, soft, flaky and lumpy. The interval from 5090 - 5110 contains a small amount of very fine-to fine-grained quartzose sandstone with some glauconite. A few light-brown iron carbonate-siltstone concretions of medium grain size are present in the interval 5110 - 5115.

[26] Darton, N. H.; **op. cit.**, p. 526, 1901.

Following is the sample description of the Fuson formation in the General Atlas Carbon Corporation Peplinski No. 1, well No. 12.

Depth (feet)	Description
1570 - 1575	Shale, medium-gray, silty, soft, lumpy.
1575 - 1616	Sandstone, white, very fine-grained, friable, calcareous cement, quartz sandstone. The samples also contain gray shale, medium-to coarse-grained angular, white and clear quartz grains, and a few light brown iron carbonate-siltstone concretions (pellets).
1616 - 1630	Shale, silty, medium-gray, soft, lumpy.
1630 - 1652	Sandstone, white, fine-to medium-grained, calcareous cement, friable, with loose grains of clear, white, angular to subrounded quartz. Iron carbonate-siltstone concretions of medium texture are present in small amounts.
1652 - 1660	Shale, medium-gray, silty, soft, massive, lumpy.

The above description of the Fuson shale does show the development of a sandstone facies in southeastern North Dakota with respect to the shales further west.

The Fuson shale was apparently never deposited in the northeastern part of the state, but this shale equivalent is up to eighty feet thick in western North Dakota. No fossils were found by the writer, but the iron carbonate-siltstone concretions (pellets) are found in the majority of the well samples for this interval. In South Dakota the pellet horizon at the top of the Fuson can be traced from the outcrop at Sergeant's Bluff, south of Sioux City, Iowa, in the subsurface all the way westward to the Black Hills.[27] In North Dakota the pellets or concretions also occur in the shales of the overlying Fall River and are not used as a correlation marker in this study.

The Fuson is very erratic in thickness, and in shale and sandstone content. In the deeper portion of the basin the Fuson shale thickness varies with the amount of reworking and sand supply of the overlying and underlying sandstones. Near the edges of the

[27] Baker, C. L.; "Additional Well Borings in South Dakota," **South Dakota State Geological Survey Report of Investigations No. 61, p. 2, 1948.**

basin the sandstone content increases. For example, in the southeastern part of the state the formation is a thin, sandy shale break between two major formations. In the extreme southeastern part of North Dakota the shale may be replaced by a sandstone facies, perhaps the Lakota.

Fall River Formation

The Fall River formation as described by Russell[28] consists of seventy-five feet of sandstone and interbedded shale underlying the Graneros shale and overlying the Fuson shale. The type locality is at Evan's quarry, on the Fall River below Hot Springs, Fall River County, South Dakota. In the subsurface of North Dakota, the Fall River formation consists of interbedded light-gray, fine-to coarse-grained, quartzose sandstone and gray, sandy, silty, soft, massive, lumpy shale.

Following is a sample description of the Fall River in the Amerada Petroleum Corporation Henry O. Bakken No. 1, well No. 15.

Depth (feet)	Description
4815 - 4950	Shale, medium-gray, dark-gray, flaky to massive and lumpy, soft, with light-gray, friable to well cemented calcareous, fine-grained quartzose sandstone. The samples from 4830 - 4840 and 4920 - 4930 contain a trace of glauconite.
4950 - 4990	Sandstone, white, fine-grained, friable, quartzose, calcareous and clay cement. With dark-gray shale. The interval from 4980 - 4990 contains a few glauconite grains and fine-to medium-grained light-brown iron carbonate-siltstone concretions (pellets).
4990 - 5030	Sandstone, white, light-yellowish-brown, fine-to medium-grained, angular to subround, loose quartz grains. Much gray shale.

In the H. O. Bakken well the Fall River formation has a tripartite division. The basal sandstone of this tripartite division is overlain by a silty shale break. The upper part consists of a silty and shaly very fine-grained sandstone that grades upward into the overlying Skull Creek shale. This tripartite division of the Fall River also occurs in the Bottineau-Benson County area, and to the south in northern Billings County. The occurrence of this three fold division is approximately limited on the south by the 300 foot isopach contour shown on the isopach map of the Cloverly equivalent (figure 6). In contrast to the tripartite development of the H. O. Bakken well the Fall River formation in the Continental Oil Company Dronen No. 1, well No. 8 consists of interbedded sandy and shaly silt and silty, shaly, fine-to medium-grained sandstone.

[28] Russell, W. L.; op. cit., pp. 136-137, 1928.

The Fall River formation can be recognized throughout the greater part of North Dakota. In the northeastern part of the state the formation is the basal marine Cretaceous sandstone. Also in this the northeastern area, in an arc extending from Benson to eastern Bottineau Counties, the Fall River is the thickest sandstone unit of the Dakota group, and appears to be deltaic and to transgress upward in the stratigraphic column to form the sandstone facies of the overlying Skull Creek shale.

In deeper parts of the basin the transitional contact with the overlying Skull Creek shale is picked on the electrical logs by means of the resistivity increase that is due to the increasing sandstone content downward. In the southeastern part of the state the Fall River apparently forms, in part, the sandstone facies of the overlying Skull Creek shale. Here the overlying shale generally thins and the Fall River sandstone generally becomes thicker.

Following is a sample description of the Fall River formation in the General Atlas Carbon Corporation Peplinski No. 1, well No. 12.

Depth (feet)	Description
1472 - 1570	Sandstone, clear, white, pink, vitreous luster, medium-to coarse-grained, angular to subrounded, loose quartz grains with a small amount of fine-grained, friable, light-gray, calcareous sandstone fragments, and well-rounded, medium, frosted quartz grains. The samples contain medium-to coarse-grained light-brown and light-brown-red iron carbonate-siltstone concretions (pellets).

There is horizontal sorting, to some extent, of the Fall River sandstone. In the deeper parts of the basin the sandstone is chiefly fine-grained, while medium grain size is predominate toward the shallower edges. Another feature of the Fall River sandstone is the general vertical gradation in the southeastern and eastern parts of the state. In this area the Fall River grades from a medium-or coarse-grained sandstone at the base to a fine-grained sandstone at the top of the formation. In the northern part of the state the vertical gradation was not recognized.

The directions of the source areas for the Fall River sediments were generally to the northeast, east, southeast, and southwest of the state. The source area near the southeastern part of the state is indicated by occurrence of very coarse-grained quartz sandstone that grades laterally west-ward into a fine-to medium-grained quartz sandstone. From the other source areas to the southwest and east the lateral gradation is medium-to fine-grained sandstone in the direction of north and west. The quartz is finer grained because of farther distance to the source. In the northern part of the state the lateral gradation also exists. From the northeastern areas of predominantly sandstone accumulation, the sandstones grade south and west into fine sandstones and silts.

The thickness of the Fall River formation varies. Locally the formation is 210 feet thick in the northwestern part of the state, but generally the thickness ranges from 30 to 100 feet. In the northeastern part of the state where the Fall River is the basal sandstone the thickness will vary from 20 feet to a local maximum of 80 feet.

Skull Creek Formation

The Skull Creek was named by Collier[29] as a member of the Graneros shale from exposures along Skull Creek southeast of Osage, Weston County, Wyoming. The Skull Creek was described by Collier as consisting mainly of dark-bluish-gray shale, about 200 feet thick, containing a few calcareous concretions and some siliceous shale near the base. In the subsurface of North Dakota the Skull Creek formation is a soft, dark-to medium-gray shale, sandy at the base, and transitional with the underlying Fall River sandstone.

Following is a sample description of the Skull Creek shale in Amerada Petroleum Corporation Henry O. Bakken No. 1, well No. 15.

Depth (feet)	Description
4620 - 4816	Shale, medium-dark-gray, soft, lumpy to massive, silty, micaceous. The samples contain traces of fine-grained, friable, calcareous, light gray, slightly glauconitic, quartz sandstone. Traces of white bentonite and small pellets are present at the 4680 - 4720 interval.

The Skull Creek interval thins from west to east, attaining a thickness of 140 feet in the western part of the state and thinning to less than 40 feet on the eastern edge of the basin.

Following is a sample description of Skull Creek shale in the Stanolind Oil and Gas Company Brusich No. 1, well No. 2.

Depth (feet)	Description
5050 - 5100	Shale, medium-gray to dark-gray, micaceous, soft, flaky to lumpy, with traces of pyrite and medium-gray silt.
5100 - 5210	Shale, dark-gray, fissile to flaky, micaceous. The interval from 5170 - 5180 contains a few grains of glauconite.

[29] Collier, A. J., op. cit., p. 76. 1922.

The Skull Creek shale is partially replaced by a sandstone facies which is identified as the underlying Fall River sandstone. Evidence for the thinning of the shale and the increase in thickness of the Fall Rver sandstone can be seen by referring to the combination log of the General Atlas Carbon Corporation Peplinski No. 1, well No. 12, on the cross-section, plates I and II. Beyond partial replacement of the Skull Creek by its sandstone facies, the Fall River, there is evidence of two other factors causing thinning of the Skull Creek shale on the eastern edges of the basin.

The second factor is the thinning of the total Greenhorn-Lakota interval to the east. The third factor is the thickening of the overlying Newcastle sandstone. Apparently the thinning of the Skull Creek shale is partially due to erosion preceding deposition of the Newcastle sandstone. For the proof of this latter statement see the cross-section of southeastern North Dakota, (figure 2).

Newcastle Formation

The Newcastle was described by Hancock[30] as a sandstone member of the Graneros consisting of a reddish to light-yellow sandstone associated with black carbonaceous shale. The member was named for the conspicuous development at Newcastle, Wyoming. In the northern Black Hills the Newcastle sandstone overlies the Skull Creek member and underlies the Mowry shale of the Graneros.

In North Dakota the subsurface Newcastle or "Muddy" is a shaly and silty, very fine-grained, light-gray, quartzose sandstone and a gray, soft, lumpy to flaky, silty, shale interval. The sandstones have developed independently in three separate areas of the state. The areas of development are in the northwestern, southwestern, and eastern-southeastern parts of the state. The sandstones have the same stratigraphic position in each area and there is no reason for applying different names to the separated sandstones.

Following is a sample description of the Newcastle formation in Stanolind Oil and Gas Company—Deep Rock Company Brusich No. 1, well No. 2.

Depth (feet)	Description
4946 - 4970	Sandstone, friable, slightly calcareous, and loose grains of white, fine-to medium-grained angular quartz, with medium-gray silt.
4970 - 4990	Shale, dark-gray, soft, fissle, micaceous, with medium-gray silt and loose grains of fine-grained white quartz.
4990 - 5042	Sandstone, fine-grained, light-gray, quartzose, silty, slightly cemented by calcareous material

[30] Hancock, E. T.; op. cit., p. 39, 1920.

Depth (feet)	Description
	in part. Loose grains of fine-to medium-grained, white, angular quartz.

In the central part of the basin the Newcastle formation is picked as a silty, shale zone that separates the underlying Skull Creek from the thin overlying Mowry shale. The separation is done by means of the electric log resistivity curves and rarely can be picked up by the samples. The "silt zone" is apparent on the electric logs of all wells lacking the sandstone, suggesting relative distance from the source of sediments.

Following is a sample description of the Newcastle formation in the Stanolind Oil and Gas Company McLean No. 1, well No. 46.

Depth (feet)	Description
3186 - 3260	Shale, medium-dark-gray, soft, lumpy and spongy, flaky, with light-gray silt. Traces of white bentonite and pyrite. Also traces of light-gray, very fine-grained, calcareous, friable, quartzose sandstone fragments.

The Newcastle sandstone had source areas near but beyond the northwest, southwest, and eastern parts of the state. The most extensive deposition of the sandstone took place in the southeastern and southwestern parts of North Dakota.

The sandstone and shale sequence found in the Calvert Exploration Company Bender No. 1, Sec. 19, T. 130 N., R. 69 W., McIntosh County, at the electric log depth of 1947 to 2072 feet is identified as Newcastle sandstone. This sandstone also occurs in the Herman Hanson Oil Syndicate Billey No. 1, well No. 27. The sandstone content increases both east and south from the Bender well. Also, this sandstone interval consists of gray shales and fine-to medium-grained quartzose sandstone in the Bender well to fine-and coarse-grained quartzose sandstone in the Billey well, suggesting a source area to the southeast.

Mowry Formation

The Mowry shale was named by Darton[31] for Mowrie (spelling by Darton) Creek, northwest of Buffalo, Johnson County, Wyoming. Ruby[32] described the Mowry shale as a siliceous claystone that is progressively harder toward the top and weathers to silver-gray chips. The Mowry shale in the subsurface of North Dakota consists of medium-gray to dark-gray, flaky, soft, spongy, bentonitic shale

[31] Darton, N. H.; "Comparison of the Stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range," **Bulletin Geological Society America**, Vol. 15, p. 400, 1904.

[32] Ruby, W. W.; "Origin of the Siliceous Mowry Shale of the Black Hills Region," **United States Geological Survey Professional Paper 154-D**, pp. 153-170, 1929.

containing light-blue-gray and white bentonite. The shale wedges out to the east in North Dakota.

Following is a sample description of the Mowry shale in the Stanolind Oil and Gas Company McLean No. 1, well No. 46.

Depth (feet)	Description
3136 - 3186	Shale, medium-gray to medium-dark-gray, flaky to lumpy, spongy to silty.

Thicker sections of the Mowry shale are present in the Carter Oil Company N.P.R.R. No. 1, well No. 1, and in the Stanolind Oil and Gas Company-Deep Rock Brusich No. 1, well No. 2. In the Brusich well the silt content increases relative to that of the N.P.R.R. well.

Following is a sample description of the Mowry shale in the Carter Oil Company N.P.R.R. No. 1, well No. 1, Sec. 19, T. 4 N., R. 62 E., Fallon County, Montana.

Depth (feet)	Description
3300 - 3486	Shale, medium-dark-gray to gray-black, fissle, micaceous, with traces of white bentonite.

The Mowry shale and the Newcastle formation have a transitional contact where the sandstones of the Newcastle are absent. Arbitrary separation from the underlying Newcastle in the center and northeastern edge of the basin is made on the basis of a "pick" on the electric log which shows a slight increase in the electrical resistivity of the Newcastle. This increase is due to a sandy, silt bed.

Belle Fourche Formation

The Belle Fourche shale was described by Collier[33] as the top member of the Graneros shale and consists of a dark-gray shale 560 feet thick, with calcareous concretions near the top zone, a Mowry-like zone 100 feet below the top, many ironstone concretions in the lower part, and a thick bed of bentonite near the base. The member was named for exposures along the Belle Fourche River and in the neighboring area near Wind Creek, Crook County, Wyoming. In the subsurface of North Dakota the Belle Fourche consists of soft, lumpy to massive, spongy and bentonitic, medium-dark-gray to dark-gray, micaceous shales with generally white, light-blue-gray to light-gray bentonite.

Following is a sample description of the Belle Fourche formation in the Stanolind Oil and Gas Company-Deep Rock Brusich No. 1, well No. 2.

Depth (feet)	Description
4490 - 4590	Shale, medium-dark-gray, micaceous, soft,

[33] Collier, A. J.; **op. cit.**, p. 76, 1922.

	spongy, to flaky, with medium-blue-gray, white, light-gray bentonites.
4590 - 4640	Shale, medium-dark-gray, olive-gray, micaceous, soft, with small amounts of pyrite, and light-gray, white, and medium-dark-blue bentonites.
4640 - 4800	Shale, dark-gray, flaky, soft, and micaceous, with a small amount of medium gray silt. The interval from 4770 - 4800 contains a small amount of white and light-gray-bluish bentonites.
4800 - 4830	Shale, dark-gray as above, with slightly calcareous bentonitic medium-gray silt.

The Belle Fourche shale is 350 feet thick in the western part of the state and 100 feet thick on the eastern edge of the basin. The silt or sand and calcareous content of the shale increases toward the eastern edge of the basin.

Following is a sample description of the Belle Fourche shale in the Stanolind Oil and Gas Company McLean County No. 1, well No. 46.

Depth (feet)	Description
2920 - 3000	Shale, medium-dark-gray, soft micaceous, flaky, lumpy, massive and spongy, traces of white bentonite.
3000 - 3136	Shale, medium-dark-gray as above. Traces of white bentonite, pyrite, and light-olive-gray silt.

The contact of the Belle Fourche and the underlying Mowry shale is picked generally by means of the gamma ray and electrical resistivity logs. The "pick" can sometimes be made on the basis of lithology if the person examining the samples is familiar with the section and the samples are carefully collected by the drilling contractor. The base of the Belle Fourche consists of a bentonitic, silty, shale zone that causes an increase in radioactivity. The separation of the two formations is then the most apparent on the gamma ray log. Also, the electrical resistivity increase is apparent on the amplified normal curve. The bentonitic, silty, shale zone can be traced throughout the state.

Greenhorn Formation

The Greenhorn formation was named by Gilbert[34] for Greenhorn Station, and Greenhorn Creek, fourteen miles south of Pueblo, Colorado. Darton[35] had applied the name to similar strata in the northern Black Hills. In the northern Black Hills the Greenhorn formation is largely a light-gray, calcareous mudstone with interbedded marl.[36]

[34] Gilbert, G. K.; "The Underground Water of the Arkansas Valley in Eastern Colorado." **United States Geological Survey Annual Report 17, Part 2, p. 564,** 1896.

In the subsurface of North Dakota the Greenhorn formation consists of dark-gray, calcareous, soft shale with thin beds of very shaly limestone. The samples generally contain a few fragments of Inoceramus shells, calcite prisms, and Globigerina and other genera of Foraminifera. The micro-fossils occur near the base of the formation in the majority of the wells studied. Where the micro-fossils occur the shale is generally broken or disaggregated into very small fragments of rock.

Following is a sample description of the Greenhorn in the Stanolind Oil and Gas Company McLean County No. 1, well No. 46.

Depth (feet)	Description
2780 - 2850	Shale, medium-gray to medium-dark-gray, flaky to massive, calcareous, with pyrite, calcite prisms, and "white specks" in the shale.
2850 - 2920	Shale, medium-dark-gray, flaky, disaggregated to massive. The samples contain calcite prisms, white and light-blue-gray bentonite, traces of light-gray shaly limestone, and "white specks" in the shale.

The Greenhorn formation is relatively uniform in thickness, ranging from 120 to 150 feet in North Dakota. The lithology of the sediments is generally uniform. The areal extent of the Greenhorn is far beyond the state boundaries, and is recognized in South Dakota, eastern Wyoming, eastern Montana, Kansas, Nebraska, and Colorado.

CONCLUSIONS

Map Evaluation

The paleogeological map of the pre-Cretaceous surface (figure 3) shows the areas where rocks of the Precambrian, Ordovician, Devonian-Silurian, Mississippian, and Jurassic ages immediately underlie the Cretaceous sediments. The most significant area shown on this map is that of southeastern North Dakota. Here the greatest number of rocks of different ages have been exposed prior to Cretaceous deposition and may indicate that the area was subject to more erosion (after western tilting) than areas further north.

[35] Darton, N. H.; "Geology and Water Resources of the Northern Portion of the Black Hills and Adjoining Regions in South Dakota and Wyoming." **United States Geological Survey Professional Paper 65**, p. 54, 1909.

[36] Cobban, W. A.; "Colorado Shale of Central and Northwestern Montana and Equivalent Rocks of the Black Hills," **Bulletin American Association Petroleum Geologists.** Vol. 35, p. 2183, 1951.

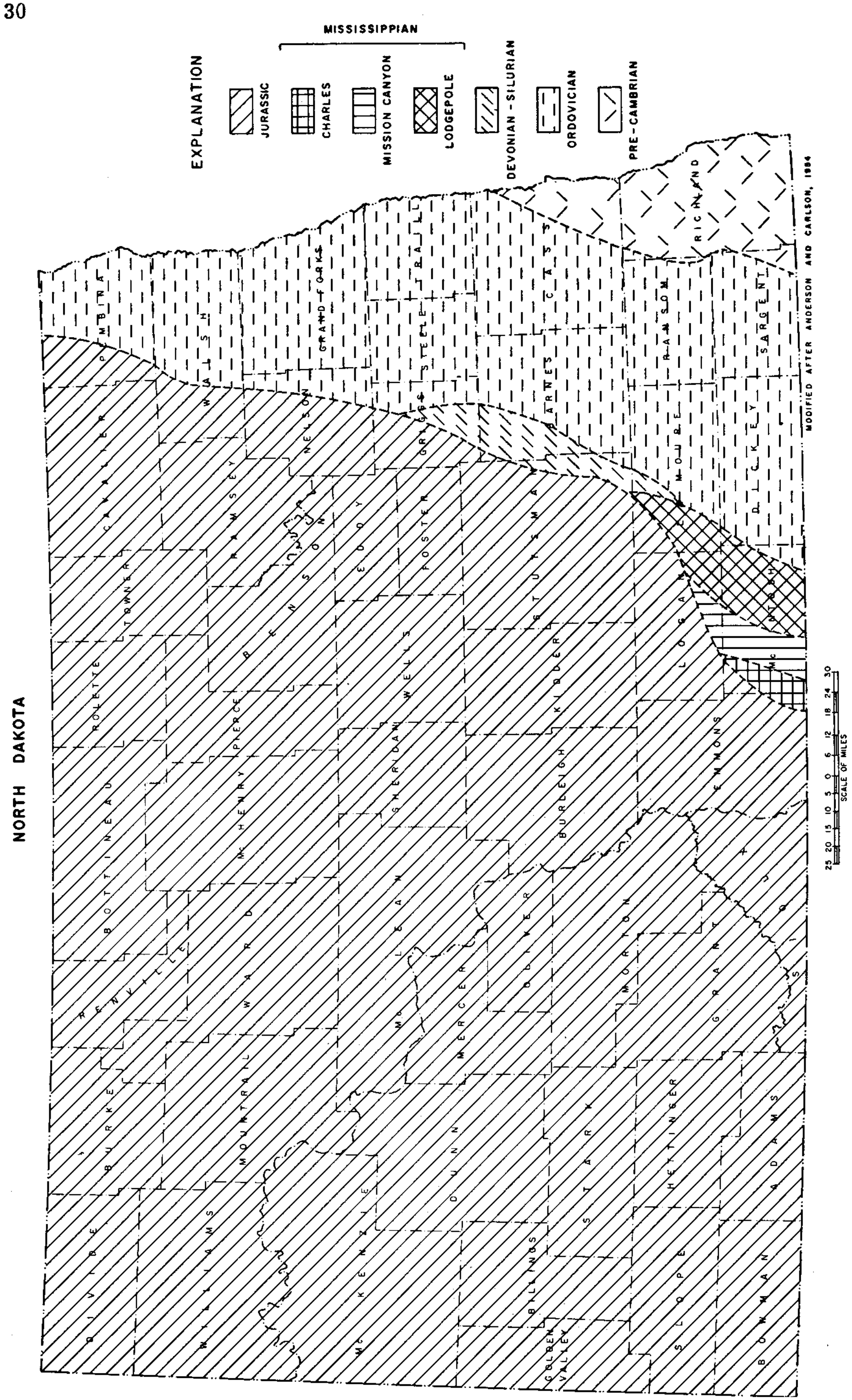


Figure 3

PRE-CRETACEOUS PALEOGEOLOGICAL MAP

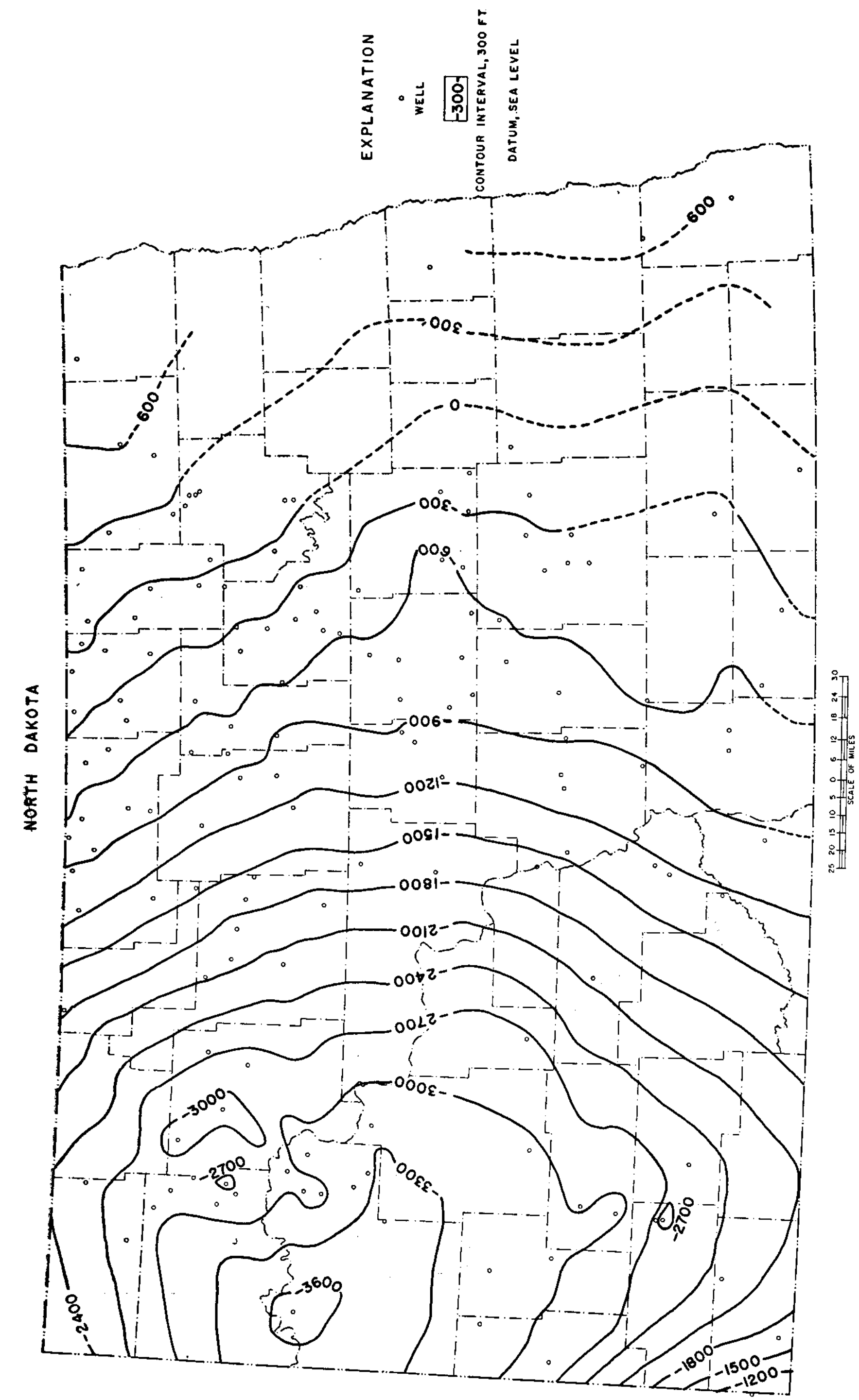


Figure 4

STRUCTURE MAP ON THE PRE-CRETACEOUS ROCKS

The structure map of the pre-Cretaceous rocks (figure 4) shows the present elevations, corrected to sea-level datum, of this rock surface. Structural anomalies that show on this pre-Cretaceous map are the small portion of the Cedar Creek anticline in southwestern North Dakota, and the Nesson anticline in northwestern North Dakota. The deeper part of the Williston Basin in northwestern North Dakota is also shown on this map. In the area of Wells, Foster, and Eddy Counties the -600 foot contour shows a sharp projection toward the east. This projection suggests a low area that separates two broad structural features in eastern North Dakota that probably existed during the deposition of the lower Cretaceous sandstones and shales. The isopach and sandstone percentage maps, and the sandstone thickness of the Greenhorn-Lakota interval show a greater thinning and a lower sandstone content of the formations to the north of this projection. To the south of this -600 foot contour projection is an area of relatively thicker formations of higher sandstone content, denoting an active source area.

The structure on the Greenhorn formation (figure 5) does not suggest separate structural elements in eastern North Dakota. The Greenhorn structure map does show that the deposition of the Cretaceous sandstone and shales have obscured the structure on the pre-Cretaceous rock surface (figure 4) in eastern North Dakota, and it also shows modifications of the Nesson and Cedar Creek anticlines. Also shown on the Greenhorn structure map is the deeper part of the Williston Basin and the regional shape of the basin in eastern North Dakota.

The isopach and sandstone percentage map of the Cloverly equivalent (figure 6) shows that the greater thickness of the Fall River, Fuson, and Lakota formations is in northwestern North Dakota. The areas of relatively thinner sedimentary acumulation were over the Cedar Creek anticline and the northeastern part of the state where a probable high area or platform existed at the time. The sandstone percentage of the Cloverly equivalent shows the increasing sandstone content over the Cedar Creek anticline. This increase is no doubt due to reworking of the sediments over pre-existing structure. Off the southwestern edge of the platform in northeastern North Dakota the increasing sandstone content is probably due to a longer period of reworking of the sediments during deposition, for source areas of quartzose sand would appear to be at some distance to the northeast.

The isopach and sandstone percentage map of the Lower Cretaceous (figure 7) includes the Lakota, Fuson, Fall River, Skull Creek, Newcastle and Mowry formations. The time designation (Lower Cretaceous) is that of Cobban and Reeside.[37] The area of greater Cretaceous sedimentary accumulation had spread out from the north-

[37] Cobban, W. A. and Reeside, J. B. Jr.; op. cit. p. 1044, 1952.

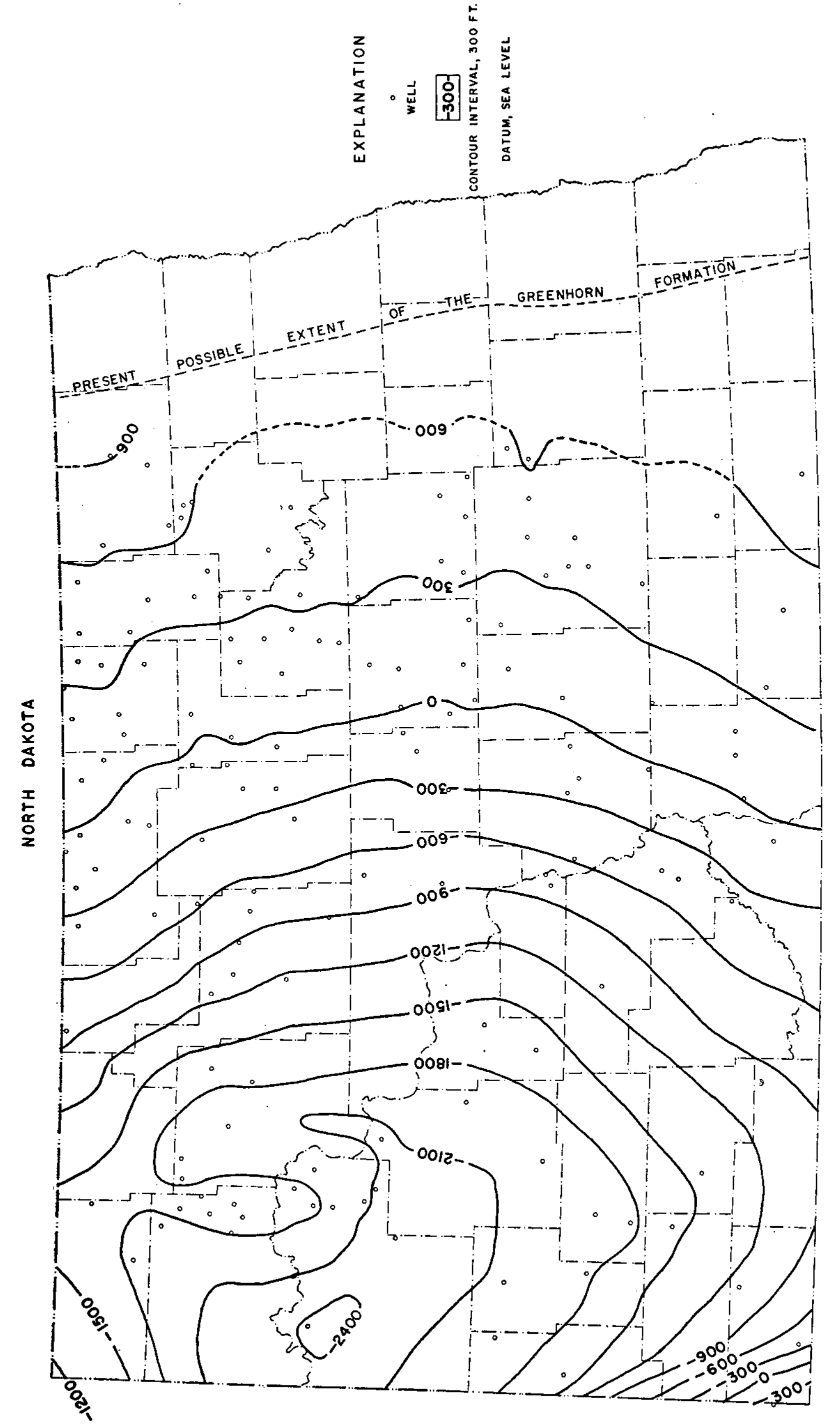


Figure 5

STRUCTURE MAP ON THE GREENHORN FORMATION

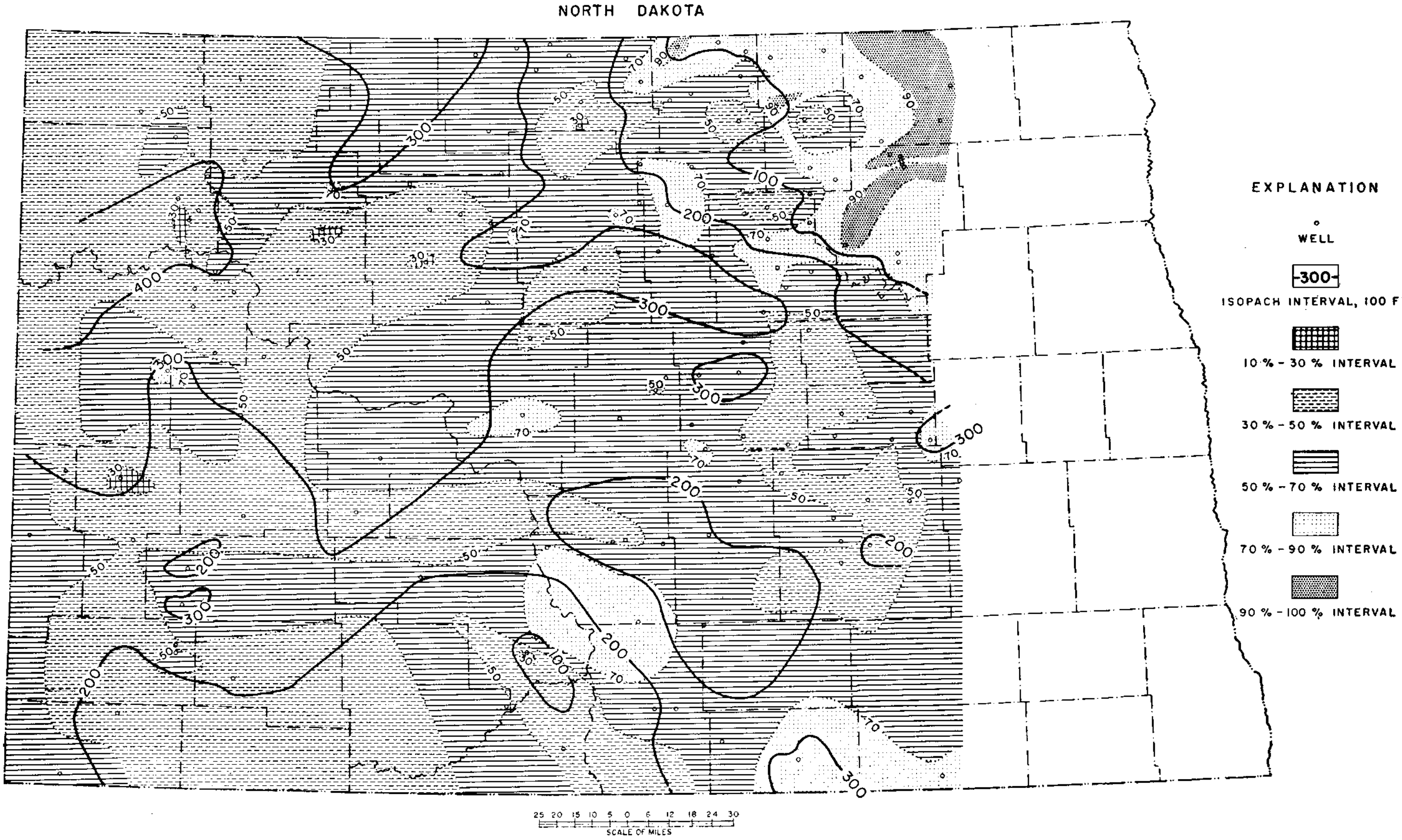


Figure 6

ISOPACH AND SANDSTONE PERCENTAGE MAP OF THE CLOVERLY EQUIVALENT

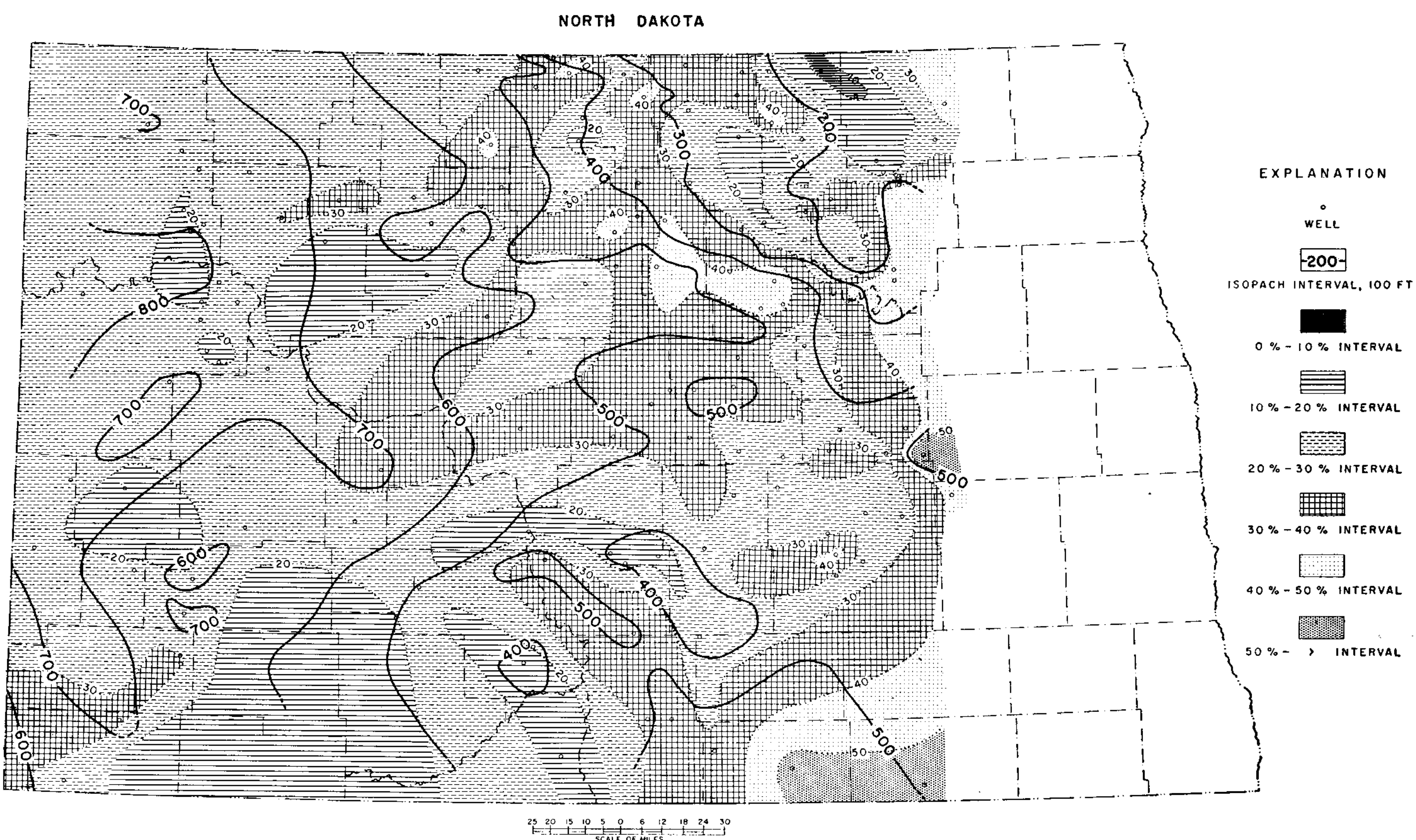


Figure 7

ISOPACH AND SANDSTONE PERCENTAGE MAP OF THE LOWER CRETACEOUS

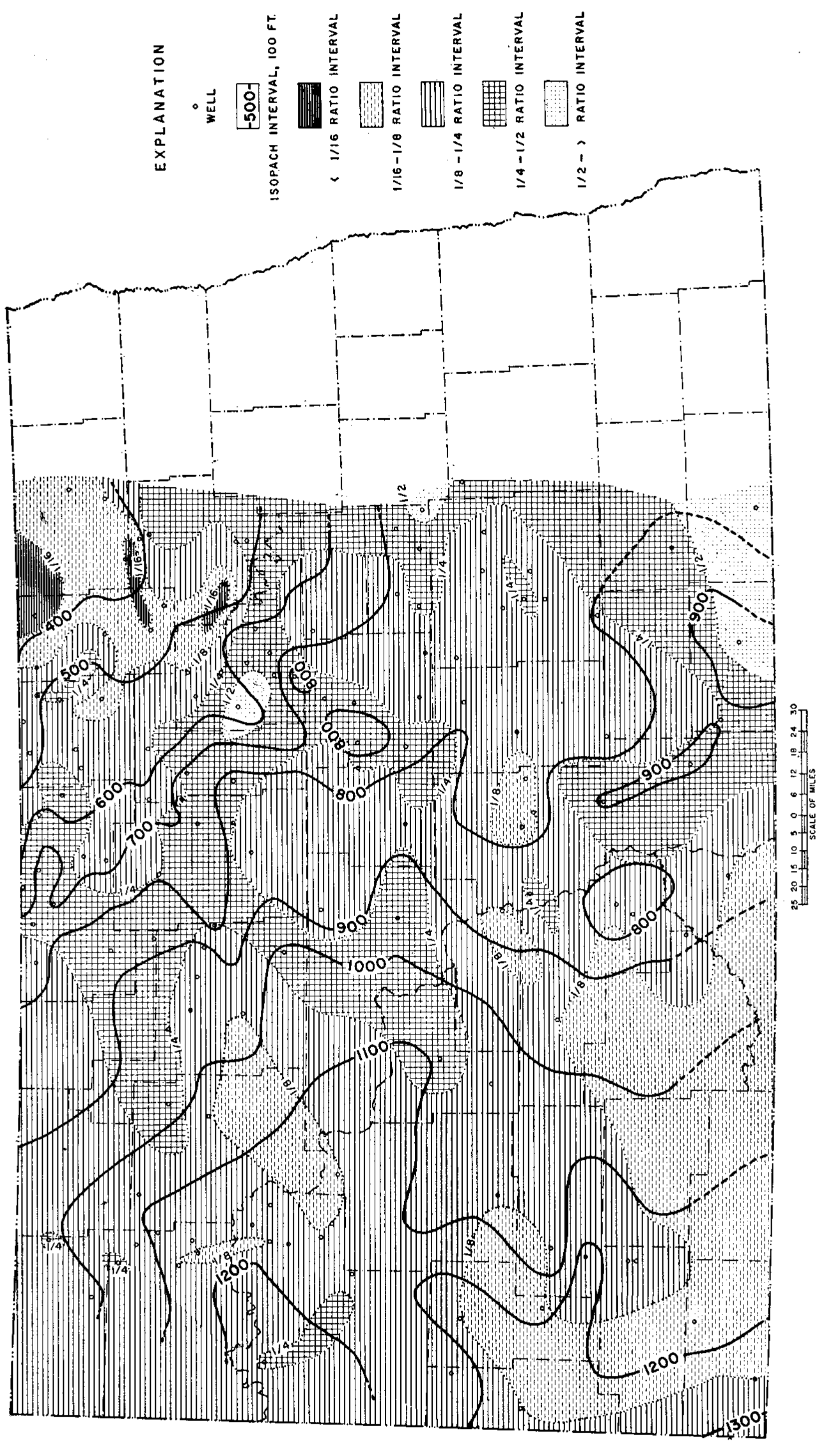


Figure 8

ISOPACH AND SAND-SHALE RATIO MAP OF THE GREENHORN TO JURASSIC INTERVAL

western part of the state. The influence of the platform in northeastern North Dakota is shown on the Lower Cretaceous map by the thinning of the formations. In all, the pattern of sedimentary accumulation was much the same as that during deposition of the Cloverly equivalent.

The isopach and sand-shale ratio map of the Greenhorn to Jurassic interval (figure 8) shows that the accumulation of sediments takes on a broader regional trend that obscures the accumulation of the Lower Cretaceous sediments. The areas of greater accumulation of sandstone shown by the sand-shale ratios are in much the same positions as that shown by the sandstone percentages of the Lower Cretaceous isopach and sandstone percentage map (figure 7). The sameness of sandstone concentration was due to little sandstone deposition in North Dakota when the Belle Fourche and Greenhorn shales were deposited. A feature that does not show on the maps discussed previously is the east-west structure in northern Bottineau County. This structure is reflected by the thinning of the Belle Fourche and Greenhorn shales in northern Bottineau County.

The total sandstone thickness map of the Newcastle formation (figure 9) shows the distribution of discontinuous sandstones. The sandstones of the Newcastle occur in the northwestern, southwestern, and eastern-southeastern parts of the state. The Newcastle sandstones probably do not occur in the form as shown by the thickness contours, but if closer control were available the sandstones would possibly show as very irregular channel deposits. The thickness of the sandstone in southeastern North Dakota suggests a deltaic type of deposition in that area. Also the increase of the grain size in a southeastern direction suggests a source area toward the southeast (see Newcastle formation). In the southwestern part of the state the thickness of the Newcastle sandstone increases very locally, and channel deposition off a structural high is suggested.

The total sandstone thickness map of the Greenhorn to Jurassic interval (figure 10) shows the combined thickness of the Newcastle, Fall River, and Lakota sandstones plus a small amount of sandstone that occurs at the base of the Belle Fourche formation in eastern North Dakota. The pattern of accumulation shows that in the northeastern part of the state the sandstones are much thinner. Immediately south and west of this area the thickness increases. The trend of this greater sandstone accumulation extends from Benson to Bottineau Counties and then southwestward to abut against the eastern flank of the Nesson anticline. This trend of accumulation includes the sandstones of the Fall River and Lakota formations, but excludes the Newcastle. The Newcastle does not occur as a sandstone in this trend being discussed. The accumulation of thicker sandstones in this trend is interpreted as a deposit of the deltaic and neritic environments that existed during deposition of all but the very last phases of Fall River time. In the southwestern part of the state the in-

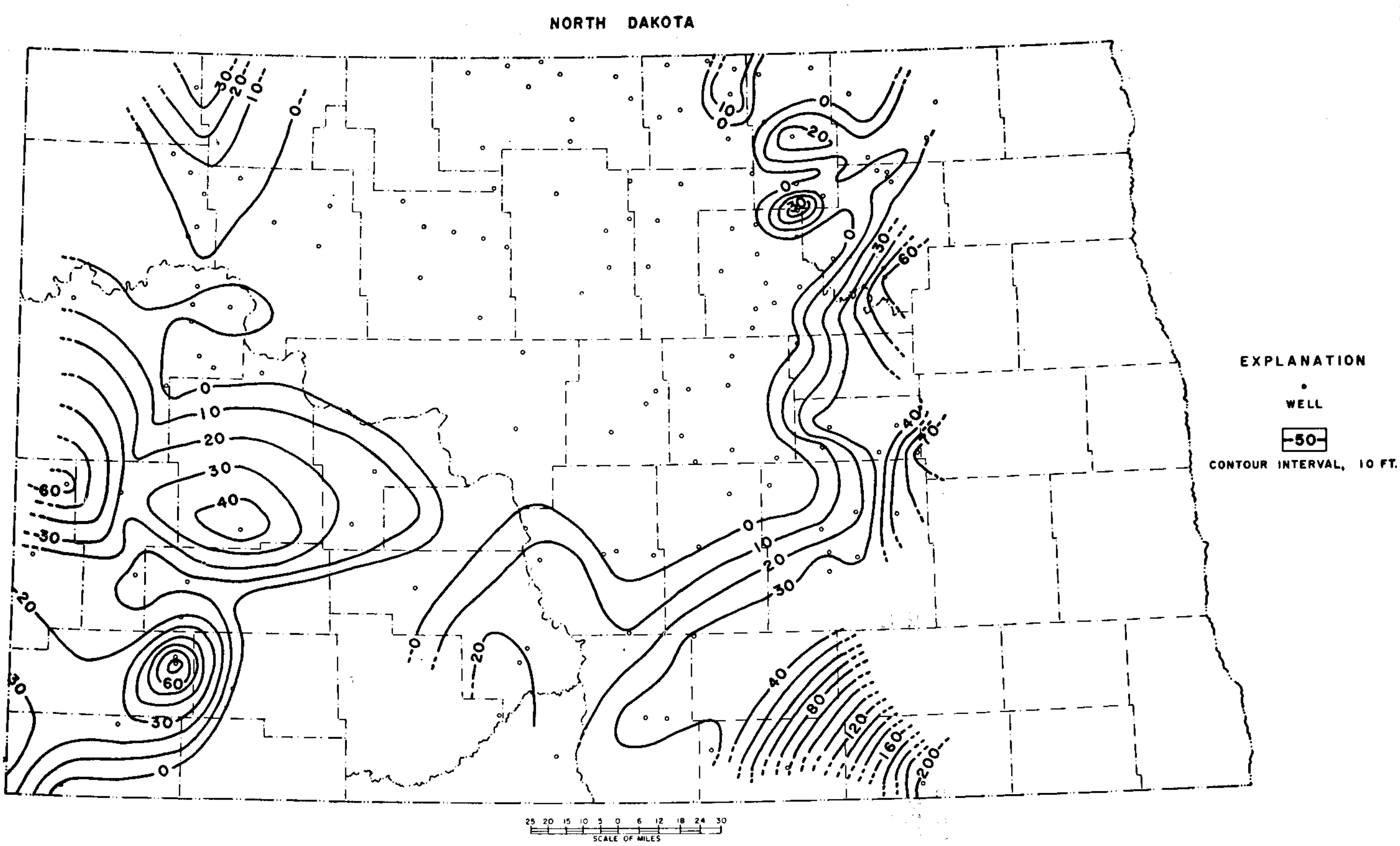


Figure 9

TOTAL SANDSTONE THICKNESS MAP OF THE NEWCASTLE OR MUDDY FORMATION

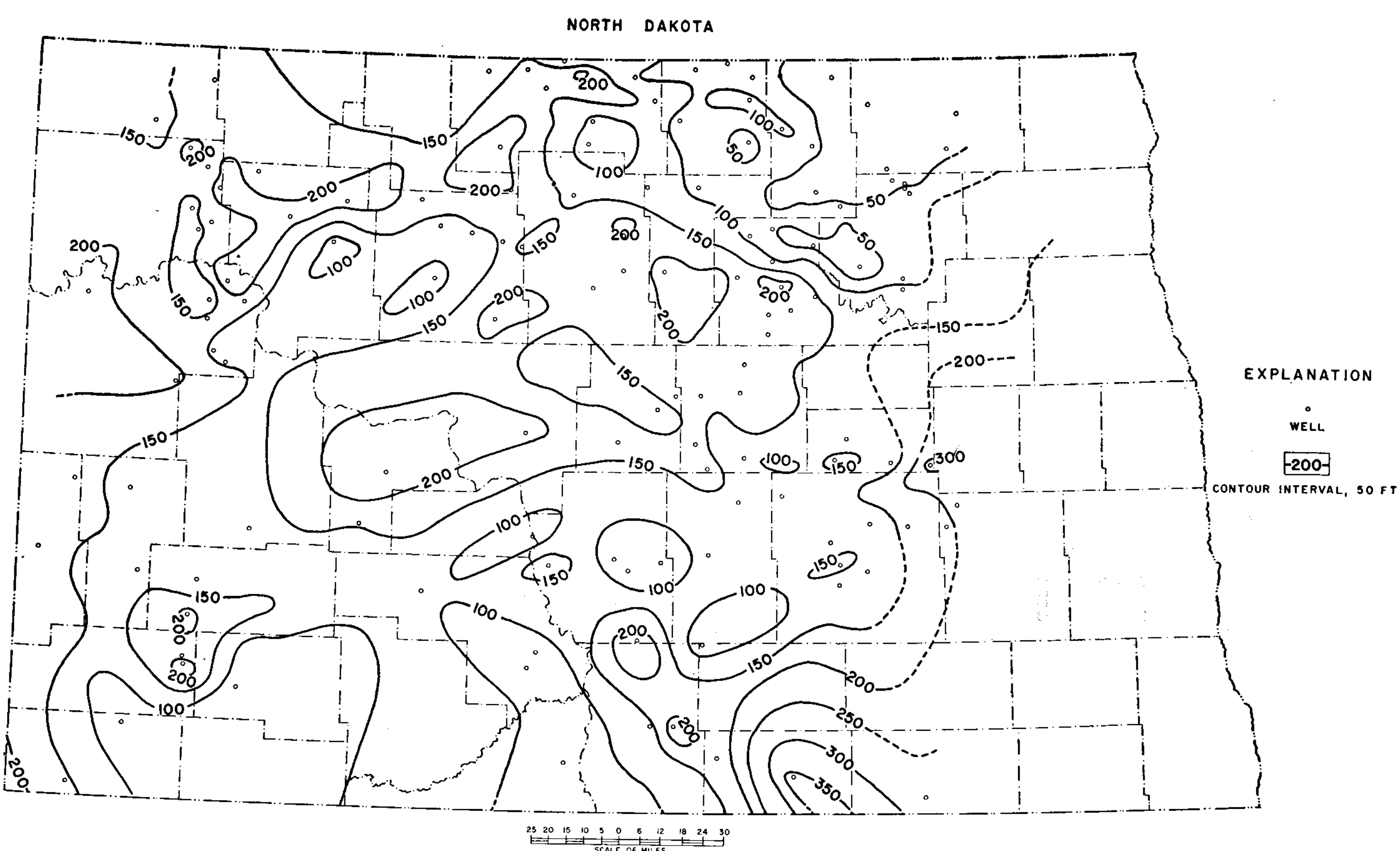


Figure 10

TOTAL SANDSTONE THICKNESS MAP OF THE GREENHORN TO JURASSIC INTERVAL crease in sandstone thickness near the area of the present Cedar Creek anticline indicates a sorting of the sediments over a structure and a source area nearby. The accumulation of the greater sandstone thickness in eastern Slope County is due in large part to the channel-like deposition of the Newcastle sandstone. In southeastern North Dakota the thicker sandstone accumulation is due primarily to nearness of the source area.

Sedimentation

Lakota formation.—The Cretaceous system in North Dakota begins with the deposition of the Lakota sandstone by the invading Cretaceous sea. The sandstone was deposited upon the eroded surface of Jurassic to Precambrian rocks. According to Twenhofel,[38] "Deposits of either the littoral or upper part of the neritic environment should be present at the base of every marine formation that is separated from the strata below by an unconformity due to the retirement of the sea."

The unconformity at the base of the Cretaceous strata and the occurrence of the Lakota sandstone are well known. The environment of deposition is not known but is interpreted. The origin of the sand was terrestial and the source areas for sediments deposited in North Dakota probably came off the area of the present day Precambrian Canadian shield to the northeast and an arc-like extension of the Precambrian into South Dakota.[39] The environment of deposition during Lakota time was perhaps the marine neritic, probably the epineritic. The environment is thought to be marine because of the sheet occurrence of the Lakota sandstone. The agency causing this widespread occurence of the Lakota sandstone is interpreted to be a transgressing sea. The transgression is thought to have been from the west and southwest because of the wedging out or thinning of the overlying shales to the east and northeast, and the successive occurrence to the east of older rocks, Jurassic to Precambrian (see figure 3), immediately underlying the Lakota. This transgression caused a redistribution of quartzose sandstones that could have originally been deposited in a continental fluvial environment of stable shelf to unstable shelf occurrence.[40] The Lakota sandstone was then redeposited in a epineritic environment of unstable shelf type. Also, the transgression of the sea from the west implies that sediments become younger in age as final deposition of the Lakota sandstone proceeded eastward.

According to Twenhofel[41] the migration of any shore line should

[38] Twenhofel, W. H.; **Principles of Sedimentation**, McGraw-Hill Book Company, Inc., 2d ed., New York, p. 102, 1950.
[39] Eardley, A. J.; **Structural Geology of North America**, Harper and Brothers, New York, plate 14, 1951.
[40] Krumbein, W. C. and Sloss, L. L.; **Stratigraphy and Sedimentation**, W. R. Freeman and Company, San Francisco, Table 12-6, p. 388, 1953.
[41] Twenhofel, W. H.; **op. cit.** p. 31, 1950.

result in a wave cut surface upon which deposition takes place as the level rises. Twenhofel states.

> "These deposits tend to be coarsest landward and finest seaward, and as the sea level rises the sheets of sediment progressively extend farther and farther in a landward direction; the sediments laid down on a wave-eroded surface, in general, are the coarsest in the section, and they become progressively overlain by finer sediments as the water becomes deeper, so that a curve of particle dimension shows an increasing fineness upward with minor fluctuations of the curve consequent to variable competencies of the transportation agencies from day to day."

The basal Lakota sandstone can be described, by following Twenhofel's principles, as a marginal deposit to other sediments that lie at different stratigraphic intervals in the section over a considerable area and would intersect time lines at a low angle.

Fuson formation.—The Fuson occurs in areas where the Lakota sandstone was deposited and like the Lakota is missing in the extreme northeastern part of the state. The Fuson shale was probably deposited in the epineritic environment of unstable shelf conditions.[42] The Fuson shale was derived from sorting of the sediments and shifting of the finer particles toward the deeper part of the basin as the transgressing Cretaceous sea deposited the Lakota sandstone in an eastern and northern direction. The Fuson is, at least in part, the shale facies of the Lakota sandstone.

Fall River formation.—For the purpose of discussing the environments of Fall River deposition and the tectonics involved, the state is divided into two main areas. The areas are northern and southern North Dakota. In southern North Dakota the deposition of the Fall River sandstone was due to uplift of the source areas or at least to an increase in the supply of sediments. The sediments constituting the Fall River were probably deposited and sorted under unstable shelf conditions in the environments ranging from the neritic to the littoral and fluvial.[43] In the areas to the west and north, where the sea persisted, fine sands and silts were deposited during maximum deposition. As the deposition continued the transgression of the sea began and the upper part of the Fall River that may have been deposited above wave base was reworked in the neritic environment under unstable shelf conditons.

In the northern area the Fall River sandstone was deposited either in front of a platform or delta area. This is indicated by the greater sandstone thickness in a trend as shown by the total sandstone thickness map of the Greenhorn to Jurassic interval (figure 10)

[42] Krumbein, W. C., and Sloss L. L.; **op. cit.** Table 12-6. p. 388, 1951.
[43] Krumbein, W. C., and Sloss, L. L.; **op. cit.**, Table 12-6 p. 388, 1951.

from Benson to Bottineau Counties. Also, the decrease in total thickness and the closer spacing of the isopach contours of the Cloverly equivalent (figure 6) from Bottineau to Benson Counties indicates an area of lesser deposition to the northeast of this trend of greater sandstone accumulation. The north eastern area of less deposition is also indicated by the isopach maps of the Greenhorn to Jurassic interval (figure 8) and the Lower Cretaceous (figure 7). In front of this platform or delta area the Fall River sandstone was probably deposited in the fluvial and littoral to neritic environments of unstable shelf conditions.[44] Further south and west in the basin the sediments were sorted into sands and shales, the final deposition depending upon local topography, currents, and supply of sediments. As the sea again began to transgress the area to the northeast, the sediments previously deposited in the transitional environment would be partially reworked in the neritic environment. This transgression of the sea to the northeast was marked by slight pause. Again the sea began to transgress the area and deposits of the neritic and littoral environments covered the sediments of the platform or delta. The transgression is marked by the extreme thinness of the Fall River sandstone over the higher areas. After the sea trangressed the area it remained until near the end of the Cretaceous.

In summary, the deposition of the Fall River sandstone probably continued for a greater length of time in northern North Dakota, as shown by more widespread and thicker sandstones than its counterpart in the southern part of the state. In the northern part of the state the Fall River consists of sandstone and a shale facies, another sandstone and another shale facies. In southern North Dakota the Fall River consists of a relatively thinner sandstone and shale facies. The comparative stratigraphic position of the Fall River in southern North Dakota corresponds only to that of the lower sandstone of the Fall River in northern North Dakota.

Skull Creek formation.—As the sea that deposited the Fall River sandstone transgressed east and north the Skull Creek shale was also being deposited. The Skull Creek shale is then a result of the sorting of the fine clastic particles or clays from the Fall River sands. The Fall River sandstones would then be deposited nearer the shore line while the shales of the Skull Creek were being deposited in deeper waters. The depth of deposition was probably never greater than that of the neritic zone. This is possible, for the sorting was chiefly in a horizontal plane, and as the Fall River sandstone was deposited in an eastern direction the shale equivalent was being deposited further west. This lateral sorting of the shale and sandstone may also account for the occurrence of the shales above the Fall River sandstone in the extreme eastern part of North Dakota. The

[44] Krumbein, W. C., and Sloss, L. L.; op. cit. Table 12-6, p. 388, 1951.

sandstone time equivalents were deposited east of the area studied. The Skull Creek shale is then a facies, at least in part, of the Fall River sandstone. Caster[45] earlier recognized a similar relationship in his magnafacies in the "Catskill Deltas." In his magnafacies belts, shale was being deposited west of belts of sandstones and conglomerates to the east. All these lithologic belts climbed the column westward in a regressive sea, a reverse situation of the eastward transgression of the sandstones and shales of the Dakota group. In North Dakota the magnafacies belts occur in couples; couples of magna facies could be the Lakota and Fuson, and the Fall River and the Skull Creek. This condition of couples of magnafacies was first recognized by Mr. F. D. Holland, Jr., Department of Geology, University of North Dakota (oral communication).

Newcastle formation.—The Newcastle or "Muddy" sandstones were deposited when the Cretaceous sea receded a short distance off the topographically "high" areas. The source areas, as indicated by the occurrence of the sandstones shown on the sandstone thickness map (figure 9), were near the southwestern, northwestern, and eastern parts of the state. The sandstones were probably deposited in the neritic environment under unstable shelf conditions.[46] The lenticular nature of the sandstone was controlled by the topography of the ocean floor. The conditions of deposition of the Newcastle sandstones in the southeastern part of the state were somewhat different. In this part of North Dakota the sandstone was also probably deposited under unstable shelf conditions but with the environments ranging from deltaic and littoral to the epineritic.[47] The lateral deltaic continental equivalents of the marine sandstones and shales are believed to be developed further south and east of the area studied. From the predominant occurrence of sandstone for this interval in the Herman Hanson Oil Syndicate Billey No. 1, well No. 27, it is deduced that the chief environments were of the littoral and epineritic and the continental sediments are represented by very small intervals, if at all.

The shales of the Newcastle formation are silty throughout the state. The shales were deposited in the neritic environment and are the result of sorting from the sandstones. In the wells of central North Dakota where the Newcastle sandstones do not occur, the silty shales contain a thin sandy silt zone that occurs in the middle of the formation. This sandy silt zone possibly marks the time of maximum regression of the Cretaceous sea during deposition of the Newcastle. The shales of the Newcastle are, in part, facies of the sandstones.

[45] Caster, K. E.; "The Stratigraphy and Paleontology of Northwesten Pennsylvania, Part I, Stratigraphy," **Bulletin American Paleontology**, Vol. 21, pp. 36, 1934.
[46] Krumbein, W. C., and Sloss, L. L.; op. cit., Table 12-6. p. 388, 1951.
[47] Krumbein, W. C., and Sloss, L. L.; op. cit., Table 12-6. p. 388, 1951.

Mowry formation.—The Mowry shales in North Dakota are medium-gray shales and are a continuation of previous shale deposition. The contact with the underlying Newcastle is, as has been noted, arbitrary. In the larger part of the state, the Mowry shales were the result of slow deposition over a wide area and are consequently thin. In the far western-southwestern part of the state the Mowry shale begins to thicken rapidly and a depositional basin had developed beyond the state boundaries in a south-westerly direction. The Mowry shales were probably deposited in a neritic environment that occured under tectonism of the stable to unstable shelf.[48]

Belle Fourche formation.—The deposition of the Belle Fourche shale follows a regional tectonic pattern that had its beginning with the deposition of the Dakota group. Local structures were less of an influence than they had been for the deposition of the lower sediments, and the accumulation of sediments was probably controlled by tectonism further west. The tectonic influence of the area east of North Dakota appears to have been negligible and detrital material probably consisted mainly of silts, very fine sands, and clays. The dark color in parts of the formation is suggestive of a restricted neritic environment in a large intracratonic basin.[49] The source area of the bentonites was probably to the west as there is no known evidence of Cretaceous volcanism on the Canadian shield. The source areas of the sediments and any zones of possible sandstone occurrence are well beyond the state. Because of the widespread extent of the Belle Fourche shale and its equivalents, and the fairly stable local tectonic conditions that existed, some source area to the southwest must have been supplying part of the sediments to the southwestern part of the state where the Belle Fourche is the thickest. The tectonics responsible for this deposition are thought to be involved with those that caused the deposition of the Frontier sandstones.[50 51]

Greenhorn formation.—The medium-gray to dark-gray calcareous and non-calcareous shales indicate that the restricted environment of an intracratonic basin may have existed during Greenhorn time as it probably did during the deposition of the underlying Belle Fourche shale. Also, the Greenhorn shales are characterized by the plentiful occurrence of **Globigerina** and **Inoceramus** calcite prisms. The factor responsible for the occurrence of calcareous shales was a decrease of tectonism of nearby areas and deposition in an intracratonic basin.[52] This decrease of tectonic activity caused a decrease in size and probably in supply of sediments. The clearing seas changed their chemical environment because of increasing temperatures and widespread

[48] Krumbein, W. C., and Sloss, L. L.; **op. cit.**, Table 12-6, p. 388, 1951.
[49] Krumbein, W. C., and Sloss, L. L.; **op. cit.**, Table 12-6, p. 388, 1951.
[50] Krumbein, W. C., and Sloss, L. L.; **op cit.**, p 292, Table 12-6, p. 388, 1951.
[51] Eardley, A. J.; **op. cit.**, plate 16, 1951.
[52] Krumbein, W. C., and Sloss, L. L.; **op. cit.**, Table 12-6, p. 388, 1951.

calcareous shales were laid down. The limits of this intracratonic basin will be found only by a regional study comprising several states and provinces.

Cretaceous Continental Deposits

In the northeastern part of the state the Fall River sandstone was thought to have been deposited against a platform area until the very final stage of deposition when the sea transgressed this part of the state. This deposition against a so-called platform area is in a trend from Bottineau to Benson Counties. Northeast of this trend the sediments below thinning Fall River sandstones were originally identified by the writer as the Jurassic Sundance formation. The Jurassic sediments consist generally of gray-greenish-gray, and varigated silts and clayey shales, which are sometimes calcareous, with thinly bedded light-gray to white, sometimes calcareous, fine-grained quartzose sandstones.

However, subsequent study of the tectonics and environments that existed during deposition of the Dakota group leads the writer to believe these so-called "Jurassic" sediments could really be the continental equivalents of the Fall River, Fuson and the Lakota sandstone. Thus, conditions of continental deltaic deposition are believed to have existed in the northeastern part of the state and perhaps in entire eastern North Dakota.

The question of continental deposits within the lower Cretaceous originally presented itself when, upon study, it was seen that the Jurassic rocks apparently increased in thickness toward the northeast contrary to the more usual regional thinning of the Jurassic rocks in an eastern direction. However, because of the similarity of this strata to the underlying Jurassic and the difficulty of picking the Cretaceous-Jurassic contact by means of lithology and mechanical logs, it was decided to adhere to the original concept and to treat, on the cross-sections (plates I and II), the rocks immediately below the occurrence of thinning Fall River sandstone (mentioned above) as Jurassic.

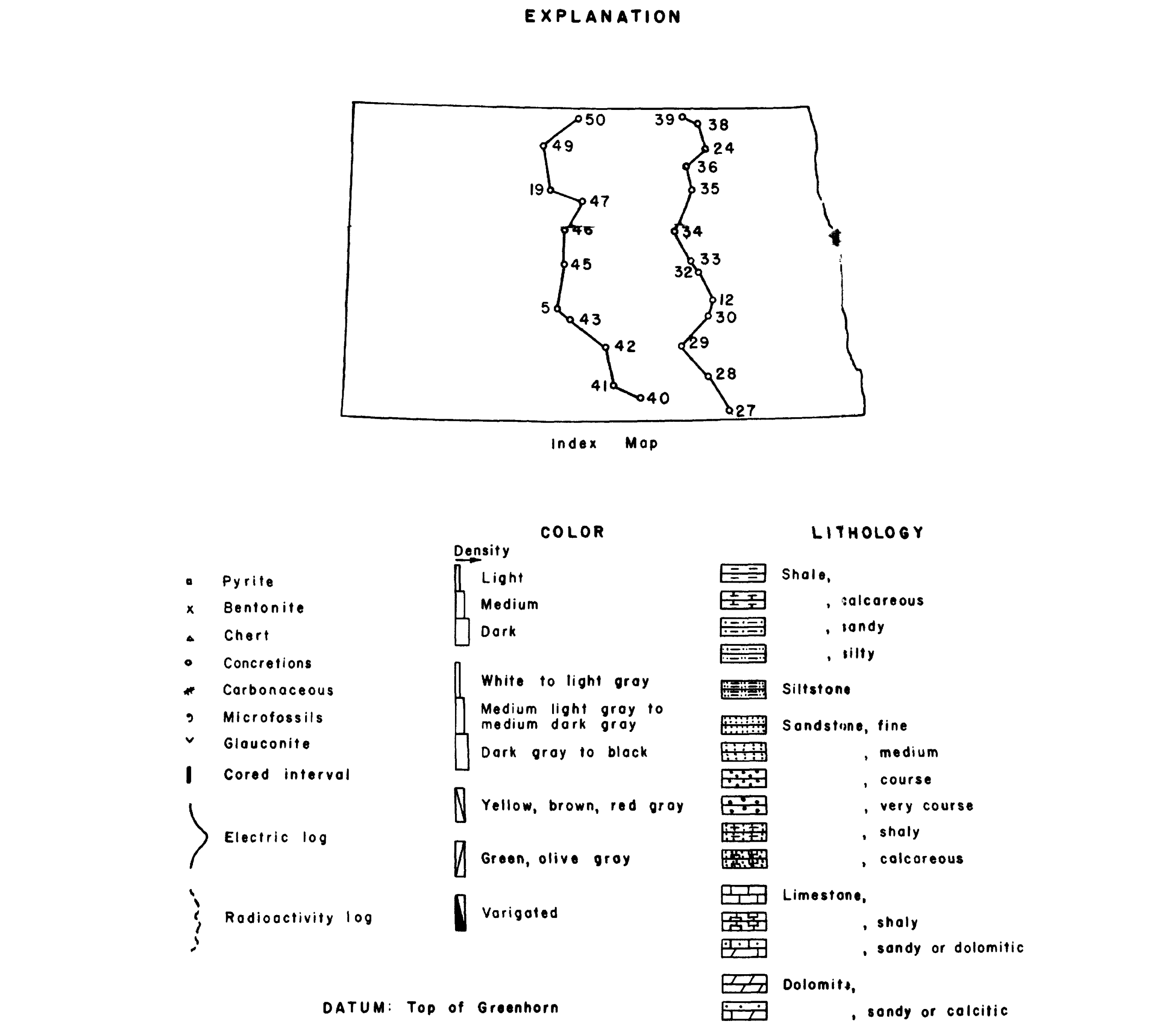
This interpretation of Jurassic age does not fit the regional picture of lower Cretaceous deposition, nor would such an emergent area exist during Lakota time, unless the rocks were much more resistant to erosion than the shales and sandstones of the Jurassic. In summary, it is now thought by the writer that lateral continental equivalents of the marine Fall River and Lakota sandstones were deposited in deltas in the northeastern part of the state and probably in the entire eastern part of the state.

Unfortunately the proof of delta deposition is not included in this paper because certain well information was not available when this study began. If the interpretation of these sediments mentioned above is correct, the maps of the pre-Cretaceous structure, the iso-

CORRELATION OF THE GREENHORN-LAKOTA INTERVAL IN NORTH DAKOTA

By Don E. Hansen

Plate I



CORRELATION OF THE GREENHORN-LAKOTA INTERVAL IN NORTH DAKOTA

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Plate II