NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, *State Geologist*

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CONTRIBUTIONS TO THE GEOLOGY OF NORTH DAKOTA

by

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Physiography of North Dakota

By Fritz J. Roth and James T. Zimmerman

North Dakota, before Pleistocene time, was typified by badland topography which exists today only in the south-western part of the state. Pleistocene glaciation greatly modified its surface and deposition by the glacier exceeded erosion. As a result of glaciation, isostatic rebound, and structural effects, five escarpments trending northwest partition the state into six major physiographic divisions. These are, Agassiz Lake Plain, Drift Prairie, Turtle Mountains, Souris and Devils Lake Plain, Couteau du Missouri, and Missouri Plateau.

Agassiz Lake Plain was formed by Lake Agassiz which is thought to have existed before, during and after glaciation, (G. L. Bell, unpublished report.) This province is bounded on the east by a granite high in Minesota, on the south by Coteau du Prairie, on the west by the first escarpment, known as the Pembina Mountains which extend into Canada.

For the most part, the relief of the lake plain is topographically insignificant. This portion consists of fertile black soil which is of great commercial importance to the state and this province is known as the "Bread Basket of the world." Other important crops are sugar beets and Potatoes. The shore line of the lake is comprised mainly of five beaches which trend northwest as longitudinal ridges. These beach deposits consist of sorted sand and gravel.

The next physiographic division to the west is the Drift Prairie This is bounded on the north by Souris Lake Plain and Devils Lake Plain, on the west and south by Coteau du Missouri, and on the east by Agassiz Lake Plain.

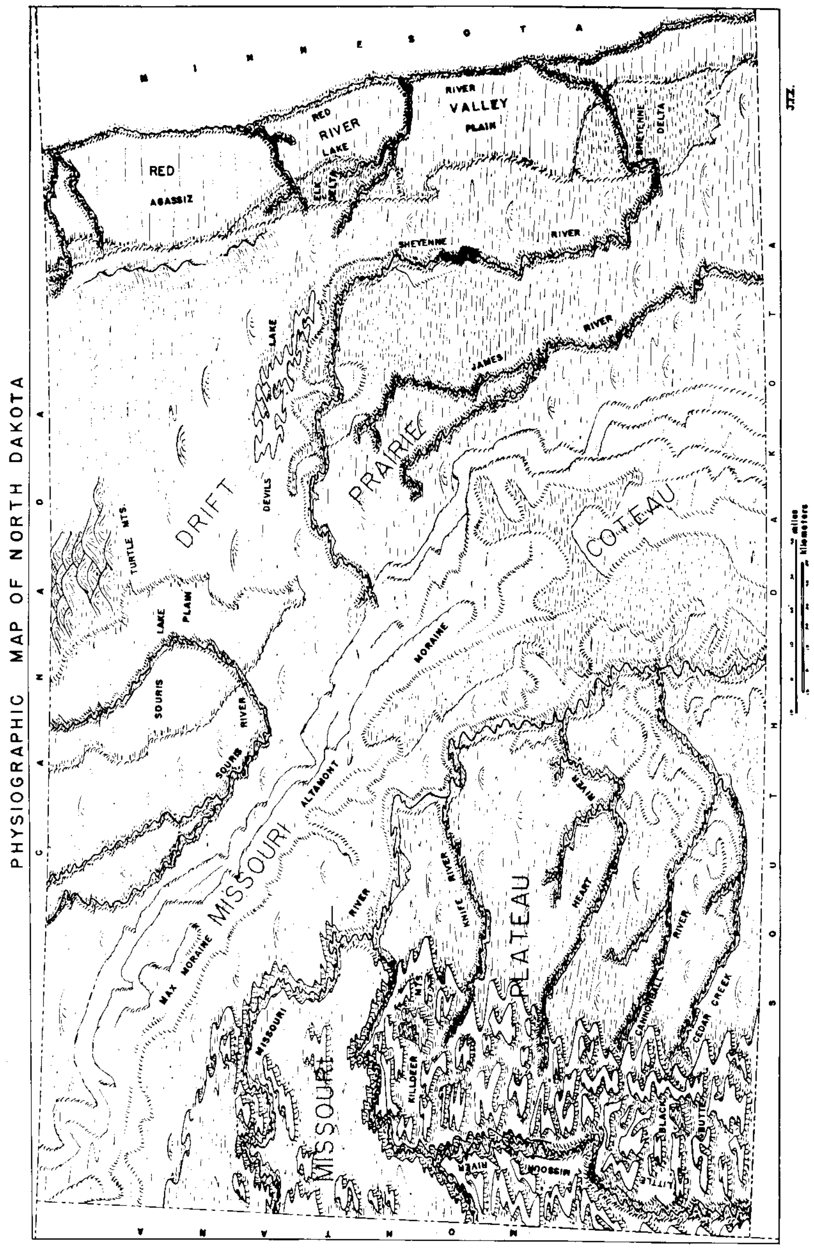
The Drift Prairie is characterized by glacial features such as, outwash plains, terminal and recessional moraines, deltaic deposits, and ice contact deposits (kames, eskers), as well as interlaced spillway systems characterized by overloaded, braided, modern streams. Also this area has a great amount of underground drainage, as well as interior drainage. This division supports most of the state's wheat crop.

To the north of the Drift Prairie is the Turtle Mountains division. This division is bordered by the Souris and Devils Lake Plains on the west and south, on the north it is bounded by ground moraine in Canada, and on the east by Agassiz Lake Plain.

The Turtle Mountains are erosional remnants of the second escarpment west. They consist of the Pierre shale and Fox Hills sandstone which are upper Cretaceous in age. The mountains have been glaciated and have a moderate degree of relief as compared to the rest of the state. The mountains are very scenic in their own respect and are characterized by kettle lakes with intervening forested hills.

To the south and east one may travel into Devils Lake Plain

CONTENTS



Feg. 1.—Physiographic Map of North Dakota.

and Souris Lake Plain. This division is not as flat as Agassiz Lake Plain. The division is bounded on the west by the Max Moraine, a new division of the Altamont Moraine, on the north partly by the Turtle Mountains, on the east by the Agassiz Lake Plain and on the south by the Drift Prairie.

The greater part of this division is gently rolling and the soil is similar to the soil of Agassiz Lake Plain but not as deep.

Going to the west and south of the Souris Lake Plain one comes to the Coteau du Missouri. The Coteou du Missouri division is one of the greatest morainic belts known in the world. This morainic belt extends from the northwest corner of the state diagonally to the center of the southern boundary of the state, and thence into South Dakota. It is bordered on the west by the Missouri River and on the east by the Souris Lake Plain and Drift Prairie.

This moraine is known as the Max Moraine north of the town of Max, and it is mainly a terminal moraine complicated by recessional moraines. It is 15 to 50 miles wide and its relief is about 200 feet. The Max Moraine is grass covered and boulder strewn. This area is tillable in places but where not it is used as grazing land.

The rest of the state to the west of the Missouri River is known as the Missouri Plateau which extends into Montana, South Dakota, and Wyoming. The present plateau is being dissected by four main rivers. The Plateau is a remnant of a pre-glacial peneplain. In the eastern portion of the division the topography is quite hilly and along the Missouri River there are bluffs 500 to 600 feet high.

The more rugged part of the division is found in the west. Here the Little Missouri River has carved an intricate maze of narrow ravines, sharp crested ridges, and pinnacles which are known collectively as badlands. The rocks of the badland are sandstone, shale, lignite, and "scoria" beds. The badlands are very picturesque and there are many beautiful combinations of red, yellow, black, brown, blue, and white. Also there are a few burning lignite beds actively forming "scoria." The Missouri Plateau division is the most spectacular of all the divisions in the state.

Today the altitude of the state increases from east to west, ranging from 850 feet in the east to 3,468 feet in the west. This highest altitude is attained by Black Butte which is situated near the Little Missouri River in the southwestern part of North Dakota. North Dakota with its variety of glacial features, contrasting with the dissected Missouri Plateau, is one of the most interesting states in the United States.

Geology of the Eldridge Quadrangle North Dakota

By Ronald J. Kresl

LOCATION OF THE AREA

The Eldridge quadrangle is defined by 98° 52' 30" and 98° 45' west longitude and 46° 52' 30" and 47° 00' north latitude. It is situated, entirely, in east central Stutsman County, North Dakota. U. S. Highway 10 crosses the southern half of the area. The city of Eldridge is in the southwestern corner of the map and Jamestown, on U. S. Highway 10, is 2.7 miles east of the quadrangle boundary.

PURPOSE OF THE SURVEY

In the latter part of the summer of 1954, the geology of the Eldridge quadrangle was mapped by the writer and Ray Huot. Reconnaissance mapping of the area was done by car with the more detailed mapping being done on foot.

The purpose of the survey is a part of the plan of the North Dakota Geological Survey to map the geology of the state. Through this plan important data are obtained on glacial geology and its relation to ground water that may be available for irrigation of parts of the state, as well as data on the location of commercial gravel and sand deposits useful for road metal and constructional materials.

PREVIOUS WORK IN THE AREA

This area received attention in the past from Daniel E. Willard in his *Jamestown-Tower folio* of the Geologic Atlas of the United States, (1909).

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Dr. Wilson M. Laird, State Geologist of North Dakota, for the opportunity of studying and mapping this area, and also to Ray Huot who worked with me in the field. The writer is especially indebted to Dr. Gordon L. Bell, of the Department of Geology, University of North Dakota, for his frequent consultations and numerous helpful suggestions if the field as well as for his invaluable assistance in the preparation of this report.

TOPOGRAPHY

The Eldridge quadrangle, Plate 1, lies within the extreme southwest section of the Drift Prairie as defined by Howard E. Simpson, (1912, p. 106-108). The relief of the region is generally moderate, with distinguishing features such as recessional moraine, pre-glacial Pipestem channel, and ground moraine plain.

Local Topography—The relief of the area ranges from 1575 feet above sea level at the recessional moraine crest on the west-central boundary of the quadrangle to less than 1300 feet on the present flood plain of the Pipestem Creek.

Three main topographic divisions are recognized in the area. The highest and most conspicuous level is occupied by the recessional moraines. An intermediate level which covers the greatest percentage of the area is defined by a gentle rolling ground moraine plain. Glacial drainage controls the third topographic division of the area which is considerably lower in relief than the previously mentioned divisions.

GENERAL GEOLOGY

The Eldridge quadrangle contains a very limited number of bedrock exposures of the Cretaceous Pierre shale, in the northeastern corner of the area, along the Pipestem Creek. The greater part of

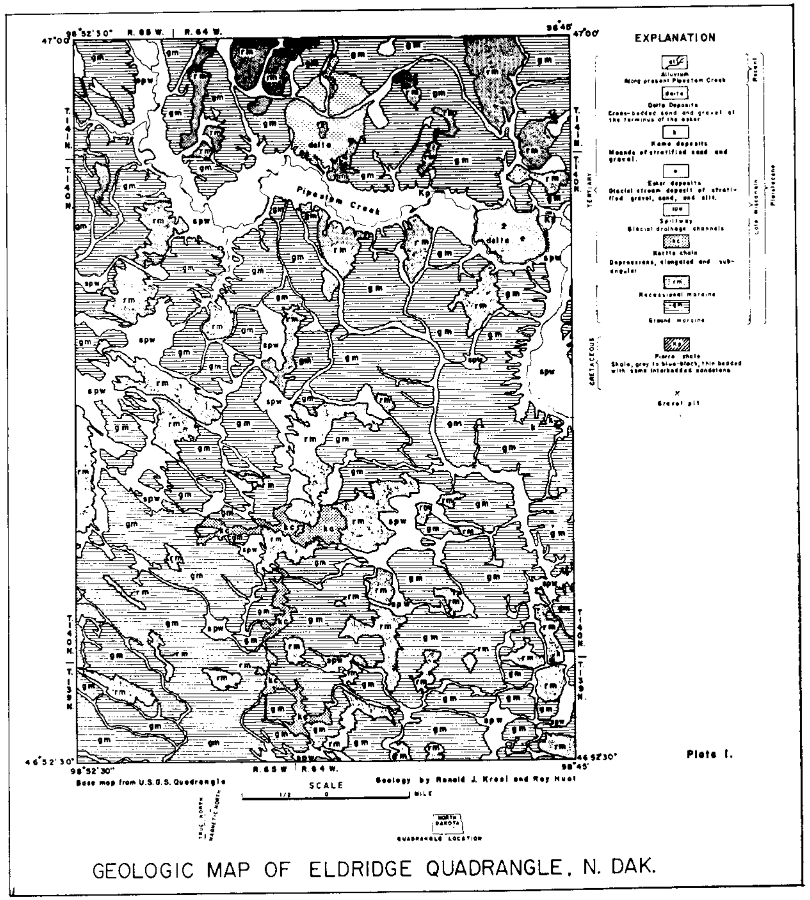


Plate 1.—Geologic Map of Eldridge Quadrangle, North Dakota.

the area is covered with glacial drift. There is no surface evidence of the bedrock formation which underlies the Pierre shale, although it is reasonable to assume on the basis of regional structure correlated from well logs of the state, that this stratum is the Niobrara formation.

The following is a generalized outline of the geologic formations of the Eldridge quadrangle:—

- Tertiary system
  - Pleistocene series
    - Wisconsin stage
      - Mankato substage
      - Cary substage?
- Cretaceous system
  - Pierre shale

PIERRE SHALE

In the few exposures of the Pierre shale in this quadrangle, it appeared blue-black with numerous limonitic concretions giving it a reddish tint. It has a pronounced rectangular cleavage causing it to weather into small blocks and thin flakes that are silvery. This formation is impervious to ground water and supports perched ground water in numerous places.

GLACIAL GEOLOGY — PLEISTOCENE SERIES
GENERAL STATEMENT

The deposits of Mankato subage are moderately weathered, light brown clay tills; in contrast to the older Cary subage deposits which are deeply weathered, light buff to yellow tills. The Cary drift is not found in this area, although there are certain indications that remnants of Cary drift are partly exposed at places along Pipestem Creek. Farther north, however, in the McVille quadrangle, Nelson County, North Dakota, Dr. Gordon L. Bell (1954, p. 54) reports till of Iowan subage; and Bell (personal communication) suggested that possibly drift of Cary subage is also present near McVille.

GROUND MORAINE

The most common type of glacial feature in the area is subdued ground moraine which has a gentle rolling and swell and swale topography. In certain areas this ground moraine is pitted, due to concentrations of ablation blocks. The ground moraine is commonly associated with recessional moraine as well as with ice contact and spillway deposits.

The ground moraine deposit is a light brown, weathered, clay till. This till owes its clay and shale particle composition to the underlying Cretaceous Pierre shale bedrock. The remaining pebble content is chiefly of crystalline rocks which were derived from the Canadian source area or possibly from an underlying older till of

Cary subage. There is less than an average amount of limestone pebbles and boulders in the Mankato drift of this area, an abundance of which should be expected from the Manitoba source area of the Cary invasion. This may indicate that these rocks did not survive the secondary weathering and reworking of the Mankato subage of glaciation (if this till was formed from re-worked Cary deposits). Another reason for not expecting limestone particles in the Mankato drift is attributed to the possibility that this limestone source area was depleted after Cary time.

No indications of stratified drift in ground moraine were found in this area, although their occurence was sought after and could just as well have been expected in these deposits.

Not too long ago, ground moraine was thought to have been exclusively sub-glacially deposited. It is now generally agreed by glacial geologists that these deposits were formed mainly by rapidly flowing, slowly melting ice at the glacial front, as well as by some sub-glacial deposition. The ground moraine deposits of this area owe their origin to these conditions, and even though they were not reworked by meltwater, they were deposited in such relative thinness under saturated conditions, that they flowed and settled to assume rather subdued topographical forms that were modified by readvance of the ice at places in the southwestern corner of the quadrangle.

RECESSIONAL MORAINE

Distinct topographic features trending both north and northwest are most common on the area which is relatively flat, with the exception of the pre-glacial Pipestem drainage system. These deposits were formed by rapid deposition and temporary hesitation in the glaciers' ablation. The materials of recessional moraine in this area are quite similar to those described for ground moraine, mainly that of a clay till with more pebbles and cobbles. This indicates deposition on a larger scale with a greater abundance of meltwater available, which in turn disected these moraines to such an extent that a great number of them are no longer continuous and appear to be two or three separate deposits.

The two directional trends of these moraines (north, and northwest) indicates a two lobe advance in this area. In the southwest corner of the quadrangle are several subdued recessional moraines trending northwest which were deposited by a northeasterly ablating lobe.

Deposition of these moraines was consistent, however, throughout the entire area, but upon the re-advancement of a lobe from due north, most of the recessional moraines were overridden, subdued, and in some cases completely obliterated. Therefore the second lobe moraines, trending in a northerly direction, today possess a more youthful appearance than overridden moraines of the first lobe.

These moraines are relatively small, and average 1.5 miles in length and 0.5 miles in width, but are not extreme enough to be classified as knob and kettle topography.

The maximum height of recessional moraines in this area is approximately 30 feet. Although deep subsurface investigations of the area were not made, it is thought that an appreciable percentage of the larger moraines are bedrock controlled, containing Pierre shale, rather than being composed entirely of till, (G. L. Bell, personal communication).

ICE CONTACT DEPOSITS

Kames—Typical ice contact deposits, exposed topographically as circular or elliptical hills or knobs, are formed by moulin action of surface and englacial waters in cracks and crevasses and are known as kames. They were deposited as cones near the outermost oblation area and are found quite widely scattered in the quadrangle. The material of these kames is poorly stratified, moderately well washed gravel and sand. The poor stratification is due to the slumping of the material after the ice melted. During slumping, these deposits assumed the angle of repose of sand and gravel. Kame gravel is used locally for road metal. A small content of Pierre shale prohibits its use as a construction material. Kames were formed both in recessional moraine and on ground moraine.

Eskers—Several northerly trending series of discontinuous ridges are found in this area. These ridges are subglacial stream deposits formed near the frontal thinning ice area of the glacier and are known as eskers. They are composed of coarse-grained gravel and sand, alternating with fine-grained, moderately well sorted, stratified sand.

Features such as these are easily recognized in the field from several criteria which are in close agreement with those set forth by F. T. Thwaites (1946, p. 52-54):

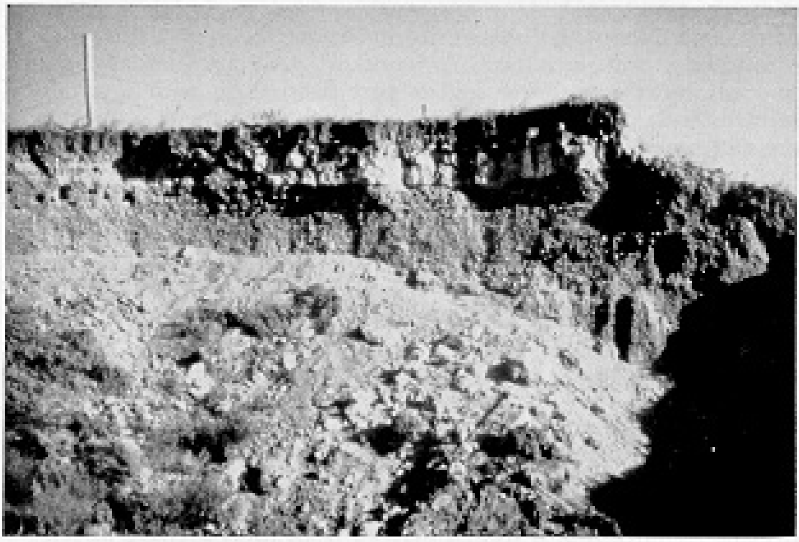


Fig. 1.—Cross-sectional view of esker delta underlain and overlain by Mankato till.

1). "A series of ridges separated by gaps," 2). extending in the general direction of glacial movement, 3). and having the ground for a few rods on the sides of the eskers lower than farther away on the ground moraine, thus forming esker troughs; 4). plus the fact that eskers mainly occur in ground moraine, 5). with their sides sloped at the angle of repose of sand and gravel (approximately thirty degrees).

The origin of esker troughs, mentioned above under No. 3, can be explained as that portion of the previously eroded subglacial river channel not heavily loaded with debris, which later became heavily loaded and deposited stratified debris in all but the flanks of its channel. As a typical glacial stream develops deltas at its mouth, so do these sub-glacial streams form deltaic deposits at the flanks and terminus. These deltaic sediments follow the normal sedimentary processes in grading outward from coarse, to medium, to fine-grained material, according to decreased velocity and consequent inability to transport the mixed load. Topographically, these esker deltas are low broad swells where they merge gradually with the ground moraine.

GLACIAL DRAINAGE

A mass of ice ranging from 2,000 feet to 10,000 feet thick carries an extreme amount of potential water and millions of cubic yards of rock debris; consequently glacial drainage concerns itself in dealing with overloaded, braided streams. Main spillways will handle the main portion of meltwater at the foot of the glacier, but a finely integrated system of braided streams is closely associated with the trunk spillways.

The deposits of the Pipestem Creek are well stratified, cross-bedded gravel and sand. At one time, this wide pre-glacial channel was completely filled with glacial drift and as the ice melted this youthful meandering post-glacial stream found its pre-glacial channel and is now at work in re-developing its past flood plain with a system of terrace levels cut in its pre-glacial channel. Four main terrace levels are recognized in this area.

An interesting feature concerning glacial drainage is seen in the extreme southwest corner of this area. It is concerned with a stream and its tributaries which drain only to the west. This may be explained by the damming effect of the ice on this stream which prevented it from draining to the east by an ice front as well as to the north and south by topography. Such a feature is herein called an "ice-diverted" stream.

Another form of glacial drainage which deserves special mention is the kettle chain—a long narrow trough, as much as two miles long and one half mile wide, formed by an extremely large block of ice from the glacier front along a fracture zone. Ablation moraine was then deposited around such blocks and in some cases, covered them. After the blocks melted, the large volume of drift which they displaced became significant as a trough derived from these melting ice blocks.

No glacial outwash deposits were found in the quadrangle. A possible explanation for the absence of outwash in the Eldridge quadrangle may be the relative deficiency of glacial material available for transportation as compared with other glaciated areas of the country. Another reason is that the amount of meltwater available for the transportation and reworking of these materials was noteworthily less than areas of abundant outwash.

SEQUENCE OF EVENTS

In Pliocene time, the relief of the area was moderately developed, somewhat greater than the relief of the area today. The mature Pipestem Creek meandered on its wide floodplain as it cut through the exposed Cretaceous sedimentary rocks of the rolling terrain.

The Mankato subage of the Wisconsin age of the Pleistocene epoch accounted for the deposition of much glacial debris. Glacial meltwaters carried many of these materials from their sites of deposition through a braided network of spillways which ultimately merged to the master drainage of the area—the Pipestem. This stream, much overloaded, deposited rapidly a load, so great in volume, that its pre-glacial channel was filled with stratified drift.

A re-entrant lobe of the same subage then flowed south to a point where it covered all but the southwest corner of the quadrangle where it hesitated long enough to deposit recessional moraines, eskers, and esker deltas, before it melted away, depositing profusely in its retreat.

Evidence of this sequence is found in section 6 of T. 140 N., R. 64 W., where glacial till on Pierre shale bedrock is overlain by esker delta deposits which in turn are overlain by another glacial till, see figure 1.

With no ice damming present in the area, and with much meltwater as energy, the Pipestem Creek found its pre-glacial channel, now filled with drift, as the path of least resistance in its erosion process and so began exhuming the valley with a resulting series of magnificent terrace levels.

Normal erosional processes are now at work modifying the area.

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Postglacial Warping in North Dakota

By Emmett R. Schmitz and Ronald J. Kresl

INTRODUCTION

The great continental glaciers which once existed over much of North America and Fennoscandia were the direct cause of changes at the surface of the earth. These adjustments resulted in warping of the lithosphere due to loading and unloading each time the ice advanced and melted away. Fluctuation of sea level appears to have occurred during each advance and retreat of the ice sheets. However, evidence of those eustatic adjustments is not recognized in North Dakota; and no attempt is made to use these data in this paper.

Acknowledgments—The authors are indebted to Dr. Gordon L. Bell, Department of Geology, University of North Dakota, for his suggestion of the problem concerning postglacial warping in North Dakota, and for his valuable advice and criticisms during the progress of this report. The helpful assistance and criticisms of Dr. Wilson W. Laird, State Geologist, North Dakota Geological Survey, and the staff of the North Dakota Geological Survey for their interest and ready assistance in this report are also greatly appreciated.

ISOSTASY

All available data on North Dakota relative to this subject were coordinated to determine the effects of glacial load across North Dakota. In addition to the published data, the report includes information from the files of the North Dakota Geological Survey concerning the Nesson anticlinal system.

It was found that the amount of tilting recorded by Warren Upham (1895-1896, p. 476) on the Herman beach "a" of Glacial Lake Agassiz corresponds to those observations and calculations of Arthur G. Leonard along the Little Missouri River in western North Dakota.

The Herman beach "a" marks the highest lake shore of Glacial Lake Agassiz. The altitude of this beach as recorded by Upham is 1055 feet above sea level at the south end of Lake Agassiz, Figure 1. Beach "a" has a northward rise of 35 feet in the first 75 miles, from the southern boundary to the latitude of Fargo and Wheatland, North Dakota where beach "a" has an altitude of 1090 feet above sea level. At the latitude of Grand Forks and Larimore, North Dakota, Herman beach "a" has an altitude of 1150 feet above sea level. This indicates a continuous northward rise of 95 feet for a distance of 150 miles from the southern limit of this lake to the Grand Forks, Larimore latitude. On the international boundary, 224 miles north of the southern limit of Glacial Lake Agassiz, beach "a" is 1230 feet above sea level. Therefore, the northward rise in 224 miles is 175 feet, with an average slope of 0.78 feet per mile.

Upham (1895-1896, p. XXII) mentions epirogenic uplifting of

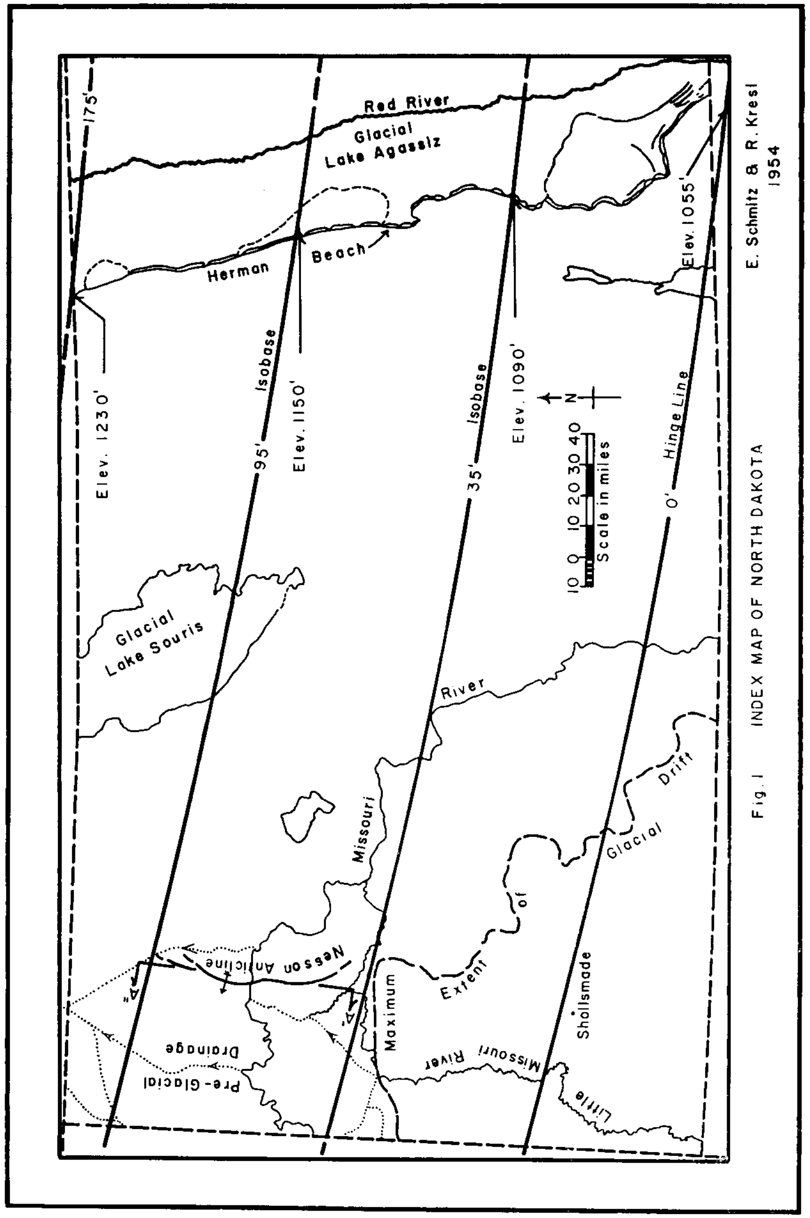

Fig. 1.—Index Map of North Dakota.

the area of Lake Agassiz, resulting from the unburdening of the land by the departure of the ice sheet, increasing in vertical extent, from west to east at half the rate as from south to north, gave to its beaches a north, north-eastward ascent, and caused the several shores of its southern part to become double or multiple as they developed northward. The multiple Herman beaches "a", "aa", "b", "bb", "c", "d", progressively younger and lower basinward, on the western shore of Lake Agassiz, gradually diminish in altitude in their northerly ascent. This is demonstrated by a comparison of Herman beaches "a" to "aa", and "d" to "dd", see Table 1.

TABLE 1

Herman Beaches	**"a"**	**"aa"**	**"d"**	**"dd"**
Numerical Order	1	2	6	7
Feet above the sea at the southern limit to Glacial Lake Agassiz	1055	1055	1045	1045
Feet above the sea on latitude of Fargo and Wheatland, N. Dak., 175 miles from southern limit of Glacial Lake Agassiz	1090	1090	1080	1075
North ascent from southern limit of Glacial Lake Agassiz	35	35	30	30
Feet above the sea on latitude of Grand Forks and Larimore, N. Dak., 150 miles north of southern limit of Glacial Lake Agassiz	1150	1145	1117	1115
North ascent from southern limit of Glacial Lake Agassiz	95	90	72	70
Feet above the sea on the international boundary 224 miles north of the southern limit of Glacial Lake Agassiz	1130	1122	1180	1175
North ascent from southern limit of Glacial Lake Agassiz	175	167	135	130

(After:—Upham, 1895-1896, p. 476.)

Proof of Flint's (1947, p. 419) ideal profile of progressive upwarping of the crust during deglaciation is found in the Herman beach data, Table 1.

Arthur G. Leonard (1916, p. 303), in discussing the evidence of the Pleistocene drainage changes in western North Dakota, states that "One of the conspicuous features of the Little Missouri Valley in Billings County and for a few miles of its course in southern McKenzie County are high, broad flats or terraces on one or both sides of the river. They have an elevation ranging from 240 feet at the south to nearly 300 feet above the river at the north and are one to two miles and over in width. They were undoubtedly formed prior to the Glacial period. These high terraces are wholly absent from the lower valley, which would seem to indicate that this portion is more recent and was formed since the region was elevated, so that the rejuvenated river cut its inner valley several hundred feet below the floor of its earlier one."

Assuming Leonard meant the southern boundary of Billings County when he stated that a river terrace above the present northerly flowing Little Missouri River has an altitude of 240 feet at the south; and again assuming that he referred to southern McKenzie County when he states that the same river terrace has an altitude of nearly 300 feet above the river at the north and having found no written evidence indicating any tilting south of Billings County, we concluded that a zero hinge line occurs near the southern boundary of Billings County. Since similar conditions exist at the southern limit of Glacial Lake Agassiz, and the southern boundary of Billings County, a zero hinge line denoting an outer limit of warping across North Dakota was constructed (see Figure 1.)

A profile, see Figure 2, was constructed north from the hinge line near Shollsmade to McGregor, North Dakota to show the present attitude of the surface. These same features are projected to their calculated positions during maximum glacial load, as indicated by the amount of rebound determined by Upham and calculated by Leonard. As mentioned above, this adjustment is 175 feet from the hinge line in southeastern North Dakota to the Canadian border and 160 feet from the hinge line in the vicinity of the Little Badlands area, north of Shollsmade to McGregor, North Dakota. Using these data, it is possible to extend the isobases or isotilt lines (lines connecting points of equal tilt), Flint (1947, p. 420), across North Dakota.

During the construction of the isobases, it was noted that the trend of the Nesson anticlinal system lies essentially parallel to the direction of maximum tilting. Consequently, it seemed advisable to consider the possible effect of tilting on the Nesson anticline as well as the surface, Figure 2. Therefore, a cross-section of these horizons of commercial importance within the oil bearing Nesson anticline was constructed. These zones were also projected to their theoretical positions during maximum load according to the surface calculations mentioned above.

It is recognized that this amount of tilting of the anticline will influence fluid migration. Members of the Petroleum Engineering Division of the North Dakota Geological Survey suggest that an

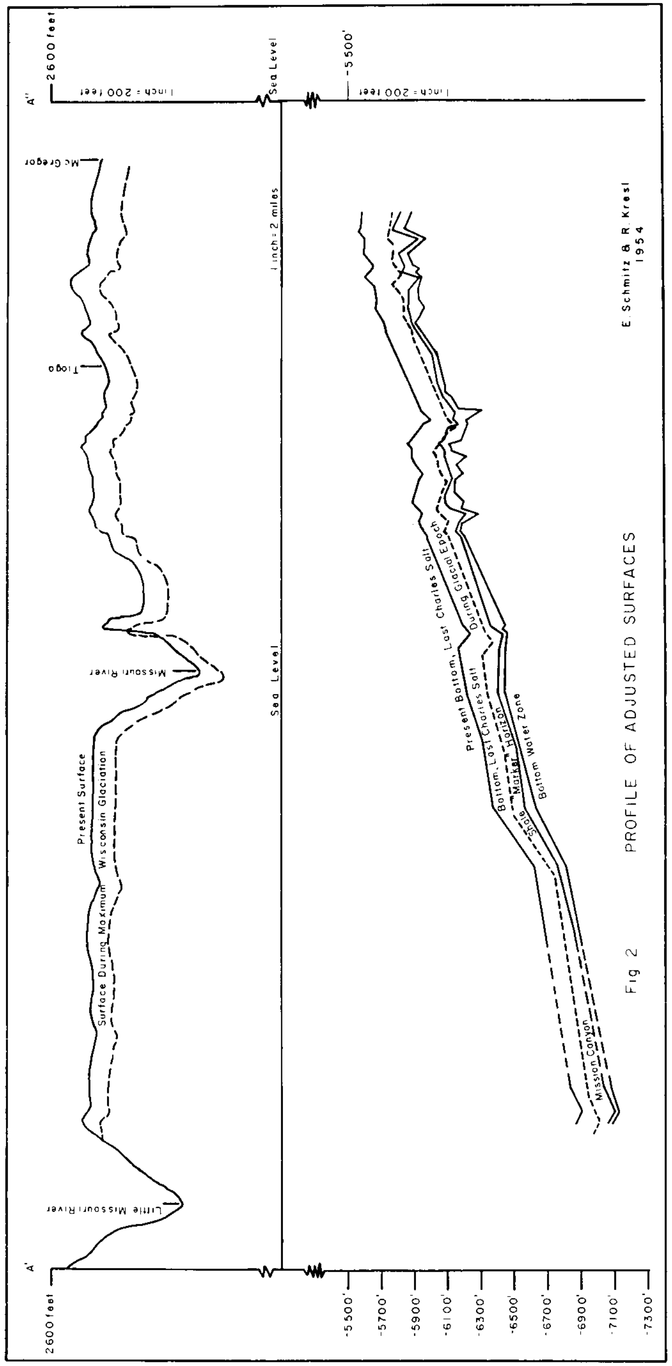

Fig. 2.—Profile of Adjusted Surfaces.

active water drive from south to north in the area of the Beaver Lodge Pool is indicated by "watering out" of certain oil wells. This is commercially important and warrants additional research, to help guide oil production. Apparently, isostatic processes are still active across North Dakota.

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North Dakota--Oil State

BY CHARLES H. WALDREN, ELMER G. MELDAHL,
AND LAVERN L. MCGOWAN

General Statement—This paper presents a brief summary of the geology of the Williston Basin within North Dakota, and the history and development of the oil industry in that state.

Acknowledgments—This is not an original investigation and the writers thank Dr. W. M. Laird, State Geologist, North Dakota Geological Survey, on whom we have drawn heavily for much of the information contained in this report. Messrs. S. B. Anderson and C. B. Folsom, North Dakota Geological Survey, for cantributing pertinent information. Thanks are especially due Dr. G. L. Bell, Faculty Advisor, Beta Zeta Chapter, Sigma Gamma Epsilon and Prof. F. D. Holland, Jr., Department of Geology, University of North Dakota for guiding, criticizing and giving valuable advice during the preparation of this paper.

Location—The Williston Basin (Figure 1) is situated in the western two-thirds of North Dakota, northwestern quarter of South Dakota, eastern quarter of Montana, southeastern and southern Saskatchewan and southwestern Manitoba. It covers an area of approximately 130,000 square miles.

GEOLOGY

Structure—The Williston Basin is elliptical in shape and situated on the shelf area of an extensive geosyncline extending east from the Rocky Mountains. The Basin is bounded on the northeast by the Canadian Shield, on the northwest by the Alberta Shelf on the southwest by the Black Hills and on the southeast by the Wisconsin Dome (Eardley, 1951, pl. 3).

The surface of the Basin is relatively simple. It consists of an area of relatively flat-lying sedimentary rocks that are folded into a series of folds such as the Cedar Creek anticline in Montana and the Nesson anticline in North Dakota. The origin of these anticlines presents a problem. According to Laird (1953, p. 27) there are two theories concerning their origin. First, the progressive downsinking of the basin may have caused the crowding and folding of the rocks in the center of the Basin. Second, recurrent faulting in the underlying Pre-Cambrian rocks may have produced folds in younger rocks of the Basin. These faults may have influenced not only the sedimentation in the area but also the draping of the sediments that were deposited over them.

The Cedar Creek anticline is probably caused by faulting in the basement rock. Evidence suggests that the Nesson anticline is the same type of structure since the crest of the fold on the Madison forma-

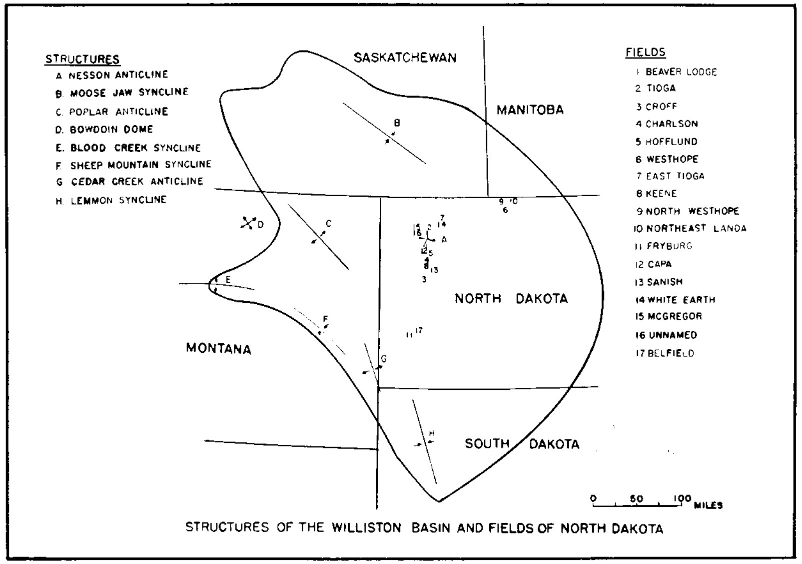

Fig. 1.—Location, structures of the Williston Basin and oil fields of North Dakota.

tion is about a mile west of the crest of the same fold on the Piper and Greenhorn formations (Laird, 1953, p. 28). Laird (1954, p. 10) and McCabe (1954, p. 2009) present evidence that faulting and rising of the Nesson anticline recurred a number of times during the geologic past. Domes on these anticlines may have resulted from cross faulting of the main structures (Laird, 1954, p. 10).

The Basin, in which all the Paleozoic systems are represented, has been an area of progressive intermittent downsinking during its geologic history. The more rapid subsidence probably started during post-Ordovician or post-Silurian time and was greatest in Devonian, Mississippian, and Cretaceous time as is evidenced by the thickening of these sediments. The center of the Basin, now situated near Williston, North Dakota, has migrated in a clock wise direction during geologic time (Laird, 1953, p. 27). The known oil traps in the area are structural and stratigraphic, anticlines have proven to be the most prolific oil producers to date.

Stratigraphy (Fig. 2)—According to Laird (1953, p. 27) and McCabe (1954, p. 2009) definite unconformities exist at the base of the following formations: the Winnipeg, Ashern and Englewood. The unconformities at the base of the Ashern and Englewood formations are especially important because oil is associated with them.

The presence of unconformities in the Mississippian system is subject to question. McCabe (1954, p. 2005) has said "The Charles formation of Meramec age conformably overlies the Mission Canyon and has a facies relationship to the Mission Canyon. As recognized

in the subsurface by the usual methods, the contact between the Mission Canyon and Charles is not considered a time line." According to Mueller (1954, p. 112) an unconformity is present between these formations. Thus it seems the relationship of the Charles to the Mission Canyon is not yet fully known. As indicated by McCabe (1954, p. 2008) the Kibbey formation unconformably overlies the Charles. This unconformity is very difficult to pick out in the Beaver Lodge and Tioga fields (Laird, 1954, p. 14). The Amsden formation unconformably overlies the Big Snowy group as a result of post-Mississippian, pre-Atokan erosion (McCabe, 1954, p. 2006).

The unconformity at the base of the Triassic and Jurassic systems is complex in view of the fact that these systems are known to transgress older rock systems in the Basin.

The hiatus at the base of the Cretaceous system probably represents much of upper Jurassic and practically all of lower Cretaceous time.

The Paleozoic rocks in the Basin are primarily carbonates (limestone and dolomite), but clastic sediments are found at the base of the Ordovician system and evaporite sediments at the top of the Mississippian system (Barnes, 1953, p. 342). The clastic sediments were derived from the Pre-Cambrian landmass situated on the east, southeast, and northwest of the Basin (Laird, 1953, p. 29). The halite and anhydrite sequences in the Devonian system indicate that at this time the Basin was constricted and arid conditions prevailed. Also the considerable amount of anhydrite in the Charles sequence indicates pronounced evaporite conditions during the Mississippian period.

The most prolific oil producing horizon in North Dakota is the Mission Canyon formation of the Madison group. This group attains a thickness of approximately 2,300 feet in northwestern North Dakota and thins toward the margins of the Basin. It consists of the Lodgepole, Mission Canyon and Charles formations in ascending order. The group is largely a carbonate sequence of shelf-like deposits that grade upward to evaporite sediments.

The Mesozoic section is primarily composed of clastic sediments except the lower part that consists of evaporites where present. This sequence indicates that evaporite conditions prevailed from Triassic formations through the Piper evaporitic sequence of the middle Jurassic.

Basal Cenozoic sedimentary rocks in North Dakota are represented by the marine beds of the Paleocene Cannonball formation. As the formation is traced westward it interlenses with continental beds of the Ludlow formation and is in turn overlain by continental beds of the Tongue River, lignite-bearing, formation.

Era	System	Series	Group	Formation	* Thickness in feet	Description
Cenozoic	Tertiary	Pleistocene		Glacial Drift	500	Moraine, dunes, delta, lake and outwash deposits. Absent in southwestern quarter of state.
		Oligocene		White River	50-200	Light colored shales, clays, and limestones.
		Eocene		Golden Valley	100-200	Light colored clays, ash, sandstones.
		Paleocene	Fort Union	Tongue River	200-800	Light and dark colored calcareous shale and sandstone and lignite.
				Cannonball Ludlow	300	Cannonball: marine sands and clays. Ludlow: continental shale sandstone, lignite.
Mesozoic	Cretaceous	Upper		Hell Creek	100-575	Gray bentonitic sandstone and shale, lignitic shale and concretions.
			Montana	Fox Hills	180-320	Brown to gray sandstone with ironstone concretions.
				Pierre	930-2300	Medium to light gray shales with ironstone concretions.
			Colorado	Niobrara	80-215	Gray calcareous and speckled shale.
		—?—		Benton	90-1360	Medium dark gray shale with bentonite. Includes Greenhorn ls. and "Muddy Sand" members.
		Lower	Cloverly	Dakota	100-300	Micaceous white sandstone with pyrite, gypsum, and lignite.
				Fuson	150	Gray shale and sandstone. Where Fuson shale is absent, separation of Dakota and Lakota not attempted.
				Lakota	20-190	Coarse white sandstone with little shale.
	Jurassic	Upper		Morrison	260	Gray and green non-marine shale, sand-stone.
				Sundance	650	Green, gray, brown shale, sandstone, small limestone.
		Middle	Ellis	Piper	350	Brown, gray shale, gypsum, anhydrite. Dense limestone at top.
	Triassic			Spearfish	900	Brown silty shale, red sandstone, gypsum, anhydrite.

Era	System	Series	Group	Formation	Thickness in feet	Description
Paleozoic	Permian			Minnekahta	40	Pink, purple dolomite, limestone. Southwestern N. D.
				Opeche	88	Red shale, anhydrite. Southwestern N. D.
	Penn.			** Minnelusa	300	White, reddish sandstone, shale, gypsum, dolomite. Southwestern N. D. Oil horizon.
				"Amsden"	250	Pink, light purple dolomite, dark shale, brown shale, small sandstone.
	Mississippian	Chester	Big Snowy	** Heath	335	Dark carbonaceous shale, gray to green shale, dolomite. Oil horizon.
				Otter	310	Gray, green, light brown shale, and anhydrite.
				Kibbey	350	Gray to brown shale, olive to pink sandstone at base.
		Osage-Meramec	Madison	** Charles	890	Pale brown and brownish gray dolomite, limestone, varicolored shale, anhydrite. Oil horizon.
				** Mission Canyon	530	Granular to oolitic very pale yellowish brown, light gray, and very pale orange limestone. Oil horizon.
				Lodgepole	880	Gray, yellowish brown, granular to crystalline limestone and shaley limestone, gray shale.
		—?— Kinderhook		** Englewood	110	Carbonaceous shale, gray limestone, gray shale, fine sandstone. Oil horizon.
	Devonian	Upper		Lyleton	190	Red, pink, moderate orange dolomitic shale, silt, dolomite, anhydrite.
			Saskatchewan	"Nisku"	125	Yellowish gray to dark brown crystalline limestone, vugular.
				** Duperow	425	Light colored sugary and dark brown crystalline dolomite, anhydrite, shale. Oil horizon.
			Beaverhill Lake	Souris River	300	Light to yellowish gray shaley and anhydritic limestone and dolomite.
				Dawson Bay	200	Light olive to yellowish gray sugary dolomite and limestone, small sand, shale, anhydrite.
		—?— Middle	Elk Point	Prairie Evap.	300	Anhydrite, red to brown shale, salt, dolomite. May be top member of Winnipegosis formation. Western N. D.
				Winnipegosis	250	Pinkish, light gray and pale brown, fine to granular and fragmental porus dolomite.
				Ashern	50	Red to pale orange dolomitic shale, anhydrite.

Paleozoic	Silurian		Interlake	**	1200	Very pale orange and pink sugary to lithographic dolomite, small shale, sandstone. Oil horizon.
Paleozoic	Ordovician	Upper		Stony Mountain	200	Gunton memb. at top is light colored sugary dolomite. Basal Stony Mtn. shale memb. is red, green, gray shale, with gray fossiliferous limestone.
Paleozoic	Ordovician	Middle		Red River	600	Very pale orange to pinkish gray dense to granular dolomitic and sandy ls.
Paleozoic	Ordovician	Middle		Winnipeg	550	Gray, greenish gray shale, white and glauconitic sandstone, small gray ls.
Paleozoic	Camb			Deadwood		Green shale, dolomite, glauconitic sandstone. Distribution uncertain.
Pre-Camb.						Granite, granite gneiss, amphibolite schist.

*Where range is not given the thickness ranges from zero to indicated maximum thickness.
**Oil horizon.

Fig. 2.—Generalized Stratigraphic Section of Formations in North Dakota.

The Tertiary system in the Basin is represented by remnants of the Eocene and Oligocene formations. The eastern part of the Basin is covered by Pleistocene glacial drift.

The advance of the glaciers from the north was the last great geologic event affecting the Williston Basin. The glaciers left a mantle of drift that is as much as 500 feet thick spread over the northeast part of the Basin. This cover of drift hampers exploration for oil by limiting surface geology and seismological operations.

HISTORY OF EXPLORATION

Oil was discovered in North Dakota on April 4, 1951, when the Amerada Petroleum Company drilled the now famous Clarence Iverson No. 1 well at Tioga. Although this event surprised the nation and probably many persons in the oil industry it was the result of a well planned exploration program on the part of the Amerada Corporation. In 1946 they started seismograph work on the Nesson anticline in Williams and McKenzie counties. This was accompanied by surface and regional subsurface studies (Laird, 1954, p. 3).

When drilling the Clarence Iverson No. 1 well insignificant oil shows were encountered in the Madison group and the Silurian system and the well was completed in the Devonian system. Later,

because of production from the Madison in nearby fields, Amerada returned to the Clarence Iverson No. 1 well and recompleted it as a producer in the Madison (Laird, 1954, p. 3).

The first oil field discovered in the Williston Basin was the Virden field in southwestern Manitoba. In February of 1951 California-Standard completed small production from that field.

The first oil or gas indication in the state was in 1907 when the Great Northern Gas and Pipeline Company discovered gas in Bottineau County at the depth of 178 feet while drilling for water. This supplied the town of Westhope with gas for several years. In 1919 the Pioneer Oil and Gas Company drilled a well to a depth of 2107 feet just south of Williston but no oil was found. The first well drilled on the Nesson anticline was by the Big Viking Oil Company sometime between 1926 and 1935. The exact date is not on file with the North Dakota Geological Survey. The well was drilled to a depth of 4642 feet, bottoming in the Dakota sandstone. In 1938 the California Company drilled the Nels Kamp No. 1 well in the same quarter section as the Big Viking well to a depth of 10,281 feet in the upper Devonian but the well was abandoned due to mechanical difficulties.

The Nesson anticline, the largest structure in the state, was first mapped in 1910 by A. J. Collier of the United States Geological Survey. In 1922 L. P. Dove, then working for the North Dakota Geological Survey and the University of North Dakota, wrote a short article on the geology and structure of the Nesson anticline. This was published in the Quarterly Journal of the University of North Dakota. In 1946 the North Dakota Geological Survey released a study of the Keene dome, a dome on the Nesson anticline.

The most important pools in the state thus far, and it seems likely they will remain so, are the first two discovered, the Beaver Lodge and Tioga fields. These are situated on the Nesson anticline, and while the limits of the Beaver Lodge field have been established, the Tioga is still open on the north end. The two fields have a total of 330 wells. South of these fields are a number of smaller and less important ones, also on the Nesson anticline. These fields are structurally controlled and produce from local highs on the anticline. They produce mainly from Madison limestone at depths of approximately 10,000 feet. The maximum reservior interval is more than 150 feet but lack of permeability prohibits the entire interval from producing.

Outside of the Nesson anticline production is obtained from the Westhope, North Westhope, and Northeast Landa fields on the eastern flank of the basin. These fields are small producers and are much more shallow than those near the center of the Basin. They produce from the Madison group at 3100 feet. Oil is found in these fields where the Mississippian carbonate is unconformably overlain by red beds of the Spearfish formation. Production seems to be controlled stratigraphically (Harris, 1953, p. B12).

The only sandstone production found in the United States part of the Williston Basin has been from a sand near the base of the Englewood formation in the Sanish field on the Nesson anticline and from the Fryburg sand near the base of the Heath formation in the Fryburg. The Fryburg field is situated off the Nesson anticlinal trend in Billings County in the south-west part of the state and was found purely on geophysical date.

Exploration—No single tool provides an adequate means for exploring the Williston Basin (Pohly and Harris, 1954, p. 119). The seismograph has been the major exploration tool but it is not very successful on the flanks of the Basin for finding stratigraphic traps. It has been used with most success on structures such as the Nesson anticline. Seismic activity has dropped considerably in the state, but as more control is established considerable reshooting will be done. Surface geology and aerial photographs have a limited use because of the mantle of glacial drift that covers the northeastern part of the Basin. The magnometer and gravity meter used in conjunction with the other methods have proven very useful (Pohly and Harris, 1954, p. 121).

Wildcat drilling North Dakota is among the highest priced in the United States. This cost is due to lack of oil field supplies and warehouses, distances to service companies, high cost of cold weather protection, truckage charges, mud change overs in deep tests and completion practices for limestone reservoirs. The cost of drilling the discovery well was $721,000 and other deep tests cost about $500,000. Extension well drilling and completion in the Beaver Lodge field cost approximately $200,000 (Harris, 1953, p. B12). Footage drilled (Fig. 3) increased greatly during 1954.

There is still much exploration to be done as is illustrated by the fact that the drilling density in the Basin was still only one well to 375 square miles up to 1954. It seems that much more will be done because 32,000,000 of the states 45,000,000 acres are under lease.

MARKETING

Until recently, oil field development was handicapped by inadequate pipeline and marketing facilities. Most North Dakota oil was transported by rail and as a result the field price was lowered. The rail rate from Tioga to Chicago was $1.41 per barrel which is much higher than the price for pipeline movement over an equal distance. This condition has been removed by the recent completion of the following refineries in the state:

1. Williston Basin Refining Corporation Plant at Williston, capacity 1,500 barrels per day.
2. Standard Oil Refinery at Mandan, capacity 30,000 barrels per day.
3. Dickinson Refinery at Dickinson, capacity 2,500 barrels per day.

In 1953 the Service Pipeline Company completed a trunk line

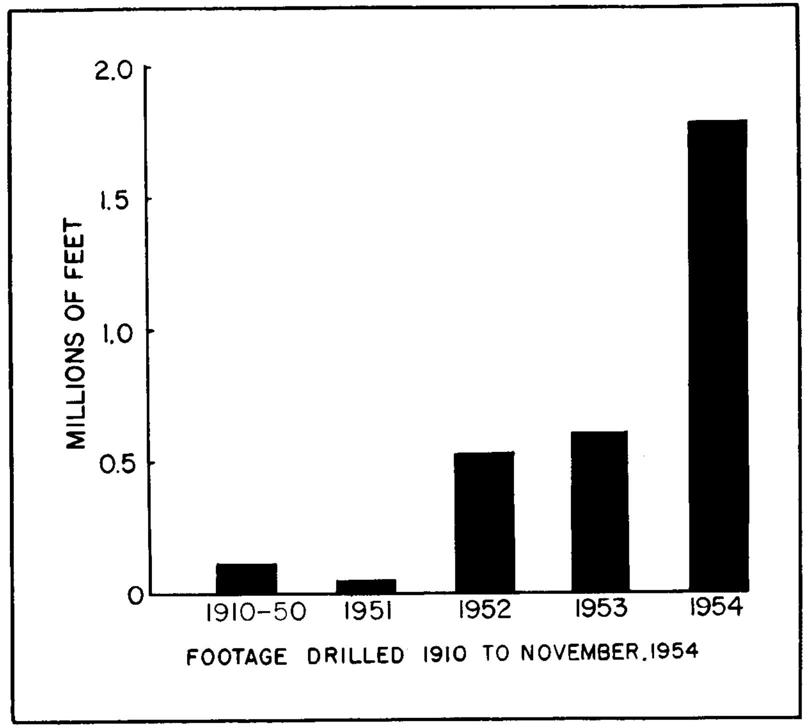

Fig. 3.—Oil exploration and development footage drilled in North Dakota.

from the Nesson anticline fields to the then uncompleted Mandan refinery. A products pipeline linking Mandan with Standards existing products line at Moorhead, Minnesota was also completed in 1953.

The Nesson anticline fields have a substantial gas to oil ratio, about 1000 to 1. The Signal Oil and Gas Company's plant at Tioga will yield an estimated 150,000 gallons of natural gasoline and LPG and 40 tons of sulphur daily. Proposals have also been made for natural gas pipe lines to market the dry gas in eastern North Dakota.

RESERVES AND PRODUCTION

Estimates of the oil reserves in the Williston Basin range up to a billion barrels. A preliminary estimate, by the North Dakota Geological Survey, revealed that the entire state can expect a total production of not less than a quarter of a billion barrels of oil. With continued exploration and development of new fields, it may soon be realized that this figure was too conservative. The crude oil is mostly 40 to 44 degrees API and has a pour point of around zero degrees Fahrenheit which is fortunate because of the low winter temperatures in the state (Harris, 1953, p. B12).

NORTH DAKOTA OIL FIELDS—WILLISTON BASIN

Name	Discovery Date	Producing Formation	Depth	1954 Production (to October)
Beaver Lodge	1951	Interlake group	11,628	
Beaver Lodge	1951	Duperow formation	10,198	7,577
Beaver Lodge	1951	Mission Canyon	8,500	1,793,523
Tioga	1952	Mission Canyon	8,200	1,534,074
Croff	1952	Mission Canyon	9,500	10,372
Charlson	1952	Mission Canyon	9,000	191,165
Hofflund	1952	Mission Canyon	8,675	71,948
Westhope	1952	Charles	3,350	887
East Tioga	1953	Mission Canyon	8,375	33,265
Keene	1953	Mission Canyon	9,100	5,339
North Westhope	1953	Charles	3,250	12,059
Northeast Landa	1953	Charles	3,075	11,272
Fryburg	1953	Mission Canyon	9,400	97,783
Capa	1953	Mission Canyon	8,325	52,488
Sanish	1953	Englewood	10,525	91,594
White Earth	1954	Mission Canyon	8,420	48,394
Fryburg Heath	1954	Heath	8,270	803
McGregor	1954	Mission Canyon	8,186	11,656
Unnamed (Agre)	1954	Mission Canyon		610
Belfield Heath	1954	Heath	8,249	227

YEARLY TOTAL PRODUCTION IN BARRELS

1951	26,727
1952	1,602,269
1953	5,277,593
1954	3,975,058 (to October)

NORTH DAKOTA OIL CONSERVATION LAWS

The North Dakota Legislature recently passed a new oil conservation law, but even prior to the discovery of oil the state had a good oil conservation law. In 1941 under the advice of Dr. Wilson M. Laird, State Geologist, The Interstate Oil Compact Commission's "Model Act" was passed. In 1953, the 1950 Model Act of The Interstate Oil Compact Commission was substituted for the earlier one.

According to the new law when a field is discovered the state Industrial Commission meets within fifteen days of the discovery and sets a temporary spacing pattern for the pool. Eighteen months later the commission must meet again to determine permanent spacing. In prorating production to market demand the 40-acre tract is the basic unit allowable. A pool with 80-acre spacing gets double the allowable production. Another provision makes allowance for producing depths and the increased cost of deep drilling. The normal unit allowable is set for a well of 5,000 feet and for wells deeper than this the allowable increases with depth. Wells having a gas-oil ratio in excess of 2000 cubic feet per barrel are penalized by the amount of excess.

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A Preliminary Correlation of Lower Cretaceous Sediments in North Dakota

BY DAN E. HANSEN

INTRODUCTION

The Lower Cretaceous quartzose sandstone and gray shale of North Dakota are correlated throughout the state by means of subsurface lithologic study, stratigraphic position, electric logs, and gamma ray logs (from radioactivity log). Fossils are not available and this prohibits any definite time study. The top of the lower Upper Cretaceous Greenhorn formation is used as a datum. The Greenhorn is easily recognized in the subsurface by lithologic characteristics and from definite patterns on the resistivity curve. It is also believed by many that time lines and formation boundaries are nearly coincident for the top of this formation.

The Lower Cretaceous has not been thoroughly studied as a unit in North Dakota because of the few exploration wells drilled prior to 1951. Not until 1952 has the number of wells increased sufficiently to give definite proof of the sedimentary correlation.

Previous work consists of very general descriptions of the Lower Cretaceous. Seager, et al, (1942) discuss the lower section of the Cretaceous in a general stratigraphic article on North Dakota sediments. Laird and Towse (1953) describe the Lower Cretaceous of North Dakota and present formation names used by the North Dakota Geological Survey. The North Dakota Geological Society (1953) published an electric log correlation of sedimentary rocks in North Dakota and nearby states. The United States Geological Survey has published ground water reports for the eastern part of North Dakota in which sands described as "Dakota" are found in the deeper test wells. Lithologic descriptions of many of the wells drilled in the state are issued by the North Dakota Geological Survey in the form of circulars. Gries (1954) describes and presents a correlation of the Lower Cretaceous sands from southeastern South Dakota to the Black Hills Region of South Dakota. A comparable situation exists in the Lower Cretaceous of North Dakota.

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NOMENCLATURE

The nomenclature used in this report conforms fairly well to that used by the North Dakota Geological Survey and to that used by Cobban and Reeside (1952) in their correlation of the Cretaceous formations of the Western Interior of the United States. The formations occuring in North Dakota are equivalents of formations in the Northern Black Hills of South Dakota, and the nomenclature is extended from that area. The following is the nomenclature used in the Black Hills of South Dakota: Greenhorn, Belle Fourche, Mowry, Newcastle, Skull Creek and the Inyan Kara Group (Fall River, Fuson, Lakota).

The nomenclature used in this report is also generally the same as used by the petroleum industry. In this report the Mowry shale and Newcastle sandstone are included as one unit. The Lower Cretaceous sandstone is included in the Cloverly Group ("Dakota"), a term suggested by the nomenclature committee of the American Association of Petroleum Geologists for the Williston Basin. Exact terminology of the group awaits correlation with the equivalent sandstone in eastern and western South Dakota. Formation nomenclature will be discussed further in the descriptions of the formations.

LAKOTA FORMATION

The Lakota formation, named and described by Darton (1899), 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 (Darton and O'Harra, 1909) is Lakota peak, a summit on Hogback range, 4 miles northwest of Hermosa, South Dakota.

In North Dakota the subsurface equivalent of the Lakota consists of white, medium to coarse-grained, quartzose sandstone with shale streaks. The thickness of the sandstone ranges from zero feet in the northeast corner of the state to 120 feet in the southeast and northwest corners of the state. The Lakota is present throughout the deeper portion of the sedimentary basin in North Dakota. In southeastern North Dakota the basal sandstone, separated from overlying sandstone lenses by thin shale strata, consists of very coarse sandstone, angular to subrounded, white, clear quartz grains, polished grains of gray chert, pale brown limestone, and a few grains of pink quartz. In areal extent the very coarse sandstone can be traced from the Herman Hanson Oil Syndicates Billey well No. 1, Sec. 11, T. 129 N., R. 77 W., Dickey County to the General Atlas Peplinski well No. 1, Sec. 21, T. 142 N., R. 63 W., Stutsman County, thence to the Pollard and Davis Gregory No. 1, Sec. 23, T. 143 N., R. 61 W. Barnes County. This sandstone practically coalesces with the overlying Fall River sandstone. The coarse sandstone indicates a nearby source area to the south and east.

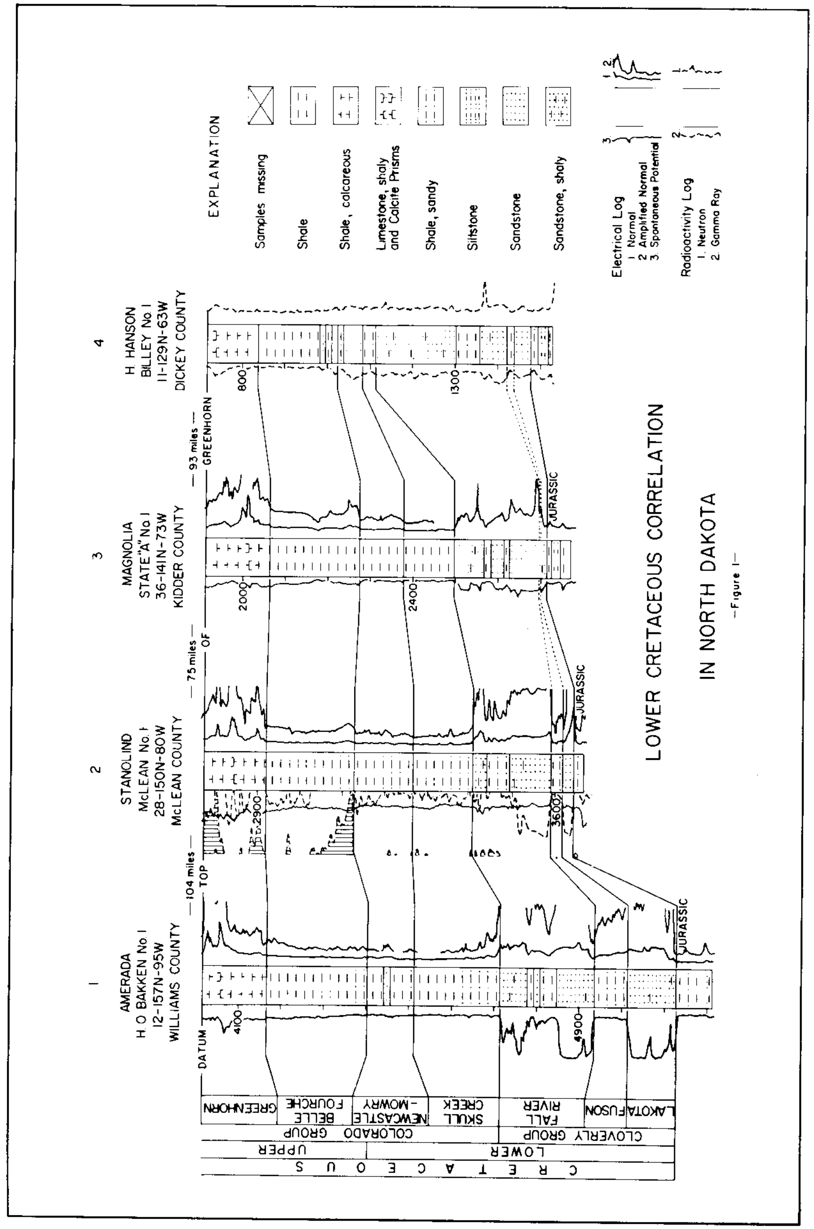

Fig. 1.—Lower Cretaceous Correlation in North Dakota.

Following is a section of the Lakota equivalent in the Stanolind Oil and Gas Company, McLean County well No. 1, Sec. 28, T. 150 N., R. 80 W., McLean County (See Fig. 1):

Depth (feet)	Description
3630-3650	Sandstone, loose grains of white, clear pink, angular to subround, quartz. Contains medium grey, soft, flaky to lumpy shale.
3650-3653 (Core)	Sandstone, slightly calcareous cemented, medium, angular to subrounded, white, pink, clear quartz grains with light gray silt and shale.
3653-3655.6 (Core)	Limestone, light gray, sandy and changes to calcareous cemented medium quartz sandstone. Contains pyrite and carbonaceous streaks.

The Lakota equivalent in North Dakota lies unconformably above the erosional Jurassic surface. The sands are lenticular, although the formation is wide spread, and are developed as a more massive unit near the crests of structures or between the Jurassic topographic high. The sandstones are a product of a sea transgressing from the west.

FUSON FORMATION

The Fuson shale was named by Darton (1901) from exposures in Fuson Canyon on the east side of the Black Hills. The Fuson is described as consisting of very fine-grained sandstone, and massive shale and clay, 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 very fine quartzose sandstones. The shale is 80 feet thick in the western part of the state to zero feet in the northeast corner of the state. The sand facies develops in the southeast corner of the state and farther east of this area the shale is probably absent.

The following is a section of the Fuson equivalent in the Amerada Petroleum Corporation Henry O. Bakken Well No. 1, Sec. 12, T. 157 N., R. 95 W., Williams County.

Depth (feet)	Description
5030-5040	Shale, dark gray, soft, micaceous flaky, with very fine white quartz sandstone.
-5080	Shale, dark gray, soft, micaceous flaky. Sample from 5060-5070 contains a small amount of fine greenish-gray glauconitic sandstone.
-5115	Shale, dark gray, medium gray, soft, flaky, lumpy. Interval from 5090-5010 contains a small amount of very fine to fine grain white quartz sandstone with some glauconite. A few light brown siltstone concretions of medium grain size are present in the interval 5110-5115.

The Fuson shale equivalent forms the interval between the lower Lower Cretaceous sandstone (Lakota) and the overlying upper Lower Cretaceous sandstone called the Fall River formation in this report. The thickness of the Fuson is the result of the amount of reworking of the sediments and the proximity to the source area. The shale is either absent or it may be present as a very thin "shale break" in the more shallow areas of the sedimentary basin. The formation is devoid of fossils, but contains a few siltstone concretions.

FALL RIVER FORMATION

The Fall River formation was named and described by Russell (1928) as 75 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 equivalent consists of interbedded light gray, shaly, fine-grained to coarse-grained quartzose sandstone and sandy gray, soft, flaky to massive and lumpy shale. The formation equivalent is 210 feet thick in the western section of North Dakota to 120 feet thick in the southeastern part of the state, where the Fall River sandstone transgresses the stratigraphic column it forms the sandstone facies of the overlying Skull Creek Shale. In northeastern North Dakota the Fall River is the basal Lower Cretaceous sandstone. In the deeper parts of the basin the contact with the overlying Skull Creek shale is "picked" by the decrease in the resitivity curves.

Following is a sample description of the Fall River equivalent in the Amerada Petroleum Corporation Henry O. Bakken well No. 1, Sec. 12, T. 157 N., R. 95 W., Williams County.

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

The Fall River is the most extensive of the Lower Cretaceous sandstone formations, and forms the major part of the sandstone facies of the Lower Cretaceous shale in North Dakota. The Fall River sandstone merges with the underlying Lakota on the eastern edge of the sedimentary basin. Throughout the state the lower sandstone lenses of the formation are of a lenticular nature. In the northeastern and southeastern parts of the state the upper sandstane is more continuous. In the western part of the state fine-grained sandstone predominates, and medium-grained sandstone predominates on the eastern edge.

SKULL CREEK FORMATION

The Skull Creek member of the Graneros was named by Collier (1922) from exposures along Skull Creek southeast of Osage, Weston County, Wyoming. The member is described as consisting mainly of dark bluish-gray shale, about 200 feet thick, and containing a few calcareous concretions and some siliceous shale near the base. In the subsurface of North Dakota the Skull Creek equivalent is soft, dark to medium-gray shalt, sandy at the base, and transitional with the underlying Fall River sandstone. The shale formation ranges in thickness from 140 feet in the western part of the state to 40 feet or less on the eastern edge of the sedimentary basin.

Following is a sample description of the Skull Creek equivalent in the Stanolind Oil and Gas Company, Bruish well No. 1, Sec. 8, T. 135 N, R. 98 W., Slope County (See Fig. 2):

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

The medium-gray to dark-gray Skull Creek shale thins to the east in the state of North Dakota and is transitional with the underlying Fall River sandstone equivalent. The contact of the shale with the overlying Newcastle sandstone is recognized by an increased resistivity on the electric log.

NEWCASTLE-MOWRY

The Newcastle sandstone member of the Graneros is described by Hancock (1920) as a reddish to light-yellow sandstone associated with black carbonaceous shale. It was named for the conspicuous development at Newcastle, Wyoming. In the northern Black Hills the Newcastle sandstone overlies the Skull Creek formation and underlies the Mowry shale.

In North Dakota the subsurface equivalent of the Newcastle sandstone is a shaly and silty very fine-grained light-gray quartz sandstone. The sandstone is lenticular and is present only on the edges or over structures in the sedimentary basin. The sandstone does, however, occupy the same stratigraphic position in its relationship to the sediments above and below. These sandstone equivalents are found in the northwest, northeast, southwest and southeast corners of the state.

The Mowry shale was named by Darton (1904) for Mowry Creek, northwest of Buffalo, Johnson County, Wyoming. Rubey

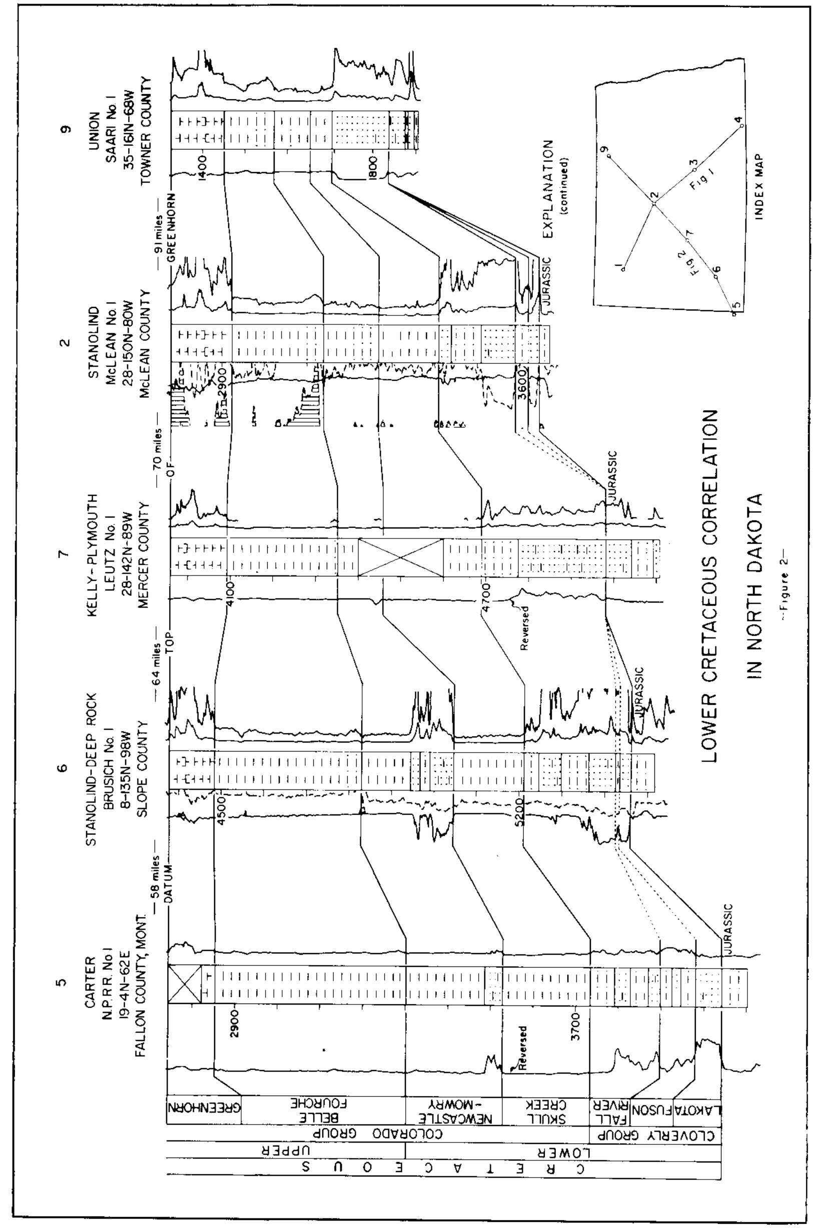

Fig. 2.—Lower Cretaceous Correlation in North Dakota.

(1929) described the Mowry shale as a siliceous claystone that is progressively harder toward the top, and weathers to silvery-gray chips. The thinning edge of the subsurface equivalent of the Mowry shale in North Dakota is present in the Carter N.P.R.R. well No. 1, Sec. 19, T. 4 N., R. 62 E., Fallon County Montana, and in the Stanolind Oil and Gas Company Bruish well No. 1, Sec. 8, T. 135 N., R. 98 W., Slope County. In both wells the shale is dark-gray to medium-gray, flaky, soft, spongy, bentonitic, and contains light blue-gray and white bentonite. In the Stanolind Bruish well the silt content increases.

Following is a sample description of the Newcastel-Mowry equivalent in the Stanolind Oil and Gas Company, McLean County Well No. 1, Sec. 28, T. 150 N., R. 80 W., McLean County.

Depth (feet)	Description
3135-3170	Shale, medium dark gray, soft, flaky to lumpy and spongy, and silty.
-3260	Shale, medium dark gray with bentonitic silt. Interval from 3190-3200 and 3220-3250 contain a few fragments of a hard, very fine, light gray, calcareous cemented quartz sandstone. A few chunks of light gray-white bentonite.

The Mowry thins out in the western part of North Dakota, and forms a silty facies with the underlying Newcastle sandstone that is present throughout the major portion of the sedimentary basin. In North Dakota the Newcastle sandstone equivalent occurs in the four corners of the state. The sandstone appears to be isolated in the northeast corner, but the other three lentils can be correlated with equivalents outside the state. The top of the Newcastle-Mowry intervals underlies a bentonitic, silty to sandy, gray shale zone that is apparent on both electrical resistivity curves and the gamma ray log, where the zone appears as the lowest large gamma ray "kick" above the less radioactive Lower Cretaceous sediments.

BELLE FOURCHE FORMATION

The Upper Cretaceous Belle Fourche shale member of the Graneros shale is described by Collier (1922) as the top member consisting of dark gray shale, 560 feet thick, containing 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 in the neighborhood of Wind Creek, Crook County, Wyoming. In the subsurface of North Dakota the Upper Cretaceous Belle Fourche equivalent 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. The shale is 350 feet thick in the western edge of the state to 100 feet thick on the eastern edge of the sedimentary basin. On the eastern edge of the

basin the Belle Fourche equivalent is more silty and sandy, and the calcareous content increases slightly.

Following is the Belle Fourche interval in the Stanolind Oil and Gas Company, Deep Rock Brusich Well No. 1, Sec. 8, T. 153 N., R. 98 W., Slope County.

Depth (feet)	Description
4490-4590	Shale, medium dark gray, micaceous soft, spongy to flaky. With medium blue gray, white, light gray bentonite.
-4640	Shale, medium dark gray, olive gray, micaceous, soft. With small amounts of pyrite and light gray, white and medium dark blue bentonites.
-4800	Shale, dark gray, flaky, soft, micaceous. With small amount medium gray silt. Interval from 4770-4800 contains small amount of white and light bluish-gray bentonite.
-4830	Shale, dark gray as above. With slightly calcareous bentonitic medium gray silt.

The Belle Fourche shale equivalent underlies the Greenhorn formation and occurs at the base of lower Upper Cretaceous described in this report. The boundary between the Belle Fourche and the underlying Newcastle-Mowry section is apparent only from the electrical resistivity and the gamma ray logs. The Belle Fourche shale is lenticular in nature, and thins from east to west across the state. The shale also appears to contain a fine-grained calcareous, sand facies on its thinner east edge.

GREENHORN FORMATION

The Greenhorn formation was named by Gilbert (1896) for Greenhorn station, 14 miles south of Pueblo, Colorado and for Greenhorn Creek. Darton (1909) applied the name to similar strata in the Black Hills. In the northern Black Hills (Cobban, 1951) the formation is largely a light-gray calcareous mudstone with interbedded marl. In the subsurface of North Dakota the Greenhorn equivalent consists of dark gray calcareous soft shale with thin-beds of very shaly limestone. Also found in the samples are calcite prisms, a few fragments of *Inoceramus* shells, and in the majority of the well samples, the lower part of the formation contains *Globigerina*. This formation is called the second white speck zone by some in the oil industry. The thickness ranges from 150 feet to 120 feet and appears to be thickest on the east edge of the basin. Following is the Greenhorn equivalent interval in the Union Oil Company Saari Well No. 1, Sec. 35, T. 161 N., R. 68 W., Towner County.

Depth (feet)	Description
1330-1480	Shale, dark gray to medium dark gray, very calcareous with white specks. Calcite prisms and fragments of light gray limestone present. The samples contain a few chunks of pyrite and bluish gray bentonite.

The Greenhorn formation equivalent is present in all but the extreme eastern part of the state. The Greenhorn boundary with the underlying Belle Fourche is gradational. The gamma ray characteristics of the Niobrara, Greenhorn, and Belle Fourche are similar.

CONCLUSIONS

The Lower Cretaceous sediments contain the major portion of the sandstone present in the Cretaceous of North Dakota. The sandstone facies are products chiefly of transgressing seas, and although locally massive their equivalents are present throughout the state. The lower sandstone facies are also localized due to the relief on the underlying Jurassic surface. The sandstone lenses probably coalesce in the extreme eastern part of the state and form a thick sandstone unit that represents the complete Lower Cretaceous sedimentary sequence. This sandstone forms a unit that has not been named or thoroughly studied in North Dakota. The sandstone sequence is thinner in the northeastern part of the state and only the upper Fall River equivalent is the product of a limited regression and transgression of the sea, hence the localized nature of the sand. With these conditions in mind the correlation of the Lower Cretaceous sandstone formations is greatly facilitated.

The contact between the Upper and Lower Cretaceous lies between the Belle Fourche Shale equivalent and the Newcastle-Mowry interval. This contact is marked by a wedging out of the Mowry shale in the southwestern part of the state. The "break" as marked by the gamma ray log is consistant throughout the state. This gamma ray increase is due to bentonitic siltstone and very fine sandstone. The Belle Fourche equivalent thins from west to east, and the main source of sediments moved from the east during Lower Cretaceous time to practically a single western source during Upper Cretaceous time. The Mowry shale may mark this transition. The characteristics of the Greenhorn and Belle Fourche equivalents are simple to locate on the electrical and radioactivity logs. The two formations appear to be genetically related on the basis of their electrical and radio activity log characteristics.

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Foraminifera of the Niobrara Formation of Northeastern North Dakota

ARLAND C. GRUNSETH

PURPOSE OF THIS INVESTIGATION

This report is written in partial fulfillment of the requirements for the Ph. B. degree in geology. It describes the results of a preliminary investigation of the microfaunal content of the Niobrara formation in northeastern North Dakota. The main purpose of the report is to describe and illustrate the foraminifera collected from an exposure of the Niobrara formation along Pembina River in Cavalier County. An attempt is also made to determine the areal distribution and the vertical range of the microfauna, by comparing the fauna of the restricted zone in the Pembina Mountains with those foraminifera described from other localities to the southwest in the thicker parts of the Niobrara.

The Niobrara is an extensive marine formation of Upper Cretaceous age. The formation ranges in thickness from 150 feet in the section under consideration, to as much as 545 feet in Deloraine in Manitoba, Canada.[1] The Niobrara formation, principally silty shale, crops out in the Pembina Mountains situated in northeastern North Dakota, and along Sheyenne River near Valley City, North Dakota.

STRATIGRAPHY

The Niobrara is the upper formation in the Colorado group of the Upper Cretaceous System; it is overlain by the Pierre Formation, and underlain by the Benton formation. The Niobrara formation was named by Meek and Hayden[2] in 1862 from exposures along the Niobrara River in northeastern Nebraska.[2] A measured section presented in the following table is reported to represent the upper 30 feet of the Niobrara formation in Pembina Mountains, North Dakota.

Table 1

SECTION IN NORTHEASTERN NORTH DAKOTA

Cavalier County, North Dakota
T. 163 N., R. 57 W., Sec. 18.

Unit A	14 feet (Samples A1-A7)
	10 feet of friable limestone
	3 inch rusty bed at base
	4 feet of medium hard limestone
	4 inch rusty bed at base
Unit B	8 feet 6 inches (Samples B1-B4)
	5 feet 6 inches of medium hard limestone
	3 inch rusty bed at base
	3 inch dense limestone bed
	2 inch rusty bed at middle and base
Unit C	Samples C1-C2
	4 feet of hard limestone
	1 inch rusty bed at base

Unit D Samples D1-D2
3 feet of bentonitic shale
Bottom of section

METHOD OF PROCEDURE

The samples studied in this report were collected by Dr. Donald F. Towse, Department of Geology, University of North Dakota. He was assisted in this work by the Micropaleontology class of 1952. The description of the section listed previously accompanied the samples. The samples were obtained by channeling down the surface of the outcrop. All samples were placed in cloth bags and properly labeled with the unit letter and its zone number.

Each sample was first crushed in a mortar, with special care not to break it down so fine that the microfossils were destroyed. The sample was then poured into a tray with a very fine screen and washed thoroughly. Each sample was dried and sieved in portions of equal size. Every sample collected in a tray of 120 mesh, was boiled slowly on an electric plate for about two hours. The sample was again washed and dried. Difficulty was experienced in cleaning some of the material. Many of the specimens were coated with a limy precipitate. The removal of this coating required one to two hours additional boiling in water to which sodium carbonate had been added.

A binocular microscope was used in picking and identifying the foraminifera. The best specimens were placed in individual trays for study, and chosen for illustrations.

In preparing the illustrations, the outlines of the foraminifera were drawn with the aid of a camera lucida. Ornamentation was then carefully drawn in and inked with assistance from Dr. Gordon L. Bell, Department of Geology, University of North Dakota. Prints were then made of these drawings, and attached at the end of this report.

GENERAL DISCUSSION OF THE FAUNA

In this report 14 species of foraminifera are described from the Pembina Mountains locality. Their distribution and relative abundance is recorded in table two.

All the foraminifera found are dwarfed, and considerably weathered. Little ornamentation is visible because of the heavy precipitate on the forms. The only specimen with a clearly defined aperture is *Gumbelina globulosa*. All other forms showed no aperture because it was either destroyed or covered with some precipitate. Many of the tests were badly compressed. Therefore, identification was extremely difficult and in some cases impossible. Many of the tests were stained with an iron oxide from the weathered silty matrix.

A summary of the foraminifera identified from the Pembina Mountains locality follows. Those marked with an asterisk are most common.

Planulina kansasensis Morrow; *Planulina complanate* (Reuss); *Planulina taylorensis* (Carsey); **Globigerina cretacea* d'Orbigny; *Globigerinella aspera* (Ehrenberg); **Gumbelina globulosa* (Ehrenberg); *Gumbelina tessera* (Ehrenberg); *Lagena globosa,* Montagu; *Bulimina elongata,* d'Orbigny; *Neobulimina irregularis,* Cushman and Parker; *Loxostoma applinae* (Plummer); *Loxostoma tegulatum* (Reuss; *Globulina lacrima,* (Reuss); *Bolivinia Incrassata* (Reuss).

SYSTEMATIC DESCRIPTIONS

Phylum PROTOZOA
Class SARCODINA
Subclass RHIZOPODA
Order FORAMINIFERA
Family ANOMALINIDAE
Genus PLANULINA d'Orbigny, 1826

Planulina complanata (Reuss)

Plate 1, Figures 1 a-c

Planulina complanata—Loetterle, Nebraska Geol. Survey Bull. 2nd. ser., Bull 12, p. 48, pl. 8, figs. 1 a-c, 1937.

Test planispiral, compressed, periphery subacute; chambers numerous, increasing slowly in size as added, later ones slightly inflated; sutures distinct, slightly depressed, somewhat limbate; wall smooth, coarsely perforate. Diameter of figured specimen, .27 mm., thickness, .09 mm.

Planulina complanata (Reuss) is a variable species. It is widely distributed in the Upper Cretaceous. This species ranges through the Fort Hays limestone in South Dakota, Nebraska, and Kansas.

Planulina kansasensis Morrow

Plate 1, Figures 2 a-c

Planulina kansasensis—Morrow, Jour. Paleontology, vol. 8, p. 201, pl. 30, figs. 2 a-b, 12 a-c, 15 a-c, 1934.

Loetterle, Nebraska Geol. Survey Bull., 2nd. ser., Bull 12, p. 49, pl. 8, figs. 2 a-c, 1937.

Cushman, U. S. Geol. Survey Prof. Paper 206, p. 157, pl. 64, fig. 12, 1946.

Test much compressed, slightly trochoid; periphery rounded, chambers numerous, eight to twelve in final whorl; sutures distinct between the later chambers, slightly depressed, gently curved backward; aperture indistinct; wall smooth, perforate, covered in the central area of some specimens by a calcareous deposit. Diameter of figured specimen, .22 mm., thickness, .10 mm.

Morrow found *Planulina kansasensis* in the basal Niobrara, and Loetterle observed it throughout the Niobrara formation. However, Loetterle found that the species is rarely found outside the Fort Hays member. In the present study, it is noted that the inner whorl of *P. kansasensis* is characteristically covered with calcareous material.

Planulina taylorensis (Carsey)

Plate 1, Figures 3 a-c

Planulina taylorensis—Loetterle, Nebraska Geol. Survey Bull. 2nd ser., Bull 12, p. 63, pl. 11, figs. 4 a-c, 1937.

Cushman, Jour. Paleontology, vol. 5, p. 314, pl. 36, fig. 6 a-c, 1931.

Cushman, U. S. Geol. Survey Prof. Paper 206, p. 158, pl. 64, figs. 14, 15, 1946.

Test large, nearly planispiral, much compressed, periphery acute; chambers numerous, usually 10-12 in the final whorl, increasing very slowly in size as added; sutures curved, distinct, slightly depressed. Diameter of figured specimen, .28 mm., thickness, .09 mm.

Planulina taylorensis is widely distributed in the Upper Cretaceous of the Gulf Coastal Plain of the United States. Loetterle states that this species is an excellent guide to the chalky portion of the lower Pierre shale.

Family GLOBIGERINIDAE

Genus Globigerina d'Orbigny, 1826

Globigerina cretacea d'Orbigny

Plate 1, Figures 4 a-c

Globigerina cretacea—Loetterle, Nebraska Geol. Survey Bull. 2nd ser., Bull. 12, p. 44, pl. 7, figs. 1 a-c, 2 a-c, 1937.

Morrow, Jour. Paleontology, vol. 8, p. 198, pl. 30, figs. 7 a-b, 8 a-b, 10 a-b, 1934.

Test trochoid, typically with six globular, inflated chambers which increase rapidly in size as added. The surface is covered with minute spines which are less well-developed in the later chambers. Diameter of figured specimen, .26 mm., thickness, .12 mm.

Morrow states that *Globigerina cretacea* is the most common species of the Cretaceous Foraminifera. It is reported from most Upper Cretaceous areas of the world. Loetterle observed this species everywhere in the Niobrara formation and the chalky zone of the Lower Pierre shale.

Genus Globigerinella, Cushman, 1927

Globigerinella aspera (Ehrenberg)

Globigerinella aspera—Loetterle, Nebraska Geol. Survey Bull. 2nd. ser., Bull. 12, p. 45, pl. 7, figs. 4 a-b, 1937.

Nauss, Jour. Paleontology, vol. 21, p. 337, pl. 48, figs. 9 a-b, 1947.

Test planispirally coiled in the adult, periphery broadly lobulate; chambers numerous, 6-7 in the final whorl, globular, inflated; sutures distinct, deeply incised. No drawing was made of this specimen.

Family HETEROHELICIDAE

Genus Gumbelina Egger, 1900

Gumbelina globulosa (Ehrenberg)

Plate 2, Figures 1 a-b

Gumbelina globulosa—Loetterle, Nebraska Geol. Survey Bull. 2nd ser., Bull. 12, p. 33, pl. 4, figs. 8 a-b, 1937.

Morrow, Jour. Paleontology, vol. 8, p. 194, pl. 29, figs. 18 a-b, 1934.

Cushman, U. S. Geol. Survey Prof. Paper 206, pp. 105-6, pl. 45, figs. 9-15, 1946.

Test elongate, V-shaped, biserial, widening rapidly; chambers few, large, inflated; aperture a large, broad, semilunar opening at the inner margin of the last formed chamber. Length of figured specimen, .35 mm., breadth .27 mm.

Morrow states that *G. globulosa* occurs in great abundance throughout the Colorado group and has been found in the upper Pierre of Kansas. It is also reported from many of the Upper Cretaceous areas of the world.

Gumbelina tessera (Ehrenberg)

Plate 2, Figure 2

Gumbelina tessera—Loetterle, Nebraska Geol. Survey Bull. 2nd. ser., Bull. 12, p. 34, pl. 5, fig. 4, 1937.

Cushman, Jour. Paleontology, vol. 6, p. 338, pl. 51, figs. 4, 5, 1932.

Test small, much compressed; chamber slightly inflated, elongate, rounded; sutures distinct, depressed; wall smooth, very finely perforate. Length of figured specimen, .19 mm., breadth, .10 mm.

Gumbelina tessera is widely distributed in the Upper Cretaceous of southeastern United States. It is a broad, compressed species, the chambers often strongly curved and the sutures decidedly depressed.[3]

Family BULIMINIDAE

Genus Loxostoma Ehrenberg, 1854

Loxostoma applinae (Plummer)

Plate 2, Figure 3

Loxostoma applinae—Loetterle, Nebraska Geol. Survey Bull. 2nd ser., Bull. 12, p. 39, pl. 6, figs. 2 a-b, 1937.

Test elongate; chambers numerous, in the early portion biserial, compressed, in the later half of the test irregularly uniserial; sutures depressed; low, poorly defined lip. Length of figured specimen, .49 mm., breadth, .20 mm.

Loxostoma tegulatum (Reuss)

Loxostoma tegulatum—Loetterle, Nebraska Geol. Survey Bull. 2nd. ser., Bull. 12, p. 40, pl. 6, fig. 3, 1937.

Test much compressed, elongate, slender, tapering; chambers numerous, only slightly inflated. No drawing was made of this specimen.

Family POLYMORPHINIDAE

Genus Globulina d'Orbigny, 1826

Globulina lacrima Reuss

Plate 2, Figure 4

Globulina lacrima—Loetterle, Nebraska Geol. Survey Bull., 2nd. ser., Bull. 12, p. 31, pl. 4, figs. 4 a-b, 1937.
Cushman, U. . Geol. Survey Prof. Paper 206, p. 96, pl. 40 figs. 11, 12, 1946

Test subglobular, the base broadly rounded, apertural end extended; chambers few, very indistinct in most specimens; sutures not depressed; wall smooth.

Lagena globosa Montagu

Lagena globosa—Cushman, U. S. Geol. Survey Prof. Paper 206, p. 95, pl. 39, fig. 26, 1946.

Rounded specimens, generally globular in form, without a basal spine. No drawing was made of this specimen.

Family BULIMINIDAE

Genus Bulimina d'Orbigny, 1826

Bulimina elongata d'Orbigny

Plate 2, Figure 5

Bulimina elongata—Loetterle, Nebraska Geol. Survey Bull. 2nd. ser., Bull. 12, p. 37, pl. 5, fig. 11, 1937.
Sandidge, Jour. Paleontology, vol. 6, p. 281, pl. 43, fig. 3, 1932.

Test elongate, slightly pointed at apical end, rounded at oval end; chambers numerous, increasing slowly in size as added; inflated; sutures distinct, depressed. Length of figured specimen, .25 mm., breadth, .10 mm.

Genus Bolivina d'Orbigny, 1839

Bolivina incrassata Reuss

Plate 2, Figure 6

Bolivina incrassata—Cushman, U. S. Geol. Survey Prof. Paper 206, p. 127, pl. 53, figs. 8-11, 1946.

Test stout, moderately compressed, greatest breadth toward the apertural end; chambers numerous, usually distinct, slightly inflated; sutures fairly distinct, very slightly depressed; wall smooth, very finely perforate. Length of figured specimen, .34 mm., breadth, .12 mm.

Genus Neobulimina Cushman and Wickenden, 1928

Neobulimina irregularis Cushman and Parker

Neobulimina irregularis—Loetterle, Nebraska Geol. Survey Bull. 2nd. ser., Bull 12, p. 38, pl. 5, fig. 12, 1937.
Cushman, U. S. Geol. Survey Prof. Paper 206, p. 125, pl. 52, fig. 13, 1946.

Test elongate and slender, tapering gradually to a bluntly pointed initial end; chambers numerous, triserial in the early stage, later becoming irregularly biserial, inflated; sutures depressed. No drawing was made of this specimen.

SUMMARY

The Niobrara formation of the Upper Cretaceous age is reported to be about 150 feet thick in the Pembina Mountians, northeastern North Dakota. A thirty foot section of the Niobrara formation was sampled and the samples are reported to represent the upper part of the formation. The contact with the overlying Pierre shale was not seen.

The microfauna of this section is dwarfed. The dwarfism may be the result of transgression of Arctic seas during Niobrara time.

The microfauna found indicates a neritic marine environment. The occurrence of the pelagic genus *Globigerina* suggests an open sea condition. Modern forms of this genus are recorded from a wide range of temperatures and depths, but they are most common in waters from 500 fathoms to 3000 fathoms.

Many of the common Upper Cretaceous species are widespread in the samples.

Planulina complanata is an important species in the Fort Hays limestone member of the Niobrara formation in eastern South Dakota and northern Nebraska. Likewise, *Planulina kansasensis* is rarely found outside the Fort Hays member. In the present study it was noted that the inner whorl of *P. kansasensis* is characteristically covered with calcareous material. This condition of the specimen is similar to that described by Loetterle for the abundant P. kansasensis in the Fort Hays member.

P. complanata and *P. kansasensis* as described above are most abundant in the limestone beds in the upper 15 feet of the Niobrara formation in the Pembina Mountains. Thus, it is inferred that the Fort Hays limestone member or its equivalent extends north from South Dakota through northeastern North Dakota.

Explanation Of Letters

A = Abundant

C = Common

F = Few

R = Rare

Units	Zone	Description	Globigerina cretacea	Gumbelina globulosa	Globigerinella aspera	Bolivina incrassata	Globulina lecrima	Gumbelina tessera	Planulina kansasensis	Planulina complanata	Planulina taylorensis	Neobulimina irregularis	Lagena globosa	Loxostoma applinae	Loxostoma teguletum	Bulimina elongata
			FORAMINIFERA													
Unit A	A-1	Sample Missing														
	A-2		C	R					A	F						R
	A-3		A	C	C				A			A		A	C	
	A-4		C		F									F	R	
	A-5	Rusty A-5							F	R		R	R			
	A-6															
	A-7	Rusty A-7	A	A	R											
Unit B	B-1		C	R	R									R	R	
	B-2		C	R							R		R	R		
	B-3	Rusty B-1	A							R	C	R				
	B-4	Rusty B-2 Rusty B-3	C								R	R				
Unit C	C-1		A	A	C		R	F					C			
	C-2	Rusty C-2	A	C	F			R								
Unit D	D-1	Dark	A	A	R	R		R								
	D-2	Shale	A	C	R			R	R					R		

Table II

VERTICAL RANGE AND RELATIVE ABUNDANCE OF SPECIES

Vertical Scale 1" = 8'

PLATE I

Fig. 1.—Planulina complanata (Reuss). X 70 122
a, dorsal view; b, peripheral view; c, ventral view.

Fig. 2.—Planulina kansasensis Morrow. X 70 122
a, dorsal view; b, peripheral view; c, ventral view.

Fig. 3.—Planulina taylorensis (Carsey). X 70 123
a, dorsal view; b, peripheral view; c, ventral view.

Fig. 4.—Globigerina cretacea d'Orbigny. X 70 123
a, dorsal view; b, peripheral view; c, ventral view.

PLATE I

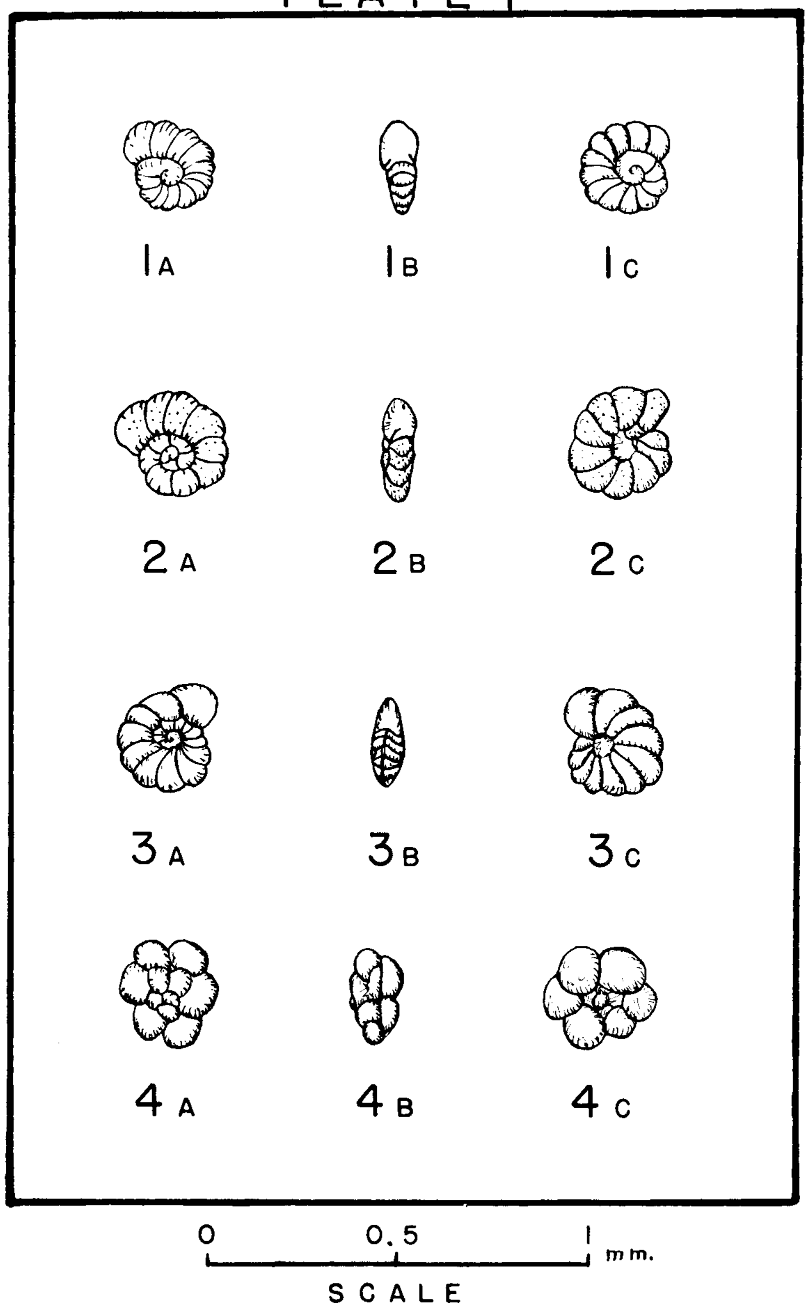


PLATE II

Fig. 1.—Gumbelina globulosa (Ehrenberg). X 70 124
a, side view; b, peripheral view.

Fig. 2.—Gumbelina tessera (Ehrenberg). X 70 124

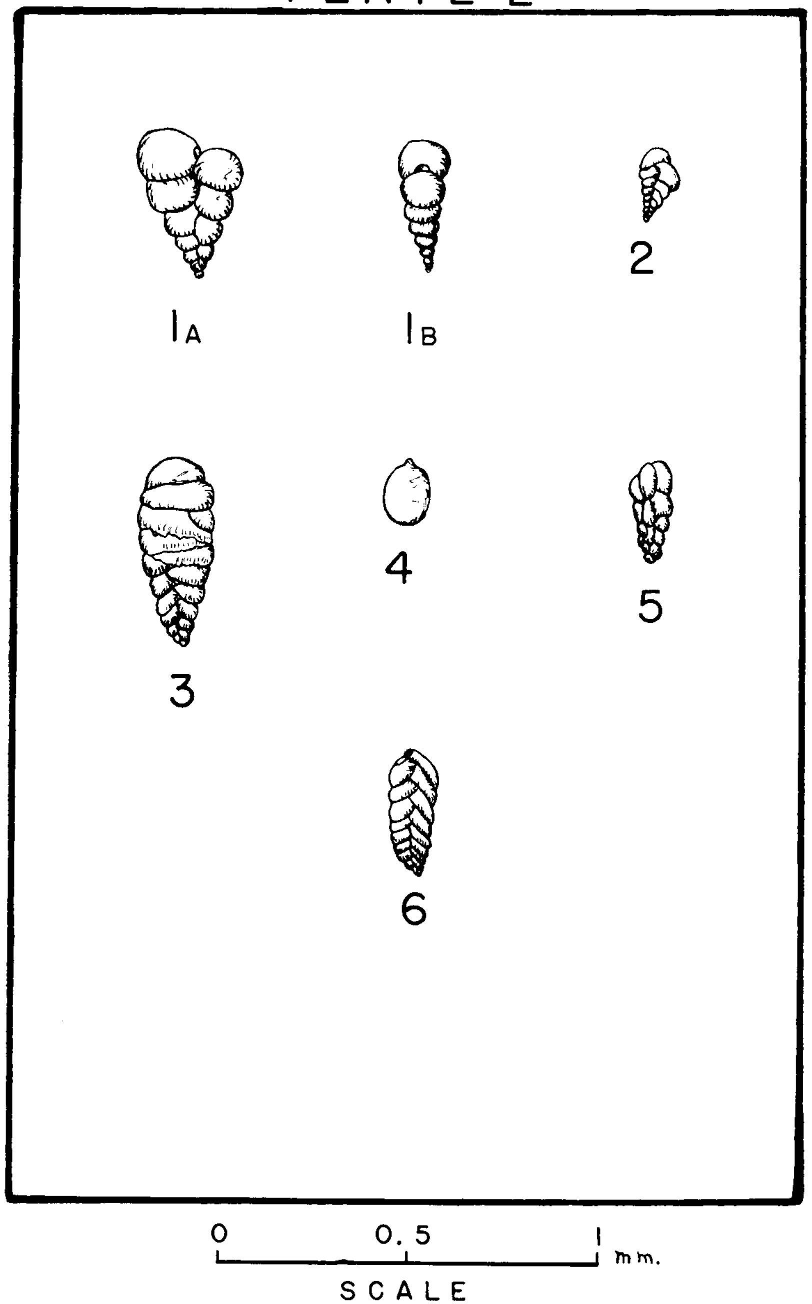
Fig. 3.—Loxostoma applinae (Plummer). X 70 124
a, side view.

Fig. 4.—Globulina lacrima Reuss. X 70 125
a, side view.

Fig. 5.—Bulimina elongata d'Orbigny. X 70 125

Fig. 6.—Bolivina incrassata Reuss. X 70 125

PLATE 2



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Lignite--Valuable Resource of North Dakota

ALAN M. CVANCARA

INTRODUCTION

This report is a general discussion on the lignite of North Dakota and represents largely a compilation of the available literature.

Thanks are particularly due to Dr. G. L. Bell, Chapter Advisor, who rendered advice, and made corrections and suggestions; and to Alex Burr and N. N. Kohanowski for the use of their new report, "The North Dakota Lignite Industry", from which the author drew heavily, especially for the mining aspect of this report.

GENERAL CONSIDERATIONS

The lignite deposits of North Dakota cover the western half of the state (see Figure 1). The lignite is part of a much larger lignite-bearing region that covers most of eastern Montana, extends north into Saskatchewan and south into Wyoming (Leonard, Babcock, and Dove, 1925, p. 1). However, not all of these deposits are considered to be of a commercial grade. Of the total 32,000 square miles, 28,000 square miles contains commercial deposits of lignite, while the remaining 4,000 square miles contains beds usually less than 2½ feet thick and are not included in the reserve estimate (Brant, 1953, p. 1).

Most of the coal in North Dakota is a brown lignite, although it may be black and lustrous in some beds. It is woody in appearance, breaks easily along the grain, shows the grain of the wood well, and fragments of flattened trunks and branches are widespread (Leonard, Babcock, and Dove, 1925, p. 6). Upon exposure to the atmosphere, it "slacks" rapidly and because of the greater surface area produced, it will ignite readily by spontaneous combustion.

According to Burr (1954, p. 32), North Dakota lignite is also chacterized by the following chemical properties:

1. High moisture content (Ave. 37%)
2. Low heating value (Ave. 6,800 Btu/lb.)
3. Moderate ash content (6%-7%)
4. Low sulfur content (.6%-1%)

North Dakota has the largest reserves of lignite in the nation; Montana is second, followed by Texas, Louisiana, Arkansas and Mississippi.

GEOLOGY

Lignite in North Dakota may be found in strata ranging from Late Cretaceous through Eocene. Specifically, it is found in the Upper Cretaceous Hell Creek formation, the Paleocene Fort Union group, and the Eocene Golden Valley formation.

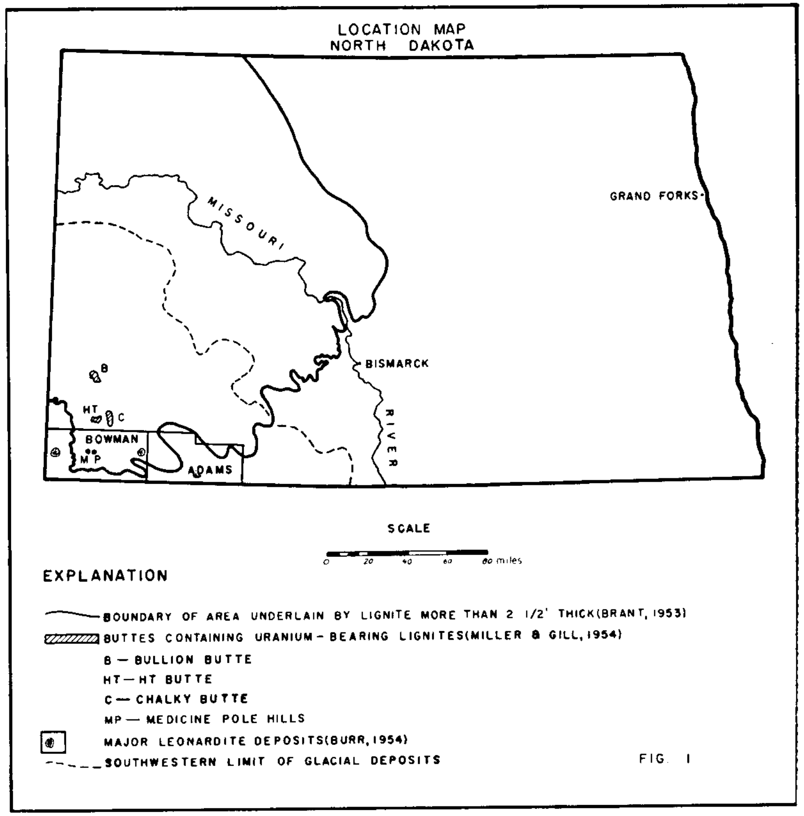

Fig. 1.—Location Map, North Dakota Lignite.

The Hell Creek formation consists of a thick continental sequence of fine-grained shaly sandstone, lignitic shale and is from 100-575 feet thick, (Laird and Towse, 1953). It also contains some lignite beds, but they are usually too thin for commercial exploitation.

Overlying the Hell Creek formation are the Paleocene formations of the Fort Union group.

The lowest of these is the marine Cannonball formation, which is devoid of coal. It is equivalent and grades with the lignite-bearing Ludlow formation to the west. Being composed largely of shale and lignite, the Ludlow, together with the Cannonball, has a total thickness of about 300 feet, (Laird and Towse, 1953). According to Hares (1928, pp. 25-26), the aggregate thickness of lignite beds in the Ludlow, in Sec. 10, T. 135, R. 105, is 39 feet 11 inches.

Overlying the Cannonball-Ludlow sequence, is the Tongue River formation, the main lignite-producing horizon in the state. It is from 200-800 feet thick; a non-marine formation consisting of fine to medium-grained sandstone, lignite, lignitic shale, and grey shale, (Laird and Towse, 1953). Most of the estimated reserves are based on this formation, for it contains numerous thick lignite beds.

The Eocene Golden Valley formation is 100 to 200 feet thick, and consists of fine-grained micaeous sandstone with minor amounts of light-colored shale and clay. The basal part is composed of hard white to dark-grey shale and with only localized beds of lignite (Laird and Towse, 1953).

PRODUCTION

The original reserves of lignite in North Dakota are estimated to be 350,909,820,000 tons, (Brant, 1953, p. 8). From 1884, when records were first kept, to and including 1953, North Dakota lignite mines have produced a total of 80,160,186 tons valued at $122,908,122 (Burr, 1954, p. 32). The Grand Forks Herald, Nov. 5, 1954, says that "North Dakota lignite mines have produced more than 2 3/4 million tons of coal at $6,488,786 in the year ending June 30." This amounts to approximately 83 million tons valued at $129,000,000.

The record year for lignite production was 1951, when 3,280,000 tons was mined (Grand Forks Herald, Nov. 5, 1954, p. 3).

MINING

Overburden—Probably the main factor to consider when mining North Dakota lignite, is the amount of overburden. According to Leonard, Babcock and Dove (1925, p. 15), glacial debris covers 15,000 square miles of the 28,000 square miles of minable lignite, see figure 1. Nearly all of the lignite-bearing region north and east of Missouri River is covered by glacial drift 50 feet or more thick, except where removed by erosion. However, in buried stream valleys, the drift may be more than 400 feet thick. South and west of Missouri River, the glacial deposits consist largely of terraces and thin deposits of till (Brant, 1953, p. 12).

Types of Mining—Before 1920 probably all the lignite was produced by underground mining methods. However, with the development of heavy earth-moving machines, there has been a gradual change to strip or open pit mining. Although there are still few underground mines in the state, they produce less than 5% of the yearly total.

Strip mining is much more efficient than any of the underground methods, attaining coal recovery that ranges from 85% to 95%; the underground methods have recoveries that range from 40% to 75%.

The machinery used in stripping depends upon the size of the operation, which includes the amount of overburden. The smallest operators use bulldozer tractors, diesel-powered shovels of ½ cubic yards to 2½ cubic yards, or larger. Larger operations are conducted in stages. First a 10 cubic yard shovel is used, followed by a Tower Stripper of the same capacity. Other machines such as draglines and clamshell scrapers are employed in some mines.

According to a survey of 17 major lignite mines in the state, the amount of overburden ranges from 23 feet to 62 feet, with a general average of 37.4 feet. Their minable seams averaged 11.2 feet (Burr and Kohanowski, 1954, pp. 1-7).

UTILIZATION

North Dakota lignite has been used extensively throughout the state as a source of fuel; the first reference to it as a source of fuel was made by members of the Lewis and Clark expedition, who quartered here during the winter of 1804-1805.

However, since that time, new uses for lignite have been found; they are listed as follows:

1. **Creosote and Tar.** These products are produced from lignite by the Dickinson Briquette and Tar Products Company, situated in the southwestern part of the state. Creosote and tar are used in road surfacing, wood preservation, roofing materials, etc.

2. **Briquettes.** These are formed by mixing the by products from creosote and tar distillation with tar, to obtain small pressed lumps about 2½ inches square to be used for fuel.

3. **Source of Uranium and Germanium.** The relationship of uranium and coal has been known since 1875, when E. L. Berthoud noted the high affinity of carbonaceous matter for uranium. Until recently, this relationship had not been exploited in North Dakota. However, since the establishment of the Atomic Energy Commission, the quest for new sources of uranium has begun. Although most activity has been concentrated in the Colorado Plateau region, some geologists have entered North Dakota with their geiger counters and have found uranium-bearing lignite in some of the higher buttes, see figure 1.

These buttes are capped with a radioactive volcanic rock, with the highest grade lignite beds directly beneath.

Even though this uranium in lignite is of low grade and efficient or inexpensive means of extraction has been found, it is a source that must be considered. With the prospect of new metallurgical techniques, it is possible that these deposits may be exploited, (Miller and Gill, 1954, pp. 36-39).

Germanium has been found in sufficient amounts in the ash of North Dakota lignite to be of commercial value. Experiments show that as much as 0.21 to 0.23 pounds of germanium oxide can be produced from one ton of coal. Germanium is used in the manufacture of transistors, (Bureau of Mines Staff, 1954, pp. 116-118).

4. **Montan Wax.** This is a natural wax obtained from lignite by suitable organic solvents. It is used in the manufacture of carbon paper, polishes, phonograph records, rubber, and electrical insulators, (Bureau of Mines Staff, 1954, pp. 113-114).

5. **Source of Gas.** Since the establishment of the United States Bureau of Mines Laboratory at Grand Forks in 1928, experiments have been made to extract gas from North Dakota lignite.

The writer shall not go into the complex process but merely say, that first powdered coal is treated with steam. Upon decomposition of the steam, is recombined with carbon to form gaseous hydrocarbons.

To date, however, the gas obtained from lignite by this method could not be produced in commercial quantities.

LEONARDITE

Leonardite is an oxidized form of lignite.

According to Burr (1954, p. 28-29), it is formed "through partial oxidation of lignite by natural processes and at low temperatures."

Leonardite occurs around the edges of lignite beds where the overburden is relatively thin and sufficiently porous to permit oxidation. Although oxidized lignite is found elsewhere, leonardite was named for the deposits in North Dakota in honor of A. G. Leonard, State Geologist, and head of the Geology Department for many years at the University of North Dakota.

The main uses of Leonardite are as follows:

1. **"Dakolite"** (Combination of Dakota and lignite). A Vandyke brown wood stain.

2. **Soil Conditioner.** Tests have been made showing increases in crop yield with the application of leonardite.

3. **Oil-well drilling-mud additive.** According to Bureau of Mines Staff (1954, p. 113), "small amounts of additive in an alkaline solution are included to improve the settling character of entrained solids."

The main leonardite deposits, see figure 1, are situated in Bowman and Adams counties, (Burr, 1954, p. 36).

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"Scoria" of North Dakota

By William S. Blain

INTRODUCTION

A striking feature of the Badlands of western North Dakota, and one which adds greatly to its picturesqueness, is the widespread development of brick-like masses of baked and fused clay, shale, and sandstone formed by the burning of lignite in outcrops of the Fort Union formation of Paleocene age. The baking and accompanying reddening of the overlying sediments have in some districts been so extensive that the landscape somewhat resembles that of the typical "Red Beds" of Jurassic and Triassic age.

Explorers and geologists who have visited this region, from the time of Lewis and Clark to the present, have noted the occurrence and characteristics of these beds, and have in most cases properly interpreted their origin. It is the intention here to summarize the work of others and in include personal observations in a short discussion of this rock type.

For many years the nomenclature used in describing the altered sediments above burned lignite has not been uniform. The term "clinker" has been used by many authors to designate the total section of burned and fused sediments. Other authors (Fisher, 1953) use "clinker" only in reference to fused slag-like masses occurring within the baked area and prefer to use the locally adopted term "scoria" to indicate the total thickness in which the effects of heat can be noticed. The term "scoria" is incorrectly used, geologically speaking, when used to describe rocks of sedimentary origin. Scoria when correctly used applies only to a vesicular igneous rock consisting largely of glassy or aphanitic material with numerous voids caused by escaping gases. It ranges in composition and color but is commonly associated with basaltic lava flows. Thus, it is an igneous rock term. The term clinker shall be used in this paper to designate the heavy, black, slag-like masses noted by Fisher (1953) that are vesicular, often showing flow structure, and are found within the section of baked material.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the helpful suggestions made by Mr. John W. Oty, member of Beta Zeta Chapter, and to Dr. Gorden L. Bell and Mrs. Nicholas N. Kohanowski, Department of Geology, University of North Dakota, for their encouragement and guidance in preparing this paper.

CAUSES OF BURNING

The burning of coal beds on the outcrop is common in all parts of the world where low rank coal is either exposed or lies close to the surface. In North Dakota burning takes place over the coal bearing area of 28,000 square miles (Leonard, 1925) in the western part of the state. Burning has been attributed to spontaneous combustion, lightning, prairie or forest fires, or to the agency of man. While ignition from an extraneous source is perfectly possible and may be the most plausible explanation in any given instance, such a great area of burning indicates a more widespread mode of origin and one less dependent on special local conditions, that is, spontaneous combustion.

Since coal first became widely used as fuel the possibility of its spontaneous combustion has been recognized. Rogers (1918, p. 3) points out that spontaneous combustion due to a set of both chemical and physical factors is probably the common cause of ignition of coal at its outcrop.

In regard to chemical composition, lignitic, or subbituminous grade coals highest in moisture and sulphur content are most liable to ignite. The physical factors promoting spontaneous combustion are a finely divided condition of the coal, a slight increment of heat from an outside source, and a sufficient volume of coal to retard loss of heat by radiation.

Lignitic and subbituminous coals exposed to air by the removal of overlying rocks through stream erosion lose moisture and tend to slack or crumble to fragments. The powdered coal, having a greatly increased surface area, promotes rapid oxidation. According to Lewis (1912, p. 23) the powdered coal absorbs oxygen in quantities two to three times its own volume. This absorption of oxygen takes place at ordinary temperatures but proceeds more rapidly at higher temperatures, and as the process generates heat, it is self-accelerating. Thus the process generates greater and greater amounts of heat until the lignite begins to burn.

Parr and Kressmann (1911) have found that the oxidation of pyrite and marcasite in the presence of moisture results in a distinct increment of heat, and as this reaction takes place at ordinary temperatures they believe that it is one means by which the mass is heated to the point at which active oxidation of the coal itself commences.

The effect of moisture on the spontaneous combustion of lignite has been a matter of controversy for many years. Some investigators have claimed that the presence of moisture facilitates the absorption of oxygen and therefore a self-heating process is promoted. Rogers (1917, p. 2) quotes Dennstedt and Bunz (1908) in saying, "self-ignition increases in a ratio corresponding to the amount of moisture (water of constitution) in air-dry coal." Levin (1939, p. 151) states that freshly mined lignite does not have an abnormally high tendency for self-heating. This is due, primarily, to the large proportion of water naturally contained which requires a large expenditure of energy to bring about its evaporation. The removal of this moisture leaves a material of greater oxygen absorption capacity and the tendency toward spontaneous combustion is increased accordingly.

Burning is most likely to occur where topographic conditions

cause the bed to crop out on a fairly steep bank where quantities of fine coal dust accumulate over the lower part of the outcrop (Rogers and Lee, 1923, p. 82). Except under very favorable conditions thin lignite beds do not burn, probably because piles of powdered coal large enough to retain self-generated heat can not accumulate along their outcrop. From field observations it is noted that a thickness of overburden over 100 feet is generally enough to prevent the ignition of even an exceptionally thick lignite bed. Although actual ignition of the coal bed may never take place, slow oxidation may proceed until the outcrop simply withers away and, for a few feet below a hillside surface, the overburden gently settles down upon the underclay. In such cases as noted by May (1954, p. 18) a 5 or 6 foot lignite bed is represented at the surface by a thin band of reddish black bloom.

Whatever the cause, the combustion, once started, spreads first along the outcrop, where the heat is for the most part lost, so that the outcropping strata are only very slightly affected. It is only as the burning progresses back under cover that enough heat is conserved to bake and fuse the overlying rocks. As the lignite burns out, the overburden collapses into the vacated space. When this occurs the beds have been baked hard and are commonly in a state of incipient fusion, so that in slumping, the large angular fragments have a tendency to cohere. This gives rise to a rock which, according to Rogers and Lee (1923, p. 82) contains 30 to 40 per cent air space. It is through this porous, fractured rock that oxygen is admitted and combustion gases are carried out, thus permitting the coal to burn farther back in the outcrop.

When the fire has worked far enough into the seam so that the burned out space does not cave but gently warps into place without fracturing the overburden to the surface, no more air will reach the burning face and the fire will go out. The maximum thickness of overburden under which a seam will burn generally depends on the thickness of the lignite.

GENERAL EFFECTS OF BURNING ON THE OVERLYING STRATA

May (1954, p. 18) has explained how the alteration of the overburden is as much a chemical process as a purely physical one due to heat. The underground combustion of lignite is mainly the oxidation of carbon with restricted oxygen supply in the presence of water; and as a result, carbon monoxide is formed. In the great heat, water is reduced to hydrogen and oxygen which promptly unites with more carbon. Thus the main combustion gases are hydrogen and carbon monoxide, both powerful reducing agents. Gypsum and pyrite in the lignite contribute sulphur dioxide, also a reducing agent. This potent mixture travels upward in the fractured overburden, transmitting its heat and acting chemically on some oxidized elements in the overlying rock, reducing them to lower valence forms. This is particularly evident in the case of iron, which is present in rock as disseminated limonite. Rogers (1918, p. 5) states that, "in the lower zone directly above the burning bed and along the paths of the escaping gases, the iron is partly or wholly reduced and gray, green, yellow, or black slag is formed." Higher up it is partially reduced to magnetite which is present in some places in sufficient quantity to effect the compass needle.

The hydrogen and carbon monoxide eventually become oxidized to water and carbon dioxide. They still retain enough heat to partially fuse and bake the rocks through which they pass. Above the zone where the gases are oxidized the iron becomes oxidized instead of reduced to give the characteristic red and pink color to the upper baked zone.

Heat transfer is by direct contact of gases, not by conduction through the rock. Small fissures control the paths of the gases and thus start the formation of well defined "chimneys." Where a major fissure has been developed the gases will move it more rapidly than elsewhere, forming a zone of higher-rank "scoria" along the fracture. As the material forming the immediate walls of the "chimneys" becomes molten, it tends to sink and clog the passage so that the gases may be slightly diverted and thus be caused to act on a greater volume of material. There are places where "chimneys" of reduced and melted clinker extend into apparently unaltered clay and sand, the effects grading out laterally within approximately two feet.

CHARACTER OF THE ROCK FORMED

Generally there is a characteristic sequence of rock type formed by the thermal effects of a thick burning lignite bed. It should be pointed out, however, that there are factors which may alter the general sequence of the rock type in any specific outcrop of "scoria". These factors are the degree of heat, rapidity of cooling, and the composition of the original rock.

Below nearly all coal beds is a sticky, gray clay called the underclay. P. R. May (personal communication) has found that the underclay, being a poor conductor of heat, is usually unaffected by burning except for about one half to 5 inches that may be turned to a dark gray, hard hornfels-like material. This layer is darkest at the top, grading downward to a light gray clay. On the underclay is a thin layer of natural coke which is black, vesicular and brittle. Generally this is all that remains of the coal bed. Above the coke is a thin layer of white ash; mostly potash, lime and other incombustible residues in the coal. If the coal has burned at very high temperatures this layer may be missing. Over the ash, in the zone where heat and reducing action are most intense, lies a layer of slag-like masses clearly resembling lava, called clinker. This zone may be an uneven layer several feet thick. It is irregular, full of open fissures, gaps, and pockets. Clinker is gray on fresh exposure and contains streaks of magnetite. Its flow structure and ropy surfaces indicate it was once in a liquid state. The melting zone grades into a zone of partial melting or sintering. By far the largest part of the material in this zone is very similar to ordinary red brick. Although the predominating hues are dark red or dark purple they are by no means the only ones, for shades of red, brown, gray, pink, orange, and purple occur. The original bedding in this zone is destroyed and flow structure is not exhibited. The rock is thoroughly brecciated, being broken in the collapse of the overburden. Small pieces rattle and ring when moved, much like chips and fragments of bricks or draintile. In some outcrops, columnar jointing produces numerous polygonal columns standing side by side. Inasmuch as the greatest cooling surface was generally the surface of the ground, the polygonal columns usually cut across the original bedding planes of the rock. Such jointing has been called pseudocolumnar by Laird (1950, p. 14). Upward in this zone the original bedding structures appear, becoming more distinct nearer the top. The color becomes hematite red until it is evident that the rock has undergone only simple baking. The baked zone resembles hard red silt, in which impressions of plant fossils are beautifully preserved. Gradually the thermal effects fade upward and the baked zone grades into unaltered rock.

The sequence given above must be considered as a general description of a typical "scoria" occurrence. As mentioned before, the character of the fused material is also dependent upon the composition of the sediments. Fisher (1953) has observed that silts and sands most often bake to a salmon or dull rose color and fractures to short columnar fragments or chunky blocks. On the other hand, the clays, which are thin bedded and usually contain appreciable iron, respond more readily to the heat, lose their original texture and become hard and massive. They bake to deeper shades of red and fracture from blocks in the lower few feet to plates or thin chips above. It is the name of this altered clay, called porcellanite by many authors, that has been erroneously adopted as a term to describe the entire section of overburden effected by the heat of a burned lignite. Porcellanite is that rock which resembles jasper (Fay, 1920) or unglazed porcelain (Tarr, 1938).

INFLUENCE ON TOPOGRAPHY

The burning of lignite and the subsequent formation of "scoria" have played no small role in the development of bad land topography. The effect of the burning is first to lower the general level of the area burned by the depth of the coal seam, and to loosen and rearrange the material lying above the seam by causing it to collapse. After the material overlying the coal seam has been changed to "scoria," it strongly resists further weathering and erosion, due to its increased hardness and gross permeability, and remains to form the cap-rock of diversified buttes which add greatly to the irregularity and roughness of the coal country.

In grass-covered prairie areas, "scoria" may be the only rock that crops out. In using it for surface structural mapping, the geologist should bear in mind that only the base of the "scoria" is a stratigraphic horizon and that it is equivalent to the base of the coal bed it represents.

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Ceramic Research in North Dakota

By Oscar E. Manz

ABSTRACT

In recent years there has been very little research done to promote the use of clay and shale of North Dakota in additional ceramic industries. Since clay or shale is the main or only ingredient for most ceramic products, the abundance of clay and shale in North Dakota providles ample opportunity for possible future development of additional ceramic industries in the state. As indicated in Fig. 1, there are only a few ceramic plants in North Dakota. The largest and oldest plant still in operation is a brick and tile plant at Hebron. A small pottery plant at Wahpeton manufactures ceramic figurines, wall plagues, and other objects, using clay from Mandan. In the spring of 1953, a lightweight aggregate plant began operation at Mandan, producing aggregate from shale for lightweight concrete, by means of a rotary kiln. A similar plant is being constructed at Noonan, and will use clay which occurs below a lignite seam.

The University of North Dakota has maintained a ceramic department since 1910 for the purpose of teaching pottery handicraft. Only North Dakota clay is used, and the pieces of pottery produced in the department are sold to the public. Around the beginning of the 20th century, there were numerous brick plants throughout North Dakota, while at the University a fairly extensive research program was carried on. It is only since 1952 that a long range program has been started to promote the use of clay and shale in additional ceramic industries.

In the fall of 1952, due to efforts of Dr. Wilson M. Laird, the State Geologist, and Dean E. L. Lium of the College of Engineering, the author, a graduate in Ceramic Engineering from the University of Saskatchewan, was hired to do clay research. To initiate a long range program of research, various outcrops and commercial deposits of clay and shale in North Dakota were sampled. The results of a preliminary investigation of 20 clays have been published as a cooperative project of the College of Engineering and the North Dakota Geological Survey.

This paper presents the following: the geologic occurrence of North Dakota clay and shale; the laboratory equipment and methods employed at the University; and the future possibilities of North Dakota clay and shale as indicated by research completed by the author.

GEOLOGICAL OCCURRENCE OF NORTH DAKOTA CLAY AND SHALE

The available clay of North Dakota occurs in the Pleistocene, Tertiary, and Cretaceous formations. Babcock and Clapp (1905, pp. 98-99) state that there is a transition period between the Tertiary and Cretaceous called the Laramie, but these beds are now referred by Benson (1952, pp. 37-38) to the Fort Union (Tongue River) of the Tertiary period and to the Hell Creek of the Cretaceous period.

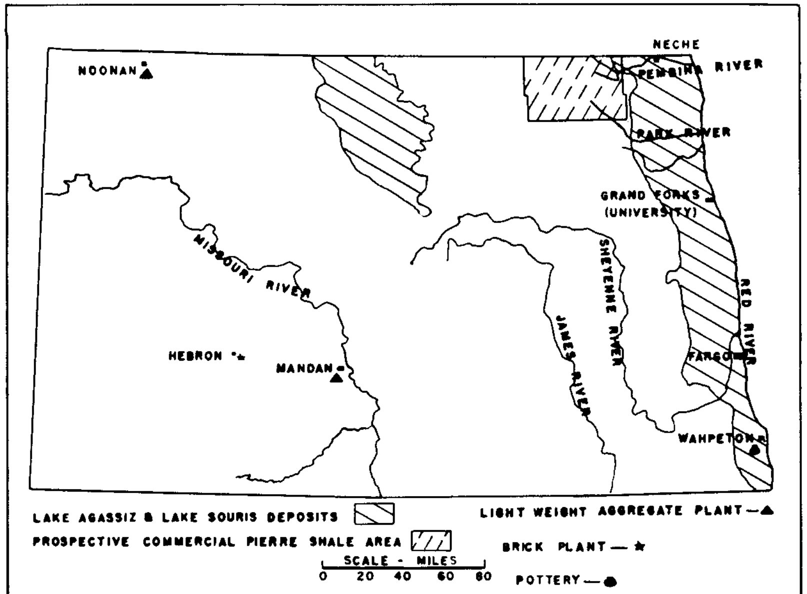

FIGURE 1 - INDEX MAP OF NORTH DAKOTA

Fig. 1.—Index Map of North Dakota.

In former years, some of the best clay used was obtained from deposits in glacial lakes similar to Lake Agassiz. Good common brick clay is found as alluvium of the flood plains and terraces of some of the rivers. Underlying the east central part of the state in a north-south belt are Createaceous deposits of clay in the Benton, Niobrara, and Pierre series. They are covered with a deep layer of drift, but the Benton and Niobrara formations are exposed in the valleys of rivers in the Pembina Mountains and the Pierre which lies above the Benton and Niobrara is exposed in the cut banks of the Pembina, Sheyenne, and James Rivers.

The western half of the state is underlain by coal bearing beds. These are referred by Babcock and Clapp (1905, pp. 98-99) largely to the Fort Union group and consist chiefly of sand and clay. They are also covered by glacial drift except in the southwestern quarter of the state. However, there are numerous outcrops of clay in valleys and buttes.

Babcock and Clapp (1905, p. 17) state that the Benton, Niobrara, and Pierre beds are marine shale and that the clay in the western half of the state, occurring with lignite, is lake deposit. They also claim that there is no residual clay as well as no loess deposits in the state.

Geologic Formations of North Dakota of Ceramic Importance

			Surficial Pleistocene moraine, lake bed, delta, outwash deposits
Tertiary	Oligocene		White River formation: light greenish-gray to white conglomeratic sandstone overlain by light greenish-gray and pink siliceous and calcareous clays.
Tertiary	Eocene		Golden Valley formation: gray to yellow micaceous sand and silt overlying basal purplish-gray to white kaolinitic clay.
Tertiary	Paleocene	Fort Union Group	Tongue River member: gray to yellow-buff sand and shaly clay with numerous persistent lignite beds. Includes the Sentinel Butte shale.
			Cannonball formation: dark brown and dark gray sandstone and sandy shale. Marine. Intertongues with and overlies Ludlow shale..
			Ludlow shale member: gray shaly clay with local sandstone beds and thin lenticular lignite beds. Continental.
			Hell Creek formation: gray sandstone and shaly clay with dinosaur bones. Few thin lignites near the base. No lignites in the upper part.
Cretaceous	Upper	Montana Group	Fox Hills sandstone: rusty brown concretionary marine sandstone. In southwest corner of state, light gray sandstone at the top may be Colgate sandstone of eastern Montana.
			Pierre shale: medium to light gray marine shale.
		Colorado Group	Niobrara formation: medium to light gray calcareous and speckled shale and cement rock.
			Benton shale: medium to dark gray shale with bentonite.

LABORATORY METHODS

It is necessary to perform several tests on both unfired and fired samples to enable one to determine how useful the clay and shale will be as ceramic materials.

The samples, as received from the field, should be visually inspected and a record made of the color, structure, hardness, texture, and any visible impurities. A screen analysis is very helpful, and a dried portion of the sample is allowed to slacken in water for several days if necessary prior to running the screen analysis. Usually screens less than 200 mesh are used, and the fractions caught on the various screens are dried, weighed and examined with a petrographic microscope.

To determine numerous other unfired properties and some fired properties, it is necessary to mold small trial pieces. Before these are made, the samples should be crushed if necessary and then ground to finer than 20 mesh. Sufficient water is mixed with a portion of the ground material to produce the best working consistency and after aging and thorough wedging, the trial pieces are molded. It is possible to determine water of plasticity, linear drying and firing shrinkage, slaking characteristics, fired color, fired apparent porosity and water absorption, using only a few trial pieces of suitable dimensions. An apparatus for determining the transverse strength of dried trial pieces is necessary for any large scale clay research program.

Since the fired properties are of utmost importance, it is necessary to fire trial pieces at intervals of approximately 50° F. to overfiring, or if the clay is too refractory, the trial piece should be fired to at least 2500° F.

As a clay is being fired, the most fusible constituents melt and take unfused material into solution. The liquid formed flows into the pores causing shrinkage; and when there is no more appreciable decrease in shrinkage, it is called incipient vitrification. When all the pores are filled with liquid, a dense body with practically zero porosity results, and a state of complete vitrification has been obtained. Not all clay can be fired to complete vitrification, because the liquid is often too fluid and the ware will deform under its own weight. When some clays are fired, gases resulting from the decomposition of carbonates, sulphates, and other compounds do not escape before the surface has been sealed by fusion, and in trying to escape, these gases cause expansion or bloating, and overfiring results.

Although the tests which have been briefly outlined here would be sufficient for determining the ceramic value of clays, a more conclusive evaluation would be possible if chemical analysis, differential thermal analysis, X-ray analysis, fusion point determinations and determinations of particles finer than 200 mesh were performed.

LABORATORY EQUIPMENT

A ceramic testing laboratory has been set up at the University, under the direction of the author. The most useful piece of equipment in operation in the laboratory is a Harer Electric Kiln with temperature range 0° to 2500° F, and with inside capacity of 1 1/2 cu. ft. A thermocouple is connected to a Micromax recorder which gives a permanent record of each firing. There are two other smaller electric kilns with temperature range 0° to 2000° F. A pyrometric cone equivalent furnace is used to determine the fusion points of the more refractory clays. An apparatus for determining transverse strength of unfired clay trial pieces is a great help in the evaluation of clays.

A differential thermal analysis apparatus has recently been installed and is a valuable aid in identifying clay minerals and other non-clay minerals by comparison of characteristic curves resulting from endothermic and exothermic reactions which occur during heating of the minerals.

FUTURE POSSIBILITIES

With the use of the Harper electric kiln, preliminary tests are being run to determine the clay and shale suitable for lightweight aggregate. A gas fired rotary kiln is being constructed for large scale testing of the lightweight aggregate possibilities of the deposits of lower grade clay and shale throughout North Dakota which are not too well suited to the manufacture of brick, building tile, or other ceramic products. With the opening of a plant at Mandan in 1953 to produce lightweight concrete aggregate from local Cannonball shale, deposits of otherwise valueless clay and shale have become important.

The cost of the lightweight aggregate is the ultimate factor that determines its acceptability. The initial cost per cubic yard over sand, gravel, and crushed rock aggregate must be offset by savings in weight, which reduces transportation costs and the steel requirements and permits the use of lighter forms or by the attainment of better thermal and acoustical insulation qualities. Concrete made from expanded shale or clay has a unit weight of 60 to 100 lbs. per cubic foot, depending on the clay or shale used and ordinarily possesses strength ranging from 1000 to 5000 psi depending on the richness of the mix. Concrete made with sand and gravel has a unit weight of approximately 150 lbs. per cubic foot.

Although clay and shale are two of the most widespread natural resources in the state, they are not being utilized to any great extent in comparison with the other major natural resources such as oil and lignite. With the ever increasing use of concrete for all types of building and with the decreasing supply of sand and gravel in North Dakota, suitable for concrete aggregate, there is a need for a substitute aggregate that can be produced in the state.

In addition to the Cannonball shale, it is feasible to produce lightweight aggregate from some of the Tongue River clay and shale occurring with lignite beds. However, if the overburden is more than 10-12 feet thick, it is not practical unless there is sufficient lignite, as for example, at Noonan where 50 feet of overburden is underlain by 8 feet of lignite and with 30-40 feet of clay below the lignite. The production of aggregate from such a deposit is ideal since the removal of overburden is charged to the lignite and the use of powdered lignite as fuel reduces production costs considerably.

Preliminary tests have shown that otherwise valueless dark blue, unstratified lacustrine clay, which was deposited in glacial Lake Agassiz, and now underlies the Red River Valley in eastern North Dakota, produces excellent lightweight aggregate. This blue clay ranges in thickness from 85 feet at Fargo to 50 feet at Grand Forks and 75 at Neche, and extends east and west as far as the highest beaches of Lake Agassiz. It rests unconformably on glacial drift and is overlain by lacustrine silt ranging in thickness from 15 to 20 feet near the center of the valley. Numerous brick plants which existed in the Red River Valley, produced common brick from this yellow silt. Although no samples were tested from glacial Lake Souris in the north central part of the state, there is a deposit of blue clay and silt similar to that found in the Red River Valley which would undoubtedly make good lightweight aggregate.

Expanded or bloated clay or shale may be considered an all-purpose aggregate, for its uses include lightweight concrete masonry units, multiple story buildings, precast roof and floor slabs, piers, and super structures of bridges, ships, and barges, and jet runways. In North Dakota, lightweight concrete made from shale aggregate has been used primarily as backup for brick work with the interior surface either plastered or painted.

Lightweight aggregate will not replace sand and gravel for every type of concrete, particularly for highway construction. However, the vast deposits of Pierre shale have promise of becoming a substitute for sand and gravel for highway construction.

Leonard (1905, pp. 71-73) states that Pierre shale has a wide distribution in North Dakota, underlying the majority of the state with the exception of part of the Red River Valley. In most places it is covered by glacial drift and appears at the surface only along stream valleys where it has been exposed. The typical Pierre shale is bluish-gray, jointed, and weathers into small flaky fragments. In the Pembina Mountains region, it is exposed along all the streams which flow into the Pembina River or Red River, and which originate in Cavalier or Walsh counties. It is excellently exposed at Milton along the valley of the North Branch of Park River, and one and half miles north of Niagara along the North Branch of the Turtle River. It appears at many points along the Sheyenne River in Nelson, Griggs, and Barnes counties. At Valley City, the Pierre and Niobrara shale are exposed along the Sheyenne River. Along the James River in Stutsman, Foster and Eddy counties, the Pierre and Niobrara shale are exposed at many points. The top of Pierre is exposed near the extreme southwestern boundary of the state along Little Beaver Creek, in Bowman county. Fisher (1952, p. 4) states that extensive outcrops occur in the lower bluffs of the Missouri River in the southeast corner of Sioux county and the southwest corner of Emmons County. An excellent exposure is found in the creek bluff at Linton in Emmons County.

Although unburned Pierre shale has no value as concrete aggregate, preliminary tests made at the University indicate that the occurrence of Pierre shale in thin, hard slabs, and the conchoidal fracture resulting from crushing produces well-sized material which makes good concrete aggregate after heat treatment. The shale has to be fired to at least 2000° F. to produce a durable aggregate which is not too porous and is not affected by weathering. Pierre shale has the desirable property of shrinking but slightly during firing, and therefore sizing of the aggregate before firing is feasible and most desirable since the raw shale crushes with ease compared to the fired material. At the University, cylinders made with portland cement, using Pierre shale fired to 2200° F. as aggregate and using a water cement ratio of five gallons per sack, developed a compressive strength after 26

days of 5700 pounds per square inch. This would indicate that fired Pierre shale is equal to and, in fact, better than most of our commercial concrete aggregates. It must be emphasized that the cost of heat treatment is the determining factor in deciding if Pierre shale would replace natural aggregates. Another important factor is the amount of overburden to be removed. Records of logs from water wells, as indicated by Simpson (1929, pp. 109-112), and from oil wells would indicate that the least amount of overburden over an extensive area is in Cavalier county, where the glacial drift ranges from 10 feet to 60 feet, and the Pierre shale is several hundred feet thick.

Experiments are to be made using naturally occurring fired clay or shale which is known as "scoria" or clinker, and is widespread over southwestern North Dakota. It seems, however, that there would be considerable variation in the physical properties of the aggregate, due to uneven burning of the lignite beds to produce the "scoria" and to variations prevalent in the Fort Union formation.

The brick plant at Hebron in Morton county, southwest of the Missouri River, uses clay from the Golden Valley formation, which forms a ridge a few miles from Hebron. Although only building brick and structural tile are manufactured, preliminary tests indicate that this clay would also be suitable for making good sewer pipe. It is thought by some that there is not sufficient demand for sewer pipe to support a plant, but the author feels that an investigation would be warranted.

There are numerous publications dealing with the less extensive deposits of pottery clay, fire clay, bentonite, and fuller's earth, and they will not be included in this paper.

Even though preliminary tests in the laboratory or even pilot plant experiments will show that a clay or shale can be made into a ceramic product, consideration must be given to the cost of mining and transportation, the cost of the property and its depreciation, the cost of erecting the plant, the cost of marketing, taxes and supervision. This should be followed by a survey to answer the following questions: What is the Nation's, State's, and communities' demand for the product? How has their general market fluctuated over the past 20 years? What non-ceramic product is competing with the product? How has the popularity of this competitive product grown?

It is hoped that after careful investigation, there will be a wider use of North Dakota's clay and shale resources and that a very extensive research center can be built up.

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Beta Zeta Chapter History

By Bruce Listoe

The Geology Club at the University of North Dakota was organized in 1937. The purpose of this Club is to further interest in geology and provide added opportunity for the exchange of ideas. During the war years of 1941-46 the Geology Club was inactive. After the influx of students in 1946 the Club was reorganized and served as an enjoyable part of the geology program. Because of the growing interest stimulated by the petroleum activities in the state and the increased number of geology majors, the Geology Club grew in size and importance on the campus, and it is still active. The need for national affiliation with some organization to expedite contact with geologists from other areas of the country was felt. Work on this matter culminated by the granting of a charter for the Beta Zeta Chapter of Sigma Gamma Epsilon in the fall of 1950. The Kansas State Chapter installed the new chapter.

Meanwhile, the Geology Club has continued with the program of furthering geology on our campus, and all geology majors, including Sigma Gamma Epsilon members, are members of the Geology Club.

Charter members of the Beta Zeta Chapter were: Donald Conner, president; Bernold Hanson, vice president; Sidney Anderson, secretary; Gordon Bauer, Charles Juni, John Klemer, Elmer Meldahl, Leonard Smith and Calvin Truax. Dr. Wilson M. Laird served as chapter advisor from 1950 to 1953. Dr. Gordon L. Bell was chosen as our advisor in 1953. Presidents since Conner were John Klemer, John Rau, Ron Kasper, and William Blain. Today we have 13 active members, nine associate members, and three active alumni.

During the four years it has been on campus, our chapter has entered many fields of activity. It has continued to organize field trips, guided by the professors, to better train its members in the practical aspects of geology. It has presented speakers and films to better educate its members in the earth sciences. It has provided a way for the exchange of ideas. The chapter has prepared exhibites for Engineers' Day and is represented on the Engineers' Council. Members have published articles in the university engineering magazine and have served on its staff in almost every position. As outside activities, the chapter has sponsored basketball teams and parties. Last spring a room was obtained in the mining and geology building for a geology study room. This room is also the center of chapter activities.

Since 1950, our chapter has reached some of its goals but higher goals are in sight. Through Sigma Gamma Epsilon, we at North Dakota like other chapters hope to better prepare ourselves for our chosen profession by augmenting our classroom training with geologic projects. Our chapter is looking forward to the coming years with anticipation, just as we are looking back on the past four years with a feeling of accomplishment.

The History of the Geology Department at the University of North Dakota

By Wilson M. Laird

Head, Department of Geology

Geology and mineralogy were among the first subjects taught at the University of North Dakota. A recent study made of all the catalogues of the University reveals these courses in the very first catalogue published in 1884. These same courses, but probably with expanded content, are still found among our offerings.

Henry Montgomery was the first professor and the courses were taught in connection with his duties as Professor of Natural Science. Departmental organization as such was lacking in those days.

It wasn't until 1895 that separate listing of courses was given under departmental headings and then the courses in geology and mineralogy were listed under the Department of Chemistry. This association with the Chemistry Department continued until 1901 although the typography of the catalogue of 1896 would suggest a separate department. Between 1896 and 1901 it was listed as a subheading under the Chemistry Department.

One of the early and outstanding teachers in the Geology Department who undoubtedly was influential in the setting of the tone of the Department was Earle J. Babcock. He taught both chemistry and geology from 1888 until 1901 when he began to devote his entire energies to chemistry and the School of Mines of which he became head. He was an indefatigable worker in the natural resources of North Dakota and this interest continued unabated until his death.

Although he was at the University for only one year, Frank A. Wilder was the first professionally trained geologist in the Department. He did much good work both in the Department and the Geological Survey during his brief tenure.

In 1902, a man came to the Geology Department who was to influence it probably more than any other. This man was Dr. Arthur Gray Leonard. He came to North Dakota shortly after obtaining his doctorate degree at John Hopkins University and a short time on the Iowa Geological Survey. Dr. Leonard introduced many new courses of a professional nature in the Geology curriculum and the training of professional geologists began with him. It is unfortunate that no record is available of the professional geologists who were trained by him. Dr. Leonard spent the remainder of his life at the University until his untimely death in December of 1932. It was said by one who knew him intimately "Dr. Leonard was always a gentleman". He was a scholarly geologist and leaves behind him many geologic reports of

During Dr. Leonard's tenure as Head of the Geology Department, he brought in Howard E. Simpson as Assistant Professor of Geology

high caliber.

in 1909. Professor Simpson was interested in physiography and geography and as a result of his interest, numerous courses in these fields were added to the curriculum. Professor Simpson early became interested in underground water and later particularly during the 1930's, did much work in this field both in North Dakota and elsewhere in the United States. This water work of Professor Simpson brought much attention to the Department of Geology.

In 1926 the course offerings in the Geology Department were listed under two divisions, Geology and Geography, and the Department was called the Department of Geology and Geography although in reality the division of courses as mentioned above had begun in 1921. At that time, there were three men in the Department. One man teaching geology, one man teaching geography and one man teaching part of both.

After Dr. Leonard's death in 1932, Dr. Simpson became Head of the Department and Dr. Simpson's place was taken by Dr. Frank C. Foley. A number of other men occupied the third man's place in the Department. They can be found by consulting the list accompanying this paper.

Immediately prior to Dr. Simpson's death in 1938, the Departmental faculty consisted of Dr. Simpson, Dr. Foley and Dr. Oliver. When Dr. Simpson died in 1938, Dr. Foley became head of the Department and several men occupied the third man position between 1938 and 1940 when the present writer became Assistant Professor of Geology.

Dr. Foley resigned February 1, 1941 after which Dr. Oliver became Head of the Geology and Geography Department. The writer was made State Geologist at the same time.

In the fall of 1942, the Geology and Geography Departments were separated and the Geology Department with the writer as Head was placed in the College of Engineering. During the war years little teaching of Geology was done for lack of students. However, in 1946, the veterans began coming back and many were interested in Geology as a career.

As a result of this very considerable interest a new professional curriculum in Geology in the College of Engineering was added in 1948. This curriculum is one strong not only in Geology but the sciences of Mathematics, Physics, and Chemistry as well. This curriculum has been modified from time to time up to the present, but it remains essentially the same as first conceived in 1948. It has a considerable number of nontechnical subjects such as Economics, Political Science and English which help broaden the students interest and background. It is our purpose not only to train good geologists but good citizens as well.

As a direct result of the discovery of oil in North Dakota in 1951, the interest in geology has risen markedly. At the present time, we have 60 majors in our professional curriculum, 5 majors in geology in the College of Science, Literature and Arts and 4 graduate students. In addition to the writer, who does no formal teaching, we have 3 full time men of professorial rank and 3 graduate assistants. Provision has been made by the University for hiring another Assistant Professor but this position has not yet been filled.

Our plans for the future will stress more attention to graduate work and the better training of our undergraduates. With the addition of another man, it is hoped that work leading to the doctoral degree can soon be undertaken. At present, we grant no degrees beyond the Masters.

Coincidental with the growth and development of the Department of Geology has been the history of the State Geological Survey. It was founded as a result of legislative action in 1895 when the Professor of Geology at the State University was made *ex officio* State Geologist. This arrangement has continued to the present.

The early work of the Survey dealt largely with the coal, clay and water resources of the State. Particular attention was given by Dr. Leonard to the lignite of the State. The results of his many years of work culminated in the publication of Bulletin 4 of the Survey. This exhaustive study of the occurrence of lignite in North Dakota has long been out of print.

For many years during the 1920's and 1930's the Survey had no appropriation. The little work done during those lean years was financed largely by the men doing the work at the University.

Dr. Simpson was instrumental in starting the ground water program of the Survey. He investigated the Dakota artesian system in the southeastern part of the State and made recommendations as to the conservation of this valuable resource. He also conducted surveys for ground water sources for a number of towns and cities in the State. Of late years, the ground water program has been carried on by a cooperative agreement with the Ground Water Division of the U. S. Geological Survey. Originally, this agreement was handled by the State Survey, but since 1945 it has been taken care of by the State Water Conservation Commission. The Water Commission has designated the State Geologist as its agent in charge of underground water work, so he is liaison man for the State in underground water matters with the U. S. Geological Survey. Under this agreement about 45 studies of specific areas in the State have been studied since 1945.

Probably the most important function of the State Geological Survey at present is its part in the oil conservation program of North Dakota. The State Geologist is by law Supervisor of Oil and Gas and works directly under the State Industrial Commission in these matters. He enforces all rules and regulations of the Industrial Commission, issues all permits and keeps all records relative to the oil and gas regulatory program in the State. A staff of petroleum engineers, geologists, and clerks are kept busy full time on this work.

In addition to the more or less immediate practical considerations of regulatory work the State Survey is also carrying out a program of geologic and other research. At present, we are engaged in subsurface studies of various formations, glacial geology of various parts of the State, terraces along the Little Missouri and structural conditions in eastern Billings County. Petroleum engineering studies are also being made of the Beaver Lodge and Tioga pools. Ceramic research is also being carried on in cooperation with the College of Engineering of the University.

In summary, it can be said that the Department of Geology and the State Geological Survey have made progress during the last half century. We hope this will continue in the future.

LIST OF GEOLOGY INSTRUCTORS—UNIVERSITY OF NORTH DAKOTA

Frank A. Wilder, Ph.D		1901-1902
Marcia Bisbee, B. A.		1901-1902
Arthur G. Leonard, Ph.D.		1902-1932
Charles H. Clapp, B. S.		1905-1907
John G. Barry, B. S.		1907-1908
Howard E. Simpson, M. A.		1909-1938
Leonard P. Dove, B. S.		1919-1925
Eula D. McEwan		1919-1920
Ewald Pietsch, B. S.		1925-1932
William J. Berry, M. S.		1927-1930
Frank C. Foley, M. A., Ph.D		1932-1941
A. Russell Oliver, Ph.D.		1933-1942
Max Demorest		1938-1938
Chauncey D. Holmes		1939-1940
Wilson M. Laird, Ph.D.		1940-
Ernest Tisdale, M. S.	(second semester)	1940-1941
J. Stephens Templeton, Ph.D.	(first semester)	1941-1942
Marie Louise Lange, M. A.	(second semester)	1942-1943
Irving Grosman, M. A.		1945-1948
Nicholas Kohanowski, Geol. Eng.		1948-
Donald Towse, Ph.D.		1951-1954
Stanley P. Fisher, Ph.D.		1952-1953
Gordon L. Bell, Ph.D.		1953-
Oscar Manz, B. S.		1952-
F. D. Holland, Jr., M. A.		1954-