NEWSLETTER

NDGS

A publication of the
North Dakota Geological Survey,
University Station,
Grand Forks, North Dakota 58202
Phone: (701) 777-2231

CONTENTS

June, 1977

READER RESPONSE--

In the last Newsletter (December, 1976), I included three background articles dealing with scoria, lignite, and potash. I asked for reader reaction, whether such items should be included in this type of Newsletter, and the response was favorable; so, I'll include several more generalized "essays" on various aspects of North Dakota geology in this Newsletter. They include articles on North Dakota's drainage pattern, on dead-ice moraine, and on fossils in the State. And two articles, the ones on Exploration Ingenuity and Strippers, were written for the Newsletter by Erling Brostuen.

GERALD EDDY--

We were saddened to learn of the death on May 24th of Dr. Gerald Eddy, former state geologist with the Michigan Geological Survey. Dr. Eddy joined the Michigan Geological Survey in 1934 and retired in 1971. He also served as Michigan Department of Natural Resources director and state supervisor of wells.

PRESONNEL CHANGES--

Dr. Howard Hobbs, who has been with the North Dakota Geological Survey for the past year, has accepted a job as Quaternary geologist with the Minnesota Geological Survey. While with the NDGS, Howard mapped Ramsey County and helped in evaluating sanitary landfill sites throughout the state.

For his first two years with the Minnesota Geological Survey, Howard will be working with a group in the Department of Natural Resources evaluating peat resources in northern Minnesota. He will spend the months from July through October in the field, mapping and field-checking the Quaternary geology of Aitkin and southeastern St. Louis Counties. He will be based at a cabin on Lake Minnewawa, near Big Sandy Lake.

Dr. Alan Kehew will begin working for the NDGS in July. Alan comes to us with a Ph.D. from the University of Idaho where he was involved in a land-use planning and geologic hazards project in the Lewiston, Idaho, area. His report on the area will provide a data base for urban planners in Lewiston, which is a rapidly growing city on the Snake River. Alan also has a M.S. from Montana State University in Bozeman. His thesis there was concerned with the environmental geology of the West Fork Basin, Gallatin County, Montana. His B.S. is from Bucknell University in Pennsylvania. Alan served in the U.S. Navy for four years. He is married and has twin daughters.

Dr. Ken Harris will begin with the NDGS in August. He has been employed as an exploration geologist for Cities Service Oil Corporation for the past two years, stationed in Jackson, Mississippi. Ken received both his M.S. and his Ph.D. degrees from the University of North Dakota. His M.S. thesis was on the glacial stratigraphy in the Red Lake Falls area in northwestern Minnesota, and his Ph.D. dissertation involved a study of the Pleistocene geology of the Grand Forks-Bemidji area, also in Minnesota. His B.S. degree from North Dakota State University in Fargo is in electrical engineering. Ken is married and has one daughter.

RESEARCH PROJECTS--

Subsurface carbonate rock studies are underway on the Red River, Mission Canyon, and Lodgepole Formations. The role of subaerial diagenetic processes in the development of porosity in the Mission Canyon is one "hot topic" in these studies, related to new major oil discoveries in west-central North Dakota. Field and laboratory studies leading to the interpretation of origins of carbonate mud in the Paleozoic Williston basin are well underway; much of the work in modern carbonate environments is now complete. We are studying the Upper Cretaceous Pierre Formation with emphasis on the sand intervals within it, in an effort to increase interest in shallow gas exploration. Initial field studies of sediment transport in the Little Missouri River have been completed.

Field research on southwestern North Dakota Cretaceous and Paleocene stratigraphy has improved our knowledge of stratigraphic relationships in the coal-bearing sediments and made it necessary for us to redefine several Fort Union Group formations. We are now in the process of reevaluating our entire stratigraphic column, taking into account current terminology in use by oil and coal geologists working in the state.

The Survey is in the process of computerizing all the exploratory and oil well data available in the state. The new well schedule will catalog and print out the exact location (county, township, range, quarter-quarter section), well name, operator, well status (producing, dry, shut-in, etc.), initial production gravity, and other information. The program will include such data as T.D., formation bottomed in, producing horizons, as well as noting the cores, samples, and logs on file at the Survey offices in Grand Forks.

SURFACE MINING-RECLAMATION PROJECTS--

It sometimes seems like we are working on so many surface-mine reclamation-related projects that it is hard to keep track of them. Many of these have been discussed in previous issues of the Newsletter, but here is a short summary anyway.

A grant from the North Dakota Regional Environmental Assessment Program (REAP) is enabling us to work out the detailed stratigraphy of the Knife River Basin area in west-central North Dakota, an area that contains much of the State's lignite resource. This study involves regional correlation and determination of the hydrologic characteristics of the lignite-bearing units in the area. A recently completed study funded by the Old West Regional Commission involved detailed sampling and analysis of overburden materials at several active and proposed mining sites and the development of a predictive geochemical model as an aid to the reclamation of surface-mined areas. A study funded by the Environmental Protection Agency involves detailed hydrologic instrumentation of several active and proposed strip-mine sites to determine the potential effect of mining upon groundwater supplies. Other reclamation-related research is aimed at determining the hydrologic characteristics of recontoured strip-mine spoils and understanding the causes of instability in recontoured spoils. We expect that these detailed geologic and hydrologic studies will assist the State in planning for the orderly development of coal resources in North Dakota.

We are continuing our contract with the USGS Conservation Branch involving a drilling and logging program to determine the depth, thickness, and quality of lignites and to correlate significant strippable lignite beds.

During 1976 we drilled a total of 44,000 feet of testhole including 21 locations in the New England area and 94 locations in Dunn, Mercer, Oliver, and Morton Counties. Last year's drilling was concentrated immediately south of the area we studied in 1975. Our preliminary inventory of overburden materials will contribute to studies related to reclamation potential or problems and will augment the data base used in making preliminary estimates of the effect of mining on local hydrologic conditions. We expect to continue the study in 1977 with another 48,000 feet of testhole.

ENVIRONMENT-RELATED STUDIES--

(Actually, it seems to me that <u>all</u> geology is "environment-related" and we geologists, by the nature of our work, have been concerned "environmentalists" since long before the term was fashionable.)

Survey geologists routinely examine waste-disposal sites throughout the State. Possible problems that might be caused by inadequate attention to geologic conditions can be detailed, and a preliminary evaluation can be made as to whether a site might be geologically suitable for the intended use. Site evaluations are based on such things as bedrock and glacial sediment composition, slope of the land, and depth to the water table. Such evaluations help insure the protection of groundwater supplies and prevent damage that might result from choosing a poor site for a lagoon or sanitary landfill or other intended use. Quick and decisive geologic advice can rule out poor sites at a minimum of expense, thereby eliminating possible costly remedial measures later.

Currently, we are conducting several environment-oriented studies to assist citizens throughout the state. We have completed three separate studies involving 17 counties, and we are working on two more areas involving an additional 16 counties. The studies are conducted in cooperation with the local Regional Councils for Development of which there are eight in the State. The studies have resulted in the preparation of county maps depicting such things as general construction conditions; groundwater pollution hazard; and the suitability for septic systems, sewage lagoons, and sanitary landfills.

Cooperation with the State Health Department in evaluating proposed waste-disposal sites continues, with 27 sites evaluated during the past year and the number steadily increasing. A recently completed report details conditions around a typical sanitary landfill in a setting of glacial topography. The results of this report will be useful in deciding on the placement of landfills in glaciated areas.

And, as part of our involvement in maintaining a safe environment, Survey geologists have received and reviewed a total of 3,468,358 Environmental Impact Statements averaging 1,743 pages each and weighing an average of 3.8--no, pardon me--1.7 kilograms apiece. (Anyway, it seems like that sometimes).

RECENT PUBLICATIONS--

Since the last NDGS Newsletter six months ago, the Survey has completed a variety of technical and educational reports. Two reports were published in our county groundwater series. A report on Benson and Pierce Counties, prepared by P. G. Randich of the U.S. Geological Survey, describes the general availability of groundwater in the two counties and provides information on quantity and quality of water with an emphasis on the major aquifers. Aquifer discussions include particle size analysis, water levels and pump test data. The report also contains information on present groundwater use. It consists of 76 pages of text, 41 figures, 2 tables, and 3 plates. A report on Ramsey County, prepared by R. D. Hutchinson of the U.S. Geological Survey, includes geologic and hydrologic data for 1,145 wells and testholes, water level measurements in 73 observation wells, lithologic and geophysical logs of 452 testholes and wells, 209 chemical analyses of groundwater, and 22 particle-size analyses. The report consists of 344 pages of text and data and one map showing locations of wells and testholes. Both of these reports can be obtained from the North Dakota Geological Survey.

Report of Investigation 60, "Stratigraphy of Offshore Sediment, Lake Agassiz--North Dakota," written by B. Michael Arndt, summarizes the stratigraphy of Lake Agassiz based largely on information obtained from highway department test borings for Interstate 29. It includes grain size analyses and engineering data for the different stratigraphic units and an interpretation of the history of Lake Agassiz during the deposition of the stratigraphic units. The report consists of 58 pages of text, 26 figures, 2 tables, and 3 plates.

The Official Oil Production Statistics and Engineering Data for the First Half of 1976 was published in February. This report contains the oil and water production by individual wells as well as other pertinent information.

Recently published maps include a colored Geologic Highway Map of North Dakota (Miscellaneous Map 19), which can be used as a ready reference to locate yourself geologically anywhere in the State. The map shows surface geology and is drawn at a 1:1,000,000 scale, a manageable size to use in a car. It includes an east-west cross section of the State and is available either flat or folded.

We recently published a new, colored, small (8½" x 11") generalized map of the surface geology of the State. This map (Miscellaneous Map 18) is intended for laymen and students.

Another map (Miscellaneous Map 20) shows all the proposed lignite-related power projects for North Dakota, both electrical and gasification facilities (also see item on page 7 of this Newsletter). Operating and proposed mines are located on the map.

A nontechnical North Dakota geology book, "The Face of North Dakota--The Geologic Story," has been printed and will be available soon. It should fill a need for earth science teachers in the State and serve as a handbook on North Dakota geology for interested non-geologists. A folded copy of the Geologic Highway Map, described above, comes with it.

Another new publication, Report of Investigations 62, deals with various engineering properties and agricultural potential of Divide, McKenzie, and Williams Counties, North Dakota. A report dealing with the problems involved in siting sanitary landfills in glaciated terrane (Open File Report OF-1) is now available.

And, finally, we have a new, up-to-date List of Publications which lists our available publications as well as those that are out of print. It also lists many of the services we provide. The List of Publications can be obtained free of charge from the Survey.

NORTH DAKOTA COAL PRODUCTION -- CURRENT AND PROPOSED--

The information in the following two tables was compiled by Gerald Groenewold of the NDGS. It is taken from NDGS Miscellaneous Map 20, which also shows the locations of each mine as well as currently-operating and proposed power plants and gasification plants. The map is available from the Survey.

ACTIVE MINES
PRODUCTION BY COUNTY (SHORT TONS)
(Tonnages are for the fiscal year ended June 30, 1976)

MINE	OPERATOR	TONNAGE AND COUNTY
Beulah	Knife River Coal Mining Company	836,919 (Mercer) 321,221 (Oliver)
Center	Baukol-Noonan, Inc.	1,659,757 (Oliver)
Gascoyne	Knife River Coal Mining Company	2,611,388 (Bowman)
Glenharold	Consolidation Coal Company	3,285,305 (Mercer)
Husky	Husky Industries	140,256 (Stark)
Indian Head	The North American Coal Corporation	1,065,021 (Mercer)
Larson	Baukol-Noonan, Inc.	352,716 (Burke)
Nelson	Geo-Resources, Inc.	10,000 (Williams)(estimated)
Smith-Ullman	Arrowhead Coal Company	14,021 (Adams)
Sprecher	Sprecher Coal Company	4,157 (Grant)
Velva	Consolidation Coal Company	419,522 (Ward)

PROPOSED MINES
PRODUCTION BY COUNTY (SHORT TONS)
(Tonnages refer to proposed annual production)

MINE	OPERATOR	TONNAGE AND COUNTY
Beulah (Expanded)	Knife River Coal Mining Company	4.3 million tons--1981 (Mercer and Oliver)
Center (Expanded)	Baukol-Noonan, Inc.	4.4 million tons--1978 (Oliver)
Coteau	The Coteau Properties Company (a subsidiary of The North American Coal Corporation)	14.0 million tons--1984 (Oliver)
Falkirk	The Falkirk Mining Company (a subsidiary of The North American Coal Corporation)	Mining beginning in 1977, 5.5-6.0 million tons annually by 1981 (McLean)
Unnamed near Dunn Center, ND	Amax Coal Company	13.0-14.0 millions of tons if one unit is constructed 52.0 million tons if four units are constructed (Dunn)
Unnamed Stark and Dunn Counties	Unknown (El Paso Natural Gas Company holds lease)	48.0 million tons if four units are constructed (Stark)
Unnamed near Beach, ND	Tenneco Coal Strip Company	--No Data--
Unnamed near Garrison, ND	Unknown (Nokota Company holds lease)	--No Data--

WILLISTON BASIN CORE STUDY LABORATORY--

A carbonate core and sample study laboratory was established this year through the generosity of individuals and corporations involved in oil exploration in North Dakota. This facility is designed for whole sample and petrographic study of Williston basin carbonate rocks.

Studies by industry scientists are now possible under terms of the grants for equipment purchase. The North Dakota Geological Survey Core and Sample Library may be better used now since materials may be studied onsite.

Initial funding for the laboratory equipment was derived from a proposal to industry representatives written by Tim Cross of the UND Geology Department and Lee Gerhard of the Survey. Although additional equipment is sought, core slabbing saws, a trim saw, grinding laps, and thin section preparation equipment have been purchased, installed, and are being used.

Renovation of Room 9 in the basement of our building was provided by the University of North Dakota. Epoxy painted walls and ceiling, replumbing, new coverings for core layout tables, and storage racks have all been provided for the laboratory.

Current plans call for acquisition of a Faxitron core slab X-ray unit for study of large fabrics and sedimentary structures and a cathode luminescence unit for study of diagenetic fabrics and paragenesis. Photomicrography capability has been provided by Dr. Cross through a separate grant.

To date, over $11,000 has been donated by corporations and individuals. We wish to express our appreciation to the following for their generosity:

Cardinal Drilling and Palmer Oil Co.
CIG Exploration Co.
Farmland International
Getty Oil Company
Gulf Oil Company
Claude B. Hamill
Ray Harrison
J. B. Hawley Trust
Hunt Energy Corp.
Tom Jordan
Marathon Oil Company
Montana-Dakota Utilities Co.
Phillips Petroleum Co.
Rainbow Resources
Shell Oil Company

Studies now underway are:

Lodgepole Formation:	Tom Heck
Red River Formation:	Kipp Carroll
Duperow Formation:	John Hoganson
Mission Canyon Porosity:	NDGS Staff
Winnepegosis Bioherms:	NDGS Staff

Most of these studies center about the localization of petroleum production or potential within these units and the depositional and diagenetic systems that caused the localization. We hope that the extension of these types of carbonate studies to Williston basin rocks will be useful to exploration geologists.

OIL PRODUCTION CLIMBS--

Crude-oil production in North Dakota in 1976 registered an increase over the previous year, as it has the past two years. There were 21,723,586 barrels of crude oil produced from 160 oil pools in the State during the year, a 6.2 percent increase over 1975. Drilling activity continued at an accelerated pace. The results of this activity are reflected in the number of new oil pools discovered during the year. The seventeen new pools that were found were nine more than during 1975 and constituted the highest number of new discoveries since 1958.

Nearly all segments of the mineral industry showed an increased interest in North Dakota during 1976. A total of 246 drilling permits were issued in 1976 for oil and gas exploration. During the first five months of 1977 (Jan 1--June 1) a total of 143 permits were issued. (Permits issued each month are listed in the Monthly Oil Production Report. Anyone desiring this information should subscribe to that publication.) The Survey issued 38 permits for coal exploration, 10 for uranium, 3 for potash, and one for Glauber's salt during 1976.

EXPLORATION INGENUITY--

The theme of the recent annual meeting of the Rocky Mountain Section of the AAPG was "Exploration Ingenuity--Key to Energy Resources." Michael T. Halbouty echoed this philosophy in his keynote address. He stated that explorers cannot possibly find the 20,000 prospects required each year to meet the needs of the immediate future with present exploration philosophy and methods.

It is generally accepted by exploration people that the more obvious surface and subsurface structures have been identified and tested. There have been recent exceptions, such as the prolific Silurian discovery in McKenzie County on the east flank of the Nesson anticline and the earlier Devonian, Silurian, and Ordovician discoveries in Williams County on the west flank of the Nesson anticline, but the greatest exploration impetus in North Dakota is taking place in areas distant from obvious structures.

Exploration ingenuity is not a new phrase or philosophy. It has been practiced by many exploration geologists and geophysicists who have developed new ideas and methods that have sometimes been used by industry with considerable success. It is apparent from the dramatic increase in discoveries in the deeper part of the Williston basin that something of this nature is taking place.

In attempting to analyze the cause or causes for the increase in discoveries and improvement in wildcat success ratio, it is necessary to consider all factors. One, of course, is the increase in the price of crude oil since the oil embargo. The increase in price could be expected to increase the rate of wildcatting, but it would not in itself tend to improve the success ratio. The improvement of the success ratio can only be due to new ideas and developments by explorationists.

A recent article in the Oil and Gas Journal illustrates this quite effectively. The Oil and Gas Journal has analyzed the exploration history of the southwestern portion of the Williston basin, specifically Bowman County, North Dakota, and Harding County, South Dakota.

The Journal report covers the period from 1953 to December, 1975, when the federal government rolled back the price of crude oil to appoximately $11.50 per barrel. During this time period, 75 wells were drilled, resulting in 28 discoveries, for a success ratio of 37% (it should be pointed out that the Oil and Gas Journal generally considers all wells not specifically drilled as development wells to be wildcats).

What is particularly significant about the Journal study is the dramatic increase in the success ratio beginning with the fiftieth well drilled. Up to that point, the probability of success had been only 16%. The drilling of wells 51 through 75 resulted in a rapid increase in wildcat discoveries improving the success ratio to 52%.

While the oil embargo and resulting increase in crude oil prices might be cited as the reason for the increased success ratio, it is significant that well number 50 and four additional successes were drilled before the embargo and rise in prices. The cause would appear to lie in developments in technology and geologic interpretation.

Stack shooting had been available for some time prior to the drilling of well number 50. Its use in conjunction with the isopach thin technique of interpretation, which became accepted as necessary by this time, has resulted in 19 new discoveries in 25 attempts. It may be concluded that the increase in the wildcat success ratio in this portion of the Williston basin is the result of the isopach thin technique and stack shooting.

The prospects for continued success look great for the area mentioned above, but what of other portions of the Williston basin? Let's consider the counties where the exploration of Madison and deeper formations is underway. These include Billings, Dunn, Golden Valley, McKenzie, Slope, and Williams Counties. During the period covering 1973 to the present, production has been found in these counties in Madison, Bakken, Devonian, Silurian, and Ordovician rocks.

For this discussion, we shall define wildcat wells as those drilled prior to and including a discovery well, excluding those wells originally permitted as wildcats and subsequently drilled as development wells following discovery. Outpost and extension wells are also omitted. Using these criteria, we find that in 1973, nine wildcats were drilled in this six-county area with nine failures for a 0% success ratio. Some improvement occurred in 1974 with eight wildcats and one discovery for a 12.5% success ratio. A dramatic increase occurred in 1975 with six out of fourteen wildcats completed as producers with an increase in the success ratio to 43%. The rate of success continued to climb in 1976 with twelve discoveries for 22 attempts giving a success ratio of 54%.

The causes for the dramatic increase in success ratios in this six-county area are difficult to analyze. There is a considerable variation in drilling depths and problems from Slope County in the south to Williams County at the northern end of the area. The Red River Formation, which may be found at a depth of 10,000 feet in Slope County, can be topped at below 14,000 feet in McKenzie County.

Discussions with explorationists reveal that the isopach thin technique, which has been so successful in the southwestern part of the Williston basin, does not appear to be applicable to the deeper central portion. It is conceivable that the greater depth and thickness of overlying formations tend to diminish the effect that deep structures may have on subsequent sedimentation. Stack shooting continues to be an important tool used in more conventional structure mapping in this area. As drilling and discovery continue, we hope to learn more about the techniques and methods responsible for the increase in wildcat success ratios. It is apparent that explorationists in the Williston basin are indeed practicing exploration ingenuity and industry management is implementing new ideas and methods with considerable success.

NORTH DAKOTA'S DRAINAGE PATTERN--

If you study a map of North Dakota on which the drainage system is emphasized (a highway map is not a very good choice--it's hard to get an idea where the rivers flow) you may wonder at the peculiar routes of some of the rivers. Southwestern North Dakota rivers such as the Little Missouri, Heart, Knife, and Cannonball, all flow northward or northeastward into the Missouri River, which flows southeast across the state. The Souris River flows into North Dakota, loops around, and flows out again. The Sheyenne River winds its way southeastward, but then loops sharply northeastward to join the Red River. And the Red River of the North flows almost straight north.

All of these rivers follow their leisurely, sometimes tortuous routes in the face of the fact that the overall slope of North Dakota is not at all complex. The state slopes northeastward from a height of about 3,500 feet above sea level on White Butte in Slope County in the southwest, to a low of 750 feet where the Red River flows into Canada in Pembina County. One might expect that the drainage should be directed in a northeasterly direction, down the regional slope; in most places streams do follow the regional slope. But not in North Dakota. Why?

To answer the question, we have to go back to the time before the state was first glaciated, between two and three million years ago. At that time, nearly all the streams did follow northeast-trending routes, their water eventually reaching Hudson Bay.

Before the first glaciers advanced into North Dakota, the ancestral Heart, Knife, and Cannonball Rivers all flowed northeastward along their present routes, continuing northeastward beyond the points where they now enter the Missouri River. They flowed into eastern North Dakota, joining a large north-flowing river that entered Canada a few miles east of the Turtle Mountains.

Similarly, the Yellowstone River entered North Dakota in the same place as it does today, but it then flowed northeastward across Divide County into Canada, probably eventually joining the same large, north-flowing river system I just mentioned. The Little Missouri River flowed northward, joining the Yellowstone River near Alamo north of Williston

The Red River of the North flowed northward just as it does today, although the location of the river has ranged over a rather broad area that coincides generally with the modern Red River Valley.

With the coming of the glaciers, much of the drainage system I have just described was changed drastically. Almost from the start, drainage to Hudson Bay was cut off, and the north-flowing rivers were dammed by the ice. Glaciers that moved into and through North Dakota forced the water to flow along the edge of the ice, rapidly eroding deep "diversion" valleys.

North Dakota was glaciated several times during the last three million years, and during each glaciation, the river systems changed. Southwestern parts of the state, which were not extensively glaciated, retain about the same stream pattern they had prior to glaciation; but in the east, which was repeatedly glaciated, the early river valleys are buried beneath several hundred feet of glacial sediment, and stream patterns are almost entirely the result of changes that took place during the ice age.

Except for the part of North Dakota southwest of the Missouri River, the modern drainage pattern is largely the result of events that took place during the ice age. The comings and goings of the glaciers through the state altered and realtered the routes of streams north and east of the Missouri River so that our modern steam pattern is quite complex.

North Dakota's modern drainage is divided into two systems. About 60 percent of the area of the state, the east and southwest, drains toward the Gulf of Mexico. The remainder of the state drains northward to Hudson Bay. These two drainage systems are separated by a low continental divide, which extends diagonally, from northwest to southeast, across the state.

North Dakota's largest river, the Missouri River, is also one of our most interesting ones. It receives most of its flow from the melting snows in the mountains of Wyoming and Montana, where it and its main tributary, the Yellowstone River, have their sources. The Missouri River is the only river flowing through North Dakota that provides the state with a reliable water supply.

The valley of the Missouri River across North Dakota is a sort of hybrid thing, a combination of old preglacial river valleys and glacial diversion valleys that have been "welded" into the valley through which the river flows today.

In some places, the Missouri River valley is broad, spanning six to ten miles from rim to rim. In other places the valley is quite narrow, nearly a gorge less than two miles wide. Generally, the wider parts of the valley extend in an east-west direction, whereas the narrower parts trend north-south.

The wide parts of the Missouri River valley coincide with old, preglacial valleys through which rivers may have flowed over three million years ago. The narrow segments are much younger and were carved when water flowed southward along the edge of the glacier a few tens of thousands of years ago.

A good example of an old, broad portion of the Missouri River valley is the part now flooded by Lake Sakakawea upstream from Riverdale.

This portion of the valley existed before the state was glaciated when it contained a river that flowed eastward, passing north of Riverdale, through what is now the Snake Creek Arm of Lake Sakakawea, and eastward beneath the present vicinity of Turtle Lake, the Prophets Mountains, and near Lincoln Valley in Sheridan County.

An example of a part of the Missouri River valley that formed when glaciers diverted the drainage, forcing it to erode a valley, is the north-south part of Lake Sakakawea southwest of New Town. The Four Bears bridge west of New Town crosses what is one of the narrowest and youngest segments of the Missouri River valley in North Dakota.

Generally, throughout the glaciated part of North Dakota, the eastern and northern parts of the state, the drainage pattern is a combination of numerous valleys that carried meltwater from the glaciers and joined into more-or-less continuous valleys. The routes of these valleys are determined largely by the distribution of glacial sediment, which was dumped as hills by the ice in some places, smoothed into plains in other places. Modern streams simply flow around the hills, resulting in a drainage pattern that otherwise seems to have neither rhyme nor reason.

Large portions of glaciated North Dakota have virtually no through drainage. Such areas consist of topography that was formed so recently in geologic time by the glaciers, that streams haven't yet had time to form. Examples are the Turtle Mountains and the Missouri Coteau.

The Souris (Mouse) River follows a looping route that is probably the result of the pattern of glacial deposition of sediment. However, it has also been suggested that the sediments overlying deeply-buried salt deposits collapsed when the salt dissolved. The area of this collapse corresponds closely with the route of the Souris River.

DEAD-ICE MORAINE--

Among the most interesting geologic features found in North Dakota are the rugged landscapes found in areas such as the Turtle Mountains, on the Prairie Coteau in Sargent County, and on the Missouri Coteau. The Missouri Coteau (known also as the "Hills of the Missouri;" "coteau" is French for "little hill.") is by far the most extensive of these three hilly areas, extending from Divide County in the northwest to Dickey County in the southeast.

The landscapes of all three of these areas were formed in the same way; as a result of glacial stagnation. (Incidentally, the Turtle Mountains receive several inches more rainfall each year than the other two areas, and, as a result, they are wooded. However, the landforms there are otherwise the same as those found on the Missouri Coteau, which is generally prairie.)

The hilly landscapes found in each of the three areas began to form about 13,000 years ago when the last glaciers, which by that time were generally melting from North Dakota, became so thin that they could no longer flow easily over high areas such as the Turtle Mountains. In fact, the glaciers became so thin that, even though they continued to flow generally southward, the three high areas caused them to undergo what geologists refer to as "compressive flow." This means that the ice was pushed into the high areas, and, rather than flowing smoothly up and over them, intense thrusting took place at the glacier's margin. As a result, great quantities of rock and other debris beneath the ice were dragged upward through the ice along shear planes in the glacier.

As the glacier melted, this debris, referred to by geologists as "glacial till," became concentrated on the surface of the glacier, forming a nearly continuous blanket several tens of feet thick on top of the ice.

The cover of till on the glacier helped to insulate the ice, causing it to melt much more slowly than ice on surrounding lowland areas. Nearly continuous sheets of stagnant glacial ice, which at first were a few hundred feet thick, covered the three areas. Much of this ice persisted for at least 3,000 years, until about 9,000 years ago.

The till cover on top of the three areas was irregularly distributed, and, as a result, the ice melted irregularly. This uneven melting caused the upper surface of the stagnant ice to become hilly and pitted with irregular depressions. The till on top of the ice was saturated with water from the melting ice and it was highly fluid. It slid down the ice slopes and accumulated in the depressions. Mudflows were common. The thick accumulation of debris in the depressions on the stagnant glacier caused the ice there to melt more slowly, and newly exposed ice from which the till cover had recently slid melted more rapidly, resulting in continual reshaping of the surface of the stagnant, till-covered glacier.

At first, the stagnant glacier melted rapidly, and the material on top of the glacier slid almost continually to new, lower positions. However, as the ice continued to melt, the cover of till on the ice stabilized, causing the ice to melt more slowly.

The environment gradually stabilized too, and water in lakes that collected in till-filled depressions on the glacier became more temperate. Most of the water in the lakes was runoff from local precipitation, rather than melt water from the glacier. Precipitation at the time was much greater than it is today, probably between 25 and 50 inches of rainfall a year, and the mean annual temperature was a few degrees cooler than it is today.

Fish and clams and other animals and plants thrived in the lakes that developed on top of the till-covered glacier. Surrounding the lakes and streams, the till on top of the stagnant glacier was forested by spruce, tamarack, birch, poplar, aquatic mosses, and other vegetation, much like parts of northern Minnesota today.

The stagnant-ice environment in the three areas was in many ways similar to stagnant, till-covered parts of certain glaciers in south-central Alaska today.

Eventually, all the stagnant ice melted, and all of the material on top of the glacier was let down to its present position forming the hilly "collapse" topography that is found in the three areas today. These landforms are referred to by geologists as "dead-ice moraine."

FOSSILS IN NORTH DAKOTA--

Fossils are abundant in only a few places in North Dakota, and the casual observer may not be successful at finding them. The following discussion is not a catalog of fossil localities, but rather a general review of what some of the formations contain.

Fish scales and coccoliths are commonly found in exposures of the Cretaceous Niobrara Formation, which is exposed in several places in eastern North Dakota. The Cretaceous Pierre Formation, which is exposed in many eastern North Dakota river valleys, as well as in the southwest corner of the state, has produced some fossils, including some echinoids, a mosasaur in Barnes County near Kathryn, and abundant fragments of the clam Inoceramus from many outcroppings.

The Cretaceous Fox Hills Formation contains several kinds of clams, snails, fossil crab burrows, and at least one type of cephalopod. The formation is especially fossiliferous in parts of south-central Sioux County, a few miles east of Selfridge, where oysters and clams are abundant, and in parts of Emmons County.

The Cretaceous Hell Creek Formation contains some dinosaur bones. Bone fragments can be found in most badlands exposures of the formation and occasionally an entire bone, or even an entire skeleton may turn up. Part of a skeleton of the dinosaur Triceratops was taken from Hell Creek Formation sediments in Slope County in southwestern North Dakota. Fish bones are common in the Hell Creek Formation near Huff in Morton County, and mollusk shells can also be found in places.

The Paleocene Cannonball Formation contains lobster, crab, and clam fossils. It also contains Teredo-bored petrified wood, North Dakota's official state fossil. Teredo-bored petrified wood was bored by worm-like clams known as shipworms before it was petrified. It is less commonly found in the Pierre Formation. The Ludlow Formation, which was

being deposited on land at the same time the Cannonball Formation was being deposited off shore, contains an abundant fossil assemblage, including fossil fish and turtles which have been collected at one site in Billings County. Fossilized crocodiles up to 16 feet long have been found along with fossil champsosaurs, which were similar to crocodiles, but not so large. A few small primate fossils and primitive horse and cow-like fossils have been found in Ludlow Formation sediment in North Dakota.

The Paleocene Bullion Creek and Sentinel Butte Formations contain fossil mollusks, but the most obvious fossil from these two formations is the abundant petrified wood and lignite, which is an accumulation of fossil plant material. It is possible to collect excellent fossil leaves and plant casts from the lignite in some places.

Well-preserved plant and animal fossils occur in the Eocene Golden Valley Formation sediments and the Oligocene White River Group sediments in some places. At White Butte, south of Dickinson, fossil fish, frogs, reptiles (including four genera of crocodilians), a small bird, and mammals, including rodents, carnivores, pantodonts, perrisodactyls, and artiodactyls, have been collected from the Golden Valley Formation. The White River Formation has yielded a few fossils in North Dakota, including titanothere bones and a rhinoceros.

The Pleistocene Coleharbor Group sediments have produced abundant fossil assemblages. These include pollen from a large variety of trees and smaller plants as well as assorted plant remains, both of which were especially common in lakes and sloughs that existed during and at the end of the ice age. Numerous fish, aquatic snail and clam shells, and land snails have been collected from glacial and postglacial lake sediments. Insect fossils and ostracodes are also found in lake sediments. Larger fossils dating to the Pleistocene in North Dakota include such animals as beaver, caribou, and mammoth remains. Bones of bison are commonly found in the banks of streams throughout the state. They date from a few hundred years old to several thousand years old.

At one fossil location in Stutsman County, North Dakota, the Seibold Site, more than 160 species of mollusks, ostracodes, insects, fish, amphibians, mammals, and plants were found. These animals and plants lived in and near a lake that came into existence while glacial ice was melting from the area. The lake persisted for several thousand years.

STRIPPERS--

Old strippers--ever wonder what happens to them? Whether the Las Vegas variety or the North Dakota variety, they tend to have been associated in their past with gamblers and high rollers; but, alas, time and action have taken their toll, and they have declined from a time when they were more attractive and exciting. Life proceeds more slowly for them now. They are tended to less frequently and no one appears too interested in working them over anymore.

But wait. We find that old strippers are alive and well in North Dakota. We don't claim to be experts on the Las Vegas-type stripper, but from the word we are getting, it appears that the North Dakota stipper is active and pretty well paid.

Now, lest you be misled, the strippers we're talking about are the approximately 655 oil wells currently producing 10 barrels of oil a day or less. Scattered throughout the oil-producing areas of the state, they make a valuable contribution to our energy requirements and to the local and state economy.

The 655 stripper wells in the state produced over one million barrels of oil in 1976. At the current stipper well price of approximately $11.50 per barrel, their gross production value was over twelve million dollars. This averages out to nearly $19,000 per well.

Their continued well-being is of considerable importance to the state and local economy. The state benefits through the gross production tax. The local economy benefits through employment of oilfield workers, and the fact that many of these wells are owned and operated by local individuals or companies so that profits received tend to stay in the community.

So, if you hear someone lamenting the fate of old strippers, tell them they are alive and well in North Dakota.