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NDGS NEWSLETTER

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COVER PHOTO

The photo on the cover shows an esker in northern Sheridan County, central North Dakota (Section 13, Township 150 North, Range 76 West). The esker, which stands 40 to 60 feet above the level of surrounding Frankhauser Lake, extends for about 4 miles through this area of ice-thrust topography. It is situated in a broad depression left when the southeast-flowing glacier thrust a large (3-square-mile 200-foot thick) block of material a short distance; the ice-thrust material is located immediately to the right of the area shown on this photo. The esker may have formed during the thrusting process, during which large amounts of groundwater were released when the ice-thrust block was removed, thereby allowing the water to escape. Similar eskers, formed during the process of "popping the cork" during thrusting, are commonly found in association with ice-thrust terrane. Photo by John Bluemle.

CONTENTS

SURVEY ACTIVITIES

--John Bluemle

As mid-year approaches, the people on the Survey staff are busy with a variety of projects and activities. One of our more important concerns is the ongoing search for a new State Geologist. Our advertisements resulted in about 25 applications for the job. These are being screened by a Search Committee, which will ultimately recommend a selection. We all hope a suitable person can be chosen soon.

We have just received a considerable amount of new computer equipment and we are in the process of installing it in the Survey offices. It includes a System 34 with several IBM PCs and a new word-processing system. Some wiring remains to be done before the entire system is completely operational; we expect our computer system eventually to be tied into the University of North Dakota main-frame computer.

Research underway by Survey geologists this summer includes several field projects as well as work being done in our offices. Ed Murphy will be mapping the surface geology in the Dunn County area during much of the summer. John Hoganson plans to study the Oligocene Brule Formation fossils in southwestern North Dakota, especially the plants and invertebrates. He and Alan Cvancara of the UND Geology Department will be studying fossil sharks from the Cannonball Formation as well as Oligocene snails. David Brekke will continue his field and geochemical studies of the Cretaceous shales in eastern North Dakota. Ken Harris expects to continue his study of the southeastern North Dakota glacial stratigraphy, using our soil probe in the area between Fargo and Grand Forks in the Sheyenne River and Goose River 1° x 1° map sheet areas. He will also be studying the airphotos of the area, getting these first map sheets ready to publish, hopefully next year.

David Fischer has expanded his heat-flow study of the Billings Anticline and he will be working on that this summer. He and Sid Anderson are completing an isopach map of the Cretaceous Inyan Kara Formation. Dave is also preparing a report to the Potential Gas Committee, which will include estimates of the amount of undiscovered gas resources in North Dakota, and he also expects to be working on a new oil and gas activity update, describing exploration and development activity in North Dakota during 1984 and 1985. Dave plans to spend several weeks inspecting coal test holes for the Survey, to be certain they have been properly reclaimed.

Randy Burke expects to continue examining Duperow Formation core samples, studying diagenesis in the Billings Anticline area. He is compiling a Devonian cross section of the state. Randy also has tentative plans to attend a session of the International Association of Sedimentologists this summer in Canberra, Australia, to present a paper he has co-authored with Lee Gerhard. Randy's attendance at this meeting depends, in part, on whether sufficient funding is available to assist in covering the cost of the expenses.

Sid Anderson, who is kept busy with his duties as Acting State Geologist, is in the process of completing his study of marginal Williston Basin Lodgepole Formation sediments in western North Dakota. He and Julie LeFever will also be continuing their study of the Nesson Anticline, including stratigraphy, structure, and petroleum engineering. Julie will be finishing her study of the Madison Formation in north-central North Dakota; we hope to publish this report, which describes the structural and depositional history of the area, within the next several months.

Marv Rygh expects to be examining several Madison cores from the Renville and Burke County area, studying the porosity and permeability of the rocks. He hopes to learn more about some of the problems that sometimes arise with these rocks when they are acidized during well-completion procedures. Marv also is doing a final editorial check for our soon-to-be published well schedule, cross checking the material we have in our computer against official statistics provided by the Oil and Gas Division. The well schedule will include legal descriptions of all North Dakota wells, and information on such things as the current and original operator, producing status of the well, logged interval and logs run, deepest formation penetrated, producing horizon, total depth, and other information. We expect to publish this information in two volumes some time in August.

My own plans (John Bluemle) include at least some fieldwork late in the summer in Ward and Renville Counties and possibly some study of the long, linear drumlins in McHenry County. I also hope to attend an American Association of Petroleum Geologists field trip in northern Scotland in July, looking at some classic geologic exposures, and in northern Ireland, where drumlins and other glacial features are well developed; if any time remains after these field trips, my wife, Mary, and I hope to spend a few days sightseeing in Ireland.

GEOLOGICAL SURVEY EDUCATIONAL PROGRAMS

--John Bluemle

Some time ago I received a copy of an article that appeared in the October, 1985 issue of The Science Teacher, a publication aimed primarily at public school teachers. The article, "Free Tips for Geologic Trips," was written by John W. McLure, an associate professor of education at the University of Iowa. Dr. McLure described some of the educational services of the state geological surveys. He stressed the fact that most of the state surveys do offer a variety of educational services, such as field trips, speakers, and a variety of types of programs including films and slide shows. Many surveys provide non-technical publications and some have rock and mineral sets available. Some surveys maintain museums and many of them have geologic libraries that are available to the public.

The North Dakota Geological Survey fares reasonably well when our educational services are compared to those offered by other surveys. Even though our main emphasis, and the emphasis of nearly all of the state surveys, is research and assistance to professional geologists, engineers, ecologists, and developers, we have always had definite commitments to educational outreach too. It's likely though, that many teachers have been unaware of the services we have routinely offered; we probably haven't done nearly enough to advertise the fact that a variety of educational services can be obtained through the Survey.

As a response to some of these concerns, we recently established an Extension Section (NDGS Extension) with Ken Harris and John Bluemle as Extension Co-Coordinators. Even though the topics we are offering through our Extension Section are not all new, establishing the section helps us to focus our educational activities, and it helps us to alert agencies and individuals around the state that we are available to help in a variety of ways. So far, we have limited our contacts to the state colleges and universities and to teachers' institutes. The initial response has been encouraging; our geologists made about a half dozen presentations during February, March, and April as a direct result of our offer. The topics we offered are listed at the end of this article.

In addition to the topics included in our NDGS Extension listing, our geologists are available to conduct field trips for various groups (we do ask that such trips be arranged well ahead of time). We provide slide programs that describe the geology of various aspects of the state's geology (these are for loan, not for sale as Dr. McLure indicated in his article). We have several non-technical publications available, including a set of guidebooks with field trips for the various parts of the state. The NDGS Newsletter is available without charge. We try to include at least one or two non-technical articles in each issue of the Newsletter on some aspect of North Dakota geology, hoping that these can be utilized by teachers in their classrooms or, simply, as general sources of information. This issue, for example, has articles on North Dakota's mountainous areas and on drainage development. And, we have a rock and mineral set with 17 typical North Dakota samples available for only a dollar.

In addition to NDGS Extension and the services I have just mentioned, we recently have been giving considerable thought to other ways that the NDGS might more effectively provide additional educational or public information services. Several ideas have been suggested, and I'll outline a few of them here.

It was suggested that we help to establish geologic markers along the state's highways. The state has already placed a number of markers along the highways promoting the state's history and an effort to describe the geology, especially at existing rest areas and other roadside stops, might be appropriate too. Such signs could include a short text; for example, a fossil site might be explained within a secure, enclosed shelter showing examples of the fossils. Other signs might include diagrams, maps, and pictures to help the visitor understand what he or she is seeing. A campaign to provide markers throughout North Dakota could make a trip through the state a much more interesting and educational experience.

It was suggested that we make a greater effort to build a publication series for tourists, or other specific groups. We might, for example, provide a book or brochure describing the geology of North Dakota's parks and public recreation areas or, perhaps, a separate brochure for each state park. Or, we could provide a series of field trip guidebooks, perhaps one for each major retail trade area in the state. Such guidebooks might be distributed through visitor and convention bureaus to hotel and motel guests. They could lay out simple geologic tours, which could be taken in that region, providing enough explanation through text discussions, maps, and diagrams to help visitors (for example), to understand what it is they are seeing.

I am interested in hearing from you about ways you think we can more effectively communicate ideas about geology. What do you want to know and what do you want to see? Are any of the ideas I just mentioned reasonable ones or won't they work? Please let us know so we can more effectively fulfill our responsibilities.

I've listed the topics for technical talks and laboratory exercises offered by NDGS Extension. If you wish to schedule one of these talks or make arrangements for a supplemental laboratory exercise, please contact Ken Harris or John Bluemle at 777-2231. Since our geologists are generally occupied with fieldwork during the summer months, we will probably have to schedule any activities for after mid-September, 1986. Please let us know too if you have ideas for additional topics or activities that would be of interest.

This is a listing of topics for technical talks and laboratory exercises offered by the North Dakota Geological Survey to colleges and universities in the state. If you wish to schedule a talk or make arrangements for a supplemental laboratory exercise, please contact John Bluemle or Kenneth Harris at 777-2231. Please allow one month lead time for talks or laboratory exercises.

AREA TOPIC FORMAT GEOLOGIST(S)

1. GEOCHEMISTRY:
   A. Isotope dating techniques; talk; Julie LeFever

2. GEOMORPHOLOGY:
   A. North Dakota landforms; talk; John Bluemle
   B. Glacial tectonics and North Dakota landforms; talk; John Bluemle
   C. The Red River Valley; geology, origin, and flooding; talk; John Bluemle

3. QUATERNARY GEOLOGY:
   A. Quaternary geology of western Minnesota and eastern North Dakota; talk; Kenneth Harris
   B. Till stratigraphy of western Minnesota and eastern North Dakota; talk; Kenneth Harris
   C. Quaternary lithostratigraphic correlation techniques used in North Dakota; talk, lab; Kenneth Harris
   D. Quaternary fossils as climatic and environmental indicators; talk; John Hoganson, David Fischer

4. GROUNDWATER GEOLOGY:
   A. The effects of drilling fluid on shallow groundwater; talk; Edward Murphy
   B. The effects of oil and gas exploration and production on shallow groundwater in North Dakota; talk; Edward Murphy
   C. Considerations in solid waste management in North Dakota; talk; John Hoganson

5. MINERAL RESOURCES:
   A. Mineral resources of North Dakota; talk; Sidney Anderson, David Brekke, John Bluemle
   B. Non-fuel mineral resources in North Dakota; talk; David Brekke
   C. Solution mining in North Dakota; talk; David Brekke
   D. Clay mineralogy in North Dakota; talk; David Brekke

6. PALEONTOLOGY:
   A. Beetles as indicators of Quaternary climates and environments; talk; David Fischer, John Hoganson
   B. North Dakota fossils; talk; John Hoganson
   C. Oligocene fossils
   D. Conservation of paleontological resources; talk; John Hoganson
   E. NDGS paleontology program; talk; John Hoganson

7. PETROLEUM GEOLOGY:
   A. Carbonate reservoir rocks and hydrocarbons; talk; Randy Burke, David Fischer
   B. Oil and gas economics in North Dakota; talk; Sidney Anderson, David Fischer
   C. Petroleum Geology; talk; Kenneth Harris, David Fischer, Randolph Burke, others
   D. Formation evaluation (wireline logs); talk, laboratory exercises; David Fischer, Kenneth Harris
   E. Subsurface exploration for hydrocarbons; talk, laboratory exercises; Randolph Burke, David Fischer, Kenneth Harris, Julie LeFever

F. Production methods; talk; Marvin Rygh
G. Oil and gas well drilling; talk; Marvin Rygh
H. Mud system engineering; talk; Marvin Rygh
I. Drill stem tests; talk; David Fischer, Marvin Rygh
J. Oil and gas property leasing practices; talk; David Fischer, Marvin Rygh
K. Oil and gas regulations in North Dakota; talk; Marvin Rygh
L. Quantitative core analysis; talk, laboratory exercises; Randolph Burke, Marvin Rygh

8. CARBONATE GEOLOGY:
A. Modern carbonate depositional environments; talk; Randolph Burke
B. Reefs through geologic time; talk; Randolph Burke
C. Porosity development in carbonate rocks; talk; Randolph Burke
D. Carbonate geology; talk, laboratory exercises; Randolph Burke, John Hoganson
E. Qualitative core analysis; talk, laboratory exercises; Randolph Burke, David Fischer

9. STRATIGRAPHY:
A. North Dakota stratigraphy; talk, laboratory exercises; staff
B. Upper Cretaceous and Tertiary sediments of western North Dakota; talk; Edward Murphy

10. STRUCTURAL GEOLOGY:
A. Tectonics; talk; Julie LeFever
B. Structural geology; talk; Julie LeFever

11. NORTH DAKOTA GEOLOGY:
A. Geology of North Dakota; talk; John Bluemle
B. Geology of the Killdeer Mountains; talk; Edward Murphy
C. Geology of selected areas of North Dakota; talk; staff

12. SPECIAL TOPICS:
A. Field geology techniques; talk; Julie LeFever
B. Analytical techniques used in geology; talk, laboratory exercises; David Brekke
C. Geological applications of the scanning electron microscope; talk; David Brekke

ALAN KEHEW LEAVING

Dr. Alan Kehew, who joined the NDGS in 1977 and later became a full-time University of North Dakota faculty member in the Geology Department, will be leaving North Dakota for a new position at Western Michigan University in Kalamazoo. After joining the Geology Department, Alan continued to work for the Survey during the summer months (his UND contract was for 9 months of the year, as is the case for most faculty). He continued to study a variety of groundwater problems for the Survey, writing a report for us on the effect of seepage from municipal waste lagoons on shallow groundwater in shallow aquifers and (with Ed Murphy) on the effects of oil and gas well drilling fluids on shallow groundwater in western North Dakota. While with the Survey, and later with the Geology Department, Alan did considerable important research on the effects of catastrophic flooding during the Pleistocene in North Dakota and the northern Great Plains. He published several papers on the subject while in North Dakota.

NEW PUBLICATIONS

Miscellaneous Map 26--"Depth to Bedrock in North Dakota," was drawn by John P. Bluemle. This map shows the thickness, in feet, of the materials overlying the bedrock surface in North Dakota. It has a 100-foot contour interval, but supplementary 50-foot contours are included in places where the covering of glacial sediment or alluvium is thin. Areas where bedrock is exposed in North Dakota are identified by colors. The map is a considerably revised and improved version of a similar map that we first published in 1971; the earlier map has been out of print for some time. The map should be valuable to drillers who want to determine the amount of surface casing that will need to be set. It should be useful to anyone who needs to know the amount of overburden overlying the bedrock in any part of the state.

Miscellaneous Map 26 is drawn at a scale of 10.5 miles to an inch (about 1:670,000) and measures about 25" x 36". It can be obtained for $1.00 from the North Dakota Geological Survey.

Slide Set Showing North Dakota Geology--"Landforms of North Dakota." We have recently made several copies of our slide program illustrating North Dakota's landforms. This series of about 80 slides shows typical and unusual North Dakota landforms and includes an explanatory text that tells how the features formed. We had similar sets of slides available a few years ago, but they gradually "evaporated" as we loaned them out. The slide sets are intended mainly for use in schools as an aid to teaching about North Dakota geology, although they could be used as part of a service club program. The slide set is available for loan from the Survey without charge, except return postage.

ANNOUNCEMENTS

(Editor's Note: I've been asked to include the following items in this Newsletter. We haven't had a "Meetings" or "Announcements" section in our newsletter before so let me know if you think this sort of thing is appropriate).

1. North Dakota Geological Society Field Trip, August 23-24, 1986, Bismarck, North Dakota.

   Registration Deadline is July 23.

   For information, contact:
   North Dakota Geological Society
   P.O. Box 82
   Bismarck, ND 58502

   Phone: Mr. C. G. Carlson: 701/224-2969
   Dr. Richard LeFever: 701/777-3014

The annual North Dakota Geological Society Field Trip will begin in Bismarck on August 23, 1986, at Bismarck. Leave from the State Office Building parking lot at 8:00 a.m.

Titled "Tertiary and Cretaceous of Southwestern and South-Central North Dakota," the trip participants will examine the section from the Slope through Fox Hills Formations in Morton, Sioux, and Grant Counties on the first day, which will end in Bowman. The second day will include study of the Pierre through White River Formations in southwestern North Dakota, with the trip ending up back in Bismarck on Sunday evening.

Registration fee is $45 for members, $55 for non-members and includes bus transportation, guidebook, and lunches.

Motel or camping is available in Bowman (cost not included in registration).

2. Computer Modeling of Groundwater Flow and Transport, October 27-31, 1986, Minneapolis, Minnesota

For information, contact:
Mrs. Rita Mendenhall, Program Coordinator
University of Minnesota
Department of Civil and Mineral Engineering
500 Pillsbury Drive, S.E. Room 292
Minneapolis, MN 55455

Phone: 612/376-7630 or 612/727-1703

The following information was supplied about this meeting:

A one-week short course will be offered on the application of computer models to regional groundwater flow and transport. The program is summarized as follows:

Day 1: Basic concepts
Day 2: Elementary analytic solutions
Day 3: The analytic element method
Day 4: Finite element and finite difference methods
Day 5: Contaminant transport

The lectures will be accompanied by computer demonstrations, utilizing large-screen projectors. Participants will have continuous access to 15 IBM personal computers, and will follow the examples given by the instructors on their own machines. The lectures will be interspersed with problem-solving sessions. All evenings will be dedicated to hands-on computer modeling; the instructors will remain available for individual assistance for as long as the demand requires.

Participants will receive complete sets of lecture notes on all material covered, as well as five diskettes with various computer programs, among which an analytic element model and several finite element programs.

The instructors are Professor Arnold Verruijt, Delft University of Technology, The Netherlands, and Professor Otto D.L. Strack, University of Minnesota, USA.

3. Fifth International Williston Basin Symposium, June 14-17, 1987, Grand Forks, North Dakota

For information, contact:
Mr. Roger Borchert, Program Coordinator
Fifth International Williston Basin Symposium
North Dakota Geological Society
P.O. Box 82
Bismarck, North Dakota 58502

Phone: Mr. Roger Borchert: 701/223-3588
Mr. Sidney Anderson: 701/777-2231
Dr. Eric Clausen: 701/857-3161

The Fifth International Williston Basin Symposium will be held June 14-17, 1987 at the Ramada Inn in Grand Forks, North Dakota. Associated with the Symposium will be a Paleozoic/Mesozoic field trip in Manitoba and adjacent regions on June 12-14. The field trip will originate in Winnipeg and will terminate in Grand Forks. A second section of the field trip will be organized for June 18-20, originating in Grand Forks, if demand justifies. A Williston Basin Core Workshop will be held in conjunction with the Symposium on June 17.

The Symposium will include 2½ days of technical sessions, poster sessions, and a core workshop at the North Dakota Geological Survey Wilson M. Laird Core and Sample Library.

Registration Fee of $90 (U.S.) before May 1, 1987, $115 after May 1 includes a Symposium Volume. Student rate of $20, does not include the Symposium Volume.

4. SEPM Fourth Annual Midyear Meeting, August 20-23, 1987, Austin, Texas.

For information, contact:
Dr. Robert A. Morton, General Chairman
University of Texas at Austin
Bureau of Economic Geology
University Station, Box X
Austin, TX 78712

Phone: 512/471-1534

THE VARIETY AND DIVERSITY OF OIL FIELDS IN NORTH DAKOTA

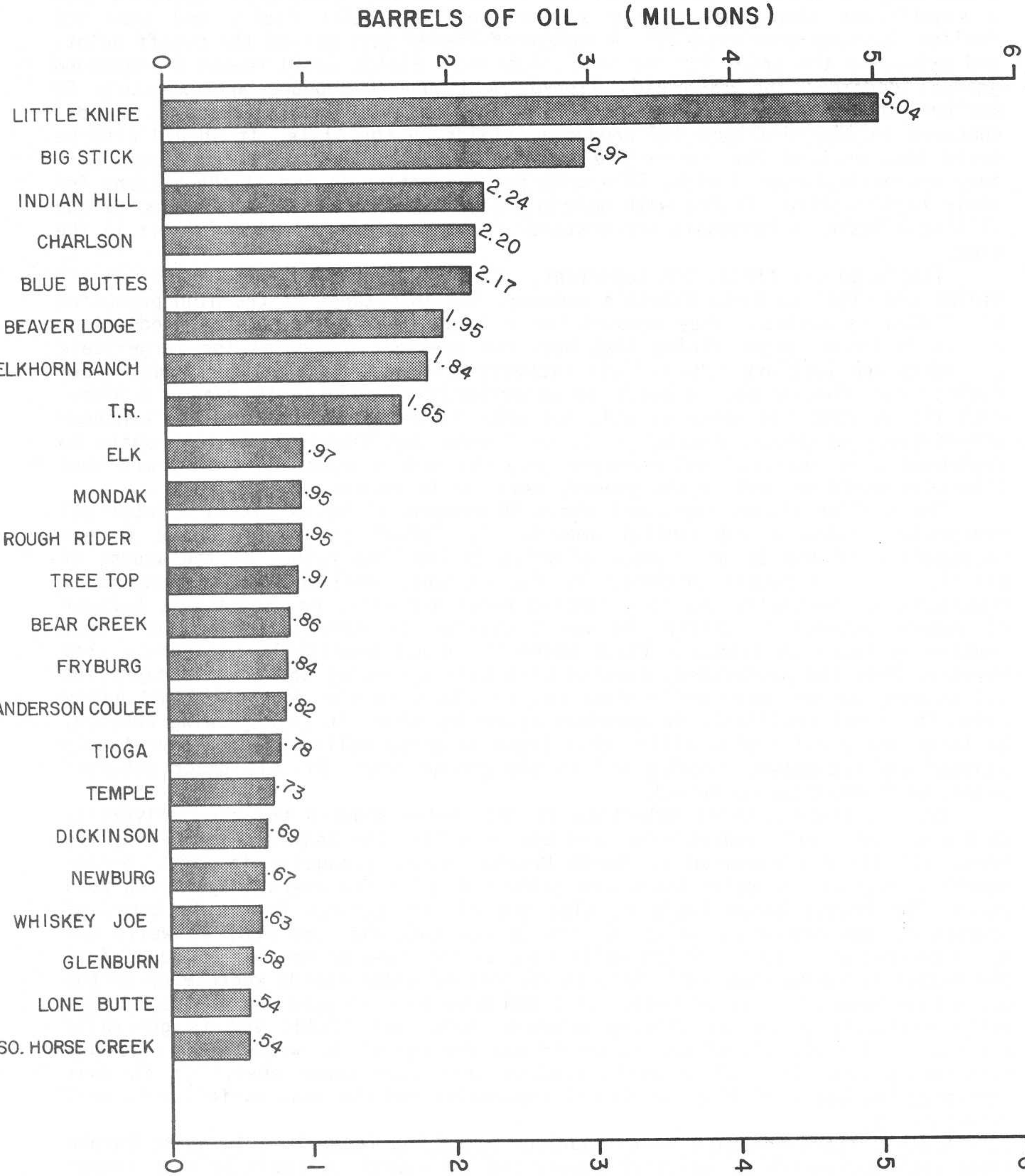
--Marv Rygh

It is interesting and enlightening to look at the variation in the types of oil fields in North Dakota. Often I am asked, "What is the average producing well in North Dakota?" Unfortunately, the nature of oil reservoirs do not fit into such simple, generalized categories. Although it is possible to quickly calculate an average, statewide, single-well production figure (about 29 barrels of oil a day), there is such a great variation in the production from well to well that averages of this kind are not really useful. It is much more instructive to understand the nature of oil production, where all of it comes from, and in what quantity.

Just to show some of the variations in North Dakota's oil reservoirs, let's look at the larger fields within the state. Figure 1 is a graph of all of North Dakota's oil fields that produced more than 500,000 barrels of oil in 1984. A cutoff point of 500,000 barrels was used for convenience, and also because it represents approximately 1 percent of North Dakota's yearly oil production. As you can see on figure 1, the Little Knife Field is the most prolific producer,

Figure 1.

1984 YEARLY PRODUCTION FOR NORTH DAKOTA OIL FIELDS PRODUCING OVER 500,000 BBLS.



accounting for about 10 percent of the state's annual production. There is then a significant step down to the second-place Big Stick Field, and then the decline becomes more gradual. A number of fields just missed the cutoff point, and extending the graph further to include more fields would reveal a continued gradual decline. The 23 fields listed on figure 1 produce approximately 60 percent of the state's total oil. This is quite a small number of fields, compared to the more than 400 producing fields in the state. It should also be noted that most of the larger fields have more than one producing formation--they are multiple-pay fields. This combined production is one of the reasons for their high ranking. Fields with multiple-pay zones occur in many areas in the Williston Basin, a fortunate circumstance for companies exploring for oil in the area.

The large oil fields are important, of course, but both large and small oil fields are vital to North Dakota's economy. The importance of the high producing oil fields is obvious; they account for a large share of the total production, and it is these larger fields that have the greatest potential for large-scale secondary and tertiary enhanced oil-recovery projects. Many of the large, older fields have already been subject to waterflooding for over 20 years. However, with the current low price of oil, not much is being done on any new enhanced oil-recovery projects. Hopefully, it will some day become economical again to implement more enhanced oil-recovery projects and recover additional oil that otherwise would be left in the ground, never to be recovered.

The smaller fields represent about 40 percent of North Dakota's total oil production, quite a substantial amount. The "size" of an oil field is not necessarily defined by the number of wells it has, but rather by the amount of oil it will ultimately produce. On the average, smaller fields have lower cumulative productivity due to a limited reservoir size, or, sometimes, because of poorer reservoir quality. As wells decline in rate of production, they eventually reach an economic limit where it is not profitable to operate them anymore. This low production, coupled with high operating costs and today's low oil prices, brings many wells down to, or close to the economic limit below which it is not profitable to continue operating them. It is a growing concern, in large and small fields alike, that these marginal wells might be prematurely plugged and abandoned, leaving oil in the ground that, for all practical purposes, will never be recovered.

Table 1 lists a brief selection of oil fields showing the great diversity in field size, well productivity, and age of wells. The Beaver Lodge Field, the first oil field discovered in North Dakota, began producing in 1951. Consequently, many of the wells there are quite old, with the average age being 28.4 years. The Beaver Lodge Field is also one of the largest fields in terms of production and number of wells. In the Beaver Lodge-Madison Pool 40 wells are still producing. A total of 204 wells have at one time or another produced from the Beaver Lodge-Madison Pool. This is typical of older fields where many of the wells have reached their economic limit and have been plugged and abandoned. The daily productivity varies greatly between individual fields and is generally affected by the quality of the reservoir and the age of the wells. This does not necessarily mean that older wells produce less than newer ones, but it does emphasize the basic differences in oil reservoirs and the wide variation in well productivity.

Table 2 lists the nine most important producing formations in North Dakota along with the number of wells producing and the number of pools in each formation. These nine formations are the most prolific of the 25 producing formations in the state. It can be seen from table 2 that the Madison Group (made up of

Table 1.--Production Summaries of Selected North Dakota Oil Fields

Data as of 1-1-85

Field & Pool	Total No. of Wells	No. of Active Wells	Avg. Cum. Prod. Per Well to 1-1-85	Avg. Daily Rate of Active Wells	Avg. Age of Active Wells
Beaver Lodge Madison	204	40	246,080 bbl	88 bbl/day	28.4 yrs
Northeast Foothills Madison	75	59	60,065 bbl	7.2 bbl/day	11.3 yrs
South Westhope Sp./Charles	71	51	140,026 bbl	12.8 bbl/day	21.7 yrs
T.R. Madison	66	59	132,568 bbl	67 bbl/day	4 yrs
Dickinson Heath	59	32	351,553 bbl	59 bbl/day	12 yrs
North Westhope Madison	30	14	70,688 bbl	6 bbl/day	21 yrs
Mohall Madison	27	26	110,372 bbl	11 bbl/day	15 yrs
Medicine Pole Hills Red River	22	21	218,217 bbl	34 bbl/day	10 yrs
Lone Butte Madison	19	18	79,000 bbl	83 bbl/day	2.8 yrs
Mackobee Coulee Madison	16	13	70,468 bbl	11 bbl/day	13.3 yrs
Rawson Madison	6	6	36,894 bbl	28 bbl/day	2.5 yrs
Scairt Woman Madison	5	3	98,559 bbl	50 bbl/day	3 yrs
Flat Top Butte Madison	4	4	177,618 bbl	91 bbl/day	3.9 yrs

Table 2.--Producing Formations in North Dakota with Over 10 Million Barrels Cumulative Oil Production

Formation	Number of Wells	Number of Pools
Triassic Spearfish/ Mississippian Charles	193	3
Pennsylvanian Tyler	195	18
Mississippian Madison	4288	278
Devonian Three Forks (Sanish)	44	1
Devonian Duperow	213	79
Devonian Undifferentiated	87	13
Devonian Winnipegosis	31	7
Silurian Interlake	172	24
Ordovician Red River and Ordovician Undifferentiated	547	179

three formations: Lodgepole Fm., Mission Canyon Fm., and Charles Fm.), is the most productive stratigraphic interval. The Madison Group accounts for 66 percent of the state's cumulative oil production (N.D. Oil and Gas Commission data), and approximately 71 percent of all the wells in North Dakota produce from the Madison Group. The Madison Group has, without a doubt, played the major role in shaping the oil business in North Dakota. Nevertheless, the other producing formations are also important because they supply vital reserves and because they provide potential for future oil exploration.

The main purpose of this article is to show the great diversity of types of oil reservoirs in North Dakota. There is a wide range of sizes of oil fields, productivity of wells, age of wells, and many other factors. It is difficult or impossible to characterize an "average" well in North Dakota because of these variables. It is more informative to look at more localized areas and individual formations. By doing this, one can get a better idea of what is happening in any particular area as well as throughout the state.

NORTH DAKOTA INDUSTRIAL MINERAL RESOURCES

--David Brekke

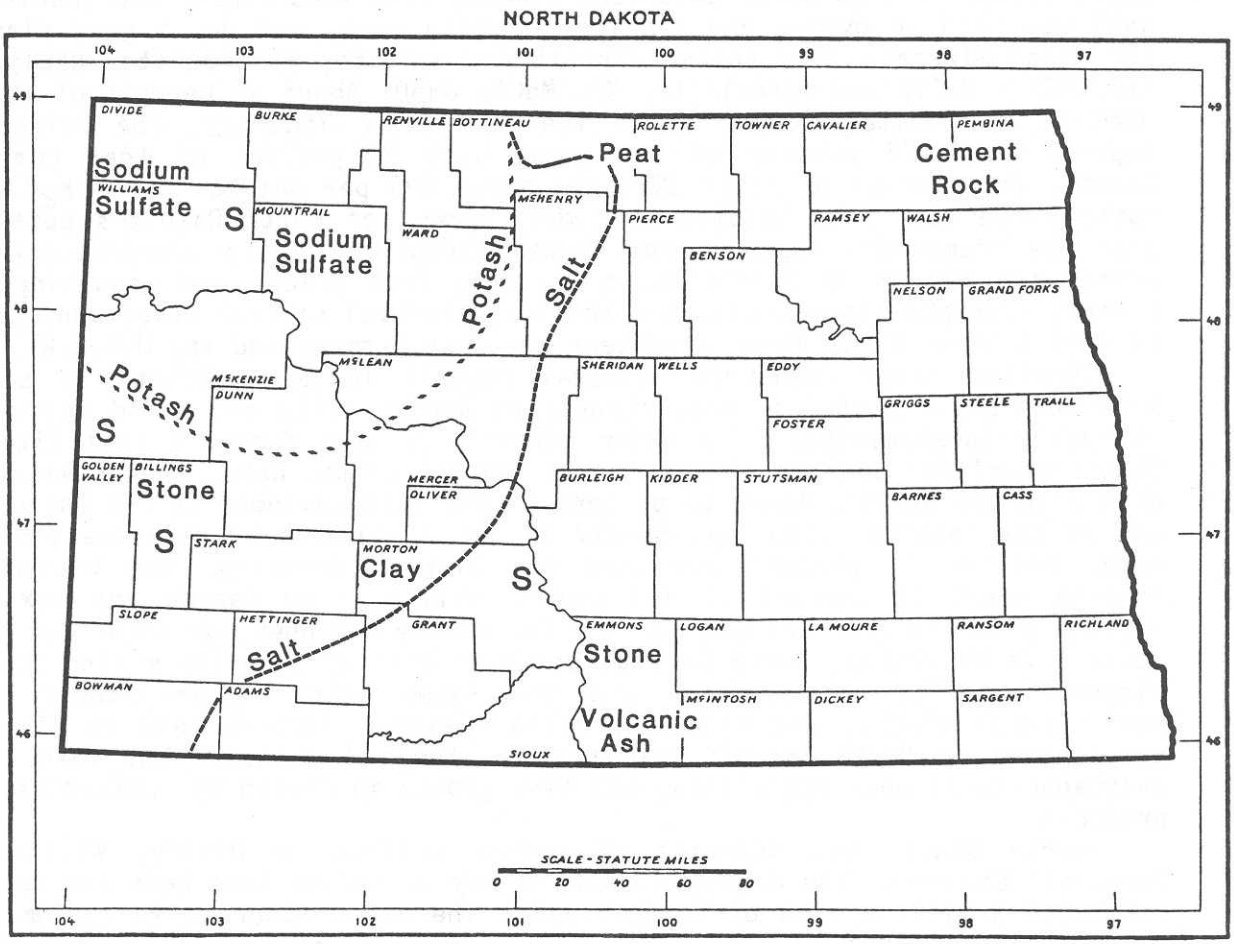
Industrial minerals are any rocks, minerals, or other naturally occurring substances of economic value exclusive of metallic ores, mineral fuels, and gemstones. They include all non-fuel and nonmetallic minerals. North Dakota has a large variety of industrial minerals, but they occur in widely varying amounts and must compete in the national and world markets. As in other commodities, the reserves available, cost of production and transportation, and market demand determine the development of these resources. Most of the state's industrial minerals are locally consumed and comprise only a small part of the mineral industry in the United States. North Dakota accounts for less than 1 percent of the total value of mineral production in the United States. The construction industry uses about 60 percent of the state's mineral output in the form of clay products and sand and gravel. The remaining output consists of salt, sulfur (recovered as a by-product during the production of natural gas), peat, leonardite, and lime. Other potential industrial mineral deposits in the state include potash, volcanic ash, zeolites, cement rock, stone, sodium sulfate, nitrogen, manganese, and molybdenum. These deposits are not currently exploited, either because no economic market exists for them or the deposits are too small to warrant development. A few of the more interesting industrial minerals are discussed below.

One of the largest and potentially most valuable industrial mineral deposits in North Dakota is potash in the Williston Basin. An estimated 4 billion tons of potash occur in North Dakota and Montana, lying between 6,000 and 9,200 feet below the surface, but currently there is no production in the United States portion of the basin. The name "potash" refers to the old practice of evaporating, in iron pots, solutions leached from wood ashes. The resulting "pot ash" was used in dyeing and tanning, to make soap, and was a good plant food. The major minerals in a potash deposit are sylvite, KCl; halite, $NaCl$; sylvinite, $KCl + NaCl$; and carnallite, $KCL \cdot MgCl_2 \cdot 6H_2O$. About 95 percent of the potash used in the United States is in the fertilizer industry. The United States imports about 77 percent of its needs with 90 percent of that coming from Canada. The average price in 1985 was about $95 per metric ton of K_2O. Several factors are currently holding back development of North Dakota's potash. They are: the tremendous reserves and large stockpiles due to overproduction right across the border in Saskatchewan; falling farm prices and resulting reduced demand; transportation costs; and the large initial capital investment necessary to open a mine. Other large producers are East Germany and the U.S.S.R.

Another large industrial mineral deposit in North Dakota is salt. The Williston Basin contains large amounts of bedded salts and world resources are virtually inexhaustible. The major mineral in salt deposits is halite, $NaCl$. Other impurities such as clay minerals and anhydrite, $CaSO_4$ are usually associated with the halite. About 50 percent of the salt consumed in the United States was by the chemical industry, mainly in the production of chlorine and caustic soda. Another 25 percent was used for highway de-icing. The United States imports about 12 percent of its needs, chiefly from Canada and Mexico. The average price in 1985 was $90 per ton for vacuum and open pan salt. One company, located in Williston, North Dakota, produces salt by solution mining and vacuum evaporation. The end products are granulated salt, water-softener pellets, agricultural blocks, and saturated brine. Several factors tend to hinder salt development in North Dakota: downturns in the oil industry and farm economy, overcapacity at most facilities, and slow growth in demand for chloralkali-based products.

North Dakota has deposits of sodium sulfate in Divide, Williams, and Mountrail Counties. The deposits occur in dry or saline lake beds and contain an estimated 3 million tons of Glauber salt. The major minerals in sodium sulfate deposits are Glauber salt or mirabilite, $Na_2SO_4 \cdot 10H_2O$ and thenardite, Na_2SO_4. About 47 percent of sodium sulfate use in the United States was in detergents, 36 percent in the pulp and paper industry, and 17 percent in the glass industry and other miscellaneous industries. The United States imports about 11 percent of its needs, mainly from Canada. The average price in 1985 was $94 per ton of natural sodium sulfate. Currently no sodium sulfate is produced in North Dakota. Some of the factors hindering development of this resource include a declining demand in the paper industry due to substitution of less expensive emulsified sulfur and caustic soda. In addition, synthetic sodium sulfate produced as a by-product of other manufacturing processes comprises about 53 percent of the total United States production. The production and consumption of sodium sulfate in the United States is at a 30-year low. Other major producing countries of the world include Canada, Spain, and the U.S.S.R.

Other deposits of industrial rocks and minerals of any amount in North Dakota include volcanic ash deposits near Linton, cement rock in Pembina County, and dimension stone in Emmons County. Information about North Dakota industrial minerals is contained in Bulletin 63, <u>Mineral and Water Resources of North Dakota</u>, and can be obtained free of charge from the Survey. This article was supplemented with information from the U.S. Bureau of Mines.



Generalized location map of North Dakota industrial minerals. Sand and gravel are mined in every county. Dashed lines represent eastern limits of potash and salt. Recovered sulfur from gas plants are represented by the letter S.

NORTH DAKOTA'S STATE FOSSIL --John Bluemle

North Dakota has a state flower (wild prairie rose), a state tree (American elm), a state bird (meadowlark), a state grass (western wheatgrass), and a state fossil (teredo petrified wood). A number of other states also have state gems, state stones or rocks, or state minerals. North Dakota has none of these. And only 12 or 13 states have state fossils. I'm not sure whether the state of Arizona has yet officially adopted their own petrified wood as a state fossil, but a bill was recently introduced there for that purpose. Arizona, for a time, even had a "state fungus." It seems that one of their legislators had been quoted as saying that "politicians in Arizona are bought and sold." In response, his fellow legislators designated him their official state fungus, a "commercial type of fungus that can be bought and sold."

In any case, table 1 lists the various state fossils. As I said, North Dakota has no official state stone, rock, or mineral. I don't know if such official designations are really very important, but I sometimes think it might be convenient if we did have a state rock because here at the Survey we often get requests for samples of our official state rock or mineral. I can't provide samples of our state fossil because it is too rare, but more on that a little later. When I answer such requests, I usually send a sample of either Knife River Flint or Scoria (natural brick) along with an explanation. Knife River Flint is unique to our state and therefore a logical choice. Scoria, and the explanation of how it formed, is sufficiently unusual to arouse interest in people who aren't already familiar with it.

Knife River Flint is a distinctive rock that was extensively used as raw material for tools by the prehistoric Indians of the Northern Plains and Midwest. It is a fairly uniform, non-porous, dark-brown chalcedony, a form of quartz that is microcrystalline. Apparently the dark-brown color results from extremely fine-grained organic material dispersed through the flint. The flint has a conchoidal fracture, like glass, making it an excellent material for stone tools.

Most of the flint used by the Indians was probably quarried from deposits along the Knife River Valley in Dunn and Mercer Counties, North Dakota. "Knife River" is the translation of an Indian name, which is said to have been given because flint for knives was quarried along the river.

The other material I often use to fill requests for a "typical rock" is scoria. True "scoria" is of volcanic origin and from a geologist's point of view the term is not really appropriate for the natural brick found in North Dakota. However, that's what everyone calls it and I won't try to argue the point. Everyone in western North Dakota has seen scoria and most people have a good idea how it formed--burning coal veins baked nearby sediments to a natural reddish brick or, in some cases, even melted the sediments to glass. The idea of natural brick is new to many people who haven't travelled through areas where it occurs and the red rock is interesting to them.

Now back to our state fossil. State Representative W. G. Sanstead of Minot proposed the state fossil in House Bill 933, which was approved on March 15, 1967. Representative Sanstead acted at the request of R. W. Carlson, formerly of Bismarck and former president of the Central Dakota Gem and Mineral Club. Promotion of "Teredo Wood" as the state fossil was largely due to the efforts of H. A. Brady of Mandan, who presented a plea before the Legislature.

Most of the following information on Teredo Petrified Wood was taken from an article by Dr. Alan M. Cvancara, a Professor of Geology at the University of North Dakota. Cvancara's article, which appeared in the Spring, 1970 issue of the North Dakota Quarterly, goes into much more detail than I will here.

Teredo Petrified Wood is a fossil wood that is riddled with irregular, very elongate borings. The fossil wood is variably preserved. It may be compact, with good preservation of wood structure, or it may be somewhat splintery. Borings in the fossil wood are the result of worm-like, bivalve mollusks ("clams"), which are common in modern seas. Originally named "shipworms" because of their riddling of wooden ships, they are now infamous because of damage they do to pilings and other wooden structures; the mollusks are exclusively woodborers.

Since living shipworms inhabit seas, one logically searches for Teredo Petrified Wood in rock formations of marine origin. In North Dakota, three exclusively marine formations are rather extensively exposed at the surface: Pierre Formation shale, Fox Hills Formation sandstone, and Cannonball Formation shale and sand. Most of the Teredo Wood has been collected from the Cannonball Formation (Paleocene age, about 60 million years old), which was deposited in the last sea that covered North Dakota. This formation is best exposed in the Bismarck-Mandan area and southwest of these two cities. I've also found a few small pieces of Teredo Wood in younger gravel deposits in glacial sediment, but these are the result of reworking of Cannonball, or older, sediment and such specimens are usually quite worn.

The phrase "Teredo Petrified Wood" is somewhat misleading because one might assume that it means a type of wood, such as oak wood or elm wood. The term "Teredo" refers instead to the animal that bored the wood; the term "Teredo-bored Petrified Wood" might be better. Also, since several types of shipworms (not just the Teredo) may have bored the wood, it might be even better to call the fossil "clam-bored fossil wood" or "shipworm-bored fossil wood."

Finally, it seems to me that a state fossil (or state rock or mineral) should be of popular appeal, fairly common, largely unique to North Dakota, and of high scientific interest. Since our state fossil is scarce, almost rare and certainly not easy to find, it was probably not a very good choice. If any of our readers think that we should have some kind of "official" state rock, please let me know what your choice would be.

Table 1.--States with Official State Fossils

California	Smilodon
Colorado	Stegosaurus
Georgia	shark's teeth
Louisiana	palm wood
Massachusetts	dinosaur tracks
Mississippi	Zygorhiza (whale)
Nebraska	mammoth
Nevada	Ichtyosaur
New York	Eurypteria
North Dakota	Teredo Wood
Ohio	Isotelus
Washington	Ginkgo

DRAINAGE DEVELOPMENT IN NORTH DAKOTA

--John Bluemle

Nine years ago (June, 1977 issue of the NDGS Newsletter), I included an article in the Newsletter about North Dakota's drainage pattern with a brief explanation of how it might have developed. Since that time, we've accumulated considerable additional test-hole data, and I think we have a much better overall understanding of the geologic events that interreacted to form our modern drainage pattern. This article is intended to be a summary, mainly conclusions, and I won't attempt to include all the documentation--the basis for many of my conclusions--because that information is included in a more technical journal article.

What I tried to do in my research was to determine where the main rivers flowed in North Dakota before the state was glaciated, how the glaciers changed the drainage patterns, where the rivers flowed during the interglacial periods, and how all of the changes eventually resulted in our modern drainage pattern. That's what I tried to do. In fact, it became a nearly impossible undertaking. In places the preglacial river routes have been completely destroyed by later erosion, by both glaciers and by interglacial stream erosion. In other places, even though I was able to identify valleys that are now deeply buried beneath deposits of glacial sediment, I still could not be certain in which direction the rivers that formed them flowed. Finally, in some places, I still didn't have enough test-hole data to accurately trace now buried river courses. In many instances I could identify what were probably important drainage routes, but I could not determine when they were used, that is, I don't know whether they formed prior to or during glaciation. Another problem arose where interglacial rivers flowed from areas where their valleys were eroded into bedrock (preglacial shale or sandstone) onto areas of glacial sediment (or vice versa) so that a valley floor that had been bottomed in bedrock was bottomed from that point on in glacial or glaciofluvial sediment. It is much more difficult to continue to trace the route of an old river when it crosses back and forth from one of these areas to another.

In any case, after careful study of all available drill-hole data, it was possible to compile a detailed topographic and geologic map of the preglacial (bedrock) surface in North Dakota. That map, which shows the shape of the bedrock surface as well as the bedrock geologic units (the preglacial formations that occur beneath the covering of glacial sediment), was published about three years ago by the NDGS (Miscellaneous Map 25) and is available for those of you who want more detailed background information and documentation than I'll include in this article. I've attempted to draw a generalized map of the preglacial drainage pattern in North Dakota and in nearby states and provinces (fig. 1). The preglacial river routes I've shown in North Dakota are reasonably accurate, I think. I've also sketched in approximate stream patterns in South Dakota and eastern Montana because major rivers from those states flowed into North Dakota in Late Tertiary time, immediately prior to the time the area was first glaciated, but the routes shown in those areas are taken mainly from other sources and do not reflect my own work.

All of North Dakota, prior to the time it was first glaciated, was drained by north and northeast-flowing rivers. The main "trunk" river was one that has often been referred to as the ancestral Missouri River (see fig. 1). The upper reaches of this river coincide with the modern Missouri River along much of its route through Montana. The ancestral Missouri River crossed northwesternmost North Dakota, flowed through southern Saskatchewan and Manitoba to the Winnipeg area, then northward, eventually reaching Hudson Bay. This major trunk river had several important tributaries. The Yellowstone River followed its modern route in Montana, but continued a short distance across northwestern North Dakota and joined the ancestral Missouri River in southeastern Saskatchewan. The Little Missouri River flowed north through western North Dakota, continuing to a junction with the Yellowstone River north of Williston.

Many of the modern rivers in southwestern North Dakota existed before the state was glaciated. All of these rivers today flow into the modern Missouri

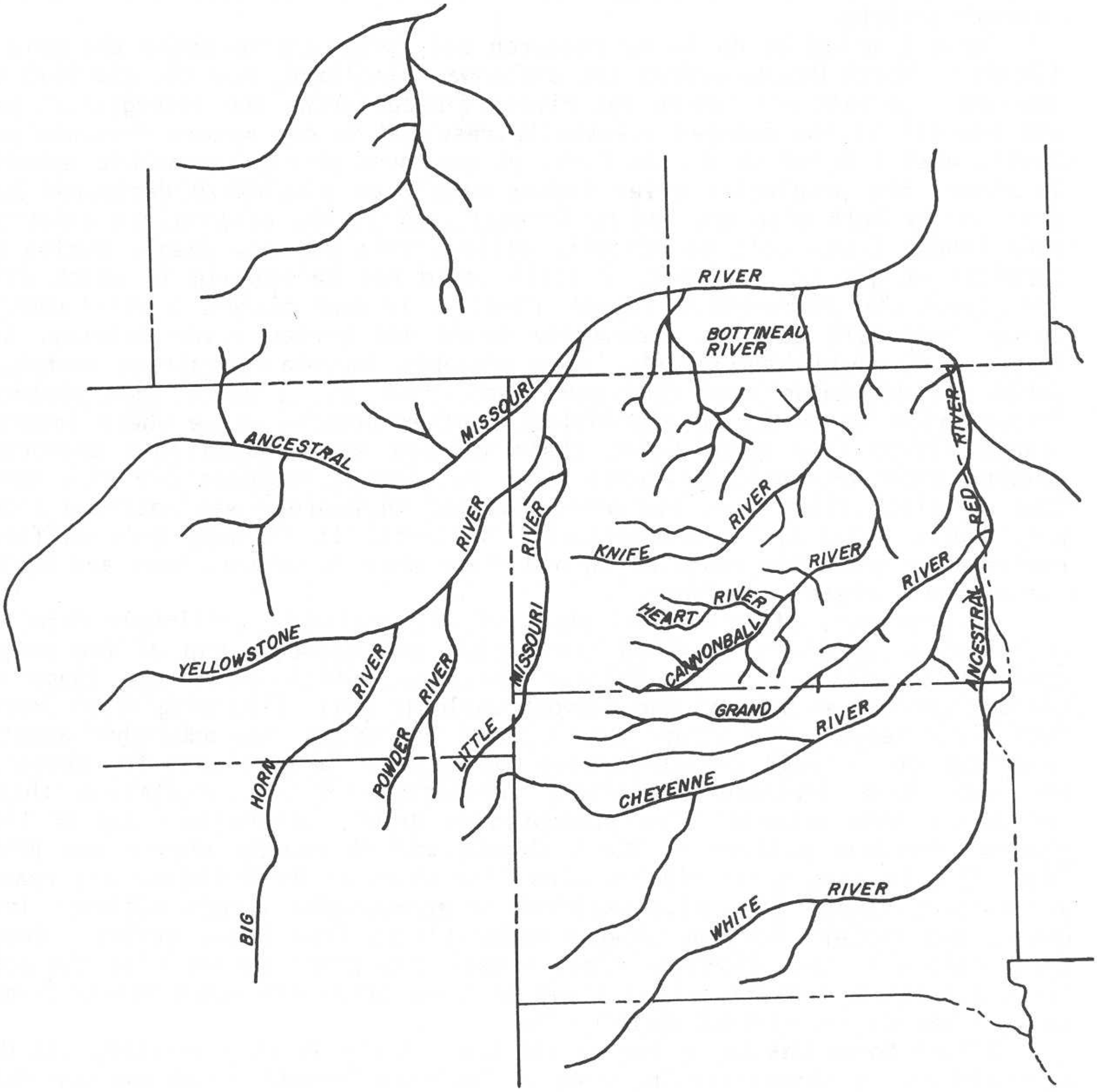


Figure 1. Preglacial drainage pattern in the northern Great Plains area. The rivers all flowed north and northwest, ultimately toward Hudson Bay. North Dakota was drained by the ancestral Missouri River and its tributaries, the Yellowstone, Little Missouri, Bottineau (an important north-flowing river west of the Turtle Mountains), and Cannonball-Knife; and by the ancestral Red River, which had several South Dakota and northwest Minnesota tributaries. The Red and Missouri Rivers apparently joined near Winnipeg and flowed on from there as a large river to Hudson Bay.

River, but prior to glaciation they continued to flow north and eastward into eastern North Dakota. Their abandoned routes to the north and east are today deeply buried beneath glacial sediment. I've shown these rivers on figure 1 where I refer to them as the Cannonball, Heart, Knife, etc. It appears that a major river flowed north into Manitoba just east of the Turtle Mountains in Towner County; it was probably part of the preglacial Cannonball-Knife River system. Finally, a large river flowed northward through the area that is today the Red River Valley. This "ancestral Red River" included a number of important tributaries: the Grand, Cheyenne, and possibly the White Rivers, all major South Dakota rivers (I don't know much about the route of the preglacial White River; it may have turned southward instead of joining the Red system). I don't have enough information from northern Minnesota to be able to say much about the routes of the preglacial rivers there, but it's likely that at least some of them flowed from the east into the ancestral Red River system.

In the remainder of this article I will deal only with North Dakota as I have not spent much time trying to determine what happened in nearby areas. Figure 2, which shows the preglacial drainage in North Dakota, is an enlarged version of figure 1. Figure 3 also shows the same preglacial drainage routes as figure 2, but I've added the main diversion routes (please read the caption to figure 3 for a more complete explanation).

By studying the types of gravel deposits in the buried preglacial valleys and glacial diversion valleys, and by determining the elevations of the various valley floors, it is possible to work out a logical sequence of events, to determine, in a general sort of way, the relative ages of the valleys. However, it is still not possible to reconstruct the entire drainage pattern at any given time during the Pleistocene Epoch (the "ice age").

We know, from our studies of the stratigraphy of the glacial sediments in North Dakota, that the state was glaciated many times during the Pleistocene Epoch, the past 2½ to 3 million years. Each time glaciers advanced into North Dakota, they disrupted the river systems, in some cases forming large proglacial lakes in the valleys of the north-flowing rivers, and causing large diversion trenches to be cut when these proglacial lakes overflowed. All of the major drainage was diverted away from its course toward Hudson Bay and forced to flow to the south and east, often right along the edge of the glacier. During the interglacial periods following the earlier glaciations, the main rivers may have returned to their original, northerly routes, provided that the amount of glacial sediment that had been deposited in their valleys was not so much that it permanently blocked their valleys. However, after repeated glaciations, the preglacial valleys became so clogged and buried beneath so much glacial sediment that many of the rivers remained permanently diverted. The main exception is the Red River Valley which, even after repeated glacial episodes, retained its northward gradient so that the modern Red River of the North still does flow north. However, the preglacial Red River probably was a much larger river than the modern one and included tributaries that drained broad areas of South Dakota and northern Minnesota. As a result of glaciation, nearly all of the Red's tributaries were diverted in other directions.

Another obvious consequence of the repeated drainage diversions during the Pleistocene in North Dakota was the gradual, step-by-step shaping of the route of the modern Missouri River. The valley of the modern 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.

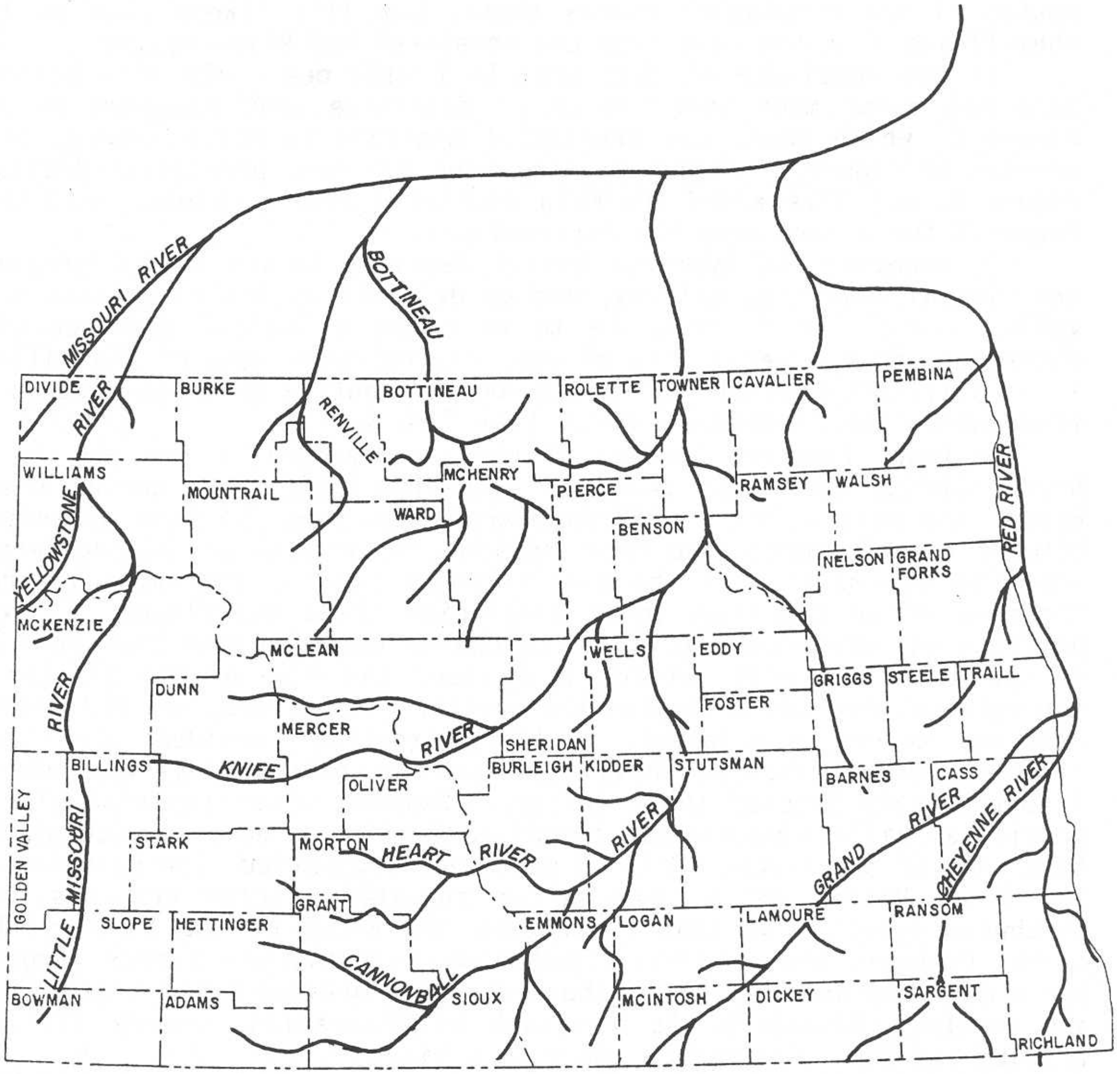


Figure 2. This map shows the drainage pattern in North Dakota immediately prior to glaciation.

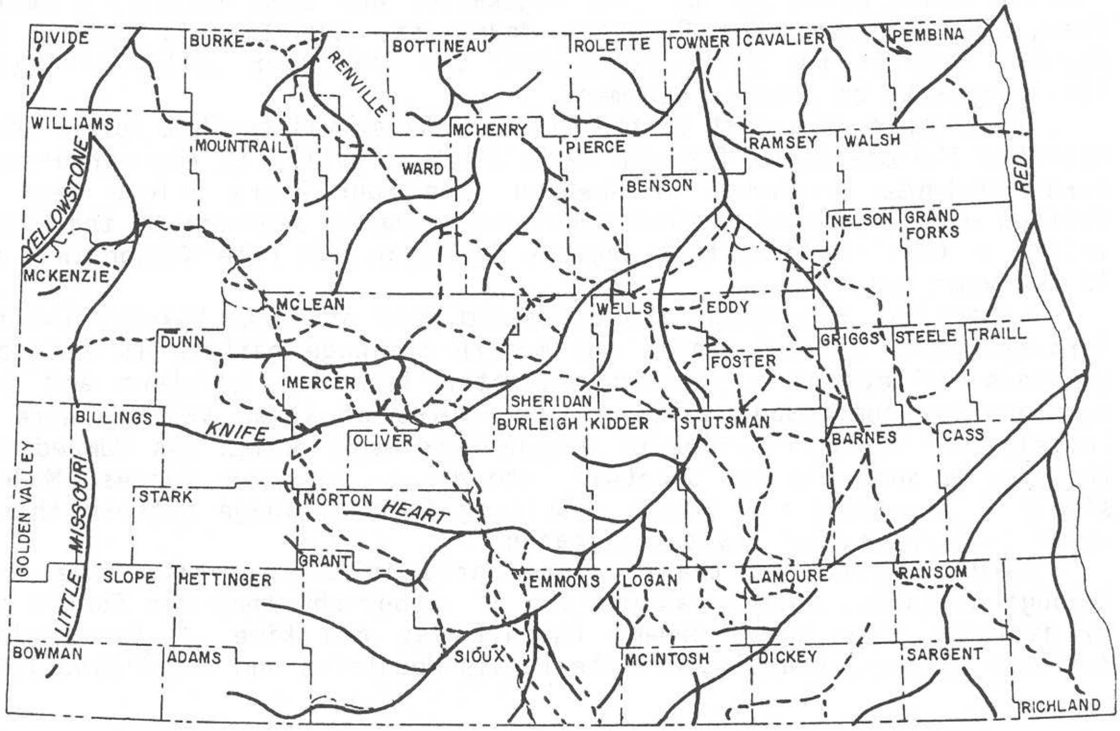


Figure 3. This map shows the major preglacial drainage routes in North Dakota (the solid lines) and the glacial meltwater diversion routes that I know about (dashed lines). The diversion trenches shown here are all incised into preglacial bedrock. In some places, diversion trenches shown on the map end abruptly; these represent streams that flowed in bedrock-floored valleys onto areas bottomed by glacial sediment. Testhole data are not complete enough in some places to distinguish between glacial diversion routes and preglacial valleys so some of the dashed lines probably actually represent preglacial routes (the converse is less likely). The existence of all of the drainage routes shown on this map have been verified, but in some cases it isn't known which direction the water flowed. Additional detail will be added as more information becomes available.

In some places, the Missouri River valley is broad, spanning six to ten miles from rim to rim. In other places the valley is less than two miles wide. Generally, the wider parts of the valley extend in an east-west direction, whereas the narrow parts trend north-south. The wider parts of the Missouri River valley coincide with old, preglacial valleys through which rivers may have flowed before the state was first glaciated. The narrow segments are much younger and were carved when water overflowed proglacial lakes or when rivers flowed southward along the edge of the glacier during the ice age.

A good example of an old, broad portion of the Missouri River valley is the east-west trending segment now flooded by Lake Sakakawea upstream from Riverdale. This portion of the valley existed before the state was glaciated when a river flowed through it to the east, passing north of Riverdale, through what is now the Snake Creek Arm of Lake Sakakawea, and then eastward beneath, more or less, Turtle Lake, the Prophets Mountains, and Lincoln Valley in Sheridan County. East of the Snake Creek Arm, the old river valley is buried beneath thick deposits of glacial sediment.

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 Newtown. The Four Bears bridge west of Newtown crosses what is one of the narrowest and youngest segments of the Missouri River valley in North Dakota; this segment formed during Late Wisconsinan time, about 12,000 years ago.

Generally, throughout the glaciated part of North Dakota, the eastern and northern parts of the state, the modern 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 were 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 the glaciated area in North Dakota have virtually no through drainage. Such areas consist of topography that was formed so recently in geologic time that streams haven't yet had time to form well-developed drainage systems. Examples are the Turtle Mountains and the Missouri Coteau.

NORTH DAKOTA'S MOUNTAINOUS AREAS: THE KILLDEER MOUNTAINS AND THE TURTLE MOUNTAINS

--John Bluemle

In looking back over all of our previous Newsletters to decide on a topic to write on this time, I saw that no one has ever said anything about the geology of either the Killdeer Mountains or the Turtle Mountains (fig. 1). It then occurred to me that it is at least somewhat peculiar that these and several other features and places in North Dakota are called "mountains;" I suppose the idea is related somewhat to scale. When viewed by a person who has recently travelled over eastern North Dakota, the features certainly are impressive, but I wonder what they might have been named if our settlers had come from Montana or Wyoming.

Besides the Turtle Mountains and Killdeer Mountains, we have many other places in North Dakota that bear the name "mountain." The town of Mountain in Pembina County was settled by Icelanders in 1873. Mountain is situated on the former shoreline of glacial Lake Agassiz, and the view to the east from there, over the Red River Valley, is quite impressive. Just north of Mountain, the hilly area along the Pembina River valley in northeastern North Dakota is

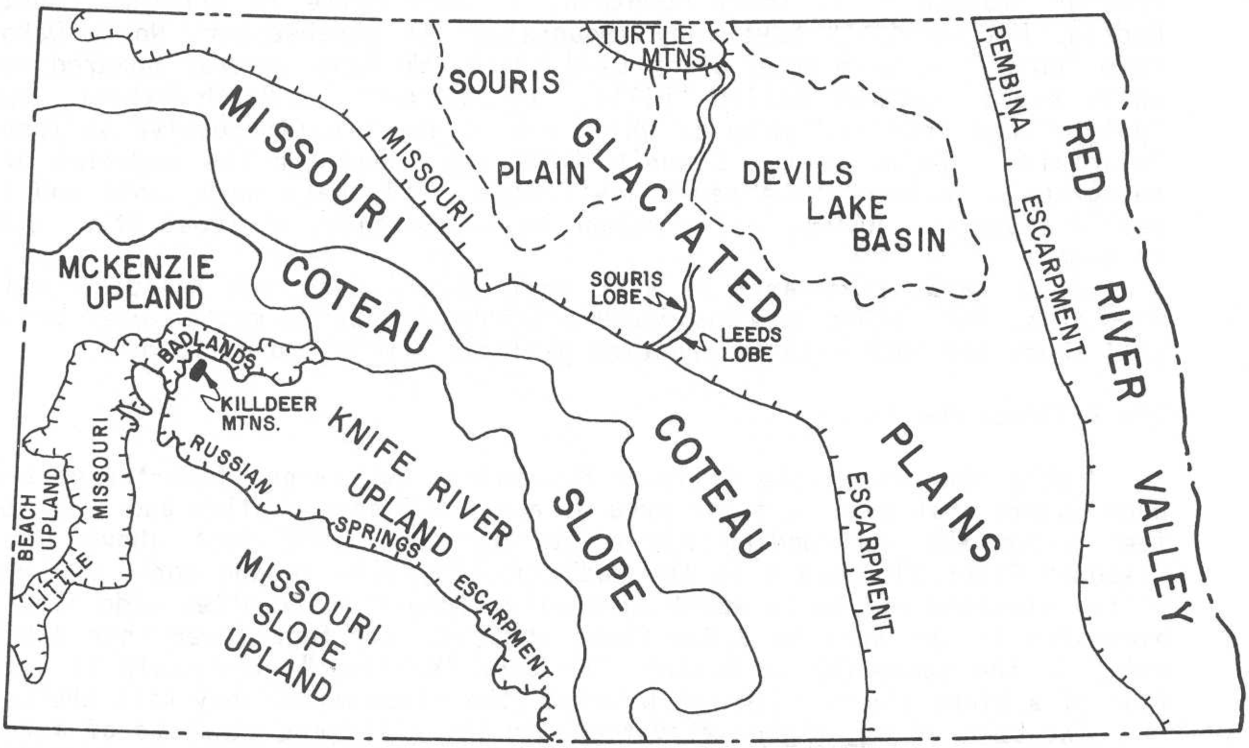


Figure 1. Physiographic map of North Dakota drawn by Lee Clayton. The location of the Killdeer and Turtle Mountains are shown along with other physiographic units. I've modified some of the northern and eastern areas somewhat from Clayton's original map. The double line south of the Turtle Mountains shows the boundary between the two main Late Wisconsinan glacier lobes, the Souris Lobe, which flowed around the west side of the Turtle Mountains, and the Leeds Lobe, which flowed around the east side of the Turtle Mountains.

sometimes referred to as the "Pembina Mountains," but the term "Pembina Hills" is also commonly used.

Other "mountains" in North Dakota include Devils Lake Mountain in southeastern Ramsey County, Blue Mountain in western Nelson County, Lookout Mountain in northeastern Eddy County, and the Prophets Mountains in western Sheridan County. All of these features are ice-thrust hills or complexes of ice-thrust topography that stand as high as a few hundred feet above the surrounding areas. Another "mountain" is Tracy Mountain, a large butte in Billings County, near Medora, but we don't have many "mountains" in southwestern North Dakota; the term "butte" is much more often used there. We have several hundred more formally named features called "hills," or "buttes" in North Dakota, and a few "points" and "ridges," many of which are at least as impressive as some of our "mountains." In any case, I won't dwell any longer on the vagaries of naming topographic features. The names don't necessarily make much sense and it's not really important anyway; we do manage to communicate, at least if we stay close to home.

As I said, this article will deal mainly with the Killdeer and Turtle Mountains, both areas of considerable scenic beauty no matter what you want to call them, and both with interesting geologic stories to be told.

The Killdeer Mountains

Let's start with the Killdeer Mountains, two large, flat-topped buttes in Dunn County that cover a total area of about 115 square miles and rise about 700 feet above the surrounding plains--as much as 1,000 feet above the Little Missouri River floodplain in the Badlands six miles to the north and west. The entire elevated region is about nine miles long and six miles wide. The highest elevation in the area is 3,314 feet, that is, 192 feet lower than the highest point in the state (White Butte). The term "Killdeer" presumably is a translation of a Sioux phrase "Tah-kah-p-kuty" (the place where they kill the deer).

The bulk of the higher elevations in the Killdeers consists of a rock unit that has been informally called the "Killdeer Mountains Strata," a 400-foot-thick layer of limestone, dolostone, sandstone, and tuffite, the age of which is not definitely known. It has been variously reported as Eocene, Oligocene, Miocene, and Pliocene, but few fossils, except for abundant animal burrows, have been found in it. A beaver skull and a peccary jaw, apparently of Miocene age, have been found in the Killdeer Mountains, so a Miocene age seems reasonable for at least some of the deposits. The "Killdeer Mountains Strata" are underlain by the Golden Valley Formation, a Paleocene to Eocene age rock unit (fig. 2). The Golden Valley Formation is poorly exposed on tree-covered, grassy, or farmed slopes around the flanks of the Killdeer Mountains. The Paleocene Sentinel Butte Formation underlies the Golden Valley Formation beneath the Killdeer Mountains and occurs at the surface in a broad area around the Killdeers (fig. 3).

The buttes that make up the Killdeer Mountains are erosional outliers, probably places where large lakes in which sandy and limy sediments and some stream deposits accumulated sometime in Middle Cenozoic time. Repeated volcanic eruptions to the west of the area produced large amounts of ash which blew eastward, fell to the ground, and washed into the lakes, forming tuffaceous sandstones. About 5 million years ago, long after the lakes were filled, a new erosional cycle began. The relatively hard tuffs and freshwater limestones and sandstones that had been deposited in the Miocene lakes were much more resistant to erosion than were the surrounding sediments. Because of their resistance to erosion, these hard materials remained standing above the surrounding area as the softer Golden Valley and Sentinel Butte sediments were eroded and carried

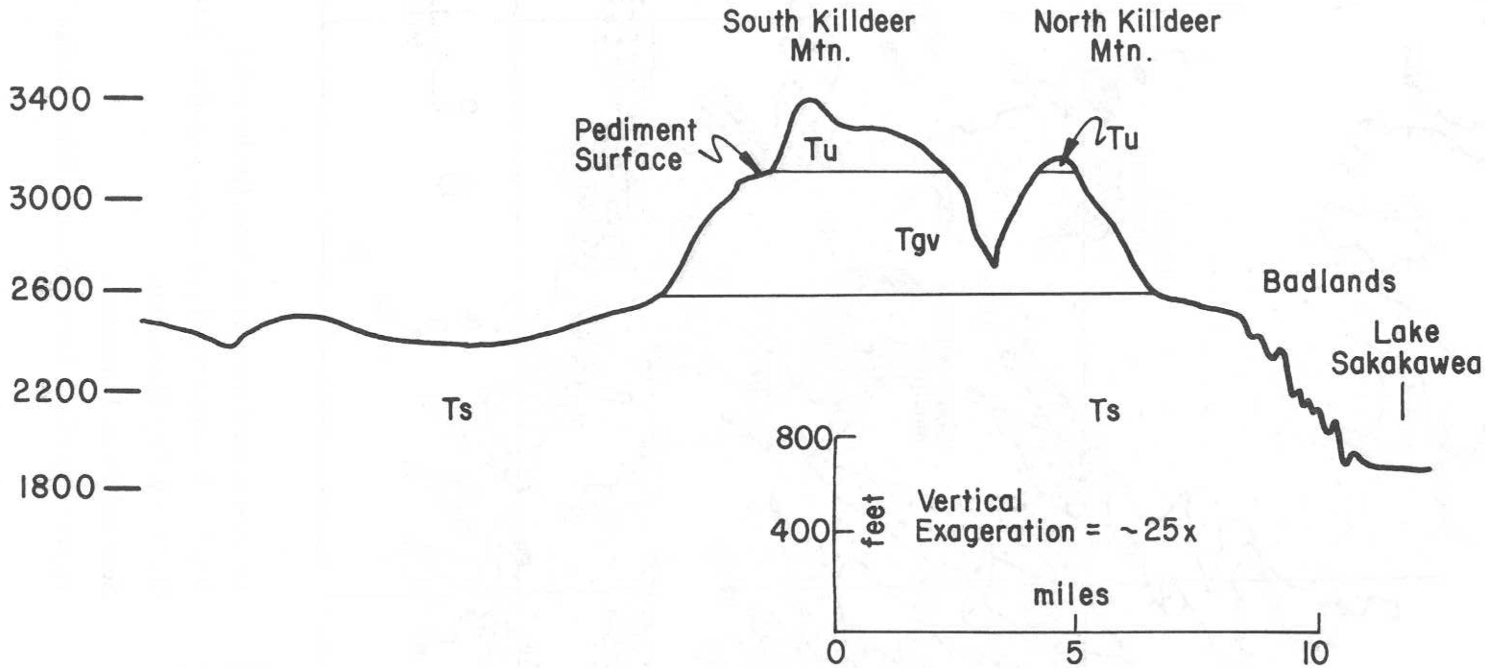


Figure 2. Cross-section drawn from southwest to northeast through the long axis of the Killdeer Mountains. Symbols used: Ts = Sentinel Butte Formation; Tgv = Golden Valley Formation; Tu = Undifferentiated Middle Cenozoic strata (these could be either Oligocene or Miocene in age).

Figure 3. Geologic map of the area around the Killdeer Mountains, Dunn County, North Dakota. This map is modified somewhat from a map prepared by Lee Clayton in 1969.

away by streams and rivers to the northeast to Hudson Bay. The Killdeer Mountains, with their resistant caprock, are the modern result of that erosion cycle.

Two sites in the Killdeer Mountains are of particular interest. The Killdeer Battle State Historic Site is located on the southeast edge of the area (sec34, T146N, R96W). The "Battle of the Killdeer Mountains" took place on July 28, 1864 when General Sully and 3,000 troops used artillery on 6,000 Teton and Yanktonai Sioux in revenge for the uprising of Santee Sioux in southern Minnesota. Sully defeated the Sioux, killing many of them and destroying their camp and equipment.

At the top of the southeast spur of the Killdeer Mountains is Medicine Hole, a cave about 10 feet across and 90 feet deep. This was the traditional location for the place where, according to Native Americans living there, all animals and people came out of the earth at the beginning of time. Medicine Hole is located on the Medicine Hole Plateau, in the south half of section 22 and the north half of section 27, T146N, R96W. In this one-square-mile area, the "Killdeer Mountains Strata" are especially well exposed.

The Killdeer Mountains support the largest deciduous forest in southwestern North Dakota, except for the forests of the floodplains bordering the major rivers. The Killdeer forest consists largely of aspen and oak, with some ash, elm, birch, and juniper, along with shrubs such as chokecherry, willow, plum, and buffaloberry. The forest is interesting in that it contains species typically found in more boreal settings, 200 miles or more to the northeast.

Although the Killdeer Mountains were not covered by the continental glaciers, their topography dates largely to the Pleistocene. Remnants of old stream-cut surfaces--pediments--flank the Killdeers. These pediments, which cut across all of the older formations, are capped by about 10 feet of sand and gravel. Old ice wedges can be seen in the gravel in places, testimony to the time when the area was subjected to tundra conditions during one or more of the glacial epochs.

In summary, the Killdeer Mountains are an erosional outlier, preserved because of their resistant caprock of tuffaceous sandstone and limestone, the "Killdeer Mountains Strata." Erosion of the area that began in late Pliocene and continued into early Pleistocene time resulted in gravel-covered surfaces (pediments) around the flanks of the Killdeer Mountains. These gravel deposits, which were derived from the sandstone and limestone beds higher up in the center of the Killdeers, are themselves resistant to further erosion and they help to retard the ongoing, modern erosion cycle. The present erosion cycle began when the nearby Little Missouri River was diverted from its northerly route by a glacier so that it flowed, instead, to the east to its modern confluence with the Missouri River. As a result of the diversion, the river began to erode vigorously, carving the badlands through which the Little Missouri flows today.

The Turtle Mountains

The origin of the name "Turtle Mountains" has never been definitely explained. Between 1810 and 1870, Metis hunters from the Red River followed trails north and south of the feature, to the buffalo herds. When viewed from the south, the mountains appeared to the Metis as a turtle on the horizon with the head pointing westward and the tail to the east. Another local, native account says that the feature was named after an Ojibway Indian, "Makinak," (turtle) who walked the entire length in one day. The Ojibway often took their names from things in Nature and the turtle was an important figure in their religious mythology. Other names that have referred to the Turtle Mountains include

Makanak Wudjiiw, La Montagne Torchue, Turtle Hill, Beckoning Hills, and the Blue Jewel of the Plain. Still another possible origin for the name might be the painted turtles, which are plentiful in the area today. The only "semi-official" information I could find that referred to the origin of the name was included in the early accounts of government cartographers, who noted that, from a distance, the profile of the plateau resembles the back of a turtle (essentially the same explanation as the first one I mentioned, above).

The Turtle Mountains rise about 600 to 800 feet above their surroundings, high enough to receive significantly more precipitation than the surrounding grasslands. As a result of this heavier precipitation, the Turtle Mountains are forested, in contrast to the surrounding, grass-covered prairies. They cover an area of about a thousand square miles, half in North Dakota, half in Manitoba and this, along with the Killdeers and the riverbottom land along the Missouri River, is one of the few wooded areas in the area.

The predominant covering of aspen is interspersed with black poplar, ash, birch, boxelder, elm, and bur oak. A large part of the vegetation consists of shrubs like hazel, chokecherry, saskatoon, nannyberry, dogwood, highbush cranberry (Pembina), and pincherry. Fire played an important role in the development of present-day vegetation. Prior to settlement, the Turtle Mountains were periodically swept by fire caused by lightning and by human activity. Plains Indians noticed that a heavy growth of new plants appeared in burned areas. They also knew that forests did not attract bison so they routinely set fire to the wooded areas. Prairie winds then carried the fires for many miles. This practice may represent one of the earlier attempts by man to attract animals by manipulating the environment.

Like the Killdeer Mountains, the Turtle Mountains are basically an erosional outlier, a broad area of younger sediments left standing when the surrounding older materials were eroded away. Unlike the Killdeers, however, the Turtle Mountains were glaciated and the landforms that resulted from that glaciation greatly changed the area. Had they not been glaciated, the Turtle Mountains might be more similar to the Killdeer Mountains, although much broader and probably not so prominent a feature.

The Turtle Mountains are underlain by rocks of the Cretaceous Fox Hills and Hell Creek Formations and the Paleocene Cannonball Formation, all covered by a thick layer of glacial sediment (fig. 4). In early Pliocene or late Miocene time (maybe 5 or 6 million years ago), the area that is now the Turtle Mountains was apparently part of a broad plain that sloped to the northeast. Rivers and streams flowed over the plain from the west and southwest, making their way to Hudson Bay. Then, in Pliocene time, maybe 5 million years ago, erosion increased markedly and large amounts of material were removed as the plain dissected deep valleys. It is not really known why this cycle of erosion began. Perhaps the area was uplifted by geologic forces so that streams began to cut into the sediments they had been flowing over, or perhaps the climate changed. As sediment was eroded away, new hills and valleys were shaped and, gradually, as the sediments surrounding the Turtle Mountains were carried away to Hudson Bay, a large mesa was left standing where the Turtle Mountains are today. The reason the outlier developed where it did is not entirely clear. The uppermost bedrock unit on the Turtle Mountains (beneath the covering of glacial sediment) is the Tertiary Cannonball Formation, which is not notably resistant to erosion. It is possible, of course, that some kind of resistant layer was present throughout much of the erosion cycle; perhaps a part of the lower Bullion Creek Formation. It is also possible that additional drilling in the area will eventually penetrate a remnant of some resistant material we have not yet found. If any resistant layer exists, it is deeply buried beneath glacial sediments.

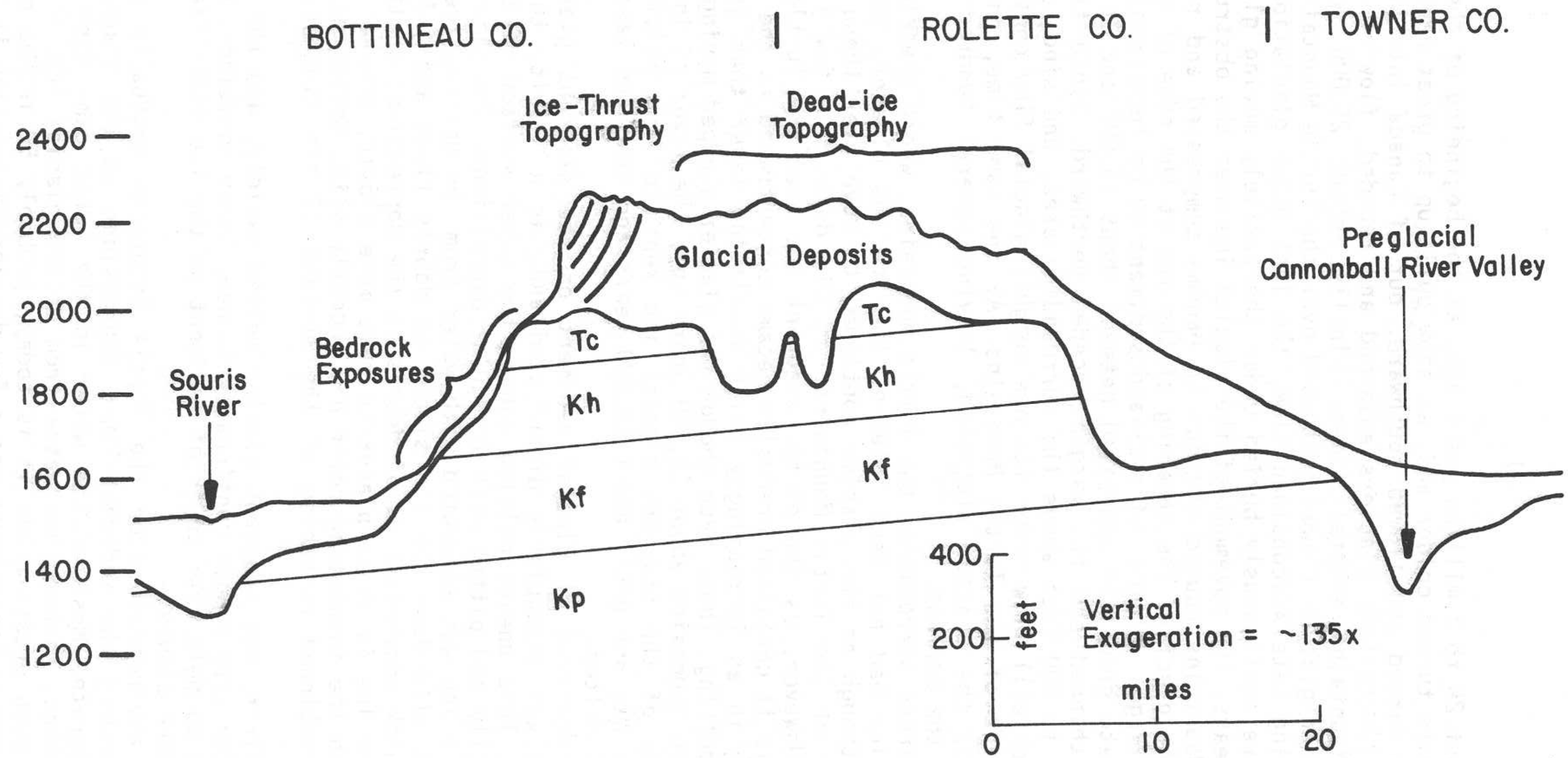


Figure 4. Cross section drawn from west to east through the Turtle Mountains at the U.S. - Canada border. Symbols are as follows: TC = Cannonball Formation; Kh = Hell Creek Formation; Kf = Fox Hills Formation; and Kp = Pierre Formation.

About 2½ to 3 million years ago, at the beginning of the Pleistocene Epoch, the climate turned colder and, as snow built up to great depths near Hudson Bay, glaciers formed and flowed southward, out of Canada into North Dakota. As the climate fluctuated, glaciers advanced and receded, flowing around and over the Turtle Mountains several times. Finally, about 25,000 years ago, the Late Wisconsinan glacier flowed southward over the Turtle Mountains.

During Late Wisconsinan time, the last major glaciation, the Turtle Mountains were continuously buried under the actively moving glacial ice for about 10,000 years. The movement of the glacial ice over the obstruction formed by the Turtle Mountains caused the ice to become compressed and resulted in shearing within the glacier. The shearing of the ice at the edge of the Turtle Mountains caused large volumes of rock and sediment to be incorporated into the ice. As the climate gradually moderated between about 15,000 and 13,000 years ago, the glacier thinned and its margin receded northward. Since the Turtle Mountains rise 600 to 800 feet above the surrounding area, and since ice only 200 or 300 feet thick will flow under its own weight, glacial flow continued for awhile on either side of the Turtle Mountains. At the same time, on top of the Turtle Mountains, the glacier stagnated, leaving several hundred feet of dirty ice covering the surface.

In areas surrounding the Turtle Mountains, where shearing of material into the glacier had not been intense, the ice was cleaner, and it simply melted away, although as the glacier continued to move over these lower areas around the edge of the Turtle Mountains, it did deposit a few feet of sediment in places. However, as the dirty, stagnant ice over the Turtle Mountains melted, the debris it contained gradually became concentrated at the surface of the ice, resulting in an increasingly thick insulating layer that greatly retarded the rate of melting. Thus, even though the glacier stopped moving and stagnated over the Turtle Mountains about 13,000 years ago, the layer of insulation that built up on top of the stagnant glacial ice kept it from melting for about 3,000 years. It was not until about 10,000 years ago that the last ice on the Turtle Mountains melted.

The covering of glacial sediment on the stagnant glacier on the Turtle Mountains was irregularly distributed and, as a result, the ice there melted unevenly. This uneven melting caused the upper surface of the stagnant ice to become hilly and pitted with irregular depressions. The glacial sediment on and within the ice was saturated with water from the melting ice and it was highly fluid. It slid down the ice slopes as debris flows and filled in the depressions. Thick accumulations of debris in the depressions on the stagnant glacier caused the ice in those places to melt more slowly, whereas newly exposed ice, from which the insulating cover had recently slid, melted more rapidly, resulting in continued reshaping of the surface of the stagnant, sediment-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 sediment on the ice stabilized, causing the ice to melt more slowly.

The environment over the Turtle Mountains gradually stabilized and the lakes flooding the sediment-lined depressions on the stagnant glacier became more temperate. Most of the water in the lakes came from runoff from local precipitation, rather than water from melted glacial ice. Precipitation at the time was much greater than it is today, probably 50 inches or more 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 sediment-covered glacier on the Turtle Mountains (fig. 5). Surrounding the lakes and streams, the covered 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 Turtle Mountains about 10,000 years ago was similar, in many ways, to stagnant, sediment-covered parts of certain glaciers in south-central Alaska today.

Eventually, all the stagnant ice over the Turtle Mountains melted, and all of the material on top of the glacier was distributed in its present position, forming the hilly "collapse" topography that is found in the area today. These landforms are sometimes referred to by geologists as "dead-ice moraine."

The modern landscape in the Turtle Mountains is marked by hundreds of lakes and ponds, hummocky topography, but with some fairly broad, flat areas that stand above the surrounding rougher land and some flat, lowland areas. Many of the flat areas are old lake plains of silt and clay that were once surrounded by glacial ice ("elevated lake plains") (fig. 5). Other flat areas are covered by stream deposits of gravel and sand.

Summary

This has been only an abbreviated description of the geology of two of North Dakota's more interesting "mountainous" areas. The NDGS has published reports in much more detail on Bottineau and Rolette Counties and these reports describe the Turtle Mountains more fully. Several students have done geologic research in the Killdeer Mountains and one of our geologists, Ed Murphy, is currently mapping in Dunn County. His report will include much more detailed information on the Killdeer Mountains. For those interested in these two areas, I've included a short list of pertinent references below.

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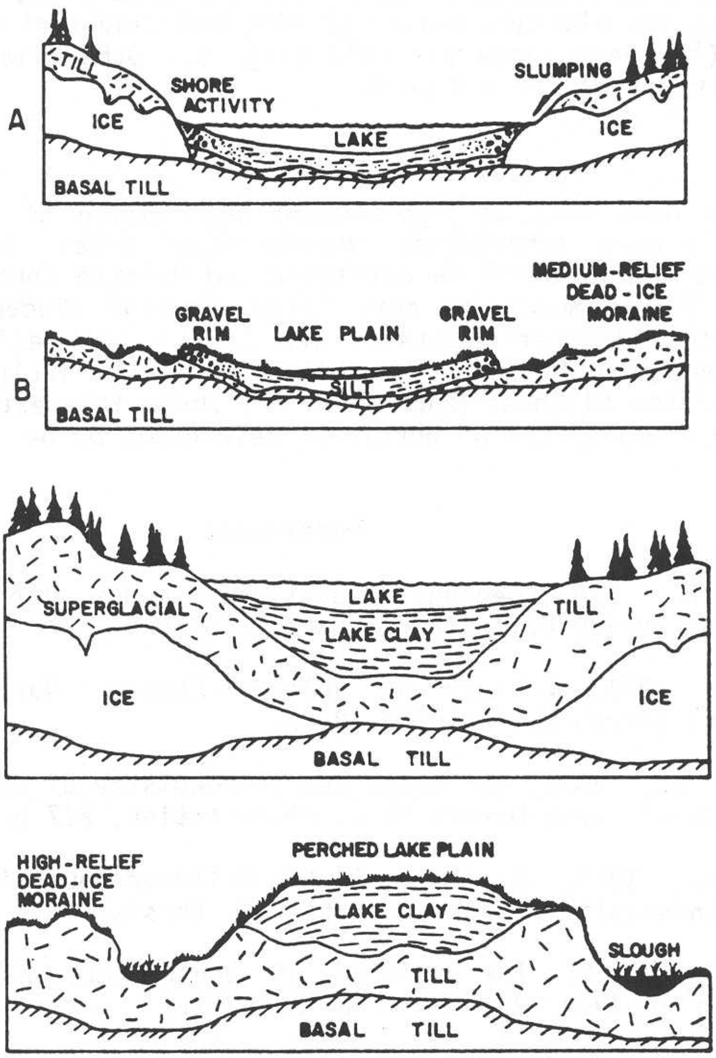

Figure 5. Generalized cross sections showing the type of modern landforms that resulted from lakes that existed in areas covered by stagnant, unstable glacial ice such as in the Turtle Mountains. Diagrams A and B show stages in the development of a gravel-rimmed, slightly elevated lake plain. C and D show stages in the development of a markedly elevated lake plain.

COMMENTS

Do you have questions, comments, or suggestions regarding the newsletter or North Dakota Geological Survey services? For additional information on any of the items mentioned in the Newsletter, please contact John Bluemle, NDGS Newsletter Editor, North Dakota Geological Survey, University Station, Grand Forks, ND 58202-8156

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