NDGS NEWSLETTER

Industrial Commission of North Dakota
North Dakota Geological Survey

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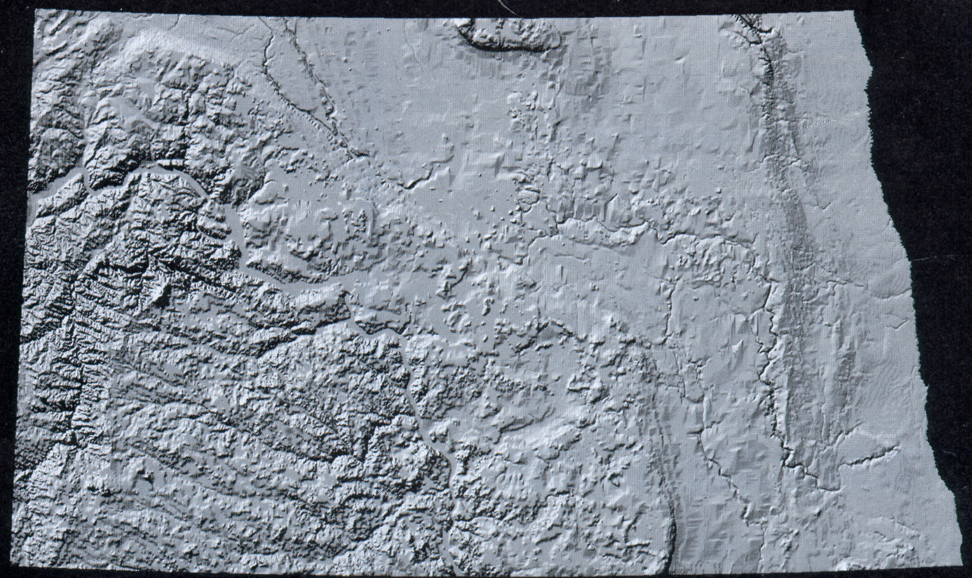

Shaded Relief of North Dakota

This map is a computer-generated model of the surface topography of North Dakota. Although it appears similar to a satellite image, the model was actually created from a data file of over 30 million elevation measurements taken at a grid point interval of approximately 200 feet across the entire state. Many of the state's most prominent geologic features are easily seen in this unique portrayal. See page 9 for an introduction to this extraordinary landscape and pages 14-15 for an introduction to the shaded relief map itself. This map is available in both poster and postcard form. To order, see page 28.

FEATURES

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Heidi Heitkamp, Attorney General
Sarah Vogel, Commissioner of Agriculture

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NDGS NEWSLETTER

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Gina Buchholtz • Layout and Design

NDGS Newsletter (ISSN: 0889-3594) is published quarterly by the North Dakota Geological Survey, a division of the Industrial Commission of North Dakota. *NDGS Newsletter* is designed to reach a wide spectrum of readers interested in the geology and mineral resources of North Dakota. Single copies of *NDGS Newsletter* are distributed free upon request. Please share the *NDGS Newsletter*; we encourage its reproduction if recognition is given.

Your comments - and contributed articles, photographs, meeting announcements, and news items - are welcome. Correspondance, subscription requests, and address changes should be addressed to: Editor, *NDGS Newsletter*, North Dakota Geological Survey, 600 East Boulevard Avenue, Bismarck, ND 58505-0840 • (701) 328-9700.

When requesting a change of address, please include the number on the upper right hand corner of the mailing label.

FROM THE STATE GEOLOGIST

By John. P. Bluemle

I have a couple of unrelated topics I'd like to discuss this issue: the changing level of Devils Lake and the Horizontal Drilling Workshop we are cosponsoring in May.

As I write this, we are still preparing for our Fourth International Williston Basin Horizontal Drilling Workshop; by the time you read this the workshop should be history. The first two workshops were held in Minot and the third was held in Regina last year. This year's workshop is being held in Bismarck at the Radisson Inn, from May 5-7. Geologists with the NDGS, particularly Dr. Paul Diehl, and our counterparts in Saskatchewan, the Saskatchewan Energy and Mines, have worked hard at organizing this year's workshop.

The workshop format is informal again this year to allow for easy discussion and communication, with plenty of opportunity to learn about the latest in ideas and activity in the Williston Basin. Talks and poster displays cover subjects dealing with geology and engineering on both sides of the border.

Our first three workshops were successful and productive, with interesting presentations and ample opportunity for industry, government, and academic people to discuss mutual concerns. This year's program includes a session on enhanced recovery techniques, such as CO_2 injection, that can be used in conjunction with horizontal wells.

Our workshops have had a tremendous impact on North Dakota's economy by transferring knowledge about horizontal drilling technology from experienced operators and service companies to others attending the conferences. The workshops have provided a forum that has allowed people from all facets of the oil industry to get together. New ideas for utilizing horizontal drilling technology that have been raised at the workshops have then been successfully applied in both North Dakota and Saskatchewan. I'll be summarizing the results of this year's workshop in the next issue of the *NDGS Newsletter*.

Once again, it's the time of year when we become concerned about the snow pack in the Devils Lake Basin and the potential for the lake rising even higher. As matters stand now, it appears likely that the lake will rise this year, but it's too early to say how much because that will depend largely on the amount of snow and rain that fall in the next several months.

I wrote an article for this newsletter last winter pointing out some of the problems of dealing with a lake in an enclosed basin. Fluctuations in the levels of Devils and Stump Lakes are caused by climatic changes. These fluctuations are cyclic, extreme, and inevitable. Barring decisive action, such as construction of an inlet and an outlet, the fluctuations will continue.

Recently, I reviewed some of the data in our files and compiled a new chart illustrating our latest concept of how the level of Devils Lake has fluctuated over the past 4,000 years (the chart is reproduced on the next page). The chart is generalized and probably the most important thing to note when looking at it is not the specific times that the lake dried up or overflowed, but the frequency and extremes of the fluctuations in the level of the lake. Devils Lake has dried up completely perhaps five or six times and it has overflowed into the Sheyenne River at least twice during the past 4,000 years and probably more often than that. Devils Lake almost certainly overflowed into Stump Lake several more times than I've shown, but our data don't allow me to determine how often with anything even approaching certainty.

As I noted in my earlier article, the actions of man during the past 100 years or so - since settlement - are *not* an important factor in ddetermining the behavior of the lake. That should be obvious from a quick look at the chart on the next page; obviously the lake rose and fell often and dramatically before European settlers arrived on the scene. Thus, even though agriculture, drainage of wetlands, road construction, etc. may have some short-term effects, these things are definitely not responsible for the overall behavior of the lake. They do not determine *whether* the lake rises or falls and they have only a minor impact in determining *how much* the lake rises or falls.

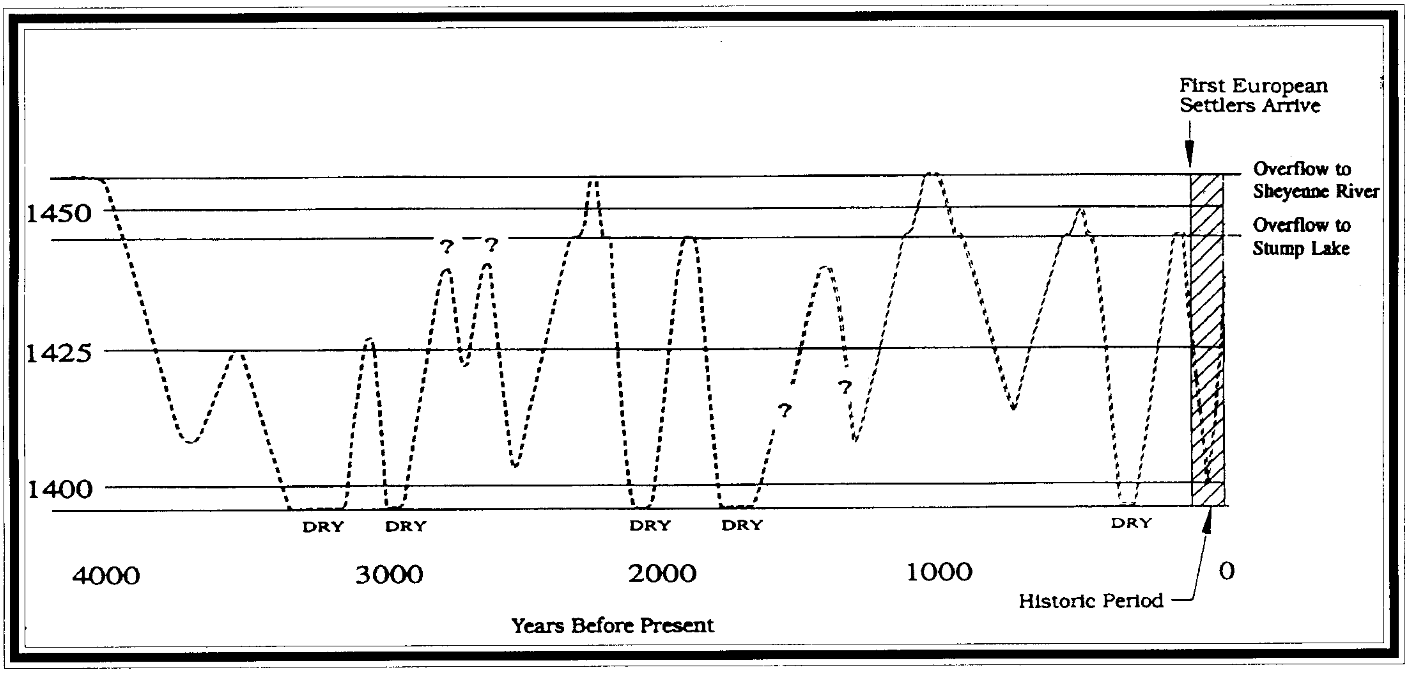
Clearly, the natural condition for Devils Lake is either rising or falling, either toward overflow or dry lake bed. The lake should not be expected to maintain a table level or to remain long at any given level. Only an inlet and an outlet can remedy this situation. Ideally, the goal should be to stabilize and freshen the lake and this would be best done by constructing an inlet near the west end of the lake and an outlet at the east end.

The behavior of Devils Lake seems to cause no end of consternation to any number of people. Residents of the area are rightly concerned as their roads and property are flooded and they feel frustrated because it seems to them that little has been done to deal with the problem.

Several plans have been proposed recently that might provide temporary relief of the immediate problem of too much water in the Devils Lake Basin, but long-term solutions that address water quantity and quality issues for the *whole* basin have been problematic.

In January, NDGS geologist Mark Luther and I met with staff from the Governor's office and proposed a list of options that address many of the short term *and* long-term problems facing residents of the Devils Lake Basin. These options have received a favorable response and are currently undergoing feasibility analysis. We will keep you posted!

❖ ❖ ❖



This generalized illustration shows how the level of Devils Lake has fluctuated over the past 4,000 years. The curve is based on study of cores taken from the bottom sediment of the lake and radiocarbon dating of soils directly overlying shoreline sediments and buried soils in the outlets from Devils and Stump Lakes. The level of Devils Lake fluctuates constantly, ranging between the extremes of being completely dry to overflowing to Stump Lake or, at times, to overflowing into the Sheyenne River drainage. The changes in the lake level are entirely in response to long-term climatic changes. Even though recent, historic changes in the level of Devils Lake may be very slightly affected by cultural circumstances (agricultural practices, wetlands drainage, urban construction and a host of other factors), it should be obvious that the lake level fluctuated widely and often prior to any human influence. Barring direct manipulation (construction of an inlet-outlet, etc.), the level of the lake will react as it always has to climatic changes.

NEWS IN BRIEF

Compiled by Bob Biek

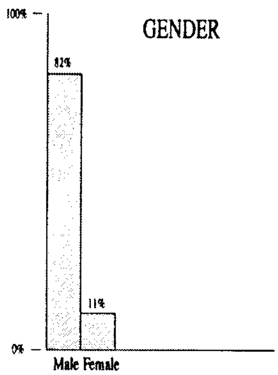
NDGS Newsletter Mailing List Updated

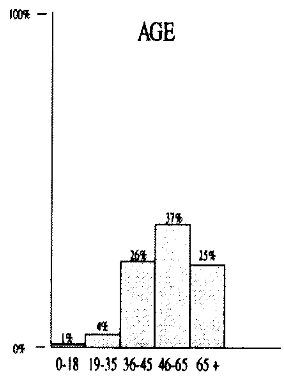
In the last issue of the *NDGS Newsletter* we asked readers to renew their subscriptions to this free quarterly newsletter, and while they were at it, respond to a few questions that would help us tailor the newsletter to better suit their needs.

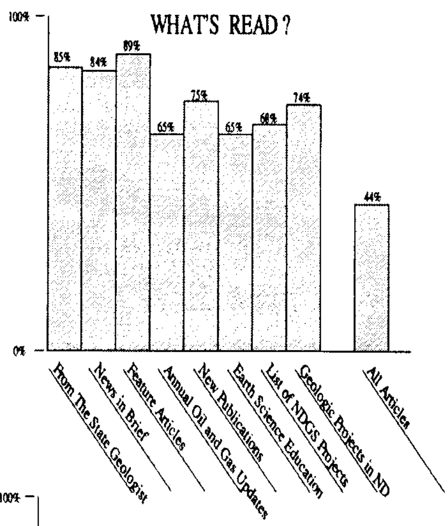
As of mid-March, we had received 651 responses. Coupled with the 250 organizations on our library exchange list (who did not have to return the renewal card), about 35% of our original subscribers choose to renew their subscriptions. I'm told that for such a mailing, this response is quite good, and if I can mentally factor in people who may simply have forgotten to send in the card, then, yes, I believe the response is ok. But I can't help wondering what happened to the issues sent to the several hundred people who did not respond.

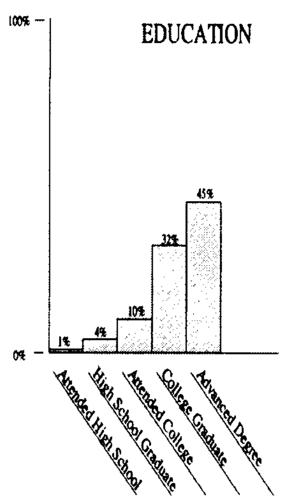
Responses to the questionnaire not only helped us get a better sense of who our readers are, but it pointed to gaps in our distribution that we will seek to fill.

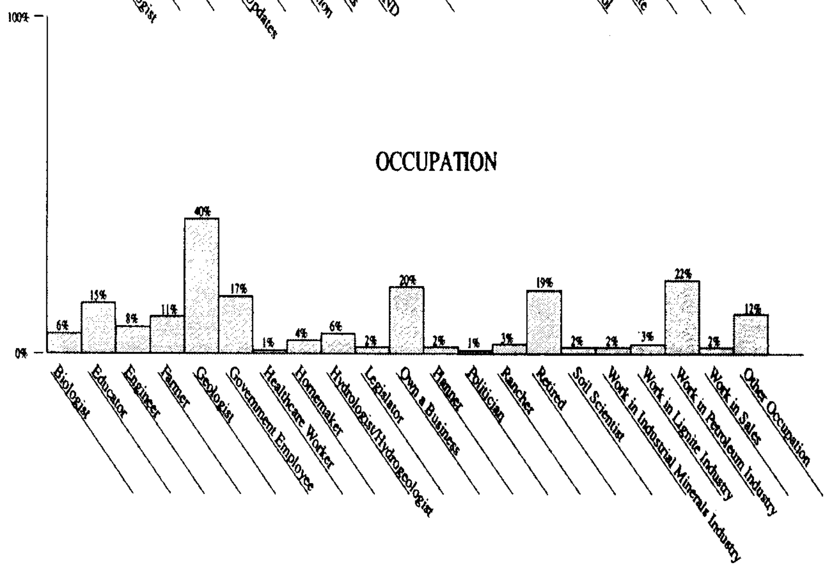
Almost 40% of you offered suggestions or comments that ranged from an inspiring pat-on-the-back to ideas for future articles. We hope to address many of your suggestions in coming issues. About 110 people jotted down the name and address of a friend that they thought might enjoy receiving the newsletter. Some other results of the survey are outlined above (percentages do not add up due to rounding, the fact that 9% of respondents submitted incomplete responses, and because many of our readers pursue multiple occupations). Once again, thanks to all of you who renewed your subscriptions and responded to the questionnaire.











NEWS IN BRIEF . . . Continued

NDGS Receives Grants for Geologic Mapping

The NDGS was recently awarded two U.S. Geological Survey Statemap grants under the National Cooperative Geologic Mapping Program: $29,682 for geologic mapping in the Bismarck-Mandan area, and $14,695 for compilation and mapping in the Grafton quadrangle. The grants will be used to match State funds on an equal basis.

USGS Contracting Officer Brian Heath noted that the 1996 Statemap program was highly competitive. Forty-five states proposed 66 mapping projects, with funding requests totaling $5,208,713. With only $3,588,648 available in the Statemap program, the NDGS is fortunate to have both mapping proposals fully funded.

Geologic mapping in the Bismarck-Mandan area will provide basic geologic information useful for landuse planning and hazard mitigation, and will form the basis for educating residents about the fascinating geology of this urban area. Mapping is scheduled to begin in June, 1996 and be completed by May of the following year. Six 7.5' quadrangles - Harmon, Mandan, Bismarck, Menoken SW, Schmidt, and Sugarloaf Butte - will be mapped at a scale of 1:24,000 (one inch on the map equals 2,000 feet on the ground).

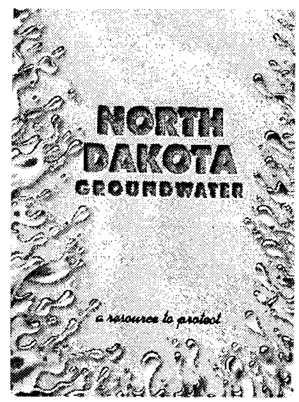
The Grafton 30' x 60' quadrangle area contains some of North Dakota's most valuable agricultural, groundwater, and gravel resources. Updated geologic maps that are available in a digital form for use in a Geographic Information Systems (GIS) are needed to minimize negative impacts that may occur in the utilization of these valuable resources. Mapping is scheduled to begin in April, 1996, and be completed by March, 1997. A digital 1:100,000 scale, lithology-based, surficial-geology map for the North Dakota portion of the Grafton 30' x 60' map area will be the final product.

For additional information about the Bismarck-Mandan mapping project, please contact Ed Murphy. Contact Mark Luther to learn more about mapping in the Grafton area.

Midwest Friends of the Pleistocene 43rd Annual Field Conference

The Midwest Friends of the Pleistocene, a loose collection of people interested in Ice Age geology of the northern plains, will hold its annual field conference in northwestern Minnesota and northeastern North Dakota the weekend of May 31-June 2, 1996. A post-meeting fieldtrip, to examine sites associated with the southern outlet of glacial Lake Agassiz, is also planned for Sunday afternoon through Monday the 3rd. The conference is being co-hosted by Ken Harris (Minnesota Geological Survey), Mark Luther (NDGS), and John Reid (UND Department of Geology and Geological Engineering). For more information about the field conference and post-meeting fieldtrip, please contact MGS geologist Ken Harris (612-627-4780).

North Dakota Groundwater: A Resource to Protect



The North Dakota Department of Health, Division of Water Quality, recently released *North Dakota Groundwater: A Resource to Protect.* This free, full-color, handsomely illustrated, 13-page booklet provides a non-technical review of North Dakota groundwater resources, potential threats to groundwater quality, and measures that state and local agencies are taking to ensure groundwater protection and management. The booklet concludes with a list of steps that individuals can take to help protect groundwater. To order, contact the North Dakota Department of Health, Environmental Health Section, Division of Water Quality (701-328-5210).

NEWS IN BRIEF . . . Continued

Earthquakes on the World-Wide Web

While it may be fun to "surf the net" to see what you can discover about a particular topic on your own, it is also nice to know that the waters have been traversed before and that many a map exists to help you find what you are looking for. Two of the best "maps" to earthquake and seismologic information available on the World-Wide Web are *Seismosurfing* (developed at the University of Washington - Seattle) and a Web page developed by Steven Schimmrich at the University of Illinois. Both link users with a variety of Web sites devoted to earthquakes and seismology. Listed below are Internet addresses for these two WWW sites, as well as several others that have earthquake and seismologic information.

Seismosurfing the Internet
http:/www.geophys.washington.edu/seismosurfing.html

Steven Schimmrich's Web page
http://www.geology.uiuc.edu/~schimmri/geology/geology.html

Earthquake information, U.S. Geological Survey - Menlo Park, CA
http://quake.wr.usgs.gov/

National Earthquake Information Center - Golden, CO
http://gldfs.cr.usgs.gov/

Earthquake Engineering Research Center - Berkley, CA
http://nisee.ce.berkeley.edu/

National Center for Earthquake Engineering Research
http://www.nceer.buffalo.edu

In the March 1996 issue of the *Journal of Geological Education*, Steven Schimmrich describes these and many other World-Wide Web resources that deal with earthquakes and seismology.

Quaternary Geology of the Southern Red River Valley

The Minnesota Geological Survey recently published Regional Hydrogeologic Assessment RHA-3, Part A, Plate 1 - *Surficial Geologic Map* (by Kenneth L. Harris) and Plate 2 - *Quaternary Stratigraphy* (by Kenneth L. Harris, Susan A. West, Barbara A. Lusardi, and Robert G. Tipping). The geologic map covers the Minnesota portion of the southern Red River Valley at a scale of 1:200,000. The lithostratigraphic map (scale 1:750,000) covers the southern Red River Valley (south of Grand Forks) in both Minnesota and North Dakota; cross sections clearly show the three-dimensional distribution of the units, including important aquifers. The maps, available from the Minnesota Geological Survey, are accompanied by text and illustrations that explain the geology of the region. Part B of the assessment - Plate 3 - Surficial hydrogeology, and Plate 4 - Sensitivity of surficial aquifers to pollution - were published separately by the Minnesota DNR, Division of Waters.

NDGS Welcomes New Staff Member

Gina Buchholtz recently joined the North Dakota Geological Survey as our new Information Processing Specialist II. She replaced LaRae Fey who left in January. Gina is a graduate of Bismarck State College with a degree in Information Processing. Her duties at NDGS include layout and design of the quarterly newsletter, brochures and other publications, cataloging of library materials, and support to staff members. She and her husband Jeff are natives of Bismarck-Mandan.

NEWS IN BRIEF . . . Continued

Bismarck Global Positioning System (GPS) Community-Base Station (CBS) Update

During the Spring of 1993, NDGS and the USGS-WRD initiated an effort to install a GPS-CBS in Bismarck. Through the cooperation of several agencies, the effort was a success and a GPS-CBS was installed at Bismarck State College. Since commencing operations during the Fall of 1993, the GPS-CBS has been used by numberous private and public parties needing data for the differential correction of GPS data collected in the field. The adjacent memorandum provides updated information about the pricing and formats of GPS correctional data available from the Bismarck GPS-CBS. *For more information about GPS technology, see the Winter 1993 NDGS Newsletter.*

NORTH DAKOTA GPS STEERING COMMITTEE

MEMORANDUM

TO: Parties interested in accessing the Global Positioning System (GPS) community-base station (CBS) located in Bismarck, North Dakota.

FROM: Mark R. Luther, Chairman, North Dakota GPS Steering Committee

DATE: November 22, 1995

SUBJECT: Obtaining differential correction data from the Bismarck GPS-CBS.

A number of North Dakota state agencies*, one federal agency**, and Bismarck State College are cooperatively operating a Global Positioning System (GPS) community-base station (CBS) located at Bismarck State College. The Bismarck GPS-CBS consists of a Trimble 4000 System SSE geodetic-grade receiver, geodetic antenna, a 486 PC running OS/2, a 28,800 modem, and Trimble Universal Reference Station (URS) software.

The GPS-CBS collects data from all visible satellites, and stores data in three formats: 15 second DAT files, 5 second SSF files, and 5 second RINEX files. Separate files are created for each hour of operation. Although the GPS-CBS operates continuously, data is stored only for the hours of 7AM - 9PM Central time. Data will be kept on-line for 30 days, after which it will be archived on tape. Archived data will be kept for 3 months.

GPS-CBS on-line data can be obtained by two methods: by modem or by 3.5" diskette. Modem access is given to those who pay a yearly fee of $1200 per calendar year or $200 per month, and use a modem with a minimum transfer rate of 9600 baud. After payment of the fee, users are given an account and password and can then obtain data 24 hours-a-day through the bulletin board capability of the URS software. The telephone/modem number of the Bismarck GPS-CBS is (701) 224-5535. For those preferring to obtain on-line GPS-CBS data on diskette, a fee of $15 per day (1-14 hours on the same day), plus $3 shipping/diskette will be assessed. All users requiring data archived on tape will receive that data on 3.5" diskette, and will be assessed a fee of $30 per day (1-14 hours on the same day), plus $3 shipping/diskette.

The coordinates of the Bismarck GPS-CBS antenna as determined by the National Geodetic Survey are (NAD 83 Coordinates):

Latitude	46° 49' 16.02778" North
Longitude	100° 49' 0.04413" West
Ellipsoid Height	552.3053 meters

The Bismarck GPS-CBS operates with a mask angle of 10°. Users of GPS-CBS data are cautioned to operate their mobile receivers with a mask angle > 10° to reduce the possibility of tracking satellites not visible to the Bismarck GPS-CBS.

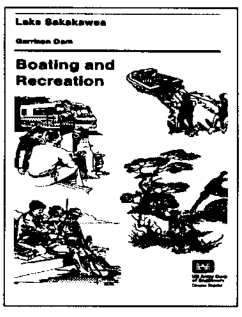
To receive Bismarck GPS-CBS data by either modem or diskette, contact: Mark Luther, North Dakota Geological Survey, 600 East Boulevard, Bismarck, ND 58505-0840 (Phone 701-328-9700, FAX 701-328-9898). Payment of fees should be made by check or P.O. payable to the North Dakota Geological Survey.

While every attempt will be made to collect and store quality data during scheduled hours, neither the GPS Steering Committee nor the North Dakota Geological Survey assumes any responsibility or liability for the availability or quality of GPS-CBS data.

* ND Dept of Agriculture, NDIC ND Geological Survey, NDIC Oil and Gas Division, ND Dept of Health - EHS, ND Dept of Transportation, ND State Water Commission

** US Geological Survey - WRD

US Army Corps of Engineers Lake and River Maps



In addition to selling US Geological Survey, USDI Bureau of Land Management, and USDA Forest Service maps for North Dakota, the NDGS now also sells US Army Corps of Engineers lake and river maps for the Missouri River in North Dakota. These boating and recreation maps are available for three sections of the Missouri River in North Dakota and South Dakota (3 separate maps). The sections are: Lake Sakakawea, Garrison Dam to Lake Oahe, and Lake Oahe. These maps *do not* show bottom contours, but do include information on recreational facilities, shorelines, access roads, river miles, submerged channels, and public land ownership. Costs for the two lake maps are $6.00 each. The cost of the river map (Garrison Dam to Lake Oahe) is $3.00. Shipping is an additional $2.75 for 1-5 maps. Please contact the NDGS Publications Clerk to order.

NORTH DAKOTA GEOLOGICAL SURVEY

600 E. Boulevard Avenue * Bismarck, North Dakota 58505-0840
Phone (701) 328-9700 FAX (701) 328-9898

John P. Bluemle
State Geologist

INDUSTRIAL COMMISSION
Edward T. Schafer - Governor, Chairman
Heidi Heitkamp - Attorney General
Sarah Vogel - Commissioner of Agriculture

Dear Fellow Geoscientists:

Once again we ask for your cooperation in completing the accompanying geologic projects report form. The form requests information about areas in North Dakota - and nearby areas of adjoining States and Provinces - being studied by geoscientists in your university or agency during 1996.

All geoscientists should complete the form - industry, academic, and government professionals, as well as graduate students. **Please circulate this form among your staff or colleagues for the required information and return by May 31, 1996.**

This annual summary is an excellent way to let people know about geologic research underway in North Dakota and nearby areas; survey results show that 74% of *NDGS Newsletter* subscribers read the summary. A summary of 1996 geologic projects will appear in the next issue of the *NDGS Newsletter*. We hope that it too will spur interaction among researchers and other interested persons.

Please detach and return the completed form to:

North Dakota Geological Survey
600 E. Boulevard Avenue
Bismarck, ND 58505-0840

Thanks for your cooperation,

John P. Bluemle
State Geologist

Please detach and return completed form!

Investigator(s): ______________________________

Organization(s): ______________________________

Address: ______________________________

City: ____________________ State: __________ Zip: __________

County(ies) (refer to county codes below): ______________________________

Location of Study: ______________________________

Type of Study (refer to study codes below): ______________________________

Title/Subject: ______________________________

Scale of Geologic Mapping (if applicable): ______________________________

Date of Inception: ____________________

Location of Information (i.e. University thesis; state or technical agency open-file report or publication; other publication; company, confidential - where, release date and provision): ______________________________

____

May the NDGS have a copy of the completed report and/or map for our library? YES ________ NO ________

✂ -

COUNTY CODES

County	Code
Adams	AD
Barnes	BA
Benson	BE
Billings	BI
Bottineau	BO
Bowman	BW
Burke	BU
Cass	CA
Cavalier	CV
Dickey	DI
Divide	DV
Dunn	DU
Eddy	ED
Emmons	EM
Foster	FO
Golden Valley	GV
Grand Forks	GF
Grant	GR
Griggs	GG
Hettinger	HE
Kidder	KI
LaMoure	LM
Logan	LO
McHenry	MH
McIntosh	MI
McKenzie	MK
McLean	ML
Mercer	ME
Morton	MO
Mountrail	MR
Nelson	NE
Oliver	OL
Pembina	PE
Pierce	PI
Ramsey	RA
Ransom	RN
Renville	RE
Richland	RI
Rolette	RO
Sargent	SA
Sheridan	SH
Sioux	SI
Slope	SL
Stark	SK
Steele	ST
Stutsman	SM
Towner	TO
Traill	TR
Walsh	WA
Ward	WD
Wells	WE
Williams	WI
Statewide	SW
Minnesota	MN
Montana	MT
South Dakota	SD
Manitoba	MB
Saskatchewan	SK

TYPE OF STUDY CODES

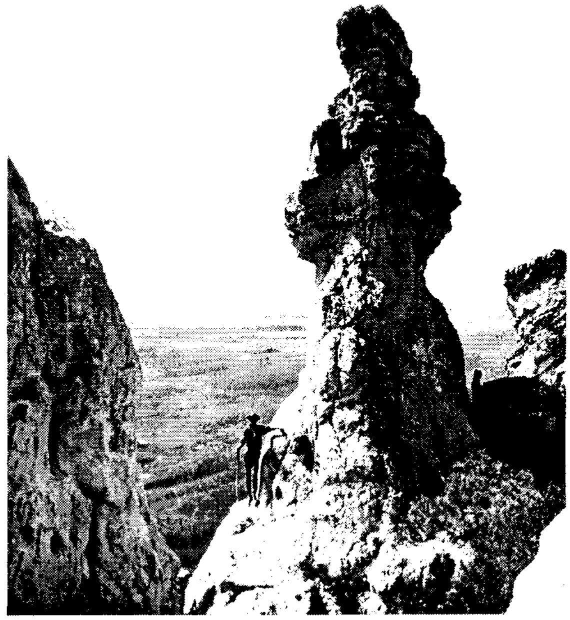
Type of Study	Code
Economic Geology:	
a. General	EC
b. Coal	CG
c. Nonfuel Minerals	NF
d. Petroleum	PG
Engineering Geology	EG
Environmental Geology	EV
Geochemistry	GC
Geochronology	GR
Geologic Hazards	GH
Geologic Mapping	GM
Geomorphology	GO
Geophysics	GP
Hydrogeology	HG
Mineralogy	MN
Paleomagnetism	PM
Paleontology	PA
Palynology/Paleobotany	PY
Petrology	PT
Quaternary Geology	QG
Sedimentology	SD
Soils	SO
Stratigraphy	ST
Structural Geology/Tectonics	SG

NO ORDINARY PLAIN:
NORTH DAKOTA'S PHYSIOGRAPHY AND LANDFORMS

By John Bluemle and Bob Biek

People like to draw lines on maps; it helps them to describe and know their world. Politicians scribe political boundaries that guide the development of government; hydrologists draw watershed boundaries that define individual drainage basins; entrepreneurs chart transitory lines on maps that guide their market development. Among the lines that geologists and geographers use are those that define physiographic regions. North Dakota has been so divided into six major physiographic regions, each defined by a suite of characteristic landforms that serve to differentiate it from its neighbors.

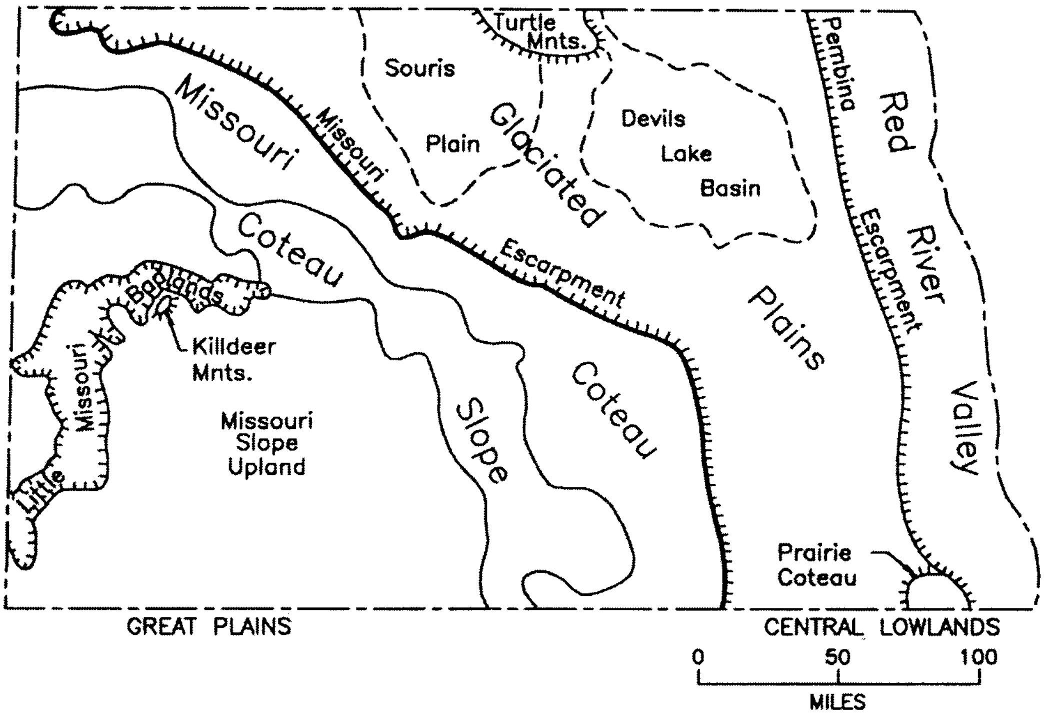
One of the best ways to "see" these physiographic regions is by using a shaded-relief map. Such a map vividly shows the dramatic differences in the landscape. Certainly the new shaded-relief map of North Dakota (see pages 14-15) dispels the myth of the uniform, monotonously flat countryside that many outsiders envision, and that sometimes even locals, traveling at highway speeds, experience. The great, wide open countryside at times makes it difficult to appreciate the diversity of landscapes within one's view. When compressed onto a page-size map, however, major topographic features are easy to visualize.



Pedestal Rock in the Killdeer Mountains, circa 1911. The Killdeer Mountains consist of two mesas that rise 700 feet above the surrounding countryside in northern Dunn County. The rocks that cap the mountain, shown here, consist of tuffaceous sandstone, siltstone, and carbonates of the Arikaree Formation.

The Coteau Slope of eastern Burleigh County. This rolling to hilly area is characterized by both erosional and glacial landforms. (R.F. Biek photo)

The boundaries of these physiographic regions are not arbitrary, not capriciously drawn like the misleading names hung on some suburban streets. Each line reflects an important underlying geologic feature. The Missouri Escarpment, for example, marks a prominent slope that advancing glaciers were forced to push up and over, eventually leaving behind a characteristic hummocky topography and innumerable prairie potholes. The remarkably flat floor of the Red River Valley mirrors the surface of the Ice Age lake, glacial Lake Agassiz, in which it formed. Beaches and wave-cut scarps now mark the lake's former shorelines and separate the valley from the glaciated plains to the west. Understanding the state's physiography is very much understanding an outline of the state's geologic history.



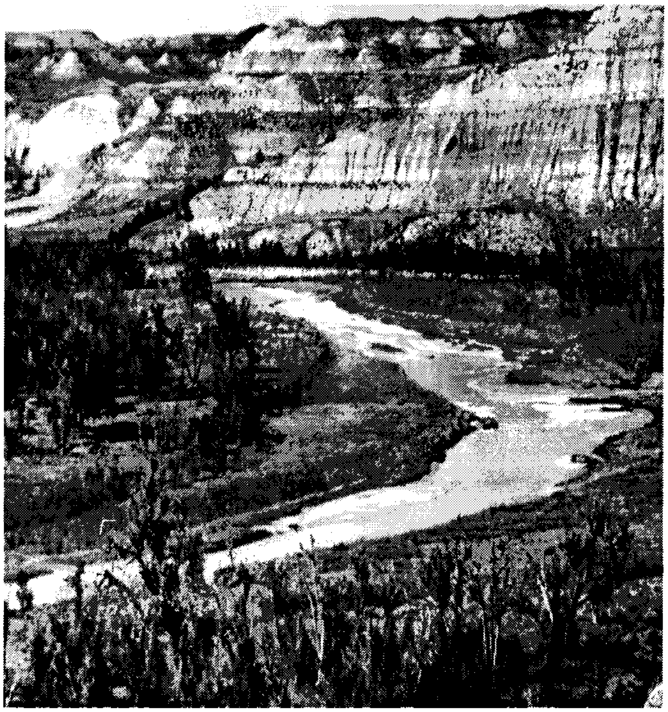
Map identifying the major physiographic regions in North Dakota. Even though landforms of considerable variation occur within each region, overall internal similarities make it possible to generalize about the geomorphic processes that operated to shape each region.

GREAT PLAINS

- ***Missouri Plateau:*** Rolling to hilly plains except in badlands areas and near prominent buttes.
- ***Little Missouri Badlands:*** Rugged, deeply eroded, hilly area along the Little Missouri River.
- ***Coteau Slope:*** Rolling to hilly plains east of the Missouri River that have both erosional and glacial landforms.
- ***Missouri Coteau:*** Hummocky, glaciated landscape that resulted from collapse of superglacial sediment.

CENTRAL LOWLAND

- ***Missouri Escarpment:*** Steep, glacially modified escarpment that marks the boundary between the Glaciated Plains and the Missouri Coteau.
- ***Prairie Coteau and Turtle Mountains:*** Hummocky, glaciated landscape that resulted from collapse of superglacial sediment.
- ***Glaciated Plains:*** Rolling, glaciated landscape.
- ***Red River Valley:*** Flat plain resulting from sedimentation on the floor of glacial Lake Agassiz.
- ***Pembina Escarpment:*** Steep, glacially modified escarpment that marks the boundary between the Red River Valley and the Glaciated Plains.
- ***Souris Lake Plain:*** Flat to gently sloping plain resulting from sedimentation on the floor of glacial Lake Souris.
- ***Devils Lake Basin:*** Closed drainage basin with drainage to Devils Lake; rolling, glaciated landscape.

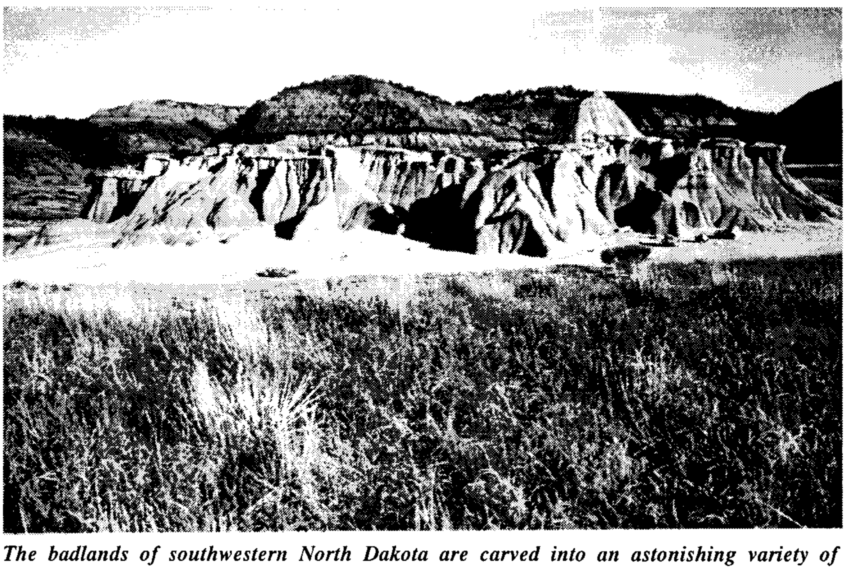


The Little Missouri Badlands are carved from 55-million-year-old river, lake, and swamp sediments of the Fort Union Group. The term "badlands" attests to the intricate, deeply dissected nature of the land, with gullies, buttes, and a maze of short, steep ridges that make travel through such areas difficult. The Sioux Indians knew the badlands as "mako sica" ("land bad"), while early French explorers translated this to "les mauvais terres a' traverser" ("bad land to travel across"). (R.F. Biek photo)

North Dakota lies within the Interior Plains, that vast region stretching from the Rocky Mountains to the Appalachians. In North Dakota, the Interior Plains are divided into two major physiographic provinces by the Missouri Escarpment. To the north and east of the escarpment lies the Central Lowlands Province, characterized by its glacially smoothed landscape. To the south and west, the Great Plains Province rises gradually westward toward the Rocky Mountains. As we shall see, the Missouri Escarpment, while prominent and readily defined along most of its length, does not neatly separate these two major physiographic divisions, but, as with most things natural, the boundary is marked by a transition zone, here called the Missouri Coteau.

The Great Plains Province is divided into the Missouri Plateau (or Missouri Slope Upland), Little Missouri Badlands, Coteau Slope, and Missouri Coteau. The Great Plains Province thus contains both glaciated and non-glaciated regions. Southwest of the Missouri River, the broad valleys, hills, and buttes of the Missouri Plateau are largely the result of erosion of flat-lying beds of sandstone, siltstone, claystone, and lignite. These sediments belong primarily to the Paleocene-age Fort Union Group and were deposited by ancient rivers flowing away from the rising Rocky Mountains between about 65 to 55 million years ago. From about 10 to 5 million years ago, streams began eroding the sediments that had so long ago been deposited, dissecting the plateau with a series of rivers flowing northeast to Hudson Bay. The modern landscape over most of southwestern North Dakota thus formed over an exceptionally long period of time, unlike the much more recent topography of the glaciated portion of the state.

The Little Missouri Badlands are carved into strata of the Missouri Plateau. The badlands are a rugged, deeply eroded area along the Little Missouri River that stretches from Bowman County north to the confluence with the Missouri River. The Little Missouri River began to carve the badlands about 600,000 years ago during Pleistocene time (the "Ice Age") when the river was diverted by glaciers from its northerly route into Canada. As a result of this diversion, the Little Missouri River was forced to flow eastward over a shorter, steeper route, thus beginning a cycle of vigorous erosion that continues today.



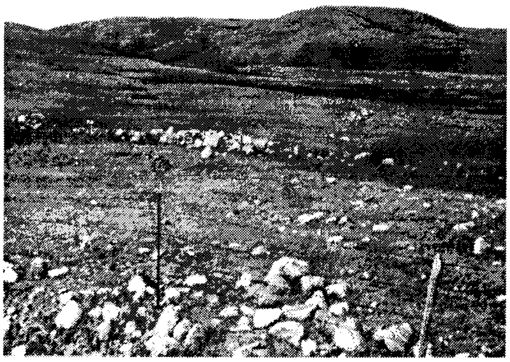
The badlands of southwestern North Dakota are carved into an astonishing variety of unusually shaped landforms. Shown here is the lower Sentinel Butte Formation in the South Unit of Theodore Roosevelt National Park. (North Dakota Tourism Department photo)

Typical prairie pothole, formed by the melting of sediment-laden glacial ice. As the ice melted, the sediment slumped and slid into low areas, creating small hills. The small lakes, or potholes, generally occupy areas where the ice persisted the longest, preventing them from becoming filled with sediment. (J.P. Bluemle photo)

The spectacular variety of landforms found in the Missouri Plateau and Little Missouri Badlands results primarily from the differences in resistance to erosion among Fort Union Group strata. Buttes, for example, form when easily eroded sediments are protected by a hard layer of sandstone or limestone. Where beds of lignite have caught fire and burned, adjacent sediments are baked and fused into a natural brick-like material called clinker. The bright red clinker also shields underlying sediments from erosion. In other places, mineralized groundwater circulated through the sediments, forming flint, petrified wood, silcrete, and concretions and nodules of all shapes and sizes, all of which, being harder than the enclosing sediments, resist erosion and so accumulate at the surface.

Although part of the Missouri Plateau south and west of the Missouri River was glaciated during the Pleistocene, in most places the only visible evidence of glaciation is an occasional erratic boulder or thin patch of glacial sediment. The glaciations that affected these areas were early ones that occurred long before the glaciations whose deposits and landforms are so evident in the eastern and northern parts of the state. Presumably, most of the evidence of these early glaciations - thick glacial sediments and glacial landforms - was removed by erosion over the past several hundred thousand years.

North and east of the Missouri River, the Great Plains Province differs markedly from that south and west of the river, principally because evidence of glaciation is so fresh and clear. Here it is divided into the Coteau Slope, a rolling to hilly land with both erosional and glacial landforms, and the Missouri Coteau, a hummocky landscape characterized by innumerable prairie potholes. Because of its distinct glacial character, many geologists consider the Missouri Coteau to be part of the Central Lowlands Province. The Missouri Coteau does in fact share features of both the Central Lowlands and the Great Plains provinces and so perhaps it would be best to think of the Coteau as a transition zone between the two regions.



Boulder-covered surface of the Missouri Escarpment. Slopewash has removed some of the finer grained sediment, leaving behind a lag deposit of boulders. (J.P. Bluemle photo)

Aerial view of typical collapsed glacial topography in Nelson County, North Dakota. Note hummocky surface with numerous prairie potholes. (J.P. Bluemle photo)

The Missouri Coteau trends through the state, parallel to and east of the Missouri River. It consists of hummocky topography - thus the Canadian French *coteau* meaning "little hill" - characterized by unintegrated drainage (meaning that ponds and sloughs are not connected to one another and no streams flow through the area). The landscape of the Missouri Coteau formed because glaciers were forced to advance up a steep escarpment before they flowed onto the uplands. As glaciers advanced over the escarpment, sediment from the base of the glacier was forced up to the surface. When the climate moderated and the glaciers stagnated, sediment melting out of the ice accumulated at the surface, insulating the ice so that it took several thousand years to melt completely. As it melted, sediment slumped and slid forming the hummocky topography. Prairie potholes are most numerous where large-scale glacial stagnation processes dominated.

The topography of the Turtle Mountains and the Prairie Coteau formed in a similar manner to that of the Missouri Coteau. They are erosional bedrock outliers draped with glacial sediments. They, too, are characterized by a hilly, irregular topography with many small ponds and lakes.

The Coteau Slope is a rolling to hilly region that contains both glacial and erosional landforms. Unlike the Coteau that bounds its eastern margin, drainage within the Coteau Slope is generally well developed, so that there are comparatively few potholes. The north and east margin of the Missouri Coteau is marked by the Missouri Escarpment. The escarpment is a prominent feature along most of its length, in places rising 600 feet above the comparatively level terrain of the Glaciated Plains.

Devils Heart Butte, located south of Devils Lake in Benson County, North Dakota. This 175-foot-high hill occurs in association with intensely ice thrust topography. It is composed of sand and gravel and may have formed as a "veblin," a hydrodynamic blowout feature, when high-pressure groundwater flowed to the surface during glacial thrusting. (J.P. Bluemle photo)

The Glaciated Plains is a rolling, glaciated landscape also known as the drift prairie. Much of the region is very gently sloping, in contrast to the deeply dissected Missouri Plateau. In other places, the ice shoved and thrust large masses of rock and sediment, forming ice-thrust hills near the ice margin. In still other areas, loose accumulations of rock and sediment piled up at the edge of a glacier, resulting in areas of especially hilly land called end moraine. Even where the landscape harbors only the gentlest of swales, interesting landforms can be seen. Washboard moraines, for example, create a corrugated landscape, each marking a small ice thrust zone. Shorelines of glacial lakes, large channels carved by catastrophic floods of glacial meltwater, sinuous ridges of sand and gravel called eskers, and a variety of other glacial landforms are found on the Glaciated Plains. The Glaciated Plains contain some of the most remarkable glacial features to be found anywhere.

Most of these landforms were shaped very late in the Pleistocene by the most recent glaciation, known as the Wisconsinan, which spanned the time from about 70,000 until 10,000 years ago. Even though earlier glaciations played an important role in shaping the landscape, the changes they wrought are largely concealed, buried beneath more recent glacial deposits.

Shaded Relief Map Now Available
By Rod Bassler

The NDGS computer generated *Shaded Relief of North Dakota* by Mark Luther, Rod Bassler, and Harlan Jirges is now available for sale to the general public. Work on the map was initiated in spring of 1994 and, in January, 1995, a full-scale (1:500,000) mock-up was complete and ready for final editing and review. The samples we produced at this scale proved to be popular with the public, but we decided that it was not economically feasible to mass-produce the map at that size (50" x 34"). Consequently, we decided to publish it at a scale of 1:1,000,000 (27.5" x 18.5"). As mentioned in the Fall, 1994, *NDGS Newsletter*, the North Dakota Geological Survey GIS Center has plans for future maps to be derived from the shaded relief base. The first of these derivations completed is a postcard-size version of the shaded relief map (see front cover of this newsletter). Although the postcard does not include a description of the computer technology used to create the map, it serves as an inexpensive means to show the fact that North Dakota has a varied and interesting topography. We have plans at the GIS Center to complete a physiographic map of the state, as well as various thematic maps using the shaded relief map as the base. We have overcome a number of technological and cartographic hurdles in completing this shaded relief map. In the next newsletter, I will give a more detailed and complete discussion of the methodology, problems, caveats, victories, and other considerations that need to be dealt with in producing such a map.

ded Relief of North Dakota

Mark Luther, Rod Bassler, and Harlan Jirges
North Dakota Geological Survey, January 1995

North Dakota
County Boundary Index

The above map is intended for locating counties of interest without covering features on the main map.

0 10 20 30 40 50
Miles

0 10 20 30 40 50
Kilometers

Scale 1:1,000,000
1 inch represents approximately 16 miles
Lambert Conformal Conic Projection

1895 - North Dakota Geological Survey's - 1995 Centennial Year

The North Dakota Geological Survey was created by an act of the North Dakota Legislature in 1895, six years after statehood. Now celebrating its one hundredth year, the Survey still serves as the primary source of geological information in the State. Its mission over the years has grown and is now threefold: to investigate the geology of North Dakota; to administer regulatory programs and act in an advisory capacity to other state agencies; and to provide public service and information to the people of North Dakota.

Geographic
Information
Systems
Center

ure of grays ranging from light to dark that represent sunlit and shadowed y with the relatively uniform gray shades illustrating the flat surfaces of the Red North Dakota. These are good examples of the distinct differences between the orth and east of the Missouri River, and the more varied topography south and

DEM data into the North Dakota Geological Survey's GIS allows the he state's topography that is much more accurate than any satellite image could ures can be more readily seen because the computer is able to emphasize . While aerial photographs covering small areas (hundreds of feet) are studies, a surface model like the shaded relief map allows geologists and res that are very large (covering hundreds of miles). For example, the diversity er is a result of relatively recent continental glaciation that "bulldozed" and stern part of the state. Features like these are easily seen on a map of this scale as opposed to an aerial photo which typically covers an area the size of Bismarck.

The NDGS uses a GIS called Arc/Info to manage, manipulate, and analyze its map information. The unique capabilities of this GIS allow the creation of products such as the shaded relief map. Electronic maps stored in a GIS can contain much more information than just the location of lines, points, and polygons. Associated information, or attributes, can be related to each of the features on the map. For example, any given line representing a road can have any number of various attributes, such as names or pavement types, attached to it. In the case of the shaded relief map, the elevation values are the attributes attached to point locations on the map. A GIS is unique in its ability to model geographic relationships between map features (such as roads, rivers, and terrain) and their related attributes. By using these capabilities, the NDGS can test various "what if" scenarios by changing variables in a model. For example, the existence of relationships between geology and topography can be investigated by simply overlaying the geology map on the DEM model. Watershed basins can be easily defined, or measurements of slope can be quickly calculated. There are many ways in which the NDGS' GIS can be used to relate the spatial information that surrounds us all.

R.F. Bassler, Cartographer
January 1995

Miscellaneous Map 32


The Red River of the North. The Red River meanders across the flat floor of glacial Lake Agassiz. (North Dakota Tourism Department photo)

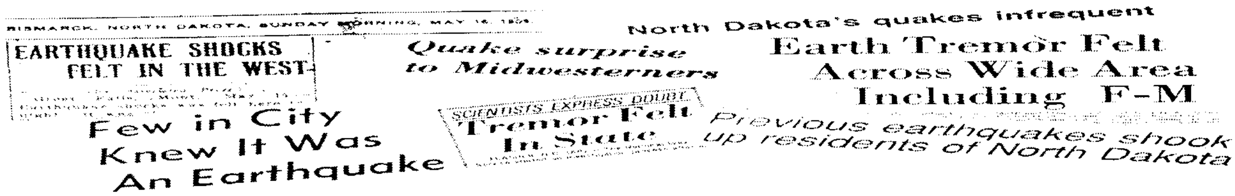
The Red River Valley is an exceptionally flat plain that marks the former floor of glacial Lake Agassiz, once the largest fresh water lake in North America. The valley covers a strip of land about 30 to 40 miles wide on either side of the Red River in North Dakota and Minnesota. The central portion of the valley is characterized by flat-lying silt and clay deposited on the lake bottom. The blackboard-like surface of the lake plain records its most recent history, including grooves scratched into its surface by icebergs and differential compaction ridges that outline the course of buried river channels. Along its margins, ancient beaches and wave-eroded scarps mark former shorelines. These beaches and scarps mark the eastern margin of the Red River Valley, and they are the southward continuation of the Pembina Escarpment. The Pembina Escarpment is most prominent in northeastern North Dakota where it rises 400 to 500 above the flat floor of the Red River Valley. There, it consists of a glacially modified bedrock escarpment, the eastern edge of a tableland of Cretaceous marine shales.

The Souris Plain is also an exceptionally flat plain, one that marks the former floor of glacial Lake Souris. Glacial Lake Souris flooded much of McHenry, Bottineau, and Pierce Counties for no more than a few hundred years at the close of the Ice Age. It had drained from North Dakota about 12,000 years ago. Flat-bedded clay and silt is found near the center of the lake plain, but much of the area flooded by glacial Lake Souris consists of glacial till that was washed by waves at the lake shore. Much of the southern half of the lake plain is covered by wind blown sand, part of the delta that formed where the Souris River entered the lake.


The Sheyenne River Valley, one of many, deep, steep-walled glacial outburst channels in the Glaciated Plains. Channels like this, now occupied by comparatively small rivers and intermittent streams, were carved at the close of the Ice Age by catastrophic floods of glacial water. (J.P. Bluemle photo)

White Butte, at 3,506 feet above sea level in the southwestern corner of the state, is the highest point in North Dakota. The lowest point in the state is 750 feet above sea level, where the Red River crosses into Manitoba. At its most basic then, North Dakota forms a gentle plain that slopes northeast. But this surface is greatly modified by landforms created by glacial ice, glacial lakes, and catastrophic floods of glacial meltwater, as well as by the relentless erosion by water and wind that created the buttes and badlands of the southwestern part of the state. Through the eyes of a geologist, the North Dakota landscape is tremendously varied, ranging from exceptionally flat plains of glacial lakes to rugged badlands.

❖ ❖ ❖



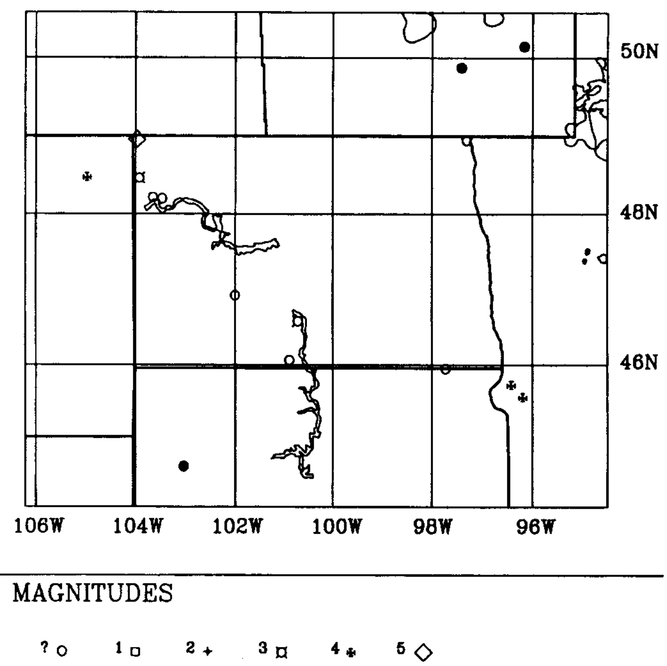
Earthquakes in North Dakota

By Bob Biek

On Monday, July 8, 1968, the State Capitol Building trembled just a little. Governor William L. Guy's secretary thought there had been a sonic boom. Others in town reported that coffee had sloshed from their cups. Most people, however, apparently had not felt or recognized the tremor for what is was - an earthquake. The quake was felt over a 3,000 square mile area. It had a magnitude of 3.7 Mn and an epicenter a few miles southwest of Huff, North Dakota.[1] Intensity IV effects - including rattled dishes and windows and wood frame houses that creaked - were felt in Huff, Bismarck, and several other central North Dakota communities.

Newspaper reports and records from the U.S. Geological Survey's National Earthquake Information Center reveal at least 12 additional events that have been felt in North Dakota. Perhaps the most widely felt earthquake in North Dakota was a May 15, 1909 shock that rocked the northern Great Plains at about 9 p.m. That tremor had an epicenter near the Montana-North Dakota-Saskatchewan border and an estimated magnitude of 5.5 Mn. It created intensity VI effects - including broken dishes and windows and cracked plaster and masonry - and was felt throughout North Dakota and western Montana as well as the adjacent Canadian Provinces. The most widely felt earthquake in U.S. history may also have been felt in North Dakota. Known as the New Madrid quakes, after the unfortunate town of New Madrid near the epicenter of the quakes, a series of three strong quakes occurred on December 16, 1811, January 23, 1812, and February 7, 1812. The largest of these tremors was felt from Canada to the Gulf of Mexico, and from the Rockies to the Atlantic coast.

Almost all earthquakes are caused by the sudden slip of a fault in the upper few hundred kilometers of the earth. Most occur at the boundaries between the seven large plates which fit together to form the earth's outermost shell. These plates are constantly in motion, in some places pulling away from one another at spreading centers such as the mid Atlantic Ridge, sliding past one another such as along the San Andreas Fault, or colliding headlong into one another, such as at the Andean or Himalayan Mountains. These great plate movements are only on the order of 1-10 mm/yr (about the rate at which your fingernails grow), but continual slow movement causes stresses to build up. When stresses exceed the strength of the rocks, the rocks break and snap into a new



Epicenters and magnitudes of earthquakes that have been felt in North Dakota. Source: U.S. Geological Survey National Earthquake Information Center. Three solid dots show location of nearest seismograph stations.

position. The area of rupture is known as the focus or hypocenter of an earthquake and the epicenter is the point on the surface of the earth directly above the focus. The process of breaking or faulting creates vibrations called seismic waves; we feel these waves as earthquakes.

Earthquakes In North Dakota*			
Date	Epicenter Location	Intensity	Magnitude
3-14-1900	Pembina Area	III	——
5-15-09	Near ND/MT/SK Border	VI	5.5 Mn (est.)
8-8-15	Williston Area	IV	——
4-30-27	Hebron Area	III	——
1-29-34	Havana Area	IV	——
10-26-46	Williston Area	IV	——
5-14-47	Selfridge Area	IV	——
7-8-68	Huff	IV	3.7 Mn
3-9-82	30 miles NW of Williston	III	3.3 Mn

* ***Earthquakes with epicenters "in" North Dakota.*** The 1968 "Huff" tremor was the first earthquake with an instrumentally verified epicenter in North Dakota. Earlier tremors have epicenters located by analysis of reported magnitudes and so their locations are less accurate. Several have epicenters on state and provincial boundaries. Their true epicenters are believed to lie within 1.0 to 2.0 degrees of the locations shown.

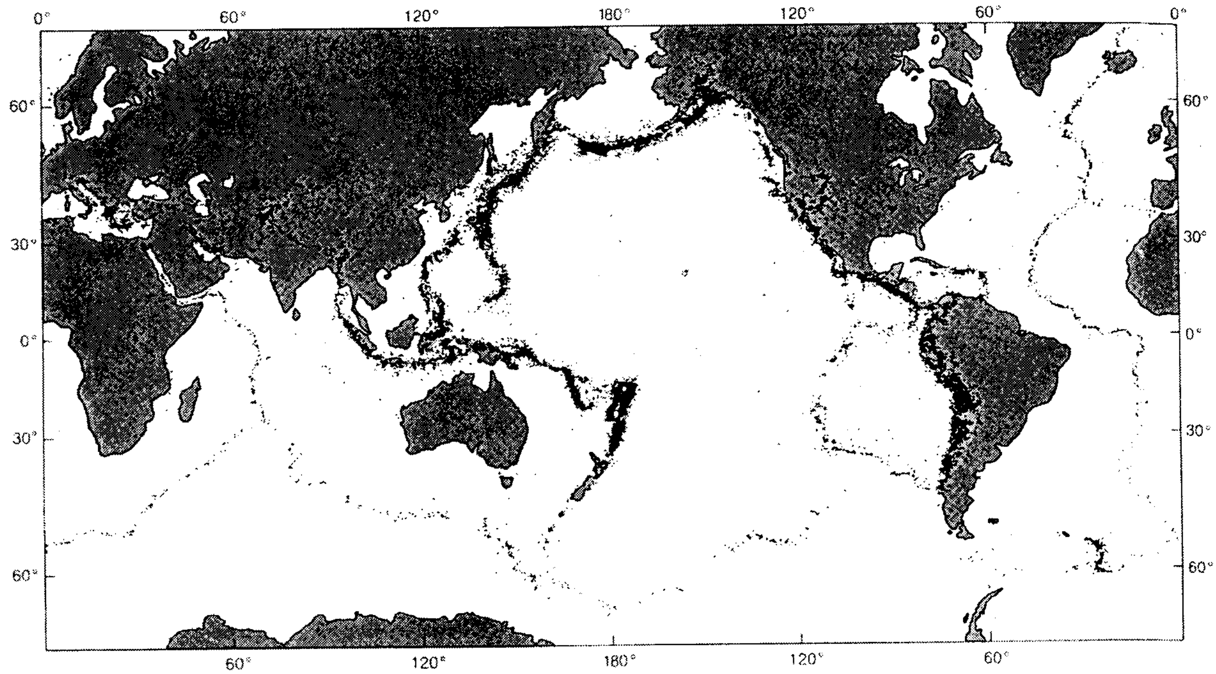
Additional Earthquakes Reported To Have Been Felt In North Dakota*			
Date	Epicenter	Intensity	Magnitude
10-9-1872	Exact Location Unknown; Felt in SE ND	——	——
6-24-43	Medicine Lake, MT - Felt in NW ND	VI	4.0 Mn
7-9-75	Morris, MT - Felt in SE ND	VI	4.6 Mn
6-4-93	Morris, MT - Felt in SE ND	VI	4.1 Mn

* ***Earthquakes reported to have been felt in North Dakota.*** Additional small magnitude tremors have been reported in adjacent Saskatchewan, Montana, South Dakota, and Minnesota, but these events were apparently not felt in North Dakota.

❖ Seismic Waves ❖

Seismic waves, from the Greek *seismos* meaning earthquake, actually consist of both surface waves and body waves. Body waves travel deep into the Earth's mantle and even through its core before reaching the surface, while surface waves travel near the Earth's surface. *When thinking about these two types of waves, imagine dropping a stone into a pond. Sound waves from the impact (which you normally don't sense unless you are a fish) travel deep into the pond, while surface waves are seen traveling away along the air/water interface. The sound waves in seismology are body waves, and the concentric ripples moving away from the source are surface waves.*[2]

Body waves themselves consist of two basic types: compression waves and transverse or shear waves. Since compression waves travel faster through the Earth, they arrive first at distant points; they are known as primary or "P" waves. P waves induce the same motion as do sound waves, that is an alternate compression and dilation of material through which they pass. When P waves reach the earth's surface, some can be transmitted to the atmosphere as audible sound waves; to many, these P waves sound like a sonic boom that rattles windows. Transverse waves travel somewhat more slowly than do P waves; they arrive slightly later than P waves at distant points and are therefore known as secondary or "S" waves. Surface waves are also composed of two basic types, known as Raleigh waves and Love waves, whose motion decreases rapidly with depth. The passage of a Raleigh wave causes a point on the surface of the earth to move in an ellipse in a vertical plane, as does a cork on water. Love waves produce a transverse and horizontal shimmy with no vertical movement. In an earthquake, people may note first a sharp thud or blast-like shock that marks the arrival of the first P wave. A few seconds later they may feel swaying or rolling motion that marks the arrival of the first S wave and finally the surface waves. It is the up-and-down motion of these later waves that is so damaging to structures.



Epicenters of some 30,000 earthquakes recorded in the years 1961-1967, with focal depths between 0 and 700 km. From Frank Press and Raymond Sevier, 1978, *Earth, Second Edition*, W.H. Freeman and Company, p. 412.

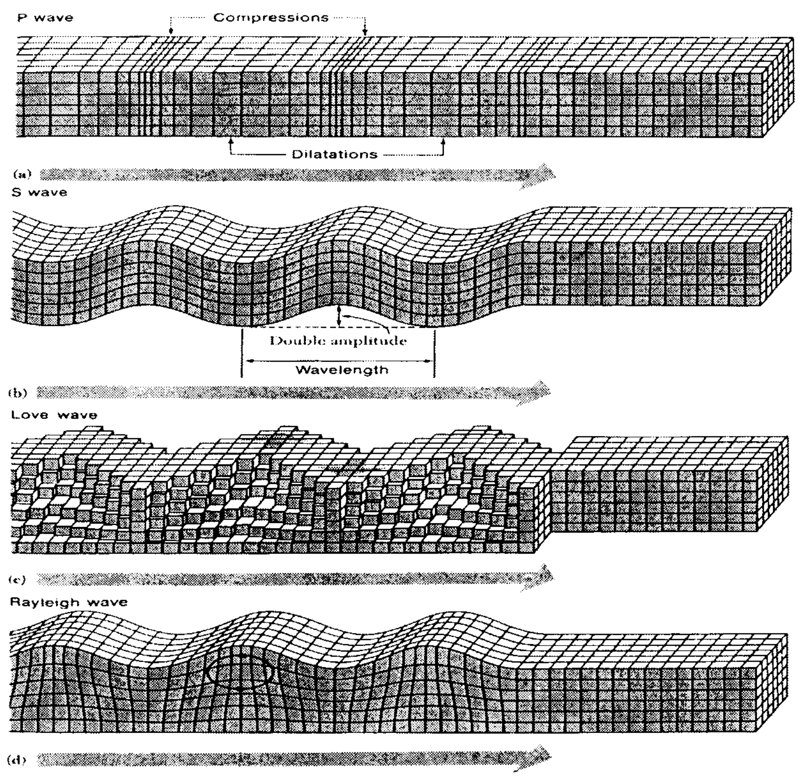


Diagram illustrating the forms of ground motion near the ground surface in four types of earthquake waves. From Bruce A. Bolt, 1988, *Earthquakes, revised and updated*, W.H. Freeman and Company, p. 29.

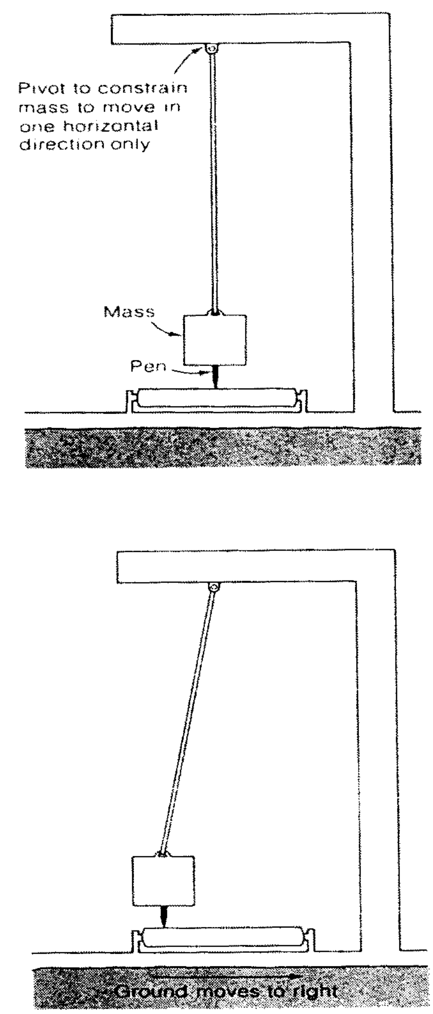
Did You Know . . . the seismic waves of large earthquakes can induce natural oscillations in the Earth and cause the entire planet to ring like a bell for hours or even days. The tone is too low for us to hear, but seismographs can record these low frequency oscillations. *It is extremely interesting to record the seismometer signal on a magnetic tape and play back the tape, say, at 10,000 times faster. We can then, as it were, listen to the earth. It is a strange experience. Generally it sounds like being in a forest on a windy day, with occasional brief falling tones and longer rather melodic tones, reminiscent of an orchestra tuning up. Every now and again there are sharp noises that sound like a branch breaking. On rare occasions there are sounds like a herd of animals stampeding through a forest, smashing off branches and breaking them underfoot.*[3]

These four main types of waves travel at different speeds depending on the density and elastic properties of the rocks and soil through which they propagate. When recorded by a distant seismograph, these different waves are readily identifiable, as each has its own distinctive signature. Conversely, when a seismograph records a nearby earthquake, the waves, having less distance to travel and therefore less time to spread out, are superimposed into a confused squiggle. The effect is not unlike that of a far away thunderstorm, with muted thunder languidly following a distant lightening strike, or the near simultaneous flash and tremendous roar of a storm overhead.

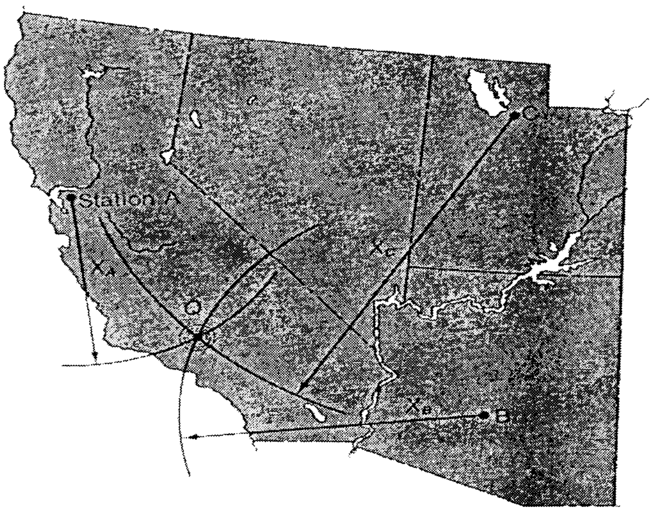
❖ How Earthquakes Are Measured ❖

The severity of an earthquake is expressed by two very different but often confused terms: intensity and magnitude. Intensity is based on observed effects of ground shaking on people, buildings, and natural features. It varies from place to place and generally decreases away from the epicenter of an earthquake. Intensity thus measures the *effect* of an earthquake as noticed by people. The scale used in the United States to express the intensity of an earthquake is the Modified Mercalli (MM) scale, which was developed in 1931 by American seismologists Harry Wood and Frank Neumann. This scale modifies the original Mercalli scale (developed in 1902 by Italian geologist Guiseppi Mercalli) to reflect construction conditions in California. (M.S. de Rossi of Italy and Francois Forel of Switzerland developed the first modern intensity scale in the 1880s. Their inspiration in turn was no doubt from the English engineer Robert Mallet, who made the first scientific study of the effects of a great earthquake, the destructive December 1857 earthquake in southern Italy.) The Modified Mercalli scale is a twelve-point intensity scale where each number on the scale represents the effects of an earthquake at the place where the observer is located (see page 20).

Magnitude is an indirect measure of the energy released during an earthquake and is based on measurement of the amplitude of seismic waves; magnitude thus measures the relative *size* of an earthquake. The instruments most commonly used are ones based on the original seismograph developed by California seismologist C. F. Richter in 1935.[4] A seismograph is to a geologist what a telescope is to an astronomer - a tool for peering into inaccessible regions. In fact, the idea behind the seismograph is similar to one used by astronomers, who grade the size of stars using a stellar magnitude scale based on the relative brightness of stars as seen through a telescope. By studying the record produced by seismographs, geophysicists can determine the time, location, magnitude, and the orientation and



Schematic diagram illustrating the principle of the seismograph. Because of its inertia, the mass does not keep up with the motion of the ground. The pen traces the difference in motion between the mass and the ground, in this way recording vibrations that accompany seismic waves. The instrument shown here records horizontal ground motion. From Frank Press and Raymond Sevier, 1978, *Earth, Second Edition*, W.H. Freeman and Company, p. 406.



Knowing the distance, say X_A, of an earthquake from a given station, one can only say that the earthquake lies on a circle of radius A centered on the station. If, however, one also knows the distances from two additional stations B and C, the three circles centered on the three stations, with radii X_A, X_B, and X_C, intersect uniquely at the point Q, the epicenter. From Frank Press and Raymond Sevier, 1978, *Earth, Second Edition*, W.H. Freeman and Company, p. 415.

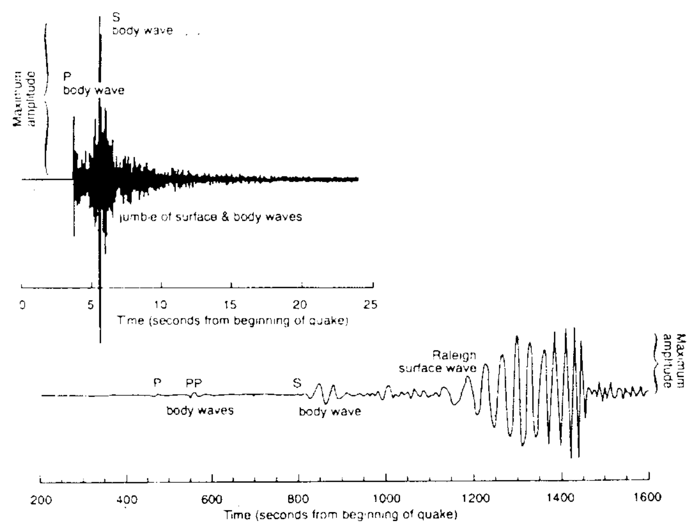
dip of the fault that produced the tremor. It takes three seismographs to locate the earthquake focus.

The zig-zag lines recorded by a seismograph, called a seismogram, record and magnify the tiny, varying amplitudes of ground oscillations beneath the instrument. The magnitude of an earthquake, recorded by the highest amplitude wave, is expressed on a logarithmic scale called the Richter scale. The logarithmic scale is a convenient way to make sense of the enormous variation in the size of earthquakes; the amplitudes of ground motions recorded by seismographs differ by factors of thousands. The logarithmic scale, from the Greek *logos* meaning reason and *arithmos* meaning number, literally makes sense of this huge span of numbers. In this scale, each whole number represents a ten-fold increase in measured amplitude of the seismic waves, and about 31 times the amount of energy released.

Truth be told, there has been much dithering about how to define the magnitude of an earthquake. No single method best defines the magnitude of all earthquakes large and small, near and far. Analysis of different waves will yield different magnitudes, and some analyses may be more appropriate for a given quake than others. The focal depth, distance between earthquake and observing station, frequency content of the sampled waves, and earthquake radiation pattern all affect what earthquake magnitude is chosen. Most seismologists in fact do not use the original Richter magnitude scale, but rather modifications of that scale. The duration magnitude, body wave magnitude, surface wave magnitude, and for very large earthquakes, the moment magnitude, are all commonly used. Generally, shallow earthquakes must have a Richter magnitude of about 5.5 or greater before significant damage will occur near the epicenter.

❖ North Dakota Tremors ❖

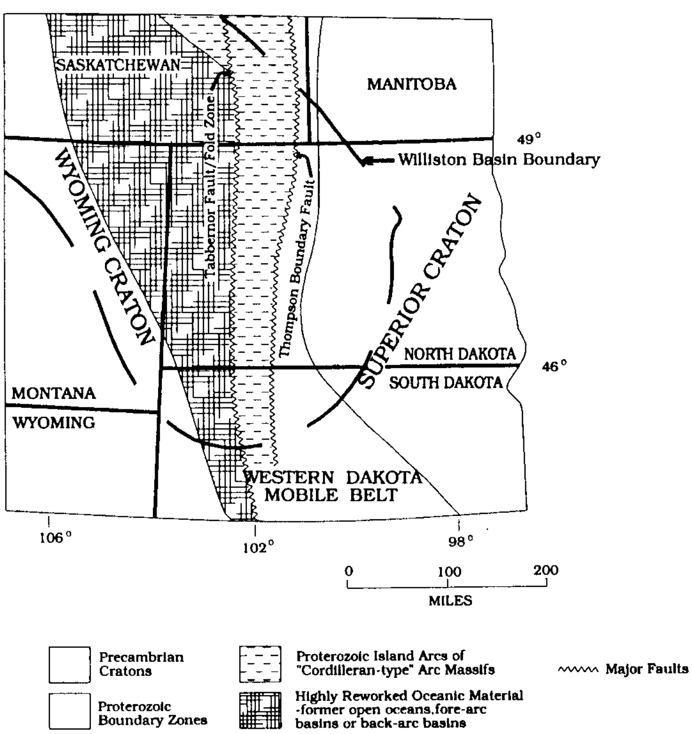
Most earthquakes that originate in North Dakota are likely related to deeply buried structures in the Precambrian basement. In extreme southwestern North Dakota, under sedimentary rocks of the Williston Basin, geologists have recognized the Wyoming Craton. The Superior Craton underlies eastern North Dakota. These two cratons, extremely old and deformed but geologically stable regions, are separated by the Western Dakota Mobile Belt, a group of slightly younger rocks that were



Seismograms of local (above) and distant (below) earthquakes showing differences in duration, arrival times of different wave types, and amplitudes. From Richard Aster, *Have You Ever Wondered... How Earthquakes Are Measured?*, in Lite Geology, Summer 1994, New Mexico Bureau of Mines and Geology.

caught between the cratons as they collided during the Precambrian. Doubtless numerous faults exist within these ancient, highly deformed Precambrian rocks, but because they are so deeply buried, their existence is speculative. Two long faults have been postulated in the Western Dakota Mobile Belt, the Tabbernor Fault and the Thompson Boundary Fault. Movement on these or other faults could produce small to moderate tremors.

Small tremors can also occur when layers of sedimentary rock collapse into voids left by the dissolution of underlying salt beds. Northwestern North Dakota is underlain by thick and extensive salt deposits at depths of about 4,000 to 12,000 feet. Salt is a geologically unstable mineral, for it is readily dissolved in water, and when burdened under the tremendous mass of overlying sediments, it can actually flow and deform. As the salt moves, the support for overlying layers is removed. These layers can settle downward gradually or collapse suddenly, creating a comparatively shallow, small earthquake.



Map showing deeply buried basement geologic structures in North Dakota and adjacent areas. This map shows the Wyoming and Superior Cratons separated by the Western Dakota Mobile Belt, a group of slightly younger rocks that were caught between the cratons as they collided in the Precambrian. From John P. Bluemle, 1991, *The Face of North Dakota, Revised Edition,* North Dakota Geological Survey, p. 94.

While the ground shaking associated with an earthquake generally decreases away from the epicenter, local ground shaking is highly influenced by near-surface geology. For example, ground shaking is generally more severe over poorly compacted sediments such as fill than it is over solid bedrock. Even topography itself can serve to amplify or diminish seismic waves due to the focusing effect of ridges and valleys.

There are few seismograph stations in the Midwest because it is, geologically speaking, comparatively stable. There are no seismographs in North Dakota or Minnesota. A seismograph located at the northern end of the Black Hills, originally installed jointly by the U. S. and former Soviet governments to monitor nuclear testing, is now operated by the U.S. Geological Survey. The Canadian federal government operates a station at Flin Flon, Manitoba, and the University of Manitoba operates a station at Winnipeg. There is also an industrial research seismograph at Pinawa, Manitoba, about 120 km east of Winnipeg.

Earthquakes with a magnitude of about 4.5 can be recorded by seismographs all over the world. The seismic waves of smaller tremors dissipate before being recorded by distant instruments on the other side of the globe. For an earthquake with an epicenter in central North Dakota to be recorded by the nearest seismograph stations mentioned above, it would have to have an magnitude of about 3.3 or greater. The "Huff" earthquake remains the only tremor with an instrumentally verified epicenter in North Dakota[5], although it is likely that other small reported tremors have had epicenters within the state. After all, it has only been since the early 1960s that a seismograph network has been set up in the Upper Midwest to record such small earthquakes. Furthermore, tremors of Richter magnitude 3.0 and sometimes less are often felt by persons favorably situated. There could, in other words, be more small tremors in the state than instrumentally verified records would suggest. Which brings to mind the classic conundrum, *"If a tree falls in the forest and no one is around to hear it, does it make any noise?"*

Abridged Modified Mercalli Intensity Scale	
Intensity Value	Description
I	Not felt. Marginal and long-period effects of large earthquakes.
II	Felt by persons at rest, on upper floors, or favorably placed.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frame creak.
V	Felt indoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes, shaken visibly, or heard to rustle.
VII	Difficult to stand. Noticed by drivers. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds, water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	Steering of cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas, sand and mud ejected, earthquake fountains, and sand craters.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Rails bent greatly. Underground pipelines completely out of service.
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

❖ Endnotes ❖

1. The "Huff" tremor was originally assigned a body wave magnitude of 4.4 and, erroneously, an epicenter just east of Ashley, North Dakota. Recently, U.S. Geological Survey seismologists re-evaluated the quake based on analysis of a different seismic wave, the Lg wave, which gives a more accurate evaluation of the magnitude of distant, small to moderate tremors in the Midwest. This magnitude is reported as the Nuttli magnitude Mn or MbLg.

2. Richard Aster, 1994, *Have You Ever Wondered ... How Earthquakes are Measured?* Lite Geology, New Mexico Bureau of Mines and Mineral Resources, Summer 1994.

3. John Elder, 1976, *The Bowels of the Earth*. Oxford University Press, p. 11.

4. Richter reportedly invented the scale because he was tired of newspaper reporters asking him about the relative size of earthquakes. Richter solved the problem of measuring the magnitude of an earthquake, which is the same no matter where it is measured, even though as we know the intensity of an earthquake generally diminishes away from the epicenter. Richter magnitude is based on the logarithm of the maximum amplitude plus an empirical factor that takes into account the weakening of seismic waves away from the focus. Thus seismologists all over the world can study their records and come up with approximately the same value for earthquake magnitude.

5. The National Earthquake Information Center lists a Mn 3.3 tremor that occurred March 9, 1982 about 30 miles northwest of Williston, near the Montana state line. While instrumentally verified, the epicenter accuracy is only within 0.1 to 0.2 degrees, making it uncertain on which side of the border the actual epicenter was located. There were apparently no newspaper reports of the tremor.

❖ ❖ ❖

Buried Glaciers and Dead-Ice Moraine

By John Bluemle

Geologists like to concoct unusual names for the things they study. I suppose "dead-ice moraine" sounds a little odd to some of you. It's a name for a kind of landform found in parts of North Dakota. Dead-ice moraine sounds odd enough, but you can believe it is found along with things called "doughnuts" and "puckered lips." What have those geologists been drinking? First of all, the word *"moraine"* is an 18th century French word that simply means a heap of earth or stony debris. I don't know when the term was first used to refer to glacial deposits. I'll explain the "dead" part later.

Dead-ice moraine is also referred to as "hummocky collapsed glacial topography" or "stagnation moraine." It is a rugged landscape that formed as the last glaciers were melting at the end of the Ice Age, between about 12,000 and 9,000 years ago. The most extensive area of dead-ice moraine is found on the Missouri Coteau, which extends from the northwest corner to the south-central part of the State. Other extensive areas of dead-ice moraine besides the Missouri Coteau are the Turtle Mountains in north-central North Dakota and the Prairie Coteau in the southeast corner of the State near Lidgerwood (*"coteau"* is French for "little hill"). The landforms of the Turtle Mountains are identical to those on the Missouri Coteau and Prairie Coteau, but the Turtle Mountains have a woodland cover, the result of several inches more precipitation each year than the other areas.

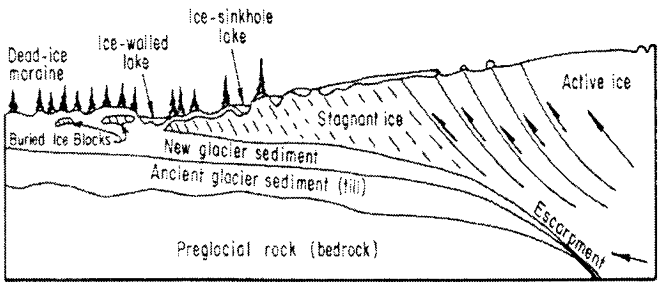
Hummocks (commonly referred to as doughnuts) in an area of collapsed glacial topography. This oblique air view is near Denhoff in Sheridan County.

North Dakota's vast tracts of dead-ice moraine generally make for poor farmland as they are rough, bouldery, and undrained. They do, however, include a lot of excellent rangeland and thousands of undrained depressions - lakes, ponds, and sloughs known collectively as prairie potholes - that serve as important nesting and feeding areas for waterfowl (the so-called North Dakota "duck factory"). The dead-ice moraine is essentially undrained, except very locally. No rivers run through it. No streams flow all the way through the Turtle Mountains or for any distance through or across the Missouri or Prairie Coteaus.

Dead-ice moraine formed when the glaciers advanced against and over steep escarpments as they flowed onto the uplands. The land rises as much as 650 feet in little more than a mile along parts of the Missouri Escarpment, which marks the eastern and northeastern edge of the Missouri Coteau. Similar prominent escarpments border the Prairie Coteau and the Turtle Mountains, especially the west side of the Turtle Mountains near Carbury. When the glaciers advanced over these escarpments, the internal stress that resulted in the ice caused shearing. The shearing brought large amounts of rock and sediment from beneath the glacier into the ice and to its surface.

Irregular, linear disintegration ridges and depressions in an area of hummocky collapsed topography on the Missouri Coteau in Ward County. This area has relatively low relief and is farmed; other nearby areas are much too hilly for farming and are used mainly for pasture land.

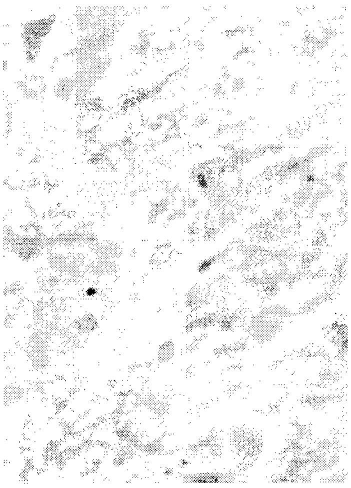
Eventually, as the Ice Age climate moderated, the glaciers stopped advancing and stagnated over the uplands (they "died"). As the stagnant glaciers melted, large amounts of sediment that had been dispersed through the glacier tended to accumulate on top of the ice, which was several hundred, possibly up to a thousand feet thick. This thick cover of sediment helped to insulate the underlying ice so that it took several thousand years for it to melt. Our geologists have determined that stagnant glacial ice continued to exist in the Turtle Mountains and on the Missouri Coteau until about 9,000 years ago.



Schematic diagram through the edge of a glacier. This illustration depicts a situation similar to the one that developed when the glacier moved over escarpments such as those at the edge of the Missouri Coteau, Turtle Mountains, and Prairie Coteau. As the glacier pushed into the escarpments, it was compressed, resulting in shearing within the ice. The shearing brought large amounts of material to the surface of the ice. The cover of superglacial material that built up on the glacier kept the ice from melting rapidly, and vegetation formed on top of the debris-covered glacier. When the ice eventually melted, hummocky collapsed topography resulted.

In places where the debris on top of the ice was thickest, the glacier melted most slowly. Over nearby areas, where little or no insulating debris cover developed on the glaciers, melting was rapid and the land was entirely free of ice by 12,000 years ago. As the stagnant ice on the uplands slowly melted, and the glacier surface became more and more irregular, the soupy debris on top of the ice continually slumped and slid, flowing into lower areas, forming the hummocky, collapsed glacial topography - dead-ice moraine - found today over the Turtle Mountains, Missouri Coteau, and Prairie Coteau.

As the stagnant glacial ice melted, and debris slid from high areas to lower ones, a variety of unusual features resulted. Long ridges formed when sediment slid into cracks in the ice. Such ridges may be straight or irregular, depending on the shape of the cracks. In some places, streams followed the cracks, resulting in eskers. In other places, mounds of material collected in holes and depressions in the ice and ring-shaped hummocks (*"doughnuts"*) formed if the mounds were cored by ice. When the ice cores melted, the centers of the mounds collapsed, forming circular doughnut-shaped ridges. Often, the doughnuts are breached on two sides. If so, geologists call them *"puckered lips."*



Vertical air photo of transversely elongated hummocks (washboards) near Lakota in Nelson County. The area shown is about 0.8 miles wide. The glacier came from the northwest (upper left).

Wherever part of the covering of debris slid off an area of ice to a lower place, the newly exposed ice melted more quickly, transforming what had been a hill into a hole or depression. Such reversals of topography continued until all the stagnant ice had eventually melted.

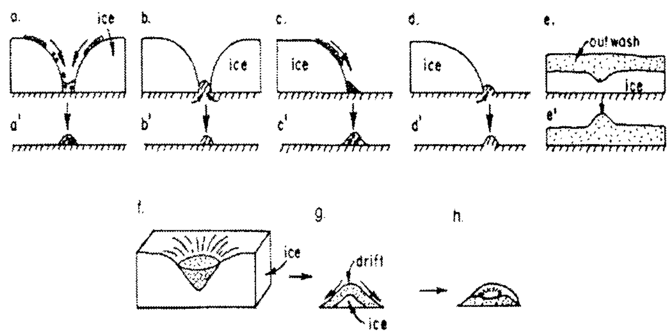
Many more depressions formed when buried or partly buried isolated blocks of glacial ice melted, causing the overlying materials to slump down. Geologists refer to these depressions as kettles. Kettles are also found in areas that were not covered by thick stagnant ice, but here they are generally much smaller and resulted when isolated blocks of buried ice melted. Today, kettle lakes, commonly known as prairie potholes or sloughs, are located in the depressions between the hummocks.

In places, the insulating blanket of debris on top of the stagnant glacial ice was so thick that the cold temperatures of the ice had little or no effect on the surface of the ground. Trees, grasses, and animals established themselves on the debris on top of the stagnant ice. As conditions gradually stabilized, water collected in lakes in depressions on the debris-covered glacier. Most of the water in the lakes actually came from runoff from local precipitation rather than from meltwater 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.

Ring-shaped and elongate hummocks (known informally as "puckered lips") in an area of collapsed glacial topography a few miles south of Stanley in Mountrail County. The area is about 0.8 mile wide. North is to the top of the photo.

Surrounding the lakes and streams, the debris 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. This stagnant-ice environment in North Dakota 10,000 years ago was in many ways similar to stagnant, sediment-covered parts of certain glaciers in south-central Alaska today. Fish and clams and other animals and plants thrived in the lakes. Wooly mammoths, elk and other large game roamed the broad areas of forested, debris-covered ice.

I imagine that prehistoric people lived on the insulated glaciers in North Dakota 10,000 years ago without realizing the ice lay only a few feet below. If they did realize it, they probably accepted it as a normal situation (and I suppose it was normal at that time). Eventually all the buried ice melted, and all the materials on top of the glacier were lowered to their present position, resulting in the hilly areas of dead-ice moraine we see today.



Diagrams illustrating how various ice-disintegration features form in areas of glacial stagnation. The top five diagrams (*a* through *e*) show ways that disintegration ridges might form. Situations *a* and *c* involve debris sliding off of the ice and piling into a ridge. Situations *b* and *d* involve pushing by a block of glacial ice or, in some instances, squeezing of material from beneath the ice, to form a ridge. Situation *e* involves sand and gravel, deposited in a crack in the ice, and left standing as a ridge when the ice melted. The lower three diagrams (*f* through *h*) show three steps in the formation of a circular disintegration ridge (a "doughnut").

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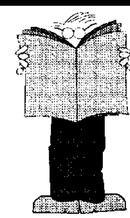
NEW PUBLICATIONS



COINCIDENCE OF AREAS FAVORABLE FOR BASAL LODGEPOLE BUILDUPS WITH THE UPPER BAKKEN SHALE EXTENT AND MATURE BAKKEN

Randolph B. Burke and Paul E. Diehl

This map, reviewed in the Winter, 1995, issue of the *NDGS Newsletter,* is now available. (Scale 1:1,000,000)

NDGS Map No. SP-038-95-2.20 $10.00

RELATION OF AREA FAVORABLE FOR BASAL LODGEPOLE BUILDINGS AND THE PRAIRIE FORMATION

Randolph B. Burke and Paul E. Diehl

This thematic map illustrates the relation between an interpretation of an area favorable for buildups in the lower Lodgepole, tests which have been drilled through the Mississippian Lodgepole Formation, and selected aspects of the Devonian Prairie Formation. Shown are the approximate present or dissolution edge of the Prairie salt, the estimated depositional limit of the Prairie salt as determined by projection of thinning gradients from basin center outward, and the 100 foot and greater isopachs of the Prairie Formation.

This map can be used to evaluate the concept of two stage or multiple stage salt dissolution as a mechanism for explaining the increased thickening in the upper shale of the Bakken Formation seen on some logs beneath Lodgepole buildups in the Dickinson area. (Scale 1:1,000,000)

NDGS Map No. SP-038-95-2.30 $10.00

COINCIDENCE OF PROXY INDICATORS OF THE LODGEPOLE SHELF SLOPE OR RAMP

Randolph B. Burke and Paul E. Diehl

This thematic map illustrates the relation between an interpretation of an area favorable for buildups in the lower Lodgepole, tests which have been drilled through the Mississippian Lodgepole Formation, and two proxy indicators of the Lodgepole shelf slope, or ramp. Shown are the contacts indicating the approximate position of the Basin Flank facies (shelf slope), and the area in which the "false Bakken" thickness is equal to or greater than 50 feet. (Scale 1:1,000,000)

NDGS Map No. SP-038-95-2.40 $10.00

PUBLICATIONS OF THE NORTH DAKOTA GEOLOGICAL SURVEY

This comprehensive list of NDGS publications updates the previous February 1994 list, which included only those publications in print. Federally produced materials available through the Survey's ESIC Office, as well as materials available from the Oil and Gas Division, are also included. Includes author, county, and subject indices. (86 Pages)

December 1995 Free on Request

SHADED RELIEF OF NORTH DAKOTA

Mark Luther, Rod Bassler, and Harlan Jirges

This long-awaited map (featured on pages 14-15) vividly portrays the topography of North Dakota. The State's main topographic features, such as the Pembina and Missouri Escarpments, Turtle Mountains, Missouri Coteau, Little Missouri Badlands, and a host of other prominent landmarks, are unmistakable and point to the diversity of landforms to be found in the State.

This map measures approximately 20"x28". An inset shows county boundaries, thereby leaving the map itself uncluttered by linework; accompanying text describes how the map was produced. The NDGS plans to issue additional versions of the map, showing such things as physiographic regions, watershed boundaries, cultural features, etc. (Scale 1:1,000,000)

NDGS Miscellaneous Map No. 32 $ 2.00

SHADED RELIEF OF NORTH DAKOTA POSTCARD

Mark Luther and Rod Bassler

This 4" x 6" postcard, shown on the front cover, also vividly dispells the myth of North Dakota as a flat, featureless plain.

Shaded Relief Postcard Free on Request