NEWSLETTER

NDGS

Industrial Commission of North Dakota, North Dakota Geological Survey Vol. 20, No. 3, Fall 1993

Air view of the Campbell Beach, near Turtle River State Park, in Grand Forks County, North Dakota. The Campbell Beach is one of the best developed Lake Agassiz beaches and can be traced from South Dakota north into Saskatchewan and northeast into Ontario. This and other glacial Lake Agassiz beaches record a time-lapse picture of postglacial rebound. See article on page 7. *Photo by John Bluemle.*

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NORTH DAKOTA GEOLOGICAL SURVEY 1895

STATE OF NORTH DAKOTA
INDUSTRIAL COMMISSION
EDWARD T. SCHAFER, Governor
HEIDI HEITKAMP, Attorney General
SARAH VOGEL, Commissioner of Agriculture

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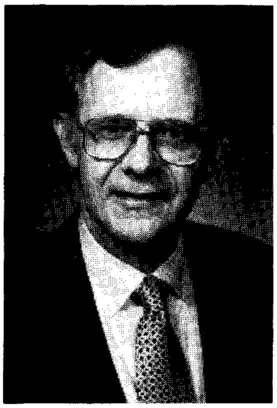
FROM THE STATE GEOLOGIST

by John P. Bluemle

North Dakota's Fossils



Interest in dinosaurs has been high for a number of years, but it reached a fever pitch this summer with the release of "Jurassic Park," the hit movie based on Michael Crichton's best-selling book. Throughout this past spring and summer dinosaurs have been featured in a number of national magazines (*Newsweek, Time, National Geographic*, and others) as well as in most of North Dakota's major newspapers and on local TV specials. The July 24 issue of the *Fargo Forum* included a feature article titled "Digging dinosaurs," as well as a second article: "N.D. towns hope dinosaurs draw tourists". The *Bismarck Tribune* also covered the topic and I expect that other North Dakota newspapers I don't get a chance to see regularly have also done articles (or soon will).

As I write this, a Tyrannosaurus rex skeleton is being excavated in Bowman County, near Rhame. This "dig," by volunteers from the Pioneer Trails Museum in Bowman, is under the technical supervision of Dr. John Hoganson, paleontologist with the NDGS. It's not yet known whether the specimen is complete but, regardless, no one disputes its importance. It is the first fossil T-rex uncovered in North Dakota and it's my understanding that only about a dozen specimens of this creature have been found. Although several excellent Triceratops skulls and skeletons have been recovered in North Dakota, and John and other paleontologists have collected many excellent mammal fossils from other geologic strata, it's T-rex that commands "respect."

The whole dinosaur topic goes well beyond the fascination many of us have in these pre-historic beasts. There's the whole problem of extinctions. Did the climate gradually become unfavorable for dinosaurs so that they were unable to compete successfully against the evolving mammals? Did an asteroid impact cause a global catastrophe that wiped out the dinosaurs? Answers to these questions might be found in North Dakota by examining the geologic contact between the Cretaceous dinosaur-bearing Hell Creek Formation and the overlying Paleocene Ludlow Formation. Two NDGS geologists, Ed Murphy and John Hoganson, are studying that contact and plan to deliver a paper on the results of their research in October at the annual meeting of the Geological Society of America in Boston; we will also be publishing their conclusions in an NDGS publication.

Then there's the problem of ownership and accessibility to the dinosaur-bearing beds. Some of these specimens, if well preserved, can be worth over a million dollars to private foreign investors. Increasingly, scientists and museums are finding they can't compete against commercial collectors who sell the fossils to private investors with the result that some of the best specimens go unstudied. Please don't misunderstand. Commercial collecting is completely legal, provided it is done on private land with the permission of the landowner. Furthermore, commercial collectors have unearthed some of the most significant paleontological finds. The issue is not a simple one though. A Tyrannosaurus rex skeleton collected by a commercial collector in South Dakota was confiscated by the federal government because it was (allegedly) illegally collected off Indian Reservation land.

We are involved in a number of fossil-related issues at the North Dakota Geological Survey. Our State Fossil Collection continues to expand. We have several projects underway with the North Dakota Heritage Center here in Bismarck. Recently, restoration of the Highgate Mastodon was completed (see the December, 1991 and winter, 1992 issues of the *NDGS Newsletter*). We continue to work closely with amateur paleontologists, supervising their collecting activities.

As a regulatory division of the State Industrial Commission, the NDGS is charged with enforcing the state's Paleontological Resource Protection Act, passed by the State Legislature in 1989. Our law is intended mainly to protect vertebrate fossils (such as dinosaurs), which are an important part of our natural heritage, although in some instances other kinds of fossils might be covered by the law. The law includes several important points. A permit is required to collect scientifically significant fossils on state lands (the key here is "significant:" casual, amateur collectors are not excluded from enjoying their hobby); fossils collected from state-owned land remain the property of the state; and, finally, commercial collecting is prohibited on state lands.

We have signed agreements with several federal agencies, including the Forest Service, Bureau of Land Management, and Corps of Engineers, to help them in their own permitting procedures for fossil collecting on their land in North Dakota. Much of the important fossil-bearing strata, particularly areas of Hell Creek Formation, occur on federal land so these agreements are particularly important. We are also hopeful that most of the fossils collected on state and federal lands — and hopefully many of those collected from private land — will eventually end up in one of several museums in North Dakota, either as donations or on permanent loan from the federal government.

People interested in viewing dinosaur and other fossil remains can see them in a number of places around the state. I already mentioned the Pioneer Trails Museum in Bowman. The geology department has a Triceratops skull on display in Leonard Hall on the University of North Dakota campus in Grand Forks. In Dickinson, ground was broken in July for the Dakota Dinosaur Museum where Larry League's excellent collection of dinosaur specimens will be displayed. In Pembina, an important new museum operated by the State Historical Society will be constructed soon. The museum will include exhibits on the Cretaceous seaway and the Ice Age. We are working with the Historical Society on these exhibits and we will be providing fossil specimens from the State Fossil Collection. Here in Bismarck, we are working with the Heritage Center on a "Corridor of Time," a review of North Dakota's geologic history that will include several dinosaur and other fossil specimens.

The move to study and display North Dakota's fossil resources right here in our own state is a healthy one. For too many years, nearly all of our best fossil specimens were collected by out-of-state paleontologists and taken from North Dakota, usually without our knowledge. This has been a problem in several other western states as well where, until recently, neither the technical expertise nor facilities existed to handle fossil resources. Consequently, most of these collections ended up at large universities and museums in the eastern United States — we hear stories of crates of dinosaur specimens languishing in their warehouses, unstudied, hidden from view, and essentially still unavailable for research. Whether these stories are true or not, we no longer need to rely on outside experts to do our scientific work for us; we have competent scientists in North Dakota. We also have civic-minded groups willing to do what it takes to provide first-class facilities to make our fossil resources available for public appreciation. And we have a public that is anxious to learn about our state's own "Cretaceous Park."

QUATERNARY MAPPING WORKSHOP
September 26-28, 1993
Bismarck, North Dakota

The North Dakota Geological Survey will convene a workshop on September 26-28, 1993 for those interested in mapping Quaternary deposits. The focus of the workshop will be a day-long meeting where participants discuss: 1) the dual role of GIS (automated map production, and standardization and data transfer of digital geologic map information), and 2) glacial stratigraphy. Other topics, such as map design and use of the maps may also be considered. The meeting will be preceded on the 26th by an informal fieldtrip to the Stumpf dinosaur site, and followed on the 28th by an all-day fieldtrip through north-central North Dakota where we will look at a variety of glaciotectonic and glacial stagnation deposits. For those who are interested and have not already done so, please contact Bob Biek at (701) 224-4109.

NEW PUBLICATION SERIES COMING SOON

by Bill McClellan

In a previous *NDGS Newsletter* we announced a new program of representative field studies that would be useful models for exploration or further development work. Results of the program will appear as a new publication series starting with Field Study 1, Wabek and Plaza Fields: Carbonate Shoreline Traps in the Williston Basin of North Dakota, which is currently in press and expected to be available within a month. Other studies in the program, in various stages of progress, involve Rocky Ridge, Lucky Mound, Landa, and South Antler Creek fields. Each study will have its own emphasis and degree of detail; for example, Wabek and Plaza fields are reviewed as exploration models, and Lucky Mound will emphasize reservoir petrology.

Most previously published studies of North Dakota fields appear in the AAPG Atlas of Oil and Gas Fields, Stratigraphic Traps I, II, III, and in several Williston Basin Symposium volumes. Each of them was written to fit a particular editorial format, while our new series should hopefully allow more geologic latitude and application. If you have suggestions for additional fields that would make useful studies let us know, because there are lots of them there, each with its own lesson.

GEM AND MINERAL SHOW

Central Dakota Gem & Mineral Society
19th Annual Show
September 25-26, 1993
Mandan Community Center, Mandan, North Dakota

MAPPING GRANT

The NDGS was recently awarded a $23,998 federal grant for geologic mapping in the Jamestown - Spiritwood Lake area. The grant comes from the State Geologic Mapping Element (STATEMAP) of the National Geologic Mapping Program. The grant was for the full amount requested by the NDGS, and will be used to match State funds on an equal basis.

As Brian Heath, USGS Procurement Officer, notes, "The STATEMAP program element was highly competitive. Forty-four States proposed 54 projects, with funding requests totalling about $3,400,000." Thirty-seven of the 54 projects were funded, but only about one-third of them received full funding. Appropriated funding for the STATEMAP program was $1.3 million, significantly less than the $15 million authorized for federal fiscal year 1993.

The STATEMAP grant will enable the NDGS to produce geologic maps of the Jamestown, Bloom, and Spiritwood Lake 7.5 minute quadrangles. The maps will be published at a scale of 1:24,000 (one inch on the map equals 24,000 inches or 2,000 feet on the ground).

Mapping of the Jamestown - Spiritwood Lake area is part of a pilot program designed to make available detailed geologic maps of important areas of the state. The maps should be useful for land use planning, environmental and mineral resource assessment, and educational purposes, and will enable a better understanding of the Quaternary history and stratigraphy of the area. To learn more about this mapping project, please contact Bob Biek at (701) 224-4109.

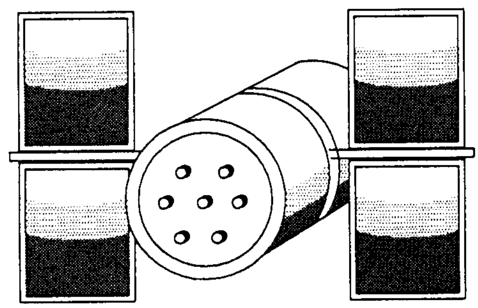
GPS Community-Base Station Established in North Dakota

by
Mark Luther

The North Dakota Geological Survey (NDGS) and several other agencies operating in the state, have cooperated to acquire and install a high-accuracy Global Positioning System (GPS) community-base station (CBS) in Bismarck, North Dakota. The base station consists of a Trimble 4000 System SSE Geodetic grade receiver, antenna, Trimble Universal Reference Station (URS) software, and a personal computer with modem. The geodetic grade receiver is capable of determining positions in 3-D with accuracies in the sub-centimeter range. The installation of the URS software in Bismarck is the fourth of its kind in the U.S. according to Trimble representatives.

The GPS CBS has been installed in Schafer Hall on the campus of Bismarck State College, and is currently undergoing testing prior to being considered fully operational. Once operational, the CBS will be capable of gathering high-accuracy GPS data that can be used for differential correction of GPS data collected by field GPS receivers. Because of its central location in Bismarck, the CBS will provide a means for correcting data gathered throughout North Dakota and parts of adjacent states (a more complete discussion of GPS operation will follow in the Winter 1993 *NDGS Newsletter*).

A North Dakota GPS Steering Committee has also been formed. Mark Luther, geologist with the NDGS, will chair the steering committee, which will oversee long-term operation of the CBS. The committee is currently working on a plan for CBS data distribution; a large number of inquiries about plans for data distribution have already been received. Other topics that the steering committee plans to address include: archiving of GPS data, inclusion of additional members on the steering committee, and cooperation with U.S. National Geodetic Survey to improve the high-accuracy reference network in the state.



Agencies that cooperated in this pioneering effort include:

N.D. Department of Agriculture
N.D. Industrial Commission - NDGS
N.D. Industrial Commission - Oil and Gas Division
N.D. Department of Health and Consolidated Laboratories
N.D. Department of Transportation
N.D. State Water Commission
Bismarck State College
U.S. Geological Survey
U.S. Environmental Protection Agency

OIL & GAS EXPLORATION AND DEVELOPMENT ACTIVITY IN 1992

by Tom Heck

Once again it's time for a brief update on oil and gas activity in North Dakota. This update on 1992 activity precedes a more complete examination that should be published around this time next year as one of our Miscellaneous Series. Reviews of pre-1992 oil and gas activity are available through our publication sales or your local library. All the wells completed during 1992 are off "tight" hole status at this time but additional development wells for some of the pools are not so the number of producing wells in a pool reflects the status as of 12/31/92. Also, the current producing rate item in Table I is the daily average production during December 1992.

A total of 166 new wells were completed during 1992. There were 42 wildcats completed and 124 development and extension wells. Of the wildcats, 11 produced oil for a 26% success rate. Eighty-three of the development or extension wells also produced oil for a success rate of 67%. Overall, the state saw 94 of 166, or 57%, produce oil. 1992 activity levels were mixed when compared to 1991, when 207 total wells, including 39 wildcats, were completed; the total number of wells completed fell by 41 but the number of wildcats rose by 3 during 1992. Despite the increase, wildcat drilling remained at near record low levels during 1992. Seven new fields or pools, listed in Table I, were discovered by wildcat drilling.

Once again the Madison was the favorite target for exploration and development drilling with 36 of 42 wildcats and 68 of 124 extension or development wells being targeted for the Madison[1]. Drilling was scattered across the state with no single field seeing a significant level of activity. Seven of the wildcats found oil and 29 were dry, a 19% success rate. Two of the seven wildcat completions were new wells in Dimond and Vanville Fields. The fields were discovered in 1961 and 1983, respectively, but had been abandoned prior to 1992's new completions.

The Bakken Shale was the next favored target with 30 of 30 completions capable of producing oil. The average Bakken IP was 312 BO + 312 MCFGPD. The highest individual well IP during 1992 was from a Bakken well in Demores Field. The Slawson Exploration Company #1-36 Pegasus, located in section 36-T142N-R102W, had an IP of 1,281 BO + 1,281 MCFGPD with no water. The total of 30 completions is a decrease of 18 for the year for Bakken targets compared to 1991. The average IP fell by 20 BO and 44 MCFGPD, but the Bakken Shale remains a significant play in western North Dakota.

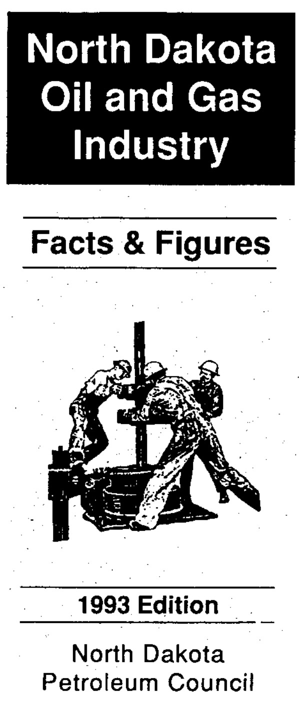
Another important play during 1992 was the Pennsylvanian Tyler Sand play in Stark and Billings Counties. The present play really began back in 1986, but, prior to 1992, was only at a modest level of activity. A new field, Tracy Mountain, was discovered during the year and 18 extension or development wells were completed in Tracy Mountain and Fryburg Fields. Of the 18 wells, 16 produced oil for a 89% success rate. The average IP of the 16 producing wells was 245 BO + 52 MCFGPD. Drilling is continuing in the area and development in the play has significantly increased North Dakota's oil reserves.

Other target formations were the Duperow (1 for 4 producing), Winnipegosis (0 for 1), Silurian (1 for 2), Stonewall (3 for 3), Red River (3 for 7) and Winnipeg-Cambrian (1 for 1). These deeper zones have been underexplored for a number of years but still hold considerable potential.

1. Several Madison wells are also counted in the Tyler well counts because of the significance of the Tyler play. In some other cases, one well accounts for two completions when the deeper zone was plugged and abandoned but a shallower zone produced oil. This means that the total completion counts for the year will not match the summed individual horizon completions.

TABLE I - 1992 NEW FIELD/POOL DISCOVERIES

COUNTY FILE NO. ORDER#	COMP. DATE	OPERATOR, WELL NAME, LOCATION	FIELD -POOL # OF PRODUCING WELL IN POOL ON 12/31/91	TOTAL MEASURED DEPTH -SPACING	PERFORATED INTERVAL	IP (CUR. -BOPD	GOR- GRAV.	WATER
Ward 13291 6318	1/12/92	Equitable Resource Energy Co. Dyke #32-22 Sec. 22, T154N, R87W	Shealey Madison 1	7,157 160	7,004-7,014	130 42	300 36°	7
Burke 13210 6386	1/20/92	Patrick Petroleum Co. Wilson #1-7 Sec. 7, T160N, R92W	Lucy Madison 1	7,540 160	7,394-7,397 7,402-7,408 7,426-7,430	55 10	1,000 35°	92
Billings 13353 6584	6/4/92	Duncan Energy Co. O'Connell #1 Sec. 9, T138N, R101W	Tracy Mountain Tyler 11	8,250 160	8,096-8,112	307 55	100 33°	2
Renville 13351 6485	6/8/92	EOG (New Mexico) Inc. Triplett #1-2 Sec. 9, T159N, R86W	Ivanhoe Madison 1	5,704 80	5,503-5,508	40 21	125 26.7°	160
Bottineau 13365 6503	7/15/92	Texas Crude Energy, Inc. Sagsveen State "21" #1 Sec. 21, T159N, R83W	Spring Coulee Madison 2	4,900 80	4,714-4,719	67 55	150 27.1°	10
Ward 13328 6519	9/15/92	Axem Resources, Inc. South Carpenter Lake #2-9 Sec. 9, T153N, R87W	Spring Valley Madison 2	7,240 160	7,102-7,114	86 29	581 34°	5
McKenzie 13442 6586	12/12/92	Wyoming Resources Corp. Missouri #1 Sec. 30, T151N, R104W	Nohly Lake Red River 1	12,800 320	12,627-12,662	193 146	N/A 45.2°	51



North Dakota Oil and Gas Industry: Facts & Figures is published annually by the North Dakota Petroleum Council. This interesting and highly informative brochure succinctly summarizes exploration and production activity for the past year and compares it to activity in previous years. It also highlights where the oil comes from; employment; tax revenues; refining and transportation; uses of petroleum; and other interesting facts. The brochure is available from the North Dakota Petroleum Council, Box 1395, Bismarck, ND 58502 (tel. 701-223-6380).

Warped Beaches of Glacial Lake Agassiz

by
Bob Biek

At the height of the last Ice Age, about 20,000 years ago, most of Canada and the northern tier of the United States lay buried under a vast continental ice sheet. The thickness of the ice may have reached 8,000 feet or more, tapering off towards the margins. The tremendous thickness of ice depressed the earth's crust into a large bowl-shaped depression. Where the load was greatest, the subsidence of the crust was over 2,000 feet, sufficient to depress vast areas below sea level. As the ice retreated, the crust began to rebound, though with a considerable time lag; for thousands of years the land retained its exaggerated slope towards the center of the former ice sheet. Consequently, vast areas once occupied by the ice were flooded by the sea or, where dammed by topography or ice, formed large proglacial lakes.

Glacial Lake Agassiz, once the largest proglacial lake in North America, was one such lake. In North Dakota, evidence of this former lake is found in the Red River Valley. Most of us are familar with the remarkably flat Red River Valley - the former lake floor of Lake Agassiz. Fewer, perhaps, recognize the subtle strandline features. These strandlines - the beaches, terraces, and wave-cut scarps that mark former shorelines - record a time lapse picture of postglacial rebound.

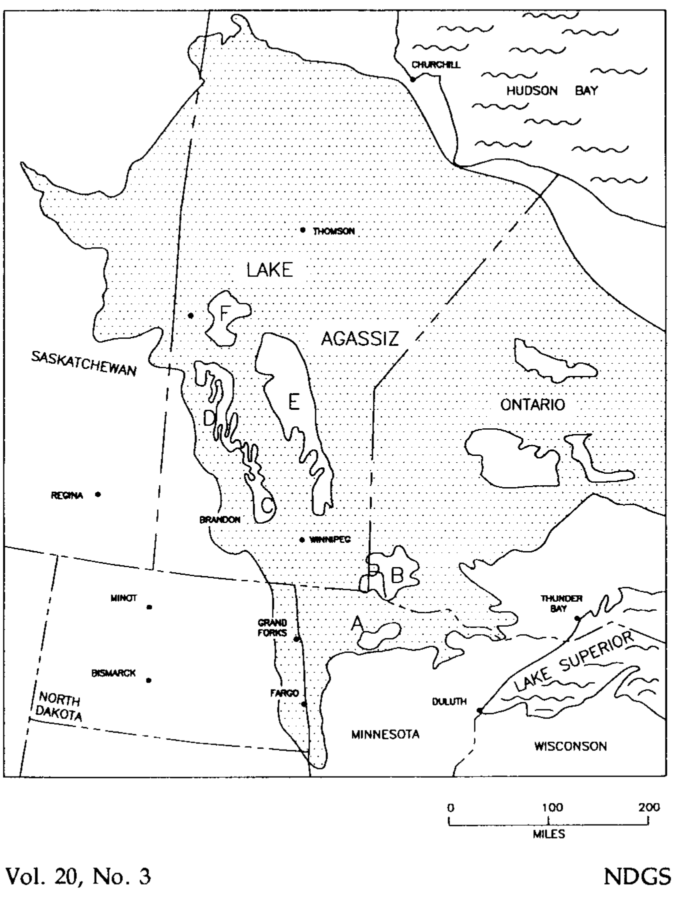


Figure 1. The total area eventually covered by glacial Lake Agassiz. The southern portion of the lake formed first while the northern portion was still covered by glacial ice. By the time ice had retreated and the lake formed in the northern area, the southern part of the lake had already drained. Remnant lakes still occupying parts of the basin are: A. Red Lakes, B. Lake of the Woods, C. Lake Manitoba, D. Lake Winnipegosis, E. Lake Winnipeg, and F. Cedar Lake. Modified from Bluemle (1991).

Glacial Lake Agassiz

Like its namesake, glacial Lake Agassiz's influence was felt far and wide. Teller and Clayton (1983) note that evidence of glacial Lake Agassiz occurs in an area of roughly 365,000 square miles although at no single time did the lake ever cover this entire area (Fig. 1). Ice margin positions and lowering of outlets by erosion combined to limit the lake size at any given time. Glacial Lake Agassiz is just the latest in a series of proglacial lakes that must have formed when north-draining rivers were impounded by ice sheets spreading south out of Canada. Little is known about the predecessors to glacial Lake Agassiz (Fenton et al., 1983).

Evidence for glacial Lake Agassiz lies principally in: 1) its stratigraphy, and 2) its ring of shoreline features. The stratigraphy of the basin implies that it has been repeatedly occupied by glaciers, lakes, and rivers. In the southern part of the basin Fenton et al. (1983) recognize five major phases of the lake (see Fig. 2 and sidebar). This sequence of sediments represents the first

2,000 years of the lake's 4,500 year history. The history of glacial Lake Agassiz is thus one of fluctuation, punctuated by periods of relative lake level stability. Fluctuations were caused by the alternate advance and retreat of ice sheets, use of different outlets, catastrophic inflows meltwater floods, and postglacial rebound (Kehew and Clayton, 1983).

Glacial Lake Agassiz's shoreline or strandline features mark former boundaries between land and water; "strand" comes from the Icelandic "strond," meaning margin or edge. Strandlines are horizontal over great distances, as a stroll along any modern lakeshore will tell you. The strandlines of glacial Lake Agassiz also formed as horizontal features, bounding the flat surface of a given lake level. Yet now they are tilted and increase in altitude towards the north and east. Successively younger strandlines similiarly increase in altitude, but to a lesser degree. The strandlines, the beaches, are warped.

Postglacial Rebound

Where a sufficient thickness of ice is present, the weight of the ice sheet depresses the earth's crust about one foot for every three feet of ice thickness (ice is roughly one third as dense as crustal rock). Normally, this deformation takes the form of gentle flexing and unflexing of the earth's crust, although it can be accompanied by faulting and reactivation of large regional structures (Dyke, et al., 1991).

Such crustal subsidence has two principle components: elastic deformation of the earth's crust and viscous or plastic deformation of the underlying mantle (Peltier, 1986). An elastic material deforms instantaneously upon sufficient applied stress and recovers immediately and completely upon release of that stress (assuming its inherent strength has not been exceeded and fracture occurs). A viscous material, however, begins to flow as soon as a stress is applied at a rate proportional to the magnitude of the stress; when the stress is removed, recovery occurs at an exponentially decreasing rate but is never fully complete. Given enough time, elastic and viscous forces act to establish equilibrium between opposing masses, a processs known as "isostasy," derived from the Greek "isos," meaning equal, and "stasis," meaning "standstill" or "stable state."

As the ice melts, rebound follows deglaciation inward toward the center of the ice sheet, but, because of the time-dependent nature of viscous deformation, does so with a time lag. Initially, rebound is very rapid, but it

Phases of Lake Agassiz

Summarized from Fenton et al. (1983).

The Cass Phase (about 11,700 to 11,600 Before Present (BP)) marks the beginning of glacial Lake Agassiz in the southern Red River Valley. The lake began when the ice sheet retreated north of the drainage divide between the Hudson Bay and Mississippi River drainage basins. North-draining rivers were blocked on the north by the ice sheet and on the south by the Big Stone moraine near the border of North Dakota, South Dakota, and Minnesota. During much of this time, the lake drained south through the Minnesota River Valley. The highest well-developed beaches, the Herman beaches, formed during the Cass Phase.

The Lockhart Phase (about 11,600 to 11,200 BP) records the northward expansion of glacial Lake Agassiz and sporadic readvances of ice into the northern Red River Valley. During this time, the lake continued to drain south through the Minnesota River Valley and its level stabilized when the outlet eroded down to resistant granite underlying the Big Stone moraine. During this time and into the following lake phase, clay of the Brenna Formation was deposited in deep water of Lake Agassiz. The Campbell beaches - the most continuous of the Lake Agassiz strandlines, which can be traced from South Dakota north into Saskatchewan and northeast into Ontario - formed about 11,500 BP. At that time, the North Dakota shoreline was characterized by an open forest of spruce and deciduous trees mixed with sagebrush-dominated openings (Ashworth and Cvancara, 1983). Wooly mammoths roamed the shore.

The Moorhead Phase (about 11,200 to 9,900 BP) began when ice retreated north of Thunder Bay, Ontario. The lake dropped through a series of still stands when successively lower outlets to Lake Superior were opened. During this time the exposed parts of the lake floor were covered by spruce and marsh. The lake floor was incised by rivers and streams that deposited river channel and overbank sediments of the Poplar River Formation. These sediments now form important aquifers in the Red River Valley. The lake probably completely drained from North Dakota during the end of the Moorhead Phase.

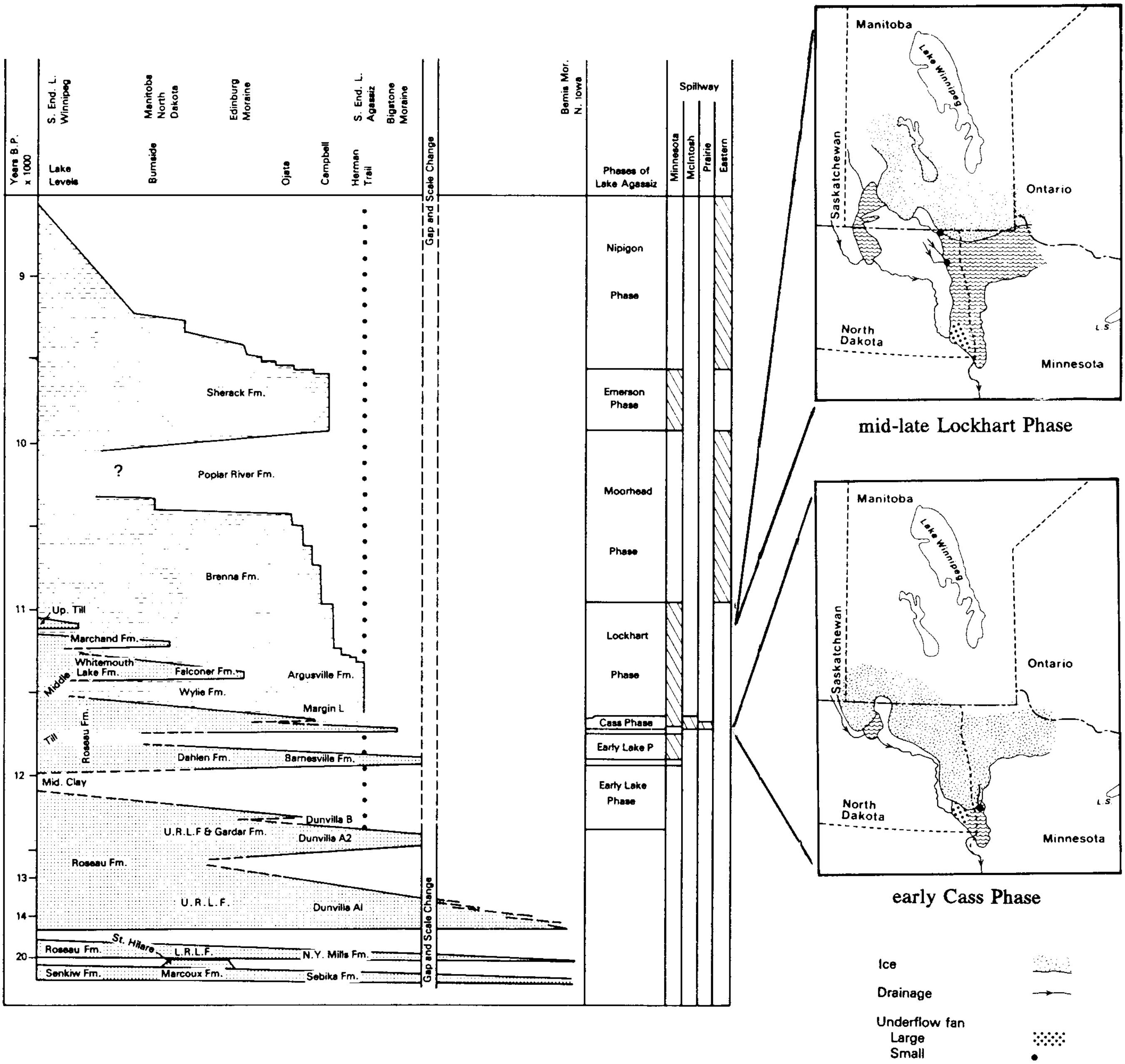


Figure 2. Time-distance diagram for the late Wisconsinian in the southern part of the Lake Agassiz basin, with two sketches showing ice margin positions and drainage features. Modified from Fenton, et al. (1983).

The Emerson Phase (about 9,900 to 9,500 BP) marks a major readvance of ice in Canada that blocked eastern drainage outlets to Lake Superior. Lake Agassiz rose back to the Campbell beach level and again discharged south through the Minnesota River Valley. The Sherack Formation, deposited during this and the following lake phase, consists primarily of offshore sediments of laminated clay, silty clay, and silt.

The Nipigon Phase (about 9,500 to 8,500 BP) marks the end of glacial Lake Agassiz. It began with retreat of the ice sheet that once again opened eastern drainage outlets to Lake Superior. The lake retreated from North Dakota by about 9,000 BP.

decreases exponentially with time. Indeed, based on our understanding of isostatic processes, a majority of the rebound occurs while the ice is melting (and thus while the load is being lessened) but before it has completely disappeared. Because no geologic record is left by this early, very rapid rebound, the rebound rates that scientists are able to measure represent minimum values.

The greatest measured rates of isostatic or postglacial rebound in North America occur in the Richmond Gulf area of southeastern Hudson Bay (presumably where the ice was thickest). There, Hillaire-Marcel and Fairbridge (1978) recognize a "staircase" of 185 Holocene strandlines that provide a continuous record of emergence from about 8,000 BP to the present. At least 935 feet of recovery has been recorded by these strandlines. By determining the age of these strandlines, and by subtracting the apparent component of uplift due to relative sea level fluctuations, scientists have been able to measure rates of isostatic rebound. Analyses by Andrews (1970) indicate that rates of uplift declined from a maximum of 33 to 39 feet per 100 years immediately following deglaciation (8,000 BP) to a current maximum of about 4.3 feet/100 years. Peltier (1986) provides a similar current maximum rate of rebound.

Rebound in North Dakota

Beach ridges, the most common strandline form associated with glacial Lake Agassiz, are easily seen from the air due to their topographic expression and vegetation changes (see cover photo). The beaches are generally 5 to 25 feet high and a few hundred feet wide. The beaches formed when wave action winnowed sediments along the shore, leaving behind the coarser sand and gravel. Beach ridges are the primary source of sand and gravel in the Red River Valley; locally they have been largely removed by quarrying.

While the beaches are normally readily visible from the air, tracing all but the best developed beaches across the countryside is difficult. Changes in beach morphology, gaps, the often blurred distinction between beaches and offshore bars, elevation changes due to postglacial rebound, and deposition over stagnant ice and subsequent collapse combine to make correlation of beaches difficult. In addition, Fenton et al. (1983) note that as they are traced northward, the highest-level beaches generally consist of multiple segments rather than single well-developed beaches.

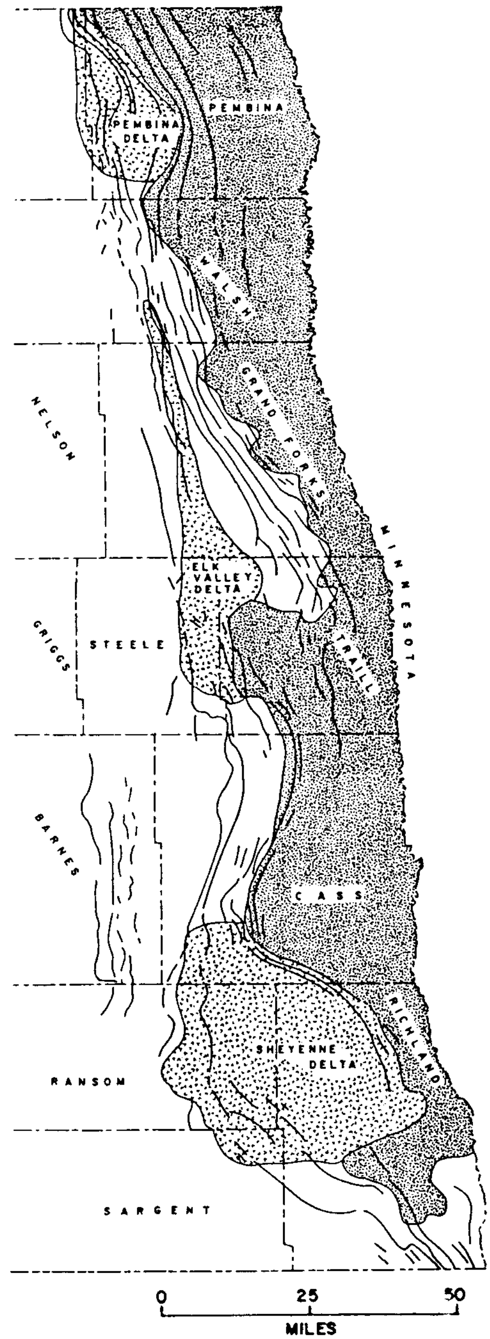


Figure 3. Map of easternmost North Dakota showing the locations of the main Lake Agassiz beaches (lines), areas of offshore lake sediment (dark shading), and areas of delta deposits where rivers emptied into Lake Agassiz (light shading). Areas of glacial sediment (mainly till) to the west of the Red River Valley are unshaded. From Bluemle (1991).

Despite the difficulty of correlation, the former shorelines of glacial Lake Agassiz have been named and traced for hundreds of miles. In the southern portion of Lake Agassiz about 55 sets of strandlines have been recognized (Elson, 1983) (Fig. 3). Table 1 lists the principle beaches. Notice how the beaches rise in elevation to the north and how the younger beaches rise less. (Analyses of strandlines in Minnesota and Ontario show that strandlines rise in elevation to the east as well, indicating that the ice was thicker - and rebound greater - north and east of the Red River Valley.) The younger beaches rise less due to the exponential decrease in the rate of rebound over time; when they formed, much of the rebound had already taken place. Research shows that rebound in North Dakota is essentially complete (Peltier, 1986), but that 100 to 150 meters of residual uplift has yet to occur in the southeastern Hudson Bay area (Flint, 1971).

Bluemle (1991) notes that this differential rebound had other important effects in North Dakota. Because the amount of uplift was at least 200 feet greater at Pembina than it was in the south at Wahpeton, the gradient of the Red River has decreased markedly since its route became established. Since Lake Agassiz retreated from North Dakota about 9,000 BP, the Red River has meandered over an increasingly broad floodplain (Fig. 4). Flooding is a recurring problem along portions of the Red River.

This decreasing gradient has also caused tributary rivers to the Red River to shift their courses as alternate steeper routes became available (Fig. 5) (Bluemle, 1991). The Red Lake River, for example, used to enter the Red River at a point about 20 miles downstream from its present mouth at Grand Forks. When its gradient became so low that the Red Lake River could no longer maintain its route, the river broke away from its established chan-

TABLE 1. ELEVATIONS OF LAKE AGASSIZ SHORELINES

Name Of Shore Feature	Southeastern North Dakota (Elevation)	International Boundary (Elevation)	(Elevation Difference)
Burnside Beach	820 feet	840 feet	20 feet
Gladstone Beach	830 feet	850 feet	20 feet
Ojata Beach	850 feet	880 feet	30 feet
Emerado Beach	890 feet	925 feet	30 feet
Hillsboro Beach	910 feet	950 feet	40 feet
Blanchard Beach	945 feet	985 feet	40 feet
McCauleyville Beach	970 feet	1,015 feet	45 feet
Campbell Beach	990 feet	1,070 feet	80 feet
Tintah Beach	1,020 feet	1,120 feet	100 feet
Norcross Beach	1,050 feet	1,180 feet	130 feet
Herman Beach	1,080 feet	1,280 feet	200 feet

Table 1. *Elevations of selected Lake Agassiz shorelines. The older, higher level shorelines rise the most because when they formed much of the Lake Agassiz basin was still glaciated (and thus isostatically depressed). The younger, lower beaches do not rise as much because by the time they had formed much of the rebound had already taken place.* Modified from Bluemle (1991).

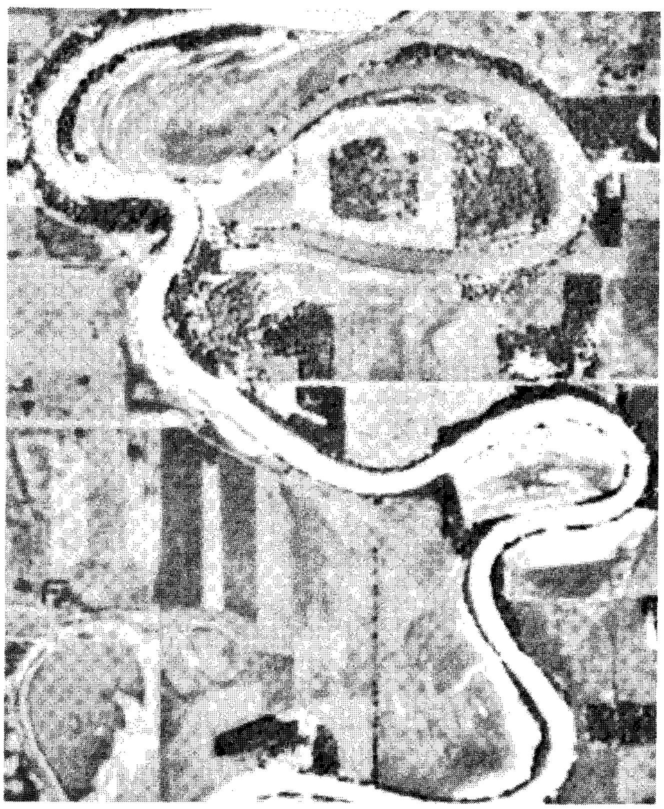


Figure 4. *The Red River of the North about ten miles south of Drayton. Oxbow lakes and meander scars are common along the floodplain (meander scars are portions of former river channel, now abandoned; oxbow lakes occur in the meander scars).* From Bluemle (1991).

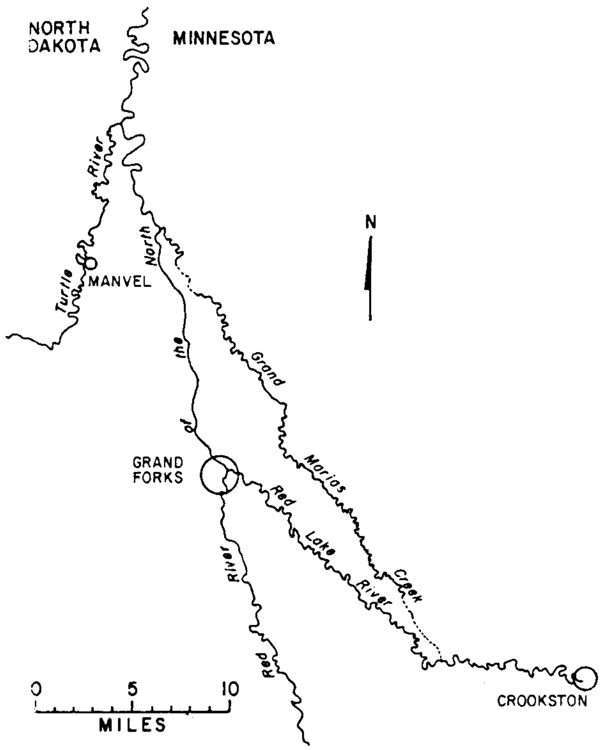


Figure 5. Diagram illustrating the shifting of the Red Lake River channel due to isostatic rebound. See text for discussion. From Bluemle (1991).

nel and followed a new steeper route that took it to Grand Forks. After the Red Lake River established its route to Grand Forks, the increased volume of water delivered to the Red River there exceeded the capacity of the channel. As a result, the meanders of the Red River were washed out and the channel straightened north of Grand Forks, downstream to the point at which the Red Lake River and the Red River had originally joined.

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For several years the NDGS has been an affiliate office of the Earth Science Information Center (ESIC) network. Coordinated by the U.S. Geological Survey (USGS), this nationwide ESIC network provides information about geologic, hydrologic, topographic, and landuse maps, books, and reports; aerial, satellite, and radar images and related products; earth science and map data in digital form and related applications software; and geodetic data. As an ESIC office, the NDGS can assist the public in locating those earth science materials dealing with North Dakota, as well as other states.

New Map Products

In addition to providing information about the availability of various earth science materials, the NDGS' ESIC office operates a distribution center for federally produced cartographic products. Descriptions of recently produced or reprinted maps that are available follow.

* Digital Elevation Models (DEM) - The NDGS through a joint funding agreement with the USGS has had DEM coverages completed for twenty-six 7.5 minute quad maps, covering parts of several cities in North Dakota. The completed quads are: Arvilla, Backoo, Burlington, Burlington SE, Hallson, Hamar, Hanks Corner, Horseshoe Lake, Larimore East, Larimore West, Menoken SW, Minot, Niagara, Oberon SW, Olga, Pekin, Pekin NE, Pekin NW, Sheyenne, Surrey, Tokio SW, Tolna, Vang, Walhalla, and Warwick (a description of DEMs can be found in the Winter 1992 *NDGS Newsletter*). The DEM files, which are approximately 1 Megabyte in size for each quad, are available from the NDGS. Costs for federally produced digital map data are provided by request.

* The Cooperstown and Stump Lake 1:100,000 scale (30 X 60 Minute Series) paper maps have recently been revised. The revised maps are topographic editions that include contour lines in metric intervals. The topographic (TM) versions of the Cooperstown and Stump Lake 1:100,000 scale maps replace the previous planimetric (no contour lines) versions. Price = $4.00 plus shipping.

To place map orders or receive additional information, contact our publications clerk or the ESIC Coordinator. Shipping costs on federally produced paper maps purchased from the NDGS are:

1 to 5 maps	$2.75
6 to 30 maps	$4.00
31 or more maps	$6.00

US GeoData

The development of geographic information systems (GIS) is a rapidly growing industry that supports natural resources studies, land management, environmental analysis, marketing, and urban and transportation planning. The increasing use of computers for storing and analyzing earth science information has greatly expanded the demand for digital cartographic and geographic data.

The ESIC network distributes digital cartographic/geographic data files produced by the U.S. Geological Survey (USGS) as part of the National Mapping Program. Digital cartographic data files may be grouped into four basic types. The first of these, called a Digital Line Graph (DLG), is the line map information in digital form. These data files include information on planimetric base categories, such as public-land survey, transportation, hydrography, and boundaries. The second type, called a Digital Elevation Model (discussed in the Winter, 1992 *NDGS Newsletter*), consists of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The third type is Land Use and Land Cover digital data which provides information on nine major classes of land use such as urban, agricultural, or forest as well as associated map data such as political units and Federal land ownership. The fourth type, the Geographic Names Information System (discussed in the Summer, 1992 *NDGS Newsletter*), provides primary information for all known places, features, and areas in the United States identified by a proper name.

For this issue of the *NDGS Newsletter*, I'd like to concentrate on DLGs, and in particular, the public land survey (PLSS) variety of DLGs derived from 1:24,000 scale maps. First, some background on DLGs.

Digital Line Graphs

The term Digital Line Graph (DLG) is used by the USGS to describe a digital map data set in vector (versus raster) form. All DLG data currently being produced are level 3 (DLG-3), meaning that they have the full range of attribute codes and are fully topologically structured. A digital file of cartographic or geographic data that maintains the spatial relationships inherent in the map is called a topologically structured data file. A topologically structured data file can support simple graphic applications, such as plotting streams and roads for base maps, and more advanced applications, such as computations and analyses involving areas and lines and their spatial relationships.

Topological Elements

A DLG-3 file is composed of three separate, but related, elements: nodes, lines, and area identifiers. Nodes define the location of the endpoints of every line, and a single node may mark the start or end of one or more lines. Thus, nodes occur at intersections of linear features and other places on linear features where the feature is subdivided into separate line segments.

A line is an ordered set of points that describes the position and shape of a linear feature on the map. Each line starts at a node and ends at a node, and has an area to the left of its direction of travel, and has an area to the right of its direction of travel. Lines connect to each other at nodes, and a line does not cross itself or any other line. A line may describe the boundary between two areal map features, such as counties, or may define a map feature by itself, such as a road.

An area is a portion of the map bounded by lines. All portions of the map must be assigned some area point. Each area is identified in a DLG-3 data file by a point chosen to represent the characteristics of the area. Every DLG data file will have at least two areas identified; one representing the area covered by the file and the other representing the area outside the coverage of the file. Additional areas will be identified as necessary to subdivide the area covered by the file.

Attribute Codes

In addition to locational and topological information, DLG data elements may have explicitly encoded attributes. Attribute codes describe the map information represented by a node, area, or line. For example, the attribute code for an area might identify a section within a township; the attribute code for a line might identify a river meander line (fig. 1). The codes are based on the cartographic features symbolized on the USGS Topographic Map Series. Each attribute code identifies the major category to which a data element belongs, as well as the specific nature of the element. Most elements are uniquely described by a single attribute

Bismarck 7 1/2' Public Land Survey DLG

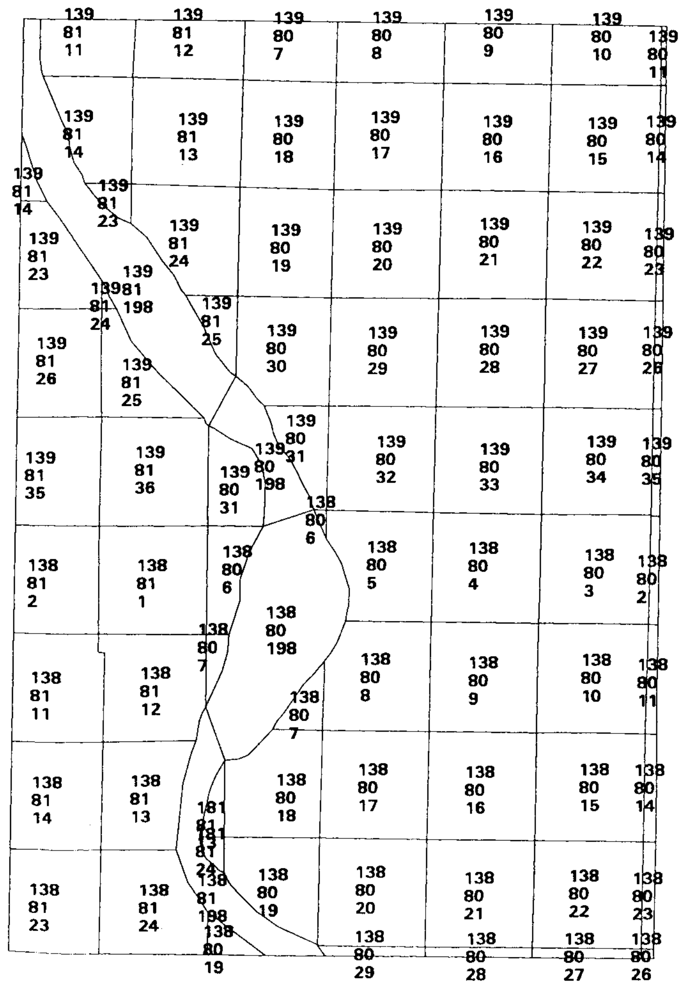

Figure 1. *This is the plot of a Public Land Survey System (PLSS) file for the area covered by the Bismarck, 7.5 minute topographic map. The file consists of section lines and boundaries of excluded areas, as well as information about the township, range, and section or category of each area. Note that the map leans to the right. That is because the map is displayed in the Universal Transverse Mercator (UTM) projection, the grid north of which is west of the true north (for this map area) along which the section lines are oriented.*

code. Others, however, may require two or more codes for a complete description.

Public Land Survey System

The Public Land Survey System (PLSS) is a category of data that describes the rectangular system of land surveys that is administered by the U.S. Bureau of Land Management. PLSS data are only collected for areas falling solely, or in part, within the States that were formed from the public domain; this includes virtually all of the western-half of the United States (including all of North Dakota). The PLSS subdivides the public domain and represents property boundaries or references to property boundaries. 1:24,000 scale PLSS files are based on the 7.5 minute USGS map series, and contain data for the area covered by one 7.5 minute map. Other characteristics of 1:24,000 scale PLSS DLGs include:

* There are two distribution formats - Standard, and Optional (the NDGS only distributes Optional Format).

* Character set is 8-bit ASCII.

* Coordinate system is Universal Transverse Mercator (UTM) for Optional Format.

* Data are derived from USGS topographic maps published as 7.5-minute quadrangles at 1:24,000 scale.

* Accuracy of well defined points should be similar to that of the published paper map, that is, no more than 10% of the well-defined map points tested shall be more than 40 feet out of its correct position on the ground.

* Datum corresponds to that of the published paper map. North Dakota maps are all based on the North American Datum of 1927 (NAD 27).

* Average file size for a 7.5-minute map area in North Dakota is approximately 65 kilobytes.

* Approximately 81% of North Dakota has 1:24,000 scale PLSS DLG coverage available; the highest percentage of any state.

PLSS DLGs are one of the very basic coverages used when constructing a map or doing spatial analysis with the use of a computer. The PLSS is often the base upon which other layers of information are placed. Figure 1 shows a plot of the PLSS file for the Bismarck, North Dakota 7.5 minute map area. Basic information illustrated includes: the margins of the map area (7.5 minutes of latitude by 7.5 minutes of longitude); section lines (with information about the township, range, and section numbers); and the area excluded from the Public Land Survey System (the area within the meander line of the river).

Several PLSS-DLG coverages joined together formed the base upon which other coverages were placed to produce the Endangered Species Habitat map illustrated in Figure 2. Other coverages used in producing this map include hydrography, transportation, boundaries, and some scanned images. Using digital coverages such as these, black and white or full-color maps can quickly be produced and/or modified.

An index showing those areas of North Dakota currently covered by 1:24,000 scale PLSS DLGs is shown in Figure 3. The NDGS, with guidance from the N.D. State Map Advisory Committee (ND SMAC), is pursuing a Joint-Funding Agreement with the U.S. Geological Survey to produce PLSS DLGs for those areas not currently completed. The time-frame for completion of statewide PLSS coverage is dependent on funding.

More information on 1:24,000 scale DLGs can be found in a document called "US GeoData - Data Users Guide 1" produced by the U.S. Geological Survey. This document and the answers to other digital data questions can also be obtained by contacting Linda McKeage at the USGS' Rolla-ESIC office (Phone number 314-341-0856).

PLSS and other categories of DLGs are very useful data sources that are being used extensively by the NDGS and others involved with GIS, automated mapping, and natural resource management.

(The NDGS' ESIC Coordinator is Mark R. Luther)

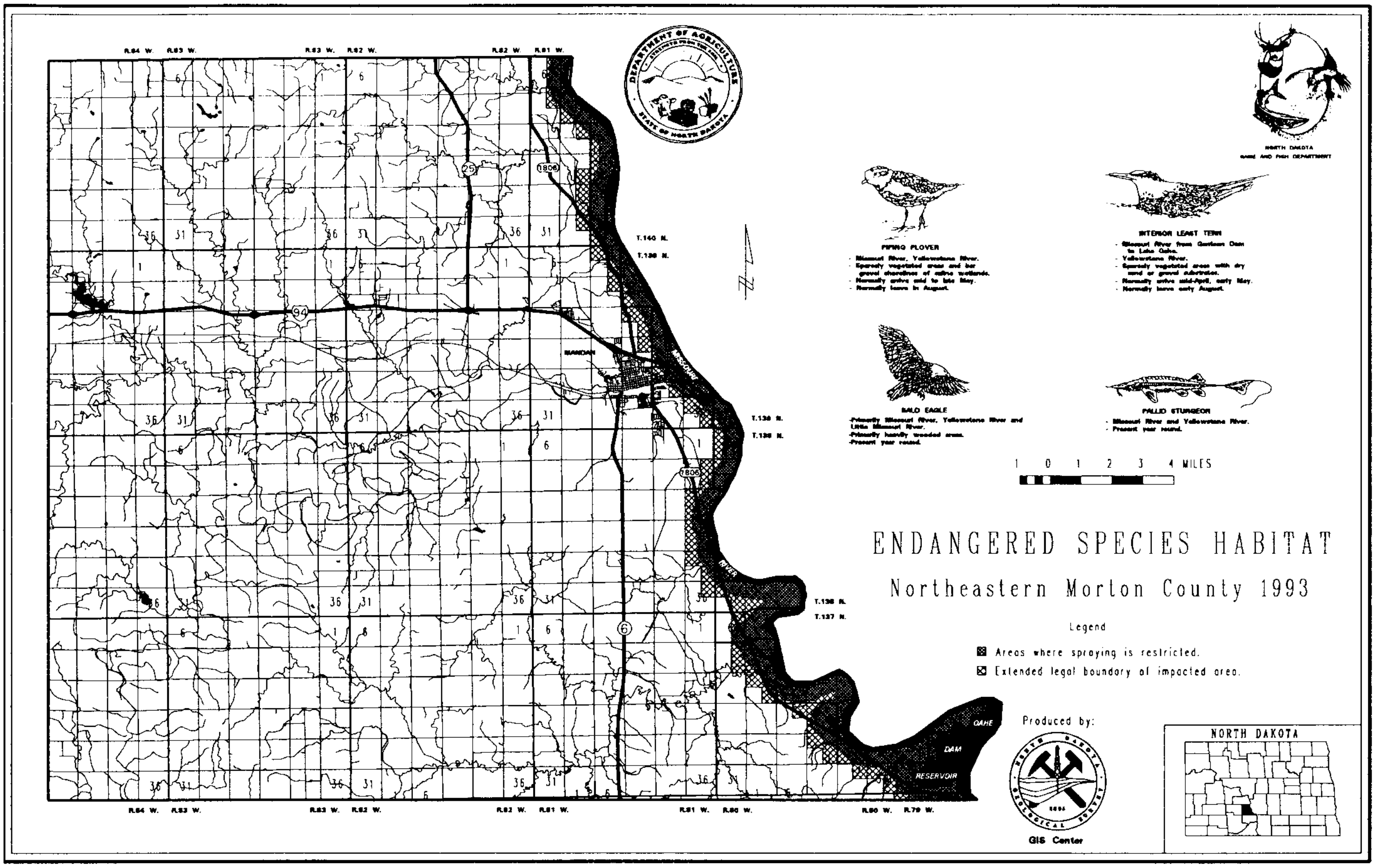

Figure 2. *This is an Endangered Species Habitat map for a portion of Morton County that was constructed using a digital PLSS coverage as the base. Other digital coverages and scanned images were overlain on the base to produce the finished map. Reduced from full-color original size of 11" x 18".*

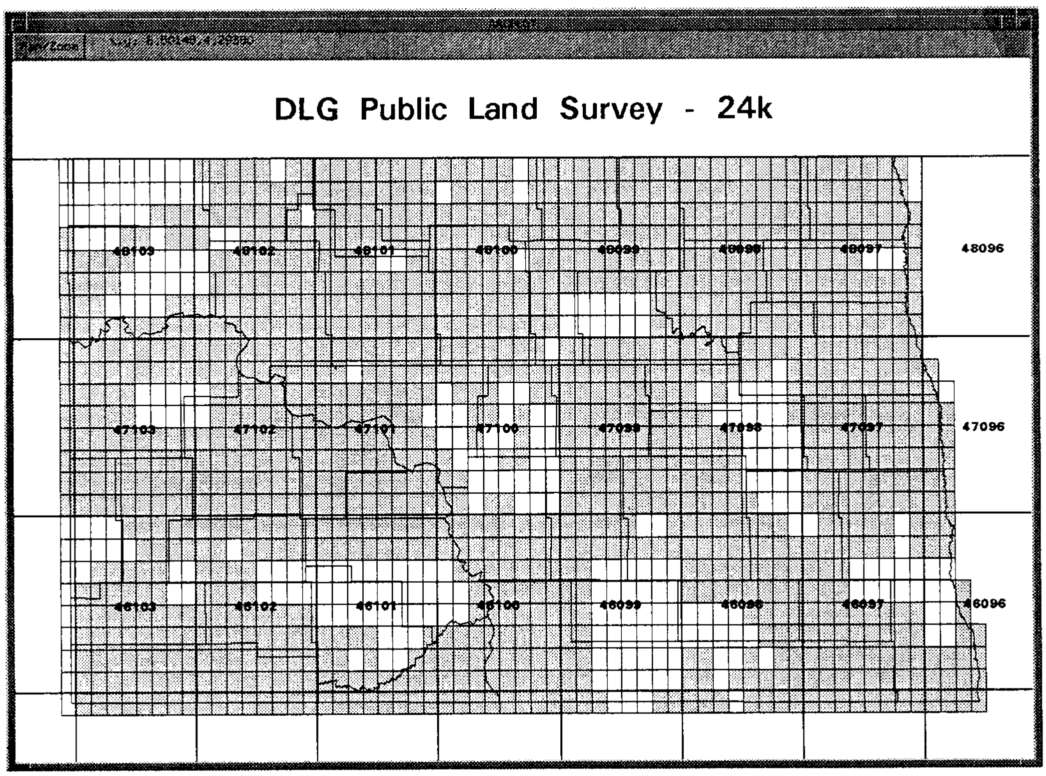

Figure 3. *This is an index illustrating those areas with completed 1:24,000 scale, PLSS coverage (shaded areas). Each small block covers an area of 7.5 minutes of latitude X 7.5 minutes of longitude, corresponding to the areas covered by standard USGS 7.5 minute topographic maps. The numbers (ie., 47100) correspond to 1 degree X 1 degree blocks, each containing sixty-four 7.5 minute map blocks.*

EARTH SCIENCE EDUCATION

by Bob Biek

Normally in this column, and in ones like it published in other newsletters and journals, we include a list of educational materials, sources of geologic information, or short explanations of geologic materials, processes, or concepts. (In a very real sense, the entire *NDGS Newsletter* is devoted to that purpose, not just this column.)

This time, however, I seek information from you, the teachers of earth science. I ask not for the information so cherished by pollsters (age, sex, income, education, profession, number of toes on your left foot, etc.), just your honest thoughts about the *NDGS Newsletter*. How might it be improved? What types of articles do you find most interesting? What would you like to see more of? Less of? I can offer no postpaid response card, but I do trust that some of you will take a moment to write down your thoughts or give me a call.

Know that your comments will be carefully considered and will help to define and refine the *NDGS Newsletter*.

NDGS publications and USGS topographic maps are available at our sales office (1022 E. Divide Ave, Bismarck), by telephone (701-224-4109), by FAX (701-224-3682), or by mail (see address below). Cash, money order, or check, payable to the North Dakota Geological Survey, will be accepted. Minimum charge per order is $1.00. Reasonable requests for items for which no price is quoted are sent free of charge. Customers will be invoiced for materials plus shipping costs, if applicable. A free copy of *NDGS List of Publications* will be sent upon request.

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