NDGS NEWSLETTER

Industrial Commission of North Dakota
North Dakota Geological Survey

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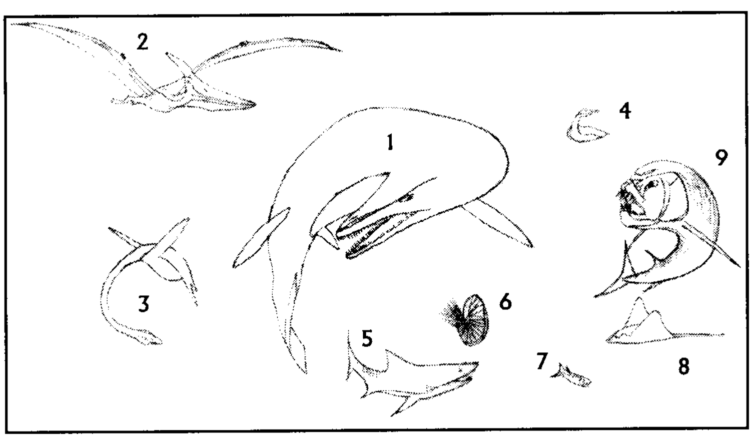
Animals that inhabited the Western Interior Seaway that covered North Dakota during the Cretaceous Period. Fossils of many of these animals have been found at the Cooperstown site. This picture is of the mural, commissioned by the State Historical Society of North Dakota, in the recently opened Pembina State Museum. *Photograph by Claudia Berg, State Historical Society.*

Features

Departments



From the front cover: 1) Mosasaur (*Plioplatecarpus*); 2) Flying reptile (Pterosaur); 3) Marine reptile (Plesiosaur); 4) Seabird *(Hesperornis)*; 5) Sand-tiger shark *(Carcharias)*; 6) Cephalopods; 7) Salmonlike fish *(Enchodus)*; 8) Rays; and 9) Tarponlike fish *(Xiphactinus)*.

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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.

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From the State Geologist

By John. P. Bluemle

[Editor's note: *In writing this article, I've drawn freely from a master's thesis written by Eric Brevik at the University of North Dakota. Dr. John Reid, Professor of Geology at UND also reviewed the article and I appreciate his suggestions.* --JPB]

I've been asked many times how thick the glaciers were that covered North Dakota. My honest response has usually been "I don't know," but sometimes I've speculated and tried to answer if the questioner has persisted. My answer then has usually been something like "It may have been as much as a mile thick in the northeastern corner of North Dakota at Pembina, which is where I think it was the thickest in North Dakota," or "I've read that it was up to 8,000 feet thick near Hudson Bay." But I've never done any kind of study myself to verify whether my estimate was even close to being correct.

There would seem to be a number of ways to get at the problem. We can make comparisons with existing glaciers in places like Greenland and Antarctica, but these may or may not be typical of the glaciers that covered North Dakota 20,000 years ago, near the maximum of the most recent glaciation, the Late Wisconsinan glaciation. Another way of indirectly getting at the problem of how much ice existed during the Ice Age is to determine the amount that sea level dropped at the time - the amount of the drop must represent the water that was tied up as glacier ice during the Ice Age.

A more direct way to get at the problem is to study the glacial geology of North Dakota and nearby areas. We know that the most recent glacier that covered eastern North Dakota extended as far south as Des Moines, Iowa. Assuming the glacier ice thinned southward to its edge in Iowa, and since we do know the characteristics of modern glaciers and how they are structured, we can speculate how thick the ice was in North Dakota. Drawing a simple profile of the glacier from Des Moines northward to the main center of accumulation, we might be able to get a rough idea of how thick the ice must have been to have flowed that far south. That's assuming, of course, that we know the kind of profile the Late Wisconsinan glaciers had.

But it's not nearly that simple. We know that the weight of the glacier ice was so great that it depressed the crust of the earth *(Figure 1)*. The earth's crust behaves as an elastic structure and glaciologists know that, once the ice reaches a certain thickness, it depresses the crust about a foot for every three feet of ice (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. Thus, when the glacier melts, the crust returns (rebounds) to the position it had been before the ice advanced over it.

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, a kind of "staircase" of 185 Holocene (postglacial) strandlines (strandlines are former shorelines) provide a continuous record of emergence from about 8,000 years ago until 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, geologists have been able to measure rates of isostatic rebound. The rates of uplift have declined from a maximum of 33 to 39 feet per 100 years immediately following deglaciation (8,000 years ago at Hudson Bay - in North Dakota deglaciation occurred about 5,000 years earlier) to a current maximum of about 4.3 feet/100 years. In other words, the shoreline at Churchill, Manitoba on the shore of Hudson Bay is currently rising about 4.3 feet a century.

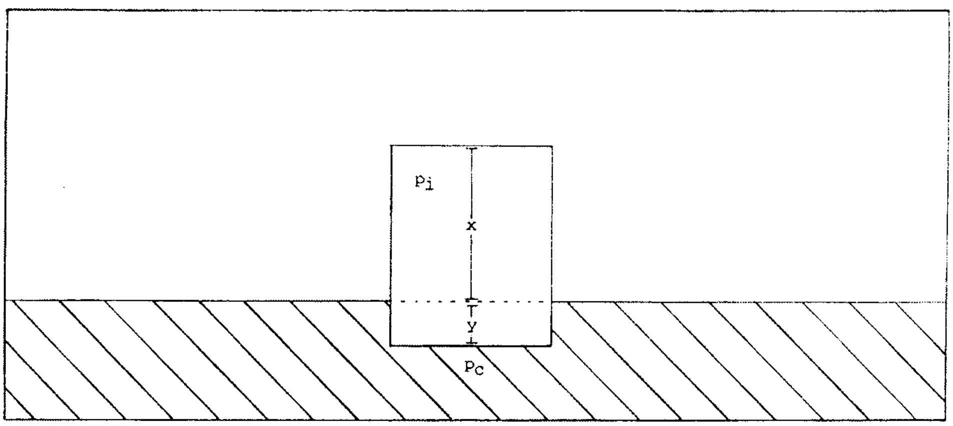


Figure 1. Depression of the crust by ice, where P_c is crustal density, P_i is ice density, y is the amount of depression, and x is the amount of ice above the depression. The dashed line marks the original level of the land, prior to depression.

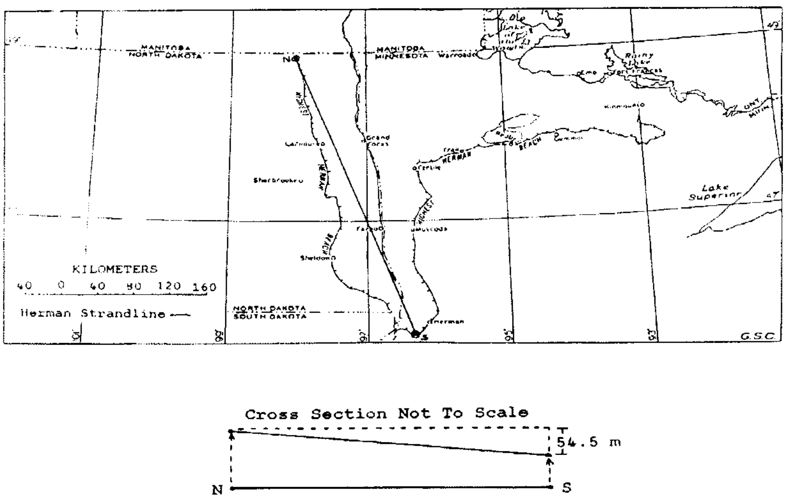


Figure 2. Elevation diagrams for the Herman strandline showing the difference in uplift between the northern (right side of diagram) and southern ends of the strandlines.

Former NDGS geologist, Bob Biek, wrote an excellent article about glacier rebound for the fall, 1993 *NDGS Newsletter*. Then, two years ago, a University of North Dakota geology student tackled the problem. Eric Brevik wrote his master's thesis on the topic "Isostatic Rebound in the Lake Agassiz Basin Since the Late Wisconsinan." His study addressed three main questions: 1) how thick was the ice that covered the Lake Agassiz basin in eastern North Dakota and how much did the ice depress the earth's crust; 2) how much rebound has occurred since deglaciation and is that rebound complete; and 3) what were the effects of this rebound on the lake basin?

These are some of the questions and considerations Brevik dealt with in calculating the amounts of isostatic rebound during and following deglaciation and that he then used to estimate total maximum ice thickness. I do not intend to include his mathematics in this short article or document all the reasoning he presented in his thesis, which is over 100 pages long. Rather, I'll simply repeat some of his conclusions and then make some comments of my own.

In order to calculate the glacier thickness in North Dakota, Brevik needed to know how much the crust was depressed - and this was best done by determining how much it has rebounded from the amount it had been depressed, when the ice was thickest. Fortunately, there is a way to estimate this, at least in eastern North Dakota in the Lake Agassiz basin: by studying the tilted strandlines left by glacial Lake Agassiz. This is what Brevik did.

Glacial Lake Agassiz formed several strandlines, each representing a level the lake occupied for a time. Each strandline is marked in places by a wave-cut scarp, in other places by a beach that was deposited at the shore of the lake. In some places the strandlines cannot be identified, either because no recognizable feature formed or because post-glacial erosion or other changes have obliterated them.

The oldest and highest continuous strandline is called the Herman (named for the town of Herman, Minnesota, where the Lake Agassiz beach is well developed. Presumably, the Herman strandline, or beach, rebounded more in the north, at the Canadian border for example, than it did in the south at the South Dakota border because the ice must have been thicker in the north. This explains why the strandlines are tilted. One problem with this is that much of the rebound took place *while the ice was thinning* so that much of the rebound had already taken place before glacial Lake Agassiz started to form at the south end of the melting glacier. It's been estimated that three-quarters of the total rebound occurs while the glacier is still thinning.

The Herman strandline is 54.5 metres (179 feet) higher at the Canadian border t[illegible] at the South Dakota border. That figure is an absolute m[illegible]m amount of rebound. In fact, we know it represents only the amount of rebound that took place after most (perhaps ¾) of the rebound had already occurred. Furthermore, it's also necessary to consider the weight of the water in the lake and the weight of the lake sediments that were deposited in Lake Agassiz; these must have kept the crust from immediately rebounding to its preglacial elevation. Brevik calculated that, at Grand Forks, the lake was as much as 100 metres (330 feet) deep. The average thickness of lake sediments there is as much as 46 metres (150 feet). These masses would cause crustal depression of 38 metres (125 feet) and 40 metres (130 feet), respectively. The sediments are still in place in the Lake Agassiz Basin, causing 40 metres of depression that was not compensated by rebound.

Brevik concluded that the tilt of the Herman strandline, when combined with the effects of the Lake Agassiz sediments represents crustal depression of between 95 and 350 metres which correspond to ice-thickness values of 280 to 1,040 metres, respectively. He therefore concluded that the actual ice thickness along the North Dakota-Minnesota border must have been somewhere between the two extremes that have been calculated.

So, how thick was the glacier in North Dakota? As I said, Brevik concluded that it was probably somewhere between 280 and 1,040 metres thick (between 920 feet and 3,410 feet thick). That's a considerable range and also somewhat shy of my seat-of-the-pants estimate at the beginning of this article (I said it thought it was up to a mile thick). I accept the results of Brevik's study, although I caution that it includes a lot of assumptions and estimates of things no longer really measurable. It would appear that I should lower my own estimate, although I still think the actual answer may be closer to Brevik's higher estimate than his lower one.

NEWS IN BRIEF

Compiled by John P. Bluemle

NDGS Paleontologist Receives Award

On May 20, 1996, at a surprise ceremony, NDGS paleontologist John Hoganson was presented with a certificate and clock by Nancy Curriden, Forest Supervisor, Custer National Forest. The award was for John's efforts in management of North Dakota fossil resources.

In 1986, as part of the newly established NDGS Fossil Resource Management Program, the NDGS signed a memorandum of agreement with the United States Forest Service-Custer National Forest to cooperatively manage paleontological resources on lands administered by the Forest Service in North Dakota. This agreement was reaffirmed last summer. As a result of this agreement, the NDGS advises the Forest Service regarding fossil resource management issues in North Dakota. Cooperative projects between the NDGS and Forest Service have resulted in the collection and restoration of fossils from Forest Service lands in North Dakota now on exhibit at the North Dakota Heritage Center. The Forest Service has also designated the NDGS State Fossil Collection at the Heritage Center as their repository for fossils found on Forest Service lands in North Dakota. Hoganson was instrumental in establishing this nationally recognized partnership to preserve our fossil resources and is responsible for administering the North Dakota Geological Survey's agreement responsibilities.

Update on NDGS Mapping

As a result of funding received through the National Mapping Program ("Statemap"), the North Dakota Geological Survey has been able to complete the mapping of three areas. Two of these, the urban Jamestown and Dickinson areas, consist of three and four 7.5 minute quadrangles, respectively. All maps were produced in a digital format and released as open-file reports by the NDGS. We are providing full-color paper copies of the maps as required. We have also written technical reports on the geology of the Jamestown and Dickinson areas that include information on stratigraphy, structure, geologic hazards, and near-surface mineral resources.

The third area mapped under the Statemap Program is the 110-square-mile Theodore Roosevelt National Park in the badlands area along the Little Missouri River in western North Dakota. The park, which consists of two main units, plus a third small ranch site, is North Dakota's main tourist destination and there has long been a need for an accurate, detailed geologic map of the area. The area consists of spectacular badlands topography of Paleocene rocks including colorful beds of clinker, petrified wood, and lignite. In addition to our work funded by the National Mapping Program, we have undertaken a 2½ year appraisal of the park's fossil resources under a separate contract with the National Park Service and this work is being coordinated with our Statemap work.

We are also working to produce a detailed map and non-technical guide that will be used to fill the park's need for a tourist-oriented publication. This will be separately funded by the Theodore Roosevelt Nature and History Association, a private group whose activities include promotion of the park.

The NDGS is currently mapping the geology of a portion of the urban Bismarck-Mandan area and the Grafton area. In addition, Survey geologists have helped supervise a UND student mapping in the Mandan area through Edmap, a part of the National Mapping Program.

Biek Leaves NDGS

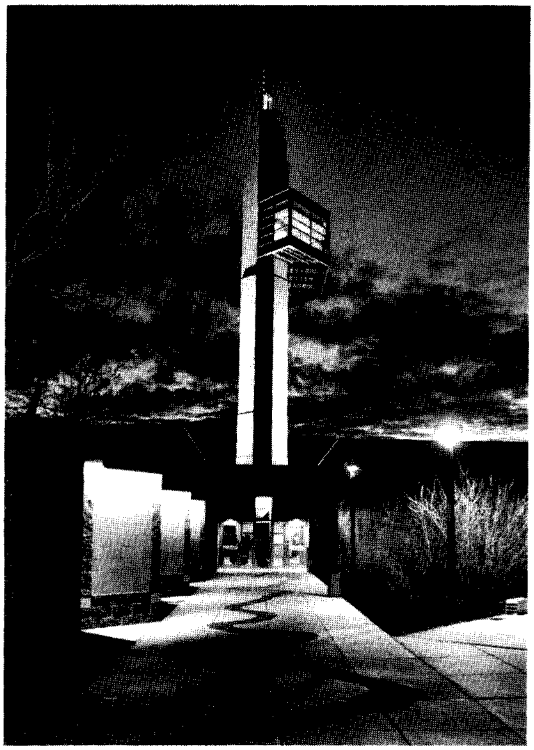
Geologist Bob Biek resigned his position with the Survey effective the end of April. Bob had been with the Survey since 1992.

He was involved mainly in surface mapping and completed three major mapping projects while he was with the NDGS. These projects, which were partially funded by National Mapping Program awards, involved detailed mapping in the Jamestown and Dickinson urban areas as well as mapping the geology of Theodore Roosevelt National Park in detail. Bob was also the editor for this newsletter. He made numerous improvements in the newsletter while he was here. Bob is now at the Utah Geological Survey.

The NDGS is currently in the process of interviewing possible replacements for Bob's position.

NEWS IN BRIEF . . . Continued

Museum Opens in Pembina



The new Pembina State Museum opened on May 19 with representatives from Canada and Minnesota joining North Dakotans to celebrate the opening.

The new museum is impressive, with a seven-story high observation deck that provides viewers with a panoramic view of the Red River Valley area explored nearly two centuries ago by fur traders.

The museum is the result of a cooperative effort between the local community, the State Historical Society, the North Dakota Heritage Foundation, the Department of Transportation, the Department of Tourism, and the Department of Parks and Recreation. In addition, the North Dakota Geological Survey helped with the preparation of the geologic exhibits, which are a major feature of the museum (see illustration on cover of this newsletter).

The permanent exhibit gallery features 140 million years of regional history from the Cretaceous Period to contemporary times. Exhibits include fossils from before the formation of Lake Agassiz, the tools of the fur trade, including the famous Red River oxcart, and remnants of the steamboating era. The people and cultures of those who have called Pembina home are also highlighted, including American Indians and the Metis people, early Selkirk colonists, and other Euro-American settlements. State Geologist, John Bluemle attended the grand opening for the Pembina Museum.

Photograph by Todd Strand, State Historical Society of North Dakota.

New North Dakota Geology Bibliography
By Tom Heck

After several years of effort by North Dakota Geological Survey geologists and Larry Greenwood, Director of the Minot State University Library, we will soon go to press with a bibliography of North Dakota geology. The NDGS has published two annotated bibliographies, both by Mary Woods Scott. The first, Miscellaneous Series 49, published in 1972, covers the period between 1806-1959, and the second, Miscellaneous Series 60, published in 1981, covers the period from 1960-1979. The new bibliography, which is not annotated, covers the period from 1980-1993. The new bibliography includes an alphabetical author index and a subject index.

The project was started with a download from online bibliographic services. Several hundred references were then added by contacting geologists who have either conducted research in North Dakota in the past or are presently active in the state. People at various colleges and universities, the U.S. Geological Survey, other state and federal agencies, and private companies graciously provided us with updated publication lists. Our own geologists were able to add several dozen references to the list. While we tried to be as complete as possible, we probably missed a few articles and had to exclude some other papers that did not have geology as a major part of the study. The Survey thanks everyone who helped us make the bibliography as complete as possible.

Our appreciation for the earlier efforts of Mary Woods Scott and other librarians involved in similar projects greatly increased as we worked on this publication. We chose to not annotate our bibliography, but did create a subject index from the key words assigned each citation. We started with more than 2,000 key words and the initial printing of the subject index contained more than 1,000 pages. The key word list was pared down to the 900 most important so that, even with the additional references, the subject index was only 300 or so pages long.

The bibliography was one of several projects undertook as a "Centennial Project" in recognition of the North Dakota Geological Survey's centennial in 1995. We had hoped to be able to publish it in 1995, but it turned out to be a massive job. Our hope now is to finish all of the remaining details by early August. The final product is expected to be back from the printers by November, 1996. If you are interested in obtaining a copy of the bibliography, be sure to check the Winter 1996 *NDGS Newsletter* for ordering information and cost.

NEWS IN BRIEF . . . Continued

Water Quality is Subject of Health Department Booklet

The North Dakota Department of Health, Division of Water Quality, has published a booklet discussing the state's water quality. The booklet, entitled *North Dakota's Water . . . Keeping it Clean*, highlights many of the successes the state has experienced in controlling water pollution over the past 30 years.

Tremendous strides have been made in the improvement of water quality from point sources like municipal and industrial wastewater treatment facilities. Other issues require continued attention, however. Challenges which remain include groundwater contamination, polluted runoff from both urban and rural areas, and other water quality concerns arising with increased economic development such as construction of larger livestock operations and agricultural product processing plants.

While previous water quality management efforts have largely been the responsibility of state and federal government, future efforts must begin at the local level to be successful. This booklet can help the public develop a better understanding of water quality issues in North Dakota, and may serve as a first step to the public's increased involvement in developing workable solutions.

For more information or to receive additional copies of the booklet, contact the North Dakota Department of Health, Division of Water Quality, 1200 Missouri Avenue, Bismarck, North Dakota 58506-5520, or call (701) 328-5210.

Association of American State Geologists Meeting in Virginia

The annual meeting of the Association of American State Geologists was held June 2-4, 1996, in Charlottesville, Virginia. The meetings are useful because, in addition to a full formal program dealing with issues faced by all the state surveys, they allow state geologists to compare ideas, programs, etc. A half a day was devoted to presentations by a number of federal agencies, such as United States Geological Survey, Department of Energy, Minerals Management Service, National Park Service, Environmental Protection Agency and several others.

The host for this year's meeting was the Virginia Geological Survey, headed by Stan Johnson. Meetings were held all day Sunday, as well as on Monday and Tuesday mornings. In addition to several geologic fieldtrips, trips to Monticello, Ashlawn, and the University of Virginia helped to make the meetings more enjoyable.

Forty-one states plus Puerto Rico were represented by their State Geologist or representative at the Charlottesville meeting. I think that's a near record turnout!

Finally, I'll include a picture taken on the Monday afternoon fieldtrip to Monticello (the home Thomas Jefferson built near Charlottesville). I am in the middle. On my left is Ned Noble, who was State Geologist of North Dakota from 1969-78, and on the end is Lee Gerhard, State Geologist of North Dakota from 1978-82, and now State Geologist of Kansas. On my right are Ned's wife, Polly, and Lee's wife, Darcy. We are standing in the garden.

NEWS IN BRIEF . . . Continued

NDGS Hosts Coal Workshop
By Ed Murphy

On May 16, 1996, the North Dakota Geological Survey sponsored a short course on coal quality issues taught by Bob Finkelman, U.S. Geological Survey, Reston, Virginia. The meeting was held in the Brynhild Haugland Room of the State Capitol and was attended by two dozen people representing the coal and utility industries and government regulators in the state.

In addition to Finkelman's fine presentation on present and future coal issues facing North Dakota, Bob also discussed the proposed National Coal Quality Inventory program. This program is proposed to be a joint effort between industry and government as a means of assessing the chemistry of coal that is scheduled to be mined in the United States within the next 20 years.

Bob Finkelman, U.S. Geological Survey, lectures on coal quality issues to industry and government personnel at the State Capitol.

Russell Prange, NDGS Technician, "manning" the booth at the 1996 North Dakota State Fair.

North Dakota State Fair Booth
By Tom Heck

For the first time in many years, the NDGS had a booth at the State Fair in Minot. We spent the entire week there, most of our geologists taking turns manning the booth. For some of us it was a new experience while others had manned a similar Survey booth in the early 1980's. The level of interest was found to be quite high with questions ranging from details about oil drilling and production to "what is geology anyway?" Visitors ranged in age from retirees to young children wanting to see the fossils. Personally, I wonder if some of our educators aren't doing too good a job teaching young people about fossils. These kids make those of who aren't paleontologists look bad by knowing all the dinosaur species that have ever been found! It was gratifying that so many people expressed an interest in geology. I expect the Survey will probably have a booth at the fair again next summer. I would also like to add that all of us who spent part of the week at the fair in Minot thoroughly enjoyed it. The North Dakota State Fair is a first-class operation!

NEWS IN BRIEF . . . Continued

DREAMS Fieldtrip
By Ed Murphy

The NDGS recently assisted the DREAMS (Disability Research Encompassing American Indians in Math and Science) program during an institute that was held at United Tribes Technical College.

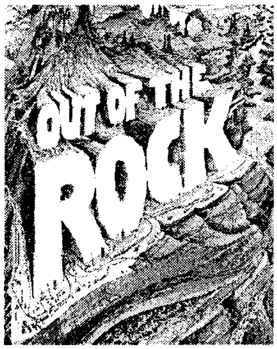
The DREAMS program was established by a National Science Foundation grant to give Native American children with disabilities "hands on" experience with math and science. The week-long institute (established to improve instructors teaching skills when working with children with special needs) was attended by over 100 students, parents, and science teachers from across the state. On August 7, 1996, Frank Karner (a professor at the Department of Geology and Geological Engineering, University of North Dakota) and I led the geologic portion of a fieldtrip from Bismarck to Fort Yates. The fieldtrip explored the Cretaceous marine and non-marine strata near the town of Solen in Sioux County. The participants also had the opportunity to examine several fossils from the State Fossil Collection.

For more information on the DREAMS program, please contact:

Kim Greenwood, Project Director
P.O. Box 8362
Grand Forks, ND 58202-8362
(701) 777-6218
kgreenwo@badlands.nodak.edu

Frank Karner (far left) answers questions on geology during the DREAMS fieldtrip. Fox Hills and Hell Creek strata are exposed in the background.

Collection of Natural Resources Learning Activities Available
By Paul Diehl



The U. S. Bureau of Mines and the National Energy Foundation have published a collection of integrated learning activities for use by K - 8 teachers. This guide is intended to help teach how important minerals, and energy resources are and how they affect our daily lives. Natural resources are not well understood and are taken for granted by most people.

Out of the Rock (544 pages) is a mineral resource education guide for teachers. It is designed to assist teachers with meaningful mineral resources instruction on topics such as mining, geology, the environment, and economics. This content can be integrated into science, social studies, language arts, math, and other disciplines. Units have been carefully developed and organized so the user will have the materials necessary in a teacher-friendly, easy-to-use format. The publication is divided into several sections, each with specific instructional purposes in mind. Contents include an introduction, background information, a conceptual framework, as well as sections dealing with careers, tool of the trade, large group activities, and additional resources. The heart of the book is its four sections (366 pages) of integrated learning activities which are divided by grade levels.

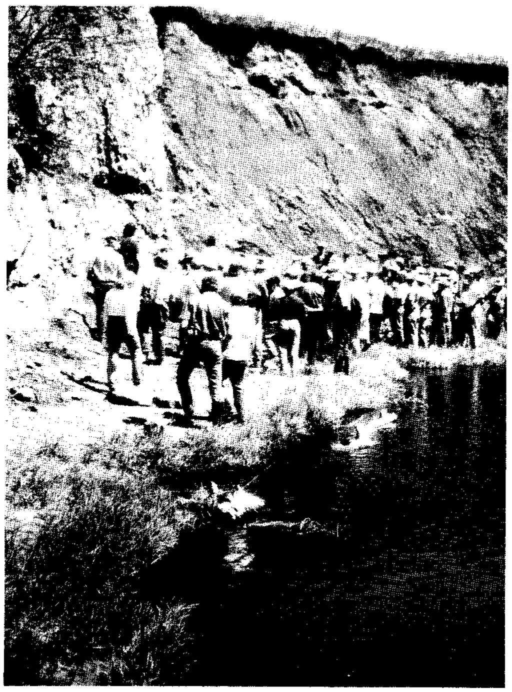
A copy of *Out of the Rock* will be available for inspection at the North Dakota Geological Survey office. The book, as well as colorful posters, and a 27-minute video pertaining to natural resources are available from the National Energy Foundation, 5225 Wiley Post Way, Suite 170, Salt Lake City, Utah 84116, (801) 539-1406. Cost of book is $25; posters are $3. However, an *Out of the Rock Teachers Kit* which includes the *Out of the Rock* curricula book, three colored 23" x 35" posters with lesson activities on the back of each, a 27 minute video, and a tote bag is available for $48. There is also a Petroleum Exploration and Development Kit designed for 5th to 9th grades. That kit with teacher's guide, student activities booklet, and two colored posters costs $12. A 20% discount is offered to educators on all NEF materials. All materials can be ordered through the internet at:

http//www.xmission.com/~nef

NEWS IN BRIEF . . . Continued

Midwest Friends of the Pleistocene 43rd Annual Field Conference

By Mark Luther



Dr. John Reid leading a discussion about two glacial tills exposed in the Park River Cut.

The Midwest Friends of the Pleistocene (FOP) held its annual field conference May 31, June 1 and 2, 1996, in the eastern North Dakota and northwestern Minnesota portion of the southern Glacial Lake Agassiz Basin. More than 80 people attended the FOP conference, including a large number of Canadian geologists that had just concluded a field trip over the Canadian portion of the Glacial Lake Agassiz Basin. Co-hosts for the FOP96 field conference were Ken Harris (Minnesota Geological Survey), Mark Luther (North Dakota Geological Survey), and John Reid (UND Department of Geology and Geological Engineering).

The meeting began Friday night (May 31) with registration and a barbecue held at Leonard Hall on the campus of UND. As with any field expedition, we were in need of a plentiful supply of mud in order to make the trip more memorable. We were blessed with a soaking rain Friday night that drove us into the receiving room (ie. garage) at Leonard Hall to eat our burgers, and filled us with eager anticipation at the prospect of driving on the clay-rich (lake sediment) roads of Walsh and Grand Forks counties.

Saturday morning (June 1) brought a beautiful, sunny day that soon (about 2 hours after our first stop from which we obtained mud enlarged boots) dried the ground sufficiently to cause no further problems. Saturday was spent driving around northeastern North Dakota and making stops at several interesting geologic features/outcrops, including: Salt Lake; the Pisek scarp; the Dobmeier Spring Pit; the Park River cut; the Elk Valley Delta; the Soo Moraine; the Dahlen Esker; and an outcrop of Pierre Shale.

Following the day's field activities, a banquet and official FOP business meeting was held. The opportunity to host the next FOP meeting was offered (no takers yet!), followed by the presentation of the "Silver Moore-pick Award" to Lee Clayton for outstanding contributions to Quaternary geology. Fred Schneider, Chairman of the Archeology Department at UND, then gave a very enjoyable presentation on archeology in the Red River Valley.

Dr. Frank Beaver and Dr. Ron Matheney looking at 40,000+ year old spruce logs contained within the Gervais Formation glacial till (Three Creeks Section).

FOP96 concluded Sunday (June 2) at noon following a very enjoyable field trip in northwestern Minnesota with stops at the Fertile

A group of FOP96 participants wind their way up onto the Dahlen Esker.

Dunes, and the Three Creeks Section on the Red Lake River. People especially enjoyed the Three Creeks outcrop, as it was freshly scoured by spring floods and contained numerous pieces of spruce wood older than 40,000 years within the Gervais Formation till.

A second, Post-FOP, field trip attended by more than 60 people then began following lunch and continued through Monday (June 3) afternoon. Highlights of the Post-FOP trip included: the Hillsboro compaction ridge; the Heiberg Section; the Ames gravel pit; the Buffalo Aquifer; the Stockwood Fill Site; the Rustad Quarry Site; the Sheyenne Delta; and the southern outlet of Glacial Lake Agassiz.

We covered a lot of ground during the three days of field trips, but we saw many outstanding examples of surficial geologic features (the food was good too!). Many complimentary comments were received by the co-hosts about the quality of the conference. The guidebook for the conference, a 165-page document containing roadlogs and details about all of the features listed above, is available from the NDGS (see page 28).

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LAKE AGASSIZ

NEWS IN BRIEF . . . Continued

Fourth International Williston Basin Horizontal Well Workshop

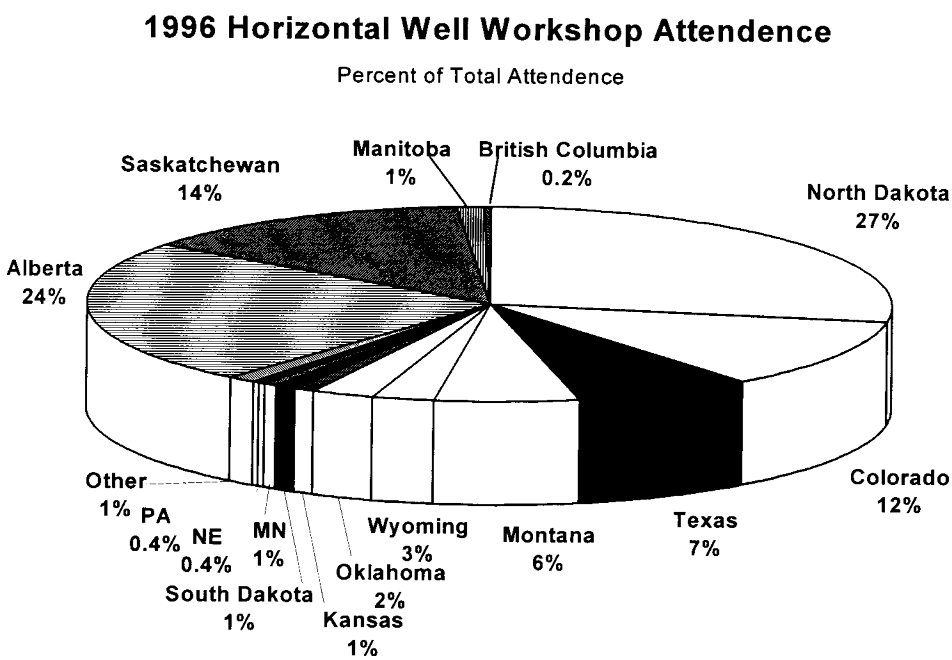
By

John P. Bluemle and Paul Diehl

The Fourth International Williston Basin Horizontal Well Workshop took place May 5-7, 1996, at the Radisson Inn, Bismarck. Sponsored by the NDGS and Saskatchewan Energy and Mines, the event was attended by over 500 oil and gas industry professionals. This was the largest oil and gas industry convention ever held in North Dakota. Unlike most oil and gas conventions, where participation is limited to a specific discipline, the Williston Basin Horizontal Well Workshop is unique in that industry representatives of many backgrounds, specialties, and positions - service company, geology, engineering, landmen, field operations, state and provincial survey and regulatory, executives, mineral owners, and others - can come together. All are directly involved in exploration and/or development of the Williston Basin. These meetings provide an opportunity for companies and individuals on both sides of the border to meet, discuss technical advances, exchange ideas, and negotiate business in a relatively informal setting.

The workshop was initially envisioned as a vehicle to promote informal communication, discussion, and transfer of technology between Canadian and U.S. industry specifically interested in horizontal well application in the Williston Basin. When we initiated the workshops four years ago, we intended to invite a few companies from each side of the border to attend a meeting to informally discuss horizontal wells and business opportunities stemming from the application of that technology. The North Dakota Geological Survey and the Saskatchewan Energy and Mines organized and sponsored the first workshop in Minot in May, 1993. At that initial workshop, 11 papers were presented to 179 registrants. Participation has grown each year with 27 papers and 45 exhibits presented at the 1996 workshop. Four provinces and 16 states were represented by 207 Canadian and 324 U.S. registrants.

Through these workshops, oil and gas industry interest and investment in North Dakota has increased. Canadian firms have substantially increased their investments and activity in North Dakota. The rapidly developing and significant Red River horizontal play in Bowman County can be traced back to a paper given at the Second International Williston Basin Workshop in which the potential for Red River production in that area was presented by then North Dakota Geological Survey geologist Bill McClellan. North Dakota Geological Survey presentations on the Lodgepole by geologists Randy Burke and Paul Diehl two years ago also helped inform workshop participants and spur interest in that play. Other horizontal well activity, such as recovering oil from old fields previously thought to be depleted and secondary recovery projects, has also been outgrowths of the three previous meetings. Increased activity in the Williston Basin has been stimulated by these workshops and has led to substantial increases of revenue to mineral owners, community businesses, oil-related service providers, sales tax revenue, and state production tax revenue.



NEWS IN BRIEF . . . Continued

GIS Clearinghouse Update

By Mark Luther

Since 1991, the North Dakota Geological Survey has operated a digital spatial data (DSD) clearinghouse to keep track of map-related digital data that has been produced for North Dakota (introduced in the June 1991 *NDGS Newsletter*). During the subsequent five years, the clearinghouse has provided many of the benefits anticipated, including greater ease of locating existing data and reductions in costly duplication of data collection/creation.

Initially, operation of the clearinghouse by the NDGS and submission of descriptions of DSD holdings by the various state agencies was voluntary. However, with the signing of Executive Order 1995-05 by Governor Schafer (see the Winter 1995 *NDGS Newsletter*), state agencies are mandated to report DSD holdings to the State GIS Technical Committee (GISTC) at the end of each fiscal year. The NDGS is further mandated to maintain a record of those DSD files in a clearinghouse format available to the public. In order to maintain a useful clearinghouse, the GISTC has designed the form shown on the opposite page. Please use either the form (if sending a hardcopy of DSD holdings) or the data fields shown if sending a listing via e-mail. <u>Please copy and use the form on the backside of this page</u> (a sample, filled-out form is shown at right for illustration).

As more contributions are made to this clearinghouse, the possibility of costly DSD duplication will be lessened, and the variety of potential mapping/modeling projects will greatly expand. All those involved with mapping and/or manipulation of DSD at the state or local level will benefit from the expansion of this clearinghouse.

For those needing to see what areas are covered by DSD of various themes and scales, we established "NDClear Online" (discussed in the Winter 1994 *NDGS Newsletter*). For those having Internet access, "NDClear Online" provides fast, 24-hour-a-day access to a number of index maps that display areas with existing DSD. To access "NDClear Online" via gopher, enter the following:

gopher gopher.state.nd.us

Upon reaching the state gopher server, a series of menus will be displayed. To reach "NDClear Online", choose "North Dakota Government" from the first menu, "State Agencies" from the second, "Geological Survey" from the third, and "NDClear" from the fourth. A "README" file will be present once access to "NDClear Online" has been gained. The "README" file will explain the types of files available and the steps required to search for the category of clearinghouse information desired.

We hope that this continually evolving clearinghouse will provide a more efficient and accurate means for those requiring DSD to enable them to locate and inexpensively aquire this most expensive part of any computer-based mapping or modeling system.

GIS INFORMATION DIRECTORY
NORTH DAKOTA GEOLOGICAL SURVEY
SFN 50621 (12-95)

Send completed form to:
GIS Coordinator
North Dakota Geological Survey
600 East Boulevard Ave.
Bismarck, ND 58505-0840
701-328-9700

Contact: John Q. Public — Telephone: (701) 222-2222
Agency Name: ND Division of Data
Street Address: 600 East Boulevard
City: Bismarck — State: ND — Zip Code: 58505

AREA (7.5', 30' X 60' 1° X 2°, County, State)	SOURCE SCALE	DATA TYPE	SOURCE/METHOD OF CAPTURE	AVAILABILITY
Almont 7.5' Quad	1:24,000	Soils	mylar - stable base/digitized	Public
Grafton 30'X60' Quad	1:100,000	Surficial Geology	stable base/scanned	Public
North Dakota	1:500,000	Aquifers	paper map/digitized	Proprietary
Billings County	submeter	Oil Well Location	differential corrected GPS	Confidential

SAMPLE:

	1:100,000, 1:24,000, etc.	roads, rivers, etc.	relative accuracy, etc.	access (public, proprietary, confidential)

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SAMPLE:

	1:100,000, 1:24,000, etc.	roads, rivers, etc.	relative accuracy, etc.	access (public, proprietary, confidential)

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Brenna Formation Selenite Crystals from Fargo, North Dakota

By Mike Hedtke

[Editor's Note: *This article was submitted by Mr. Mike Hedtke of Clearbrook, Minnesota. Through his work with a North Dakota based construction company, Mike has been studying the geology and surface mineralogy of the state for 22 years. Please let us know if you would like to see similar contributions by non-NDGS people, amateur geologists, or others for the* NDGS Newsletter.]

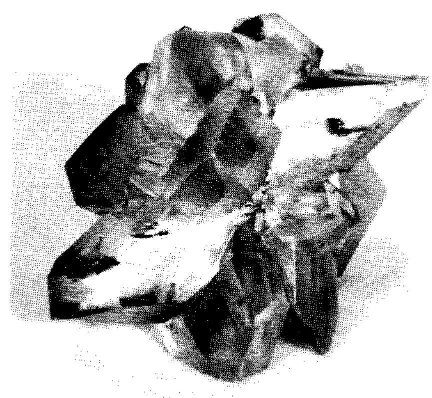
During the summer of 1995, a number of large, well-formed selenite roses were found in Brenna Formation clay excavated for a proposed lift station along 32nd Avenue South in Fargo, North Dakota. The Brenna Formation is a soft clay that was deposited on the floor of glacial Lake Agassiz.

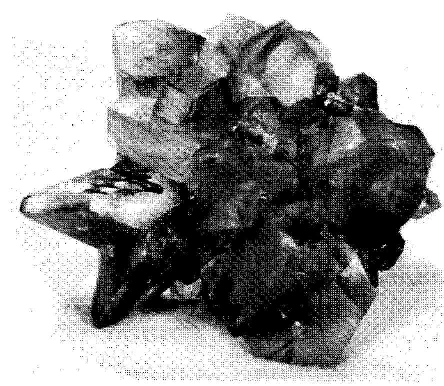
Because these specimens were found after excavation, exact stratigraphic location can only be theorized. It appears that they occur in several separate horizons below the Brenna-Sherack transition zone. The individual crystals in the roses have a fairly complex structure that produced a sector zoned yellow and water-clear crystal. A number of possible causes may account for this growth habit. Two possibilities are: a time-related scheme of crystal growth, post-growth erosion, and subsequent crystal regrowth on the eroded cores, or the fact that a screw dislocation or other crystal deformity can cause impurities to be included in the crystal matrix as it grows. On analysis, the zone impurity was identified as hydrocarbon molecules which fluoresce white in ultraviolet light (Barwood, *personal communication*).

Further quantitative analysis and description of the crystals in an undisturbed section is now being done to gather more information. I believe the crystals could be indicators of the chemistry, hydrology, and depositional environment of the Lake Agassiz sediments in the Fargo area.

References and Credits

- Henry Barwood, Indiana Geological Survey, did the x-ray diffraction analysis of the specimens and provided preliminary structural analysis.
- Bernhardt Saini-Eidukat, Donald Schwert, and Alan Ashworth, North Dakota State University, provided background information and discussed other occurrences of these crystals at a meeting in the fall of 1995 at North Dakota State University.
- Russ Colson, Moorhead State University, provided information on the possibility of identifying stratigraphic levels in the Brenna sequence by difference in flake size after weathering induced exfoliation of the clay.
- Harlan Niles, Research Coordinator, Coleraine Resources Research Institute, Coleraine, Minnesota and Midwest Testing Laboratory, Fargo, North Dakota, provided boring log information.
- Bruce Schmidt and Steve Skyberg, field inspectors, Fargo District Office, North Dakota Department of Transportation, verified the source of the excavated material that enabled this study to begin.
- John Bluemle, State Geologist, North Dakota Geological Survey, for encouragement and cooperation in reviewing the initial phase of this investigation.
- Photographs by Bonik Photography.





Top left photo: Doubly terminated trapezoidal crystal from Brenna Formation clays. Crystal four inches in diameter.

Bottom right photo: Large Brenna cluster with projecting twins. Crystal 5¾ inches in diameter.

Sodium Sulfate Deposits in North Dakota

By Ed Murphy

In the fall of 1929, Oscar Quarne waded into a shallow lake near his hometown of Grenora to retrieve a duck he had shot. To his surprise, he did not sink into the underlying soft, black mud, but instead his weight was supported by a thin layer of white crystals on the lake bottom *(Figure 1)*. A sample was sent to the University of North Dakota where it was identified as Glauber's salt. Glauber's salt is a compound of sodium sulfate named after the German chemist J.R. Glauber who first created it in his laboratory in 1658. Quarne was not the first to discover these salt layers - Native Americans had long referred to this salt as "summer ice". In addition, several early explorers including Lewis and Clark in 1804, Henry Brackenridge in 1811, and Maximilian in 1833, noted the occurrence of Glauber's salt in western North Dakota. Following Quarne's rediscovery of this resource, several local men began prospecting the shallow lakes in this area.

Resource Evaluation

In 1934, the North Dakota Geological Survey convinced the Federal Emergency Relief Administration (FERA) to fund a study of the sodium sulfate deposits of the state. Irvin Lavine, Professor of Chemical Engineering at the University of North Dakota, led a group to the northwestern part of the state to locate, map, and prospect the sodium sulfate deposits in the area. The work was supervised by the North Dakota Geological Survey and was sponsored by FERA as a means of employment for those on the county relief rolls in this drought-stricken region. By 1934, this area had suffered through six years of drought, many in this area would not bring in a crop from 1929 through 1940, and newspaper editorials questioned whether the hardened soil would ever be able to support crops again. It was under these desperate conditions that the sodium sulfate project was initiated. Hopes and prayers were that this work would result in the construction of a processing plant that would provide badly needed employment. A special dedication ceremony was held at Grenora when the FERA project began on August 24, 1934. Governor Ole Olson led the list of distinguished speakers at the event which attracted people from all over northwestern North Dakota.

Beginning in early July to late December, 1934, 63 men from the county relief rolls hand-augered over 2500 holes (some down to depths of 80 feet) and obtained thousands of samples from lake deposits in shallow or dried-up lakes from Stanley in Mountrail County, to Alkabo in Divide County. Working conditions were terrible for the men who ranged in age from their early twenties to their sixties. The drought had dried up many of the lakes making exploration much easier - area residents recall that "blizzards" of white sodium sulfate salt blew across the countryside from the dried lake bottoms. However, prior to freeze up, the men often stood knee deep in water and mud, many without hip boots or waders. In some areas, the mud was so soft that planks were laid on the surface to help distribute the worker's weight so they would not break through the surface and into the foul smelling mud. The crews slid a table from site to site and stood on it during drilling to avoid the water and mud. The table could accommodate three or four men and had a hole in the center that allowed the hand auger to slip though. Francis Walsh of Chino, California, (a crew chief on the project), recalls that the tools were crude, consisting of auger heads, chisel points, ½-inch and ¾-inch pipe, pipe fittings, and pipe wrenches. Everything was done manually - the crews had to raise and lower, as well as rotate, the pipe by hand. Portions of the salt crystal beds had the hardness of concrete and were extremely difficult to penetrate.

As if things weren't bad enough, the men had to contend with deteriorating weather conditions in the fall and early winter. After 60 years, Emanuel Seyfert of Great Falls, Montana, still vividly recalls the bone-chilling winds that blew unrestrained across the frozen lakes. Seyfert says "it was some of the hardest work he ever did for 40 cents an hour." He added, "the work was very difficult, but few men quit because they were glad to have work." Marv and

Figure 1. As the lake temperatures cool in the fall, layers of Glauber's salt begin to form on the bottom and the edges of the lake. North Lake, Divide County, late summer, 1995.

Harlow Freund remember their father (Elmer) and their Uncle John coming home caked in mud from the waist down as they stood in the entry way removing layer after layer of clothes worn in an attempt to ward off the cold. When Francis Walsh was asked about the deplorable working conditions, he replied "you have to remember that these men were farmers, tough and able people" *(Figure 2).*

The FERA study evaluated hundreds of dried lakes and determined that there were at least seven large deposits in northwestern North Dakota. These seven deposits occurred in three general areas: Alkabo, Grenora, and Stanley *(Figure 3).* The FERA study determined that the major deposits all occurred in lakes that contained no drainage outlet, were the lowest depression that drained a large area, and were surrounded by a number of springs. Workers observed that the salinity of these lakes increased through the summer as the lake temperatures rose and the salt became more soluble. In the fall, the water temperatures dropped and the salt-saturated brines would precipitate sodium sulfate, initially as a sheet of crystals on the water surface that would settle to the bottom of the lake as it became too heavy. The thin surface layer of salt would often go back into solution in the spring, but the underlying salt beds that had formed over a period of thousands of years remained as crystals year round *(Figure 4).*

The FERA project estimated there was a total of 23.4 million tons of Glauber's salt in these deposits. Studies of additional lakes by the North Dakota Geological Survey and the U.S. Bureau of Mines in the late 1940's and early 1950's revised this estimate to over 30 million tons.

Figure 2. A work crew from the FERA project hand-augers a hole on a dried lake bottom in Divide County, fall, 1934.

Resource Development

A few years after the FERA reports identified a lake near Grenora as the largest deposit of sodium sulfate known in the state, the site was purchased by Ozark-Mahoning Mining out of Tulsa, Oklahoma. In 1937, as the company drilled wells in search of a water supply to be used in processing they were informed by the North Dakota Attorney General's office that the state of North Dakota maintained ownership of the lake bottom and therefore any minerals derived from it. Ozark-Mahoning worked out a lease agreement with the state and then, in 1938, began a lawsuit to quiet its title. In 1948, judgment was rendered for the company and the state appealed the decision which was upheld by the court. In 1961, after 24 years of inactivity at the site, two settling ponds were constructed on the west end of the lake and talk resumed in the local newspapers that a $500,000 processing plant would be built near Grenora. No salt was ever processed from the site. Local landowner Dave Jensen recalls that the summer of 1961 did not get hot enough to raise the lake temperatures to the desirable point and the company, disappointed over the unpredictability of our seasons, left the state.

A site just west of Alkabo in Divide County was developed by George Krem, a Chicago businessman (president of Holland America Company of Chicago), under the name Sodium Corporation of America. Work began in 1948 with construction of a dam across the southern end of North Lake which created a holding pond. In the fall, water was pumped from Miller Lake into the holding site, allowed to precipitate and waste water was drained back into Miller Lake. The remaining salt was scraped into a pile in January when the ground was sufficiently frozen to support the weight of vehicles *(Figure 5).*

It was anticipated that mining would continue at this locality for 40 years and plans were to establish a processing plant at Westby, Montana. Shortly thereafter, the plans changed and it was determined that the plant would be located near Alkabo, North Dakota. Initially it was projected that the project would require a permanent work force of 50 people, but only about a half a dozen were ever employed because the processing plant was never built. George Krem very much wanted to build a plant at Alkabo and at one point had raised the needed investment capital, but conditions would have required him to relinquish sole control over the project, something that he could not bring himself to do.

Because Glauber's salt is approximately half water, it is desirable to dry it prior to shipping to cut costs. A dryer, fueled by coal mined south of Westby, Montana, was used to dry the salt prior to shipping on the Soo line, but the operation was unable to remove a sufficient amount of water and the coal soot created a contamination problem for the salt. In the early 1950's, a railroad spur was built to within a mile of the site and several boxcar loads were

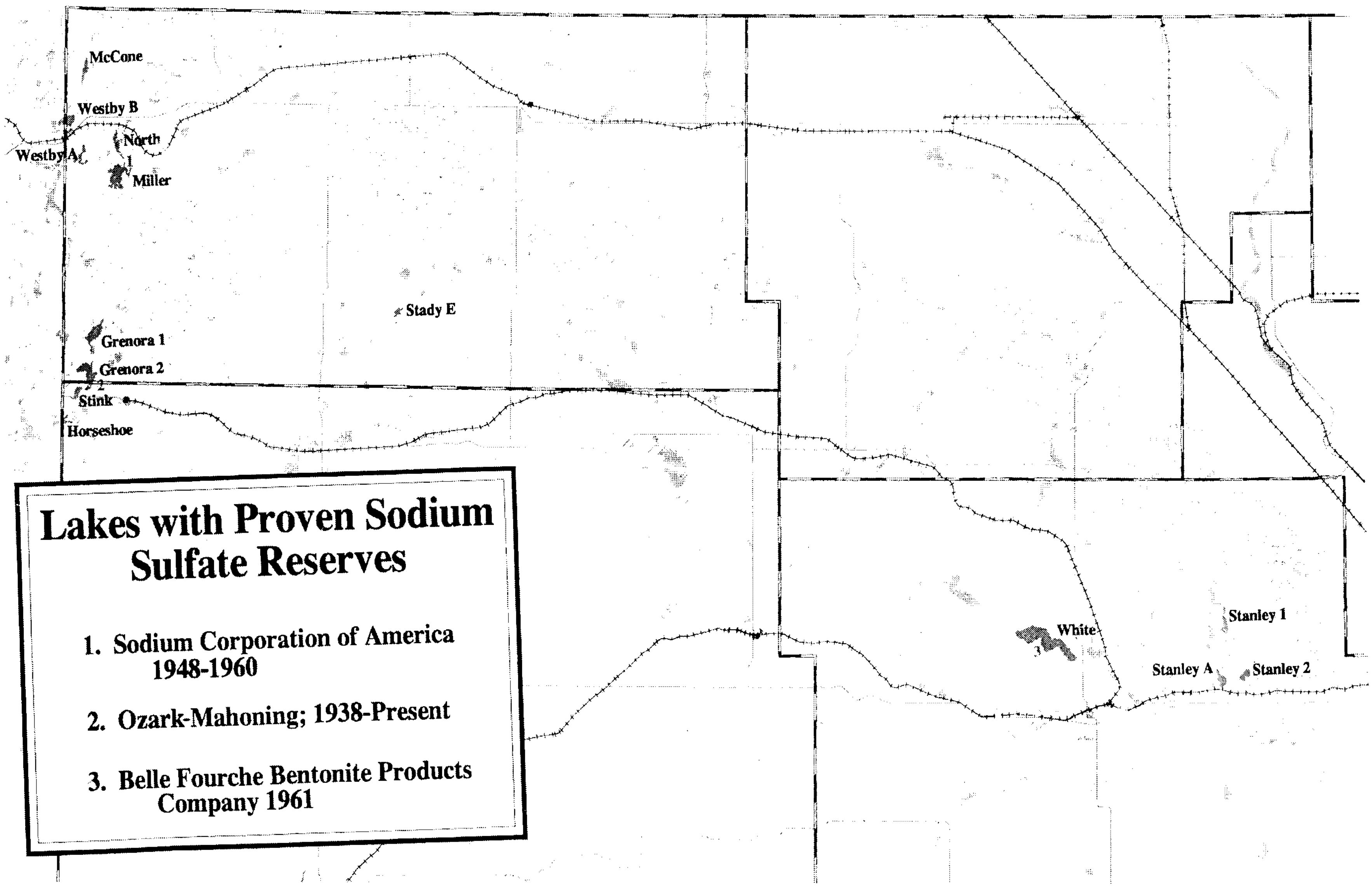


Figure 3. Map of the lakes in northwestern North Dakota. The highlighted lakes (darker colored) are those known to be underlain by layers of Glauber's salt.

Figure 4. Many of these lakes go completely dry in the fall leaving a layer of Glauber's salt several inches up to ½ foot thick. North Lake, Divide County, fall, 1995.

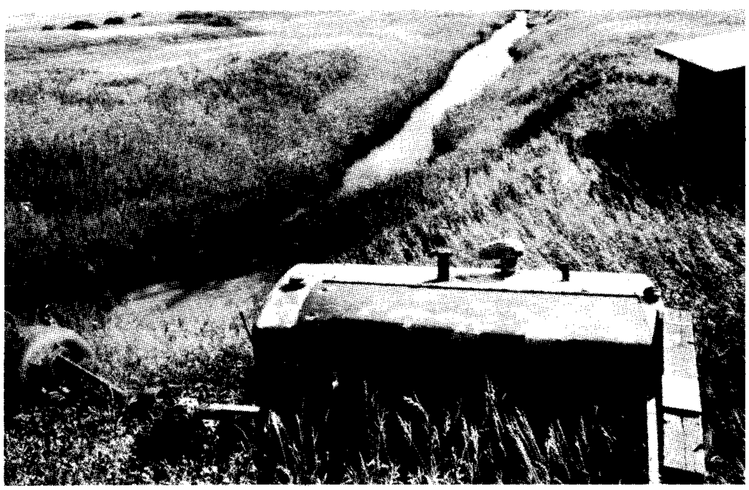
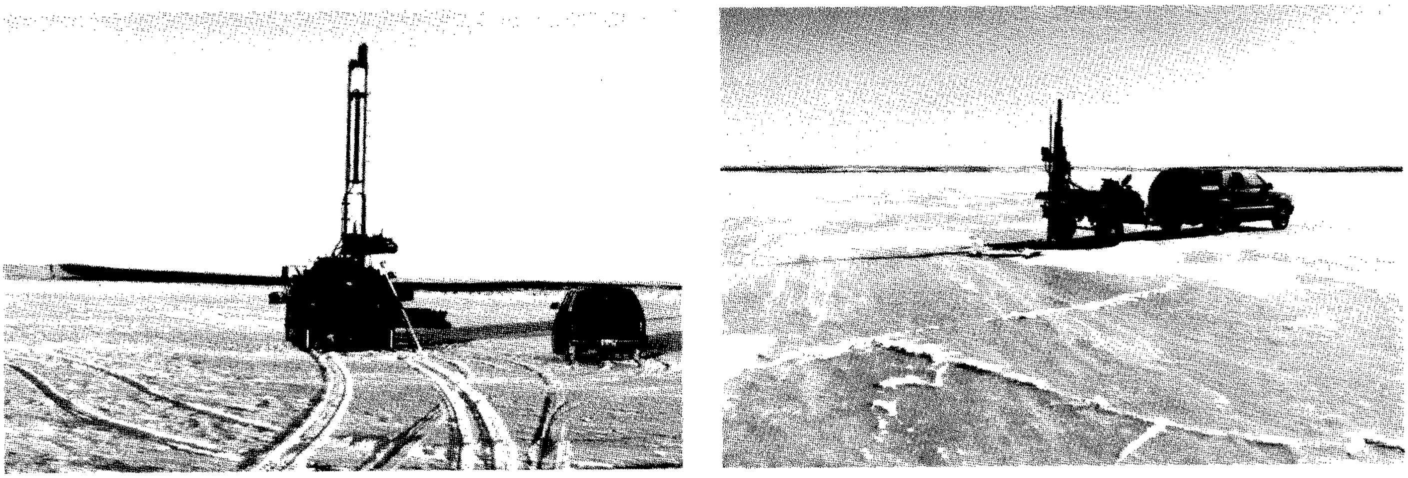


Figure 5. The Sodium Corporation of America's pump used to transfer brine from Miller Lake into their settling pond on North Lake, Divide County.

Figure 6. A large stockpile of sodium sulfate originally mined in 1961 from a reservoir adjacent to White Lake near Stanley in Mountrail County. The 20 acre reservoir is in the foreground.



Figures 7a and 7b. Drilling apparatus used by the Geological Survey to core through the sodium sulfate deposits beneath frozen lakes in the northwest corner of the state.

shipped east in an attempt to interest industry in the product. In 1951, records indicate that 996 tons of Glauber's salt was shipped out of state from this site. In the mid-1950's, several carloads of Glauber's salt were sent to Iowa. Unfortunately, this salt hardened in the boxcars like cement and had to be blasted out with dynamite, a setback that likely scared off any potential clients. Due to lack of markets and shipping costs, the site was abandoned in 1960. A stockpile of 10,000 tons of Glauber's salt left at the site eventually eroded away. Gillferd Rust, an employee of the company at the time, believes that they could have made a go of the operation had natural gas been readily available in the area at the time to cut their operating costs. Ten years prior to the abandonment of this site, George Krem listed "high and rising freight costs" along with an "unfavorable tariff situation with Canada" as two of the major obstacles to overcome in establishing a successful sodium sulfate processing plant.

In 1961, the Belle Fourche Bentonite Products Company out of Belle Fourche, South Dakota, began construction of a holding pond for processing sodium sulfate adjacent to White Lake near Stanley in Mountrail County. The site operated by pumping approximately 50 million gallons of water from White Lake into a 20-acre settling pond and then pumping the remaining water out just prior to freeze-up. The resulting salt was then dozed into a large pile to the east of the reservoir. The company had planned to erect a processing building west of Stanley to prepare the salt for shipping, but the plant was never built. A large pile containing approximately 120,000 cubic yards of sodium sulfate has sat at the site for nearly 35 years *(Figure 6)*.

Recent Study

The North Dakota Geological Survey began another study of the sodium sulfate deposits in 1995. Our purpose was to obtain more accurate information on the estimated reserves of salt and to collect cores and samples that would be available to industry for study. Holes were cored on five of the frozen lakes during early 1996 *(Figure 7)*. The unstable nature of the ice, due to its high salt content and the numerous springs around the lakes, made travel on the lakes treacherous.

The most troublesome aspect of the drilling program was posed by gas encountered in some of the sediments beneath the lakes. Although no tests were run on the gas, it was assumed to be a mixture of methane and hydrogen sulfide. Methane is a by-product of the decay of the organic matter in the mud and hydrogen sulfide is a product of the reduction processes involved with the sulfur ion in the layers of crystal salt. At times, the concentration of these gases were sufficient to pose a health hazard and drilling had to be discontinued.

The recent study by the North Dakota Geological Survey has resulted in an upward revision of the estimated sodium sulfate resources in the state to over 43 million tons (nearly double the initial FERA estimate). The thickest individual salt bed encountered was ten feet, although 20-foot-thick beds have been reported from at least one of the other lakes in this area *(Figure 8)*.

These brine lakes are too salty for most fish but do support aquatic life primarily in the form of *Artemia salina*, a small red or white colored crustacean. In some lakes in this area, Artemia is so plentiful their bodies give a pink to red hue to the Glauber's salt. Artemia are being harvested for tropical fish food from some of the lakes in Saskatchewan, Canada.

Status of Industry

Currently seven major sodium sulfate processing plants are operating in North America (four in Canada, two in the United States [Texas and Utah], and one in Mexico). Saskatchewan has had a long history of sodium sulfate production beginning in 1919, at Muskiki Lake. Over the past 75 years, more than 20 companies have mined sodium sulfate from ten sites in the province. In the early part of the twentieth century, sodium sulfate was used in the pulp and paper industry, glass, dye, textile and nickel industries, and to a lesser extent, in medicinal and tanning preparations and the manufacture of sodium sulfide. Historically, the largest percentage of sodium sulfate produced was consumed in the production of kraft paper, a trend which continued until the early 1990's. Historically, a fluctuating market has caused problems for the industry. Unpredictability in the natural sodium sulfate market stems from a decline in reliance of the kraft paper industry upon sodium sulfate and the large amount of sodium sulfate produced as a by-product in U.S. manufacturing. The U.S. Bureau of Mines estimated that world production of sodium sulfate in the early 1990's was approximately 51% natural and 49% by-product. The industry faces an unpredictable future. However, at the present time, sodium sulfate processors are experiencing an increased demand from the detergent industry.

A recent development in southern Saskatchewan, Canada, may hold promise for the development of the state's sodium sulfate resources. A sodium sulfate plant is in the process of converting to sodium bicarbonate production. This procedure requires the addition of carbon dioxide and anhydrous ammonia to sodium sulfate and results in the formation of sodium bicarbonate and ammonium sulfate. The Saskatchewan plant is currently looking at marketing the sodium bicarbonate to replace lime in sulfur scrubbing systems for smoke stacks, as sand blasting material, and eventually as food-grade items such as baking soda. There are seven coal-fired electric generating stations in North Dakota plus the Dakota Catalyst plant in Williston that potentially might benefit by using a sodium bicarbonate scrubbing system. In addition, ammonium sulfate is also marketable as fertilizer. Both carbon dioxide and anhydrous ammonia are scheduled to be marketable by-products of the Dakota Gasification Plant at Beulah.

The recent development of sodium bicarbonate production from these sodium sulfate deposits is an example of how changing technologies and markets can make natural resources that have sat idle for years suddenly become viable economic resources. This illustrates the importance of characterizing these resources so that we can supply the needed scientific information if and when opportunities, such as this, arise.

Figure 8. A three-inch drill core of a crystal layer of sodium sulfate salt obtained from a depth of 32 feet below Miller Lake in Divide County.

Mosasaurs, Sharks, and Other Marine Creatures from the Cooperstown Pierre Shale Site

By

John W. Hoganson, Michael Hanson, Dennis L. Halvorson, and Verla Halvorson

Figure 1. Mike Hanson and Dennis Halvorson at the Cooperstown site. Note "Indian Mounds" in background exposing the fossil-bearing Pierre Shale.

Fossil collectors with avocational interest in the science of paleontology have played a major role in the development of this science since fossils were first recognized as being the remains of prehistoric life. A few years ago I received a telephone call from Mike Hanson, an electrician from Cooperstown, North Dakota stating that he and a friend, Dennis Halvorson, Cooperstown's resident plumber, had discovered some fossil bones in the Sheyenne River valley south of Cooperstown (Figure 1). I visited Mike and Dennis in Cooperstown and discovered that they had found vertebrae, teeth, and other mosasaur remains in the Cretaceous age Pierre Shale. Mosasaurs were giant marine lizards that inhabited the Western Interior Seaway that covered most of North Dakota, including the Cooperstown area, about 75 million years ago (Figure 2). Isolated occurrences of mosasaur bones had been reported from the Pierre Shale in eastern North Dakota previously, and I did not view Mike and Dennis' fossils of particular significance, but asked them to keep me apprised of any additional discoveries. Shortly thereafter they began to find the remains of marine fishes, particularly sharks, and invertebrate animals with the mosasaur fossils. My interest in the site was stimulated by these new finds and Mike, Dennis, Dennis' wife Verla and I have been working together on fossils from this site since.

The Cooperstown site encompasses an area of about two square kilometers along the Sheyenne River southeast of Cooperstown, Griggs County, in a place referred to locally as the "Indian Mounds". The name refers to the haystack-shaped hills in the valley, which were thought by some to be Indian burial mounds. These hills, however, are erosional remnants of the once much more extensive Pierre Shale rock formation. It is in these rocks that the most diverse assemblage of fossils ever found in the Pierre Shale in North Dakota is located. In this part of eastern North Dakota the landscape has mostly been sculpted by glacial processes. There are large glacial erratics (boulders) in this valley resting on Pierre Shale surfaces which were deposited thousands of years ago when the Sheyenne River valley was choked with flood waters from melting of the last continental glaciers. Erosion of the valley at that time and since has exposed one of the thickest sections of Pierre Shale in the state. The lower part of the section, measured fom the level of the Sheyenne River, consists of 4.5 meters of the Gregory Member of the Pierre Shale. It is overlain by 38 meters of the DeGrey Member of the Pierre Shale. The Gregory Member consists of light brown to tan, calcareous claystone. Yellow-brown ironstone concretions occur in this member. The Gregory is highly fossiliferous and has yielded many different kinds of invertebrate fossils. The DeGrey Member is a light to dark gray noncalcareous shale. Thin beds (one to 15 centimeters thick) of very light gray bentonite (altered volcanic ash) occur throughout the

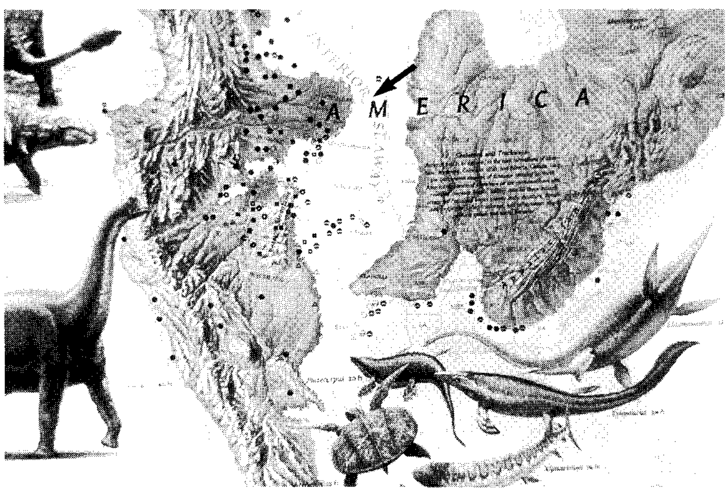


Figure 2. National Geographic Society map of the Western Interior Seaway showing location of the Cooperstown site.

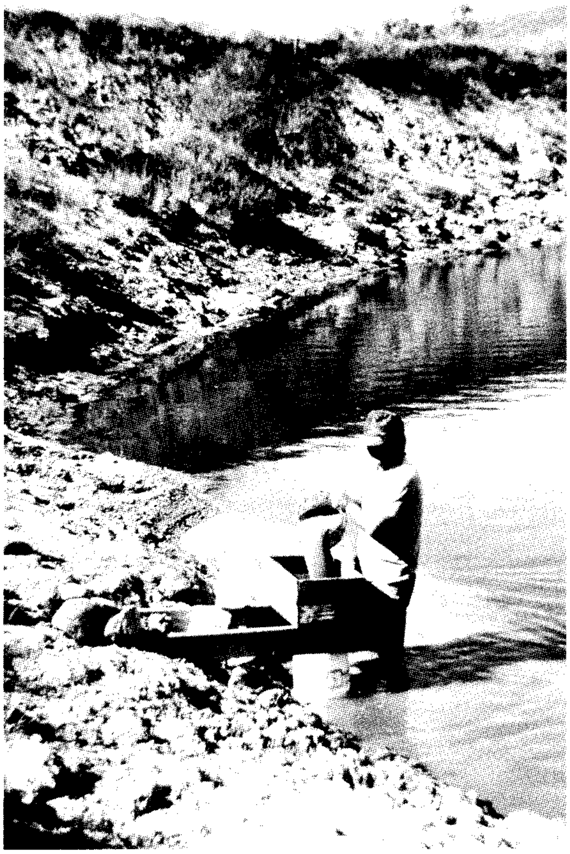


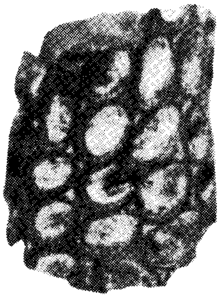
Figure 3. Mike Hanson screen washing Gregory Member claystones for fossils along the Sheyenne River.

Figure 5. Smithsonian reconstruction of a Cretaceous age seafloor community containing many of the animals represented by fossils at the Cooperstown site.

DeGrey, but are more common in the lower 6 meters of the member. Black, iron-manganese carbonate and light gray, phosphatic concretions are common in the lower part of this member. These concretions are often fossiliferous containing fragments of clams and other invertebrates. The upper 24 meters of the DeGrey Member is obscured by vegetation and glacial drift containing erratics that cap the hills. The remains of mosasaurs and other marine vertebrates are found in the bottom 7.5 meters of the DeGrey Member.

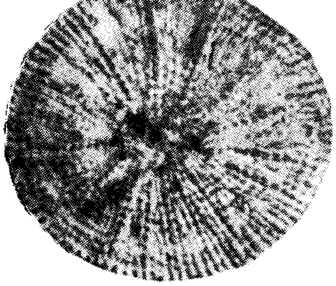
Screen washing of the fossiliferous claystones of the Gregory Member has yielded an extensive array of invertebrate fossils of creatures that inhabited the Pierre Sea (Figure 3). This fauna includes foraminifera (one celled organisms that secrete minute shells), bryozoa (lace animals--Figure 4A), brachiopods (*Lingula* -- Figure 4B), corals (*Micrabacia* -- Figure 4C and others -- Figure 4D), scaphopods (tusk shells), clams (*Inoceramus, Nucula* -- Figure 4E, *Nuculana, Pteria, Nemodon?* -- Figure 4F, oysters, and many others), snails (*Margaritella* -- Figure 4G, *Trachytriton* -- Figure 4H, *Atira, Oligoptycha, Graphidula?,* and many others -- Figure 4I), cephalopods (*Baculites gregoryensis* -- Figures 4J & 4K, *Didymoceras cohleatum, Didymoceras* -- Figure 4L, *Solenoceras mortoni* -- Figure 4M), annelids (worm tubes), crustaceans (the crab *Dakoticancer,* the lobster *Hoploparia,* the shrimp *Callianassa* -- Figure 4N, and the tiny bivalved crustaceans called ostracodes), starfish -- Figure 4O, and sea urchins (*Eurysalenia* -- Figures 4P & 4Q). The Cooperstown site is the only place in North Dakota where many of these kinds of fossils are found although similar fossil faunas have been recovered in South Dakota and Wyoming. These fossils suggest that the Pierre Sea, in the Cooperstown area 75 million years ago, was shallow and warm. The cephalopods indicate that the Gregory Member at the Cooperstown site is middle Campanian in age. That is, these rocks (including the fossil shells) were deposited on the floor of the Pierre Sea about 75 million years ago (Figure 5).

Several kinds of interesting fossils of vertebrate animals are found in the lower part of the DeGrey Member, just above the fossil bed containing the invertebrate fossils. These fossils provide information about the kinds of vertebrate animals that inhabited the Pierre Sea. Included are the teeth of several different kinds of sharks such as *Squalicorax* (extinct cow shark -- Figure 6A), *Pseudocorax* (another extinct cow shark -- Figure 6B), *Cretolamna* (Figure 6C), *Carcharias* (sand-tiger shark -- Figure 6D and cover), and *Squalus* (dogfish shark -- Figures 6E & 6F). The remains of bony fish are also present in the DeGrey, including the teeth of the salmonlike *Enchodus* (Figure 6G and cover). A tarso-metatarsal bone of the hesperornithid bird *Hesperornis* was also found in

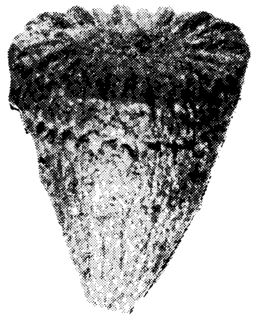


4A. Bryozoa
height 3 mm

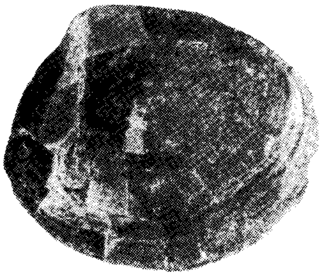
4B. Brachiopod *(Lingula)*
height 3 mm



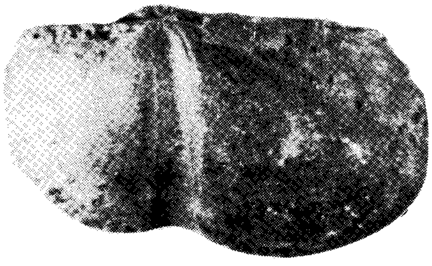
4C. Coral *(Micrabacia)*
width 4 mm



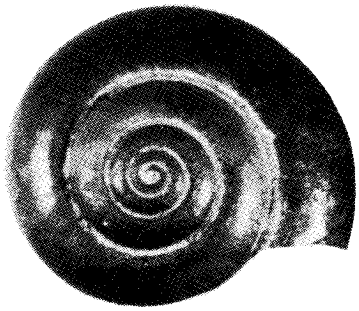
4D. Coral
height 11 mm



4E. Clam *(Nucula)*
width 17 mm

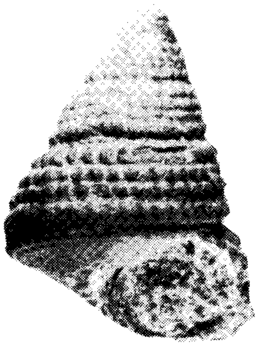


4F. Clam *(Nemodon?)* - width 3 mm

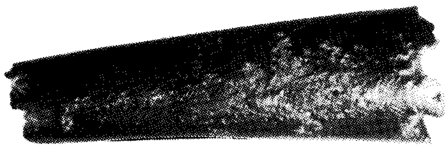


4G. Snail *(Margaritella)* - width 8 mm

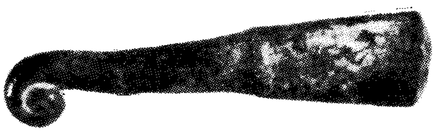
4H
Snail *(Trachytriton)*
height 20 mm



4I. Snail
height 12 mm

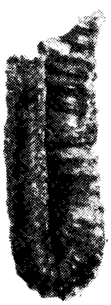


4J. Cephalopod *(Baculites gregoryensis,* adult*)*
length 55 mm

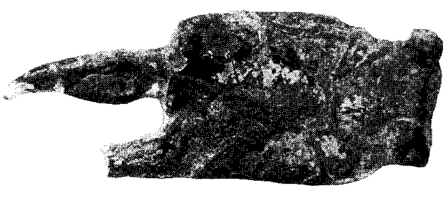


4K. Cephalopod *(Baculites gregoryensis,* juvenile*)*
length 11 mm

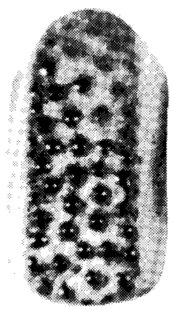
4L. Cephalopod *(Didymoceras)*
height 27 mm



4M. Cephalopod
(Solenoceras mortoni)
height 19 mm

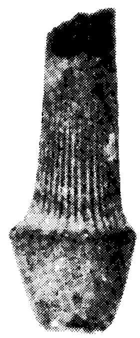


4N. Shrimp *(Callianassa,* claw*)*
length 20 mm



4O. Starfish (single plate)
height 7 mm

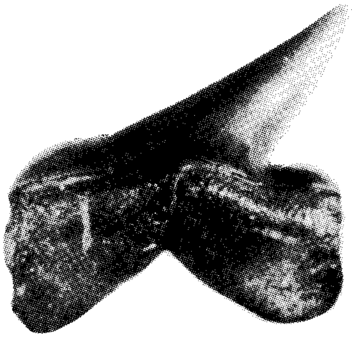
4P. Sea urchin *(Eurysalenia)*
width 7 mm



4Q. Sea Urchin
(*Eurysalenia,* spine)
height 4mm

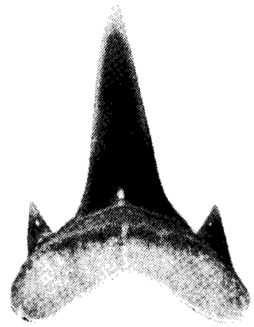
Figures 4A - 4Q. Fossils of invertebrate animals recovered from the Gregory Member of the Pierre Shale.

6A. Shark tooth *(Squalicorax)*
width 20 mm



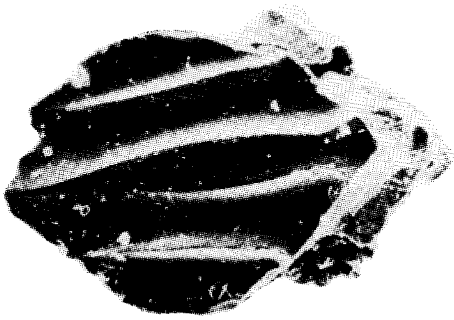
6B. Shark tooth *(Pseudocorax)*
width 10 mm

6C. Shark tooth *(Cretolamna)*
height 24 mm

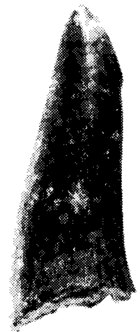


6D. Shark tooth *(Carcharias)*
height 10 mm

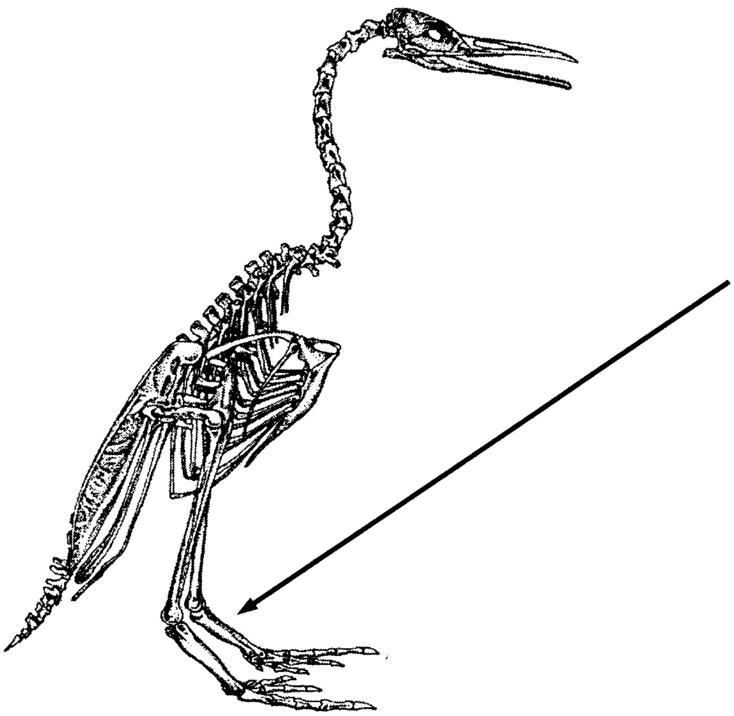
6E. Shark tooth *(Squalus)*
width 6 mm

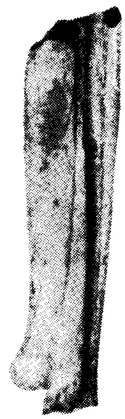


6F. Shark placoid scale *(Squalus)*
width 1 mm

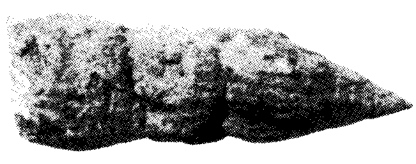


6G. Salmonlike fish tooth *(Enchodus)*
height 4 mm





6I. Tarso-metatarsal of a *Hesperornis* bird
length 90 mm



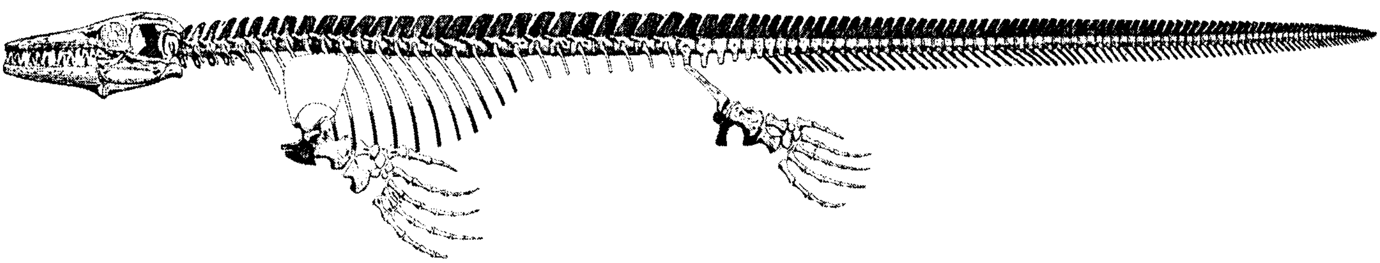
6J. Coprolite, fossilized excrement
length 31 mm

6H. Diagram of a *Hesperornis* bird skeleton. (From Carroll, 1988)
height 2 m

Figures 6A - 6J. Fossils of vertebrate animals recovered from the DeGrey Member of the Pierre Shale.

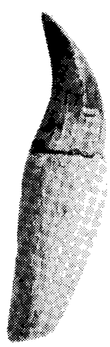
this interval (Figures 6H & 6I). *Hesperornis* was a large, up to about two meters tall, flightless seabird (see cover). This bird was equipped with sharp, pointed teeth and probably preyed on fast-moving fish and squids underwater. Although this bird was incapable of flight, it was a shift swimmer that propelled itself through the shallow, coastal waters of the Pierre Sea with its powerful hind legs similar to the modern loon. Coprolites, fossilized excrement, are trace fossils found at the site (Figure 6J). These fish and birds existed with the large marine reptiles, the mosasaurs, that inhabited the Pierre Sea.

The remains of twelve mosasaurs have been found in the lower part of the DeGrey Member from an area of about one-square kilometer at the Cooperstown site. Fossils of two kinds of mosasaurs, *Plioplatecarpus* and an unidentified mosasaurine, are present. Mosasaurs were marine lizards that inhabited tropical to subtropical oceans, like the Pierre Sea, in coastal areas with water depths of probably less than 100 fathoms (90 meters) during the last part of the Cretaceous Period (see cover). They, like the last of the dinosaurs, became extinct at the end of the Cretaceous, about 65 million years ago. Although they were large reptiles, and lived at the same time as dinosaurs, they were not dinosaurs and were most closely related to the living varanid (monitor) lizards (e.g., Komodo dragon of Indonesia). Like many dinosaurs, however, many mosasaurs were huge animals with long lizard-like bodies attaining lengths in excess of 7.5 meters (Figure 7A). Unlike their terrestrial lizard relatives, the limbs of mosasaurs were modified to form flippers. Mosasaurs swam by lateral undulations of the posterior part of their elongate bodies and laterally compressed tails. Their flippers were used primarily for steering rather than for propulsion as the animal glided through the water. The shape of the skeleton of *Plioplatecarpus* suggests that it was probably a slow but agile swimmer, similar to the living seal. Mosasaurs were active carnivores and among the main predators in the Pierre Sea as attested to by their large jaws studded with sharp, conical teeth (Figures 7B & 7C). They probably preyed on other mosasaurs, fish, turtles, cephalopods and other invertebrates. It has been suggested that mosasaurs relied on highly developed senses of sight and smell to locate and catch their prey.

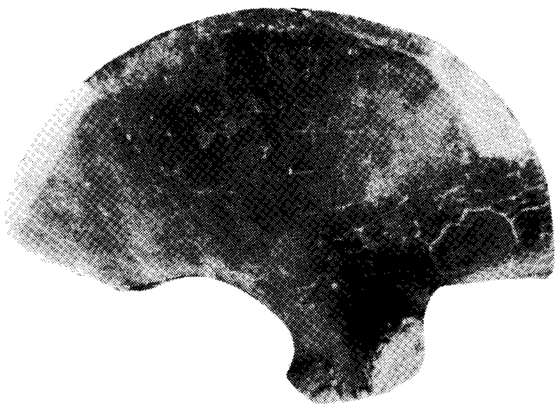


7A. Diagram of a mosasaur skeleton similar to the ones found at the Cooperstown site. (From Russell, 1967)

7B. Lower jaw of excavated *Plioplatecarpus* length 550 mm



7C. Tooth of excavated *Plioplatecarpus* height 70 mm



7D. Shoulder blade of excavated *Plioplatecarpus* width 308 mm

Figure 8. Tips of the lower jaws of the mosasaur, *Plioplatecarpus*, being excavated by Johnathan Campbell.

Figure 9. Dennis Halvorson, Johnathan Campbell, Mike Hanson and Seth Hanson excavating the *Plioplatecarpus* skeleton.

Figure 10. Mapping the position of the bones at the *Plioplatecarpus* excavation. (Left to right) Larry Robjent (St. Lawrence University, Canton, NY), Johnathan Campbell, John Hoganson, Orville Tranby. *Photograph by John Bluemle.*

Until last fall, the only mosasaur remains found at the Cooperstown site were isolated vertebrae, teeth, and other small skeletal parts. While exploring the far western portion of the Pierre outcrop area at the site, Mike and Dennis discovered a eight-centimeter-long section of mosasaur jaw, with teeth, beginning to weather out of the Pierre Shale on a small hill (Figure 8). Johnathan Campbell (the Survey's fossil preparator) and I traveled to Cooperstown expecting to spend two or three hours at the site extracting the jaw from the rock. Four days later we were still there excavating what was beginning to emerge as a fairly complete mosasaur skeleton. We had to terminate the dig because of bad weather, but returned to the site this July to complete the excavation. As expected, most of the skeleton was preserved, the most complete mosasaur skeleton ever found in North Dakota. It is difficult to determine at this point exactly how complete the skeleton is because the bones were removed in two very large and several smaller plaster field packages (blocks of rocks containing the fossil bones are encased in plaster casts before removal to help preserve the fragile bones -- Figures 9-12). The lower jaws with teeth (Figure 7B), disarticulated skull, first 20 vertebrae (articulated), shoulder blades (Figure 7D), coracoids, and front and back flipper elements are present and many other bones are hidden in the field packages. Preservation of the bones is excellent, allowing us to identify the skeleton as a six- to eight-meter-long specimen of the mosasaur called *Plioplatecarpus.*

We have begun preparation and study of the fossils from this important Pierre Shale site and have presented some preliminary results of our findings (Figure 13 and see list of additional readings). These fossils provide a glimpse of what life was like in the shallow, subtropical sea that covered the Cooperstown area. It was obviously teaming with life reflected by the variety of fossils found at the site. We expect to learn more as work continues on the fossils. One of the intriguing questions is how the mosasaurs at this site may have died. Is it possible that these animals all died at about the same time, suffocated by volcanic ash? The mosasaur bones are found in the Pierre Shale associated with layers of bentonite, altered volcanic ash. Did volcanic eruptions far to the west create enough air fall ash in North Dakota to decimate the mosasaur population in the Pierre Sea? We are also interested in how these animals interacted as a community. During preliminary cleaning of some of the mosasaur bones, teeth (Figure 6E) and placoid scales (Figure 6F) of dogfish sharks were found with the mosasaur bones. Sharks often lose their teeth while feeding. Could it be that dogfish sharks scavenged this mosasaur carcass? Or, perhaps the mosasaur preyed on the dogfish sharks and these teeth and scales are undigested residues. Hopefully we will be able to answer some of these questions.

Mike, Dennis, Verla, and I would like to thank Orville and Beverly Tranby and family and the Tim Soma family for allowing us to collect and study fossils from their properties (Figure 14). These fossils are currently in our laboratory at the North Dakota Heritage Center in Bismarck for curation and study. Most of the fossils, however, will eventually be exhibited at the Griggs County Museum in Cooperstown. We believe that the *Plioplatecarpus* mosasaur skeleton is complete enough to restore as a three-dimensional skeletal mount exhibit. Because of the importance of this specimen, Orville and Beverly and Beverly's sisters, Mrs. Gloria Thompson, Mrs. Jacqueline Evenson, and Mrs. Susan Wilhelm have decided to donate this fossil to the North Dakota State Fossil Collection for study and exhibit at the North Dakota Heritage Center. We thank them for this donation as it will be an educational and a popular exhibit that will be viewed by many. Chris Dill, Museum Director, State Historical Society of North Dakota, enthusiastically supports a mosasaur exhibit and has given us the authorization to proceed with the exhibit plans. A fossil restoration project such as this is a major and expensive undertaking and will be accomplished only through private donations. If any of you are interested in financially supporting the restoration of the Cooperstown mosasaur for exhibit at the Heritage Center please contact me at the North Dakota Geological Survey (701) 328-9700.

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Figure 11. Applying a plaster cast on some of the *Plioplatecarpus* bones. (Left to right) Johnathan Campbell, John Hoganson and Mike Hanson.

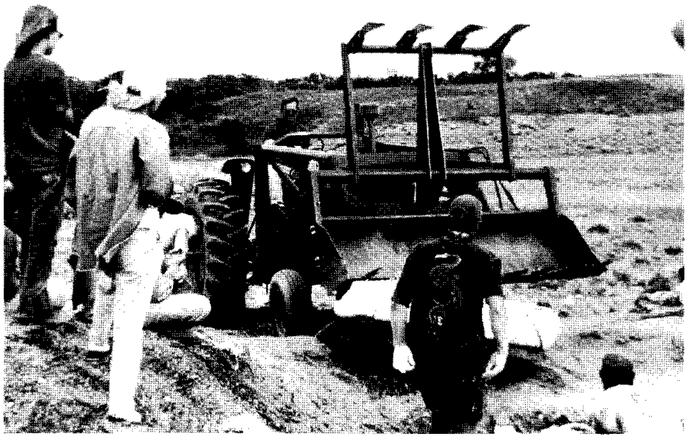


Figure 12. Orville Tranby lifting one of the large plaster casts containing *Plioplatecarpus* bones. Bev Tranby in foreground.

Figure 13. Johnathan Campbell restoring one of the *Plioplatecarpus* jaws in the NDGS paleontology laboratory at the North Dakota Heritage Center.

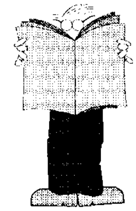
Additional Reading

Hoganson, J. W., Hanson, Michael, Halvorson, D. L., and Halvorson, Verla, 1996, *Stratigraphy and paleontology of the Pierre Shale (Campanian), Cooperstown site, Griggs County, North Dakota:* Proceedings of the North Dakota Academy of Science, v. 50, p. 34.

Hoganson, J. W., Hanson, Michael, Halvorson, D. L., and Halvorson, Verla, 1996, *Mosasaur remains and associated fossils from the DeGrey Member (Campanian) of the Pierre Shale, Cooperstown site, Griggs County, east central North Dakota:* Geological Society of America, Rocky Mountain Section, abstracts with programs, v. 28, no. 4, p. 11-12.

Figure 14. Mike Hanson, Dennis Halvorson, Gene Loge, Beverly Tranby, Orville Tranby, Johnathan Campbell, and Scott Tranby at the mosasaur excavation site.

NEW PUBLICATIONS



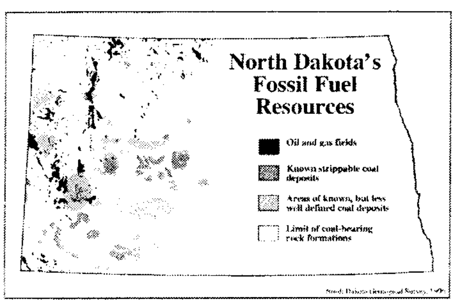
"North Dakota's Fossil Fuel" Postcard

Mark Luther and Rod Bassler

The NDGS has produced a new 4" x 6" black and white postcard that illustrates the locations of North Dakota's major energy-related mineral resources. *North Dakota's Fossil Fuel Resources* highlights the state's energy industry, showing the locations of major energy resources and activities within the state. Oil and/or gas fields are shown in black, while lignite coal deposites are shown in various shades of gray.

Created in the Survey's GIS Center by Mark Luther and Rod Bassler, *North Dakota's Fossil Fuel Resources* is a combination and modification/update of two previous Survey maps: the *Oil and Gas Fields Map of North Dakota* (originally created by Marv Rygh and modified by Tom Heck) and MM-20 *Active and Proposed Lignite Mines and Related Consuming Facilities in Western North Dakota* (created by Gerald Groenewold).

Fossil Fuels Postcard — Free on Request



The First 100 Years

The History of the North Dakota Geological Survey

1895-1995

John P. Bluemle

Compiled in recognition of the 100th anniversary of the North Dakota Geological Survey, this 125+ page report details the history of the Survey and its changing duties over the years. In addition to the chronology of geologic study in North Dakota, the volume includes numerous anecdotes and background relating to the times.

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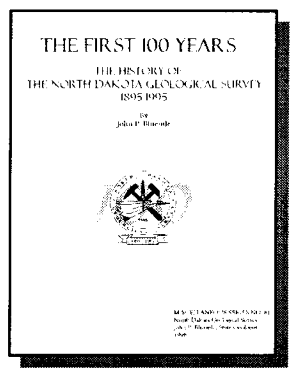

Quaternary Geology of Southern Lake Agassiz Basin Guidebook

Kenneth Harris, Mark Luther, John Reid

The guidebook for the 43rd Annual Midwest Friends of the Pleistocene Meeting held May 31-June 3, 1996. A 165-page document containing roadlogs and details about all of the features listed on pages 8 & 9.

NDGS Miscellaneous Series No. 82 — $10.00