NEWSLETTER
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Industrial Commission of North Dakota, North Dakota Geological Survey

Vol. 22, No. 3, Fall 1995

Johnathan Campbell with restored *Champsosaurus gigas* skeleton in the NDGS Paleontology Lab. *Champsosaurus gigas* was a crocodile-like reptile that inhabited swamps in western North Dakota about 55 million years ago, when the climate was subtropical, probably similar to that of Florida today. *Champsosaurus gigas* is believed to have been an aggressive underwater predator with large, powerful back legs; the specimen here is shown as if it were springing off the bottom of a pond after a fish. See page 8 for more on *C. gigas*, which is now on display at the North Dakota Heritage Center. *Photo by John W. Hoganson.*

FEATURES

DEPARTMENTS

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

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

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NEWSLETTER

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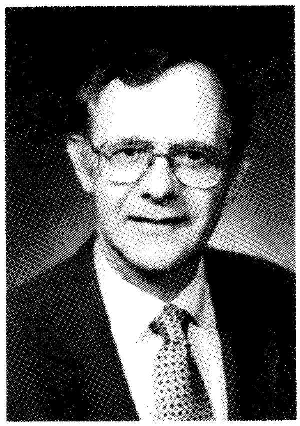
NORTH DAKOTA GEOLOGICAL SURVEY 1895

FROM THE STATE GEOLOGIST

by John P. Bluemle



The Seventh International Williston Basin Symposium was held in Billings, Montana from July 23 to 25. The Symposium was sponsored by the Montana, North Dakota, and Saskatchewan Geological Societies and the Fort Peck Tribes, which made a substantial financial contribution. People attending the Symposium came from at least 16 states and 5 provinces; Alberta with over 100 attendees was probably best represented, followed closely by Montana and Colorado.

By all measures, the Symposium was a success. The attendance was exceptional (something over 450), the core workshop had to turn away dozens of additional applicants, both field trips were sold out, the program featured a slate of excellent papers and poster displays, and there was an interesting and pertinent array of commercial, educational, and government-agency displays (regarding the last, I want to thank Duncan McBane, who made display space available to the North Dakota Geological Survey without charge).

Interest in the current Lodgepole Play in North Dakota was high (someone commented that the whole gathering might as well have been dubbed the 7th International Lodgepole Symposium). That's an overstatement, but interest in the Lodgepole and the play that began in the Dickinson, North Dakota area was certainly intense. The Lodgepole play is one of the most exciting things going on in North America in the oil patch today. I'm not sure whether I discussed the Lodgepole with every one of the 450 or 500 people who were there — some of them may not have been interested in the Lodgepole, but if so, they were few.

The North Dakota Geological Survey was well represented. Survey geologists authored or co-authored six of the 34 papers that were presented and three of the 16 poster presentations. Survey geologists Randy Burke and Paul Diehl presented the Lodgepole reef portion of the Core Workshop and Tom Heck gave a talk at the Workshop on the Lodgepole Formation. Topics discussed during the technical sessions by NDGS geologists included Waulsortian Mounds (Randy and Paul), salts (Julie LeFever), the Wiley Field (Mark Luther), resource assessments (Tom Heck), and the petroleum potential of the Birdbear Formation (Julie). I think the efforts of our geologists helped measurably to make the symposium the success it was. The symposium volume table of contents is reprinted on page 4; the volume itself is available for $75 plus shipping from the North Dakota Geological Society, P.O. Box 82, Bismarck, ND 58502 (customers will be invoiced).

I was personally disappointed to have to miss the pre-meeting Central Montana fieldtrip ("Mississippian Shallow to Distal Ramp Settings") led by Don Kent from the Department of Geology at the University of Regina. I heard a lot of positive comments about the trip. It's my understanding the trip will be run again next summer when the Rocky Mountain Section of the American Association of Petroleum Geologists meets in Billings; maybe some of us will get another chance. There really isn't any substitute to seeing these rocks in the field and exposed Mississippian rocks are hard to come by in North Dakota. Of special interest to me are the exposed Lodgepole reefs, which will be revisited.

I am especially enthusiastic about this symposium because it is bound to have a positive impact, not only in North Dakota (and I'll admit that's the most important thing to me), but also throughout the Williston Basin. Most of the attendees were geologists and it's geologists who initiate oil plays. The ideas expressed in July in Billings will result in next year's new oil plays. It's probable that North Dakota will be the main beneficiary of the meeting; certainly North Dakota topics figured prominently in the symposium. Even prior to the symposium the Survey had been experiencing an overwhelming recent demand for information on current projects as well as things done years ago by our geologists, and calls and personal visits by people researching the Lodgepole and Red River keep coming in. It seems that it wasn't long ago when interest in North Dakota oil was close to zero; certainly not so today! We are going to be seeing a lot of activity.

Finally, I want to congratulate Kipp Carroll, who was General Chairman of the Symposium; Dennis Rehrig, Program Chairman; Bob Fisher, who organized the Core Workshop; and all the other members of the Montana Geological Society whose hard work made the whole thing such a success.

Centennial Celebration

1995 is the centennial year of both the NDGS and the State Historical Society, and both agencies and many friends and supporters celebrated that fact with a noon-time gathering at the Heritage Center Plaza on June 23rd. Lunch and a large cake were enjoyed by all, accompanied by the beautiful songs and ballads of Mandan-area musician Chuck Suchy. At the close of the party, State Geologist John Bluemle (left), former Governor Art Link (center), and State Historical Society Superintendent James E. Sperry (right) planted a larch tree in the Centennial Grove on the west side of the capitol grounds. *Photos by Todd Strand, Photo Archivist, North Dakota State Historical Society.*

INDUSTRIAL COMMISSION OF NORTH DAKOTA

Edward T. Schafer, Governor — Heidi Heitkamp, Attorney General — Sarah Vogel, Commissioner of Agriculture

RESOLUTION

WHEREAS, the North Dakota Geological Survey is celebrating 100 years as the State's primary source of geological and mineral resource information, and

WHEREAS, the North Dakota Geological Survey, in evaluating the extent and occurrence of oil and gas, lignite, and other mineral resources, recognizes the importance of the State's mineral resource industry, and

WHEREAS, the North Dakota Geological Survey provides accurate, objective geological information to assist other State agencies in their regulatory duties, and

WHEREAS, the North Dakota Geological Survey's mission is to investigate the geology, hazards, and resources of the State; to administer regulatory programs and act in an advisory capacity to other State agencies; and to provide public information and service to the people of North Dakota,

BE IT THEREFORE RESOLVED: that the Industrial Commission joins the North Dakota Geological Survey in celebrating its 100th anniversary and strongly supports its role as the State's primary source of geological information, and

BE IT THEREFORE FURTHER RESOLVED: that a very special 'thank you' be extended to all of the employees, past and present, who have devoted time, energy, and talent to assure that the North Dakota Geological Survey's mission is accomplished and evolves to meet the needs of all North Dakotans.

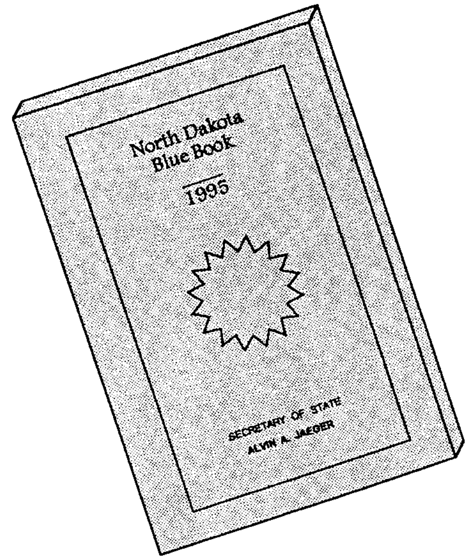
Dated this 8th day of June 1995.

INDUSTRIAL COMMISSION OF NORTH DAKOTA

Edward T. Schafer, Governor — Heidi Heitkamp, Attorney General — Sarah Vogel, Commissioner of Agriculture

Karlene K. Fine, Executive Director and Secretary
600 East Boulevard Avenue - State Capitol - Bismarck, North Dakota 58505
Phone: (701) 224-3722 FAX: (701) 224-2820

North Dakota Blue Book



The 1995 edition of the *North Dakota Blue Book* was recently published by the Secretary of State's Office and is available at the State Historical Society museum store. The book offers a comprehensive overview of North Dakota's history, government, resources, and diverse people, and represents a collaborative effort by a variety of individuals across the state. To order the *North Dakota Blue Book*, send $17.00 (plus $2.50 shipping and handling; Bismarck residents add 6% sales tax; others add 5%) to The Glass Box, State Historical Society, 612 East Boulevard Avenue, Bismarck, ND 58505-0830. Make checks payable to the State Historical Society.

NDGS Hires New Publications Clerk

Bismarck-native Sheila Senger recently began work as the Survey's Publications Clerk. Sheila graduated from Bismarck High School in May of 1985, and in 1990 she graduated from the Secretarial Program at Interstate Business College in Bismarck. Sheila worked at National Car Rental in Bismarck until 1992, when she moved to Dickinson to work for Southwest Area Child Support Enforcement.

Sheila replaces Eula Mailloux who retired last December after 15 years with the Survey. If you call or write requesting maps or publications, odds are that Sheila will take care of your order. Take a moment to say hello and wish her well in her new position.

USGS Topographic Map Prices Increase

Effective September 1, 1995, the cost of U.S. Geological Survey 7.5-minute topographic maps will increase from $2.50 to $4.00 per map; the cost of other USGS maps is unchanged. The 7.5-minute series (1:24,000 scale, or 1 inch on the map equals 2,000 feet on the ground) is perhaps the most popular USGS map product, used by all manner of scientists, engineers, planners, and outdoor enthusiasts. The NDGS sells these and other federally produced map products through our Earth Science Information Center.

Readers Respond

In the last issue of the *NDGS Newsletter* I included a short article on an unusual example of the Taylor Bed silcrete, pleading, in a sense, for help in explaining how the pillow-like upper surface formed. The article caught the attention of several people who kindly shared their ideas. Russ Pigors, Mike Hedtke, Gordon Bell and others have suggested a variety of possible mechanisms for the formation of these unusual structures, including concretionary growth, exfoliation, organic growths, settlement due to differing sediment densities, and — my personal favorite — complete replacement of pillow lava. To anyone who has seen pillow lavas, the silcrete does indeed bear a striking resemblance of form!

Though I remain uncertain how these structures formed, it seems likely that differences in sediment density and composition, and thus behavior under load, were in some way responsible. For those who want to see the rock in person, I have found another more accessible occurrence — a similar stone is used as rip rap along the northwest side of Garrison Dam. I want to thank all of you who brightened my day, and enlarged my mind, with your comments. I'll try to have similar articles in future issues.

1995 GUIDEBOOK
SEVENTH INTERNATIONAL WILLISTON BASIN SYMPOSIUM
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GEM AND MINERAL SHOW

Central Dakota Gem & Mineral Society
21st Annual Show
September 23-24, 1995
Mandan Community Center, Mandan, North Dakota

Wanted: Volunteers to Work with Maps

The United States Geological Survey (USGS) Volunteer for Science Program is pleased to announce a unique volunteer opportunity. USGS Earth Science Corps (ESC) volunteers, either individuals or groups, adopt areas near their home or favorite recreation spot and provide Federal agencies with earth science data. ESC volunteers begin by annotating USGS maps with changes that aid in future map revision. The areas are defined by one or more of the over 54,000 USGS topographic map quadrangles in the conterminous USA. The ESC has a toll free telephone number, 800-254-8040, a fax number (703) 648-6265, and an internet address of escorps@usgs.gov. Or write us at USGS Mapping Volunteers, MS 513, Reston, VA, 22092.

Oil and Gas Exploration and Development Activity in 1994

By Tom Heck

Once again I review the past year's drilling. During 1994, one-hundred and eleven wells were drilled and completed. Only two years in North Dakota's previous history, 1972 and 1951, saw fewer wells drilled. In those two years, 90 and 10 wells were drilled, respectively. If you focus only on the number of wells drilled one might conclude that 1994 was a very bad year. You would be wrong. 1994 was a year of unusual contrasts with a number of important development, extension, and wildcat wells drilled in the Lodgepole mound play and the horizontal Madison and Red River plays. One such completion was the Duncan Oil Inc. #1-11 Knopik (see Table 1). This was the discovery well for Eland Field and it caught the attention of the domestic oil industry with its exceptional flow rates. The well had an initial potential of 2,707 barrels of oil per day (BOPD) and was the confirmation discovery well for the Lodgepole Waulsortian mound play in the Dickinson area. The existence of more than one mound has implications for other parts of North Dakota. Where there are multiple mounds in one area there can easily be two or more mounds in another. Companies are currently searching for another concentration of mounds similar to that at Dickinson.

Another area of interest was in north-central North Dakota where Tidal Resources (USA) Inc., Camwest Limited Partnership, Amerada Hess Corp., and Ballantyne Oil all drilled one or more horizontal Madison wells in existing fields. Tidal drilled seven wells in Haas Field, Camwest drilled two in Rival Field, Amerada Hess drilled one in Newburg Field, and Ballantyne Oil drilled one in Wayne Field. Many of these wells will not produce significant volumes of oil but the interest in the play, so much like the Madison play in southeast Saskatchewan, remained high during the year.

A few horizontally drilled wells were also still being completed in the horizontal Bakken play in western North Dakota but the second-most exciting play in North Dakota was heralded by the discovery of Cedar Hills Field in Bowman County. The horizontal Ordovician Red River B zone play was successfully extended into North Dakota from Montana, where it was first drilled in 1987, in an area where vertically drilled B zone wells were marginally economic at best. Meridian Oil Inc. completed the Larkin #14-18H in section 18, T131N, R105W for an IP of 250 BOPD and, as a result, Bowman County has become another hot area. While the flow rates are not up to Lodgepole mound standards, the IPs are promising and the wells will almost certainly be money makers. The play has the potential to cover tens of thousands of acres and there will be many more wells drilled in the play.

Besides Eland and Cedar Hills Fields, eight other new pools were discovered. Data on all ten discoveries are listed in Table 1. The mixture of different stratigraphic horizons containing the discoveries is typical for the state. Four of the pools are Madison pools, the main producing horizon in the state. A fifth pool is in the Lodgepole Formation and could be included with the Madison pools as the Lodgepole belongs to the Mississippian Madison Group. The remaining five pools include two Devonian Birdbear, one Silurian, and two Ordovician Red River pools. The multi-pay potential of North Dakota is well-known, but the deeper potential has been overlooked for the last few years. Most of 1994's deeper new-pool discoveries were either re-entries or recompletions and, for a number of years, several new pool discoveries have been made within known fields. Each such new pool reinforces the idea that all zones must be evaluated before abandoning a well. In a state where fewer than 4,000 wells even penetrate pre-Mississippian strata the potential for many undiscovered fields and pools is significant.

I've described the highlights of 1994 and, hopefully, pointed out areas where some future highlights will be from. When all things are considered, I think 1994 was a very good year!

TABLE 1. 1994 NEW POOL DISCOVERIES

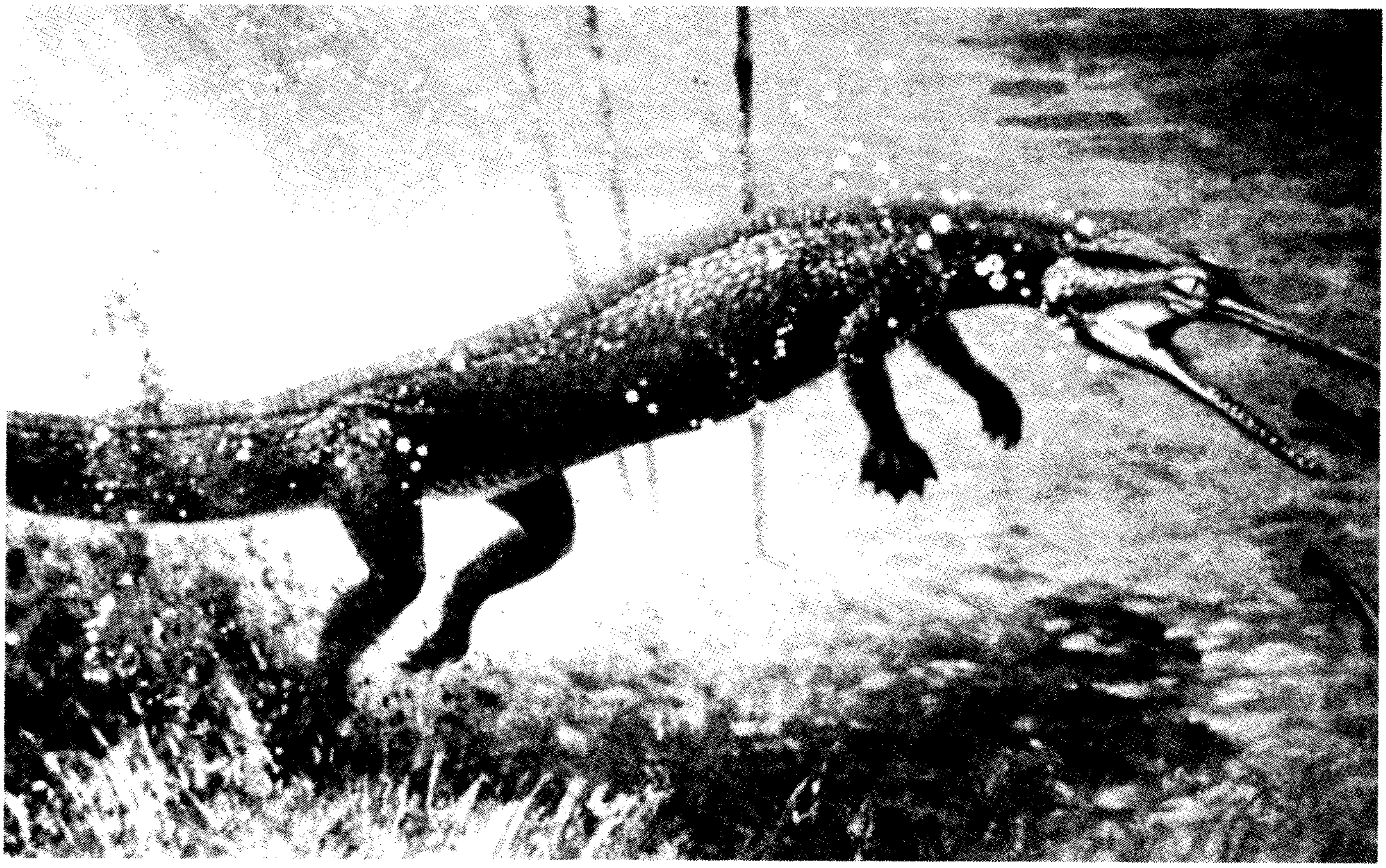
COUNTY FILE NO. ORDER #	COMP. DATE	OPERATOR WELL NAME LOCATION	FIELD -POOL	MEASURED DEPTH -SPACING	PERFORATED INTERVALS	IP-BOPD	GOR- GRAV.	WATER
Ward 13642 6850	4/5/94	Texas Crude Energy, Inc. Smetana "31" #1 Sec. 31, T160N, R83W	Great Northern Madison	4,800 80	4,656-4,666	128	204 29.4°	3
McKenzie 12550 6919	7/1/94	Pantera Petroleum North Branch #22X-35 Sec. 35, T148N, R102W	North Branch Madison	11,500 160	11,000-11,010 11,022-11,038	122	673 35°	7
McKenzie 8933 6896	7/5/94	Flying J Oil & Gas, Inc. Flying J State #13-26 Sec. 26, T150N, R97W	North Fork Silurian	13,760 320 12,578-12,588	12,526-12,536 12,548-12,552 12,628-12,634	80	3,125 49.1°	355
McKenzie 13635 6922	8/26/94	Meridian Oil, Inc. Nelson Flat Top Butte #11-24 Sec. 24 T146N, R102W	Flat Top Butte Birdbear	13,000 320	10,709-10,712 10,676-10,678	303	993 42.6°	25
McKenzie 9707 6936	9/3/942	Geolinear Co. Young Bear #32-4RE Sec. 4, T148N, R92W	Heart Butte Madison	9,870 80	9,106-9,134	145	690 40.7°	140
McKenzie 13452 7028	9/28/94	Meridian Oil, Inc. MOI Cinnamon Creek #31-7 Sec. 7, T145N, R102W	Cinnamon Creek Birdbear	13,200 160	10,913-10,921	548	800 41.9°	89
Bowman 6050 6965	10/12/94	Castle Resources Inc. Boonedog #1 Sec. 30, T129N, R98W	Cow Butte Red River	9,226 160	9,055-9,062	40	250 37°	100
Billings 12331 7002	10/13/94	Meridian Oil, Inc. MOI Roosevelt #44-27H R/E Sec. 27, T1463, R102W	Roosevelt Madison	10,875 160	9,023-9,029	43	0 35.4°	204
Bowman 13695 7045	10/31/94	Meridian Oil Inc. Larkin #14-18H Sec. 18, T131N, R105W	Cedar Hills Red River B	12,104 320	open hole 9,104-12,104	250	320 32.1°	24
Stark 13715 7032	12/2/94	Duncan Oil, Inc. Knopik #1-11 Sec. 11, T139N, R97W	Eland Lodgepole	10,150 320	9,714-9,724 9,730-9,740 9,746-9,760	2,707	573 45°	0

RESTORATION AND DISPLAY OF A CROCODILE-LIKE *CHAMPSOSAURUS GIGAS* SKELETON AT THE NORTH DAKOTA HERITAGE CENTER

by
John Hoganson and Johnathan Campbell

While hunting sharp-tailed grouse on a hot September afternoon in 1992 geologists Mark Luther (NDGS) and Chris Quinn (Dickinson) discovered several vertebrae of a crocodile-like champsosaur weathering out of the Sentinel Butte Formation. Mark and Chris escorted us to the site — in badlands terrain on United States Forest Service-administered land near Tracy Mountain, Billings County — in October, 1993 to examine the fossils. We determined by additional prospecting for fossils and preliminary excavation that the site had the potential of being one of the most important Paleocene (about 55 million years old) champsosaur sites yet discovered. Additional excavation in the summer of 1994 by us and representatives of the U. S. Forest Service led by Carol McCoy Brown, USFS geologist in Billings, produced two nearly complete skeletons of *Champsosaurus gigas*. The most complete skeleton (about 85%), with a fairly well preserved skull, was chosen to be reconstructed into a three dimensional skeletal mount for display at the North Dakota Heritage Center.

Champsosaurus gigas (*champsos*=crocodile, *sauros*=reptile, *gigas*=very large), initially described by Dr. Bruce Erickson of the Science Museum of Minnesota, is one of several extinct species of crocodile and crocodile-like reptiles that once inhabited western North Dakota. As suggested by its name, *C. gigas* was the largest species within the *Champsosaurus* group, attaining lengths up to about 10 feet. The eosuchian reptile *C. gigas*, although not a true crocodile, resembled the living long-snouted gavial crocodilians. *C. gigas* skeletal parts, particularly vertebrae, are commonly found in Paleocene-

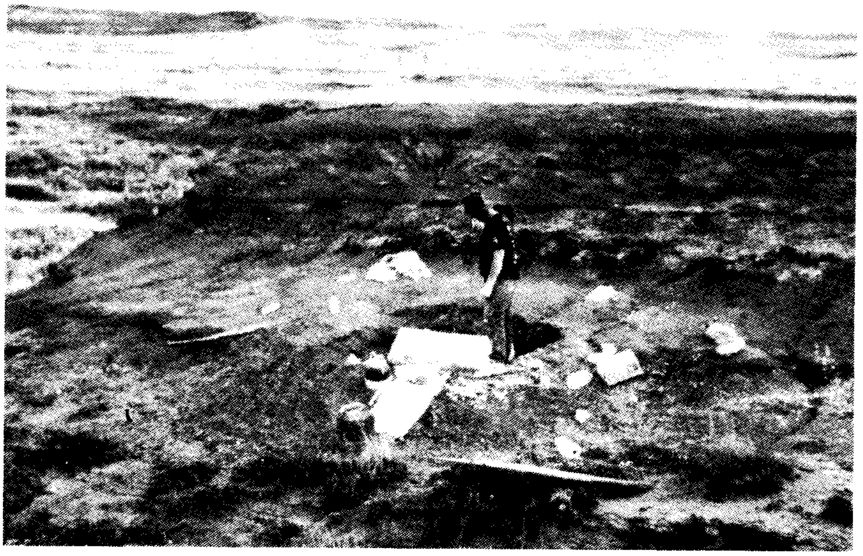


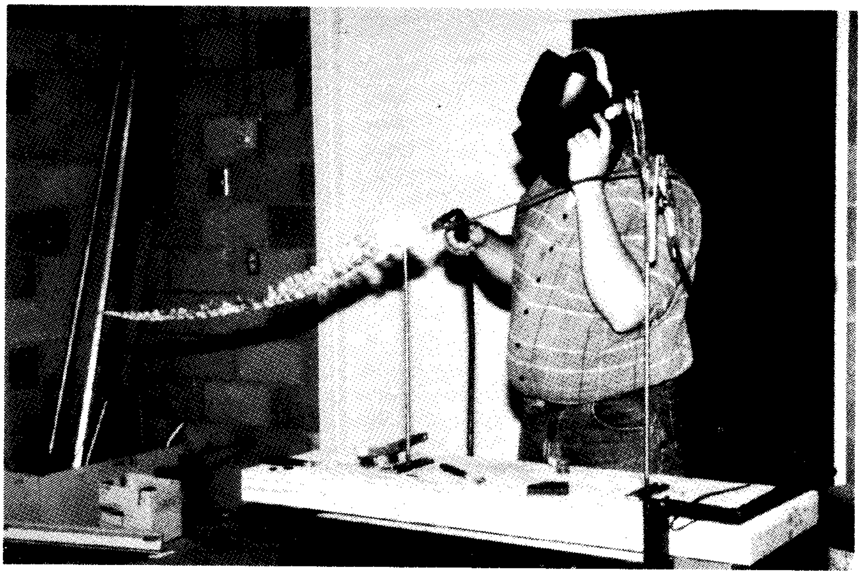
Life restoration of Champsosaurus lunging off the bottom of a pond after a fish. Painting by Jerome Connolly, The Science Museum of Minnesota.

age rocks in North Dakota, but nearly complete skeletons are extremely rare. We have also recovered many other fossils from the thin, fossil-bearing carbonaceous claystone at the Tracy Mountain site including the remains of turtles, alligators, crocodiles, fish, and freshwater snails and clams.

Vertebral centrums are present from the cervical to about the middle of the tail in the restored specimen. Six caudal vertebrae are estimated to be missing from the back part of the tail. If this estimate is correct, the tail of *Champsosaurus gigas* is shorter than previously thought (Campbell and Hoganson, 1995). The skull is complete but was badly crushed due to compaction and the lower jaws were fused to the uppers. Separation of the skull from the lower jaws and re-inflation of the skull to its three dimensional original shape was accomplished by prying apart and removing bone pieces and gluing them back together with either Super Glue or 5-minute epoxy. Most limb bones were present. Parts that had to be fabricated were either broken or missing and included pieces of the pectoral and pelvic girdles, neural arches, ribs, chevrons, and some foot bones. These were made from Plaster of Paris with internal wire supports.

Champsosaurus gigas inhabited ponds and swamps in western North Dakota about 55 million years ago when the climate was subtropical, probably similar to Florida's climate today. This was about 10 million years after the last of the dinosaurs became extinct. It is believed that *C. gigas* was an aggressive underwater predator that fed on fish because of its hydrodynamic



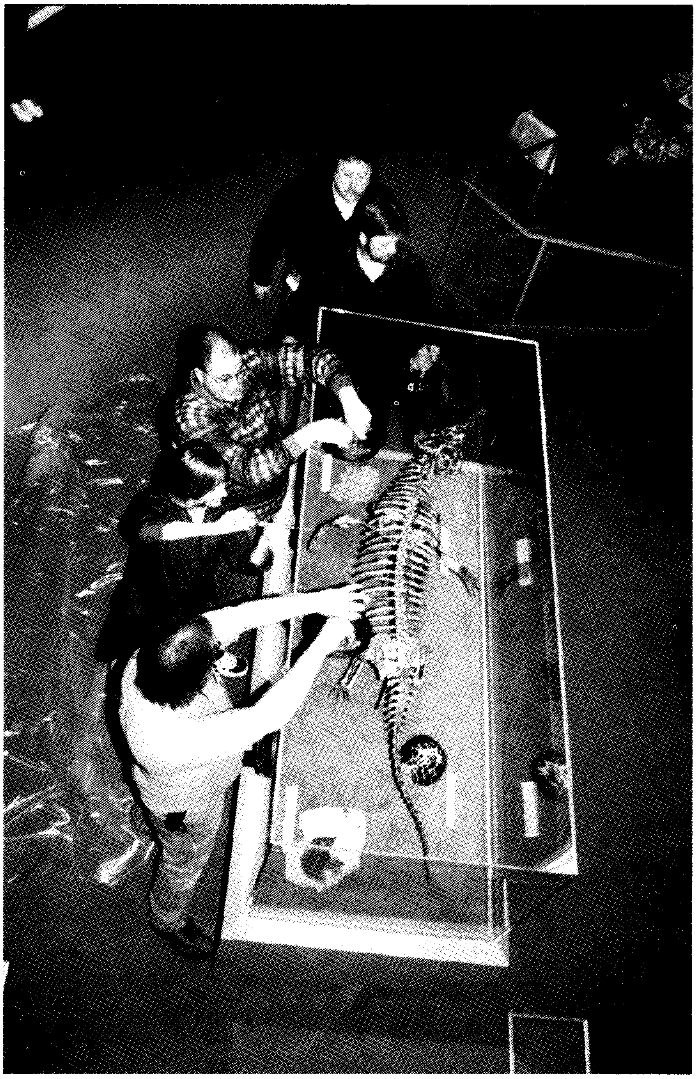


Top - Champsosaur skeleton encased in a plaster field jacket at the Tracy Mountain site.

Middle - Johnathan Campbell freeing the champsosaur skull from rock.

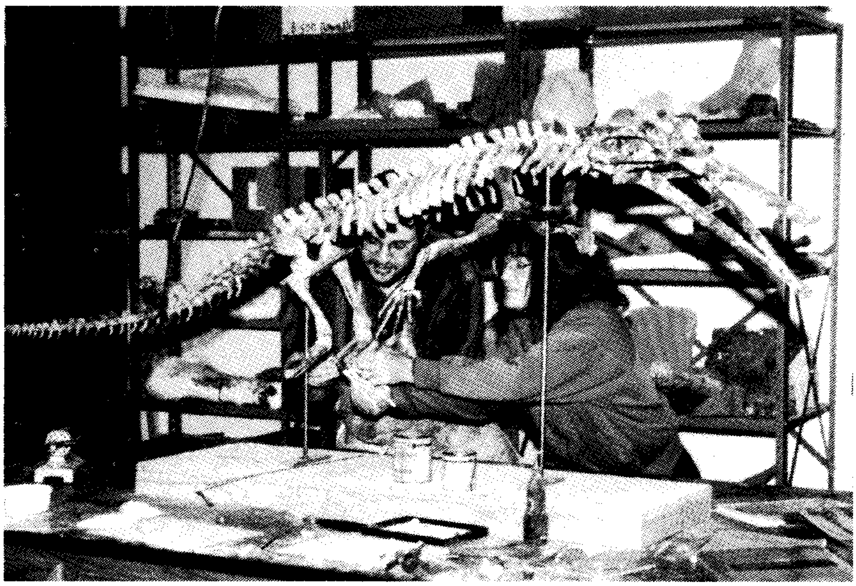
Bottom - Johnathan Campbell welding a support frame for the champsosaur skeleton.

body, powerful back legs, and long snout lined with sharp, pointed teeth. It is likely that these animals spent much of their time submerged in water, lying on the bottom waiting for prey. When a fish swam by, the champsosaur would quickly lunge off the bottom after it, propelled by its large, powerful back legs. We hope that the posture of the restored skeleton suggests that activity to the viewer.



Restoration of the skeleton by Johnathan Campbell took three months to complete. Claudia Berg and Brian Hushagen of the State Historical Society of North Dakota were responsible for exhibit design and specimen cabinet construction. Funding for the restoration and exhibit was from the United States Forest Service--Custer National Forest, State Historical Society of North Dakota, and North Dakota Geological Survey.

Campbell, J. M., and Hoganson, J. W., 1995, *Champsosaurus gigas* Erickson: a restored and mounted skeleton (ND94-225.1) in the North Dakota State Fossil Collection: North Dakota Academy of Science Proceedings, v. 9, p. 64.



Top - Installation of the Champsosaurus skeleton in the Heritage Center. l. to r. Mark Halvorson, Claudia Berg, Johnathan Campbell, John Hoganson, and Brian Hushagen. Photo by Todd Strand, Photo Archivist, North Dakota State Historical Society.

Bottom - Johnathan Campbell and Carol McCoy Brown, U. S. Forest Service, attaching foot bones to the skeletal mount.

Commitment to Cooperatively Manage Paleontological Resources on United States Forest Service-Administered Lands in North Dakota Reaffirmed by the NDGS and USFS

by
John W. Hoganson

In May, 1995, John Bluemle, State Geologist of North Dakota, and Nancy Curriden, Forest Supervisor for the USFS-Custer National Forest, signed a memorandum of agreement to establish a cooperative effort with respect to management and protection of significant paleontological resources on National Forest lands in North Dakota. This MOA revised and updated a similar agreement that was established between the NDGS and USFS in 1987. The 1987 MOA was the first of its kind between the USFS and any state regarding management of fossil resources. Subsequently, other states have established similar pacts with the USFS. The 1987 MOA established a timely and active working relationship between the NDGS and USFS regarding fossil resources, but it was decided that a few minor revisions to the agreement were appropriate to enhance the effort.

The salient points of the revised MOA are:

1) The USFS will notify the NDGS when they receive an application for a permit to conduct paleontological investigations on USFS lands in North Dakota and will send a copy of the activity proposal to the NDGS for evaluation. The NDGS will evaluate the proposal and advise the USFS of the appropriateness of the proposal and make recommendations to the USFS as to whether or not a permit should be issued for the activity and if so, under what conditions. If the NDGS receives a request to collect paleontological resources on National Forest lands in North Dakota, the NDGS will notify the applicant that a federal permit is required and inform the applicant of how to obtain a permit.

2) The USFS and NDGS will exchange site information regarding fossil occurrences on National Forest lands in North Dakota. The NDGS will evaluate the significance of paleontological sites on National Forest lands in North Dakota to aid resource management planning.

3) The agreement allows qualified professional paleontologists with the NDGS to conduct surface collection of fossil specimens on National Forest lands in North Dakota. Fossil finds by the NDGS are to be reported to the USFS with an evaluation of the significance of the fossil site.

4) When a potentially significant paleontological site is discovered or threatened by human activities or natural events that could impact or destroy the site on National Forest land in North Dakota, a qualified paleontologist with the NDGS will make a site significance determination and, if appropriate, identify mitigation measures.

5) Although all significant fossil specimens collected from federal lands remain the property of the United States government, those collected from National Forest lands in North Dakota are to be catalogued into the NDGS-administered North Dakota State Fossil Collection at the Heritage Center. In addition, after appropriate study, a representative sample of fossil specimens collected in North Dakota under a USFS permit will be required to be deposited with the NDGS for permanent curation in the North Dakota State Fossil Collection. The NDGS agrees to take care of these USFS fossil specimens and maintain records regarding the specimens.

The NDGS has similar agreements concerning the management of paleontological resources with the U.S. Bureau of Land Management and U. S. Army Corps of Engineers. We view these agreements as integral to our Fossil Resource Management Program.

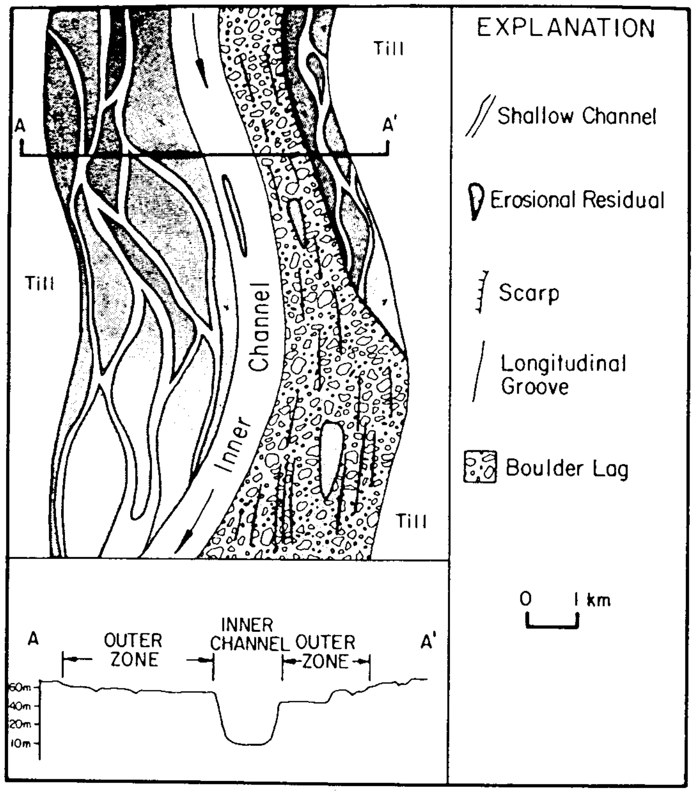
CATASTROPHIC ICE-AGE FLOODS

by Bob Biek

The North Dakota countryside is dissected by a network of deep, interconnected, remarkably steep-walled channels through which flow puny rivers or intermittent streams. The rivers are not big enough for their britches; in the jargon of the hydrologist, they are "underfit streams." The Souris, James, Pembina, and Sheyenne River Valleys are spectacular examples of such channels. Former NDGS geologist Alan Kehew first clearly articulated the hypothesis that large, catastrophic floods of glacial meltwater were responsible for the formation of these channels. Kehew stated that:

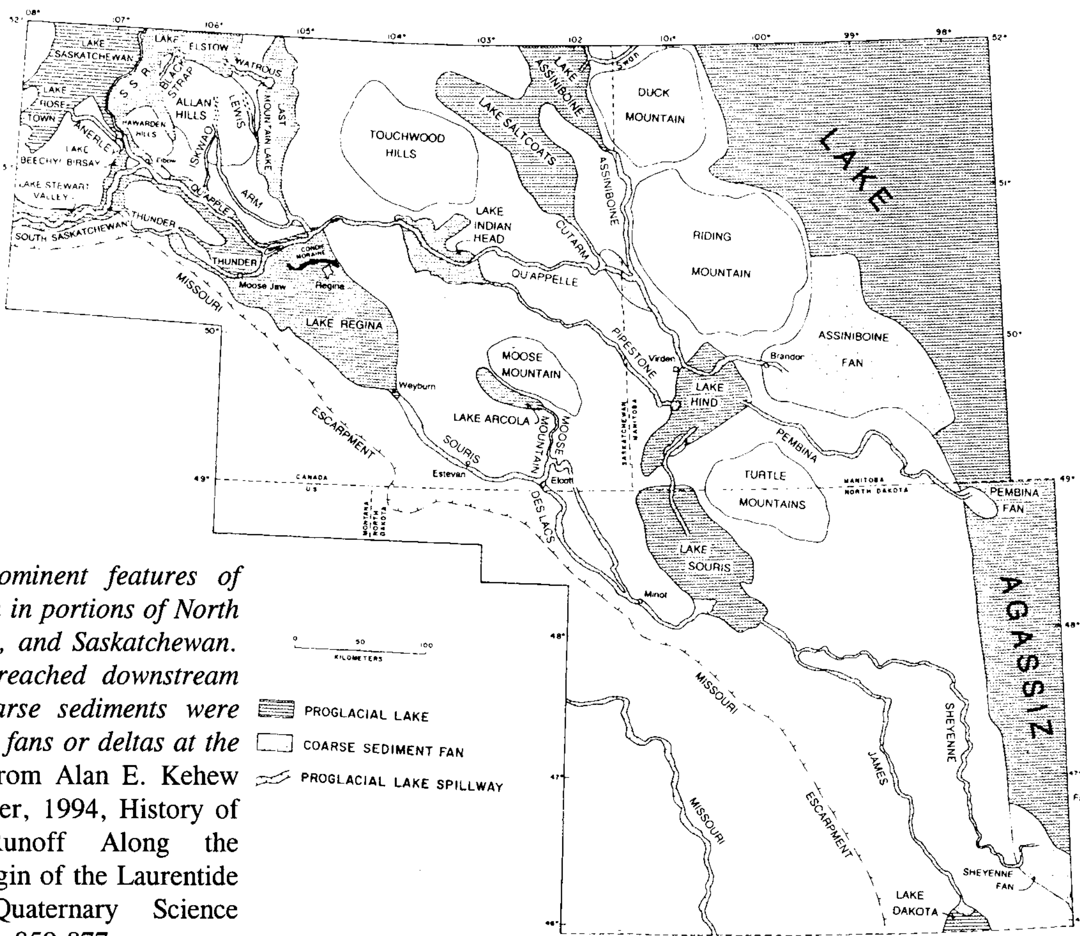
> *As the glaciers retreated down the regional slope to the north and northeast at the end of each glacial advance, meltwater became ponded in depressions along the ice margins between ice and higher ground to the southwest. Each proglacial lake expanded until a low-lying segment of the basin was breached. It is apparent that once drainage was initiated, narrow, deep diversion trenches (spillways) were cut along the ice margin toward the next downstream proglacial lake basin."*[1]

Glacial lake spillways are thus not typical river valleys that evolve over a long period of time, but actual river *channels* carved by rivers of colossal magnitude. Thus, the channels flowed full, brim to brim, with rivers that may have been 100 or more feet deep. The main, or inner, channel of these spillways is often 75- to 300-feet deep and over one-half mile wide. The channels tend to have uniform, trench-like shapes and very widely spaced, open meanders. The main, or inner, channel is typically flanked by a broad, scoured zone, or outer channel, that contained the tremendous flow before the inner channel developed. The outer channel can be several miles wide and is characterized by comparatively shallow, anastomosing channels, boulder lag deposits, and streamlined landforms, called erosional residuals, that were shaped by the flowing water. The catastrophic floods that carved these channels were highly erosive; huge, very coarse gravel deposits are found within the channels, but most of the sediment eroded from the channels was deposited in downstream glacial lakes as large deltas.



Generalized geomorphic model of glacial-lake spillways in the northern Great Plains. From Kehew and Lord, 1986.

An unusual name for the agent that carved these valleys is the Icelandic term jökulhlaup, meaning glacial outburst flood. Perhaps the most famous jökulhlaup is one that originated from glacial Lake Missoula in western Montana. When the Cordilleran Ice Sheet blocked the Clark Fork River at the close of the Ice Age, a 3,000 square mile lake, glacial Lake Missoula, formed. At its largest, the lake was 2,000 feet deep and held about 500 cubic miles of water. When the ice dam finally failed, about 12,700 years ago, the world's greatest known flood occurred, ravaging northern Idaho, Oregon and Washington. The peak discharge is estimated to have been 9.5 cubic miles per hour, equivalent to 10 times the flow rate of all the world's rivers combined, or 200 times the flow rate of the Mississippi River at its maximum flood. Geologists now believe that repeated ice advances across the Clark Fork River, subsequent lake formation, and eventual dam collapse and catastrophic flood occurred at least 40 times during the Ice Age.



Map showing prominent features of drainage evolution in portions of North Dakota, Manitoba, and Saskatchewan. As flood waters reached downstream glacial lakes, coarse sediments were deposited as large fans or deltas at the river's mouth. From Alan E. Kehew and James T. Teller, 1994, History of Late Glacial Runoff Along the Southwestern Margin of the Laurentide Ice Sheet: Quaternary Science Reviews, v. 13, p. 859-877.

The jökulhlaups that scoured North Dakota were also unimaginably huge. The Souris, James, Pembina, and Sheyenne Valleys are each about the size of the lower Mississippi River channel. The estimated volumes of upstream proglacial lakes, such as glacial Lakes Regina, Souris, and Hind, require that bankfull discharges were maintained for days to perhaps several weeks in these channels. The colossal floods had colossal effects on the North Dakota landscape, forming most of the large valleys in the glaciated part of the state, scouring the adjacent countryside, and creating huge, sandy deltas where the flood waters entered glacial lakes Souris, Agassiz, and Dakota. They stand in stark contrast to the other major Ice Age fluvial system in North Dakota, that is sediment-laden glacial meltwater that flowed away from the ice margin to form vast outwash plains. *In short, spillways in the mid-continent region were incised by a few, geologically instantaneous events of colossal magnitude in comparison to modern river discharges.*[2]

Kehew, and former UND student Mark Lord, noted that in the northern Great Plains, the failure of one ice dam probably initiated a domino-like series of dam failures downstream as proglacial lakes were suddenly inundated with huge volumes of water. The modern Souris spillway formed about 11,500 years ago with the failure of the dam impounding glacial Lake Regina in Saskatchewan. This outburst, like the others, was highly erosive and so few sediments were deposited within the channel. Coarse gravel bars are found, however, at places where the channel widened and along the inside bends of meanders. There, as the river flow rate decreased and the river's ability to carry sediment was reduced, the coarsest sediments were deposited. Some of the gravel bars are over one mile long and 100 feet thick and contain boulders up to 9 feet in diameter. One of the larger such bars, extensively quarried for sand and gravel, is just west of Minot. Most finer sediments were swept into downstream glacial lakes, where they formed huge deltas.

Point bar along the Souris River. Point bars form along the inside bends of meanders, where the river's flow rate and thus carrying capacity decreases. Note the abundant large boulders and lack of bedding.

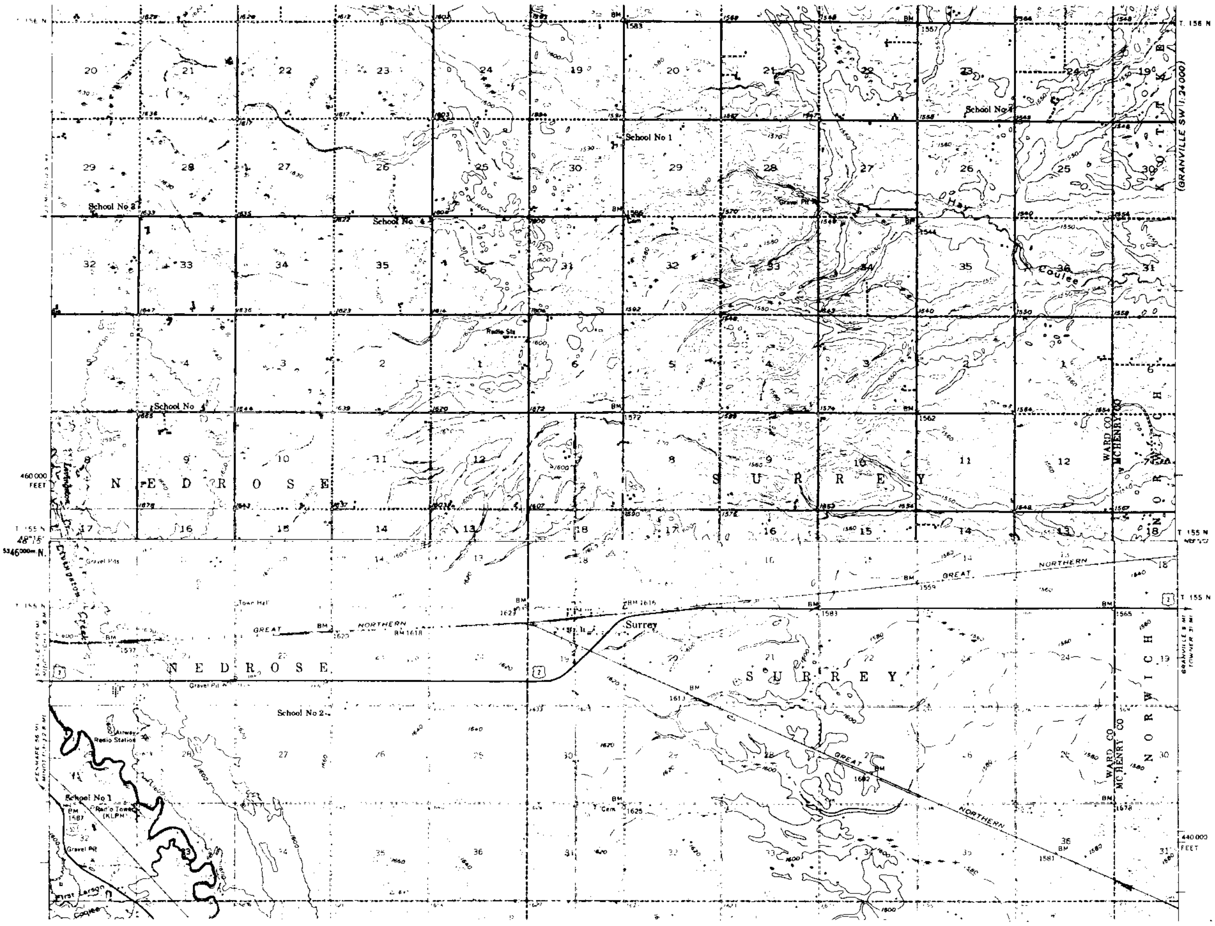
Former UND graduate student Mark Lord studying a boulder bar along the Souris River.

The lower reaches of the Souris and Des Lacs spillways lack outer channels and are somewhat larger than the channels farther upstream, indicating that both spillways were probably pre-existing drainageways that were scoured and deepened by the glacial Lake Regina flood. Even so, water overflowed the Souris spillway at several points where the channel made a sharp bend. Just southwest of Minot, where the Souris spillway makes a sharp bend to the southeast, flood waters spilled out of the main channel and flowed along a more direct path to glacial Lake Souris. There, flood waters eroded a maze of shallow channels.

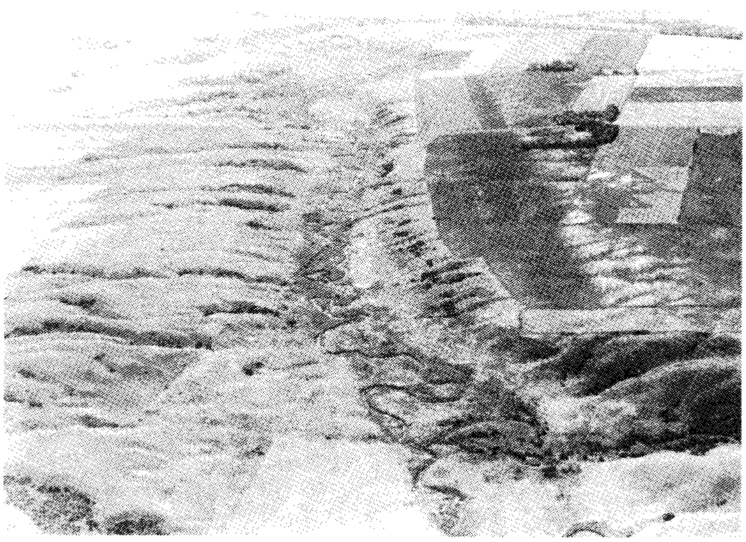
Most of the meltwater valleys we see today in North Dakota formed at the close of the Ice Age, about 12,000 years ago. Many more, filled with groundwater-bearing coarse sand and gravel deposits, lie buried beneath deposits of younger glacial advances. Most towns in the glaciated portion of the state depend on these buried channels for their water supply.

The Souris, James, Pembina, Sheyenne, and other glacial meltwater channels form rugged, often heavily wooded valleys through which most of the state's principal streams and rivers meander. They form some of the most picturesque places in glaciated North Dakota. It's not surprising that many of North Dakota's cites and towns, including Minot, Jamestown, and Valley City, are sheltered within these valleys. That they were formed by jökulhlaups is hard to imagine, especially when one is down at the bottom of such a valley, wading in a small, peaceful stream. But a jökulhlaup is not to be confused with a jackalope, that mythic creature of the American West. Jökulhlaups are for real, and the channels that they carved in North Dakota are there for all to see.

The Pembina River Valley. The steep, often forested valley walls are characteristic of meltwater valleys. The Pembina River itself is an example of what hydrologists call an underfit stream, a remnant of a much larger river that carved the valley. North Dakota Tourism Department photo by Dawn Charging.



Topographic map of scabland area about 5 miles east of Minot. Flood water breached and eroded the side of the Souris spillway (lower left) and flowed eastward to Glacial Lake Souris. The anastomosing network of shallow channels outline a number of streamlined erosional landforms (visible in the center of the map). Reduced from portions of the Deering and Sawyer 15-minute quadrangle maps (scale 1/2 inch per mile).



Aerial view of the Sheyenne River Valley in Benson County, one of many glacial outburst channels in North Dakota carved by Ice Age floods. Note the well defined outer zone to the right of the main valley. The outer zone is a broad, scoured area that contained the tremendous flow of flood water before the inner channel developed. Photo by John P. Bluemle.

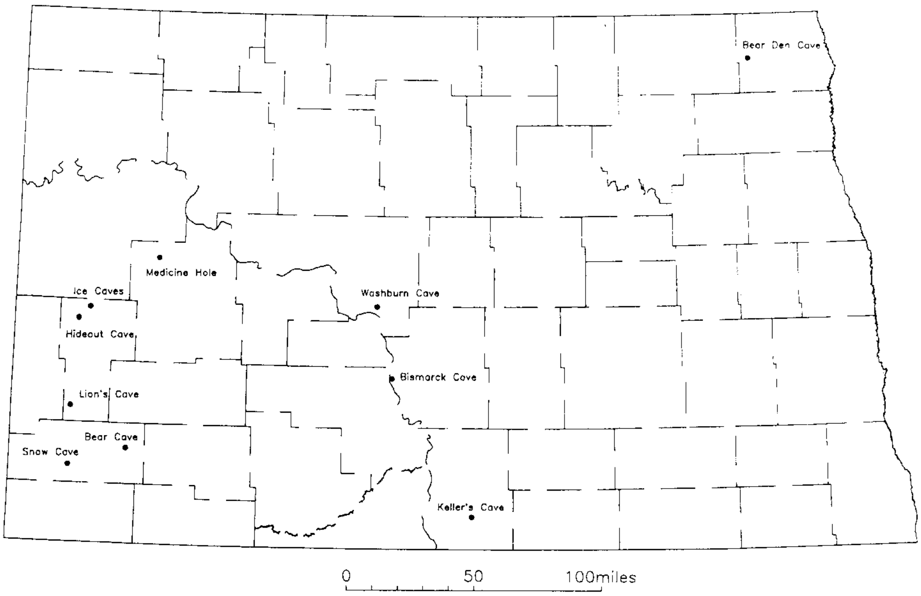
1 Kehew, Alan E., 1982, Catastrophic flood hypothesis for the origin of the Souris spillway, Saskatchewan and North Dakota: Geological Society of America Bulletin, v. 93, p. 1051.

2 Kehew, Alan E., and Lord, Mark L., 1986, Origin and large-scale erosional features of glacial-lake spillways in the northern Great Plains: Geological Society of America Bulletin, v. 97, p. 165.

CAVES IN NORTH DAKOTA

by Ed Murphy

The well-known cave systems throughout the country formed over millions of years as groundwater flowed through and dissolved carbonate rock. Except for the Killdeer Mountains, North Dakota has no deposits of thick carbonate rocks at or near the surface, although thin carbonate beds do cap many small buttes in eastern Stark and Hettinger Counties, and Paleozoic carbonates are present as shallow as 200 to 300 feet beneath the surface in the Red River Valley. As a result, North Dakota does not have a large near-surface cave system such as Mammoth Cave, Kentucky or Carlsbad Caverns, New Mexico. One of the few caves in the state does occur, at least partly, in carbonate rocks in the Killdeer Mountains, but it was formed by slope failure, not dissolution. Several features in the state fit Webster's definition of a cave as "a hollow place inside the earth" and have historically been referred to as caves. The two most prominently mentioned are Medicine Hole in the Killdeer Mountains and Ice Caves in Billings County. All of the "caves" in the state are a result of erosion or slope failure.



The primary source of information for this article was the *WPA Guide to 1930s in North Dakota* published in 1990 by the State Historical Society of North Dakota. In the 1930s and early 1940s, the WPA (Works Progress Administration) set out to document the occurrence of interesting things (be it historical, geographical, or geological) in the state. This was done under the direction of the North Dakota Writer's Project, the records of which are housed in the North Dakota Heritage Center. Several additional "caves" are listed in these records and are discussed in this article as a means of presenting as complete a list of caves in the state as is possible, with, however, the understanding that most if not all of these sites are not what we traditionally think of as caves.

Several additional reports of caves were found in the records of the State Historical Society (Jim Davis, personal communication, 1995). These include Keller Cave Hole near Strasburg, Condo Cave near the site of the old Northern Pacific freight house in Bismarck (*Williams County Leader*: July 29, 1909), and Washburn Cave 30 miles north of Bismarck (*Bismarck Weekly Tribune*: June 3, 1887).

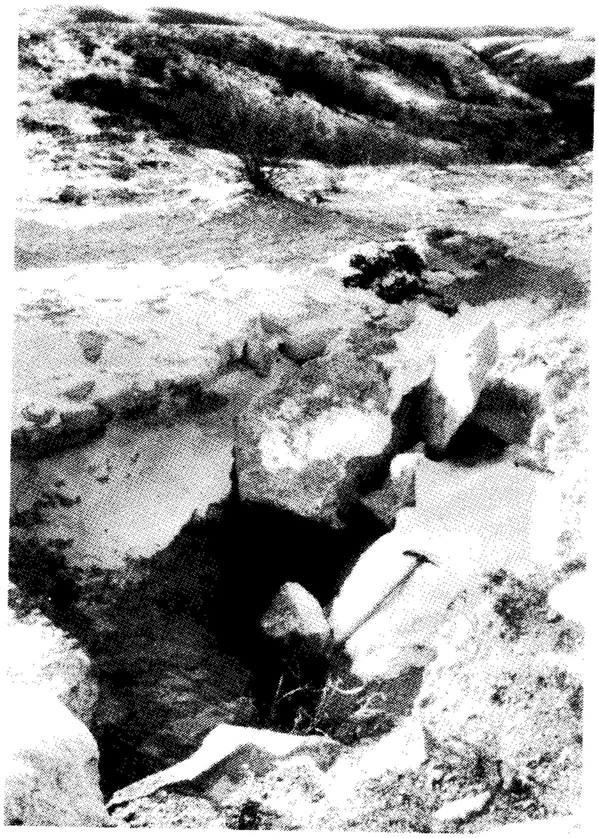
Medicine Hole

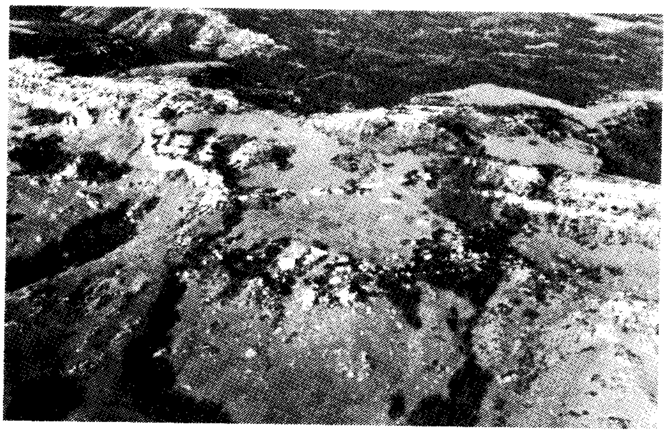
Medicine Hole Plateau is located on the southeast edge of South Killdeer Mountain, Dunn County (T146N, R96W section 27). The site overlooks the abandoned hamlet of Oakdale. The small, narrow plateau is developed on tuffaceous (volcanic rich) carbonates and sandstones of the Arikaree Formation (Oligocene-Miocene); it rises 600 to 700 feet above the surrounding countryside and is 100 feet below the top of the mesa. Medicine Hole, located near the southern edge of this plateau, has long been a special place for locals and tourists because of the mysterious appearance of the hole and the scenic vista offered of the area from the plateau. A rugged trail leads from a small park on the southeast corner of South Killdeer Mountain up to Medicine Hole Plateau. Native Americans were also intrigued by the site. One version of Indian folklore contends that the first buffalo emerged from the earth at Medicine Hole, and another attributes Medicine Hole as being the place from which all life emerged.

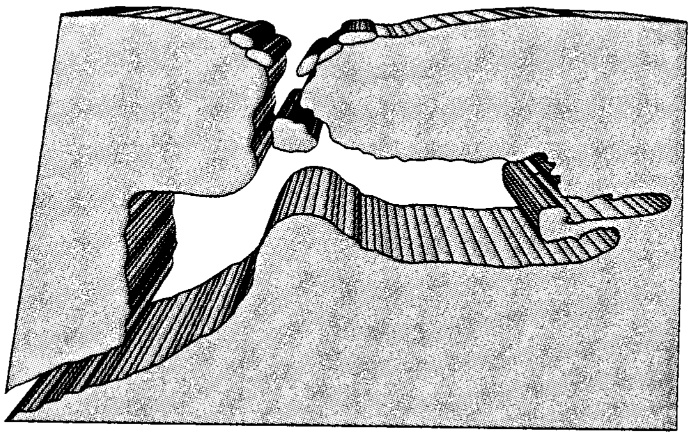
Medicine Hole is an east-west trending crack or fissure that resulted when a block of Arikaree strata broke away from the mountain. The crack runs for approximately 100 feet and the opening is less than 2 feet wide. The cavern varies from 5 to 30 feet high, and the deepest point is approximately 70 feet below the surface (Forney, 1977). The crack apparently has an exit because air can be felt escaping from the entrance at the top of the plateau. Medicine Hole may connect with a rattlesnake den which is present to the southwest approximately 80 feet below the top of Medicine Hole Plateau.

Several additional cracks or fissures were noted by T.T. Quirke in his 1914 map of the Killdeer Mountains. I found that several of the reported fissures on the northwest end of North Mountain had been filled in but I was unable to locate a cave that he noted beneath the caprock along the southeast end of North Mountain.

Fissures or cracks resulting from slope movement (such as rock topples or gravity slides) are generally present in the caprock of buttes in western North Dakota. I have walked the perimeter of all of the major buttes in western North Dakota (Sentinel Butte, Square, Black, White, Chalky, East and West Rainy, etc.) and have come across only one cave that extended more than 12 feet into the rock.







Top - Medicine Hole in winter. This photograph was taken in 1985. In more recent years the rocks that were placed over part of the entrance to discourage cavers have been removed. Spelunker Jerry Forney noted while exploring Medicine Hole that there was a pile of pebbles on the floor of the cave below the opening which had formed from people over the years dropping pebbles to test the depth of the 70-foot-deep crack.

Lower left - Aerial photograph of the southeast end of South Killdeer Mountain. The trail leading up to Medicine Hole Plateau is visible in the foreground.

Lower right - Schematic cross-section through Medicine Hole, drawn by Jerry Forney.

Ice Caves

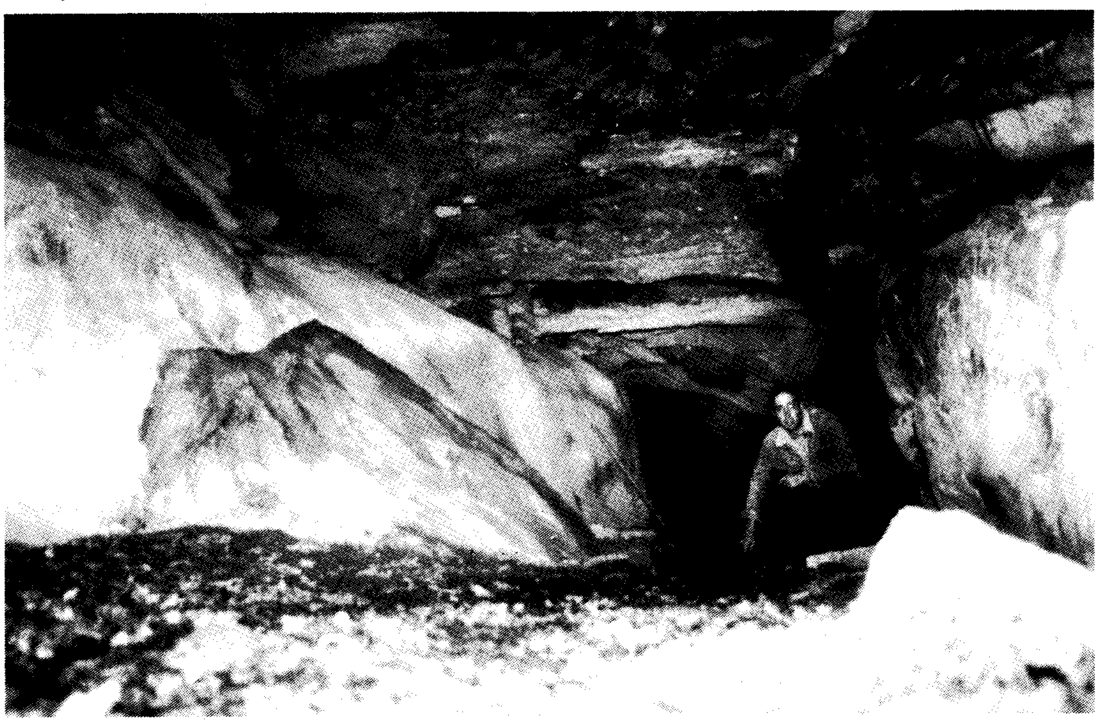
The Ice Caves, also known as O'Brien Ice Caves (named for a long-time ranching family south of the caves) or Wonderful Ice Caves, are located on the northern edge of Billings County along the drainage of Magpie Creek (T144N, R100W section 6). The Ice Caves were reportedly discovered by Joe Quinion or John O'Brien in the early 1900s (*Dickinson Press*, 1995). The Ice Caves are located along the southern slope of a ridge capped by 30 feet of fluvial channel sandstone in the Sentinel Butte Formation. Large blocks of sandstone have become detached from the ridge cap and toppled or slid down the slope. Many of these blocks have come to rest at various angles against other large blocks, which has created void spaces or chambers. Percolating water from melting snow and early spring rains drips into these well-insulated chambers where it freezes and remains frozen into late spring or summer. The largest chamber is approximately 30 feet long, 10 feet wide, and 9 feet high. When I visited this area in May, 1988, there was 2 to 3 inches of ice on the floor of many of these chambers. It has been reported that ice remains in some of these areas into late summer and, in some instances, year round. The insulation offered by the thick sandstone blocks and the restricted air flow due to the single main openings in the chambers is the reason that ice is preserved for weeks or months after it has melted everywhere else.

In the 1920s, William Brennen placed butchered beef in the caves and was able to keep it fresh through the summer, although there were problems with animals getting in and helping themselves to the meat. In the early days, the caves were a popular attraction as people would come from miles around to picnic in the area with the highlight of the trip being the making of ice cream from the available ice.

Snow Cave

Snow Cave was located on the south side of Black Butte (originally called HT Butte), Slope County (T134N, R102W N1/2 section 25). As with the O'Brien Ice Caves, Snow Cave reportedly was a void space or chamber formed when several sandstone blocks in the Sentinel Butte Formation calved off of the caprock of Black Butte. Etha Lawson, a long-time resident of the Black Butte area, recalled that in the 1930s, local ranchers would picnic beside the cave and make homemade ice cream just as they did during this same time period at the O'Brien Ice Caves.

According to local rancher Doug Pope, falling rock and erosion over the years have destroyed Snow Cave. Therefore, the same processes which formed Snow Cave also led to its destruction. These same processes, the calving of sandstone blocks from the thick caprock and subsequent erosion, will continue to alternately form then destroy these ice caves until the butte ultimately erodes away.



The inside of this, the largest Ice Cave, measures approximately 30 feet long, 10 feet wide, and 8 feet high. This cave is the space left between four or five blocks of sandstone. I am pointing to ice on the floor of the cave. Photograph taken near the entrance.

Bear Cave

Bear Cave is situated in the Arikaree sandstone caprock along the northeastern edge of East Rainy Butte (T135N, R98W northeast section 34). It extends approximately 12 feet into the rock and narrows in height from 5 feet to two feet. This depression was carved out of the rock largely by wind and rain brought in by the prevailing northwest winds.

Just a few hundred yards west of Bear Cave is the largest cave that I have encountered in any of the sandstone-capped buttes in western North Dakota. Although it might be more appropriate to refer to this larger cave as "Bear Cave", the smaller cave matches the dimensions given for Bear Cave by the WPA Guide. The entrance to the larger, north-facing cave is approximately 9 feet above the base of the sandstone caprock and 8 feet below the top of the butte. The shear face of the caprock in this area makes entry into the cave difficult. This cave extends at least 25 feet into the caprock, averages 3 feet in height, and obtains a maximum height of 4.5 feet just inside the 4 foot by 3 foot cave entrance. The irregular nature of the roof of this cave provides evidence that blocks of sandstone calved from the roof. These blocks have been broken down and removed from the floor of the cave by a combination of erosion,

Top - The southwest edge of Black Butte, Slope County. Note that numerous sandstone blocks litter this slope. These blocks broke from the caprock and toppled and slid down the slope. Snow Cave was located in this general area.

Middle - The northeast edge of East Rainy Butte. Both of the caves mentioned in this article are located in this area.

Bottom - Photograph of entrance of Bear Cave from the back of the cave looking towards the town of New England.

burrowing animals and perhaps humans. The floor of the cave is littered with scat which, according to landowner Ken Urlacher, likely is porcupine, skunk, or raccoon, all of which are reportedly abundant in this area. Judging from the relatively few initials that have been carved into the cave wall as compared with the adjacent Bear Cave, few have ventured into this cave.

Both of these East Rainy Butte caves formed in conglomeratic lenses near the middle of the sandstone caprock. These lenses are more susceptible to erosion because they are not as well cemented as the surrounding sandstone and contain easily weathered clay clasts. Additional caves are reported to be present at the same horizon on West Rainy Butte. The larger cave is situated in a north-trending joint which likely aided in its development by providing a passage way for infiltrating water. Burrowing animals and Native Americans may have aided in the forming of these caves.

The entrance to East Rainy Butte is locked and permission must be obtained from landowner Ken Urlacher before venturing up on this butte.

Lions Cave

Lions Cave is reportedly located on the side of Bullion Butte, Billings County. It was named for a pair of mountain lions that made their den there and harassed cattle during the late 1890s. I was unable to locate this cave although there are numerous overhangs in the caprock along the north and northeast edge of the butte.

The rugged badland terrain in northern Billings County that reportedly contains Hideout Cave.

Hideout Cave

Hideout Cave is located in northern Billings County (T144N, R101W section 26). The space was reported to measure 12 by 16 feet and is 8 to 10 feet high. During World War I, two draft evaders hid from the local draft board in this cave subsisting on wild game and supplies hauled by a friend from the town of Gorham. The pair stayed in the cave for 1 1/2 years before leaving for Canada where they reportedly enlisted in the Canadian army.

I was not able to find this cave. There are two channel sandstones in the Sentinel Butte Formation in this section (at an elevation of 2400 and 2600 feet). If the cave was located in either of these two sandstones it may have survived to the present. If the cave was an erosional feature that developed in mudstone in this area, it likely has been destroyed.

Bismarck Cave

On July 29, 1904, the *Williams County Leader* reported the existence of a cave near the Northern Pacific freight house in Bismarck (T138N, R80W section 5). The freight house was located along the river bank south of the Bismarck railroad bridge. The cave was discovered when a team and wagon sank 8 feet into the ground while being loaded with fruit from a railroad car. Orland Davidson, an old Indian Scout, remembered that, during the early days of Bismarck, a band of cattle rustlers occupied the cave and upon further investigation several old weapons and some ammunition was found. No other record of the cave has been found and it likely was an erosional pipe formed as runoff flowed into the Missouri River.

Washburn Cave

The June 3, 1887 edition of the *Bismarck Tribune* noted the discovery by two Bismarck men (Isaac Clark and Isaac Ross) of a cave thirty miles north of Bismarck. The entrance of the cave was 10 feet high and 6 feet wide and was marked by three large rocks. The pair reported that the cave was over 100 feet long and with a middle passage way that measured 12 by 12 feet. They noted that beads were found in the cave and that notched stones were strewn about that had likely been used to tether horses. On the entrance to the cave was the following inscription:

ANTOINE FRENORE
July 24, 1851
Born 1824
600 Lodges Have Camped Here

The Tribune reported that a scientific party was being assembled to explore the cave but Jim Davis (State Historical Society of North Dakota) and I have been unable to find any other references to this cave in subsequent Tribune articles. It may have been an outright hoax, or the size may have been greatly exaggerated. From the crude location given by the Tribune it could have been located in northwestern Burleigh, southeastern McLean, or southwestern Sheridan Counties.

Keller Cave

In the early 1970s, a hole opened up on the Keller farm near Strasburg in Emmons County (T131N, R75W near the center of section 16). Frank Vyzralec, formerly with the State Historical Society of North Dakota, and several others investigated the site and determined that most of the hole was only a few feet deep but on one end the opening extended 7 feet below the surface and was at least 20 feet long. Over the last twenty years, the depression has grown through surface collapse from roughly 2 by 4 feet to 5 by 12 feet and an additional hole has opened up 50 feet away. Both the longest dimensions of the holes and holes themselves are aligned on a northwest-southeast trend. The site is

Two collapse features at the Keller Cave site. The holes are spaced 50 feet apart on a northwest-southeast trend. The holes may have an underground connection.

The northwest edge of the northern hole contains a small cave or den that extends 7 feet below the surface.

located in glacial drift on a small topographic high which does not appear large enough to generate the runoff that would be needed to create an erosional pipe this size and there is no apparent exit which is needed for an erosional pipe to form. However, the northwest-southeast orientation is roughly parallel to some of the major drainage channels in this area. The general shape of the cave suggests it may have been a den, although no direct evidence was observed that would support this.

Bear Den Cave

Bear Den Cave is located 3 miles south of Walhalla, just north of Highway 32 in Pembina County (T163N, R56W southwest of section 32). It reportedly is located midway between a spring and Eagle Lake. Bear Den Cave was named by people in the area who assumed it had been the den of a bear. As it turns out, it was created by George Emmerling in 1882 when he dug into the hillslope to find rocks for the mill he was constructing.

Exit of an erosional pipe in the Sentinel Butte Formation in badland topography in Billings County. Opening is about two feet wide.

Erosional Pipes

Erosional pipes or small caves are common throughout western North Dakota. These erosional features often form near the base of steep-sided slopes and in gullies and ravines where surface runoff is focused. These pipes form when surface runoff erodes vertically downward through the soft rock. Piping is prevalent where runoff can flow into small cracks and joints and, with time, the moving water erodes these initial pathways, expanding some to the size of small rooms. An erosional pipe may contain stretches where it is roofed and others where the roof has collapsed or eroded. As a result, one has to be very wary while walking along hill sides in western North Dakota because of the possibility of stepping onto a thinly roofed portion of a pipe. Eventually these pipes expand to the point that the roof collapses and the process begins all over again.

Many of these pipes branch and coalesce and would likely offer some interesting caving or spelunking opportunities if it were not for the dangers posed by their instability and their frequent habitation by rattlesnakes.

Underground Mines

The closest thing to extensive cave systems in North Dakota are abandoned underground coal mines. Although some of these mines extend over very large areas and would offer many of the same challenges that natural cave systems do (i.e., a chance to explore, the challenge of finding your way in and out, etc.) they are also extremely dangerous because of their instability. As many of the rooms in these mines were being abandoned, the miners went in and "robbed" coal from the pillars that had been intentionally left for stability. As a result, as early as 1925, L.P. Dove, with the North Dakota Geological Survey, noted that collapse of abandoned underground mine workings were rendering a substantial amount of farmland unusable in North Dakota. On one occasion I had an opportunity to walk into an abandoned underground mine at Haynes, North Dakota by following the slope of a sinkhole. I quickly retreated from the site when I noticed that the rubble I was walking on had recently been the mine roof. I would recommend that no one attempt to enter any of these old mines.

A tunnel was reportedly used to mine lime-rich

The collapse of a segment of an underground mine in the foreground has created a crawl space into a partially collapsed room at a mine near Haynes in Adams County.

shales from the Niobrara Formation near the town of Concrete in northeastern North Dakota. The shales were mined to make natural cement from 1899 to 1909. Approximately 900 feet of tunnel was dug at this site before it was abandoned. Local landowner Howard Olson and his father climbed around in the tunnels in the 1940s and Mr. Olson recalls that the timbered tunnels had several narrow passageways due to collapse. Mining for "fuller's earth" about this time exposed some of the old tunnels. The entrances to the tunnels have since been buried by slumps along the hillside.

Exploring in North Dakota

I've tried to provide a quick guide to some of the interesting things that can be found by doing a little exploring in North Dakota. The true spelunker or caver will be disappointed in what North Dakota has to offer regarding caves. However, all will enjoy the scenery afforded from the buttes and badlands in western North Dakota and along the Pembina River in northeastern North Dakota. Please be cautious when entering any type of underground opening and keep in mind that in the western portion of the state rattlesnakes are attracted to these cool settings in the summer. Remember too that the processes that formed these natural openings are ongoing and collapse or falling rock may occur without warning. Always obtain permission from the landowner before exploring.

If you know of additional caves or other interesting geological phenomena please contact our office so that we can add them to our file.

Sources

Dickinson Press, July 9, 1995, p. 1, *Valley of the Ice Caves*, by Cary Shimek.

Williston Daily Herald, December 9. 1977, p. 1, *They know more than most about North Dakota caves*, by Connie Beggs.

Bismarck Weekly Tribune, June 3, 1887, p.6.

Williams County Leader, July 29, 1909, p. ?, *Found a cave.*

The Windy City Speleonews, Vol. 17, August, 1977, p. 68-71, *Medicine Hole, Dunn County, North Dakota*, article by Gerald G. Forney.

Archives of the State Historical Society of North Dakota, including the notes of Frank Vyzralec.

WPA Guide to the 1930s in North Dakota, 1990, State Historical Society of North Dakota, 376 p.

NEW PUBLICATIONS

Geology of the Davis Buttes, Dickinson North, Dickinson South, and Lehigh Quadrangles, Stark and Dunn Counties, North Dakota, 1995, by Robert F. Biek and Edward C. Murphy: NDGS Open-File Report 95-1, 64 p., 9 plates, 1:24,000. $5.00.

This report and accompanying geologic maps describe the surface geology of the greater Dickinson area. The report includes sections on the stratigraphy, structure, geologic hazards, and near-surface mineral resources. The maps portray both Tertiary-age bedrock (the Sentinel Butte, Golden Valley, and Chadron Formations) and unconsolidated deposits of Quaternary age; they emphasize geologic units and sediment types that directly underlie the soil horizon and so complement existing soil maps.

Detailed mapping of the Bear Den Member of the Golden Valley Formation, a readily identifiable marker bed, demonstrates that this unit has been warped into a very gently folded, northeast trending syncline. This syncline is apparently the same structure exposed to the southwest in the Little Badlands and may be present in the subsurface as well.

This report, including a full-color geologic map, geotechnical map, and a roadlog of the area, should be available as a NDGS Report of Investigation later this year.

The Cretaceous/Tertiary Boundary in South-Central North Dakota, 1995, by Edward C. Murphy, Douglas J. Nichols, John W. Hoganson, and Nels F. Forsman: NDGS Report of Invesigation No. 98, 74 p., 2 pl., $3.00.

The Cretaceous/Tertiary boundary in south-central North Dakota occurs near the lithostratigraphic contact between the Upper Cretaceous Hell Creek and lower Paleocene Ludlow Formations. These strata are of continental origin and are composed of alternating beds of poorly lithified sandstone, siltstone, claystone, and mudstone. Palynologic data indicate that the K/T boundary and the contact between the Hell Creek and Ludlow Formations are essentially coincident at many of the 32 sites where stratigraphic sections were measured, but may be as much as 10 to 20 feet apart at some of the others.

Palynologic data also reveal a significant reduction or extinction of Cretaceous plant taxa at the close of the Cretaceous. Vertebrate fossils were generally sparse at the sites studied, but, where present, support the placement of the K/T boundary as determined by palynological analysis. Field observations at these sites indicate that an identifiable boundary clay layer is not present in this area.

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