NEWSLETTER
NDGS

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gravel is overlain by 1 to 2 m of loess; however, a polygonal pattern can sometimes be seen on air photos because the vegetation may be more lush where the loess is thicker over the troughs. Polygonal networks have been seen on 1:20,000 air photos at about 200 sites in southwestern North Dakota. The polygons have four or five sides and are 10 to 100 m in diameter. Most have been preserved on gravel terraces and pediments, where the soil is so permeable that there has been no runoff and, therefore, no erosion. These features are known to have formed before late Wisconsinan time, because they occur only beyond the limit of late Wisconsinan glaciation, and they are overlain by late Wisconsinan loess.

Halvorson, Don L., 1981, Volcanic orgin for Devils Tower, Crook County, Wyoming: Abstracts with Programs 1981, Rocky Mountain Section, Geological Society of America 34th Annual Meeting, Rapid City, South Dakota, p. 199.

Devils Tower is a prominent columnar feature located in the northeastern corner of Wyoming, on the northwestern edge of the Black Hills. It is an elliptical-shaped, steep-sided igneous body of Eocene age, rising 230 m above its Jurassic platform. Composition of Devils Tower is analcime phonolite, grading upward into analcime trachyte. This change in rock composition is due to the infiltration from below of magmatically derived late-stage Na-rich fluids during the cooling process. Chemical analyses indicate the rocks are moderately undersaturated, sodic in character, and follow a typical trachyte-phonolite trend. The analcime-liquid stability field indicates a crystallization depth of 18 km to 43 km at a temperature of 600°-640° C. Differentiation occurred by fractional crystallization through the mechanisms of flotation and flow differentiation. The presence of alloclastic breccia with a crystal-charged volcanic glass matrix, the collapsed depression around the Tower, the orientation of the columnar jointing, and the occurrence of extrusive volcanism in the vicinity lead to the conclusion that Devils Tower is the erosional remnant of a volcanic neck.

Mahaney, W. C., Halvorson, Don L., and others, 1981, Evaluation of dating methods used to differentiate Quaternary deposits in the Wind River Range, western Wyoming: Quaternary Dating Methods, Dowden, Hutchinson, and Ross, Stroudsburg, PA. In Press.

Glacial and nonglacial deposits in the Wind River and Teton Ranges of western Wyoming have been dated by radiocarbon, topographic position, surface morphology, weathering characteristics, lichenometry and soil stratigraphy. Of these many methods, radiocarbon, lichenometry, weathering features, and soil stratigraphy appear to be the most useful in differentiating deposits which formed mainly during periods of glaciation. Soils in the sequence are named from youngest to oldest: post-Gannett Peak, post-Audubon, post-Indian Basin, post-Pinedale, post-Bull Lake, and pre-Bull Lake.

A radiocarbon age of 7940 $\pm$ 190 yrs. BP (Gak-8216) establishes a minimum date for late-Pinedale moraines found above 2800 m. A buried paleosol dated at 3050 $\pm$ 120 yrs. BP (Gak-6024) documents a rise in lake level at the close of the Indian Basin advance of Neoglaciation in the Wind River Range. No lichen growth-rate curve is available for the mountains of western Wyoming. Numerous lichen transects across Neoglacial deposits, however, yield relative data on lichen size and percent cover that correlate with the Front Range, Colorado, where growth rates for *Rhizocarpon geographicum* are known with precision. Surface weathering features that assist in deposit differentiation and correlation include: ratio of fresh/weathered stones, weathering rind thickness, and depth of pitting on stone surfaces.

SHORT AND LONG RANGE SURVEY PLANS

--Don L. Halvorson

North Dakota is at the present time enjoying a surge in mineral and resource development which will provide increased revenue and employment opportunities within the state, but at the same time will place a strain on our natural resources and our environment. Appropriately, the North Dakota Geological Survey's plans for the future include basic and applied research that will be helpful in locating and developing our natural resources. This necessitates an in-depth, forward-looking program that will minimize unforeseen damage to our environment. Such a program is applicable not only to natural resource development, but also to the geotechnical studies of urban areas, geothermal research, and land and water resource studies in which the Survey is also currently involved.

Many other state agencies share this concern and responsibility for the wise use and development of North Dakota's resources, and the Survey has traditionally served as geological advisor to these agencies. We hope that this relationship will continue to grow. In light of the complexity of some of the problems the state will be facing, it is obvious that a strong cooperation among agencies is advisable both in terms of effectively solving the problems, and also in terms of cost efficiency.

With the passage of House Bill 1536 by the Forty-seventh Legislative Assembly, the Survey's Oil and Gas Division, which was responsible for oil and gas permitting and regulation, was moved from Grand Forks to Bismarck and placed directly under the authority of the State Industrial Commission. Although this action gives the Survey less contact with the oil and gas industry in the state, it is still our responsibility to provide technical service and assistance to the Industrial Commission in matters of oil and gas exploration, development, and production. It is our intention that this service, plus the Core and Sample Library, the Williston Basin carbonate studies, and various ongoing studies of facies, fabric, and porosity of the hydrocarbon-bearing formations of the basin will complement the work of the Oil and Gas Division. Other current projects related to oil and gas include: subsurface studies of ten known or potential hydrocarbon-bearing stratigraphic units; development of WELLFILE, a computerized stratigraphic oil well file; and plotting of oil-field decline curves.

The exploration and development of North Dakota coal continues to be a major area of research for the Survey. Studies in coal stratigraphy are ongoing; an estimation of total strippable coal in western North Dakota is also in progress. In addition, our Cenozoic Project is well underway. This is an exhaustive, integrated, regional study of Cenozoic rocks in the Williston and Powder River Basins, dealing with the potential for coal mining, uranium occurrence, and related groundwater problems.

Using WATERCAT (USGS water well data), geothermal gradients, and heat-flow studies, members of the Survey are also working on the evaluation and possible utilization of geothermal resources in the state.

Other areas of research include the completion of county studies; detailed geotechnical studies of urban areas (Bismarck and Fargo completed, Minot nearing completion); reviewing of environmental studies; Quaternary paleoclimatic research; evaluation of geologic, geochemical, and geotechnical aspects of surface mine reclamation; and evaluations of the impacts made on groundwater by disposal of thermo-electric utility wastes, by reclamation of abandoned surface mines, by oil and gas mud pits, and by sanitary landfills and municipal lagoons. We anticipate that increasing attention will have to be given to groundwater concerns associated with the disposal of wastes from coal gasification and liquefaction, as well as hazardous wastes and possibly nuclear wastes.

Plans are now underway to begin work on 1° by 1° maps of North Dakota, which will be compiled from existing county maps, and will be part of an atlas containing lithostratigraphic surface maps, a Pleistocene stratigraphic framework, land-use and planning derivitive maps, resource maps, landfill suitability studies, and other useful geotechnical information.

It is imperative that the Survey provide all necessary information to assist the petroleum industry in its efforts at building a new oil- and gas-development cycle in North Dakota after the present one has run its course. Toward this end, we are considering a number of studies of marginally producing formations within the basin, and a detailed look at pore geometries and clay development within pores. These studies may be instrumental in improving recovery methods.

The mineralogy and geochemistry of North Dakota potash deposits is another focus of future research, along with continuation of related stratigraphic studies, leading to an evaluation of this natural resource in our state.

Because almost countless problems and projects could be pursued by the Survey, careful consideration and planning is needed to assure that our research priorities are timely, applicable, and responsive to present or anticipated needs in the state and in the nation.

CHANGES IN PERSONNEL

As reported in the last NDGS Newsletter, Dr. Lee C. Gerhard, State Geologist of North Dakota since September, 1977, resigned effective August 1, 1981. He is now employed by Supron Energy Corporation in Denver. Dr. Gerhard was succeeded by Erling Brostuen, who became Acting State Geologist when Lee Gerhard left. Erling had been Assistant State Geologist since 1979, and a Survey geologist since 1965; however, he resigned effective December 1, 1981, to become manager of exploration services for Resources Engineering Management International, Inc. (REMI) in Denver. REMI is a broad-based consulting firm of geologists, engineers, geophysists, and general management specialists that provides on-site assistance to private and national oil companies and governments. It operates all over the world.

During the first 10 years of his 17-year tenure with the North Dakota Geological Survey, Erling was stationed in our Williston office where he was in charge of oil and gas field inspection and supervision. After coming to our Grand Forks office, he was involved with oil and gas regulation and conservation, subsurface minerals regulation, and uranium exploration and development. He was frequently called upon to address formal and informal groups, classes, and seminars. Erling was also regularly involved with Survey negotiations with federal and state agencies.

Dr. Don Halvorson is currently serving as Acting State Geologist pending a permanent appointment by the North Dakota Board of Higher Education. Don is originally from Wildrose in northwestern North Dakota. He earned his BS in Geology at the University of California in 1965, an MST from the University of North Dakota in 1971, and his PhD from the university of North Dakota in 1979. Don has had considerable administrative experience, serving on numerous University curriculum, finance, search, and graduate-student advisory committees and in carrying out administrative duties for the University of North Dakota geology department. He has also been quite involved in various public service activies, such as serving on the 1981 Bike Ride Against Diabetes Committee, and acting as Program Director for the Northern Lights Council Boy Scout Show in April, 1981, as well as being heavily involved in church activities.

Dave Ruddy, who had worked with the Survey as a draftsman since 1978, recently took a job with Supron Energy Corporation in Denver.

Our new draftsman is Ken Dorsher, who comes to us from an engineering firm in Grand Forks. With six years of experience, Ken is a valuable addition to our staff.

FOSSIL DINOSAUR BONES FOUND IN WESTERN NORTH DAKOTA --Ed Murphy

While doing fieldwork this past summer in western North Dakota, I came upon a large number of fossilized dinosaur bones. The bones, which are exposed at the surface of the ground (see photos), are weathering out of sediments of the late Cretaceous Hell Creek Formation, which is about 65 million years old. Although these particular vertebrate fossils have not yet been identified, the present consensus is that they are probably from the herbiverous (plant-eating) dinosaur, triceratops. The abundance of fossilized triceratops bones within upper Cretaceous sediments has led to the theory that triceratops was probably one of the last dinosaurs to become extinct. For this reason, the Cretaceous-Tertiary boundary is commonly defined as being at the highest vertical occurrence of triceratops' teeth.

Both plant and animal fossils are valuable tools that are often used by geologists to determine both the age of the rocks they are found in and the environments that prevailed while the rocks were being deposited. Consequently, it is extremely important to keep from disturbing the fossils and to report all fossil finds to either the State Historical Society in Bismarck, or to the North Dakota Geological Survey. An example of an important fossil discovery by a non-geologist is the Wannagan Creek site in Billings County, North Dakota. The initial collection was made by a vacationer in the area who was not specifically searching for fossils. She reported the find to the U.S. Forest Service, which in turn contacted Dr. Bruce Erickson, a paleontologist with the Science Museum of Minnesota in St. Paul. Since the fossil quarry was opened in 1971, large numbers of fossil crocodiles and other animals and plants have been discovered and studied by paleontologists from the Minnesota Museum.

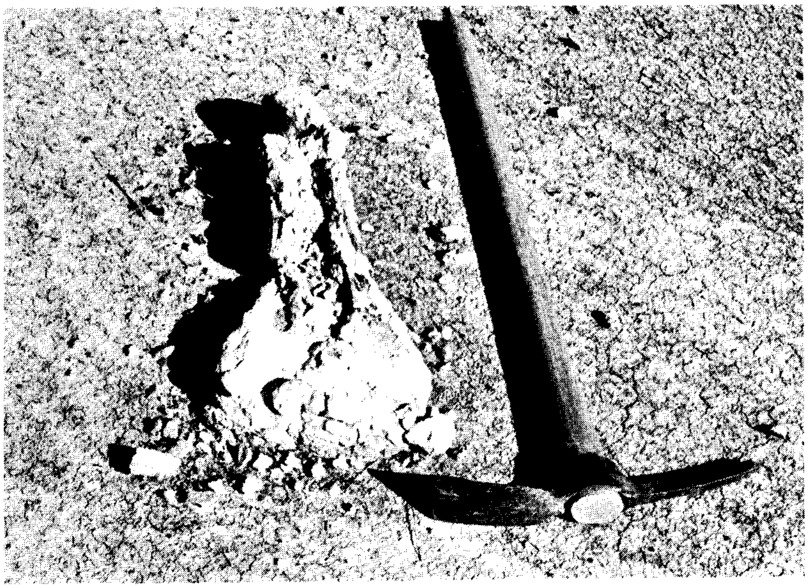
The North Dakota Century Code assigns the regulatory authority over archeological and paleontological artifacts or sites to the State Historical Society; however, the Survey has always cooperated with the Historical Society on matters of paleontological interest, and we expect to continue this cooperation in the future.

The following paragraph is taken from the North Dakota Century Code, Chapters 55-02 and 55-03.

> 55-02-07. Protection of prehistoric or historic artifacts or sites.--Any historical, archaeological, or paleontological artifact or site that is found or located upon any land owned by the state of North Dakota or its political subdivisions or otherwise comes into its custody or possession shall be cared for, handled, protected, excavated, or stored under the direction of or in the manner prescribed by the superintendent of the state historical society board.
> Source: S. L. 1965, ch. 379, § 18.

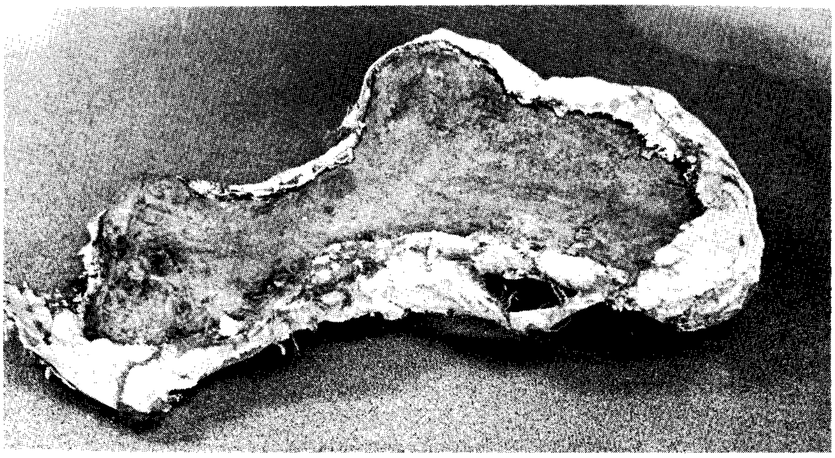
CHAPTER 55-03

Protection of Prehistoric Sites and Deposits



Photos of fossil dinosaur bones (probably Triceratops) found in the Hell Creek Formation in southwestern North Dakota. The two-foot long pick shows how large the bones are. The middle photo illustrates the poor condition of some of the bones. The lower photo is of two fossil vertabrae.

An example of how a bone in poor condition can be salvagec A plaster cast was poured around the bone prior to its removal from the discovery site.



A rib bone weathering out of carbonaceous shale in the Hell Creek Formation.

The Triceratops skull on displa in Leonard Hall (the building shared by the North Dakota Geological Survey and the University of North Dakota geology department) in Grand Forks. The skull was discoverec in southwestern North Dakota in the summer of 1964.

THE ORIGIN OF DEVILS LAKE

Devils Lake, the largest natural body of water in North Dakota (the man-made lakes Sakakawea and Oahe are larger), is located in a large closed drainage basin of 3,580 square miles that extends from the southeastern edge of the Turtle Mountains in Rolette County to a range of prominent hills south of the lake. Runoff from throughout the basin ends up in Devils Lake. The total area of Devils Lake is approximately 90 square miles.

Extensive test hole drilling in Ramsey and Benson Counties and in nearby areas has helped us to learn that the preglacial drainage in the area that includes the Devils Lake Basin, and in fact all of eastern North Dakota, was northward to northeastward. The main river system that flowed through the immediate Devils Lake area was probably a tributary to the ancestral Knife River, which itself followed a northward route past Minnewaukan to Cando and on into Canada through Towner County (figure 1). A smaller, northwest-trending tributary valley that joined the ancestral Knife River Valley just south of Churchs Ferry, flowed in a position near the southern edge of the modern Devils Lake.

Each time glaciers advanced southward into eastern North Dakota (the area was glaciated several times), the northward drainage was blocked and the rivers and streams were dammed by the glacier. Large lakes were dammed in front of the glaciers, both when those glaciers advanced and when they melted back, and in fact, test holes drilled in the Devils Lake Basin have penetrated several buried layers of lake sediment. The most recent of the glacier-dammed lakes in the Devils Lake area, the one that flooded the area when the last glacier melted from eastern North Dakota, was glacial Lake Minnewaukan. Lake Minnewaukan flooded an area perhaps three times as large as that now flooded by Devils Lake. Sediments of Lake Minnewaukan are not buried (because later glaciers never advanced over them), and they can be seen in numerous exposures throughout the area.

In addition to forming lakes, the water dammed by the glaciers overflowed when the lakes were full, and valleys, known as meltwater diversion trenches, were eroded southeastward along the edge of the glaciers. These "diversion trenches" represent the routes of rivers that carried the runoff southeastward along the ice margin, and there must have been many of them. Each time the glaciers advanced, they covered the earlier diversion trenches and caused new ones to form. Many of the older diversion trenches are now buried beneath as much as 500 feet of glacial sediment. One especially deep and narrow diversion trench, the route of which is shown by the dotted line on the map on page 9, that is now deeply buried beneath the glacial sediment was eroded by a river that flowed southeastward from near Cando, southward past Crary, and then continued toward McVille in Nelson County. Another, more recent meltwater diversion trench that was not buried by a later advance of the ice is the Sheyenne River valley (not shown on the map).

A further major result of the glaciation and the accompanying disruption of the existing drainage systems was that large amounts of water, including both runoff from the as-yet unglaciated parts of the state (or from recently deglaciated parts of the state if deglaciation was taking place) and water from the melting glacial ice flooded the area ahead of the glacier, saturating both the preglacial and glacial sediments that were present there.

The surface of the ground ahead of the advancing glacier was probably permanently frozen (permafrost) to a depth of several hundred feet. As a result of the fact that the sediments beneath the permafrost layer were saturated with water, high excess pore-water pressures built up in these sediments. When the water in the ground was subjected to great pressure, as a combined result of the weight of the glacier overriding the area and the downward migration of the "freezing front" at the base of the permafrost layer, it did <u>not</u> compress, because water is virtually incompressible (consider how a hydraulic jack works). Instead, it tended to support the weight of the overlying materials and cause them to "float" on the water that filled the pore spaces in the rock and sediment.

All of this somewhat theoretical discussion leads us to the most important point of this article. Because of the great pressures that developed in the groundwater, large blocks of frozen sediment and rock that were, as I said, almost floating on the high-pressure water zone, were easily transported by the advancing glacier. This resulted in large-scale thrusting in certain areas. One of the most spectacular areas of thrusting to be found anywhere in North America occurred in the Devils Lake area, where exceptionally high pore-water pressures built up, apparently because the confluence of the ancestral Knife River and its tributary was at that location.

The glacier moved--thrust--huge amounts of material a short distance, excavating it from the area that is now flooded by Devils Lake, and depositing it just south of the lake, in the Fort Totten-Sullys Hill area. The ice-thrust materials are represented by the shaded areas on the map. As soon as the thrusting episode took place, the pressurized water beneath the ground was able to escape from the hole from which the ice-thrust material had been quarried; this hole is now the location of Devils Lake. Because the pressure had been dissipated, further thrusting did not take place; however, the large volumes of water that flowed from beneath the ground as the thrusting was occurring did carry tremendous volumes of gravel and sand. Some of the gravel and sand can be seen in the hill that is known as Devils Heart, near Tokio.

We don't know for sure just when the thrusting event that formed the Devils Lake-Sullys Hill complex took place, but because the features were not overridden by later glaciers (we know this because the hills are not smoothed over and the depression is not filled in), it is likely that the thrusting occurred during Late Wisconsinan time, perhaps as recently as 12,000 years ago.

The history of Devils Lake since it was formed is also interesting. As I mentioned earlier, at the end of the last glaciation, the lake that flooded the Devils Lake area was much more extensive than is the modern Devils Lake. The glacial Lake Minnewaukan overflowed into the Sheyenne River as long as it stood at a level as high as 1453 feet. When it dropped below that elevation, it no longer drained out of the basin and the closed basin came into existence. We do have some further knowledge of the post-glacial history of Devils Lake, but much more work needs to be done before we understand it adequately.

The level of Devils Lake has fluctuated considerably since the end of the glacial epoch. Prior to about 8,500 years ago, the lake level stood above 1440 feet in elevation; this level was probably reached again sometime between 2,500 and 1,500 years ago, but during the 6,000-year period between 8,500 and 2,500 years ago, it was at somewhat lower levels. By the middle of the 19th century, when the area was settled by European immigrants, the lake level was at about 1435 feet. The lake level dropped from then until 1940, when it stood at a low of 1401 feet. Since then, however, the lake has risen to about 1428 feet.

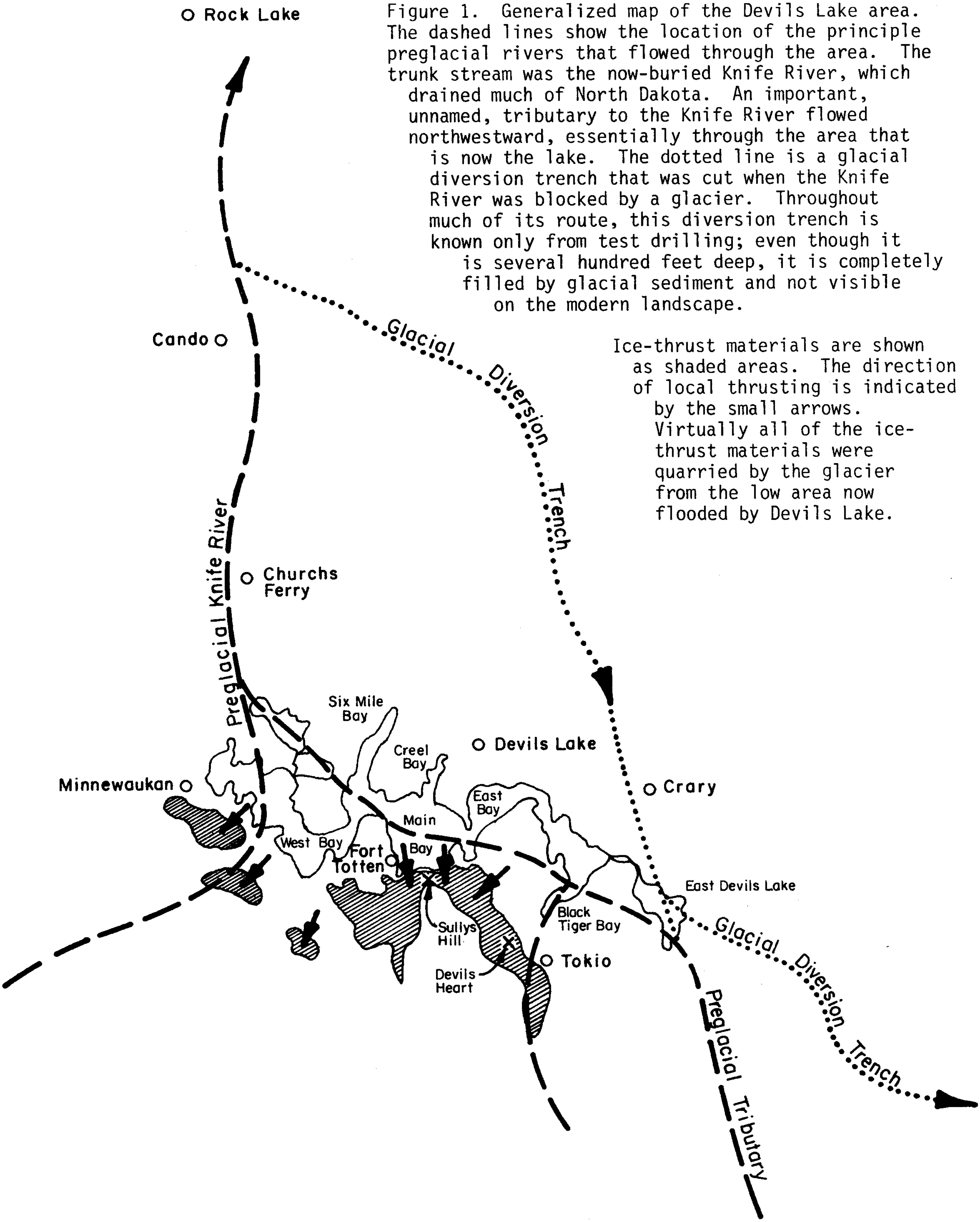
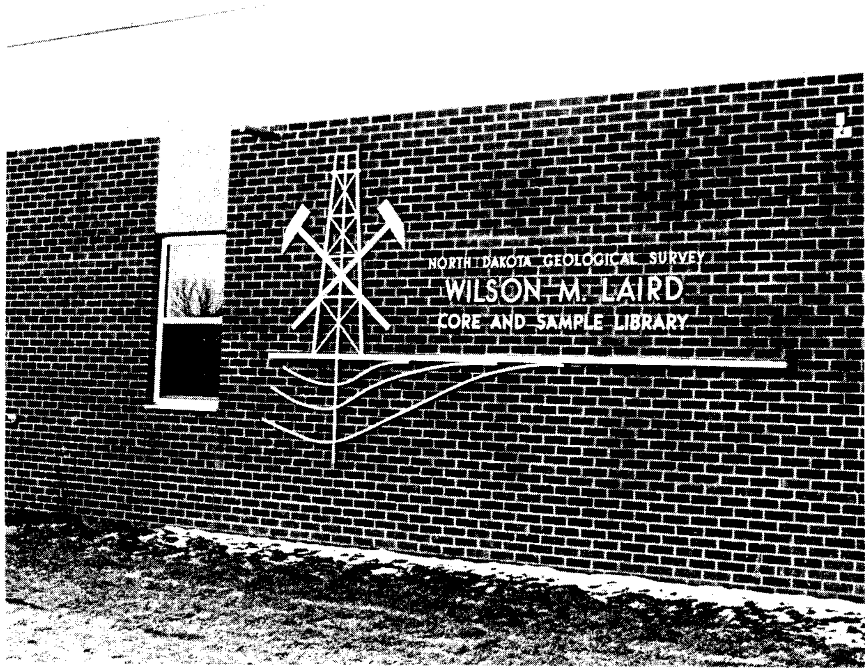


Figure 1. Generalized map of the Devils Lake area. The dashed lines show the location of the principle preglacial rivers that flowed through the area. The trunk stream was the now-buried Knife River, which drained much of North Dakota. An important, unnamed, tributary to the Knife River flowed northwestward, essentially through the area that is now the lake. The dotted line is a glacial diversion trench that was cut when the Knife River was blocked by a glacier. Throughout much of its route, this diversion trench is known only from test drilling; even though it is several hundred feet deep, it is completely filled by glacial sediment and not visible on the modern landscape.

Ice-thrust materials are shown as shaded areas. The direction of local thrusting is indicated by the small arrows. Virtually all of the ice-thrust materials were quarried by the glacier from the low area now flooded by Devils Lake.

NDGS CORE LIBRARY

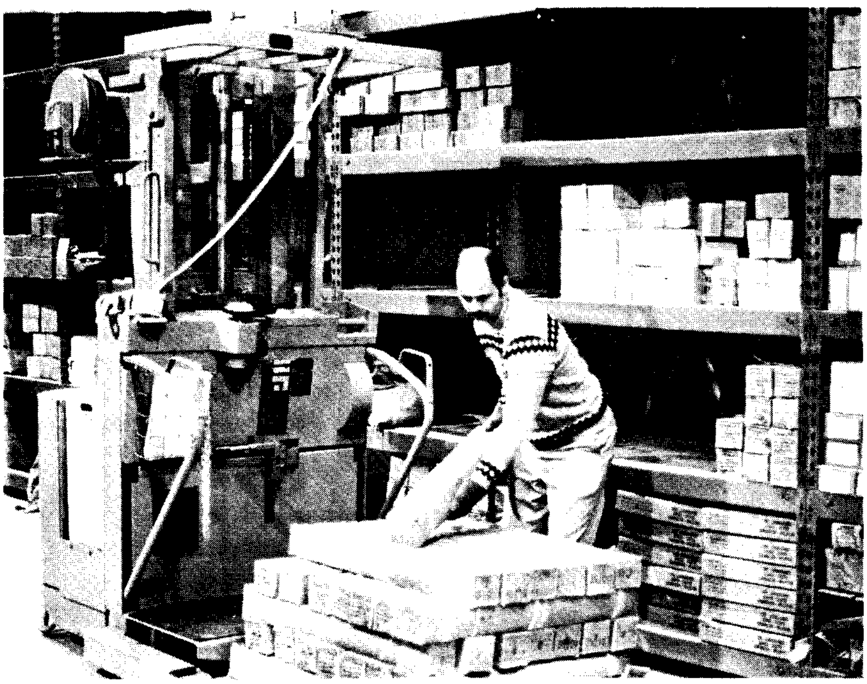


Shelving was installed in the new Wilson M. Laird Core and Sample Library this fall and some of our core has already been transferred from the old core shed to the new building. We expect to complete the moving job shortly after the first of the year. Study areas and laboratories are also ready and in use in the new building.

Core is being received at the Survey at a rapid rate. At the end of 1976, we had a total of 43,434 boxes of core that we collected over a 27-year period. The oldest well for which we have a complete core is the Union Oil of California--Aanstad #1, which was drilled in Ramsey County in 1949. This was drilled under NDGS Permit Number 20 (the state has now issued over 9400 permits and well over 9000 wells have been drilled). Between January 1, 1977 and October of 1981, we received 22,499 boxes of core and our current total is over 66,000 boxes. During the past five years, we have received about 35% of our total core. This drastic increase is due in part to the increased number of holes being drilled, partly due to the greater depths being tested, and partly because more core is being cut per well. The last time we calculated a total, we found that the average well now being drilled in North Dakota has about 90 feet of core cut.

Non-geologists sometimes ask why we require oil companies to supply us with core. The answer is that the core is an extremely valuable research material. Although well logs that measure such petrophysical characteristics as radioactivity, spontaneous potential, resistivity, and many other things, are extremely valuable research tools (and indeed, the Survey requires that oil companies supply these to us also), all of these are indirect methods of measuring various characteristics of the materials. There is often no substitute for looking at the rock itself.

Most cores are about 4 inches thick and cylindrical in shape. They are cut by a special coring bit and forced into a core barrel. By the time they reach us, cores are packed in boxes, each containing a 3-foot length of rock. Some of the more obvious things that can be seen by examining a well core are: crude oil (if it is present), the composition of the rock, and the amount of pore spaces. Geologists studying our cores look at many other characteristics too, some of them much more subtle than those I just mentioned. They may cut thin-sections, study fossils, or perform various chemical tests.



Here, Rod Stoa, who is in charge of our Core Library, is shown stacking core on a shelf in the new Core and Sample Library. Our new electric fork lift (a "Clark Rider Order Selector"), which can handle core as high as 16 feet is also shown.

RECENTLY RELEASED PUBLICATIONS

Since our last Newsletter was published in June, the Survey has released several new publications.

Bulletin 73, Part III -- "Ground-water resources of McIntosh County, North Dakota" was prepared by R. L. Klausing of the U.S. Geological Survey. The report is one of three parts dealing with the geology and groundwater flow systems in McIntosh County. It is the result of an investigation to determine the quantity and quality of groundwater available from glacial-drift and preglacial bedrock aquifers. The major glacial-drift aquifers that have the greatest potential for development are the Spring Creek and Wishek aquifers, which may yield as much as 1000 gallons of water per minute and 1500 gpm, respectively. Other important glacial-drift aquifers are the McIntosh, Zeeland, Dry Lake, and South Branch Beaver Creek aquifers, which may yield from 500 gpm to as much as 1000 gpm. Water in the glacial drift aquifers is hard. Groundwater in preglacial bedrock aquifers, which is also hard, is most readily obtainable from the Fox Hills and Dakota (Inyan Kara) Formations. The report is 37 pages long and includes maps showing the Pierre Formation surface and groundwater availability as well as several geohydrologic cross sections. The report is available free of charge from the North Dakota Geological Survey.

Bulletin 75, Part I -- "Geology of Sheridan County, North Dakota" was prepared by John P. Bluemle. With the publication of Part I of this bulletin, all three parts are now available. The report describes the subsurface and surface geology, the geologic history, and economic geology of Sheridan County. Emphasis is on description of the glacial deposits and on surface landform development. The report includes a colored geologic map of the county, and 59 pages of text and figures. It is available free from the North Dakota Geological Survey.

Miscellaneous Series 60 -- "Annotated bibliography of the geology of North Dakota, 1960-1979" was prepared by Mary Woods Scott. The bibliography is a companion to NDGS Miscellaneous Series 49, which is a bibliography of all known geologic literature on North Dakota that was published between 1805 and 1960. Some references to the literature prior to 1960 are also included in the present volume, since they were omitted from the earlier one.

Entries in the bibliography are arranged alphabetically by author. Several reports done by the same author are arranged chronologically from oldest to youngest. Several reports published during a single year by the same authors are arranged alphabetically by title. Reports by two or more authors are listed following the reports done by the first author alone. Each entry includes keywords and/or keyword phrases to describe the contents of the report; in this respect the new bibliography differs from the 1972 version covering years prior to 1960, which included annotations for many of the entries. The keywords are supplemented by terminology from the referenced reports. In most instances, stratigraphic,geographic, and paleontologic terminology were selected from the report.

The subject index has major headings that are subdivided where necessary and where possible. Cross references indicate that the term listed is not used as a heading and the user is referred to the correct index term.

The exhaustive subject index helps the user to locate references to specific topics. The subject index has major headings that are subdivided where necessary and where possible. The Annotated Bibliography includes a total of 290 pages. It is available from the North Dakota Geological Survey, University Station, Grand Forks, North Dakota 58202-8156. The cost is $5.00.

Miscellaneous Series 61 -- "Williston Basin Stratigraphic nomenclature chart" was compiled by John P. Bluemle, Sidney B. Anderson, both North Dakota Geological Survey geologists, and Clarence G. Carlson of the North Dakota State Industrial Commission, Oil and Gas Division. The chart measures 23" x 35". It is printed partly in color and includes two basic elements. Part A is a time-correlation chart of Williston Basin stratigraphic units in use by geologists working in the basin. Part B is a column of the central basin scaled strictly according to time (1 inch = 24 million years). The part of the chart scaled according to time will help non-geologists--teachers, students, and other interested people--understand geologic time and how it affected North Dakota. The major portion of the chart, however, is a series of 15 correlation columns that depict the geology throughout the Williston Basin, including eastern Montana, northeastern South Dakota, much of North Dakota, and southern Saskatchewan and Manitoba. This correlation chart should be valuable to geologists working in the basin. The chart includes global and North American series/stage designations as well as the more traditional systems terminology.

The Williston Basin stratigraphic nomenclature chart is an outgrowth of an American Association of Petroleum Geologists research project entitled Correlation of Stratigraphic Units of North America (COSUNA). The Williston Basin portion of the research project is being conducted by the North Dakota Geological Survey. The chart is available for $1.00 from the North Dakota Geological Survey, University Station, Grand Forks, North Dakota 58202-8156. Folded copies will be mailed and rolled copies may be obtained at the Survey office.

"Geothermal Resources of North Dakota"--Map compiled by K. L. Harris of the North Dakota Geological Survey with assistance from other NDGS and University personnel. For the past 2½ years, the North Dakota Geological Survey has been working under a cooperative agreement with the U.S. Department of Energy, Division of Geothermal Energy, studying North Dakota's geothermal resources. The results of the first phase of the study have been summarized on a 1:500,000 scale (approximately 40" x 50") map that is now available from the Survey.

The colored map indicates areas of the state with higher than average geothermal gradients; it summarizes the available terrestrial heat flow data; it includes an inset showing depth, thickness, water quality, and expected water temperature of the Mississippian Madison Formation; and it describes some existing and proposed applications of geothermal energy in the state.

The Geothermal Resources map, published for the NDGS by the National Geophysical and Solar-Terrestrial Data Center, National Oceanic and Atmospheric Administration, is available free of charge from the North Dakota Geological Survey, Grand Forks, North Dakota, 58202-8156.

A new List of NDGS Publications is also available. The new List of Publications is effective through October, 1981. It includes all publications ever released by the Survey, including exhausted numbers that may still be seen in libraries. A description of each publication is listed, along with its price. The List of Publications may be obtained by writing or calling the North Dakota Geological Survey, University Station, Grand Forks, North Dakota, 58202-8156.

SOON-TO-BE-RELEASED PUBLICATIONS

Lexicon of Stratigraphic Names of North Dakota

The "Lexicon of stratigraphic names of North Dakota" was compiled by Joanne V. Lerud, formerly a Librarian with the North Dakota Geological Survey, who is now employed by Marathon Oil Company. The Lexicon includes as complete as possible a listing of all terms that have been applied to the various stratigraphic units recognized in North Dakota. The listing includes a history of the terminology applied to each unit, its age, area of extent, lithology, thickness, relationship to other units, characteristic fossils, economic significance, depositional environment, and references to type sections. Two appendices to the Lexicon list are: 1) the named lignite beds in North Dakota, and 2) Pleistocene and Holocene stratigraphic names.

Some of the information on general lithologic descriptions, maximum thickness, mineral resources, and relationships to other units are shown in the "North Dakota Stratigraphic Column," a copy of which is included in a pocket at the back of the Lexicon; some of this information is therefore not listed in the text. A system of capitalization and underlining was used to distinguish startigraphic names as to their current status. Each unit in the Lexicon was given a ranking so that one not familar with the stratigraphy of North Dakota would be able to understand the relative importance of each name.

The price of the Lexicon, NDGS Report of Investigation 71, has not yet been determined.

The Wannagan Creek Quarry

We have a short, non-technical report nearly ready on the Wannagan Creek fossil quarry in Billings County, North Dakota. The fossil site is described by Dr. Bruce Erickson of the Science Museum of Minnesota in St. Paul. The Wannagan Creek Quarry is a remarkable fossil site in that so many species of animals have been found there. Some of them are similar to younger fossils, and a few are closely related to living kin. Because Paleocene-aged strata have had rather limited study, the Wannagan site has produced many new species and further excavations will likely add to the list. As of the end of 1980, 7 new species had been described and at least an additional 18 new ones are believed to be present among all the groups.

Reptiles account for the majority of the fossilized vertebrate remains. They also include the only complete skeletons from the site. So far, the reptiles are represented by two crocodilian taxa, five *chelonians* (turtles), one *champsosaurid* (a crocodile-like swimming reptile), at least two species of lizard, and one possible snake. Among the mammals, *multituberculates* (small plant-eating animals), *insectivores* (insect-eating animals), *primates* (the order of mammals that includes the apes, as well as man; the Wannagan Creek primate forms were small animals); and *condylarths* (ancestors to the modern hoofed animals) are represented by dozens of mandibles (jaw bones), solitary limb and girdle bones, and many isolated teeth. At least three different species of birds were found, including a new species, *Dakotornis*. Several amphibians and fishes were also present, but only an estimate of about 10 different types can be made from their incomplete record.

The invertebrate fauna has not yet been studied in detail, but laboratory preparation of materials from the quarry indicates that a variety of insects and mollusks (snails, clams and other soft-bodied animals) are present.

In addition to expanding our knowledge of Paleocene animals and plants that lived in what is now western North Dakota 58 million years ago, this fossil site has given us a detailed look at a paleocommunity, showing us what the environment was like at that time. Comparisons of the fossil record at Wannagan Creek and contemporary crocodile communities provides a means of reconstructing the climate and depositional setting in western North Dakota at the time the lignite-bearing strata of the Fort Union Group were being deposited.

The Wannagan Creek Quarry is NDGS Report of Investigation 72. It is 12 pages long and includes 9 illustrations. The price has not yet been established.

Groundwater Recharge in Western North Dakota

"Mechanisms, distribution and frequency of groundwater recharge in an upland area of western North Dakota," was written by Bernd W. Rehm, Gerald H. Groenewold, and William Peterson. The report reviews effects to be expected when large areas of lignite coal are mined over the next 20 to 30 years in western North Dakota. By 1983 it is expected that 850 square kilometres (325 square miles) of land will be disturbed each year and an additional 1000 square kilometres (390 square miles) will be disturbed each year beginning in 1990. The disturbance of the landscape may drastically alter the potential for groundwater recharge. If recharge rates through reclaimed landscapes are significantly less than through the currently undisturbed landscapes, water levels in shallow flow systems may decline to the point where groundwater supplies are disrupted and stream baseflows are decreased. Proposed regulations developed by the Office of Surface Mining recognize the potential of surface mining to change groundwater recharge rates. This paper first reviews the factors that control the movement of groundwater through the unsaturated zone. The remainder of the paper then focuses on data collected from the Falkirk area in central North Dakota. Most of the study area will have been disturbed by surface mining for lignite by the year 2010. Mining operations have already begun on the southwestern edge of the site. The data included in the report is being collected as part of a largerstudy, which is designed to evaluate the impact of surface mining and reclamation on groundwater and surface water quality and quantity.

This report, NDGS Report of Investigation 75, should be released in January or February of 1982. The price has not yet been determined.

HYDROTHERMAL STUDY RELEASED

-- Ken Harris

The Final Technical Report of Phase II of our Department of Energy cooperative study (DOE-FC07-79ID 12030) of the hydrothermal resources of North Dakota has been released.

Phase I of this study (March 7, 1979 to March 7, 1980) consisted of an evaluation of potential hydrothermal aquifers based on the North Dakota Geological Survey's records of oil and gas wells drilled in the state. The Phase I study assembled a computer library system (WELLFILE) of the oil and gas well data, and used this data to construct a geothermal gradient map of North Dakota and summarize the characteristics of potential hydrothermal aquifers.

Most of the oil and gas wells drilled in North Dakota have been drilled in the western two-thirds of the state, and most of these wells have had Paleozoic rock units as their objective. Consequently, the oil and gas well data contained in WELLFILE is concentrated geographically in the western two-thirds of the state and stratigraphically in Paleozoic rocks.

In addition to expanding our knowledge of Paleocene animals and plants that lived in what is now western North Dakota 58 million years ago, this fossil site has given us a detailed look at a paleocommunity, showing us what the environment was like at that time. Comparisons of the fossil record at Wannagan Creek and contemporary crocodile communities provides a means of reconstructing the climate and depositional setting in western North Dakota at the time the lignite-bearing strata of the Fort Union Group were being deposited.

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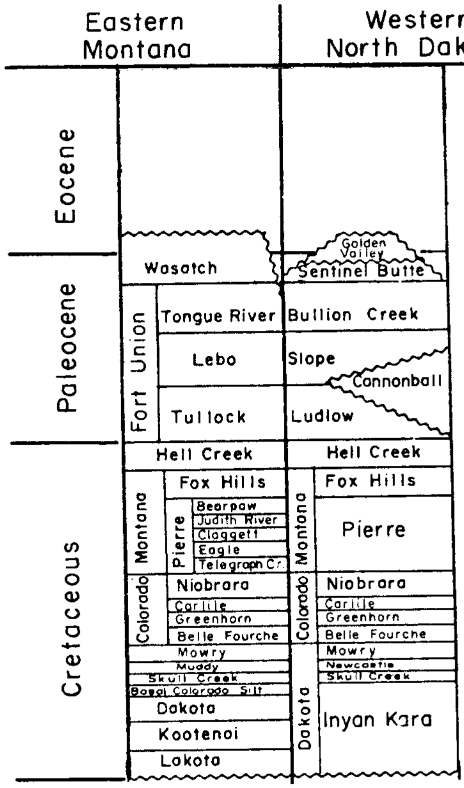


Figure 1

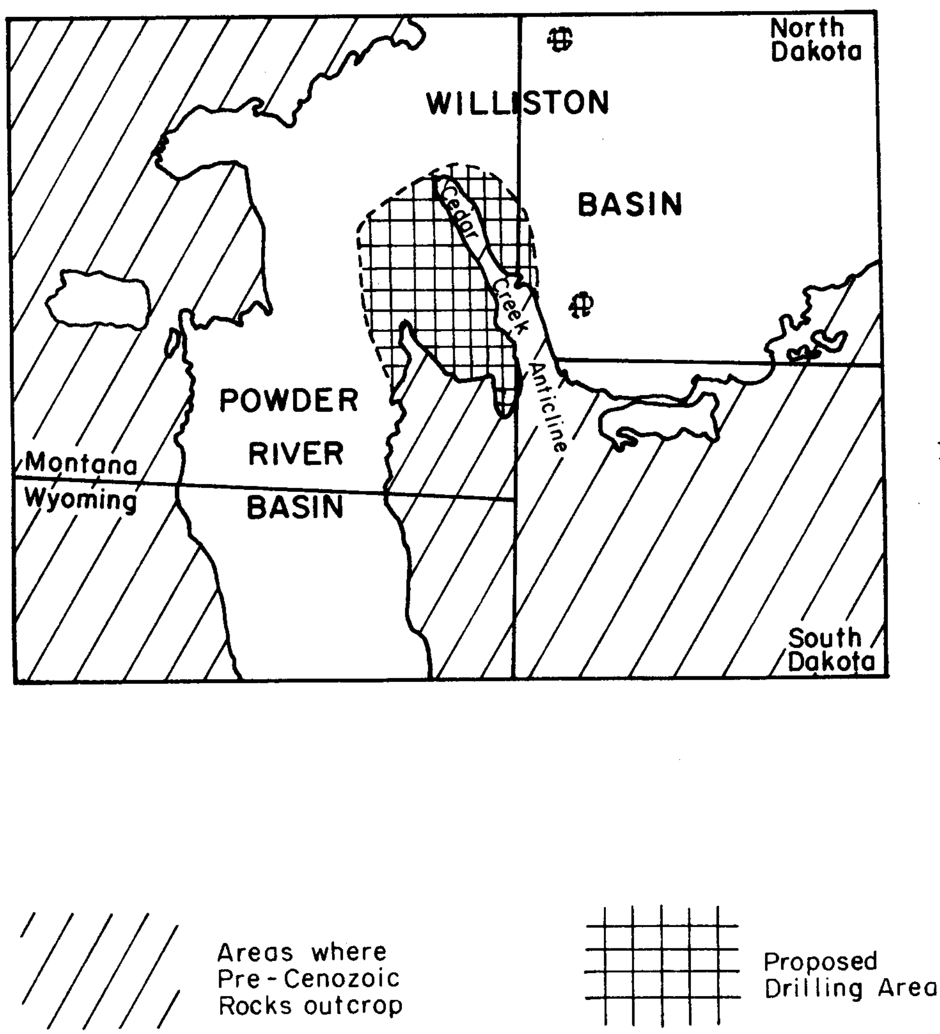


Figure 2

universities. The conference participants examined and discussed the stratigraphic and sedimentologic character of the Paleocene sections in the two basins (fig. 1). The conference gave the participants a greater appreciation of the unresolved problems in these areas, and it enabled us to focus on specific questions about the interpretation of these rocks.

During the summer of 1982, we will conduct a drilling program in areas where data is insufficient, as determined by the studies we have so far completed. Next summer's drilling program will concentrate in an area adjacent to the Cedar Creek Anticline in southeastern Montana (fig. 2). This drilling should provide sufficient data to enable us to determine the effects the Cedar Creek Anticline had on sedimentary processes between the Powder River and Williston Basins. It should also give us insight into the correlation of the various stratigraphic units between the basins. The Cedar Creek Anticline is known to have had four major periods of activity, three in pre-Cenozoic time and one during the Cenozoic. Minor amounts of drilling will also be done outside of the proposed area to enable us to attain better control on the interpretation of available oil- and gas-gamma logs. This last drilling will be minor due to budget limitations.

We are now in the process of constructing a structure contour map on top of the Cretaceous Pierre Formation and the Cretaceous Bear Paw Shale, using existing oil-and-gas electric logs. We are extending our existing Pierre structure map of North Dakota into eastern Montana and northeastern Wyoming. When completed, this map should provide us with a good estimate of maximum projected depths for the proposed drill holes.

The results of our drilling, as well as interpretation of already-available well logs from North Dakota, Montana, and Wyoming, should enable us to make subsurface identifications and correlations of the lithologic units in this interval, which are of regional significance.

The interpretation of the stratigraphy and sedimentology will be further aided by field work next summer in some of the less-well known parts of the Williston Basin.

Our third major objective is the construction of a data base, using the information gathered during the earlier phases of the study. This data base will be accessible to anyone interested in the data. It is intended to provide scientists with information for their own uses and for extensions of the base data, and to give the public a data-compilation for regional and local use.

The data base is expected to include the material in the computer data file as well as cross-sections and geologic maps, rock and resource descriptions, interpretive descriptions and the stratigraphy and sedimentology of the Fort Union Group, and overview-reports in less technical language for the non-geologist.

SUBSURFACE STUDIES OF PALEOZOIC AND MESOZOIC ROCKS IN THE NORTH DAKOTA WILLISTON BASIN

-- Randy Burke

The more we learn about the stratigraphic rock units in the Williston Basin, the better we will be able to evaluate the state's mineral resources. Presently, the North Dakota Geological Survey is supporting eleven independent subsurface studies by both Survey personnel and by geology graduate students at the University of North Dakota. Stratigraphic units included in these studies are the Cretaceous

Niobrara; the Jurassic Swift; the Mississippian Ratcliffe, Frobisher-Alida, and Bakken; the Devonian Birdbear, Duperow, Ashern, and Winnipegosis; and the Silurian Interlake. Most of these studies are far enough along so that various aspects of them will be presented at the Annual Meeting of the American Association of Petroleum Geologists in Calgary, Alberta, Canada during the week of June 27 to July 1, 1982.

Abstracts of the talks have been accepted for presentation at the technical session entitled "Williston Basin Reservoir Geology." In addition, an abstract was submitted to present a poster session/core workshop to display core slabs and photomicrographs of the characteristic types of facies, fabrics, and porosity of some Kaskaskia Sequence rocks in the Williston Basin.

The Survey also expects to publish most of the talks presented at the AAPG meeting. Follow-up papers will be presented at the Fourth International Williston Basin Symposium to be held in Regina, Saskatchewan, Canada, between October 5th and 7th, 1982.

THE EFFECT OF OIL-AND-GAS WELL DRILLING FLUIDS ON SHALLOW GROUNDWATER IN WESTERN NORTH DAKOTA

-- Ed Murphy

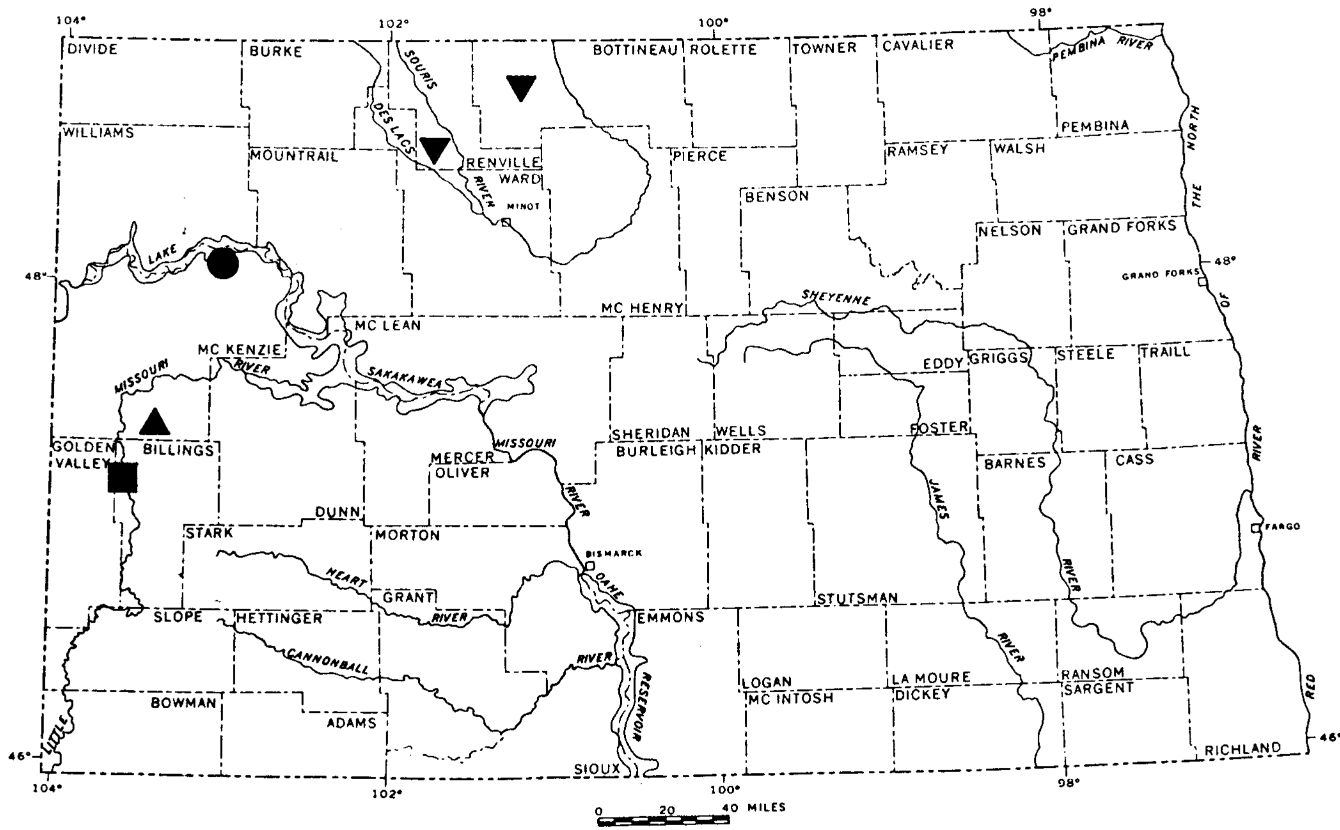
For the last year and a half, the North Dakota Geological Survey, with the assistance of the North Dakota State Department of Health, has been conducting a study to determine the effects of reclaimed oil-and-gas well drilling fluid pits (reserve or mud pits) on the shallow groundwater supply in western North Dakota. A total of four mud pits are being monitored by the use of piezometers (five-foot screened water wells) and soil water samplers, which provide water samples for major ion and trace metal analyses. The soil water samplers retrieve samples from above the water table by the induction of a vacuum.

Three drilling sites are being monitored in McKenzie County and a fourth one in northwestern Billings County (fig. 1). These sites were chosen in an attempt to include all of the major variables associated with drilling fluid pits in western North Dakota: the geologic and geohydrologic conditions; the age of the pit (date the well was drilled); the drilling fluid additives that were used; the presence or absence of workover and completion fluids; and whether or not a liner was installed in the pit.

Two of the sites are located in sediments and under geohydrologic conditions that are typical of most oil-and-gas drill sites in the western part of North Dakota. These sites are within alternating sand, silt, clay, and lignite beds of the Bullion Creek and Sentinel Butte Formations. The water table at these two sites is at least seventy-five feet below the surface. The other two monitoring sites are located within more permeable slopewash and alluvial deposits where the water table is at depths of twenty-five to thirty feet beneath the surface. The last two sites were chosen because they represent geohydrologic conditions that have the highest potential for groundwater pollution in western North Dakota.

The drilling fluid pits are commonly about 150 feet long, 60 feet wide, and 10 feet deep (figs. 2,3). Where the sediment beneath and adjacent to the pit is determined to be too permeable, a plastic liner is commonly used to line the pit and contain the drilling fluid. Bentonite clay was commonly used to line the pits prior to the introduction of plastic liners six or seven years ago. Upon completion of drilling, the mud pit is usually reclaimed by "trenching." This method consists

PROPOSED AND EXISTING MONITORING SITES



■ Apache Federal 1-5

● Texaco Inc. Charlson Madison North Unit

▲ Texaco Inc. Gov't. "A" NCT-1#2 and Belco Petroleum Corp. B.N. Sheep Ck.#1-11

▼ Proposed additional sites

Figure 1

Figure 2.
Plastic-lined mud pit.
Note lignite along
slope cut.

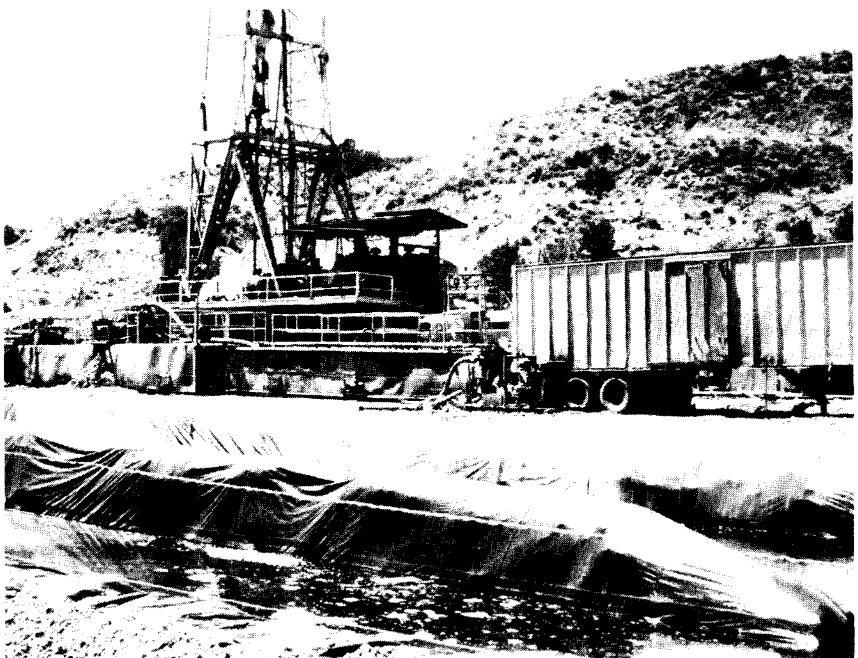


Figure 3.
Drilling site with
lined pit. Depth of
fluid in pit is
approximately 7 feet.

Figure 4. Trenched mud pit.

of digging a series of trenches (12-22 feet in depth), which radiate out from one side of the mud pit (fig. 4). The opposite side of the pit is then pushed in until most of the fluid is in the trenches. Sediment is then backfilled over the trenches and the site is leveled and completed.

It has been my observation during the last two summers of field work in western North Dakota that approximately 95-100 percent of all oil-and-gas drilling fluid pits are reclaimed by the trenching method. This method, which is used regardless of whether or not the pit was lined, essentially defeats the purpose of using a liner in the first place.

The last batch of quarterly water samples is in the process of being analyzed by the State Health Department and the results should be available shortly. Laboratory work on shelby-tube sediment samples is ongoing and should be completed within the next two months. In the absence of this data, conclusions cannot yet be made concerning the movement of the leachate from these drilling-fluid pits. We do know that at least some of these chemical ions will migrate out of the drilling fluid and possibly degrade the shallow groundwater within a localized area around the drill site.

Clay particles are the greatest single source of ion attenuation and their abundance has a direct influence on impeding the rate of movement of the ions. Fortunately, the Tertiary sediments in western North Dakota do contain a high percentage of clay, which helps to reduce the potential problem of leachate migration.

We are presently soliciting funds to expand our study into areas of north-central North Dakota covered by glacial sediment (fig. 1). There is a need to be concerned about the potential for drilling-fluid leachate migration within the highly permeable glacial meltwater channel sediments. These sands and gravels contain only small amounts of clay to retard the movement of leached drilling-fluid ions.

The results of our study will be published in a North Dakota Geological Survey Report of Investigation that should be available by the end of 1982.

OIL AND GAS ACTIVITY DURING 1981

(Editor's note: the information included in this article is based on unofficial statistics pending release of the official figures).

Thirty of North Dakota's 53 counties were affected by oil and gas exploration activities during 1981. In 6 of the 30 counties, however, no actual drilling was done, although permits were issued for exploratory wells which may yet be drilled. A total of 1072 drilling permits were issued in 1981. (Several sources have recently listed the total number of drilling permits issued during 1981 at 1098. This is 26 too high because new numbers were designated for 26 oil wells that had been redrilled under the original permit number; to avoid the confusion of having two wells with the same permit number, these 26 wells were arbitrarily given new numbers). This compares with 773 permits issued during 1980, 644 in 1979, and 417 in 1978. In 1980, 540 holes were drilled for oil and gas in North Dakota; by early December, 1981, 700 holes had already been drilled.

Interest continues to be most intense in McKenzie and Billings Counties where the wildcat (wells drilled in unproven areas) "success ratio" through November, 1981, has held at 55% and 60% respectively (success ratios were calculated only in counties where 20 or more exploratory wells were drilled, but even with that many wells, the percentages can be somewhat misleading). Williams and Dunn Counties, with wildcat success ratios of 30% and 25% respectively, are also comparatively active areas. Conversely, the wildcat success ratio is, of course, zero percent in the 10 counties where only dry holes were drilled. Statewide, about 25% of the wildcat wells drilled for oil and gas in 1981 were successful; a total of 80 new pool discoveries were recorded (through November) from 12 different counties.

The trend toward deeper discoveries is continuing. Thirty-eight of the new pool discoveries so far recorded in 1981 were from the Ordovician Red River Formation. Twenty-one Mississippian Madison Formation discoveries were recorded. Discoveries were also made in the Devonian Duperow Formation (8 new pools), Mississippian Bakken Formation (5), Pennsylvanian Tyler Formation (2), and Ordovician Gunton Formation (2). One discovery each was recorded from the Cambro-Ordovician Winnipeg-Deadwood Formations, Silurian Interlake Formation, Devonian Dawson Bay Formation, and Devonian Birdbear Formation. So, 59 of the 80 new pool discoveries were from horizons deeper than Madison.

All new pools that have been assigned temporary spacing and field rules by the State Industrial Commission in 1981 are included in the compilation used in this article. This method of calculating discoveries may lead to some discrepancies when official figures are released as it does not take into account the actual date the discovery well was completed. Thus, some 1980 discoveries that had temporary orders signed in 1981 are included whereas some late 1981 discoveries will not have orders signed until early in 1982. Nonetheless, I think a reasonably accurate overall picture of 1982 drilling activity is shown.

TALKS AND FORMAL ADDRESSES BY NDGS GEOLOGISTS

Survey geologists have given a considerable number of talks over the past several months at various technical sessions. Our geologists have also spoken to various service groups and other informal gatherings. I've asked each person to list and summarize some of the talks they have given recently so you can get an idea of the sort of things people request and some of the topics we are involved in.

Ken Harris included two talks in his list. They were titled: "Some factors affecting the development of the hydrocarbon resources in North Dakota," and "Hydrothermal resources of North Dakota." The first talk, given in Bismarck last July at the Energy Development and Public Policy for Educators Summer Institute, was a semi-technical talk intended to help give teachers an idea of some of the energy-development projects underway in North Dakota. It also included a field trip to Amerada's Fryburg Field and an Amoco drill rig. Ken's second talk was delivered at the 26th Annual Midwest Ground-Water Conference in Bismarck last October. Francis Howell of the University of North Dakota physics department co-authored that paper.

Gerald Groenewold gave me a list of four talks, all delivered at technical sessions. Their titles are: 1) "Applicability of column leaching data to the design of fly ash and FGD waste disposal sites in surface-mined areas" delivered at the Low-Rank Coal Symposium in San Antonio, Texas in June (see the abstract on page 27 of this newsletter for more detail on the San Antonio talk); 2) "Hydrologic and geochemical considerations in mined-land reclamation and design in thermo-electric waste disposal sites" delivered in Bismarck at the Energy Development and Public Policy for Educators Summer Institute in July; 3) "Research needs associated with the disposal of thermo-electric utility wastes" given at the Electric Power Research Institute Workshop in Nashville, Tennessee, in November; and 4) "Aqueous transport of inorganics" given at the Basic Coal Research Workshop in Houston, Texas in December.

John Hoganson listed three talks, two at technical sessions, and one presentation at an informal gathering. The titles are: 1) "Late Llanquihuen climatic history of southern Chile depicted by fossil beetle assemblages" delivered at the North Dakota Academy of Science annual meeting in Dickinson last spring: 2) "Late glacial climatic history of southern Chile interpreted from Coleopteran (beetle) assemblages" delivered at the annual meeting of the Geological Society of America in Cincinnati in November; 3) "Microfacies analysis and depositional environments of the Duperow Formation (Devonian) in the North Dakota part of the Williston Basin" given at the North Dakota State University Geology Club meeting in Fargo. The first two talks were co-authored with Allan Ashworth of the North Dakota State University geology department. In addition, John will address the January meeting of the North Dakota Geological Society in Bismarck on "Recognition of past climatic changes: the key to prediction of future climatic trends."

Don Halvorson presented a number of talks and I'll list some of the more interesting titles here. He gave a talk entitled: "A scientific and climbing expedition to the Mt. Kenya area, East Africa" to the Dakota Drifters organization in Grand Forks last January. Don's responsibilities at the Geological Society of America Sectional Meeting in Rapid City last April included a technical talk, "Volcanic Origin for Devils Tower, Crook County, Wyoming (see the abstract I've included on page 29 of this newsletter). He also gave a talk entitled "Volcanic history of the Canary Islands" to the American Institute of Mining Engineers meeting in Grand Forks in

October, and "Petrology and Geology of the Black Hills" for the Sigma Gamma Epsilon meeting in November. Also in November, Don gave a technical presentation, "Geology and Petrology of the Devils Tower-Missouri Buttes area, Crook County, Wyoming," at the North Dakota Geological Society meeting in Bismarck.

Most of the talks I've (John Bluemle) given have been non-technical, intended primarily for groups of non-geologists, and I've generally dealt mainly with North Dakota topics. I gave a half-day field trip and seminar for the Annual Muscular Dystrophy Association camp held at Turtle River State Park last summer. I really appreciated the chance to talk about the geology of the park to such an interested group of young people. In July, I addressed the Society for Range Management Annual Convention meeting in Bismarck, discussing the geology of North Dakota and our mineral resources. Again it was an opportunity to tell people from all over North America, Europe--even Australia, about North Dakota's geology and let them know that it is more than flat land covered with snow (at least it wasn't on the day I talked to them in July!). Finally, I addressed the Fargo-Moorhead Rock Club annual Christmas Banquet in Moorhead during December. That was an especially enjoyable experience as the group kept me there answering questions for several hours. I'll also be participating in the 8th Annual Greater Grand Forks Communiversity next month, offering a 4-session course on the "Geology of North Dakota" on the four Sunday evenings during February.

Many of us have given several additional informal talks and field trips around the state, dealing with various aspects of North Dakota geology. My own field trips usually deal mainly with geologic history, how the landscape formed (especially the glaciated areas), and the state's mineral resources. All of our geologists are regularly called upon to lecture to University of North Dakota geology classes and to other departments on campus as well as at North Dakota State University and other colleges around the state, and sometimes in other states.

Before they left, Lee Gerhard and Erling Brostuen were frequently called upon to speak at meetings and to groups; they dealt most often with the state's mineral resources and economy. I do not have a ready listing of the many talks these two men gave over the past several months.

ABSTRACTS OF ARTICLES PRESENTED IN PROFESSIONAL JOURNALS

In addition to the reports and articles that have been published by the North Dakota Geological Survey, most of our geologists published one or more technical papers in professional journals during 1981. The abstracts I have included here by no means represent the total Survey effort, but they should give an indication of some of the research topics NDGS geologists are involved in. Also, see the article in this Newsletter describing talks and formal addresses (p. 24). Those of you who want additional information about the topics covered in the following abstracts should contact one of the authors listed above the abstract. Also, I'd appreciate hearing from you--is the information in this article useful to you? If it is, I will try to warn our geologists ahead of time to keep in mind that I'll be asking them for their "list." It's not an easy task to recall, on short notice, everything you have been involved in over a whole year, or even a six-month period.

Harris, Kenneth L., Howell, Francis L., Winczewski, Laramie M., Wartman, Brad L., Umphrey, Howard R., and Anderson, Sidney B., 1981, An evaluation of the hydrothermal resources of North Dakota: State Coupled Geothermal Resource Assessment Meeting, Glenwood Springs, Colorado, May, 1981, Symposium Volume, pages 238-246.

(Please see the article in this Newsletter entitled "Hydrothermal Study Released" as it essentially summarizes the content of the Glenwood Springs paper).

Groenewold, Gerald H., Rehm, Bernd W., and Cherry, John A., 1981, Depositional setting and groundwater quality in coal-bearing sediments and spoils in western North Dakota: Society of Economic Paleontologists and Mineralogists Special Publication No. 31, p. 157-167, August, 1981.

Studies of several active and proposed surface coal-mining sites in western North Dakota have resulted in the development of a hydrogeochemical framework which accounts for the chemical characteristics of groundwater in coal-bearing strata. Data from surface mining sites in other western states and provinces indicate much regional similarity in the hydrogeochemical characteristics of shallow aquifers. $SO_4^{=}$ and HCO_3^- are commonly dominant anions. Na^+ and $Ca^{+\!\!+}$ are generally the dominant cations. $Mg^{+\!\!+}$ is occasionally dominant. The pH of the groundwater normally ranges from 7 to 9. The electrical conductance of the groundwater ranges from 500 to 4500 μS. Groundwater at depth is generally of the $Na\text{-}HCO_3$ type.

Critical hydrogeochemical processes include pyrite oxidation, carbonate mineral dissolution, gypsum precipitation and dissolution, cation exchange, and sulfate reduction. The key components of this framework are mineralogical variables in the sediments. These variables are, in turn, largely dependent upon fluctuations in the fluvial depositional settings of the sediments.

During surface mining operations unweathered materials are commonly emplaced in the zone of active weathering. Hydrochemical data from postmining landscapes suggest that severe degradation of groundwater quality is possible in some settings. The degree of weathering, dissolution, and ion exchange, as in premining settings, is largely dependent upon mineralogical variables in the overburden sediments. Degradation of groundwater quality in postmining landscapes can be minimized if these factors are understood and integrated within the framework of mine design.

Rehm, Bernd W., and Groenewold, G. H., 1981, Groundwater response to coal strip-mining and reclamation in North Dakota: 26th Annual Midwest Ground-water Conference, October 28, 29, and 30, Bismarck, North Dakota.

The responses of groundwater levels to mining and reclamation have been monitored at three mine sites in central North Dakota (Falkirk Mine, Center Mine, and Indian Head Mine). The quality of the records is highly variable between the sites but some general conclusions can be drawn from the six years of available data. Declines in groundwater levels in aquifers affected by mining generally do not extend beyond 1.5 to 2.5 km from the actual mine pits. In certain geological settings the drawdowns are limited to the area within 0.6 km or less of the mine highwalls. The actual response to mining at a given site can be highly variable, ranging from 5 metre declines in 2 months to a decline greater then 10 metres in 5 years. The declines in water levels generally show a steady rate of decrease; however, in some situations the water levels decline in steps over a period of years.

The resaturation of reclaimed mine spoils has also been monitored over the last 5 years. A 40 ha area of reclaimed spoils at the Indian Head Mine was instrumented within one year following recontouring. The water levels rose several metres within 4 to 6 months following the installation of observation wells. Little change has been observed since the initial resaturation of the spoils. At this site there is a downward gradient from the base of the spoils to the underlying units.

The Center Mine spoils show a highly variable pattern of resaturation. The water table in the spoils is very irregular with both vertically upward and downward gradients occurring within a 250 ha area. Horizontal gradients within the instrumented area show flow toward the active mining pits, away from other mine pits and radially outward from small mounds on the water table. Limited isotope data (^{3}H and ^{18}O) suggests that some of the water in the spoils has infiltrated vertically from the ground surface. At the Falkirk Mine water is re-entering the spoils from unmined areas adjacent to the active mine pits and reclaimed lands.

Rehm, Bernd W., Moran, S. R., and Groenewold, G. H., 1981, Natural groundwater recharge in an upland area of central North Dakota: Groundwater, Vol. 20, No. 2.

The magnitude of groundwater recharge to coal aquifers in a 150 km^2 area in west-central North Dakota was determined using three separate approaches: 1) the net water level rise in water-table wells; 2) calculations of the fluid flux between nested piezometers using the Darcy equation and measured values of hydraulic conductivity and vertical gradients; 3) evaluation of the inputs to and outputs from the coal aquifer using a steady-state control volume approach in which the aquifer was divided into semi-rectangular cells bounded by equipotential lines and flow lines. Measurements of potential gradients and hydraulic conductivity permitted indirect determination of all components of flow into and out of the cell except the recharge input, which was determined by difference.

All methods yielded consistent results on the order of 0.04 to 0.01 m/yr. These values, which represent 2 to 9 percent of the annual precipitation, are consistent with results of other studies on recharge throughout the prairies of North America.

Evaluation of site hydrology and stable isotope data indicates that recharge is restricted in both time and place. Most recharge occurs in late spring and in the fall following heavy rainfall events. During these seasons the ground is not frozen and vegetation is not transpiring large amounts of water. Some recharge may occur during very heavy, localized summer storms, but it is not considered volumetrically significant. Major, permanent depressions on the site are a source of significant recharge. In addition, the extensive area of ephemeral standing water bodies that result from snow melt can produce significant amounts of infiltration over the entire site.

Groenewold, Gerald, H., and Rehm, Bernd W., 1981, Applicability of column leaching data to the design of fly ash and FGD waste disposal sites in surface-mined areas: Low Rank Coal Symposium, San Antonio, Texas, June 17-19, 1981.

Fly ash and FGD waste constitute the two major solid by-products of coal-burning power plants. Emplacement of these wastes in mined areas is a common method of disposal at mine-mouth operations. Little is known about the effects on groundwater quality of fly ash and FGD waste emplaced in mined areas.

An ongoing project, presently funded by DOE, is evaluating the potential impacts of these wastes on groundwater quality at the Center Mine near Center, North Dakota. The fly ash and FGD waste are generated by Unit #2 of the Milton R. Young Station. The FGD waste is generated by using the fly ash as an SO_2 sorbent. The research emphasizes field monitoring of disposal sites and laboratory column leaching experiments.

FGD waste from the Milton R. Young Station, when placed in contact with water in column experiments, generates leach fluids with high SO_4 and other major ions and pH within the range of natural groundwater. The highest concentrations of dissolved constituents occur in the first few pore volumes. The degree of ion pairing and complexing of SO_4 with Na and Mg determines the solubility of gypsum accounting for the high concentrations of SO_4. With the exception of molybdenum, toxic metal and non-metal concentrations in FGD waste leachate are typically not in excess of drinking water standards.

Fly ash from the Milton R. Young Station, when placed in contact with water in column experiments, reacts very similarly to the FGD waste with respect to major ion trends. In contrast to FGD waste, the pH of fly ash column effluent is typically within the range of 10.5 to 12.0 and concentrations of toxic metals and non-metals are often in excess of drinking water standards.

Analyses of groundwater samples from piezometers in and near buried fly ash and FGD waste at the Center Mine suggest considerable similarity, with respect to all parameters, between groundwater quality and trends in disposal sites and the quality and trends of effluent from column studies. Long-term monitoring of these sites is needed to verify these observations. These studies suggest that column leaching data, in conjunction with waste mineralogical data and detailed hydrogeological data from the proposed disposal site, are critical input to the evaluation and design of disposal sites for these wastes.

Bluemle, John P., 1981, Quaternary and Holocene stratotypes in North Dakota and adjacent areas: (to be included as a part of a United States Geological Survey publication describing formally named Quaternary and Holocene stratigraphic units in the United States) in Richmond, Gerald (editor).

(No formal abstract was written). The paper describes 17 Quaternary and Holocene stratigraphic units that have been recognized and formally named in North Dakota and nearby areas of northwestern Minnesota. Information included on each unit is: 1) reference to original person or persons responsible for naming the unit plus additional pertinent references; 2) source of name; 3) holostratotype (or stratotype) locality; 4) definition of the unit; 5) holostratotype or stratotype section; 6) boundaries of the unit; 7) regional extent of the unit; 8) geologic age; 9) thickness; 10) additional information where appropriate.

Bluemle, John P., and Clayton, Lee, 1982, Permafrost polygons in southwestern North Dakota: Geological Society of America Abstracts with Programs, Rocky Mountain Section, Bozeman, Montana.

A variety of possible periglacial features occur in southwestern North Dakota, but the only well-documented permafrost features are fossil ice-wedge polygons. Cross sections of the fossil ice wedges have been observed in 20 gravel pits in upland areas, especially in the western part of the Cannonball River basin. Fossil ice wedges in fluvial gravel are zones, generally less than 1 m wide and more than 5 m deep, with the original bedding obliterated and with vertical foliation. Troughs about 2 m wide and 1 m deep developed on the gravel surface when the ice wedge melted. These troughs generally have no topographic expression because the

Soils, sampled largely from topographically high sites, in deposits containing granitic and granodioritic gneissic clasts, are used to establish relative age. Soil morphology, particle size, organic constituents, selected soil-chemical parameters, primary mineral alteration, and clay mineral composition are all used to establish a soil sequence. In particular, changes in organic properties of surface horizons in Neoglacial profiles, variations in clay mineral composition with depth, and changes in the ratio of oxalate-extractable to dithionite-extractable iron are seen as important age indicators. Petrographic analysis of the fine and very fine sand separates (250-63 μm) reveals stages of feldspar alteration as seen in thin section, as well as changes in the ratio of quartz/plagioclase feldspar, all of which assist in age differentiation.