NEWSLETTER

NDGS

A publication of the
North Dakota Geological Survey
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JUNE, 1979

EDITOR'S NOTE--

The first article in this Newsletter was provided by Dr. Lee Gerhard, State Geologist. It is followed by a letter, also from the State Geologist, that will help to publicize information about surface owner's rights to compensation for damages caused by oil and gas drilling operations.

In keeping with the practice of including essays on general geology-related topics in the Newsletter, as well as our coverage of current events, I am including several articles dealing with various aspects of water, especially groundwater, as well as one on flooding. I am also including an article on the impact of the mineral industry on North Dakota's economy and one dealing with geologic time.

Finally, in an effort to make this Newsletter more readable, we are photo offsetting rather than mimeographing it. The number of addresses receiving the Newsletter has grown to well over the limit of our mimeograph machine to run acceptable copies and we have had some complaints that some of the past issues have been hard to read. We hope this change will meet with the approval of our readers.

INCREASED ENERGY RESOURCE DEVELOPMENT FORCES CHANGES IN GEOLOGICAL SURVEY OPERATIONS--

Dramatically increased oil and gas drilling and production activity along with continued work in coal, uranium, and other resources has necessitated increased staffing and organizational changes within the North Dakota Geological Survey. A Legislative performance audit of the North Dakota Geological Survey, performed in 1977 and 1978, resulted in the 1979 Legislative Session approving a budget for the Survey that provides for an increase in staffing to handle the increased energy resource development workload. Twelve new positions were added to the Survey, and new core library was funded. Most of the new positions are dedicated to the increased workload of oil and gas exploration and development and the accompanying administrative support. Four new field inspectors and two petroleum engineers are included in the twelve positions. These new people will enable the Geological Survey to meet its responsibilities in supervising exploratory activities, and they will insure the continuation of the environmentally sound energy development that North Dakota has become accustomed to in its oil and gas industry.

It is difficult to envision the level of oil exploration activity now occurring in western North Dakota. During oil booms in other states in past years similar phenomena have been seen, but the present North Dakota oil boom has to be ranked as one of the largest in the country in recent years. It is almost difficult to drill a dry hole in McKenzie County! Our wildcat success ratio hovers around 28 percent for the State as a whole this year and somewhere around 90 percent in McKenzie County. In addition, we face the problem of aging oil fields with diminishing production and the accompanying problems that come with the plugging of old wells and lease cleanup.

The stress being caused by energy resource development is reflected in Geological Survey research programs, as well as in the additional staffing and facility of the entire organization. Our subsurface geological study programs, particularly in the carbonate rocks, have been fruitful and these are continuing as an integral part of our evaluation of North Dakota's oil and gas potential. A new program is geothermal studies may well presage the large-scale evaluation of that resource as a potential for energy in North Dakota. Coal reclamation studies continue at a high level. Studies of surficial sediments and their engineering characteristics continue to be important as the population of North Dakota expands and demands for housing and sanitary disposal become ever more acute. The Geological Survey is now cooperating with the Department of Energy and with the U.S. Geological Survey, as well as with the U.S. Bureau of Mines, in a number of studies designed to increase our knowledge of the occurrence and potential of our energy resources.

The projected increase in Survey personnel from 31 to 43 has necessitated some organizational changes. The Bismarck branch office will have increased staffing and it has moved into new, larger quarters. We now have two people operating out of our Williston branch office.

As announced elsewhere in the Newsletter, I am most pleased to relay the appointment of Erling Brostuen as Assistant State Geologist and of Wesley Norton as Chief of Field Engineering. Both of these people play crucial roles in Geological Survey programs.

Several pieces of recent state legislation have also affected Geological Survey operations. House Bill 1198 provides for the Geological Survey to provide notice to surface owners of their rights to compensation for damages (see the letter of notification by the State Geologist elsewhere in this Newsletter). House Bill 1250 modifies and clarifies the role of the Geological Survey and Industrial Commission in subsurface mining and formalizes the definitions of mining and mining-related items to include not only drilling, but extraction of resources. Senate Bill 2214 provides for the Industrial Commission and the Geological Survey to permit and control the placement of waste materials into subsurface strata. This gives the State of North Dakota protection, under statute, providing that any waste materials disposed of in subsurface reservoirs or caverns of any kind be properly handled and that such storage or disposal will not adversely affect any other resources.

The role of the Industrial Commission and the State Geologist in the determination of qualification of gas wells and associated gas in North Dakota for various price categories was also approved by the North Dakota Legislature. That bill provided not only for gas deregulation operation, but also, in the event it occurs, the handling of oil deregulation responsibilities through the Industrial Commission and the State Geological Survey.

Federal regulatory agencies and Federal statues have placed an ever-increasing load upon the State Geological Survey. It is sometimes not possible to reconcile the relatively detailed Federal regulations governing geological operations with actual practice and geological materials. There is no way of telling at the present time whether the trend of increasing Federal regulation and intervention will continue or whether the increased cost associated with increased regulation will encourage the Federal government to intrude less upon the prerogatives of the states to control their own resources. There seems to be little argument that both State and Federal agencies are trying to maximize the recovery of resources while minimizing environmental damages. However, we have seen conflicts between Federal agencies and State needs over the detailed interpretation of Federal powers and Federal rules in some of our North Dakota operations. We hope that most of these conflicts have now been resolved and we are doing our utmost to form cooperative bonds with the various Federal agencies that operate within North Dakota in the exploration for and development of natural resources.

SURFACE OWNERS (TENANTS) NOTICE

RIGHTS OF DAMAGES–OIL & GAS DRILLING OPERATIONS

NORTH DAKOTA GEOLOGICAL SURVEY
UNIVERSITY STATION · GRAND FORKS, N. DAK. · 58202

The 46th Legislative Assembly passed a law (codified as Chapter 38-11.1 of the North Dakota Century Code) which provides that all persons should be justly compensated for injury to their persons and property and interference with the use of their property occasioned by oil and gas drilling operations commenced after June 30, 1979, and any production operations that follow. This letter is furnished you so that you will be advised of your rights and options under this law.

The law provides that a "surface owner" (defined as "the person who has possession of the surface of the land either as an owner or as a tenant") shall be paid by the mineral developer a sum of money equal to the amount of damages sustained for loss of agricultural production and income, lost land value, and lost value of improvements caused by drilling operations. These payments cover only land directly affected by drilling operations and are intended to compensate the person who is actually in possession of the land as an owner or tenant. Reservations or assignments of these payments to someone other than the person in possession of the surface estate is prohibited.

The amount of damages may be determined by any mutually agreeable formula. When determining damages, you may consider the period of time during which the loss occurs, and you may elect to be paid damages in annual installments over such period of time; except that you are entitled to be compensated for harm caused by exploration only by a single sum payment.

Except for certain exploration activities governed by other law (such as seismograph exploration) you are entitled to written notice of any contemplated drilling operations. This notice is given by obtaining your address from the land records of the appropriate county register of deeds office. This form and the information disclosing the plan of work and operations contemplated by the mineral developer are intended to assist you in evaluating the effect such activity will have on the use of your property. You are responsible for negotiating the terms of any settlements. You should consult private counsel if you need advice or assistance in making a settlement.

Other provisions of this law provide that the mineral developer shall be responsible for damages to persons or property (real or personal) resulting from the mineral developer's "lack of ordinary care" or resulting from a "nuisance" caused by drilling operations. In the event any person (not just a "surface owner") suffers damage, notice of the damage sustained must be given the mineral developer within two years after the damage occurs or should have been discovered. Unless a written agreement made between the mineral developer and injured person provides otherwise, a mineral developer has 60 days to offer to settle a claim for damages. If the injured person receives a written rejection from the mineral developer, rejects the offer of the mineral developer, or receives no reply from the mineral developer, a court action for damages may be commenced; if the injured person receives a court award greater than the offer of settlement made by the mineral developer the court shall also award reasonable attorneys fees and any court costs in addition to the damage award.

The remedies provided by this law do not preclude seeking other legal remedies. This law, however, does not apply to damages resulting from the operation, maintenance, or use of a motor vehicle on highways (e.g. public road rights-of-way).

Lee C. Gerhard
State Geologist

OIL EXPLORATION AND PRODUCTION IN 1978--

The year 1978 was an unusually successful one with respect to the number of oil discoveries in North Dakota. A total of 350 holes were drilled for oil and gas last year. Of these, 125 were exploratory (wildcat) wells, drilled away from already-existing production. Twenty-seven of the wildcat wells produced oil and 98 were dry, for a success ratio of 22 percent. This compares with the 27 percent success ratio for wildcat wells in 1977 (29 producers in 106 wildcat wells). During 1978, a total of 21 new oil pools were discovered. A total of four gas wells were completed.

Discoveries included 10 from the Madison, 3 from the Red River, 5 from the Duperow, and one each from the Tyler, Silurian, and Bakken. Some of the discoveries are new pays or new pools in already-existing oil fields, but most of the discoveries are located in areas where no production had existed before.

So far in 1979 (to May 1), 10 new pools have been discovered already.

Crude oil production in North Dakota during 1978 rose to nearly 25 million barrels, up from about 23 million barrels in 1977 (see the accompanying tables).

RECENT PUBLICATIONS--

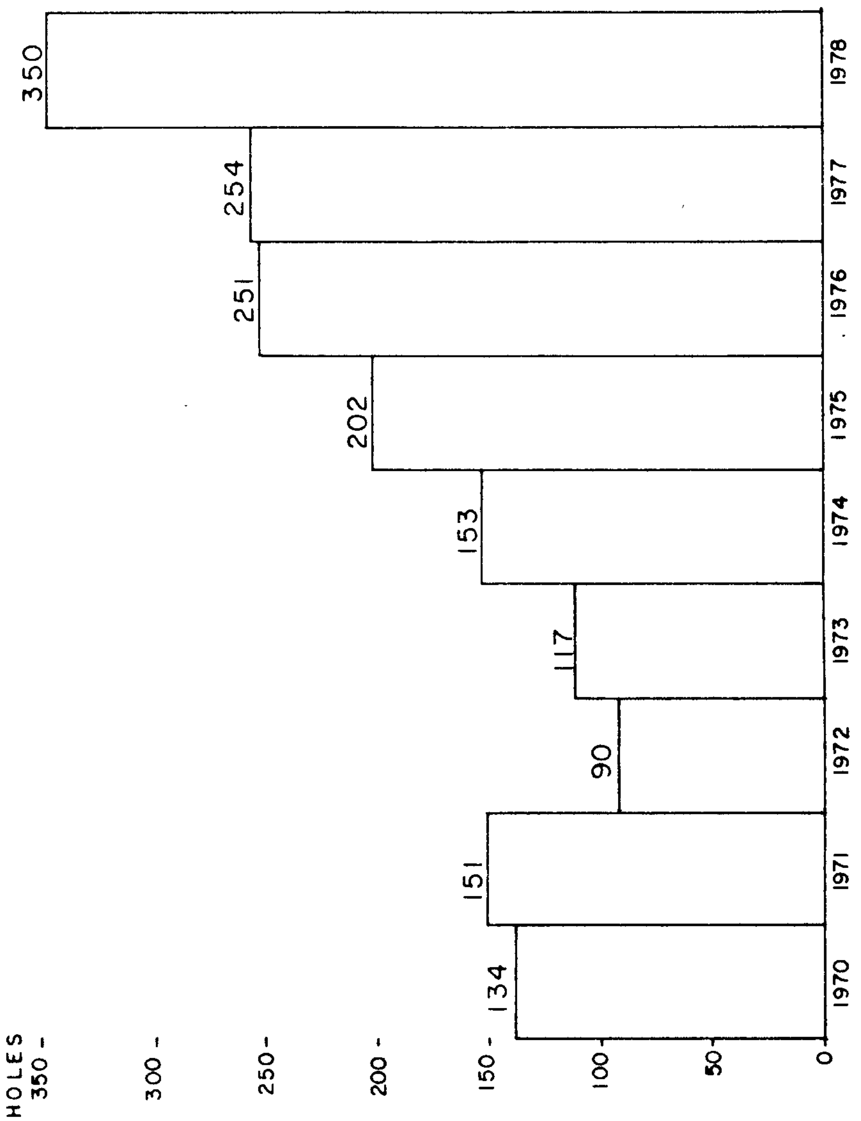
Since our last Newsletter in December, the Survey has published the following reports:

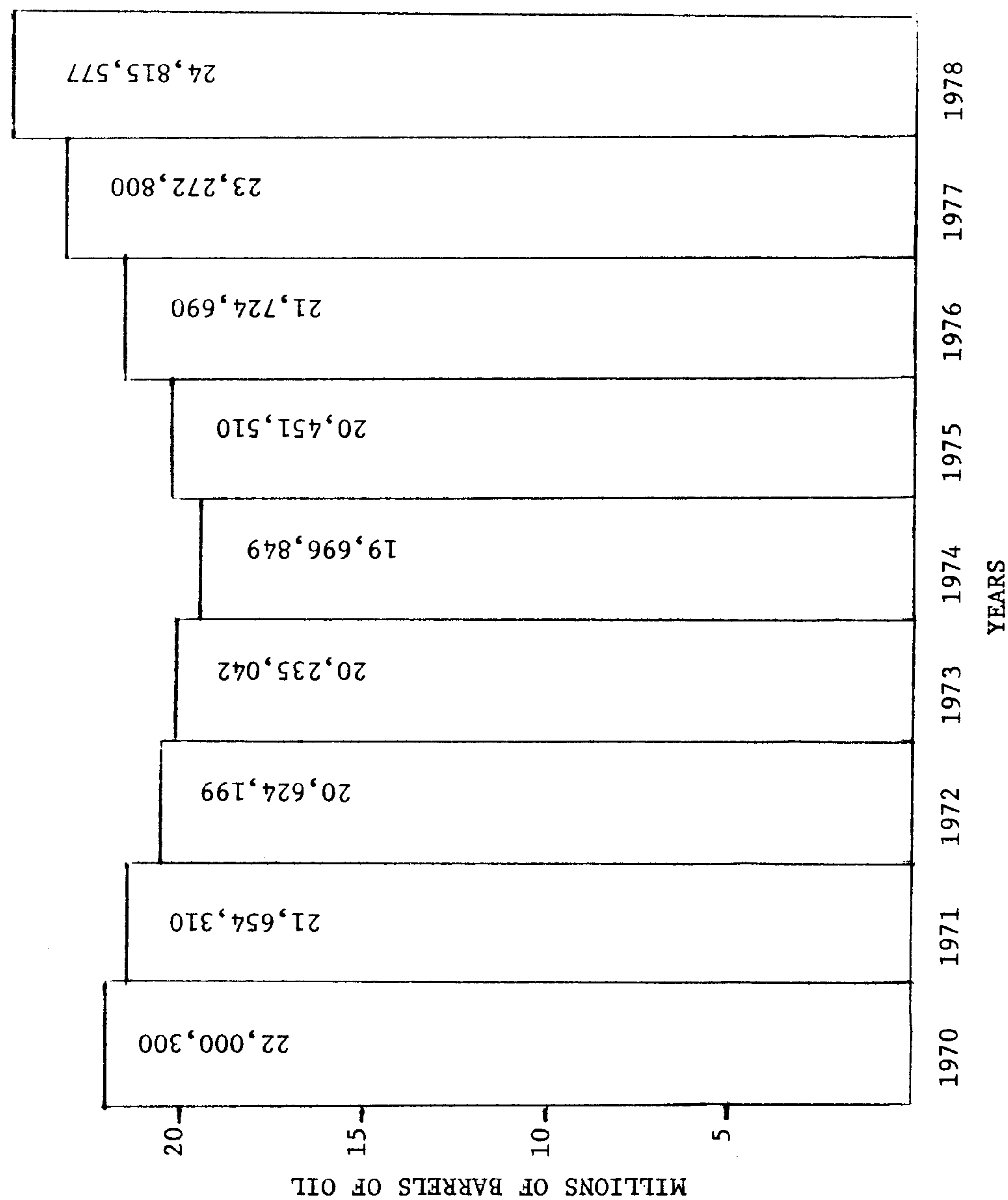
Report of Investigation 61 -- "Geology, Groundwater Hydrology, and Hydrogeochemistry of a Proposed Surface Mine and Lignite Gasification Plant Site Near Dunn Center, North Dakota." The report was written by Stephen R. Moran and six others. It deals with the general stratigraphy of the lignite-bearing strata and was based on data obtained from 26,000 feet of drilling at 68 sites and nests of observation wells at selected sites. It includes an analysis of the groundwater flow systems and summarizes the likely impacts of strip mining on post-mining water supplies. The report is available from the North Dakota Geological Survey for $5.00.

Report of Investigation 66 -- "Depositional Environments and Paragenetic Porosity Controls, Upper Red River Formation, North Dakota" was written by W. Kipp Carroll. It provides a detailed look at facies within the upper Red River Formation. Carroll interprets the "D" zone as consisting of two primary facies, a shallow subtidal burrowed mudstone and skeletal packstone and an impermeable organic skeletal wackestone and packstone deposited in an intertidal or supratidal barred pond environment. The overlying "C," "B," and "A" sequences consist of open-shelf, bioturbated, skeletal wackestone overlain by porous, primary supratidal dolomite overlain by anhydrite and a thin argillaceous bed. Carroll regards the dolomitization in the "A," "B," and "C" zones as penecontemporaneous with deposition. Porosity in the "D" zone is from syndepositional dolomitization of sediment in burrows. Topographic highs are regarded as favorable for porosity development in the "A," "B," and "C" zones while marginal structural positions may be more favorable for "D" zone porosity development. This report consists of 51 pages of text, figures, and tables and 4 plates. It is available from the Survey for $2.00.

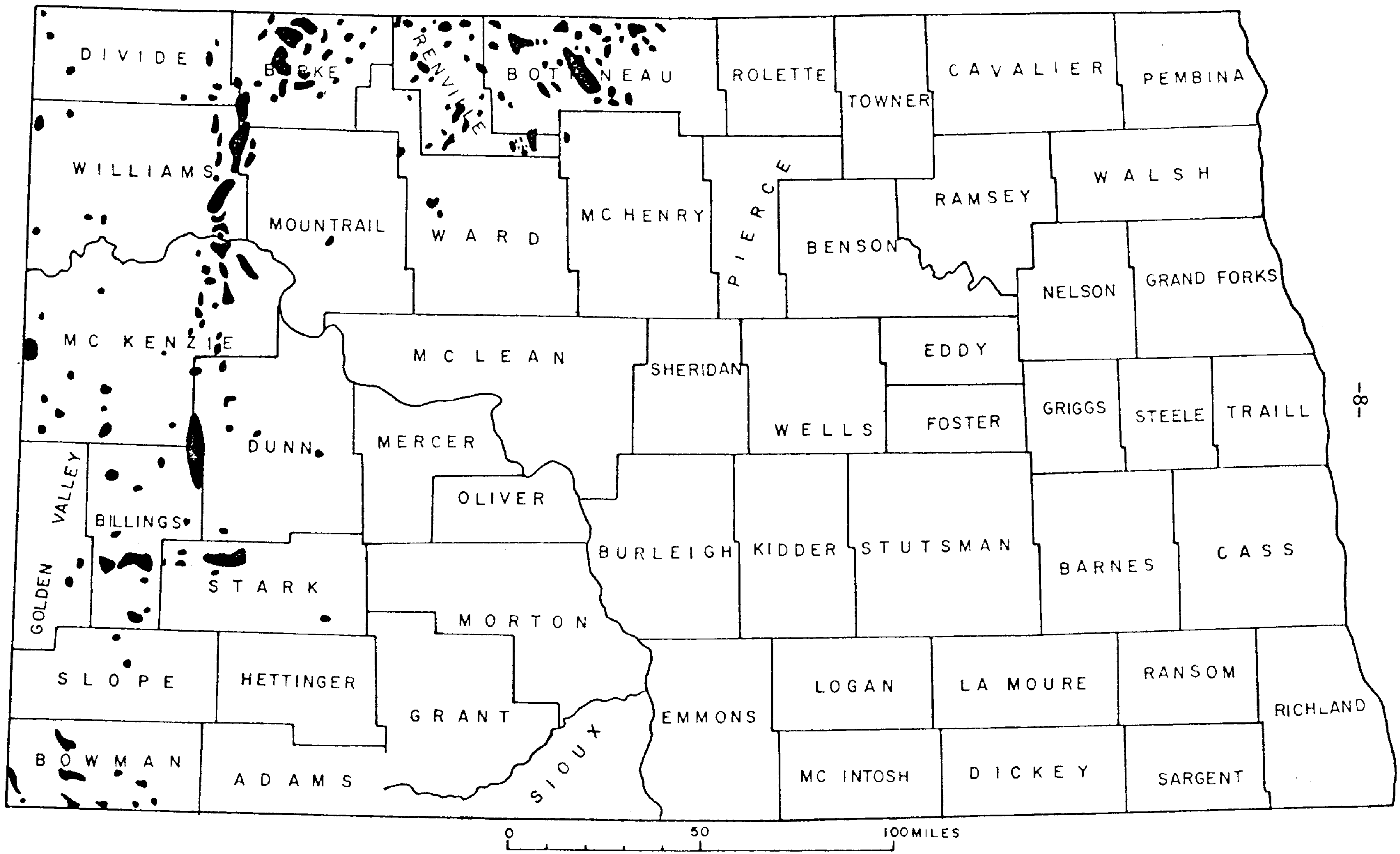
Report of Investigation 67 -- "The Carrington Shale Facies (Mississippian) and its Relationship to the Scallion Subinterval in Central North Dakota" was written by Peter F. Bjorlie. The report provides a geologic description of the Carrington shale

NUMBER OF HOLES DRILLED ANNUALLY FOR OIL AND GAS
IN NORTH DAKOTA





ANNUAL CRUDE OIL PRODUCTION (BARRELS) IN NORTH DAKOTA



1978
Present Fields

facies and an analysis of how it formed in North Dakota. Bjorlie describes petroleum traps that exist where the Carrington shale facies overlies erosionally truncated Devonian strata. He points out that abrupt facies changes occur within the Scallion subinterval, and along the pre-Mesozoic subcrop of the Scallion. Bjorlie also points out that conditions necessary for the concentration of uranium beneath or within the Carrington shale facies may have occurred after the deposition of the shale facies. The report is available from the North Dakota Geological Survey for $2.50.

Miscellaneous Series 57 -- "Oil Exploration and Development in the North Dakota Williston Basin" was written by Lee C. Gerhard and Sidney B. Anderson. It provides a history of oil development in North Dakota from the discovery in 1951 through 1978. Three cycles of exploration are recognized with the third cycle continuing into 1979. The report contains a history of production and economic impacts of oil and gas development, a review of regulatory trends, and a look at the future. It consists of 19 pages of text and figures and is available from the Survey for $0.50.

Bulletin 68, Part III -- "Ground Water Resources of Dunn County, North Dakota" was written by Robert L. Klausing. The report describes the hydrology of ground water in Dunn County. Sandstone, lignite, and glacial melt-water channel aquifers have been identified and potential water yields and quality have been determined and set forth in the report. Aquifers in the preglacial (bedrock) materials have a greater areal distribution than do those in the glacial drift, but those in the drift provide higher yields to individual wells. The report is 48 pages long and includes several maps including a ground-water availability map of Dunn County. It is available free of charge from the North Dakota Geological Survey.

Bulletin 73, Part II -- "Ground Water Basic Data for McIntosh County, North Dakota" was compiled by Robert L. Klausing. The report includes geologic and hydrologic records for 747 wells, test holes, and surface-water sites; water-level measurements in 105 observation wells; lithologic and geophysical logs of 497 test holes and wells; chemical analyses of 185 ground-water samples, chemical analyses of water from four selected lakes; and chemical analyses of minor elements of water from three municipal wells. The report is 458 pages long and is available free of charge from the North Dakota Geological Survey.

THE VALUE OF MINERAL REVENUE TO NORTH DAKOTA--

Even though North Dakota is overwhelmingly an agricultural state, the value of mineral resources plays an important role in the State's economy. The value of mineral resources produced in the State ranks fourth among the major sources of revenue, behind agriculture, tourism, and manufacturing.

The value of fuel-related resources in 1978 totaled $282 million (oil: $222 million; natural gas: $12.6 million; and lignite coal: $47.2 million). The value of non-fuel mineral production was $18.4 million. The most important non-fuel mineral resource was gravel, but small amounts of clay, lime, salt, sulfur, and other minerals were also produced.

According to the U.S. Bureau of Mines, at the beginning of the third quarter of 1978, the mineral industry in North Dakota employed 4,018 people, or two percent of the total State nonagricultural work force of 205,227 persons. Those employed in mining during this period were the highest earning-level group in the State's total private nonagricultural work force. Average weekly earnings for those engaged in mining were $442, compared with $190 for the entire nonagricultural sector.

Mineral resources account for a major source of tax revenue to the State. State income derived from mineral bonuses, royalties, rentals, and mineral taxes is shown the accompanying table, which has been reproduced from "Minerals in the Economy of North Dakota" published by the U.S. Bureau of Mines in cooperation with the NDGS (we have some copies of this publication available for free distribution.)

North Dakota has a gross production tax on oil and natural gas and a severance tax on coal. In fiscal year 1978 (July 1, 1977 to June 30, 1978), these taxes produced more than $19.6 million. (Much of the information I have included here on taxes has been excerpted from a publication entitled "State Taxation of Mineral Deposits and Production" by Thomas F. Stinson. It is dated September, 1978 and was published by the U.S. Dept. of Agriculture as Rural Development Research Report No. 2 Additional information about North Dakota's new coal severance tax was obtained from the North Dakota Tax Department.)

Source	1976	1977	1978
Federal[1]	$950,934	$974,866	$718,333
State:			
Bonuses[2]	336,396	8,736,306	19,666,496
Rentals[2]	561,598	1,658,195	815,671
Royalties[2]	946,791	1,464,649	1,409,386
Severance tax[3]	5,773,193	6,989,950	8,908,8[illegible]
Production tax[3]	8,837,376	10,057,295	10,729,6
Total	17,406,288	29,881,261	42,248,411

[1]Mineral bonuses, royalties, and rentals paid to North Dakota by the Federal Governme under provisions of Section 25 of the Mineral Leasing Act of Feb. 25, 1920. (Base on July-June Federal fiscal year in 1976 and October-September Federal fiscal year in 1977 and 1978).
[2]Calendar year basis. (Source: State Land Department.)
[3]State fiscal year basis of July-June. (Source: State Tax Department.)

Table 1. North Dakota's income from mineral bonuses, royalties, rentals, coal severance tax, and gross crude oil production tax.

The gross production tax on oil and gas is levied at five percent of the gross value of production at the well. This tax is in lieu of all ad valorem (value-rated) taxes imposed by the State, counties, cities, townships, school districts, and other taxing jurisdictions on the property rights attached to producing oil or gas, upon machinery or equipment used in the production of gas or oil, or on the gas or oil produced.

One percent of the gross value of the gas and oil at the well (20 percent of the tax revenue) is credited to the State's general fund. The remaining 80 percent of the production tax revenue is divided as follows:

1) Of the first $200,000 of revenue from each county, 75 percent goes to the county and 25 percent to the State's general fund.
2) Of the second $200,000 of revenue from each county, 50 percent goes to the county and 50 percent to the State.
3) All annual revenue above $400,000 produced in any county is allocated 25 percent to the county and 75 percent to the State's general fund.

The 1975 Legislature placed a severance tax on coal and provided that a portion of the funds collected be available to assist local governments affected by the impacts of development. The severance tax, which was to have a life of two years, was reenacted in 1977. It was a flat-rate tax with an inflation escalator; for each point rise in the wholesale price index (producer price index), the severance tax rose one cent. During the last quarter of 1978, the tax was 83 cents per ton; during the first quarter of 1979 it was 87 cents; and during the second quarter (April, May, June, 1979) it has been 97 cents per ton.

As a result of action by the 1979 North Dakota Legislature, the coal severance tax will be set at 85 cents a ton effective July 1, 1979 for the period July 1 through September 30. Thereafter, it will rise one cent for every four-point rise in the wholesale price index (information obtained from the State Tax Department). Adjustments will be made quarterly. This new law has no cut-off date and will remain in effect until the Legislature changes it.

Revenue collected from the coal severance tax goes to a specially created Coal Development Fund. Revenue deposited in the Fund is apportioned as follows:

1) Thirty-five percent of the funds are credited to a special fund for distribution through grants by the Coal Development Impact Office to affected cities, counties, school districts, and other taxing districts.
2) Fifteen percent of the revenue is credited to a special fund to be held in trust by the State Treasury and administered by the Board of University and School Lands. This fund is available for loans to affected units of local government.
3) Twenty percent of the revenue is allocated to the coal-producing counties in proportion to the number of tons of coal produced in each county. Within the county, the allocation is distributed as follows:
   a. 30 percent to incorporated cities of the county based on the population of each city;
   b. 40 percent to the county government; and
   c. 30 percent to school districts in the county apportioned on an average daily membership basis.
4) Thirty percent of the revenue is deposited in the State's general fund.

Generally, the development of energy resources in North Dakota and other rural western states does create large amounts of revenue and increased tax receipts, but it also results in social and financial problems. Population migration into areas of new development results in greater demand for public services in newly developed areas, which in turn requires increased government revenues. The gross production tax and the severance tax are probably the most desirable ways to generate these new revenues.

HYDROTHERMAL RESOURCE STUDY UNDERWAY--

The North Dakota Geological Survey has entered into a one-year cooperative agreement with the Department of Energy (DOE), Division of Geothermal Energy, to evaluate North Dakota's hydrothermal resources. No known hot springs occur in North Dakota, but hydrothermal energy is currently being used in Emmons County where an enterprising citizen is utilizing 80°F groundwater to supply heat to a heat pump for residential heating. The waste heat from his system is used to supply heat to his barn and dairy facilities.

The current NDGS investigation is being conducted by Ken Harris of the Survey. It will utilize information contained in our oil well file to evaluate the depths and expected temperatures of major aquifers in the State. About 7,000 oil-well records are contained in the file, which includes information from throughout the State, with the greatest concentration of data from the western half of the State.

The hydrothermal resource evaluation involves coding and incorporating the location, elevation, bottom-hole temperature, and selected formation tops into a computer library program. The library program can then be integrated and the data presented in a variety of formats. Maps that will be generated by computer will show the apparent geothermal gradient present throughout the State, the depths and expected temperatures of major aquifers, and areas of anomalous temperatures and their deviation from expected values.

Additional information being recorded in the computer library for each well includes: owner-operator name, total depth, well status, producing formation, perforated interval, initial production, field designation, electric logs available, and cores and samples available.

The project is being funded principally by the Department of Energy (grant funding totals $41,597 under cooperative agreement #DE-FC07-79ID12030), but since the agreement is a cooperative one, the project receives NDGS support as well. People involved in the study include both Survey staff members and University of North Dakota students hired by the Survey.

Ken Harris is the principle investigator. He is currently "picking" the formation tops on the approximately 2,500 wells needed for the stratigraphic framework. Other NDGS staff participating in the project include Sid Anderson, the stratigraphic advisor who developed the previous NDGS computer well file, which is incorporated in the system being assembled. Mike Scott is managing certain aspects of the coding, key punching, and the indexing of core and sample storage locations. University of North Dakota students involved in the project include Laramie Winczewski, geology graduate student, who is the computer reduction expert. Laramie designed the GEOSTOR computer library system we are using with funds provided by the Surface Environment and Mining (SEAM) research group of the U.S. Forest Service. Dan Walker (geology), Alan Gatheridge (geology), Rob Kerian (geology), Linda Johnson (geology), and Laura Anderson (engineering) are the geologic data transfer engineering staff (coders). Howard Umphrey (computer science) is the computer programer.

Even though this evaluation of the hydrothermal resources of North Dakota is only a preliminary study, we hope to designate potential areas of usable hydrothermal energy. The study may also lead to further research on the application of this potentially valuable resource and, perhaps, to its eventual utilization as an added source of energy.

THE CAVALIER SANITARY LANDFILL--

For the past year and a half, the Survey, in cooperation with the State Health Department, has been conducting a study at the Cavalier, North Dakota sanitary landfill. In April, the results of this study were presented in a paper entitled "Effect on Groundwater of the Cavalier, North Dakota Sanitary Landfill" at the 17th Annual Engineering Geology and Soils Engineering Symposium in Moscow, Idaho. Co-authors of the paper were Alan Kehew of the Survey and Gerald Knudsen, Director of the Office of Solid Waste Management, State Health Department.

The Cavalier landfill is located in sandy sediment that was deposited along the shoreline of glacial Lake Agassiz. The water table is quite high in this area, ranging from 6 to 12 feet below land surface at the landfill. The water table is at its highest point in the spring just after the snowmelt and then drops gradually about 3 feet during the summer and fall. The landfill is operated by excavating long trenches in the soil. Garbage is pushed into the trenches and then covered with the soil that was removed from the trench. When water comes in contact with buried solid waste, it can dissolve certain chemicals, which are then carried along with the slowly moving groundwater. These chemicals may or may not be hazardous, depending on the type of waste that was buried at the landfill. The polluted groundwater, or leachate, from a typical municipal landfill usually is not particularly toxic, but can be unfit to drink because of the high levels of some substances compared to their concentration in normal groundwater. Landfills such as the one at Cavalier, which are located in areas with high water tables, have the greatest potential for contaminating groundwater because the water table will actually intersect the buried, solid waste. The situation is somewhat better where the water table is deeper and the groundwater can be polluted only by precipitation slowly infiltrating through the solid waste and down to the groundwater.

The method of study at the Cavalier landfill involved the installation of monitoring wells, or piezometers. In these wells, the depth to the water table can be precisely measured so that the direction of movement of the groundwater can be determined. In addition, samples can be taken from the piezometers for chemical analysis.

The results of the study at Cavalier indicate that the groundwater is moving at a rate of approximately 16 ft/year, which is also the rate that the leachate will be moving after groundwater moves through the solid waste trenches. Near the water table, however, the groundwater must be moving more rapidly because leachate was detected in low concentrations at a greater distance away from the trenches than it could have reached at a rate of 16 ft/year.

Water samples analyzed at the State Health Department labs in Bismarck indicate that groundwater near the center of the Cavalier landfill is highly polluted, with a concentration of dissolved solids (TDS) about 10 times the TDS concentration of the normal groundwater in that area. This leachate will continue to move with the surrounding groundwater at the average rate of 16 ft/year.

Once groundwater is contaminated, there is little that can be done at a reasonable cost to correct the situation. At Cavalier, no water supply wells are located near the landfill in the direction of flow, so the landfill will not be polluting anyone's drinking water.

The knowledge gained from this study will help us to better evaluate other existing or proposed landfills in similar geologic settings. Proposed landfills are examined much more carefully than they were 20 years ago when the Cavalier landfill site was chosen. Each landfill must now have a permit from the State Health Department. The permit applications are reviewed by the State Geological Survey and sometimes by other state agencies to minimize the potential for groundwater contamination.

THE FLOODING PROBLEM IN GRAND FORKS-EAST GRAND FORKS--

Even though this article is largely of local interest to people in eastern North Dakota and northwest Minnesota, I think it is justified for this Newsletter in view of the great amount of controversy surrounding the recent Red River Valley flooding and widespread dissatisfaction with National Weather Service flood forecasts and predictions. I've excerpted the material here from a report I am writing that should be ready in a few months.

The April, 1979 flood is still a subject of considerable controversy as this analysis is written. Charges of inaccurate predictions by the National Weather Service; charges that drainage of wetlands and farm drainage ditches aggravated flood conditions; the unexpected flood by the English Coulee in Grand Forks -- all of these and other considerations make it difficult to present an accurate and objective "instant analysis" of a flood only recently subsided.

Flooding in the Red River Valley is the result of several factors. During the winter, snow accumulates over the entire drainage basin, more than 30,000 square miles of land upstream from Grand Forks. Much of the snow and ice is retained until spring, when it is released, more or less suddenly, by melting. The effect is as if the precipitation for several months fell within a few days time. As this water is carried out of the basin by the Red River, at least some flooding usually occurs. The magnitude of the flooding depends on the amount of moisture stored in the drainage basin, how fast it is released by melting, how much can be absorbed by the ground, and how much water is added by spring precipitation.

Many factors affect this accumulation-melting-flood relationship. The most important ones can be divided into two groups: "constant" and "variable." Constant factors relate to the drainage basin and river channel characteristics. The gentle northward slope of the river results in low streamflow velocities. As a result, the area drains slowly, increasing the likelihood of flooding. Moreover, the flatness of the lake bed (the Red River Valley is the floor of the glacial Lake Agassiz) allows the flood water to spread out over a large area.

Obstructions such as bridge foundations restrict the flow of water by constricting the channel. They also greatly increase the likelihood of ice jams. Although dikes do, in many cases, prevent floodwaters from inundating lowlands along the river, they also tend to restrict the river to a narrow, artificial channel. The net result is a slight increase in the height of the river just upstream from the dikes as the water is forced through a relatively narrow neck in the channel during floods.

Artificial drainage ditches facilitate draining of valuable farm land, but they also result in faster and more complete transfer of rainfall and snowmelt to the river. Water that was once stored on the flat lands bordering the river is now poured into the river during the critical spring thaws.

The rural road system plays an important role in determining the manner in which melt water runs off the land. In many places where culverts are too small to handle a large flow, water becomes dammed against the roads, forming lakes in the northeast corners of the sections (on the North Dakota side of the river; on the Minnesota side lakes form in the northwest corners of the sections as the regional slope there is northwestward). Water then pours over the roads, washing out bridges and stripping the gravel off the road surface or even washing out the roads.

The expansion of urban areas and paving of large areas has resulted in a decrease in the surface available for infiltration (seepage into the ground) and it has increased the speed with which an area can drain, as a result of streets and sewers.

Variable factors, over which man has no control, relate mainly to the weather. It is the interplay of climatological factors from year to year that determines the magnitude of the individual floods. Flooding can occur at any time of year that temperatures are generally above freezing, but in this area, flooding usually occurs in early spring. Flooding can occur in the summer months after an especially heavy rainfall over a large portion of the drainage basin. Most of the "summer floods," however, do not reach flood stage, which is 28 feet, and have little direct effect on the Grand Forks area (the July, 1975 flood was a major exception). The flooding season is dependent on the factors involving temperature and precipitation, which are discussed below.

1. Snow Accumulation. The history of flooding in the Red River Valley shows that nearly all large floods were preceded by unusually heavy winter snowfall or late spring precipitation, or both. However, other factors besides the amount of winter snowfall affect the magnitude of spring floods.

2. Thaw Rate. Following a winter of unusually heavy snowfall, the factor that is most important in determining whether or not a large flood will occur is the rate at which the snow melts. The shorter the melting period, the greater must be the flow of the river to carry the meltwater away. Cool days with temperatures in the low 30s and night temperatures below freezing allow for slow release of the meltwater. However, an unusually cool or late spring with temperatures remaining below freezing is likely to be followed by a sudden warming trend which causes a rapid release of moisture. Floods occurring after April 15 are apt to be more severe than are earlier floods.

3. Precipitation During Thaw. The amount and kind of precipitation which falls during the thawing period is also important. Any precipitation, even snow, increases the quantity of water that must be drained by the river. Moreover, a warm rain during the thawing period results in much faster melting of snow and ice on the ground than does warm air.

4. Timing of Crests. The drainage basin of the Red River at Grand Forks-East Grand Forks is divided between the Red Lake River to the east and the Red River south of Grand Forks. In fact, the Red Lake River can account for as much as 40 percent of the flow during a flood. The timing of the flood crest on each of the two rivers is controlled by factors within their respective drainage basins. If the crests from both of them reach the two-city area at the same time, the flood hazard is considerably increased.

5. Condition of the Soil. If heavy rainfall occurred in the autumn of the previous year, the soil within the drainage basin is saturated with moisture when it freezes. It is therefore able to soak up very little moisture from the spring thaw. A wet autumn, then, contributes to spring flooding by increasing the percentage of early spring moisture that must be carried by the rivers.

Like saturated ground, a frozen soil is unable to soak up moisture, increasing the percentage of runoff into the rivers. The colder the winter, the greater the depth of frost penetration into the soil, the slower the ground will thaw in the spring, and the greater will be the amount of runoff to cause flooding. The coldness of the winter also affects the amount of snow remaining when the spring thaw arrives.

6. Ice Thickness. An unusually cold winter, especially if early winter snowfall is light, results in a greater-than-average thickness of ice on the rivers. The thicker the ice, the longer it will remain on the river in the spring. Until the ice is cleared from the river, flow of floodwaters is impeded and threat of ice jamming remains.

The soil throughout the Red River drainage area was reported to be low in subsurface moisture prior to the first snowfall in November, 1978. This condition would normally have helped to minimize flooding. However, several factors combined to more than offset this single favorable factor. The winter of 1978-79 was unusually long and unremitting, with above-normal snowfall and a very late thaw. Winter unofficially arrived about November 10, with snow and cold. Except for a few days in mid-December, temperatures were below freezing continually for about five months. The Grand Forks-East Grand Forks area received about 54 inches of snow, about 20 inches more than normal, during the winter. This was equivalent to about 5 inches of water in the snow pack when the melt began during the second week of April, about a month later than usual. Virtually all of the snow that fell through the winter was still on the ground when the spring thaw began. The base of the snow pack had been transformed during the winter into a layer of ice several inches thick. Finally, nearly two inches of rain accompanied the mid-April thaw and very little sunshine was available during the thaw to help evaporate snow and runoff.

When temperatures rose suddenly into the 50's and 60's on April 16, the snow cover melted rapidly. Apparently, much of the water from the melting snow flowed over the frozen ground and over the basal ice pack so rapidly that almost none of it was absorbed by the supposedly dry subsoil. Furthermore, the very rapid melt immediate. saturated the uppermost fraction of an inch of topsoil wherever ice was not present. This resulted in swelling of the clay-rich soil, forming an essentially impermeable seal at the top of the soil zone. The melt water flowed off over the sealed soil surface instead of replenishing the subsoil mositure supply. Had the melting been only slightly less rapid, the swelling of the surficial clay layer would have been much less effective in forming a seal. The clay would have dissociated and broken down, allowing a far greater percentage of the water to penetrate the soil zone. The soil did become saturated in areas where the runoff water accumulated, against the south and west sides of roads in the northeast corners of nearly all sections.

The April, 1979 flood was characterized by an extremely rapid rise of the Red River. The crest of 49.09 feet came on April 26. Many farmsteads and communities--Warren, Minnesota and Emerado, North Dakota, for example--were inundated by "flash" floods of runoff water from nearby fields, not by the river itself. In Grand Forks, the rapid runoff caused a severe flood on the English Coulee, a situation few people anticipated.

(NOTE: The flood report from which this material was taken, is scheduled for publication later this year. It includes much more detailed descriptions of many other flooding factors, including a detailed analysis of the English Coulee flood.)

GROUNDWATER IN NORTH DAKOTA - AN OVERVIEW--

About half of the Nation's population uses groundwater for drinking and for oth domestic purposes. In most rural areas of America, groundwater is the only practical source of fresh water and in many areas it is the only source of any kind of water.

Groundwater is a major source of supply for many municipalities and farms in North Dakota. In fact, about 45 percent of North Dakota's urban communities depend on groundwater and nearly 100 percent of the rural water is groundwater. Larger cities like Fargo, Bismarck, and Grand Forks generally depend on river water. Recent years have also seen a growing demand for groundwater in irrigation, and irrigation wells producing several hundred to over a thousand gallons of water a minute have been constructed in several parts of North Dakota. Nationwide, more than a third of the water used for irrigation is supplied from groundwater reservoirs.

Groundwater is found in minute pores or fractures in the sediment beneath the ground surface. Pores are the open spaces between individual pebbles or sand or silt grains or particles of clay. Fractures are found in the harder and more compact sediment such as sandstone, shale, clay, or lignite. Vertical fractures are seldom more than a fraction of an inch across, and horizontal ones are generally closed tight. North Dakota's groundwater resources are ultimately derived from precipitation. Water that enters the ground and contributes to groundwater aquifers is called recharge, and areas where water enters the ground are called recharge areas.

Groundwater is found beneath the water table where the sediment is saturated with water. Above the water table, much of the pore or fracture space is drained and filled with air. Most sediment beneath the water table contains between 10 and 35 percent of its total volume in water. The rate at which water can seep through sediment is defined as its permeability. The permeability depends in part on the size of the pore spaces or fractures. For example, groundwater will seep through gravel, sand, or lignite more readily than it will seep through silt or clay. A "seam" of water-bearing sediment -- an aquifer (rhymes with "Jennifer," not "~~retire~~ wildfire") -- consists of a permeable layer of gravel, sand, or other porous material beneath the water table. The water in the pore spaces or fractures seeps readily into any well that penetrates the sediment of such an aquifer. Even though a clay layer may contain a large amount of groundwater in its pore spaces, its permeability is too low to allow the water to seep into a well easily. (See the article on the Cavalier sanitary landfill in this Newsletter; it is the relatively high permeability of the sediments in this landfill that make it a generally unsuitable landfill site).

The chemistry of groundwater is controlled by its seepage path through the sediment. Near the recharge end of the seepage path where the water enters the ground, the sediment has been largely flushed of the more soluble material and the groundwater has been in contact with the sediment only long enough to dissolve small amounts of mineral material. As a result, calcium-bicarbonate groundwater, with small amounts of total dissolved solids (TDS), commonly occurs in upland areas where the groundwater has either moved slowly through a few hundred feet of poorly permeable silty or clayey sediment, or moved rapidly through a few thousand feet of highly permeable gravel or sand. Such water tends to be hard. Hardness refers to the amount of calcium and magnesium ions in a water sample.

Near the discharge end of deep seepage paths, such as areas in eastern North Dakota where the Dakota aquifer discharges into flowing wells, the more soluble material has not yet been flushed out of the sediment and the groundwater has been in contact with the sediment for a great length of time. As a result, sodium-sulfate or sodium-chloride groundwater with large amounts of TDS commonly occurs at great depths and in valley bottoms (such as the Red River Valley). This water tends to be soft.

In general, water obtained from wells is commonly of such quality that it can be used for domestic or industrial purposes without treatment, although there are many exceptions to this generalization in North Dakota. Some people believe that groundwater is difficult to pollute because dirty water becomes purified by passing through soil and rocks, but this is not necessarily true. This misconception can be strikingly illustrated by two instances I looked into several years ago, both about the same time. In the first case, a farmer north of Grand Forks had a shallow, dug well, about 30 feet deep, in the middle of a cattle feed lot. Very convenient for the cattle and it provided large quantities of water. Unfortunately, the cattle were dying. I had the water tested and it was extremely high in nitrates, the obvious source of which was the cattle manure and urine leachate seeping downward to the water table and contaminating the well. In another case, I visited a home in a small town where a lady had both an outdoor privy and a shallow well for drinking water, which she pumped, by hand, in her house. The well had just recently begun to smell bad. The privy was located uphill from the house, only 50 or 60 feet away (no need to say more?). Surprisingly perhaps, in both cases, the people remarked how good the water tasted. I didn't try it so I can't say whether they were right about that.

North Dakota has been lucky to have had a relatively small number of cases such as the two I just described because of our low population and relatively small industrial development. In other states, millions of dollars are being spent to study and clean up groundwater pollution. The U.S. Environmental Protection Agency has proposed strict new regulations to prevent the contamination of groundwater by disposal of hazardous wastes.

It is usually difficult and expensive to follow the movement of pollutants underground, and once a body of groundwater is polluted, it is likely to stay that way for a long time because of the slow movement of the water. To make the situation worse, many of the measures taken through recent laws to protect surface water from pollution tend to transfer the problem directly or indirectly into the groundwater system.

Groundwater bodies can become polluted in many ways--through agricultural practices, development of urban-industrial complexes in recharge areas, surface or subsurface disposal of wastes, and extraction of natural resources. Natural solution processes can also adversely affect the quality of groundwater by adding mineral and organic substances from the soil or from the aquifer materials. Merely pumping the groundwater can induce the movement of poor-quality water into the aquifer from adjacent polluted or saline groundwater bodies. Leaks in oil well casings can pollute groundwater supplies; for this reason, the Survey enforces strict laws governing the casing of oil wells in North Dakota.

Groundwater contamination can usually be prevented by determining the local groundwater flow pattern. Industrial wastes and sewage will not usually contaminate the groundwater if they are disposed of properly in discharge areas that are permanently moist, especially where the permeability is low. Contamination of groundwater is likely, however, if wastes are disposed of in recharge areas such as dry uplands or temporary streams or sloughs that are losing water seepage to the ground (although such areas can be suitable if sufficiently thick deposits of low permeability material cover the ground). Precipitation in North Dakota ranges from 13 inches in the northwest to more than 20 inches in parts of the Red River Valley and in the southeast, but of this amount, only a small proportion is available as recharge to aquifers.

The low recharge is due to several factors. Most of the precipitation falls during the growing season when crops and other plants consume large quantities of water, thereby preventing much of the potential recharge from penetrating beneath the root zone. Evaporation and transpiration losses are high during the growing season. Large areas of North Dakota are covered by glacial sediment and other fine-grained material, which, because of its low permeability, does not allow efficient movement of water. In addition, during the winter months, precipitation is held in the form of snow and ice, and, at this time, the top several feet of ground are frozen so that infiltration of water cannot take place.

Conditions are favorable for recharge to North Dakota's groundwater aquifers if precipitation is adequate. For example, glacial outwash deposits of gravel and sand, which are permeable and absorb precipitation readily, are the most important sources of groundwater in the state. Most of these aquifers consist of gravel and sand that was deposited in valleys ahead of the melting glaciers or as outwash deposits. Surficial outwash deposits are also the type of aquifer that is most easily polluted by poor waste disposal practices.

In spite of its utility and abundance, groundwater represents a greatly underused source of fresh water in many parts of the United States. The North Dakota Geological Survey, in cooperation with the State Water Commission, the U.S. Geological Survey, and nearly all of the counties in North Dakota, have been studying the State's groundwater supplies in detail for nearly 20 years. As a result of these studies, we have identified nearly all of the important aquifers and we have determined the amount and quality of groundwater available from them. The results of these groundwater studies are being published as part of our Bulletin series (see the reference to two recently-published groundwater studies elsewhere in this Newsletter) and as part of the State Water Commission's County Groundwater Series. The groundwater studies are usually done in three parts. The State Geological Survey studies the geology of the area and helps to determine the geologic framework in which the groundwater aquifers can occur. The State Water Commission is generally responsible for the test drilling and the U.S. Geological Survey groundwater branch works out the hydrology of the aquifers. Many of the county groundwater studies have been published, and others are completed, but not yet published. These studies have proved to be an invaluable source of information for many purposes such as the location of wells for water supplies and irrigation, the evaluation of land for use as construction sites and waste disposal sites, and the location of sand and gravel deposits. Very few states have a data base which is as detailed, accurate, and comprehensive as North Dakota's Groundwater Studies.

NORTH DAKOTA GROUNDWATER POLICY--

The growing concern over the use and protection of our groundwater resources was the subject of a meeting last March between several North Dakota State agencies which are involved in groundwater research and regulation. Representatives of the State Water Commission, the State Health Department, the Public Service Commission, and the State Geological Survey attended the meeting. One purpose of the conference was to facilitate cooperation and information exchange between the agencies which have a groundwater-related function. Each agency presented its role and programs in groundwater research and/or regulation. Another objective of the meeting was to discuss the impact and implementation of the increasing number of federal programs and regulations which apply to groundwater in North Dakota. These programs apply to such concerns as waste disposal and the effect of energy development on groundwater resources.

The meeting adjourned with an agreement to attempt to establish a permanent committee composed of groundwater experts from each state agency involved. This committee will meet periodically to provide guidance and direction for a unified state groundwater policy. Ind addition, the committee, with its broad expertise, would serve as an advisory group to any of the individual agencies when important groundwater problems arise.

CHANGES IN SURVEY FACILITIES--

Changes are in the wind for the NDGS physical plant on the University of North Dakota campus at Grand Forks. They include the expansion of Survey office space on the third floor of Leonard Hall and the construction of a new core and sample library facility on the former site of the old winter sports building, which was located immediately across the street, south of Leonard Hall.

Plans for Leonard Hall include remodeling the petrology laboratory into two labs and a conference room. One lab will also be utilized as an office by the new carbonate geologist (see article elsewhere in this Newsletter). Other changes involve moving the Survey's drafting department from its present location into the air photo lab, currently being used for storage by the geology library. This will necessitate remodeling of the library stacks and will require close cooperation with the library committee in order to provide for the needs of the library and the Geological Survey with a minimum of disruption to library operations. In addition to increasing the space available to the drafting department, the space vacated will be utilized for offices for current and new staff members.

The new core and sample library facility is planned to provide 19,000 square feet for core and sample storage and 3,000 square feet for labs and a receiving room. The labs and receiving area will be heated and air conditioned--welcome news to anyone who has spent any time here during the winter working in our present core and sample building. The present core and sample library was constructed in 1953 and enlarged in 1961. It is now filled to capacity. Funds for the construction of the core and sample library were appropriated by the 1979 Legislative Assembly from the Lands and Minerals Trust Fund of the Board of University and School Lands.

DEPARTURES AND ARRIVALS--

Geraldine Klug retired from the Survey this month after 17 years of dedicated service as receptionist. Born in Mineral Springs, Texas, and raised and educated at Mandan, North Dakota, Gerry arrived at the Survey in August, 1962. For 17 years, Gerry has been the first contact most individuals have had with the Survey. Her cheerful greeting, and her helpful and pleasant ways have resulted in the good first impression that most people have of the Survey. Gerry's husband, Ralph, is a civilian employee at Grand Forks Air Force Base. With their daughter, Kim, they will continue to reside in Grand Forks.

Karol-lyn Knudson, drafting technician with the Survey since January, 1971, has resigned from her position this June. A native of Minneapolis, Karol joined the Survey following her graduation from the University of North Dakota where she received a B.A. degree with a major in art. Karol's expertise in drafting, and in the preparation and organization of materials for publication, will be sorely missed. Her husband, Curtis, is a research scientist with the Department of Energy Research Center at Grand Forks, where they will continue to make there home with their two sons, Carl and Brant.

Nick Tucci, field inspector stationed at Minot since August, 1978, has accepted a position with UV Industries and resigned from the Survey in May. Nick came to the Survey fresh out of the University of Southern Colorado with a degree in geology. He and his wife Connie have departed for the warmer climes of Colorado and New Mexico where he will be involved in mining geology.

The Survey's new carbonate geologist is Randolph B. Burke, who comes to us from the U.S. National Museum where he was a Research Collaborator in marine geology since 1976. Randy has completed the requirements for his M.S. degree in marine geology at the Marine Science Institute, University of South Florida. His master's dealt with the morphology, structure, and benthic communities of the Belize Barrier Reef. His B.S. is in geology from the University of Southern Colorado. In addition to his experience with the National Museum, Randy has held research positions with the U.S. Geological Survey and the Marine Science Institute at the University of South Florida. Randy's extensive experience with modern reefs and carbonate sediments will be a definite plus to the North Dakota Geological Survey in furthering our studies and understanding of Williston basin oil-producing carbonate formations.

Our new geologic technician is Daniel M. Walker. Dan's most important responsibilities will be to oversee the operations of the Survey's Core and Sample Library, a job certain to be a challenge as we begin construction of a new building for core and sample storage and study. Dan has been employed as a driller for the Survey for over a year, managing our truck-mounted rig. As a driller, he was involved in wellsite geology as well as operation and routine and major rig maintenance. Dan has completed most of the requirements toward his B.S. in geology at the University of North Dakota and expects to receive his degree in the near future.

Replacing Gerry Klug as the Survey's new receptionist is Donna M. Beaudry. Donna comes to us from Argyle, Minnesota although she now lives in East Grand Forks. She attended the East Grand Forks Area Vocational Technical Institute and the Tri-River Coop Center at Warren, Minnesota.

Glenn Wollan is the newest addition to the staff of field inspectors working out of the Bismarck office of the NDGS. Glenn is a North Dakota native who holds degrees in history and earth science from the University of Colorado and North Dakota State University, respectively.

John Priddy will be joining the staff of the Survey as a field inspector effective July 1. John is a recent graduate of Southern Colorado University at Pueblo with a major in geology. He will be located at the Bismarck office of the Survey.

NEW APPOINTMENTS WITHIN THE NDGS--

Erling A. Brostuen, Assistant State Geologist

Mr. Erling A. Brostuen has been appointed to the position of Assistant State Geologist for the North Dakota Geological Survey, effective April 1, 1979. Erling has been involved with oil and gas regulation and conservation, subsurface minerals regulation, uranium exploration and development here in our Grand Forks office since

1974. Prior to then, he was a petroleum engineer at the Survey's Williston branch office where he was involved with oil and gas field inspection and supervision for ten years. Erling also has industry experience with Tenneco Oil Company and Dakota Salt and Chemical Corporation.

A Williston, North Dakota native, Erling has his Ph.B. in geology and in history from the University of North Dakota; he also has engineering training from the Northrop Institute of Technology as well as marine engineering training, courtesy of the U.S. Army.

Since moving to Grand Forks, Erling has assumed increasing duties in the administration of the Survey. He has an unusual talent for "getting things done." He is frequently called upon to address formal and informal groups, classes, and seminars, and he is regularly involved with Survey negotiations with Federal and State agencies. He represents the State Geologist on the Natural Resources Council.

Wesley D. Norton, Chief of Field Engineering

Mr. Wesley D. Norton has been appointed to the position of Chief of Field Engineering at our Bismarck office, effective July 1. Wes has been with the Survey since 1960, first as a field inspector in our Williston office, then a petroleum engineer in our Grand Forks, and since 1968, as Manager of our Bismarck office. He holds a B.S. degree in mining engineering with a petroleum option from the University of North Dakota. Wes is responsible for all field engineering and regulatory compliance activities in oil and gas. His staff includes eight field inspectors, one engineer, one geologist, a secretary, and a clerk. Wes is also the principal advisor to the State Geologist for field implementation of regulatory decisions.

NDGS RECEIVES REGIONAL ENVIRONMENTAL ASSESSMENT PROGRAM MAPS--

As many of our readers are aware, the Regional Environmental Assessment Program (REAP) was not funded during the last session of the North Dakota Legislature and, for this reason, many of REAP's materials have been supplied to other agencies. The North Dakota Geological Survey will act as the repository for certain REAP map-related materials. The materials being supplied to us include county and state-wide land cover maps.

The land cover maps, which have been compiled for each county, show a total of ten categories of land including cropland, fallow, exposed subsoil or saline seep, built-up urban areas, rangeland, forest, water, barren, and wetlands. The categories are derived from computer processing of LANDSAT-II (along with some LANDSAT-I) satellite imagery from an altitude of 570 miles. The smallest unit shown on the maps is 1.12 acres (pixel) and the maps have been printed at a scale of about ½-inch to a mile. The land cover maps were prepared for REAP in 1976 by the Bendix Aerospace Systems Division. They are available either flat or folded for each of North Dakota's 53 counties. In addition to the individual county land cover maps, the maps have been merged to produce a map of the entire state at a scale of 1:500,000 or approximately 8 miles to an inch (total size of the state map is about 36" x 48"). The state map is also available either flat or folded.

A brochure entitled "Land Cover Maps of North Dakota" describes the maps, explain how to use them, how they were compiled, and some of their short-comings. It is available along with the maps.

Some background information on the land cover maps might be of interest (this information has been excerpted from the brochure describing the maps). The LANDSAT-I and II satellites circle the Earth once every 103 minutes at a height of 570 miles. Because of their paths, each satellite passes over a given spot in North Dakota at the same local time once every 18 days. With two Landsat satellites in orbit, any given site in North Dakota is viewed from space an average of once every 9 days. Each satellite pass over North Dakota is about 60 miles farther west than the previous pass. As it passes over the state, light reflected from the Earth's surface is collected by the satellite. Four different wavelengths (bands) of light are recorded as the light is dispersed by an oscillating mirror to recorders in the satellite. Two of the bands are of visible light (green and red) and two are near infrared. The reason for using more than one band is because water, for example, reflects better under one band, while wheat reflects better under another. The combination of the four bands provides maximum possible differentiation of individual land cover types. North Dakota is completely covered by 19 overlapping scenes. The usefulness of a given scene, however, is dependent upon any cloud cover or airplane contrail present, whether or not all four bands are operating normally at that time, and the intended purpose for the data (a scene taken in January, for example, is not useful for identifying crop types).

The land cover maps and brochures will be available from the North Dakota Geological Survey after about July 1.

PAPER RECEIVES SPECIAL RECOGNITION--

The Matson Award Committee of the American Association of Petroleum Geologists has accorded special recognition to W. Kipp Carroll and Lee C. Gerhard for a paper they presented at the annual meeting of the AAPG in Houston three months ago. The paper was entitled "Dolomitization in Upper Red River Formation (Upper Ordovician), North Dakota" (see the listing of new NDGS publications for a description of a new Report of Investigation that covers some of the same material). Mr. Carroll is now with Gulf Oil Exploration and Production Company, Casper, Wyoming, and Dr. Gerhard is North Dakota State Geologist.

THE LENGTH OF GEOLOGIC TIME--

Geologists, like historians dealing with the development of civilization, need some method of relating important events to one another. Unlike the historian, however, the geologist thinks in terms of millions of years, not years or centuries. Time is a fundamental consideration in all geological research, but it is difficult for many people to comprehend the immensity of geologic time.

Early speculations about the nature of the earth inspired much of the lore and legend of ancient civilizations. At times, ancient people had considerable insight. The Greek historian, Herodotus, in the Fifth Century B.C, made one of the earliest recorded geological observations. After finding fossil shells far inland in what are now parts of Egypt and Libya, he correctly inferred that the Mediterranean Sea had once extended much farther to the south. Few people believed him, however, and his idea did not catch on. In the Third Century B.C., Eratosthenes depicted a spherical earth and even calculated its diameter and circumference, but the concept of a spherical earth was beyond the imagination of most men. Less than 500 years ago, sailers aboard the Santa Maria begged Columbus to turn back lest they sail off the earth's "edge." Similar opinions and prejudices about the nature of the earth have waxed and waned down through the centuries; however, most people appear to have trad tionally believed the earth to be quite young, that its age might be measured in terms of thousands of years, but certainly not in millions.

The evidence for an ancient earth is found in the rock record, the materials that form the earth's crust and surface. The rocks and sediments are not all the same age, or even nearly so, but, like the pages in a long and complicated history book, they record the earth-shaping events of the past. However, the record is incomplete. Many "pages" are missing and many others are tattered, torn, or difficult to decipher. Even so, enough of the record is preserved to allow geologists to determine that the earth is many millions of years old.

Two time scales are used to date geologic events and to measure the age of the earth: a relative time scale, based on the sequence of layering of the rocks and sediments; and an atomic time scale, based on the natural radioactivity of chemical elements in some of the rocks. The relative scale evolved along with the science of geology; the atomic scale is a recent development borrowed from the physical sciences and applied to geologic problems.

At the close of the Eighteenth Century, the haze of fantasy and mysticism that tended to obscure the true nature of the earth was being swept away. Careful studies by geologists showed that rocks have diverse origins. Some rock layers, containing clearly identifiable fossil remains of fish and other forms of aquatic animal and plant life, originally formed in seawater. Other layers, consisting of sand grains winnowed clean by the pounding surf, formed as beach deposits that marked the shorelines of ancient seas. Some layers are in the form of sand bars and gravel bands, rock debris spread over the land by streams. Some rocks were once lava flows, or beds of cinders and ash thrown out of ancient volcanoes; others are portions of large masses of once-molten rock that cooled extremely slowly beneath the earth's surface. Still other rocks were so transformed by heat and pressure during the heaving and buckling of the earth's crust in periods of mountain building that their original features are obliterated. Some sediments were deposited by glaciers, like those that once flowed over North Dakota, or by the lakes and streams that formed from the melting ice.

From the results of studies on the origins of the various kinds of rocks (petrology), coupled with studies of rock layering (stratigraphy), and the evolution of life (paleontology), geologists reconstruct the sequence of events that have shaped the earth's surface. Their studies show, for example, that during a particular episode, the land surface was raised in one part of the world to form high plateaus and mountain ranges. Following the uplift of the land, the forces of erosion attacked the highlands and the eroded rock debris was transported and redeposited in the lowlands. During the same interval of time in another part of the world, the land surface subsided and was covered by the seas. With the sinking of the land surface, sediments were deposited on the ocean floor. In this way, sand, silt, and clay eroded from the North Dakota badlands by the Little Missouri River were carried by the Little Missouri, Missouri, and Mississippi Rivers to the Gulf of Mexico, which has subsided to receive the sediments. The evidence for the existence of ancient mountain ranges lies in the nature of the eroded rock debris, and the evidence of the seas' former presence is, in part, the presence of fossil forms of marine life that accumulated with the bottom sediments.

The discovery of the natural radioactive decay of uranium in 1896 by Henry Becquerel, the French physicist, opened new vistas in every field of science. In 1905, the British physicist, Lord Rutherford, after defining the structure of the atom, made the first clear suggestion for using radioactivity as a tool for measuring geologic time directly. Shortly thereafter, in 1907, Professor B. B. Boltwood, radiochemist at Yale University, published a list of geologic ages based on radioactivity. Although Boltwood's ages have since been revised, they did show correctly that the duration of geologic time would have to be measured in terms of millions, not thousands, of years.

The next 40 years was a period of expanding research on the nature and behavior of atoms, leading to the development of nuclear fission and fusion as energy sources. A byproduct of this atomic research has been the development and continuing refinement of the various methods and techniques used to measure the age of earth materials. Most of the precise dating has been accomplished since 1950.

A chemical element consists of atoms with a specific number of protons in their nuclei, but different atomic weights, owing to variations in the number of neutrons. Atoms of the same element with differing atomic weights are called isotopes. Radioactive decay is a spontaneous process in which an isotope (the parent) loses particles from its nucleus to form an isotope of a new element (the daughter). The rate of decay is conveniently expressed in terms of an isotope's half-life, or the time it takes for one-half of the nuclei in a sample to decay. Most radioactive isotopes have rapid rates of decay (that is, short half-lives) and lose their radioactivity within a few days or years. Some isotopes, however, decay slowly and several of these can be used as atomic clocks.

Dating rocks by using these radioactive timekeepers is simple in theory, but the laboratory procedures are complex. The numbers of parent and daughter isotopes in each specimen are determined by various kinds of analytical methods. The principal difficulty lies in precisely measuring extremely tiny amounts of isotopes.

At the present time, the potassium-argon method is one of the most useful dating methods available to the geologist because it can be used on rocks as young as a few thousand years as well as on the oldest rocks known. Potassium is found in most rock-forming minerals. The half-life of its radioactive isotope, potassium-40, is such that measurable quantities of argon (daughter) have accumulated in potassium-bearing minerals of nearly all ages. The amounts of potassium and argon isotopes can be measured accurately, even in very small quantities. Where feasible, two or more methods of analysis are used on the same specimen or rock to confirm or verify the results.

Another important atomic clock used for dating purposes is based on the radioactive decay of the isotope carbon-14, which has a half-life of 5,730 years. Carbon-14 is being produced continuously in the earth's upper atmosphere as a result of nitrogen-14 isotopes being struck by neutrons that have their origin in cosmic rays. This newly-formed radiocarbon becomes uniformly mixed with the nonradioactive carbon in the carbon dioxide of the air, and it eventually finds its way into all living plants and animals. In effect, all carbon in living organisms contains a constant proportion of radiocarbon. After the death of the organism, the amount of radiocarbon gradually decreases through radioactive decay as it reverts to nitrogen-14. By measuring the amount of radioactivity remaining in organic materials, the amount of carbon-14 in the materials can be calculated and the time of the organism's death can be determined. For example, if carbon from a sample of wood is found to contain only half as much carbon-14 as that from a living plant, the estimated age of the old wood would be 5,730 years; if it contained a fourth as much, the age would be 11,460 years.

The radiocarbon clock has become an extremely useful tool in dating the important episodes in the recent prehistory and history of man but, due to the relatively short half-life of carbon-14, the clock can be used for dating events that have taken place only within about the past 50,000 years.

Some of the oldest known rocks found in North America are in Southwestern Minnesota. The Morton Gneiss appears to have formed about 3½ billion years ago. Other rocks with similar ages occur in South Africa, Finland, and Australia. Estimates of the age of the earth are based on the decay rates of radioactive isotopes. One such estimate is based on two long-lived isotopes, uranium-238 and uranium-235. It places the maximum age of the chemical elements that make up the earth at about 6 billion years. The reasoning behind this estimate involves theoretical concepts about the origin of uranium, which stiuplate that not more than half of the first-formed uranium consisted of the uranium-235 isotope. But, because of the changes in isotopic composition that have taken place throughout geologic time as a result of radioactive decay, uranium today contains only about 0.7 percent of the uranium-235 isotope. Calculations based on the known decay rates for these two isotopes indicate that a span of about 6 billion years is required for the isotopic composition of uranium to have changed from 50 percent to 0.7 percent uranium-235. Had uranium originally consisted of more than half of the uranium-235 isotope, the calculated age of uranium would exceed 6 billion years.

Another estimate of the earth's age is based on the progressive build-up in the earth's crust of lead isotopes that have been derived from radioactive decay or urani 238, uranium-235, and thorium-232. Studies of the relative abundance of these "radic genic" leads suggest that the earth is not older than 5.5 billion years.

Finally, it is interesting to try to visualize just what 4 or 5 billion years really means. Suppose that the earth is 5 billion years old and then suppose that all of those 5 billion years could be compressed into a single imaginary year. At that scale, each second of our contemporary time would be equivalent to 160 years of geologic time, each day to 14 million years. Dinosaurs did not come on the scene until mid-December, and then they lasted six days. The ice age began in North Dakota at about 6:45 p.m. on December 31 and ended only one minute before midnight. Primitive man arrived on earth between 10 and 10:30 p.m. in the midst of the ice age. At 13 seconds before midnight, Christ was born, and at 6 seconds, Leif Ericson discovered America. The United States of America, now over two centuries old, has existed for less than two geologic seconds.