NEWSLETTER
NDGS

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COVER PHOTO

In the foreground is an exposure of the Golden Valley Formation in northwestern Dunn County, North Dakota. The arrows point to the contact between the Bear Den Member (BDM) and the overlying Camels Butte Member (CBM) of the Golden Valley Formation. This contact also marks the boundary between Paleocene and Eocene rocks as recognized by the first occurrence of an Eocene index fossil, Salvinia preauriculata (a floating fern). The steep, nonvegetated slopes and bright coloration (white, grey, and yellow orange) of the Bear Den Member make it conspicuous in outcrop. The Sentinel Butte Formation (TSB) is at the surface (though covered by vegetation) between this small outcrop and the Killdeer Mountains in the background. The Golden Valley Formation (TGV) is present along the slopes of the Killdeers but is covered by vegetation. The Killdeer Mountains are capped by Oligocene-Miocene (TM) (undifferentiated) sediments.

Photo by Ed Murphy (view toward the northwest).

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REVIEW OF CURRENT NDGS ACTIVITIES --John Bluemle

The danger in writing an article on our current projects and activities for each Newsletter is that I seem to repeat much of what was in our earlier Newsletters (some of you may have already noticed this). Part of the reason for this is that many of our projects are long-term, requiring several years to complete. In any event, I'll try again to give you an update of some of the things we are doing. This is meant only as a sort of progress report on some of our ongoing projects; it is not complete, especially in that I haven't attempted to cover day to day "crises," which sometimes require considerable attention by Survey staff.

Our geologic and engineering studies of oil and gas producing formations, and exploration for these resources, as well as exploration for other mineral resources, are all ongoing concerns of nearly all members of the Survey staff. A few of the projects underway include a study by Julie LeFever of the Spearfish Formation in north-central North Dakota and a study by David Fischer and Sid Anderson of some little-known, mid-Paleozic salts in northwestern North Dakota. The salts occur in the Silurian Interlake Formation and the Devonian Ashern, Souris River, and Duperow Formations. We hope to publish the results of these studies in the near future.

We believe it is important to provide all the necessary information we can to assist the petroleum industry in its efforts at building a new oil and gas development cycle in North Dakota and, to that end, we have undertaken a number of stratigraphic studies within the Williston Basin. Our plans call for core studies involving detailed analyses of pore geometries and clay development within the pores. Studies we have planned involving x-ray and SEM analysis of oil field cores should help us to devise ways to improve recovery methods. We have undertaken subsurface studies of several known (or potential) hydrocarbon-bearing stratigraphic units. Additional studies and activities relating to oil and gas include the adaptation of our computerized oil well file to the Survey's IBM System 34 from the University's IBM 4341 Mod II. This adaptation will allow an easy transfer of digitized data (Wellfile) to a format we can publish. We hope to publish the new well schedule sometime in 1984. We are plotting oil field curves (Marv Rygh, our petroleum engineer, compiled a volume of oil field curves which we published last summer). We have compiled a volume of oil field summaries which we also plan to publish. We also expect to publish three volumes of oil and gas production figures. Kathleen Miller is compiling these. We've just released the volume for 1980 and the volumes for 1981 and 1982 should be ready within the next few months.

The NDGS stores and indexes all samples (well cuttings) and cores received from exploratory oil wells drilled in the State and it will continue to do so in the future. Our Core and Sample Library receives heavy use by consultants, oil company representatives, and other researchers. Rod Stoa, our Core Librarian, reports that, through the first 10½ months of 1983, a total of 580 people have used our Core and Sample Library facilities; most of these are industry geologists. Storage in the core library is already filled, but we have added additional shelving to tide us over until we can expand the building to the size we originally planned it. We are pleased at the positive feedback from companies and individuals taking advantage of the facility. Our geophysical log files, located in the Survey offices, are also used to their best advantage by geologists from the Survey, Industry, and the University. We also continue to maintain and expand our microfilm file of well logs.

By statute, the NDGS is charged with enforcing the rules and regulations of the Industrial Commission regarding the development of subsurface minerals, including uranium. The Survey issues exploration permits under the signature of the State Geologist and maintains exploration and production records. As noted elsewhere in this Newsletter, Dave Brekke has drafted new rules and regulations governing geothermal and underground injection wells. These rules and regulations should be in effect soon.

We have been assessing the lignite potential of North Dakota for the past several years. Survey geologists studying lignite have been actively involved in exploration drilling, geophysical logging, and the interpretation of acquired data. All exploratory work conducted by industry must, by statute, be permitted by the Geological Survey under the signature of the State Geologist and basic exploration data consisting of logs, samples, and cores must be filed with NDGS. Generally, our coal evaluation studies are ongoing and will continue indefinitely, depending on funding and staff resources.

Since 1962, we have been cooperating with the State Water Commission, U.S. Geological Survey, and the various North Dakota counties in assessing the geology and groundwater resources of the State. The Surface Section of the NDGS is responsible for conducting geological field studies and preparing the geological portions of the reports. The data acquired and presented in these county reports have proven valuable to State and local government, industry, and the public as a basis for formulating sound decisions on land-use, mineral development, source water, and industrial siting. We have a report on the geology of Towner County nearly ready to publish and reports are underway on Dunn, Emmons, and McKenzie Counties. These four reports should be published in 1984 and, following these, we hope to complete our studies of Bottineau and Ramsey Counties.

The long-term study we have initiated of 1° x 1° -sized areas in North Dakota takes up where our county groundwater studies leave off. These new studies will include geologic maps and derivative maps showing such things as potential mineral resource availability, construction problem suitability for various types of installations, and interpretations of geologic landforms, stratigraphy, and history. Ken Harris spent part of the past summer field-checking the area covered by the southeast North Dakota 1° x 1° sheet, which consists of Cass, Richland, Ransom, Sargent, and parts of adjacent counties. This sheet is probably the first one we will publish. Ed Murphy is working on a western North Dakota area, which will comprise a sheet consisting mainly of Dunn and McKenzie Counties.

John Hoganson continues his research on North Dakota's paleontology with studies of some of the fossiliferous Tertiary formations of the southwest part of the state. He recently worked with Dr. George Lammers of the Manitoba Museum of Man and Nature in Winnipeg, excavating a site near Dickinson. The fossil site contains important Oligocene mammal remains. We'll have more information on these studies in a later Newsletter.

Our involvement in educational activities continues with new, nontechnical publications on the history of coal development in North Dakota and a new brochure describing the geology along North Dakota Interstate Highway 94. We continue to make our series of Program Aids available to service clubs, school classes, and other groups. Our geologists are regularly called upon to lead field trips, speak to schools and other groups, and participate in a variety of seminar situations.

We continue to cooperate with the North Dakota State Health Department, the North Dakota Water Resources Research Institute, the Mining and Mineral Resources Research Institute, and the University of North Dakota in evaluating existing and potential sites for municipal waste disposal. Such evaluation is aimed mainly at protecting surface water and groundwater resources from pollution. Evaluations may consist of onsite inspections, sampling of materials, instrumentation and monitoring of groundwater systems, and interpretation of acquired data. These studies are intended to evaluate the effects of both solid waste and waste derived from unlined sewage lagoons. We will soon publish the results of a just-completed study by Alan Kehew of the University of North Dakota Geology Department, of six unlined municipal waste stabilization lagoons in various geologic settings in North Dakota. These lagoons are located in McVille, Larimore, Fordville, Esmond, Lidgerwood, and Underwood.

The NDGS is involved in a series of studies to develop data to enable the legislature, involved governmental agencies, and industry to formulate sound legislation and decisions in mine planning and reclamation programs. The reclamation studies have been conducted under the sponsorship of the Environmental Protection Agency and Bureau of Mines. The Mining and Mineral Resources Research Institute, which is located on the University of North Dakota campus, coordinates funding of these and numerous other projects.

Generally, the continuing growth, which we expect in North Dakota's energy industry will result in additional strain on the environment. This, in turn, is going to require solutions to the environmental problems related to reclamation, engineering properties of materials, and other population growth-related problems. 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 waste disposal. We are evaluating the impacts 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 expect soon to publish the results of Ed Murphy's study of the effects of oil well drilling fluids on groundwater resources (see article elsewhere in this Newsletter).

The State Geologist has regulatory responsibilities regarding underground injection and storage and is a member of the Water Pollution Control Board and the Air Quality Advisory Council. On numerous occasions, we have assisted the State Industrial Commission in making decisions on deep well disposal of oil field wastes.

OIL & GAS ACTIVITY IN 1983 --John Bluemle

Through the first nine months of 1983, North Dakota oil production has totaled 38 million barrels. If the current production rate continues for the remainder of 1983, total production should top 50 million barrels in 1983, compared to the 47.3 million barrels that were produced in 1982 (the previous annual high) and 45.7 million in 1981.

Thus far in 1983, a total of 27 new pool discoveries have been recorded (preliminary, unofficial, and incomplete statistics). This compares with over 100 new pool discoveries in North Dakota during all of 1982 (see the June, 1983 Newsletter article on Oil and Gas Activity for a listing of the discovery wells in 1982).

Permitting activity in 1983 is about the same as last year with a total of 133 companies applying for the 523 drilling permits issued by the Oil & Gas Board between January 1 and December 1, 1983. This compares with 156 companies which were issued 605 total permits in 1982. A total of 1072 permits were issued to 193 companies in 1981. Of the 133 companies that have applied for permits to drill this year, 45 were not active in North Dakota last year (they did not permit any wells last year; they may have had existing production). Approximately 130 of the 1983 permits, 25 percent of them, were for exploratory activity and the remainder were for developmental activity (please note that all of these figures are unofficial).

As of December 15, 1983, a total of 73 oil rigs were operating in North Dakota. The rig count held around 40 most of the summer, then jumped by about 20 in October and has held over 60 since then, going as high as 75 in early December.

Just as a point of interest, I've included two tables with this article, the first table compiled from NDGS files, the second mainly from data provided by the American Petroleum Institute (API). Table 1 shows the number of wells drilled in North Dakota each year for oil and gas since 1951. This information is broken down into exploratory and development wells (for purposes of this compilation, I've included extension and outpost wells in the development category as they represent drilling activity near areas of known production). The percentage of succesful exploratory wells is also listed (successful wildcat wells divided by total wildcat wells drilled).

Table 2 indicates the average number of drilling rigs operating in North Dakota each year since oil was discovered in the State. It should be noted that the figure of 47 for 1983 is mine, not the API's and it is an average only since April; the figure would be slightly lower if I had statistics available for the entire year.

TABLE 1. Wells Drilled in North Dakota Each Year Since 1951

Year	Exploratory Wells	(Successful)	Percentage of Successful Wildcats (%)	Development Wells	Gas Wells	Strat. Tests	Total Wells
Prior to 1951	21	(0)	0	0	39	4	64
1951	10	(1)	10	0	0	0	10
1952	46	(7)	15	92	0	0	138
1953	82	(13)	16	180	0	3	265
1954	110	(4)	4	193	0	4	307
1955	58	(6)	12	200	0	26	284
1956	69	(7)	10	210	0	14	293
1957	126	(17)	13	201	1	0	328
1958	104	(18)	17	333	0	17	454
1959	63	(6)	10	361	0	4	428
1960	62	(7)	11	202	0	0	264
1961	63	(6)	10	194	0	0	257
1962	67	(2)	3	155	0	0	222
1963	59	(8)	14	121	0	0	180
1964	90	(11)	12	184	0	0	274
1965	71	(1)	1	151	0	1	223
1966	65	(6)	9	117	0	5	187
1967	45	(3)	7	112	0	0	157
1968	148	(4)	3	85	0	52	285
1969	127	(9)	7	79	0	29	235
1970	64	(3)	5	69	0	1	134
1971	82	(7)	9	68	1	0	151
1972	43	(4)	9	47	0	0	90
1973	57	(1)	2	54	0	6	117
1974	48	(4)	8	105	0	0	153
1975	69	(6)	9	133	0	0	202
1976	76	(8)	11	175	0	0	251
1977	75	(12)	16	172	0	7	254
1978	126	(27)	21	213	4	0	343
1979	115	(29)	25	304	20	0	439
1980	182	(48)	26	304	11	0	590
1981	286	(83)	29	502	-	-	848
1982	208	(102)	49	494	-	-	689

TABLE 2. Average number of drilling rigs operating in North Dakota each year since 1950.

Year	Rigs	Year	Rigs
1950	1	1967	11
1951	4	1968	13
1952	24	1969	12
1953	31	1970	9
1954	32	1971	9
1955	23	1972	7
1956	24	1973	10
1957	31	1974	12
1958	33	1975	17
1959	30	1976	19
1960	16	1977	24
1961	15	1978	39
1962	14	1979	56
1963	9	1980	83
1964	14	1981	119
1965	12	1982	69
1966	12	1983	47

Taken, in part, from American Petroleum Institute.

NEW GEOTHERMAL, UNDERGROUND INJECTION RULES AND REGULATIONS TO BE ENACTED

--David Brekke

Two new sets of rules and regulations will be in place the first quarter of 1984. The Survey has been granted authority by the North Dakota Century Code (NDCC) to regulate and administer an underground injection control program pertaining to Class III wells and to regulate geothermal energy extraction facilities. These rules and regulations are designed primarily to prevent the contamination of underground sources of drinking water and to provide for reclamation of the facility sites after operations have ceased.

The State of North Dakota has entered into an agreement with the Environmental Protection Agency to assume primacy of the Underground Injection Control Program as described in the Safe Drinking Water Act. The North Dakota State Department of Health has been designated as the lead agency for this program. A memorandum of agreement between the State Health Department and the Industrial Commission, acting through the Office of the State Geologist, has given the authority over all Class III injection wells and the responsibility for administering the Class III injection wells program to the Industrial Commission, acting through the Office of the State Geologist. Class III injection wells refer to wells which inject for the extraction of minerals, including mining of sulfur by the Frasch process, in situ production of uranium or other metals, and solution mining of salts or potash.

The proposed rules and regulations are designated as chapter 43-02-02.1 of the Administrative Code and are written under the authority of Chapter 38-12 of the North Dakota Century Code which governs the regulations, development, and production of subsurface minerals. The rules and regulations are written to conform to the Code of Federal Regulations and therefore, in order to prevent extensive duplication, the proposed state rules make references to the federal rules.

The main purpose of the rules and regulations is to prevent and prohibit the contamination of underground sources of drinking water by activities involving a Class III injection well. The proposed rules and regulations provide for this by 1) requiring the issuing of permits with specific permit conditions and technical requirements; 2) requiring monitoring and regular reporting by the operator; 3) allowing public hearings; and 4) providing the penalties in the event of non-compliance of these regulations by the operator.

The proposed rules and regulations concerning geothermal energy production are designated as chapter 43-02-07 of the Administrative Code and are written under the authority of chapter 38-19 of the North Dakota Century Code, which governs geothermal resource development regulation. The statute gives jurisdiction, authority, and responsibility of enforcement to the State Industrial Commission acting through the Office of the State Geologist.

The purpose of the proposed geothermal energy production rules and regulations is to regulate geothermal energy in a manner so as to prevent waste, to protect the correlative rights of all owners, to prevent the contamination of underground sources of drinking water, and to avoid the creation of secondary geologic hazards. These rules apply to the extraction well of a geothermal energy facility; they are not meant to apply to a private residence that uses geothermal energy for heating or cooling purposes. An injection well associated with a geothermal facility is classified as a Class V injection well. Such wells are authorized and regulated by rules of the State Health Department under Chapter 33-25-01 of the North Dakota Administrative Code.

The proposed rules and regulations are intended to prevent contamination of underground sources of drinking water, prevent waste, and protect correlative rights by 1) issuing permits, 2) requiring specific construction techniques, 3) requiring regular reporting, and 4) requiring sufficient financial responsibility to abandon and reclaim the facility site.

Copies of the new rules and regulations can be obtained free of charge from the Survey.

THE DECLINE IN COAL EXPLORATION IN NORTH DAKOTA

--Ed Murphy

In 1975, the North Dakota Geological Survey, by authority of the Industrial Commission, began regulating coal exploration within the state. Prior to that time, coal exploration was overseen by the counties and by the State Land Department when the exploration occurred on state-owned land. The rules and regulations governing coal exploration within North Dakota were established to protect the shallow groundwater and the land surface by requiring the proper plugging and site restoration of coal-exploration drill holes. In addition, companies performing the exploration must furnish our office with a copy of the data they obtain under these permits. This data aids the NDGS in its studies of subsurface stratigraphic correlations and in assessing shallow mineral resources within the state.

The basic exploration data submitted to our office by private companies is protected by law under a two-year period of confidentiality. The Century Code (38-12-1-04) further states "...such periods of confidentiality shall, upon application, be extended for one-year periods by the state geologist, for a total period not to exceed ten years unless it is demonstrated that such period should be further extended in order to prevent possible resulting harm to the person, his successors, and assigns, who delivered such basic data to the state geologist..."

During the last eight years, more than 20,000 coal exploration holes have been drilled in western North Dakota. The peak of exploration, which came in 1977, was spurred by rising oil prices and the subsequent reinterest in coal and the expectation that the country might switch from oil and gas consuming facilities back to coal or synthetic fuel. The decline in coal exploration since 1977 is reflected not only in the decrease in the number of permits issued and holes drilled, but also in the reduction in the number of companies active in the state (figs. 1 and 2). Since 1980, with few exceptions, the only companies that have been exploring for coal in North Dakota have been those companies actively mining lignite in the state. The holes they have drilled have been in areas adjacent to the location they are already actively mining.

The decline in coal exploration can be attributed to a number of reasons. The discovery of vast amounts of natural gas during the late 1970's alleviated the immediate need for a large-scale conversion to coal. The future of synthetic fuels plants, such as the ANG Plant near Beulah, is uncertain; the gas they produce is expected to be expensive. Also, much of the "exploratory" drilling done during the 1970's was intended simply to delineate previously known economic deposits more accurately.

Although coal exploration has declined, coal production in the state has more than doubled in the last seven years to an annual total of 17,805,767.60 short tons in 1982 (fig. 3). This increase is the result of opening new mines in the mid to late 1970's and the expansion of pre-existing mines. The Falkirk mine near Underwood is currently the largest strip mine in North Dakota, producing 5,149,493 short tons of coal in 1982.

The circumstances which brought about the decline in coal exploration are expected to continue and coal exploratory activity is not expected to increase in the foreseeable future.

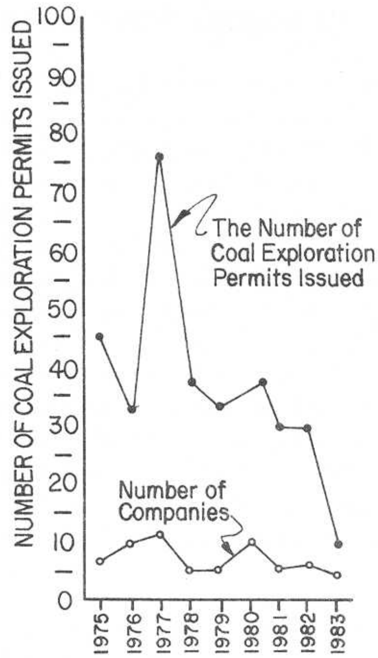

Fig. 1

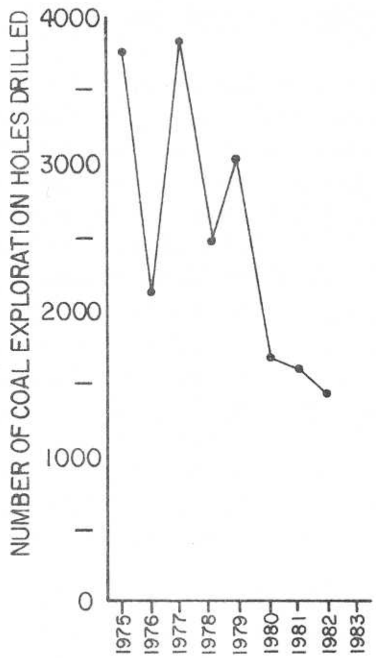

Fig. 2

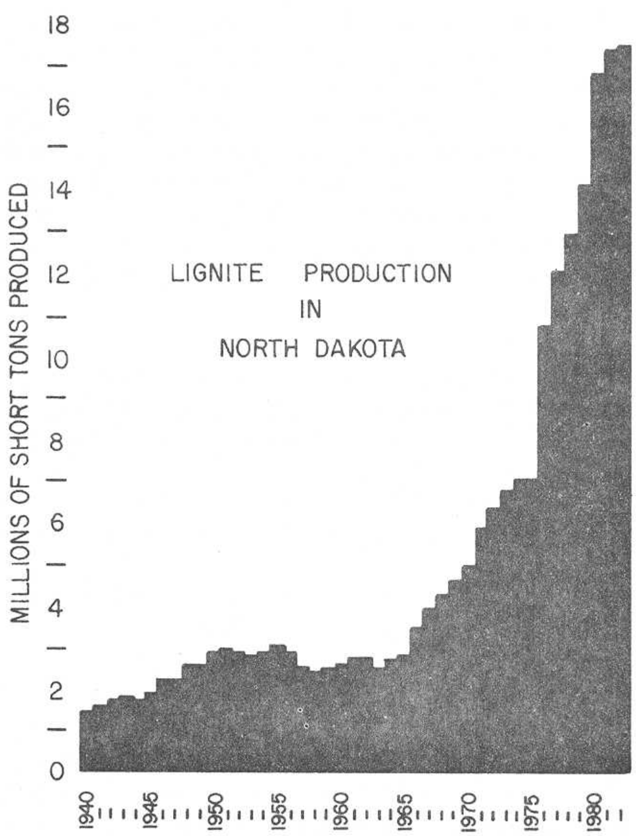

Fig. 3

EVALUATING ABANDONED SURFACE-MINED LANDS IN WESTERN NORTH DAKOTA --Ed Murphy

A group consisting of Dr. Gerald Groenewold and Mr. Craig Schmit (N.D. Mining and Minerals Resources Research Institute), Dr. Robert Koob (North Dakota State University), and myself (Ed Murphy, North Dakota Geological Survey) recently completed a 282-page report to the North Dakota Public Service Commission entitled "Hydrogeological and Hydrogeochemical Data Base for Abandoned Surface-Mined Lands -- Phase 1." This report is the result of a project funded by a grant from the Public Service Commission to the North Dakota Mining and Minerals Research Institute. It is the first part of an anticipated three-phase project to evaluate the geohydrology and geochemistry of four, selected, abandoned surface mines in west-central North Dakota. These abandoned surface mines, which were mined prior to the time North Dakota had a law requiring reclamation, were never reclaimed, but simply left in their post-mined condition--ridges of spoil material separated by topographic low areas. The purpose of the study is to generate scientific data that will aid the Public Service Commission in its decision whether the abandoned surface-mined spoils should be recontoured or left as they are.

A special fund has been created to pay for the cost of reclaiming both abandoned surface-mined spoils and underground lignite mines within the state. One cent from the $1.02 per ton severance tax is allocated to this fund.

A total of 51 abandoned surface-mined sites in western North Dakota were field-evaluated and grouped into four generic categories. One representative study site was chosen from each of the four categories. The four study sites are located at the Davenport, Noonan, Velva, and Indian Head Mines (fig. 1). Test holes were drilled at each mine site to determine the local geology and for the purpose of installing subsurface water-monitoring equipment. Each site was instrumented with pressure-vaccum lysimeters and piezometers to obtain both porewater and groundwater samples for chemical analyses. In addition, water-table wells were installed to monitor the position of the groundwater table. The instrumentation within the abandoned spoils was generally limited to trails that bisected the mines because of the general inaccessability of the steep spoils slopes by vehicle (fig. 2 & 3).

The results of our Phase 1 study indicate that the water quality at the abandoned mine sites is, in most cases, not distinguishable from that of the adjacent unmined areas. Piezometer measurements also indicate that expected premine water tables have been reestablished. Isotopic data indicate that groundwater recharge results from rapid infiltration, and is most likely restricted to the topographic low positions between spoil ridges.

The hydrogeochemical characteristics of undisturbed and reclaimed surface-mined lands suggest two possible explanations for the groundwater chemical conditions observed at the study sites. The first alternative is that the increased mineralization, known from previous studies to be associated with fresh spoils and evident in new water in fresh spoils, has been attenuated by groundwater infiltration and flushing of salts from all the spoils over a period of many years (fig. 4a & 4b). This has resulted in water within the spoils that is no longer distinguishable, chemically, from background. If this is the case, regrading of the spoils will have little impact on groundwater and plant growth and decisions regarding possible recontouring of abandoned spoils may be made on criteria other than potential effects on plant growth and water quality.

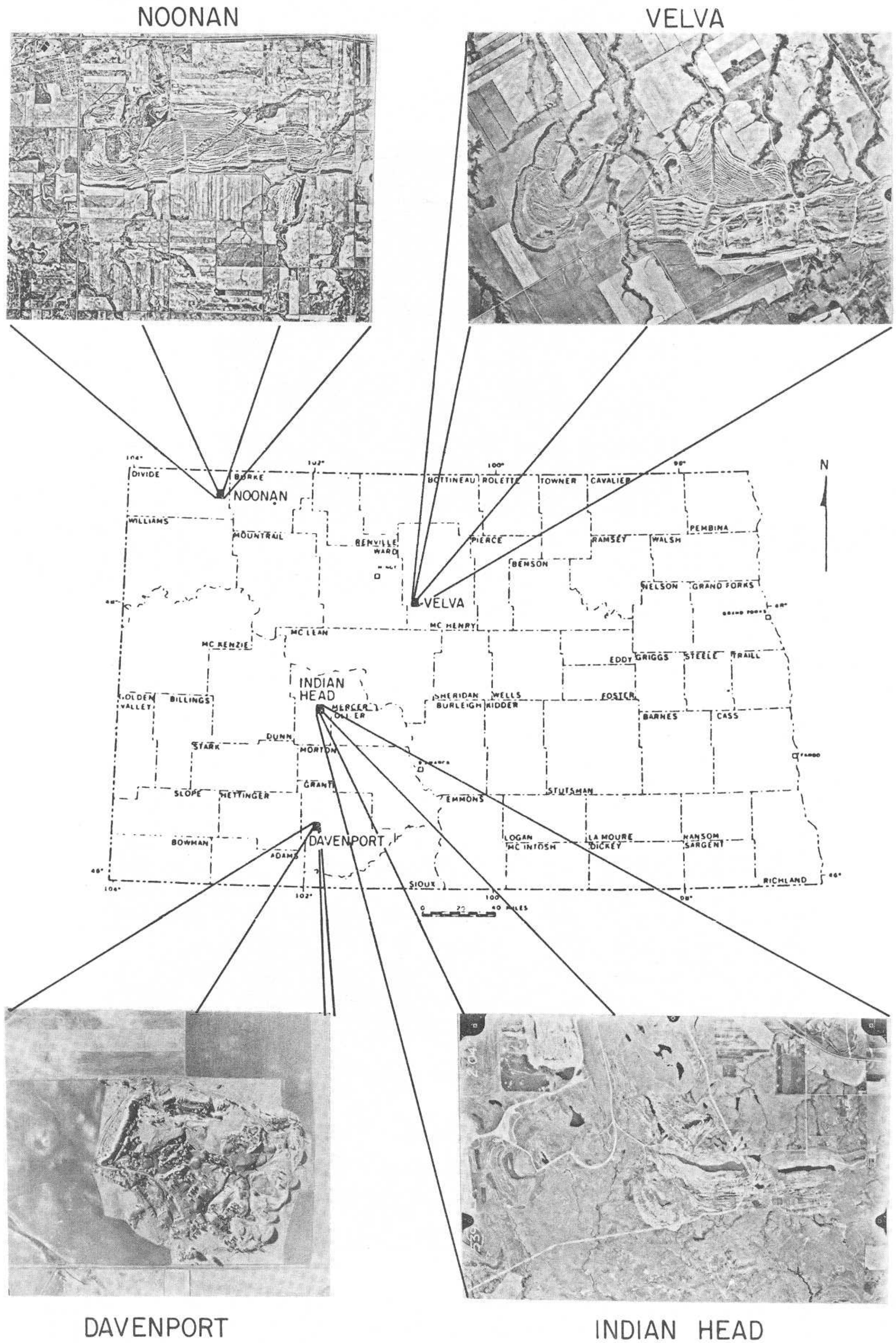

FIGURE I - LOCATION AND AIR PHOTOS OF STUDY SITES.

FIGURE 2 - DRILLING TESTHOLE NO. 10 IN THE NOONAN MINE. THE HOLE IS ADJACENT TO ONE OF THE MAJOR TRAILS THAT BISECT THE MINE AND JUST NORTH OF THE FINAL PIT. PHOTO LOOKING NORTH. NOTE SPARSE VEGETATIVE COVER.

FIGURE 3 - AUGERING LYSIMETER BORING NO. 7 IN THE NOONAN MINE. ACCESS LIMITED TO LOCATIONS OF LYSIMETERS TO THE V'S OF THE SPOILS. NOTE THE STEEPNESS OF THE SPOILS AND THE SPARSE VEGETATION. THE GEOPHYSICAL VAN IS LOGGING PIEZOMETER TEST HOLE NO. 12.

The second alternative is that only the salts that were present in the material in the topographic low positions have been flushed (fig. 4c). As a result, the increased mineralization known to be associated with fresh spoils still resides within the spoil ridges due to minimal infiltration in areas of steep slopes, and thus has not made its way into groundwater at the sites. This is a reasonable possibility since the steep slopes associated with spoil piles would not be expected to be conducive to infiltration. If this is the case, then regrading of certain generic types of spoils could have a major impact on both plant growth and groundwater quality and this must be taken into account in any decision-making process. Such sites would probably be most productive if left as wildlife habitat.

The Indian Head Mine site contains an area of reclaimed abandoned spoils adjacent to the abandoned spoils area. The groundwater beneath the reclaimed abandoned spoils is of lesser quality i.e., it contains a much higher concentration of major ions than that beneath the abandoned spoils. This appears to support the second alternative theory-that the abandoned spoils are still highly mineralized and the recontouring of these spoils at the Indian Head Mine increased infiltration and flushed a large amount of salts into the groundwater.

The North Dakota Mining and Minerals Resource and Research Institute is presently soliciting funds from the North Dakota Public Service Commission to begin Phase II of this study. This phase would involve detailed evaluation of the mineralogy and distribution of salts within the spoils and would determine which of the two alternatives correctly depicts the hydrogeochemical conditions operating within the four generic types of abandoned surface-mined spoils. The results of Phase II will significantly affect decisions regarding recontouring of the various generic types of abandoned surface-mine silts in North Dakota. The results of Phase II will also direct future research on this topic.

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The 1st Phase Report: Groenewold, G. H., Murphy, E. C., Koob, R. D., and Schmit, C. R., 1983, Hydrogeological and Hydrogeochemical Data Base for Abandoned Surface-Mined Lands -- Phase I, Final Report to the North Dakota Public Service Commission, Bulletin No. 83-10-MMRRI-02, 282 pp.

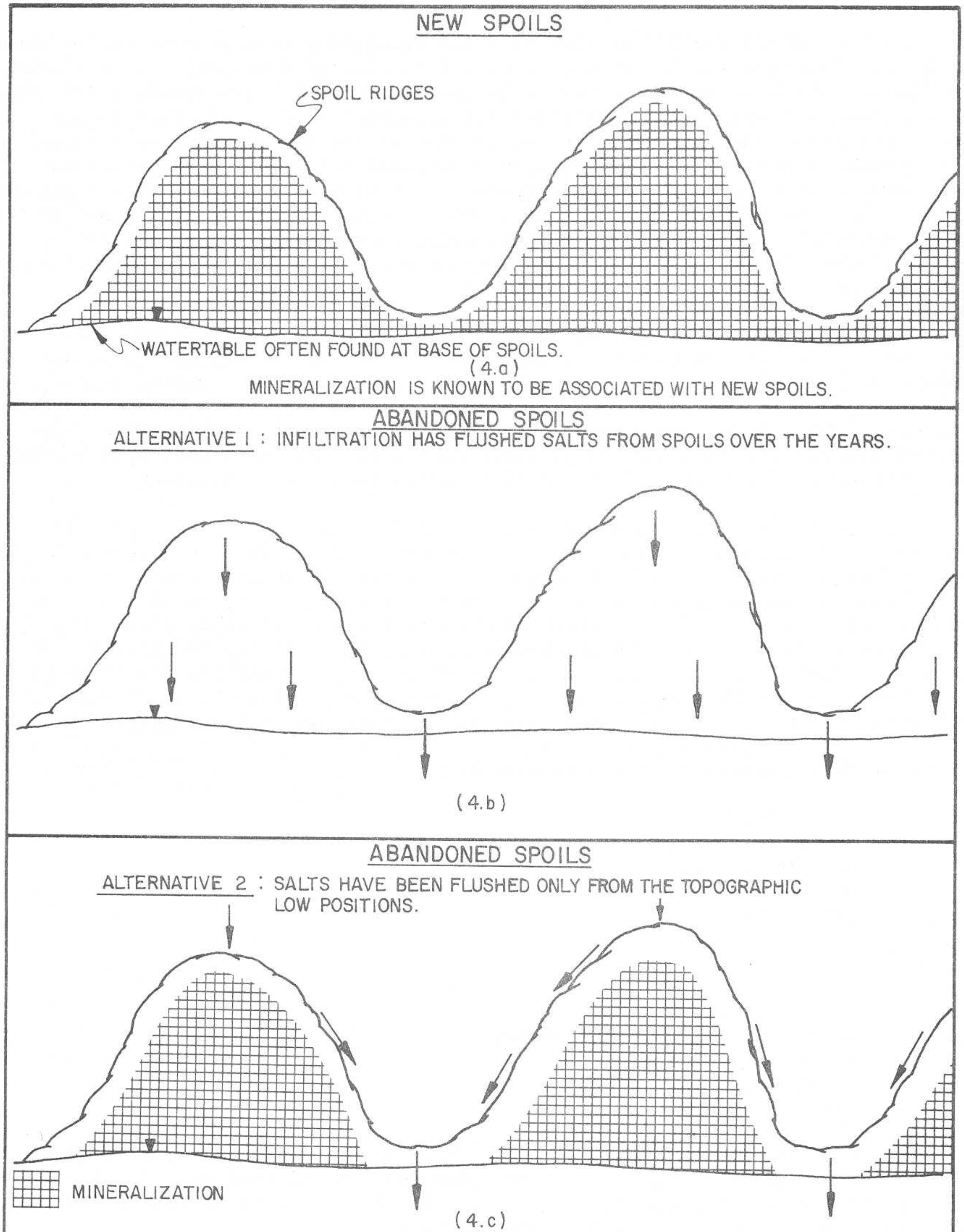


Fig. 4. A generalization of the geochemical conditions present in new spoils and two possible alternatives to explain the generally unaffected groundwater beneath abandoned spoils.

LEACHATE GENERATED FROM BURIED OIL AND GAS FLUIDS

--Ed Murphy

A report by Dr. Alan Kehew of the University of North Dakota geology department and myself should be available late this winter. This report, NDGS Report of Investigation No. 82, will be entitled "The Effect of Oil and Gas Well Drilling Fluids on Shallow Groundwater in Western North Dakota." The report is the result of a two-year study of four reclaimed oil-and-gas reserve pit sites in western North Dakota. (Editor's Note: we included a preliminary report of this study in the December, 1981 NDGS Newsletter).

Upon completion of an oil and gas well in North Dakota, drilling fluid is buried in the reserve pit at the site. Reclamation of the drill site is expedited by digging a series of trenches, which radiate out from the reserve pit. Most of the buried drilling fluid is ultimately contained within these 5- to 7-metre deep trenches. These fluids are commonly salt-based, that is they contain a concentration of 300,000 ± 20,000 ppm NaCl. In addition, the drilling fluids contain additives including toxic trace-metal compounds.

The ages of the study sites ranged from 2 to 23 years. The sites chosen were selected in an effort to encompass as many as possible of the geologic and geohydrologic variables that exist in this area. A total of 31 piezometers and 22 soil-water samplers were installed in and around the drill sites and quarterly groundwater samples were obtained from these instruments. The local groundwater flow conditions were also determined at the sites.

The study concluded that leachate is being generated by buried oil and gas well drilling fluid in western North Dakota. However, the areal extent of groundwater adversely affected by the leachate is generally localized; the effects are not noted more than 75 to 100 metres from the site. The limited extent is due to a number of contributing factors including: 1) the relatively small amount of buried waste involved (1,530 to 2,549 m^3), 2) the low amounts of subsurface infiltration of precipitation, 3) the thick unsaturated zone (i.e., the depth water has to infiltrate to reach the groundwater table), and 4) the high clay content of the sediments at the sites and the subsequent attenuation of leachate ions by these clays.

Although the effects of the buried drilling fluid on the groundwater at most sites in western North Dakota are believed to be local, they could be greatly reduced if the buried drilling fluid could be confined to the plastic-lined reserve pit. The trench reclamation method has been used because it is quick and allows heavy machinery to drive over the site immediately upon completion. A new method has recently been used to reclaim the pits with apparent success. This method might be likened to using a snow blower; sediment is blown back into the reserve pit. The drilling fluid is thereby confined to the pit and it is reported that heavy machinery can drive over the reclaimed pit with no problems.

When we determined that leachate was being generated by buried oil and gas drilling fluid, we decided to direct our attention to the glaciated central part of the state where very permeable and low clay-content sediments occur (in meltwater channels) and the water table is relatively high. We incorporated our research interests and directions with those of five other scientists from the University of North Dakota, the North Dakota Mining and Mineral Resources and Research Institute, and North Dakoa State University. We received funding from the North Dakota Water Resources Research Institute this fall to study the effects of salts and other chemical constituents from buried brine and drilling fluid pits in north-central North Dakota. This study will deal with the effect on both surface and shallow groundwater from these two types of wastes. We expect to complete this study by early 1985.

NEW PUBLICATIONS

The following new publications were issued by the Survey during the past six months:

Bulletin 76, Part 1--"Geology of Billings, Golden Valley, and Slope Counties, North Dakota," was written by C. G. Carlson. Recent reports are also available on the groundwater basic data and on the hydrology of these three counties. This report deals with the geology and mineral resources of the near-surface materials; oil and gas are extremely important resources in the three-county area, but they are not treated in detail in Bulletin 76. This has been done in numerous other North Dakota Geological Survey reports.

Bulletin 76, Part 1 is 40 pages long with 15 illustrations and 5 plates including a colored geologic map at a ½" to a mile scale. The report is available free of charge.

Bulletin 77, Part 3--"Ground-water Resources of Logan County, North Dakota," was prepared by Robert L. Klausing of the U.S. Geological Survey. This report deals with the geology and groundwater flow system in Logan County. The report is the result of an investigation to determine the quantity and quality of groundwater available from glacial-drift and bedrock aquifers. With the publication of Part 3 of this bulletin, all three parts of the Logan County Ground Water Study are complete. Part 2, which was published in 1982, includes basic data on the groundwater in the county. Although no formal Part 1 is planned, a comprehensive report on Logan and McIntosh Counties was published by the North Dakota Geological Survey in 1962. This report, by Lee Clayton, includes a geologic map and detailed description of the geology in Logan and McIntosh Counties.

Bulletin 77, Part 3 is 42 pages long and includes a ½-inch to a mile scale map depicting the bedrock topography and the availability of groundwater from the major glacial-drift aquifers. Geohydrologic sections of the Fox Hills and glacial-drift aquifers are also included. The report is available without charge from the North Dakota Geological Survey.

Report of Investigation 78--"Aquatic Mollusks of North Dakota," was written by Alan M. Cvancara. This 142-page volume includes descriptions and illustrations for each of the 44 species of mollusks (clams, pill clams, and snails) found in North Dakota. It provides state distribution maps for each species, identifies species associations and their relationship to general habitat, evaluates ecological factors limiting mollusk occurrence, and it speculates on the origin of the aquatic molluscan fauna. The author avoids using a great deal of technical jargon so that non-specialists, as well as the specialist in mollusks, can use the report. Several plates in the back of the volume will enable any interested layman to identify North Dakota mollusks in the field.

Among the conclusions stated in the report are the following: aquatic mollusks are significant to man as biologic monitors of water quality; food for game fish and birds and fur-bearing animals; and vectors of human disease. More species of aquatic mollusks occur in the Hudson Bay drainage (42 species) than in the Mississippi (Missouri) drainage (30 species); they reach greater densities, too, in the Hudson Bay drainage. Study of mollusks can be important, especially as they are indicators of changes (degradation) of the environment by man, as indicators of pollution of our streams, rivers, and lakes.

"Aquatic Mollusks of North Dakota," Report of Investigation 78 of the North Dakota Geological Survey is available for $5.00.

Report of Investigation 79--"Geological and Geochemical Controls on the Chemical Evolution of Subsurface Water in Undisturbed and Surface-Mined Landscapes in Western North Dakota," was written by G. H. Groenewold, R. D. Koob, G. J. McCarthy, B. W. Rehm, and W. M. Peterson. The report concludes that negative hydrogeochemical impacts resulting from surface mining in the Northern Great Plains will include increased mineralization of groundwater, sodic and salt effects on plants, and increased mineralization of surface waters. The degree of these impacts will be dependent upon site-specific hydrogeologic, geochemical, and mineralogical variables.

North Dakota Geological Survey Report of Investigation 79 is 299 pages long and includes 30 illustrations. It can be obtained from the North Dakota Geological Survey for $5.00.

Report of Investigation 80--"Effect of Seepage From Unlined Municipal Waste Stabilization Lagoons on Chemical Quality of Groundwater in Shallow Aquifers," was prepared by Alan E. Kehew, Francis J. Schwindt, and David J. Brown. This report presents the results of investigation of six unlined municipal waste stabilization lagoons in North Dakota. The sewage lagoons, located at Esmond, Fordville, Larimore, Lidgerwood, McVille, and Underwood, were constructed in permeable sediments directly over shallow, unconfined aquifers.

At McVille, the site with the most severe contamination, untreated wastewater is maintained in one cell throughout the year except when short intermittent discharges of wastewater are made into an adjacent cell. Groundwater quality is much poorer downgradient from the intermittently used cell relative to groundwater just downgradient from the primary cell. Seepage water quality is apparently better when adequate holding time is maintained in a cell with a basal sludge layer. Water downgradient from the intermittently used cell has a very high ammonium concentration, which is subsequently decreased by adsorption. Evidence suggests that coliform organisms can move several hundred feet away from the lagoons in groundwater under favorable conditions. Contamination at the other sites was not as severe at McVille, although levels of some parameters exceed concentration limits for drinking water in the vicinity of the lagoons. Lagoons in geological settings similar to the study area should be lined, particularly if wells are nearby.

Report of Investigation 80 is 140 pages long and includes 36 illustrations. It can be obtained from the North Dakota Geological Survey for $3.00.

Report of Investigation 81--"Carbonate Bodies Within the Basal Swift Formation (Jurassic) of Northwestern North Dakota," was written by Tina Langtry. The carbonate bodies of the basal Swift Formation are coarsening-upward sequences composed of predominantly sand-sized, recrystallized mollusk grains. The carbonate sand bodies are analogous to offshore-bar deposits of similar age that are recognized across the midcontinent region. The carbonate bodies are up to 22 miles long, 7 miles wide, and as thick as 155 feet.

The shape of the carbonate bodies, their high moldic porosity and good permeability of the grainstones, makes these basal Swift carbonate bodies good reservoir rocks. The shallow depth of burial and the thermal immaturity of the surrounding shales makes it unlikely that thermally generated hydrocarbons will be found in the carbonate bodies. However, the possibility of the existence of biogenic gas, derived from the surrounding shales, makes these deposits potential sites for exploration.

Report of Investigation 81 is 74 pages long with 32 figures and 16 plates. It is available for $5.00 from the North Dakota Geological Survey.

Miscellaneous Map 25--"Geologic and Topographic Bedrock Map of North Dakota," was drawn by John P. Bluemle. This colored map, drawn at a scale of 1:670,000 (approximately an inch to 10 miles) shows North Dakota's bedrock surface, the preglacial materials throughout the state. Each bedrock formation is shown in a different color. The contours on the map show the configuration of the bedrock topography (100-foot contour interval east and north of the Missouri River; 200-foot interval southwest of the river).

The new map is used best in conjunction with land-surface maps as a means of studying hydrologic, environmental, and geologic problems. For example, the map can be used as an aid in locating supplies of groundwater, which occur in gravel and sand within the glacial deposits and in alluvium that overlies the bedrock in deep valleys in unglaciated areas.

Information about the bedrock surface is especially valuable to state, regional, and local planners concerned with environmental problems such as the location of landfill sites. The thickness and hydrologic properties of the material overlying the bedrock surface is an important consideration in insuring the protection of aquifers from potential sources of contamination such as landfills, mining operations, and oil well drilling. The map should be especially useful to drillers concerned about how much surface casing to set when drilling oil wells in northern, central, and eastern parts of North Dakota.

Miscellaneous Map 25 measures 36" x 34" and is folded to a 4½" x 9" size. It can be obtained from the North Dakota Geological Survey for $2.00.

Educational Series 15--"A History of Coal Mining in North Dakota, 1873-1982," was written by Colleen A. Oihus, who is Assistant Coordinator of Special Collections at the University of North Dakota Chester Fritz Library.

The 100-page publication concentrates primarily on the principal mining enterprises and on the problems associated with the growth of the lignite industry from 1873 to 1941. It treats the history of mining in 4 stages: the birth of the coal industry, 1873-1900; the rise of the commercial mining firms, 1900-1920; the technological shift from underground mining to strip or surface retrieval, 1920-1941; and the emergence of lignite as the major catalyst in the production of electrical energy, 1941 to the present.

About 30 pages of photos are included, many of them from the State Historical Society and the Department of Special Collections at Chester Fritz Library. The publication is extensively referenced for anyone who wants to study the topic in greater detail. Footnotes are included after each chapter and the publication also has a 10-page bibliography. Educational Series 15 is available for $3.00 from the North Dakota Geological Survey.

Educational Series 16--"Geology Along the North Dakota Interstate Highway 94," was compiled by John P. Bluemle. This is a completely revised version of our first Educational Series Publication (ED-1, published in 1972). It is a single-sheet brochure, folded to 11" x 4", consisting of a simplified map of the geology along Interstate Highway 94 along with colored diagrams and photos. Important geologic features along the highway are noted and background information on North Dakota geology is also included. Educational Series 16 is available from the North Dakota Geological Survey free of charge.

"General Rules and Regulations for the Exploration, Development, and Production of Subsurface Minerals" was compiled by the North Dakota Geological Survey for the North Dakota Industrial Commission. This 23-page publication states the State Industrial Commission's rules and regulations for the exploration for, development, and production of subsurface minerals (except oil and gas). It includes pertinent information from the statutes governing subsurface minerals (38-12-01 through 38-12-05) and rules governing drilling of wells, abandonment and plugging of wells, operating practices, as well as miscellaneous rules. It also includes special rules (Special Rules of Order on Procedure in Promulgation of Rules and Regulations Governing the Regulation of Development of Certain Subsurface Minerals).

The General Rules and Regulations for the Exploration, Development, and Production of Subsurface Minerals can be obtained without charge from the North Dakota Geological Survey.

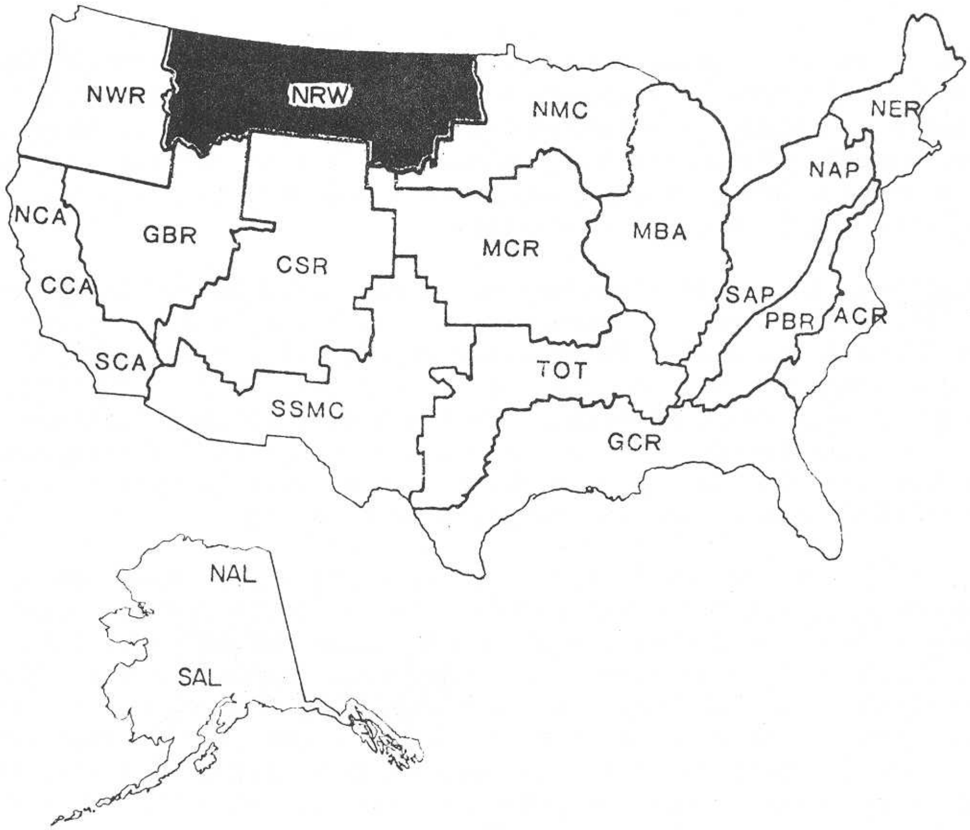
"Oil in North Dakota--Production Statistics and Engineering Data for 1980" is now available. This 678-page compilation of statistics includes the monthly oil and water production figures for each well operating in North Dakota during 1980. Additional information is also included (gravity, gas/oil ratio, well status, runs and lease use, etc.). Statistics on oil field production and annual production are also included in the volume, which is available from the North Dakota Geological Survey for $15.00.

A new List of NDGS Publications, effective through August, 1983, is now available. 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. Phone (701) 777-2231.

CORRELATION CHART FOR NORTHERN ROCKIES/WILLISTON BASIN PUBLISHED --John Bluemle

The American Association of Petroleum Geologists (AAPG) has released the COSUNA (Correlation of Stratigraphic Units of North America) chart for the Northern Rocky Mountains and Williston Basin. This is the first of 16 such correla-

COSUNA CHART INDEX MAP



ACR Atlantic Coastal Plain Region.

CSR Central and Southern Rockies Region

GBR Great Basin Region

GCR Gulf Coast Region

NAL Alaska Region, Northern Province

SAL Alaska Region, Southern Province

NER New England Region

NWR Northwest Region

PBR Piedmont/Blue Ridge Region

TOT Texas-Oklahoma Tectonic Region

NCA California Region, Northern Province

CCA California Region, Central Province

SCA California Region, Southern Province

MBA Midwestern Basins and Arches Region

MCR Mid-Continent Region

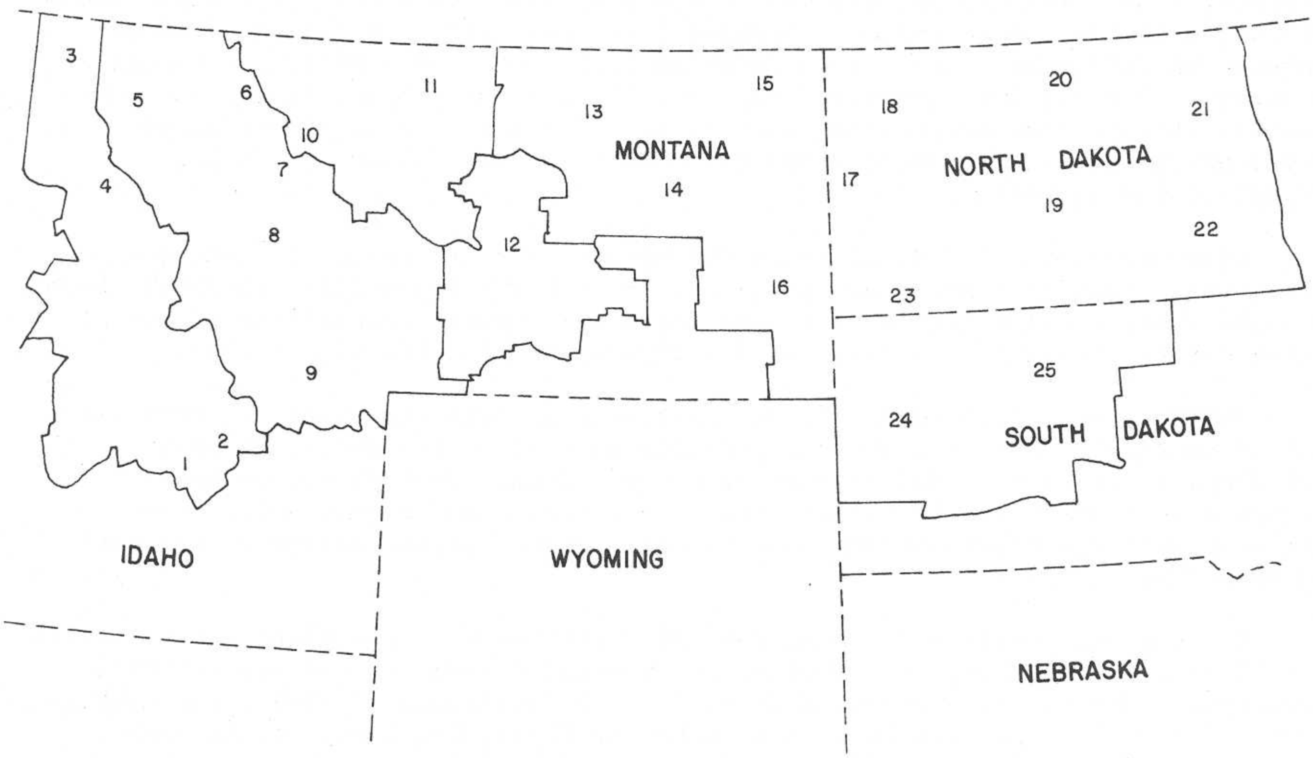
NAP Appalachians Region, Northern Province

SAP Appalachians Region, Southern Province

NMC Northern Mid-Continent Region

NRW Northern Rockies/Williston Basin Region

SMC Southwest/Southwest Mid-Continent Region tion charts that will be published by the AAPG within the next year. (I've included a map of the United States showing the areas covered by each chart). Each chart will represent a different geological province of the United States, including Alaska. The charts are intended to show stratigraphic terminology and regional correlations among the many geologic units in use throughout the United States. In essence, this is a collection of composite geological columns with particular emphasis on the age designation of the recognized lithologic units. In order to provide generalized information, each rock unit is colored to represent the dominant lithology of the unit. Also, the normal (metric) thickness of the unit is shown by numbers within the named unit.



The Northern Rockies/Williston Basin chart includes a total of 25 stratigraphic columns (see the accompanying map of the north-central United States). It includes 4 representative columns for northern Idaho, 12 for Montana, 7 for North Dakota, and 2 for South Dakota. The new chart measures approximately 47" x 42". The COSUNA charts are being printed and sold by the AAPG and will not be available from the North Dakota Geological Survey.

PETROLEUM WORK FORCE PROFILE RELEASED --John Bluemle

I recently obtained a copy of a report entitled "Profile of North Dakota's Petroleum Work Force, 1981-82," by Robert A. Chase and F. Larry Leistritz of the Department of Agricultural Economics at North Dakota State University, Fargo. The 67-page report assesses the socioeconomic effects of the rapid petroleum development in western North Dakota during the recent "oil boom". The authors have analyzed the characteristics of the petroleum industry's work force in North Dakota's Williston Basin. They have attempted to estimate the occupation, locational origin, housing requirements, commuting patterns, and other socioeconomic characteristics of the petroleum-related work force in North Dakota during 1981-82. Theirs is the first comprehensive work-force profile of an onshore petroleum development area.

Among their findings, Chase and Leistritz report the following facts:

Slightly over half of the 1377 people who responded to the Survey were nonlocal workers, moving into the region at a migration rate of 503 per 1,000 workers. The remainder had resided in the area prior to working for a petroleum-related establishment. Nonlocal workers came from eastern portions of North Dakota, 36 different states, four Canadian provinces, and a Western European country. Of every 100 in-migrant workers, 18 previously lived in eastern North Dakota, 34 came from neighboring states, and 32 moved from other petroleum development areas. The average age for both local and in-migrant worker groupings was 30 years.

Predominantly male, 63 of every 100 workers were married. In contrast to the construction of large-scale projects, 86 of every 100 married nonlocal workers brought their familes with them to the field development communities. Each of these workers brought an average of 2.2 dependents with him to the area.

Workers were employed by a wide assortment of companies involved in various petroleum-related activities--from geophysical exploration and development drilling, to production and processing of petroleum. Over 15 occupational groups were represented in the survey, with managers and supervisors, well-drilling workers, truck drivers, and clerical worker groups garnering the most respondents.

The regional centers of Dickinson and Williston were the places of residence for 57 of every 100 workers. Most of the remainder lived in the smaller field development centers near active exploration and development fields. Substantial numbers of workers resided in Watford City, Belfield, New Town, and Killdeer. The workers commuted an average distance (one way) of 18 miles to work.

Overall, workers had been employed with their present companies for about two-and-a-half years. Local workers had been employed in the Williston Basin "oil patch" twice as long as in-migrant workers. The difference suggests that a number of nonlocals had been transferred by their company from other petroleum development areas.

Local workers had lived, on average, in their present residence for over nine years. For every 100 local workers, 54 resided in single family homes. In contrast, only 32 of every 100 nonlocals lived in single family homes. The majority of those workers (60 percent) lived in either multiple housing or mobile homes.

In light of the uncertain future of petroleum development in North Dakota, the Chase-Leistritz study has several implications for manpower and community planning. Expansion of the industry may further enhance employment opportunities for the state's rural labor force, and vocational and technical training may result in local workers qualifying for more of the higher skilled jobs. Expanded exploitation of the state's petroleum reserves also may lead to a substantial influx of workers with their dependents into the Williston Basin. Information on worker characteristics, residential requirements, commuting patterns, and family characteristics may provide state and local policy officials with the appropriate basis of planning for this new population.

The Chase-Leistritz report includes over 40 tables, which provide a variety of information on the characteristics of various segments of the work force. Just for example, the median age of all oil field workers (during the oil boom) was about 26 years old; of the total work force, 19.2% were managers and supervisors (the largest single category), 11.9% were well-drilling workers; 9.9% were truck drivers, etc.

I found the report quite informative and I'd think it would be useful to anyone interested in the social and economic impacts of such a rapid influx of workers into the rural western North Dakota setting. Copies of the report, which is listed as Agricultural Economics Report No. 174, are available without charge from the Department of Agricultural Economics, P.O. Box 5636, North Dakota State University, Fargo, North Dakota 58105. Their phone number is (701) 237-7441.

NORTH DAKOTA HAS "AVERAGE" WATER YEAR IN 1983 --USGS

(Editor's Note: The information in this item was provided by the United States Geological Survey Water Resources Division district office in Bismarck. Working in cooperation with other Federal, State, and local agencies, the USGS compiled the following information on streamflows, groundwater levels, and reservoir storage in North Dakota for the water year ending September 30, 1983. A water year, as used by USGS hydrologists, runs from October 1 of one year, through September 30 of the following year. It is designed to coincide with the growing season and to begin and end during a period of generally low streamflows.)

Heavy winter snows followed by abundant summer rains added up to an average water year during 1983 for streams, wells, and reservoirs in North Dakota, according to the U.S. Geological Survey. The Red River of the North at Grand Forks, the Cannonball River at Breien, the level of groundwater in the Sheyenne Delta near Wyndmere, and storage in Lake Sakakawea were monitored.

<u>Red River of the North</u> at Grand Forks had an average flow of 3,400 cubic feet per second (cfs), or about 2.2 billion gallons per day (gpd), which was 46 percent more than normal for the 100 years that records have been kept on that river; average flow during 1982 was 3,600 cfs. Average monthly flows ranged from a low of 1,500 cfs (969 million gpd) in February to a high of 7,120 cfs (4.6 billion gpd) in April.

The highest flow of the year on the Red River of the North occurred April 6, when a flow of 13,500 cfs (8.7 billion gpd) was recorded at USGS index station at Grand Forks. That rate of flow, however, didn't come close to the all-time record daily flow of 85,000 cfs (55 billion gpd), which occurred April 10, 1897. The lowest 1983 daily flows, 1,260 cfs (814 million gpd) occurred February 23 and 24 (the record low is 1.8 cfs (1.16 million gpd), which occurred September 2, 1977.

Cannonball River at Breien had an average flow of 210 cfs (136 million gpd), about twice the long-term average for the 48-year period of record (the average 1982 flow was 820 cfs). Average monthly flows ranged from high of 730 cfs (472 million gpd) in March to a low of 22 cfs (14 million gpd) in September.

The highest daily flow of the year on the Cannonball was 1,900 cfs (1.2 billion gpd) March 6. That figure, however, is far below the all-time record daily flow of 63,100 cfs (40.8 billion gpd), which occurred April 19, 1950.

In contrast to many years when the Cannonball River has several days of no flow, Cannonball flowed each day during the 1983 water year.

In response to the above-average precipitation, ground-water levels in two USGS observation wells were at or above long-term averages throughout the water year. The level in a well tapping the Sentinel Butte Formation near Dickinson established new monthly highs for November, December, January, and February. Highest level for the year was 16.82 feet below land surface May 19, which was one foot below the all-time high level of 15.82 feet below land surface in May, 1970.

The level of a well tapping the Sheyenne Delta aquifer near Wyndmere dropped to 7.23 feet below ground surface September 26, which was the low for the year, after a peak of 3.42 feet below ground surface in December. The all-time low for that well was 8.73 feet below ground surface in February, 1977 and the record high was 1.12 feet below ground surface in April, 1969.

Storage in Lake Sakakawea remained relatively stable through the year, peaking at 21.3 million acre-feet at the end of July and finishing the water year with 20.2 million acre-feet, which was 92 percent of the lake's normal maximum capacity. (One acre-foot equals 325,851 gallons.)

CHANGES IN PERSONNEL

Our new publications clerk is Jana Diemert. Jana is a 1981 graduate of Grand Forks Central High School and she attended UND for one year. Prior to coming to the NDGS, Jana worked as a cashier for Rhodes Furniture in Ft. Myers, Florida.

Cheryl Schreiner, who was secretary for the geologists for the past three years, resigned recently to become Biology Department Secretary. Anne Behl, who was formerly our publications clerk, has taken the secretary position.

SURVEY PROFILES

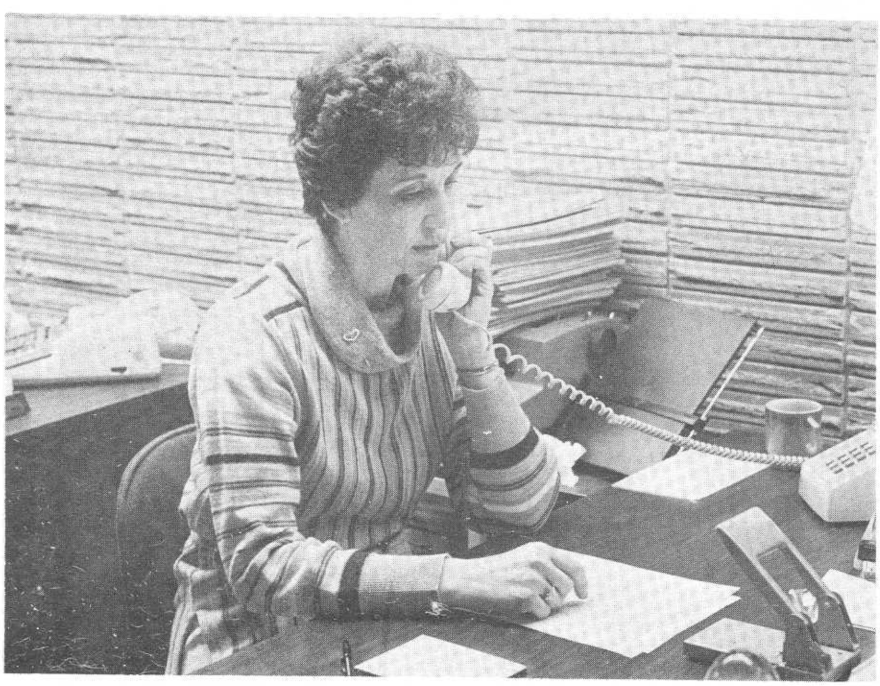
Marvelyn Anderson

Marvelyn Anderson, our Receptionist, is shown here, appropriately, on the telephone. She has been with us since last spring when she moved "upstairs" from her position as Geology Department Secretary. Prior to working with the Geology Department, Marvelyn lived in Grafton, North Dakota where she was Deputy Treasurer for Walsh County for 14 years. She has a son and daughter, both of whom live in California.

Ken Dorsher

Ken Dorsher has been working with us as a draftsman for the past two years. Ken is a native of Grand Forks and a 1975 graduate of Grand Forks Central High School. He also has studied at the University of North Dakota and he had 6½ years of experience as a draftsman with a Grand Forks engineering firm before coming to the North Dakota Geological Survey.

Ken is a talented artist as well as a precise and rapid draftsman. He prepares virtually all of our colored maps for the printer as well as nearly all of the drawings and other illustrations for our publications. Ken and his wife, Patricia, enjoy various sports.

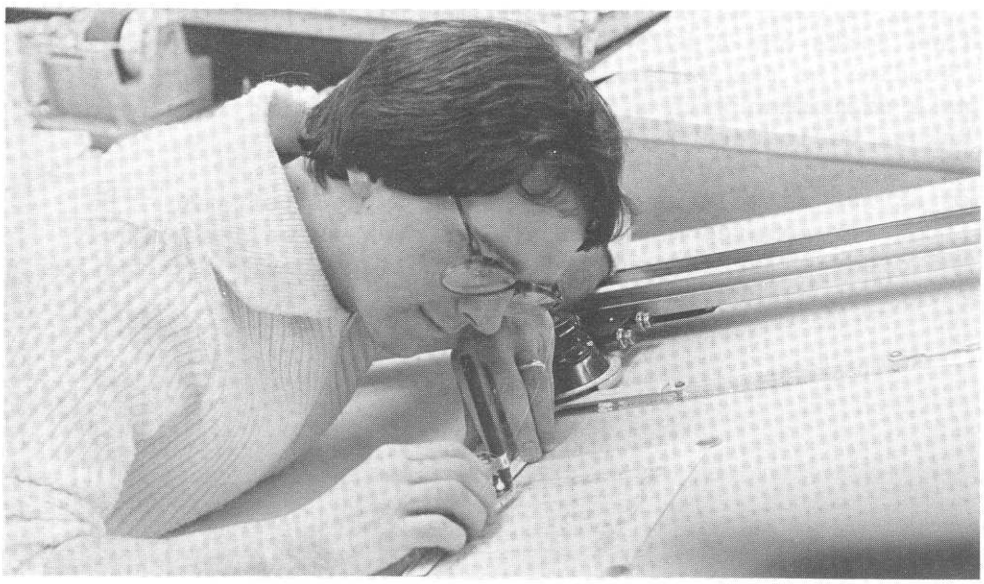


Marvelyn Anderson

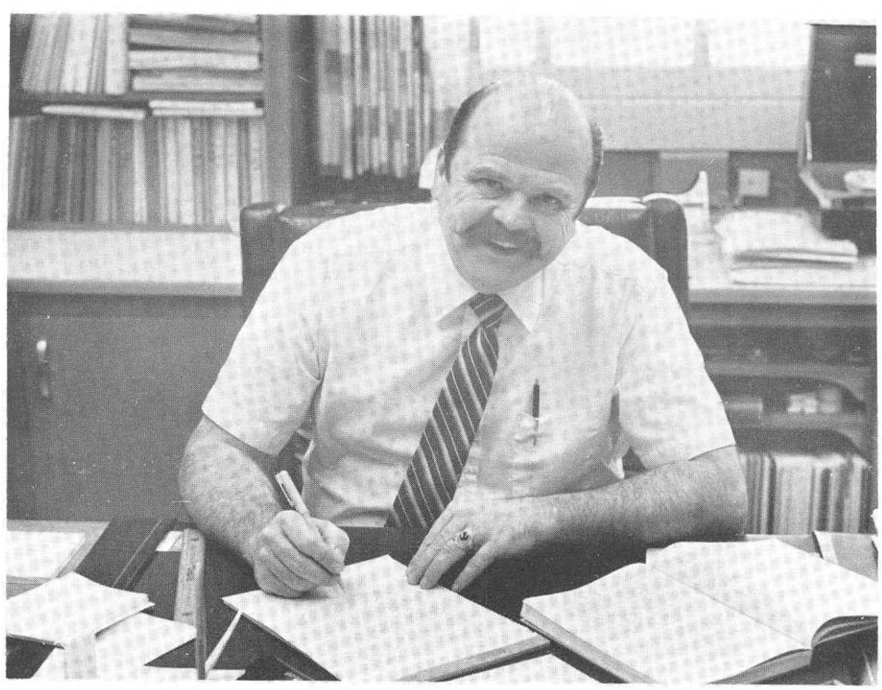
Robert E. Seidel

Bob joined the North Dakota Geological Survey in the summer of 1982 and was appointed Deputy State Geologist on January 1, 1983. His responsibilities are divided between administration, research coordination, and personal research, which is in the areas of glaciology, geomorphology, and meteorology. Bob's research background includes geologic investigations in Quaternary and glacial geology, including research on surging glaciers in the Yukon with the Arctic Institute of North America. He is currently completing a Ph.D. at the University of North Dakota; this involves working on a paleoclimatic study of southwestern North Dakota.

Bob has experience teaching both geology and geography in Michigan, Minnesota, Indiana, and at the University of North Dakota. Bob's wife, Jaymee, is secretary to the Superintendent of Schools here in Grand Forks. They have two children, Erik and Amy, who attend Grand Forks Central High School and South Junior High School in Grand Forks.



Ken Dorsher



Bob Seidel

CENOZOIC PROJECT

--Ed Murphy and R. D. LeFever

(Editor's Note: R. D. LeFever is an Assistant Professor and Assistant Chairman of the Geology Department at the University of North Dakota.)

In May of 1980, former State Geologist, Dr. Lee C. Gerhard, submitted a proposal to the Office of Surface Mining - U.S. Department of Interior through the North Dakota Mining and Minerals Resources Research Institute (see following article). Objectives of this proposal were to establish a data base of the Cenozoic sedimentary sections of the Powder River and Williston Basins, compile a bibliography of materials on this subject, and interpret the three-dimensional stratigraphic framework and depositional setting of the Cenozoic sedimentary section. The proposed funding was for three years and the projected time for project completion was ten years. The project was originally funded at the proposed level, but was cut at the end of the first year to only one additionally funded year as a result of federal budget reductions. This reduction reduced the number of realistic goals that we could hope to accomplish in this shortened time period and the budget funding restraints also reduced the number of people involved in the project.

As reported in the December, 1981 NDGS Newsletter, this project funded a field conference in North Dakota, Montana, and Wyoming. This conference was probably the most important single contribution resulting from the project. A total of 19 participants, representing state and federal agencies and private industry, who were working on the Cenozoic sediments in the two basins met during the conference. The conference generated both questions and ideas and opened lines of communication that will continue to add knowledge and insight into these sediments for years to come.

A bibliography of approximately 800 references on the Cenozoic sediments of the two basins has been compiled. This bibliography is in the process of being cross-referenced and will probably be published by our agency.

A computer data base has also been established. This contains approximately 12,500 entries from 8,508 localities within the 19,000 sq. mile (49,000 sq. km) study area. Storage, retrieval, and manipulation of the data were handled by the Statistical Analysis System (SAS) resident on the computer at the University of North Dakota. The data were grouped into six files on the basis of the type of data involved: geographic/geologic, lithologic, groundwater, geochemistry, coal chemistry, rock geochemistry, and rock mineralogy.

Groundwater chemistry, coal chemistry, and gross lithology values were contoured from the control data points within the Cenozic section throughout the two basins. The groundwater isoconcentration maps did not demonstrate any overall patterns or trends, but did show a strong similarity between the overall groundwater chemistry in the two basins. The coal chemistry does not show any pronounced regional tendancies, but does show significant local variation. The lithologic values did not show a strong pattern through Fort Union time.

The money allocated for drilling was cut in half by the budget reduction. We proceeded with our original intentions and drilled primarily in the area of poor outcrops between the Cedar Creek Anticline in eastern Montana and the Little Missouri River in western North Dakota. However, not enough data were generated by this drilling program to attempt paleogeographic reconstructions of these sediments or to begin to address the effects of the Cedar Creek Anticline on sedimentation during Fort Union time. Over the next seven years this data will be combined with existing data and these subjects will be addressed.

One of the original long-term goals of this project was to provide data that would enable identification of areas where surface extraction of minerals could pose a problem because of the local geochemistry of the sediments and/or the groundwater chemistry. The data control does not exist to identify these areas and it is doubtful that such control will be available in the near future. For this reason, detailed geologic, hydrogeologic, and geochemical studies must be undertaken at each site prior to mining to determine the local characteristics and to minimize any adverse effects of such mining.

The most important outcome of this project is that it got a number of workers in this area looking at these sediments from a regional standpoint. The close cooperation between the various individuals and agencies that were generated by this project will benefit research on the Cenozoic sediments in the Williston and Powder River Basins for many years to come.

The following report was submitted to the Office of Surface Mining: LeFever, R. D. and Murphy, E. C., 1983, Mineral Resources and Potential Problems Associated with Mining of Cenozoic Rocks of the Williston and Powder River Basins, Northern Great Plains, Report to Office of Surface Mining, Bureau of Mines, 181 pp.

NORTH DAKOTA MINING AND MINERALS RESOURCES RESEARCH INSTITUTE

The objective of the MMRRI is to coordinate and serve as a focus for mining, mineral resources and energy research and education in North Dakota. This objective is being met by 1) providing the necessary environment and facilities for the expansion of these activities; 2) providing a liaison with the industry and various key governmental and educational entities in North Dakota; 3) providing for information dissemination, and 4) providing for the training of scientists and engineers oriented toward mining, and mineral resources, and energy development in North Dakota.

Funding for the MMRRI was initially authorized under Title III of Public Law 97-87--August 3, 1977. The initial allotment grant period was subsequently extended in one-year increments through June 30, 1984. In addition to allotment funding, the North Dakota MMRRI was awarded approximately $250,000 for scholarships and fellowships for graduate and post-doctoral students who are involved with research related to mining and mineral resources. The majority of the scholarships and fellowships have been awarded to graduate students in the Department of Geology at the University of North Dakota.

The MMRRI actively seeks contract research funds through proposals submitted by faculty from the institutions of higher education in North Dakota (this includes scientists from the NDGS). Ongoing research projects funded through the MMRRI include lignite resource evaluation, distribution of inorganics in coals, coal combustion solid waste disposal, coal gasification solid waste characterization and reuse, hydrogeological and geochemical characterization of abandoned surface-mined lands, effects of surface mining on groundwater, effects of seismic testing on shallow wells, innovative techniques for the delineation of abandoned underground mines, and refinement of mined-land reclamation techniques.

Dr. Gerald Groenewold, on leave from the Survey, is Director of MMRRI.

ENHANCED OIL RECOVERY

--Marvin Rygh

The term "enhanced oil recovery" (EOR) means to recover additional oil from a reservoir by using artificial methods including pressuring, cycling, pressure maintenance or injection of gas or fluids into the reservoir. Under normal conditions, when an oil well is initially put on production, the natural energy within the reservoir is sufficient to push the oil towards the well bore. If the pressure is great enough, the oil will flow to the surface and be considered a "flowing well." When the pressure is such that the oil comes up part-way in the well, a pump is used to lift it the rest of the way to the surface. The well is then said to be "on pump." Both of these methods, flowing and pumping, are considered primary recovery. The oil is flowing into the well bore utilizing the natural energy contained within the reservoir.

As the well is produced, the reservoir energy is depleted and at some point in time it will become uneconomical to continue production due to low output. The purpose of EOR is to increase the total production from the reservoir by restoring or replenishing the reservoir energy, thereby extending the life of the well. Six general categories of EOR techniques are waterflooding, gas injection, in situ combustion, steam injection, miscible fluid displacement, and microemulsion flooding.

Waterflooding is the most common type of EOR process used in the U.S. Water is injected into the producing formation to increase reservoir pressure and push oil towards producing wells. Injection wells are located around the periphery of the field or in a regular spacing pattern throughout the field. In many cases, some of the existing oil wells are converted to injection wells.

Waterflooding is popular because it is a proven economic oil recovery technique that is widely applicable. One reason for this is that water is a readily available resource. Water produced with the oil can be reinjected as well as compatible water obtained from various other aquifers. One such source of water is the Inyan Kara (Dakota) aquifer in North Dakota. Many areas of North Dakota have been subject to waterflooding with varying degrees of success. These areas are the Nesson Anticline, Burke County, Newburg, Medora, Fryburg, Dickinson, Grenora, and Cedar Creek fields.

Even if a waterflood is successful, significant amounts of oil are bypassed in the reservoir. For this reason, other techniques are being tried to recover additional oil in reservoirs that have previously been subjected to waterflooding.

Polymer flooding is a variation of waterflooding in which water is thickened with a polymer and used as an injection fluid. This more viscous fluid is advantageous because smaller volumes of fluid are needed and coverage within the reservoir is increased. Polymer flooding is presently being tested in the South Heart Field in Stark County.

Surfactant flooding is another variation of waterflooding. A detergent or surfactant is injected along with the water. The surfactant should reduce the interfacial tension between the water and oil, thus mobilizing more of the trapped oil in the reservoir. There is not much surfactant flooding being tried in the U.S. presently. This is probably because of a high cost-benefit ratio and the uncertainty of good oil recoveries.

Immiscible gas injection is another general category of EOR. Different types of gases can be injected into the reservoir. Natural gas can be reinjected as well as flue gas or nitrogen. In most instances, immiscible gas injection will not be as efficient as waterflooding, but might be profitable because of accessibility and ease of injection. The gas will serve to repressure the reservoir and possibly push more oil to the producing wells. Gas reinjection is to be utilized in the Red Wing Creek Field in McKenzie County. The problems encountered with gas injection is that the gas has a much lower viscosity than the reservoir fluids so gas breakthrough to the producing well may occur, resulting in prohibitively high gas-oil ratios.

In situ combustion, or fireflooding is an EOR method whereby air or oxygen is pumped down into the formation and ignition is initiated to create a combustion zone of burning oil that will raise the temperature of the formation, mobilizing the hydrocarbons and moving them toward a production well. Ignition in the formation can occur spontaneously with the injection of air or artificially started with a downhole electrical device. In situ combustion projects are normally attempted on reservoirs with low gravity, high viscosity oil, although higher gravity reservoirs have been fireflooded. In February of this year, Koch Exploration Company will attempt a fireflood in a portion of the Capa Field on the Nesson Anticline. One advantage of fireflooding is that it is relatively inexpensive compared to many other EOR methods.

Steam injection is another method of EOR that is used mainly for heavy, low gravity oils. Hot steam is injected into the producing formation to increase the temperature thus lowering the oil viscosity enabling the heavy oil to flow more easily through the formation to the production wells. Steam injection has been successful in California and other areas of the U.S. Cyclic steam simulation is another method commonly used in which steam is injected into a specific well for a period of time, usually 2-3 weeks. Injection is then stopped and the well is put back on production. This is called the "huff and puff" process. Although steam injection is a proven success in some areas, the cost-benefit ratio is very high because of the expense of the steam generating equipment and water treating equipment. Steam injection is also limited to formations shallower than approximately 6000 ft. deep. Higher formation temperatures in deeper horizons negate the usefulness of injecting steam into those reservoirs. Problems also occur with heat loss through long strings of tubing and casing.

Miscible fluid displacement is an EOR process that uses solvents to completely displace the oil in the reservoir. These solvents can be an alcohol, a ketone, a refined hydrocarbon, carbon dioxide, natural gas, or flue gases. The key to this method is that the injected solvent dissolves the oil, then another liquid or gas is injected to sweep out the remaining solvent. This method is gathering interest in the oil industry. A number of pilot tests have recently been done throughout the U.S. using miscible flooding. Carbon dioxide is being tried in specific oil fields and has been tested in the Little Knife Field in Billings County. As in other EOR methods, economics and profitability play a large role in miscible fluid displacement. Large initial investments are required along with obtaining a solvent (CO_2, refined hydrocarbons, etc.) in sufficient quantities and at reasonable prices.

Microemulsion flooding is a variation of miscible fluid displacement. The intent of this method is to displace the oil toward production wells using a microemulsion slug. These microemulsions are mixtures of water and hydrocarbons stabilized with a surfactant. The advantage of this process is that it is widely applicable to different reservoir conditions. In general, if a waterflood has been successful, a microemulsion flood may also work in the same reservoir.

This was a general overview of the different types of enhanced oil recovery. All the processes have a common purpose, that is to ultimately get more oil out of the ground.

Before a full scale EOR project is initiated, a detailed reservoir and economic analysis must indicate that the particular process chosen will be cost effective.

Certain factors are likely to help EOR projects in the future. These are:

1. favorable economics,

2. depleted primary reserves,

3. high cost of exploration, and

4. improved EOR technology.

It appears that with improved technology and a better understanding of reservoir properties, enhanced oil recovery is gradually becoming commonplace throughout the oil industry.

DETECTION OF UNDERGROUND LIGNITE MINES BY GRAVITY SURVEYS --William Gosnold, Jr.

(Editor's Note: This article, by William Gosnold, Jr., who is an Associate Professor in the University of North Dakota Geology Department, was taken from a report submitted to the North Dakota Public Service Commission in September, 1983. The report was written by Dr. Gosnold and two graduate students, Chris Quinn and Mark Luther.)

A fundamental problem in reclamation of abandoned mine lands is determining the locations of mine tunnels that are not mapped. Possible methods for detecting underground mines include drilling, electrical resistivity, seismic reflection, and micro-gravity. Of these methods, only drilling uses a direct approach that provides certain results. The other three methods use an indirect approach--they measure a physical quantity that is influenced by the mine tunnel, and they provide direct information only on that physical quantity. Various methods of mathematical interpretation are utilized to determine the nature of the source of the disturbance to the physical quantity, and reasonably accurate results can be obtained from these methods. Drilling and seismic reflection are several orders of magnitude more expensive than resistivity and gravity surveys; thus, the latter two should be favored in an initial survey.

The study involved a test of the gravity method on four sites in North Dakota. These were located near New Leipzig, Beulah, New England, and about 15 miles south of Minot. The primary objective of the study was to conduct micro-gravity surveys at sites where abandoned lignite mines were known to exist to test the feasibility of detecting and mapping those mines by micro-gravity methods. A secondary objective was to test the feasibility of using micro-gravity methods to determine the extent of reclamation of underground mines by slurry-filling or collapse. The secondary objective was precluded because reclamation of the study sites did not commence until the contracted term for the gravity survey had expired.

Detection and mapping underground mines by micro-gravity methods is a multi-phase operation involving planning, field operations, and laboratory analysis. Field operations include precise surveying and meticulous care in operation of the gravity meter. Gravity data collected in the field are meter readings in units characteristic of the gravity meter and they must be "reduced" to provide useful information. The data reduction is accomplished by computer and includes allowances for: meter drift, earth tides, topography, latitude, regional gravity, and gravity meter characteristics.

The objective of a gravity survey is to detect variations in the earth's gravitational field and to draw conclusions about the significance of the observations. Variations, or "anomalies," in the gravity field are normally caused by inhomogeneous distributions of rock types having different densities. The effect of a tunnel in the subsurface is essentially that of a mass deficiency that tends to reduce the gravity field near the tunnel. Because the gravity field has vectorial properties, a mass excess or a mass deficiency generates a field over a full 720 degree solid angle. However the normal procedure is to treat only the vertical component of the earth's field in determining the nature of anomaly sources. It is important that the gravity meter be precisely levelled so that only the vertical component is measured.

In a micro-gravity survey, the vertical component of the earth's gravity field is measured with an accuracy of one micro-gal. One gal is an acceleration of 1 cm sec -2, and the earth's gravity field at the surface is on the order of 980 gals. The actual gravity value at a point on the earth's surface is influenced by a number of factors, each of which can have magnitudes greater than the signals generated by shallow tunnels. Consequently, reduction of gravity data to allow for these factors is essential to obtain useful results from gravity data.

Data collection at the four mine sites was generally a routine operation. Problems were encountered at some sites, such as New Leipzig, where a significant number of collapsed tunnels affect the surface topography. In most cases gravity readings were not made in the collapsed areas. However, omission of those few data points is not considered detrimental to the data set. Even if the data were taken for those points, the local terrain effects would make the value of data point dubious. (It is also worth noting that working in the sanitary landfill at New Leipzig was occasionally unpleasant because of the rotten cattle carcasses that lay uncovered in some of the pits.)

Working around fenced areas can be a problem with a LaCoste and Romberg gravity meter. Moving the meter over a barbed wire fence increases the likelyhood of tilting the meter and thus creating tares in the instrument readings. Tares in the readings are the result of permanent deformation of the spring in the gravity meter. They can be caused by slight accelerations or tilting of the gravity meter while moving from one station to the next. In future surveys we recommend that all readings within a fenced area be taken without removing the meter from the fenced area. This recommended operation necessitates locating a base station within the fenced area. This precaution is necessary because of the extreme sensitivity of the meter to even the slightest tilt or acceleration and because of the small amplitudes of the signals from the tunnels.

Reduction of the data was facilitated by availability of micro-computers with high-resolution graphics capabilities. The computers used in this project were IBM Personal Computers equipped with graphics systems and dot matrix printers. The ease of operation and the flexibility of the systems greatly enhanced the data reduction and interpretation phases of the project.

Gravity anomalies of magnitudes greater than expected from the preliminary model studies were encountered at most sites. These anomalies were of two types: high-amplitude short wave-length types and moderate amplitude long wave-length types. The half-widths of the anomalies, that is, the width of the anomaly where the amplitude is equal to one-half of its maximum amplitude, can be used to estimate the approximate depth to the anomaly source. For the simple case where the anomaly is assumed to be generated by a spherical source, the depth to the source is 1.3 times the half-width. The small half-widths of the high-amplitude anomalies indicate that they are caused by near-surface density contrasts. The preferred interpretation is that these anomalies are caused by cavities nearer to the surface than the coal horizon. For the cases where the half-widths of the anomalies are approximately equal to 1.3 times the depths to the coal horizon, the preferred interpretation is that the anomalies are caused by closely spaced tunnels at the coal horizon. In the latter case it is not possible to identify the exact locations of individual tunnels.

We concluded that gravity lows occur throughout all of the sites and many of these gravity anomalies may be caused by tunnels directly beneath the anomalies. A majority of the gravity lows at the sites coincide with surface observations of line of sight connections between collapsed pits. These gravity lows probably indicate the presence of uncollapsed segments of tunnels at the coal horizon. The data collected in this study are adequate for identification of individual tunnels and mined regions.

Gravity surveys require a relatively short time for planning and field operations. Reduction of the data also can be rapidly accomplished with the aid of computers. However, interpretation of the data and preparation of maps showing the results can take several weeks of concentrated effort. For this reason, we recommend that future gravity studies be scheduled at least two months prior to the dates scheduled for reclamation operations. Although the results of this study indicate that gravity anomalies can be detected and mapped at sites which have been mined, verification of the anomalies as tunnels remains to be done. We are interested in continuing to evaluate the results of our study as drill hole data are acquired by the Public Service Commission. We consider this continued evaluation of our study important if gravity surveys are to be a useful component in the reclamation of abandoned mine lands.

THE GALILEAN SATELLITE IO

--Frank Karner

(Editor's Note: Frank Karner is a Professor of Geology in the University of North Dakota Geology Department. He is involved in a NASA-funded study of Jupiter's moon, Io.)

Study of volcanoes on Jupiter's planet-sized satellite, Io, is part of a photogeologic mapping project supported by NASA through the Planetary Geology Program. Voyager spacecraft high-resolution and geophysical data, along with earth-based observations of the chemistry and physics of Jupiter and its satellites, have been used in a geologic mapping project of the Kane Patera, a quarter-million-square-mile quadrangle in the southern hemisphere of Io. (The term "patera" is used for any prominent crater or vent on Io. Io, by the way, is named for the great god Jupiter's mistress who was changed to a heifer by Jupiter's wife Juno for responding too favorably to Jupiter's attention.)

Since the 1979 Voyager 1 and 2 encounters with Jupiter, Io, the innermost of Jupiter's four, major, planet-sized satellites, has been singled out for special attention because of its volcanic activity. Io's reddish color and other spectral characteristics suggest a surface rich in several allotropes of elemental sulfur, in black to red to brown lava flows, dust-covered regions of yellow to brown sulfur and sulfates, and white, sulfur dioxide-frosted areas. Io's surface is young, free of meteorite impact craters, and probably renewed completely by volcanism every few million years. Eleven known volcanic eruptions occurred during and between the four-month interval between the Voyager 1 and Voyager 2 flights past Io. Huge, sulfur volcanoes and calderas erupted large plumes, shaped like umbrellas, up to 170 miles high. Thermal centers, as much as 150° C hotter than the surroundings, dot the surface of the satellite, corresponding generally with plumes or volcanic landforms. Energy for the hyperactivity of Io apparently comes from tidal flexing caused when alternating gravitational distortions change the moon's shape when it is pulled periodically out of circular orbit by sister satellites Europa and Ganymede.

Large calderas and two types of shield volcanoes are three major volcanic forms that occur within the Kane Patera high-resolution map quadrangle of Io. Low-relief shield volcanoes typically have a central vent region 10 to 20 miles in diameter and sulfur flows extending typically asymmetrically from the vents for 100 to 200 miles. Talos Patera (fig. 1) with major recent flows extending to the northeast and southwest is an example. Initial study suggests that, topographically, the volcano is a low, broad cone with a shallow depression containing several craters at the top.

Dome-shaped shield volcanoes consist of a central vent 5 to 10 miles in diameter surrounded symmetrically by sulfur-silicate (?) flows extending 30 to 100 miles from the vent to a marginal scarp. Taw Patera (fig. 1) is an example with nearly rounded form.

Calderas are large depressions, 25 to 150 miles in diameter, that are typically developed on low-relief plains and surrounded by thin surface deposits and low-relief flows. Vahagn Patera (fig. 1) is an example.

Further study by us is being directed toward: 1) detailed study of individual examples of the major types of volcanic forms in the map quadrangle; 2) comparison with features in other regions of Io; and 3) evaluation of the interrelationships and processes of formation of the types of volcanic features.

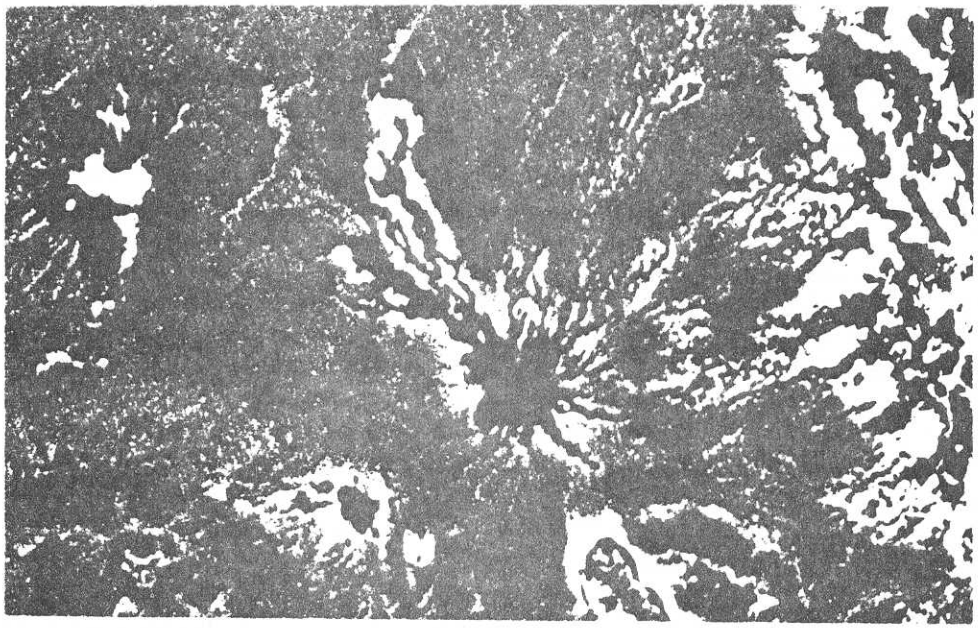


Figure 1. The low-relief shield volcano, Talos Patera with related flows is in the central part of the photo. Recent sulfur flows are darkest and have light margins or haloes of sulfur dioxide frost. The central vent region appears to consist of several irregular to rounded depressions consisting of elongate, black, filled fracture regions, which may be lava. The dome-shaped volcano, Taw Patera, with related flows, is in the upper left part of the photo. The sulfur-silicate flows from Taw Patera appear to have steeper dips and higher relief than those of low-relief shields with sulfur flows. A scarp partly outlines the outer margins of the uppermost sulfur-silicate flows. The vent appears to be a small black crater with an asymmetrical bright halo of sulfur dioxide frost. A medium-sized caldera, Vahagn Patera, is partially shown on the lower margin of the photo.

FRECKLED LAND

--John Bluemle

The study of geology sometimes leads in unexpected directions. I am currently preparing a report on the geology of Towner County in northeastern North Dakota, and during the course of report preparation, I examined several hundred aerial photographs. For the benefit of non-geologists, I should explain that the air photos we use in our work are usually black and white, approximately 3 inches to a mile, the view straight down from an airplane. The photos overlap and, by viewing two of them through a stereoscope, we can "see" the relief (hills and valleys) in a greatly exaggerated form; farm buildings look like skyscrapers, etc. This exaggeration enables geologists to identify subtle features that we might otherwise overlook. The photos come in different scales, taken from various altitudes, and we also sometimes use satellite photos, natural color photos, color-infrared photos, and other photos of various types.

In the past, our geologists studying air photos have noted assorted "non-geological" features such as bison trails, the Red River cart trails of the 1860s, the old Bismarck to Deadwood stage route, recent tornado paths and hail-storm paths, ancient Indian village sites, even ant hills (large ones), and other items as well as a host of previously unknown, and sometimes unexpected geologic features.

While examining the Cando area in Towner County, I noticed several areas with peculiar, small, white spots on the photos that generally are randomly arranged, although in a few places the spots seem to be aligned in rows (see fig. 1). During the time I was in Towner County two summers ago, checking the surface geology for several weeks, I did not notice anything on the ground that might correspond to any of the white spots I saw on the photos. However, the photos I was using were taken in 1959 and I have no reason to suppose that the spots are long lived--new spots might be visible on more recent photos and the ones that were present in 1959 may have disappeared. It's common for features that are the result of various changes in vegetation patterns to be quite short-lived.

The best-known similar appearing landform that I was aware of, and which came to mind first, is the "mima mound," typically a low, circular or oval dome composed of loose, unstratified, gravelly silt and soil material, usually built upon glacial outwash. Mima mounds range from 10 to 100 feet in diameter and they are up to 6 feet high. Named after Mima Prairie in western Washington State, mima mounds are probably initiated by pocket gophers or other burrowing rodents, which disturb large amounts of material, moving it from beneath the ground to the surface. According to Dr. Robert Seabloom of the University of North Dakota biology department, mima-type mounds appear to result from the interaction of burrowing rodents and their mammalian predators.

The Towner County spots have much less relief than typical mima mounds and, according to Seabloom, mima-type mounds are mainly restricted to native prairie, usually with a high water table. Finally, I recalled that, in the late 1960's, Dr. Dwight Deal, who was then a student at the University of North Dakota geology department, noted nearly identical features (he called them "freckled" areas) in Rolette County, just west of Towner County, when he mapped the geology of that area. Deal described the Rolette County features in detail. They are light-colored, circular areas, 30 to 60 feet in diameter, occurring on flat or gently undulating surfaces on lake sediment or wave-eroded glacial sediment, and they are extremely difficult to locate on the ground. The Rolette County freckles are not more than a few inches higher, if any, than their surroundings. Deal described them as slightly lighter color than their surroundings, probably because calcium carbonate from the Cca soil horizon had been brought to the surface of the ground.

The freckles I saw are essentially identical to the features Deal observed in Rolette County, except that they seem to be restricted almost entirely to areas of sandy lake sediment in Towner County; I did not see them on glacial sediment.

According to Deal, identical features have been reported in some parts of Minnesota where they have been described as low mounds, 10 to 130 feet in diameter, and 6 to 30 inches high. The mounds in Minnesota are sites used for hibernation by the Manitoba toad (Bufo hemiophrys). It was shown in a study of the Minnesota mounds that 3276 toads used one large mound during the winter of 1961. It was further estimated that that many toads could move as much as 85 cubic feet (about 3

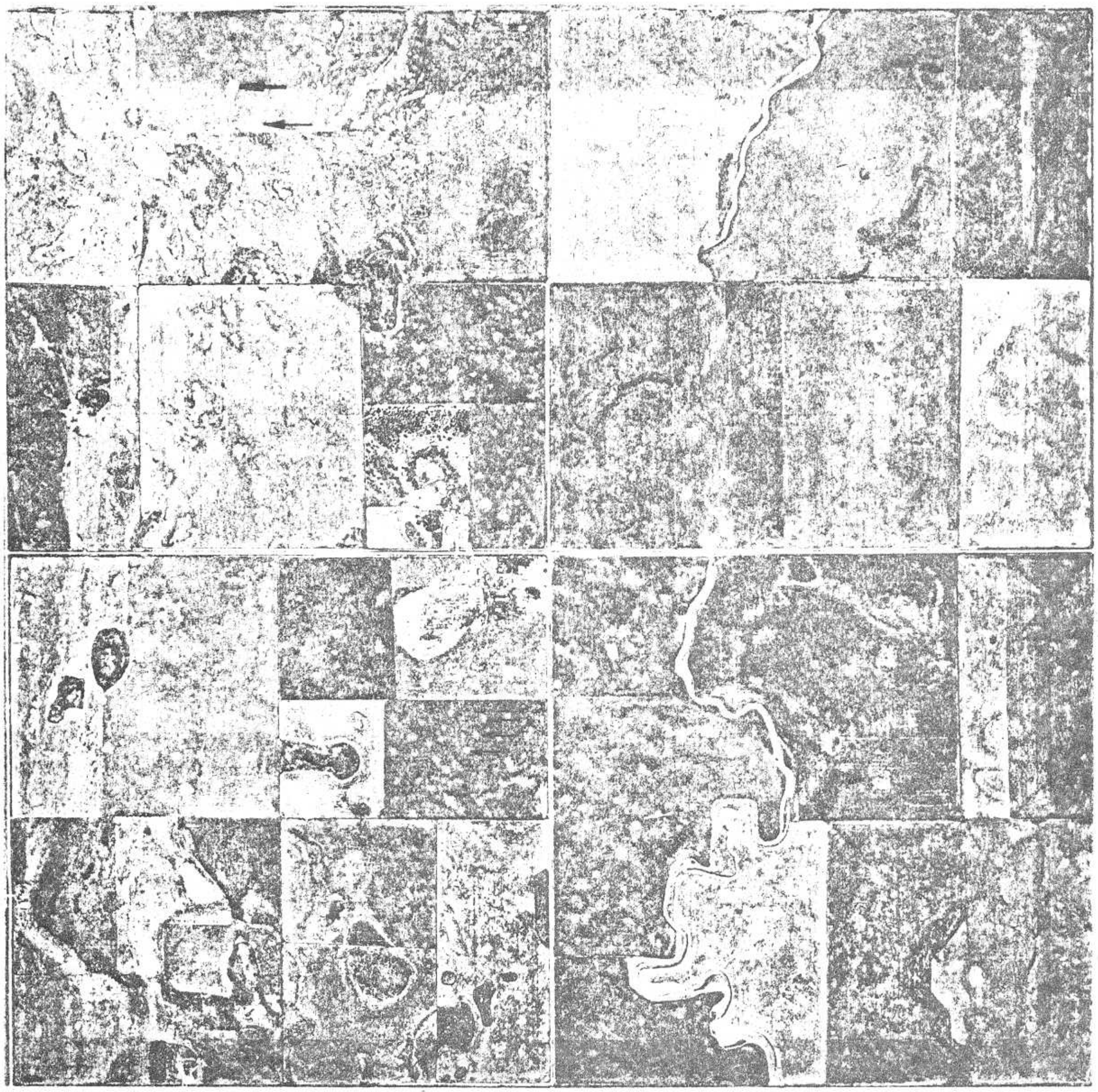


Figure 1. A four-square-mile area in southeastern Towner County, southeast of Cando (Sections 28, 29, 32, and 33, Township 157 North, Range 65 West). The sharply defined white specks, which are seen most easily in the black, freshly plowed fields, are the "freckles" described in this article. The three small arrows (lower center) point to individual freckles. The two larger arrows near the top of the photo point to typical "swells" slightly higher areas where erosion has removed the topsoil, exposing the lighter colored materials beneath. Such light-colored blotches are abundant throughout the glaciated plains of North Dakota; freckles are less common. The photo shown here was taken on July 28, 1959.

yards) of material per year in one large mound. The following quotation is from a report entitled "Ecology of mimatype mounds in northwestern Minnesota" by B. A. Ross, J. R. Tester, and W. J. Breckenridge, published in 1968 in Ecology, volume 49, number 1, pages 127-177:

> The most striking feature of most of the mounds is the disturbance of their soil by pocket gophers (Geomys bursarius), ground squirrels (Citellus spp.), toads (Bufo hemiophrys) and other animals. This has probably caused the change in vegetation, the lower bulk density, the lack of soil structure, and the increased water permeability. Animal disturbance of the soil may also account for the lack of sod, the high organic content of the subsurface silt loam, the zone of gradation of silt into clay, the discontinuity of the zone of carbonate accumulation, and most of the anomalies such as pockets of pebbles. Comparison of the mound and adjacent prairie soils suggests that the mounds are, in effect, "puffs" of soil formed primarily by animals disturbing and mixing the soil in a particular spot.

Have we solved the "mystery" of the white spots? Not really. Dr. Seabloom disagrees with Deal's toad hypothesis, as he believes it is doubtful that such a feature could develop on an area that's under cultivation. He points out that my (Deal's) hypothesis would have to be ground-truthed (checked by actually examining one of the spots). Of course he is right about a field check, and perhaps I'll try to dig up one of the spots next summer when the ground is not frozen. To do so, I'll need to get some recent photos and scale off a spot from a section corner or other known position because, as I pointed out, the spots are probably not long-lived (especially if they are, in fact, caused by toads or some other organism) and they are practically invisible to the ground-based observer.

Seabloom contends that he has seen the type of spots I've described, but that he has generally written them off as due to soil erosion--localized loss of the A horizon. He states: "In prairie soil, the calcareous layer at the base of the A horizon would show up as quite a spot." However, I'm not referring to the ubiquitous blotches caused by the erosion of slightly higher areas (swells). These are a well-known characteristic of the cultivated prairie soil and many of them can be seen on the photo I've included with this article and on nearly all photos of glaciated terrain in North Dakota. The light-colored, erosional blotches are several hundred feet across (up to a quarter inch across on the photo), with poorly defined edges. The "freckles," on the other hand, are white points only a few tens of feet across (1/100 to 1/50 of an inch across on the photo) and much more sharply defined. The "freckles" are certainly not the result of wind and water erosion of swells.

Until someone is able to field check the features on the ground, we really won't know what causes the freckles. I still like my toad hypothesis because I know toads sometimes suddenly show up in abundant numbers, under a tractor and plow (by the thousands) when the ground is plowed here in the Red River Valley. The plain of glacial Lake Cando in Towner County and the Lake Agassiz plain in this area should be analogous. It's also possible that the freckles may be apparent only on photos of cultivated land that was recently converted from native prairie or long-term pastureland. I haven't seen them on prairie land, probably because such features might not be visible on grassed over areas.

Does anyone have a better explanation for the "freckled land?"

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