NEWSLETTER
NDGS

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NORTH DAKOTA GEOLOGICAL SURVEY
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CONTENTS

COVER PHOTO

Collecting ice cores on East Stump Lake, Nelson County. East Stump Lake is included in several water-control proposals for the Devils Lake Basin. The NDGS has been cooperating with the North Dakota State Department of Health and Consolidated Laboratories on several studies in the area. The activity shown on the cover took place during sub-zero weather in March, 1989. Marv Rygh, who is shown coring on the photo, now works for the Oil and Gas Division in Bismarck. Dave Lechner (observing) is now with the Energy and Environmental Research Center in Grand Forks. Photo by Mark Luther.

CURRENT SURVEY ACTIVITIES

--John Bluemle

The 1989 Legislature transferred regulatory authority over permitting for collecting of paleontological resources on state lands from the State Historical Society to the Geological Survey. This new responsibility should enable us to more closely monitor institutions and individual collectors who are collecting fossils in North Dakota. We have been concerned for some time that some of our best specimens have been leaving the state, in many instances for display in museums in eastern universities and colleges.

This summer the Central Region Cluster Meeting of the USGS was held in North Dakota for the first time. Also a first: the Geological Survey of Canada was invited to attend and participate in this meeting, along with the Provincial Surveys of Alberta, Manitoba, and Saskatchewan. All of these agencies sent representatives to the meeting, which was held in Bismarck from September 11 to 13. The main purpose of the cluster meetings is to allow the USGS and various state geological surveys to get together to discuss cooperative projects and report on research underway by the various agencies. Approximately 75 people attended and we had many favorable comments about the meeting.

The North Dakota Geological Survey has been funded by the USGS to continue work on our COGEOMAP project. This 3- to 6-year project to date and map the Oligocene, Miocene, and Pliocene sediments of western North Dakota began in 1987. We have an article on the project elsewhere in this newsletter.

The Survey has been included in the Geoscience Institute for Enhanced Recovery. Sid Anderson was recently appointed by North Dakota Governor Sinner as the state's representative to the Institute.

Last year, the USGS flew Side Looking Radar over a 1° by 2°-size area of north-central North Dakota, along the Canadian border. We have a copy of the mosaic that was compiled by the USGS as a result of the flights, but we have not yet received and studied the flight-line strips, which will allow 3-D interpretation of the area.

The NDGS is involved in a number of environmentally oriented studies. We are cooperating with the State Health Department and EPA in an ongoing study of radon occurrence in the state. We are also working with the State Health Department on a study of water quality in Devils and Stump Lakes in eastern North Dakota (see article on Stump Lake).

We are continuing our study of the geochemistry of Cretaceous shales in North Dakota. Chemical analyses of 40 samples were completed by the USGS Branch of Geochemistry last year and another 40 samples have been submitted for analysis. This study is an outgrowth of the discovery of high arsenic levels in the groundwater in southeastern North Dakota. We hope to create a geochemical database of the materials and develop a geochemical model of the occurrence of arsenic and other trace metals. The project uses samples collected in the field as well as core samples we already have on hand. No target date for completion has been set.

Other projects currently underway include a study of the occurrence of gas in the Winnipeg/Deadwood Formations along the Nesson Anticline and a study of the potential of the Mississippian/Devonian Bakken Formation. The Bakken has attracted considerable interest lately because a number of successful horizontal holes have been drilled in it (see other articles in this newsletter).

The Survey recently completed the first phase of an analysis of the oil and gas potential on lands administered by the U. S. Forest Service (see separate article). The information we supplied the Forest Service will help them to complete an environmental impact statement that will help to determine whether they should lease their mineral acres for development.

SURVEY AND OIL AND GAS DIVISION LOCATED IN NEW QUARTERS

The North Dakota Geological Survey and the Oil and Gas Board moved to their new location in August. Our agencies are located at 1022 East Divide Avenue, northeast of the State Capitol grounds in Bismarck. The building we moved into, the Manhattan Building, was originally built for an insurance company, and we are sharing it with several other tenants. We are occupying parts of the lower two floors of the bright and airy building and all of the upper floor (actually a mezzanine.

The lower level of the building houses the Oil and Gas Division's well logs and files, along with working space for clients (consultants, etc.) along with our publications operations, mail room, laboratory and office space for three people. Most of the geologists and engineers for both the Oil and Gas Division and the Geological Survey are on the main floor (18 people in all). Another ten people have offices on the mezzanine. Our library and computer operations are also on the mezzanine.

Stop by and see us when you are in Bismarck!

NEW PUBLICATIONS

<u>Miscellaneous Series 73</u>--**"Mississippian Correlation Cross Section, Southwestern to North-Central North Dakota,"** was drawn by Julie A. LeFever and Sidney B. Anderson. This cross section incorporates 46 wells along the eastern margin of the Williston Basin from Stark County to Bottineau County. The cross section shows a portion of the Mississippian Madison Group, with its informal subdivisions within the Mission Canyon and Lower Charles Formations. A table is included showing the nomenclature used in the report and how it relates to the terminology used in the rest of the Williston Basin.

This report will be useful to geologists working in the Williston Basin. It is available for $5.00 from the North Dakota Geological Survey, 600 East Boulevard Avenue, Bismarck, ND 58505-0840.

<u>List of Publications</u>--We have a new List of Publications available. We will provide the list without charge to anyone who requests it.

CHANGES IN PERSONNEL

During the past six months, since the last NDGS Newsletter was published, two of our geologists and our draftsman quit.

Dr. Kenneth Harris accepted a position in September as Senior Scientist with the Minnesota Geological Survey. Ken had been with the North Dakota Geological Survey as a Quaternary geologist since 1977. Most recently he was in charge of our Atlas Series mapping program, which he designed. This program has been underway for the past four years. Ken's job with the Minnesota Survey includes directing their County Atlas Program and helping them to develop a sub-regional studies program.

David Fischer recently resigned his position with the Survey. He had been with us since 1983, working primarily on local and regional geologic studies of the Williston Basin and on the petroleum geology of certain oil fields. He was most recently in charge of a joint project we had with the U.S. Forest Service to evaluate the potential for oil and gas production on their land. David will be working as a private geologic consultant. He is currently living in Grand Forks.

Ken Dorsher worked as a draftsman for the Survey for eight years. He has taken a position with Concrete, Incorporated in Grand Forks.

Three new people have recently been hired by the Survey. **Tom Heck** will be working on subsurface problems, especially the geology of the oil and gas bearing formations in the Williston Basin. Tom earned a B.S. degree from the University of Wisconsin-Milwaukee and an M.S. from the University of North Dakota. He worked for Conoco from 1979 until 1987. During that time, he was stationed in Louisiana, where he worked on the geology along the Gulf of Mexico; in Denver, where he worked on the Williston and Powder River Basins; in Oklahoma City, where he worked on the Wichita Mountain Front; and in Houston, where he worked on the Texas Gulf Coast.

Since 1987, until he was hired by the NDGS, Tom worked as a consulting geologist, mudlogging for Tooke Engineering, Sunburst Consulting, and as a private consultant, generating drilling prospects.

Mark Luther is a native of Idaho, where he received a B.S. in geology, with an archeology minor, from Idaho State University in 1982. He received an M.A. in geology in 1988 from the University of North Dakota, where he studied depositional environments and digenesis of Mississippian carbonates and evaporites taken from the Wiley Field.

Mark worked for several seasons as a geoarcheologist for private consulting firms and state and federal agencies, most recently for the Bureau of Land Management in Salmon, Idaho. Immediately prior to coming to the NDGS, he worked for the North Dakota State Department of Health and Consolidated Laboratories, where his primary duties consisted of investigating groundwater contamination by nonpoint source pollution. Marks's main duties with the NDGS involve the Atlas Series mapping program.

Mark's wife, Katie, is also a geologist. She works in the groundwater section of the Health Department. Mark and Katie have two children: Megan, age 5, and Jed, age 4 months.

Rich Baker, our new draftsman, is a native of Minot. After high school, Rich attended the North Dakota School of Science in Wahpeton where he studied

Architectural Drafting. He worked for Webster, Foster & Weston Engineering in Minot before moving to Bismarck in 1982 to take a job with Toman Engineering. Rich was employed by the State Water Commission as Head Draftsman since 1985 until taking the job with the Oil & Gas Division/North Dakota Geological Survey. Rich is married, with two children. His wife Joann works for United States Postal Service.

SEASONAL EVAPORITE PRECIPITATION IN EAST STUMP LAKE --Mark Luther

Introduction

The NDGS has been working cooperatively with the North Dakota State Department of Health and Consolidated Laboratories (NDSDHCL) since the winter of 1987-88 on a data-gathering mission on East Stump Lake in Nelson County (fig. 1). Gathering of this data was initiated by the NDSDHCL in response to proposals that included diverting excess water from Devils Lake through East Stump Lake and into the Sheyenne River.

Determination of lake sediment depth, and collection of lake sediment and ice cores (figs. 2 and 3) have been accomplished by NDGS personnel. Sediment cores have then undergone elutriate testing, and ice cores have been split into four equal sections, melted, and the water analyzed for common ions. These analyses, and the collection of water samples, have been conducted by NDSDHCL personnel.

The History of East Stump Lake

East Stump Lake is located within the Devils Lake Basin (DLB) (fig. 1). In the past it was part of a much larger Devils Lake (Glacial Lake Minnewaukan), but even so, the East Stump Lake basin has a much different origin than the series of basins in which the nearby Devils Lakes occur. The series of depressions in which Devils Lake is located are the result of glacial thrusting of sediments near the margin of a glacier, which resulted in the creation of the depressions and associated adjacent hills to the south of Devils Lake. In contrast, the depression containing East Stump Lake is a remnant of a much larger and deeper northwest-southeast trending valley that was almost completely filled by glacial outwash sediments and till. This valley, the McVille Trench, was incised nearly 300 feet into the bedrock by north-flowing preglacial rivers and/or southeast-flowing glacial meltwater rivers diverted along the southwest edge of a glacier.

Sand and gravel outwash from receding glaciers later filled much of the McVille Trench. A still later glacial readvance and subsequent retreat filled the remainder of the trench with glacier sediment and removed most of the surface expression of the trench. The water-saturated sand and gravel deposits filling the lower portion of the trench form the present-day McVille Aquifer. The depressions in which the modern Stump Lakes are located probably coincide with places where large ice blocks remained in the trench after the main body of the glacier had melted away. These large blocks did not melt until after filling of the trench with glacier sediment was nearly complete. Thus, the Stump Lakes may be considered to be large kettle lakes.

Since its formation, East Stump Lake has undergone a series of lake level changes; these changes, and

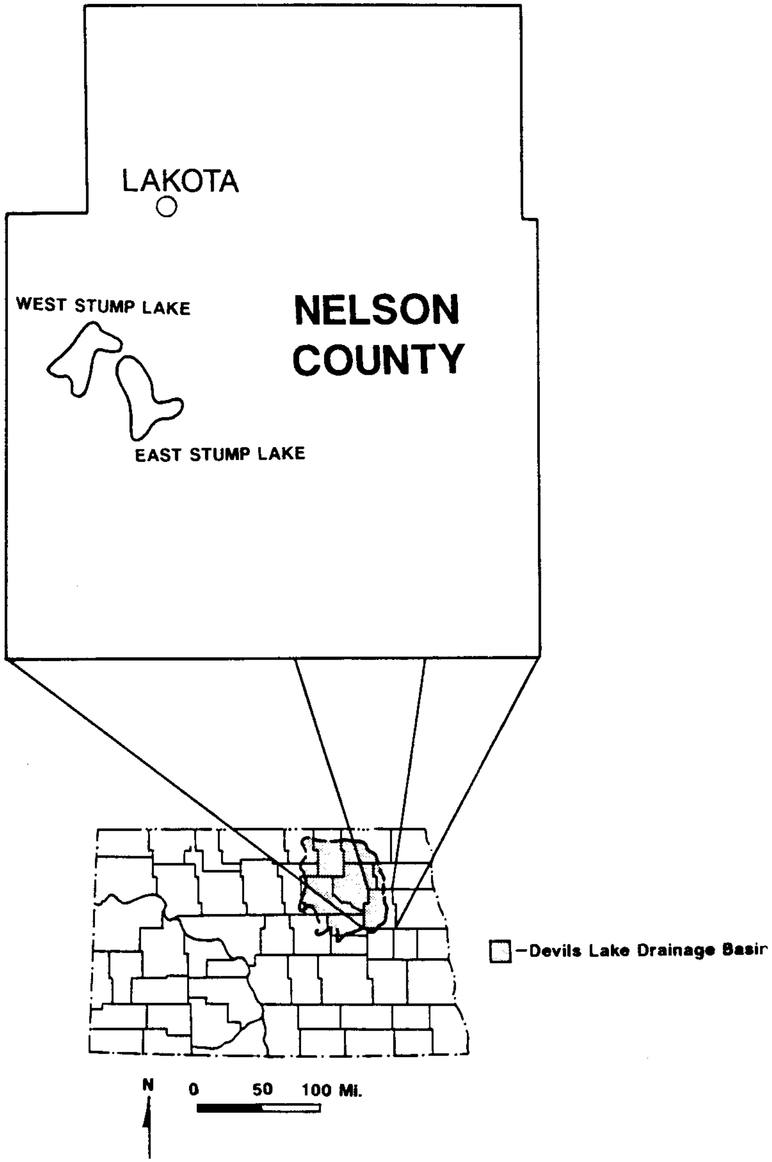


Figure 1. Map showing the locations of East and West Stump Lakes within Nelson County, and the position of Nelson County within the Devils Lake Basin.

Figure 2. Mike Ell (NDSDHCL) and Marv Rygh (previously NDGS) collecting lake sediment cores in March, 1989.

the lake's position relative to other lakes in the DLB, are responsible for the present-day chemistry of the water in the lake. East and West Stump Lakes are at the end of the Devils Lake chain-of-lakes. The outlet from the DLB consists of a channel extending from West Stump Lake into the Tolna Coulee, and from there into the Sheyenne River. NDGS personnel have recovered organic remains from alluvial sediments deposited in the outlet area and are presently awaiting C-14 dates. The dates, when received, may give an indication of how recently water has been discharged from the Devils Lake Basin.

Water cannot flow out of the Devils Lake Basin until lake levels are at or above 1453 feet elevation. At that elevation, Devils Lake and the two Stump Lakes would all be connected to form one large lake. At the time when water discharged through the outlet, water containing dissolved salts from the entire DLB would have flowed southeast toward the present Stump Lakes. Large differences in water chemistry between East and West Stump Lakes (discussed later) are likely due to the peculiarities of each lake depression relative to the outlet.

The West Stump Lake depression would have had water flowing into it at its northwest end and out through its outlet to the south. The East Stump Lake depression however, had no such flow through it. If the water level in Stump Lake was higher than about 1400 feet elevation, the east and west depressions would be connected, but below that elevation they would be separated by a low bar or sill, which stands approximately 20 feet above the floor of East Stump Lake. This sill is exposed today and separates the two modern lakes. Because of its isolation from the flowing system, dissolved salts entering the East Stump Lake depression may have become concentrated and, due to the salt brine's greater density, became trapped at the bottom of the East Stump Lake closed depression. In contrast, much of the dissolved salt load entering the West Stump Lake depression flushed through the system into the Sheyenne River or into the East Stump Lake depression. As lake levels fell, due to evaporation, and the Devils Lakes and Stump Lakes became individual water bodies again, water and dissolved salts filling the Stump Lake depressions became even more concentrated and dense.

The rising and falling of lake levels in the DLB has undoubtedly happened several times. Even in the relatively recent past large fluctuations in lake levels in the DLB have occurred (table 1). Salt concentrations may have increased during each successive cycle of lake-level rise and fall in the East Stump Lake depression, resulting in the high concentrations found there today. Flushing of dissolved salts from the West Stump Lake depression (perhaps into East Stump Lake--USGS, 1968) is the most probable scenario to account for modern, dissolved-salt concentrations that are less than half the value of those found in adjacent East Stump Lake.

<u>Seasonal Salt Precipitation</u>

Values for total dissolved solids (TDS), especially for sodium and sulfate ions, are extremely high in East Stump Lake (table 2). Comparison of selected ions from water samples taken a) during the winter, under the ice, b) during the summer, and c) from melted lake-surface ice, reveal some interesting trends. Ice formation on East Stump Lake should lead to the concentration of dissolved salts in the remaining liquid; this appears to be true for most ions analyzed. However two ions, sodium and sulfate, do not appear to increase in concentration in the water; rather, they remain the same or exist at slightly reduced values (table 2).

The chemical reactions responsible for this apparent reversal in concentration in water of sulfate and sodium ions by ice formation are now more fully understood. During the winter of 1987-88, NDGS personnel collecting ice and sediment cores from East Stump Lake detected a fairly consolidated "crust" at the bottom of the lake, but on top of the lake sediments. The "crust" was not recovered during operations that winter. During the winter of 1988-89 however, a team of NDGS and NDSDHCL personnel managed to recover some of the "crust". The "crust" turned out to be a solid layer of hydrated sodium sulfate salt that had precipitated from the cold, concentrating lake waters onto the sediment surface. X-Ray diffraction analyses of the "crust" revealed that it was composed of the mineral **mirabilite** (Na_2SO_4 * 10 H_2O), which quickly dehydrates when exposed to heat to the mineral **thenardite** (Na_2SO_4) (Fig. 4).

An intact piece of the"crust" was not recovered from the lake bottom, but probing with a thin, metal rod enabled team personnel to estimate "crust" thickness at 2-4 cm. The crust is composed of prismatic, mirabilite crystals (many euhedral) measuring 1-2 cm by 0.5-0.75 cm. The crystals are colorless and transparent, although some contain small zones of impurity that may consist of clays or organics. Analysis by the NDSDHCL indicates that the crystals are slightly greater than 58% water. When the mirabilite crystals dehydrate, the crystal structure collapses, and a fine-crystalline, white, nearly opaque powder (thenardite) is formed.

Mirabilite had been noted in East Stump Lake by previous researchers studying the lake under open water conditions in the fall and late spring. These studies were conducted during the 1950's and 60's, when lake elevations were lower than at the present, and dissolved salt concentrations were much higher. At that time, mirabilite precipitated with the cooling of the lake water, and although in a different form (thenardite?), much of it persisted through the summer.

During the present study, sodium sulfate crystals have not been detected on the lake bottom during the summer. Only under ice conditions, and immediately after ice-out, have crystals (mirabilite) been recovered. During the formation of lake ice, relatively fresh water is removed from the lake water and dissolved salts are concentrated in the remaining liquid. As mentioned above, this trend is true except for sodium and sulfate ions (table 2). This reversal in trends is due to the preferential precipitation and removal from the water of sodium sulfate crystals (mirabilite). Both a decrease in water temperature and freeze-drying (ice formation) is probably required to initiate mirabilite precipitation under current dissolved salt concentrations.

Future Studies

Additional studies of East Stump Lake will likely be initiated over the next few years to answer questions concerning both water quality and economic benefits/impacts of the sodium sulfate contained in the lake. Several options for controlling water levels in the Devils Lake Basin depend upon acquiring a thorough knowledge of seasonal variations in the water chemistry of East Stump Lake, and using that knowledge to modify and/or improve the quality of its water. Economic opportunities may also exist for the state in the form of a salable mineral resource. There may be as much as 200,000 tons of sodium sulfate contained in the seasonal "crust"

Figure 3. Marv Rygh (left) and Mike Ell (right) removing ice from coring device and bagging cores.

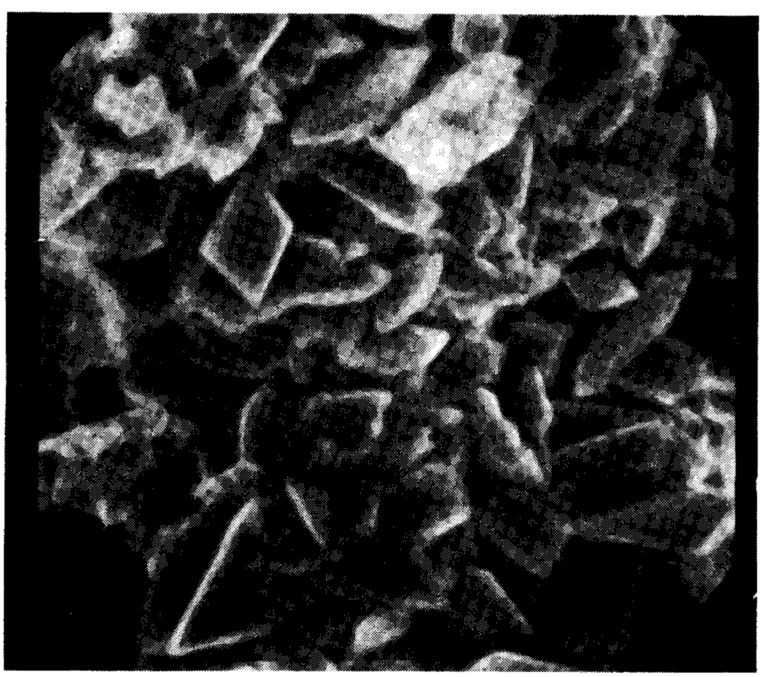


Figure 4. An SEM image (SEI) of thenardite (Na2SO4) crystals magnified approximately 2200X.

from a single year. Sodium sulfate mined in Canada sells for approximately $100 per ton. Thus, if an economical method can be devised to mine the crust from the bottom of the lake, the state could benefit doubly with improved water quality and an additional mineral resource. The NDGS and NDSDHCL will likely continue to work together at East Stump Lake, gathering data and pursuing plans that will benefit the Devils Lake Basin and the State.

Table 1. **Stump Lake (corrected elevations): Inferred lake-level history**

1300 A.D.	Stump Lake below 1400 feet mean-sea-level (msl)
1535 A.D.	Increased moisture; lake began to rise.
1541 A.D.	Stump Lake rose above 1405 feet msl
1830 A.D.	Lake level about 1443 feet msl
1887 A.D.	Lake level 1417 feet msl
1910 A.D.	Lake level 1410 feet msl
1951 A.D.	Lake level 1388 feet msl
1979 A.D.	Lake level 1393 feet msl
present	Lake level about 1390 feet msl

Table 2. **Selected chemical concentrations from East Stump Lake, Station #4, 1989.**

Analyte	Ice (top)	Ice (bottom)	Under Ice	Summer
Sulfate (mg/l)	21,100	13,800	40,300	40,400
Sodium " "	9,580	5,350	15,400	18,200
Chloride " "	1,340	2,620	9,060	6,290
Magnesium " "	769	1,470	5,190	3,590
Potassium " "	160	302	1,050	400

HORIZONTAL DRILLING IN THE BAKKEN FORMATION IN NORTH DAKOTA

--John Bluemle

We've had articles in two past NDGS Newsletters (December, 1987; December, 1988) dealing with horizontal drilling in North Dakota. More and more wells are being drilled in the Bakken Formation using this technology as more companies are adapting the new procedures in the state. This article is a general appraisal of recent developments, the current state of the horizontal drilling play, and maybe some observations about what may happen next. I am writing this mainly for the benefit of our interested non-geologist readers, not for geologists, engineers, and oilmen who are actually involved in exploration, drilling and production. Several readers have called or written, asking how it is possible to drill a horizontal hole. I'll include some general information on the subject for these people, but I don't intend to say much about the engineering problems involved in horizontal drilling; the next article in this newsletter by Julie LeFever goes into somewhat more detail about some of these procedures and problems.

Up to now, the Bakken horizontal drilling play has focused on a relatively small area in western North Dakota, the so-called "Bakken Fairway," which covers parts of Billings, Golden Valley, and McKenzie Counties (fig. 1). This area includes such oil fields as the Elkhorn Ranch, Bicentennial, and Buckhorn. Most of the wells have been drilled by a relatively few companies. Meridian Oil has had the most experience drilling horizontal holes in North Dakota. It has drilled over half of the wells, but other companies are now also involved; BWAB, American Hunter, Leede, Conoco, Oryx, Maxus, Pacific Enterprises, and others.

The Mississippian-Devonian age Bakken Formation consists of three members: an upper and lower, calcareous organic-rich black shale, a middle member composed of limestone, dolomite, sandstone or siltstone (fig. 2). The formation has generally been considered to be a "source rock," one in which oil formed and was later squeezed out into more porous "reservoir rocks." Many geologists consider it to be the principal source of oil for the Williston Basin. In North Dakota, the upper and lower shale units reach maximum thicknesses of 23 and 50 feet respectively, but they thin out at the depositional limit of the upper shale member along the southwest flank of the Williston Basin. In the so-called fairway area that I mentioned earlier, the productive unit, the upper black shale, is less than 10 feet thick. That ten-foot-thick layer is the one in which the horizontal holes are being drilled.

It has been calculated, by a variety of experts, that the Bakken Formation has generated a huge amount of oil--figures like ten billion barrels are sometimes mentioned (to give some perspective, in November, 1989, North Dakota noted the production of its billionth barrel of oil--the total amount produced since oil was discovered in the state in 1951). Using conventional (entirely vertical) drilling methods, very little of the Bakken oil reserve could ever be recovered because of the low permeability of the formation. However, it's been suggested that as much as half of the ten billion barrel resource might ultimately be recoverable as a result of horizontal drilling, but at this point I don't think anyone knows if this is correct or possible.

As I just mentioned, the Bakken Formation is generally impermeable, meaning the rock is

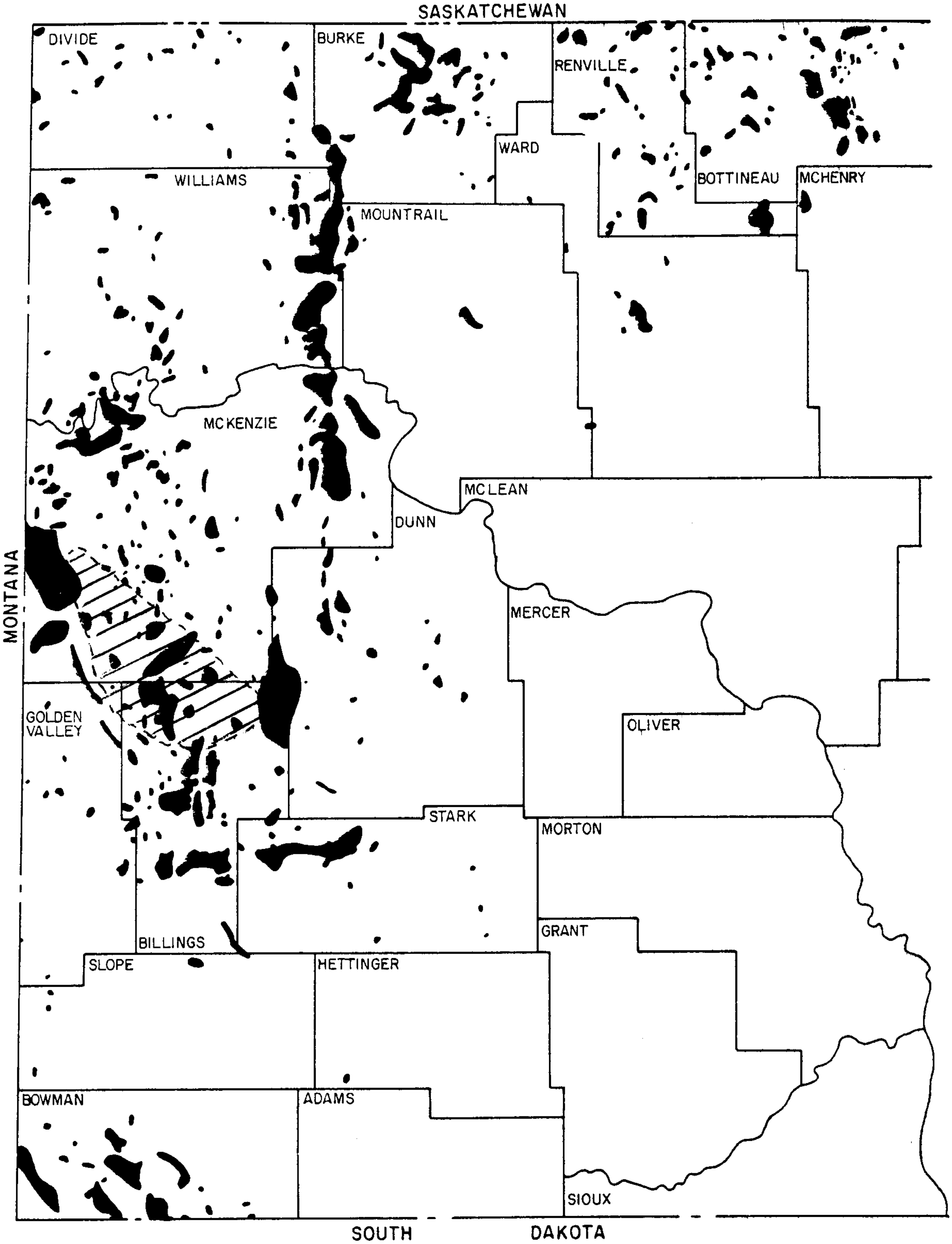


Figure 1. The lined areas on this map approximates the area where horizontal wells have been drilled in the Bakken Formation. The black areas on the map represent producing oil fields (production from all geologic horizons, not just the Bakken.

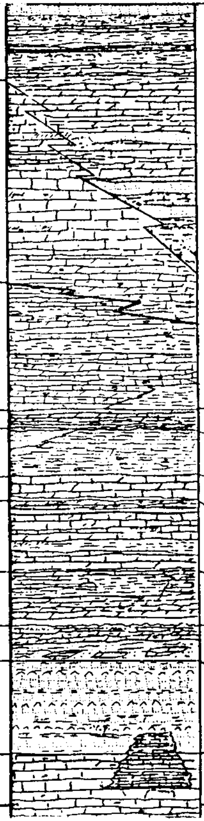
System	Formation	Member		Lithology	Thickness ft (m)	Description
MISSISSIPPIAN	CHARLES		oil		2 000 (600)	The Charles, Mission Canyon, and Lodgepole Formations are facies that cut across log markers. Several marker-defined stratigraphic intervals, recognized on geophysical logs, are commonly informally used to define Madison Group stratigraphy. The term "Madison Undifferentiated" is used in the central Williston Basin where geophysical log markers, used for correlation purposes elsewhere, are absent. Poplar interval: evaporites; interbedded anhydrite, halite, dolomite, mudstone, and shale; iron staining common; the Poplar interval contains most of the halite of the Madison Group; maximum thickness: 600 ft (185 m). Ratcliffe interval: limestone, pale-yellow-brown, dolomitic, oolitic; alternating with dolomitic limestone, anhydritic, and shale beds; Midale marker at the base is dolomitic limestone; Ratcliffe interval includes the deepest Madison salt on the Nesson Anticline ("last salt"); maximum thickness: 250 ft (75 m). Frobisher-Alida interval: limestone, yellow-brown to pink, fine, fragmental, oolitic, and pseudo-oolitic; intertonguing lenses of anhydrite and shaly dolomitic limestone; increasingly evaporitic eastward; Rival marker at the top of the interval is anhydrite and dolomitic limestone; includes the "X salt," the lowermost Mississippian salt; maximum thickness: 585 ft (180 m). Tilston interval: limestone, pale-yellowish-brown to pink, dolomitic, fine-grained to coarsely crystalline, oolitic and crinoidal, cherty; anhydrite; minor gray shale; maximum thickness: 230 ft (70 m). Flossie Lake, Whitewater Lake, Virden, and Scallion intervals (collectively approximately equivalent to the Bottineau interval): limestone, dark-gray to brown to pale-orange or pinkish, argillaceous to cherty to dolomitic, fragmental, finely crystalline to granular, oolitic, dense, vuggy to fine intergranular; maximum thickness: 630 ft (190 m). Carrington shale facies: shale, dark-gray to red with green mottling, noncalcareous, clayey. Present on the eastern flank of the basin only; maximum thickness: 90 ft (30 m).
	MISSION CANYON		oil			
	LODGEPOLE		oil			
	BAKKEN		oil		110 (35)	Shale, black, noncalcareous, carbonaceous, fissile, pyritic; gray, argillaceous dolomite in middle part; pebble conglomerate at base near basin margin.
DEVONIAN	THREE FORKS		oil		240 (75)	Siltstone and shale, grayish shades of red, green, and orange, interbedded and interlaminated, dolomitic, anhydritic; sandstone ("Sanish sand") locally at top, silty to fine-grained.
	BIRDBEAR		oil		125 (40)	Limestone and some dolomite, light-gray to medium-brownish-gray, thick-bedded, finely crystalline, porous, fossiliferous; anhydrite, brownish- to medium-gray. Called Nisku Formation by some.
	DUPEROW		oil		460 (140)	Limestone, light-brownish-gray, crystalline to granular, dense; dolomite, grayish-brown, microcrystalline to sucrosic, anhydritic, porous, and permeable; interbedded shale, siltstone, sand, and cyclical evaporites.
	SOURIS RIVER		oil		350 (105)	Dolomite and limestone, light- to dark-gray and brownish-gray, crystalline to dense, anhydritic, clayey or silty in part, interbeds of silt, shale, and evaporites. "First Red" at base.
	DAWSON BAY		oil		185 (55)	Limestone, gray to brown, dense, fossiliferous, clayey, silty, and sandy near the eastern limit; dolomite, brown, microcrystalline to microgranular, anhydritic, porous. "Second Red" at base.
	PRAIRIE	MOUNTRAIL BELLE PLAINE ESTERHAZY			650 (200)	Evaporites: potassium and sodium salts interbedded with thin anhydrite beds; locally absent due to salt solution; multiple sequence salt solution has resulted in development of complex structural features over stratigraphically limited intervals. Three potash beds recognized are the Mountrail Member, Belle Plain Member, and Esterhazy Member.
	WINNIPEGOSIS		oil		220 (65)	Limestone and dolomite, shades of gray, shaly, anhydritic, crystalline, dense; has marked thickness variations due to the development of reef and inter-reef facies.

Figure 2. A portion of the North Dakota Stratigraphic Column, showing parts of the Mississippian and Devonian geologic section and the stratigraphic position of the Bakken Formation. The thicknesses noted are in feet and metres; thus the maximum thickness of the Bakken in North Dakota is 110 feet.

tight and the oil doesn't move easily or uniformly through the it. Instead, it tends to travel along fractures in the formation. These fractures are oriented in certain directions, and one way to get the oil out--the best way found so far--is to drill a hole in such a way that it intersects the maximum number of the fractures. So, if the fractures are vertical, and if they trend (for example) from northwest to southeast, the best way to intersect them might be to drill a hole horizontally from northeast to southwest. So, basically, the main advantage of drilling a horizontal hole is that the well bore penetrates a much longer portion of the oil-productive rock and it intersects many more fractures along which oil can move to the well bore. Some Bakken wells that tested so low in their vertical section that they would have been plugged, have been shown to have reserves of nearly 400,000 barrels of oil after a horizontal leg was drilled. Horizontal wells also have the potential to increase oil reserves in enhanced recovery projects (CO_2) by increasing the portion of the reservoir swept by displacing fluids.

Successful horizontal well completions can be expected to have higher initial production rates and to recover much higher total percentages of the in-place oil. Some experts think as much as 50 or 60 percent of the oil can be recovered in a horizontal well bore, as opposed to less than 25 percent in conventional vertical wells. Horizontal wells have a much better chance of being completed successfully, since they are drilled through more of the potential producing section, two or three thousand feet, as opposed to about ten or twenty feet in a vertical well. The higher initial flow rates may also help to shorten the time it takes to pay off the costs of drilling the well.

There has been some controversy about how horizontal wells should be spaced--how close together the wells should be drilled. So far, some wells in North Dakota have been drilled on 160-acre spacing units (one well drilled on a quarter section of land), some on 320-acre spacing (half sections), and some on 640-acre spacing (full sections). Although other considerations enter in, generally, the proponents of larger spacing units argue that a horizontal well is able to efficiently drain a larger area than could a vertical well and therefore larger spacing units should be assigned.

Since horizontal wells drain larger areas, recovering more oil than two or more vertical wells in the same area would, ultimate production costs may be lower, even though the cost of drilling and completing a horizontal well may be considerably more than the cost of drilling a vertical well. However, the costs of horizontal drilling are coming down as companies learn more about the drilling techniques. Meridian Oil's first horizontal Bakken well, the MOI 33-11 in Elkhorn Ranch Field, took 116 days to complete and cost about two million dollars, for a cost of $158 per foot. The current average for Meridian is about 45 days for $1.25 million, or $95 per foot. Total costs for some recent horizontal wells have been less than a million dollars.

Articles in past NDGS Newsletters have included discussions about some of the procedures followed in drilling horizontal holes. Generally, the well bore can be deviated from vertical to a completely horizontal position within a radius of only 400 feet (figs. 3 and 4).

According to an article in the November, 1989 issue of the AAPG Explorer, the longest horizontal hole so far drilled in North Dakota--that part of the hole drilled after the

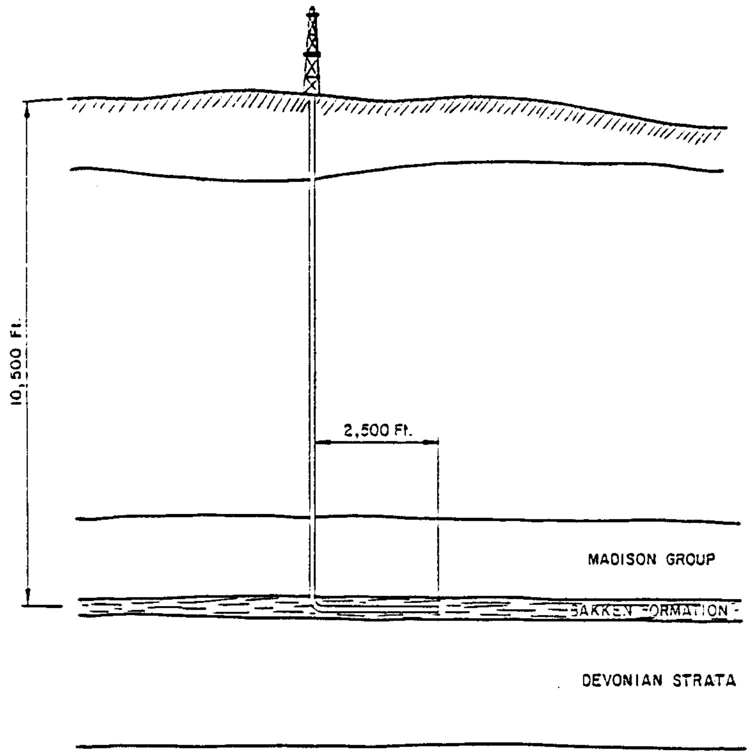


Figure 3. Schematic diagram showing horizontal well bore penetrating the Bakken Formation. The vertical and horizontal distances are approximately to scale, although the thickness of the Bakken is greatly exaggerated.

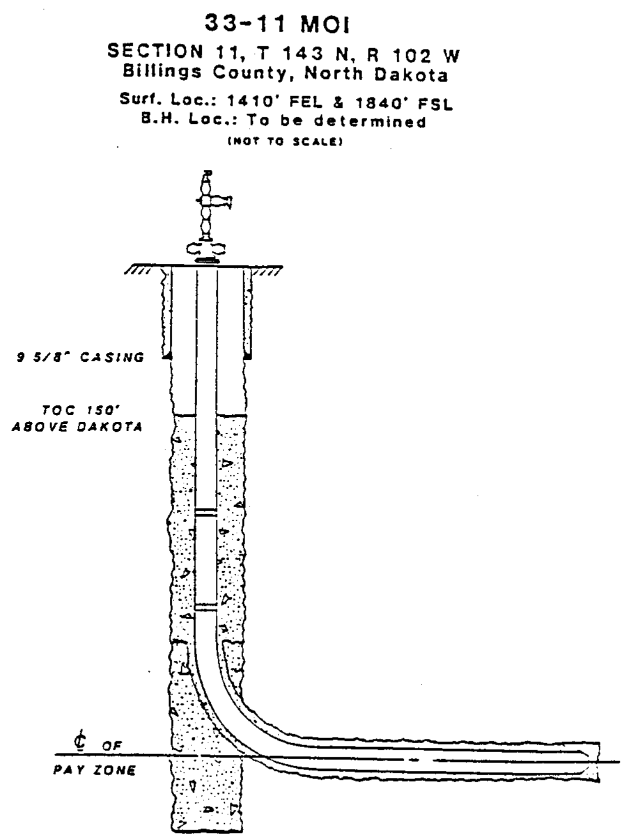


Figure 4. Schematic diagram of a completed horizontal well bore from N. D. Industrial Commission hearing #4296. These two diagrams were included in an article by Marv Rygh in the December, 1987 NDGS Newsletter.

deviation from the vertical--is 3,516 feet for Meridian's No. 14-33H Well in Roosevelt Field. The horizontal wellbore for that and other wells is 8.5 inches (in other states, 4.5 inches has been more common in horizontal holes that were not drilled nearly so deep).

Operators of most horizontally drilled Bakken wells request confidential status on each well. The period of confidentiality that the state allows is six months. At the present time, 25 horizontally drilled Bakken wells are off confidential status. Since all of the horizontal wells have been drilled within the last two years, it's not yet possible to be certain just how the wells will perform over even more extended periods of time. Even so, Meridian's No. 33-11 Well, which is now about two years old, has shown little decline in production since it was drilled. In fact, it has actually increased output from its initial flowing rate of 258 barrels a day of oil, with 299,000 cubic feet of gas per day and no water. The well now flows at 289 barrels of oil a day and, through September, 1989, the well had amassed cumulative production of 192,067 barrels.

Some oil industry people think that, nationwide, in a few years many oil wells will be drilled horizontally. Certainly, the technology has the potential to recover great amounts of resources, perhaps as much as has already been recovered in the United States to date. Although the horizontal technology has been successful, especially for Meridian Oil, a lot remains to be learned before its full potential can be realized. Completion techniques are still not well refined and the technique of using horizontal drilling procedures in different types of rock are still being developed.

HORIZONTAL DRILLING TECHNOLOGY

--Julie LeFever

The previous article dealt with some general considerations about horizontal drilling in the Bakken Formation in North Dakota. This article goes into somewhat more detail about some of the engineering considerations and explains some of the specific problems involved with drilling horizontal wells.

As noted in the previous article, the Bakken Formation oil reservoir is highly fractured. Two sets of fractures are involved (fig. 1). One is a widely spaced set of fractures related to basin tectonics. This first set of fractures is overprinted by a second set of microfractures, which have resulted from generation (formation) of oil. The fracture system in the part of western North Dakota where horizontal drilling is currently underway is probably more pronounced due to an increased brittleness related to the thickness of the formation. Production from vertically drilled Bakken wells is poor without the presence of the fractures.

Advances in drilling technology have made the Bakken Formation a prime target for horizontally drilled wells. Meridian Oil Inc., in testimony before the North Dakota Industrial Commission, listed four reasons for developing a horizontal drilling program: 1) increase in the probability of success, 2) increase in the profit potential, 3) increase the effective drainage area and maximize recoverable reserves, and 4) increase productivity by encountering more naturally occurring fractures.

Horizontal drilling technology has developed significantly since the first horizontal wells were drilled in the late 1970's in Canada. The targets for early horizontal wells were larger than today's and they were not as well defined. Generally, horizontal wells were considered to be expensive and subject to cost overruns. They rarely provided estimated rates of production, and they were difficult to workover. New technology has made the future of horizontal drilling brighter, providing higher production rates and a higher ultimate recovery.

At the present time, horizontal wells can be categorized into three types, or classes (fig. 2). These classes are based on the **build rate** (the building angle from vertical to horizontal) or resulting radius of curvature. Wells of the first class are drilled using conventional drilling technology. These are the long-radius wells that have build rates of less than 10°/100 ft. Medium-radius wells comprise the second class. These have build rates ranging from 8° to 50°/100 ft., turning the wellbore from vertical to horizontal within 200 to 1100 ft. The build portion of the hole is drilled with specially modified motor assemblies containing two bends and two or three stabilizers. The assembly cannot be rotated. The horizontal section is then drilled using rotary assemblies or steerable motor assemblies (Gust, 1989). Horizontal sections more than 1500 ft. long can be drilled. Medium-radius wells are ideal for horizontal wells that are required to hit a small target, drill a long lateral section (1000 ft. or greater), have precise control over azimuth (1° to 4°/100 ft.), and higher penetration rates.

The third class of horizontal well is the short-radius horizontal well. This system uses specialized rotary assemblies and a flexible drill pipe. Deviation of a wellbore from vertical to horizontal can be done at rates of 1.5° to 3°/ft., and a vertical well can be turned to a horizontal well in 30 to 60 drilled feet. The average length of the resulting horizontal section is 200 to 400 feet beyond the vertical wellbore.

The short-radius drilling system is used primarily as a recompletion technique for re-entering existing wells to improve production, to solve unwanted formation fluid problems, or where conditions require that the wellbore be within the target formation. Eastman Christensen states that this system can accurately maintain an inclination set "at any angle from vertical to 30° above the horizontal plane, with an accuracy of ±2°. Hole direction can be controlled to within ±20°." This system can be used in either open hole or cased intervals in vertical or directionally drilled wells.

Completion techniques for horizontal wells are developing along with the drilling technology. Depending on the situation, the hole can be left open or cased. Vertical completion techniques used for the Bakken Formation included a fracture-stimulation program. Horizontal completions in the Bakken are different. The horizontal portion of the wellbore is lined with a pre-perforated casing to limit formation damage. Once in place, the plugs are drilled out and the well is placed on production.

The cost of a horizontal well is nearly twice as much as a vertical well (see previous article), but this cost may be offset by doubling the reserves and increasing the initial production of the well by as much as five times. Economics of the horizontal play within the Bakken appear to confirm these ideas. The economics should continue to improve as drilling technology and completion practices improve and rig time shortens (and thus, operating costs decrease).

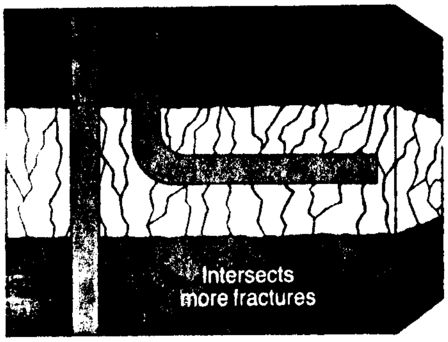


Figure 1. In vertically fractured reservoirs, productive zones lie in vertical planes and typically are separated by 20 to 200 feet of nonproductive formation. A vertical well may hit a single productive zone, or it may miss the production entirely. A horizontal well, drilled perpendicular to the productive bedding planes, could intersect a number of producing fractures and yield significantly more oil than a vertical well.

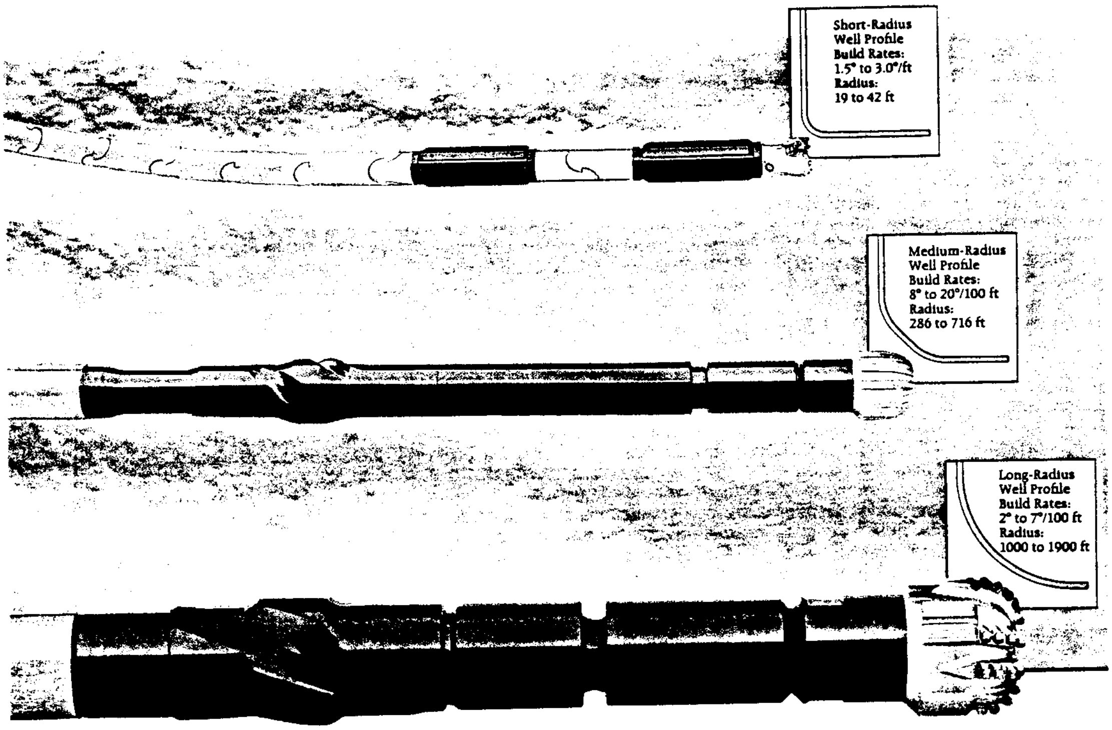


Figure 2. Three diagrams showing short, medium, and long-radius build rates (see text).

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[Editor's note: this article appeared as an editorial in the July-August issue of **Environmental Geology and Water Science.** It was written by Wilson M. Laird, who was State Geologist of North Dakota from 1941 until 1969. Dr. Laird is now retired and lives in Kerrville, Texas. I think Dr. Laird's ideas about environmental matters are pertinent and relate directly to problems we have in North Dakota. I've followed his article with some additional thoughts on the topic--John Bluemle.]

"Wise use" is more than a catchword with me when thinking about environmental matters. To me it means that the Earth should be used by man in the best and most efficient manner possible to maintain his existence on this planet. It also means that there should be no more disturbance to both animate and inanimate objects than is absolutely necessary.

To many who claim to be "environmentalists," "wise use" means that there be no use of the land anywhere whatsoever regardless of the geology, and regardless of the nature of the biotic community. Certainly, I agree that, in some places, "no use" really is the best use and, along with other environmentally conscious geologists, I would regard "no use" to be the best course of action in certain cases. However, realistically, in a majority of situations we must opt for multiple use of the land and its resources.

The stark fact is that we are facing, on a world-wide basis, an explosion of population that is making the protection and care of environmentally sensitive places more and more difficult, even impossible in the long run, unless the population is controlled. What is said here about land also applies to the air and waters of this planet.

What must we do to slow or halt the degradation of our planet?

First, we must attempt to control the increase of the present human population insofar as we can. This obviously is difficult, but not impossible, as some of the Asian countries, notably China, are trying to do it today.

Secondly, we must utilize our natural resources such as oil, minerals, and water in the most efficient manner we can. We must obtain these where the geology is favorable, whether it be on the Arctic National Wildlife Refuge or some other equally environmentally sensitive place. While we might like to drill or mine somewhere else, we are forced by the nature of the geology to conduct these activities where the geological conditions are most favorable.

Thirdly, we must use our resources sparingly and conserve them at every opportunity. This means a slowing of the high standard of living in all the developed countries, doing without high-powered cars and fancy wrappings on our food and other items, ending our practice of using water as if there was no end to it. It means recycling and properly disposing of our waste. Many other things we have come to believe are necessities will be shown not to be such. All of these are major problems that are expensive to cure and which we have so far refused to face because they are so tied to our way of living that we can't bring ourselves to face them realistically. Some progress has been made, but it is pitifully slow and most inadequate.

Unless we solve these problems, we will, most certainly face a much reduced standard of living, coupled with severe governmental restrictions of our lives.

Finally, we can do all of the things mentioned above if we have the will to do them and cooperate with others--if we quit being so selfish about where we develop our resources and dispose of our waste.

Let's get out of this "Not in my backyard" syndrome. The American public and the most developed countries in Europe cannot go on indefinitely using the resources of other less-developed countries without due regard to the effect that such use has on the people of those areas. Nor can one state in the United States continue to dump its refuse in another state while at the same time refusing to do anything about the creation of its own refuse.

Conservation and proper use of this planet is a gigantic job and we must get on with it NOW.

****

I agree with what Dr. Laird has said in his thoughtful editorial. I'd like to make some additional comments, mainly from my own point of view of a geologist. First concerns the difference between "environmentalist" and "preservationist." This difference is one of philosophy and training, as well as emotion. My definition of an environmentalist is one who is concerned about the environment and wants to protect it. As a group, environmentalists include people from all walks of life. I consider myself to be an environmentalist.

The preservationist, on the other hand, wants to keep things as they are; no exceptions. This preservationist goal may be a noble ideal that may be possible to achieve in some of our parks and wilderness areas, but it is impossible to fulfill this ideal in many places as long as we have one species, <u>man</u>, who is set on changing things to suit himself.

As editor of this newsletter and also, recently, as President of the North Dakota Natural Science Society (I just completed my second term as president), I get large amounts of mail from many "environmental" groups, at least a dozen of them, asking for my support for worthy causes (and--usually--for my contribution). Many of these groups are strictly preservationist in their emotional appeal. A letter I got a few days ago, for example, refers to "giant polluters" (oil companies), "privateers" (timber barons), and "well-heeled, well-organized smokestack industries that cause acid rain" (automobile manufacturers, coal-fired generating plants, etc.). This particular organization does a lot of good things, but I'd strongly disagree that oil companies are, by definition, polluters or that timbering or coal mining are, by definition, "bad" things. It's not nearly that simple.

It seems to me that the true "environmentalist," recognizes that it is not possible to avoid violating certain aspects of the environment. This is inevitable. In fact, if we expect to maintain our present standard of living, we have to remember, "If it can't be grown, it has to be mined" (a quote from friend with the Missouri Geological Survey). The environmentalist philosophy is an attempt to ameliorate man's impacts so that a minimum of damage is done to the environment. This is where geologic advice is desperately needed--in such matters as water pollution (especially underground water), waste disposal, geologic hazards, siting of structures, etc. Geologists can provide much of the necessary physical information to help insure that rational decisions are made when development is being considered. Not always, but too often it seems, decisions about important planning efforts, construction projects, etc.--all of which may impact the environment--are implemented without the benefit of sound geological advice.

It seems to me that geologists, as a group, care very much about their surroundings, and in that sense most of them are, almost by definition, true environmentalists. Geologists, by their training, understand the constraints nature places on repairing the environment, once it is damaged. They realize how slowly Earth's life-support systems regenerate themselves. Exploitation, for its own sake, is inexcusable, but so is the pressure from the preservationist lobby that won't allow for any development at all. We need to preserve and protect our environment while we use our natural resources for the benefit of mankind.

We could argue that, because we are trained to analyze the architecture of scenery (my own specialty, for example, is geomorphology), we have a great deal to offer in the continuing struggle of trying to balance man's requirements for mineral resources with his need for a healthy, well-balanced, aesthetically pleasing environment.

All of us need to work toward this goal.

EARTHQUAKES IN NORTH DAKOTA

--John Bluemle

Since the earthquake in San Francisco last October 17, several people have written or called asking about the possibility of an earthquake in North Dakota. Although it is not impossible, it is highly unlikely that North Dakota will ever have a serious earthquake.

The United States has been classified into several zones according to earthquake risk. The "seismic risk" map (fig. 1) subdivides the country into four zones. North Dakota is located in Zone I, which means that, if an earthquake did occur, it would be expected to cause only minor damage. It is interesting to note though, that although North Dakota is placed in the minor damage zone, parts of the United States, including much of Texas, Florida, Oregon and Maine are in Zone O, where the risk is even less than it is in North Dakota.

The strength of an earthquake can be measured in any of several ways. Though the surface damage and other effects depend to some extent on the local geology, various "scales of intensity" have been devised that are based on subjective criteria such as noticeable movement and amount of damage. Most of the scales now in use are modified from a scale proposed in 1914 by an Italian priest/geologist named Guiseppi Mercalli (fig. 2). The Mercalli scale extends from I to XII and is purely descriptive and based largely on observation. Each number on the scale describes the effects of the earthquake <u>at the place where the observer is located</u>. These effects are expressed as a **Modified Mercalli Number (MM)**.

The Modified Mercalli Number depends on the reports of observers and not on instruments. If most chimneys come down, and some buildings are damaged, the earthquake would be rated about MM8; if everyone sleeping was awakened, but no damage observed, it would be MM5. A single earthquake has different effects in different places, depending on distance from the actual location

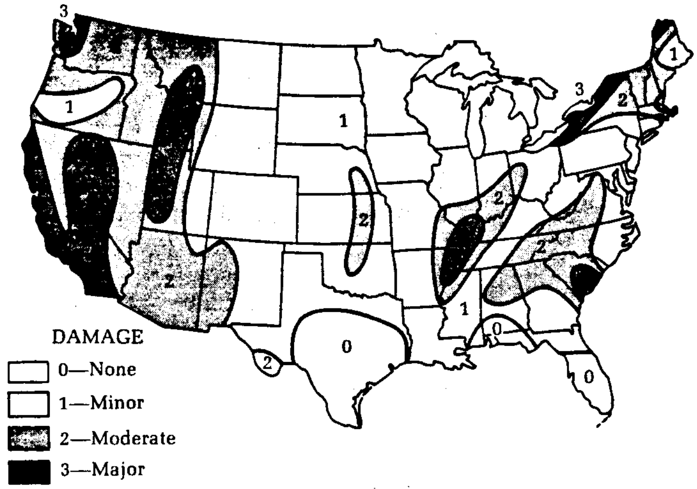

Figure 1. Seismic risk map for the United States (except Alaska and Hawaii). The map divides the U.S. into four earthquake zones: Zone 0, areas with no reasonable expectancy of earthquake damage; Zone 1, expected minor damage; Zone 2, expected moderate damage; and Zone 3, where major destructive earthquakes may occur. Map is adapted from Environmental Science Services Administration, 1969.

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets and architectural ornaments. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames cracked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Figure 2. Modified Mercalli intensity scale (1956).

where the earthquake occurred, so that the Mercalli Number will be less with increasing distance from the center of the earthquake. For this reason, if only one figure must be chosen to describe an earthquake, the **Richter Scale** (described later) is more appropriate.

When an earthquake occurs, energy is released from a limited volume of rock and travels outwards in the form of waves, like ripples on a pond. These waves are of two kinds, the faster **P-waves** (with a push-and-pull motion) travelling at about five miles/second, and the slower **S-waves** (shear waves) at about three miles/second. These waves register on seismographs, instruments which continually record the motion of the ground. The records produced by the seismographs must then be analyzed by seismologists to determine where the earthquake occurred, its **epicenter**. The actual point of origin of the shock is known as the focus, and the epicenter is the point on the Earth's surface directly above the focus. The depth of the focus is also determined. In some parts of the world, foci may be as much as 400 miles deep, but most are less than 25 miles deep.

Energy from earthquakes can travel all the way around the world, through its deep interior and along the surface. A large earthquake on the opposite side of the world will be recorded here about 20 minutes later. By studying this arriving energy, seismologists can deduce many properties of the Earth which there is no other way of determining. The size and physical properties of the Earth's core, for example, have been determined by this means.

The size of an earthquake is called its magnitude, and magnitude figures are a measure of the total amount of energy released. Magnitudes are usually expressed on a scale proposed by Professor C. F. Richter in 1935. The smallest felt earthquakes have a magnitude of about 3 or sometimes less. Minor damage is caused by shocks of magnitude 5, those of 8 and above are disastrous. The largest known shock (Colombia, 1906) had a magnitude of 8.6. The scale is logarithmic, which means that the amount of energy released by an earthquake increases about 30 times for each step of the scale. That is, a magnitude 6 earthquake is 30 times a large as one of magnitude 5, and so on. The nuclear explosion detonated at Hiroshima in 1945 was equivalent to an earthquake with a magnitude of about 5.3. The San Francisco earthquake of 1906 had a Richter number of 8.3; the 1989 San Francisco earthquake was 7.0.

As you can see from the seismic risk map of the United States (fig. 1), strong earthquakes are not limited to California, or the Rocky Mountain region. Probably the most severe earthquake on the North American continent during the past two centuries was centered in Missouri. In 1811-1812, several earthquakes occurred in the New Madrid area in southeastern Missouri. The most severe of these earthquakes was felt over a 1,000,000-square-mile area, which would have included North Dakota. Over 1,800 earthquakes were felt over a two-year period, and many more would have been recorded if seismographs had been available at the time. These earthquakes caused a remarkable amount of damage in a part of the country that was only sparsely populated at the time.

North Dakota's location in the middle of the continent has spared it from much earthquake activity. However, the boundaries between three deeply buried basement rock units or "cratons," of Precambrian age cross the area in various directions (see fig. 3). The cratons are large segments of the earth's crust. The three crustal units that

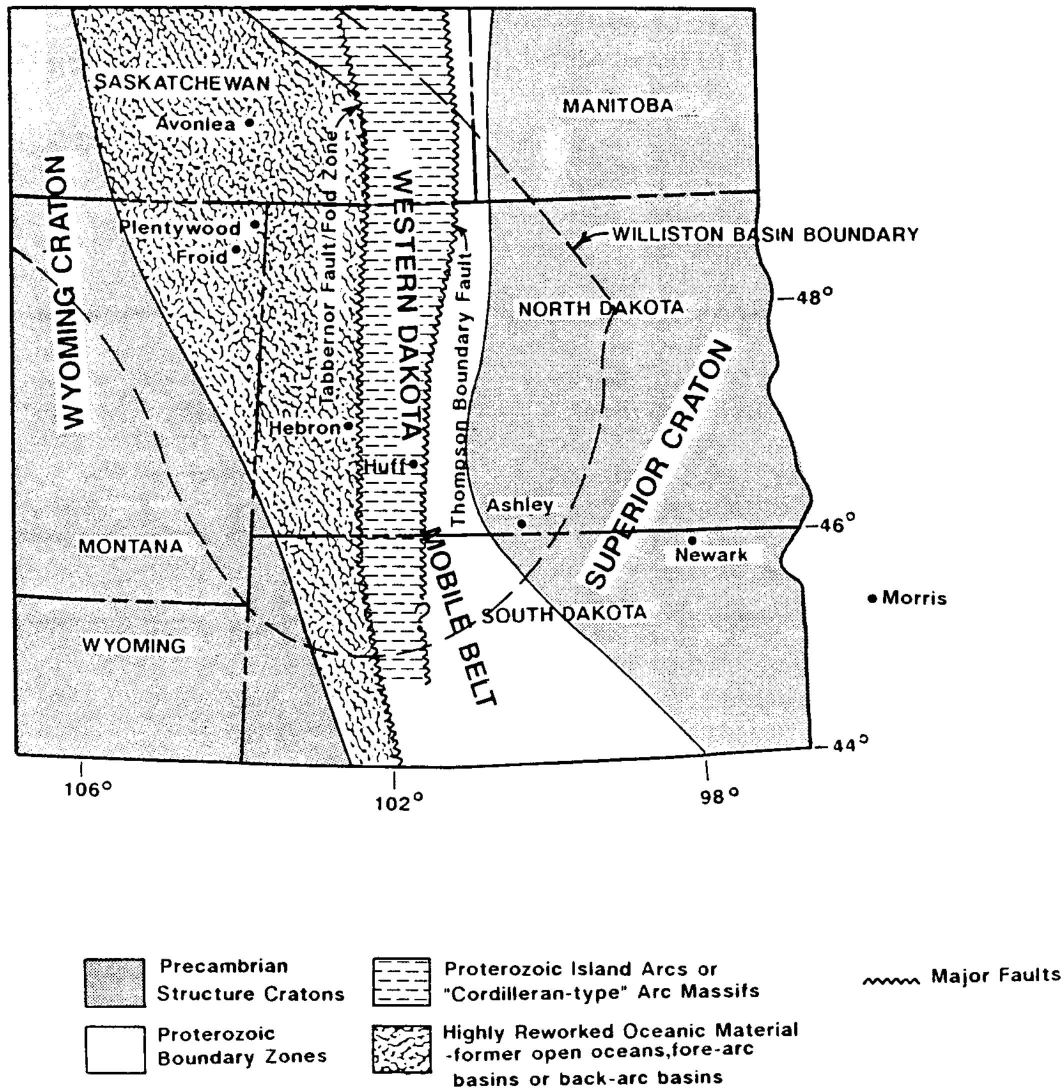

Figure 3. Map showing the main basement geologic structures in North Dakota and the surrounding area. The map shows the major Precambrian structural provinces (Superior Craton, Western Dakota Mobile Belt, and Wyoming Craton). Two deep faults, the Thompson Boundary Fault and the Tabbernor Fault/Fold Zone, extend north-south through the Western Dakota Mobile Belt in western North Dakota. All of these features are deeply buried beneath younger materials throughout the area.

Localities where earthquakes have occurred are noted on the map.

All of the features shown on the above map are buried beneath younger materials throughout the area and, because they are hidden and cannot be studied directly, the map is quite speculative. Other structural maps of the area, compiled by other geologists, differ from this one in various ways.

have been recognized are the Western Dakota Mobile Belt, the Wyoming Craton, and the Superior Craton. However, the nature and extent of the various Precambrian rock units in North Dakota are still very poorly known and the interpretation I have shown on figure 3 is only one of many; other geologists have interpreted the Precambrian geology in other ways. The main difficulty in understanding the basement geology is that all of the Precambrian rock units in North Dakota are deeply buried beneath younger sedimentary rocks. In western North Dakota, as much as 16,000 feet of sedimentary rocks overlie the basement; in the eastern part of the state the basement is buried beneath somewhat lesser amounts of younger rock, but it is still completely hidden. Because of this covering of sedimentary rocks, it is difficult to be certain of the exact locations of the boundaries separating the crustal units.

The Western Dakota Mobile Belt extends from north to south through western North Dakota, separating the Superior Craton from the Wyoming Craton. East of the Mobile Belt, in eastern North Dakota, the Precambrian rocks of the Superior Craton are about 2.5 billion years old. Rocks in the Mobile Belt are slightly younger--less than 2 billion years old, and west of the Mobile Belt, rocks of the Wyoming Craton are generally more than 2.7 billion years old.

Faults--fractures in the earth's crust--can usually be identified in the vicinity of earthquake-prone areas. Earthquakes result when movement occurs between the various blocks of the earth's crust, such as along the San Andreas fault in California. In North Dakota, earthquakes are possible if and when movement between any of the three crustal rock units takes place. Faults may be present at the boundaries between the cratons and, in fact, two long faults have been postulated within the Western Dakota Mobile Belt. These faults, which extend south from Canada, are the Thompson Boundary Fault and the Tabbernor Fault (fig. 3). Very few faults can be identified at the ground surface in North Dakota and those that we do know about are quite small. Any faults that might be responsible for movements great enough to cause earthquakes are buried so deeply that they are not apparent at the surface.

Another way that earthquakes could occur in North Dakota is as a result of collapse of the thick layers of sedimentary rock overlying areas of salt solution. Northwestern North Dakota is underlain by thick and extensive salt deposits, which are between about 4,000 and 12,000 feet deep. Some of the salt beds are several hundred feet thick. Throughout geologic time, much of this salt has dissolved, due to groundwater seeping through it. As a result of the solution of this salt, the overlying materials have settled. Continued settling of the sediments above the areas of salt solution could result in earthquakes. Salt collapse that might cause earthquakes is probably most likely to occur in the area just west of the Turtle Mountains, in Bottineau, Renville, and Burke Counties.

North Dakota was too far from the recent San Francisco earthquake to feel its effects, but several small earthquakes have been felt in North Dakota. On July 8, 1968, an earthquake registering about 4.4 on the Richter scale was felt near Huff, about 15 miles southeast of Bismarck. The actual epicenter of the earthquake felt in Huff was apparently located about 50 miles to the southeast of Huff, near Ashley. This earthquake may have been the result of movement on one of the faults in the Western Dakota Mobile Belt or between any two of the other rock bodies mentioned earlier.

The Huff (Ashley) earthquake, which was felt over a 9000-square-mile area, is the only one with an epicenter that was instrumentally verified in North Dakota, although several other earthquakes that have been felt in North Dakota had nearby epicenters in adjoining states and provinces. Another earthquake that may have had an epicenter in North Dakota (although it was not verified by seismographs), occurred near Hebron on April 30, 1927. This earthquake was felt by one person who reported fairly rapid trembling and rocking, mostly east-west, hanging pictures and lights moving, and plaster cracking. An earlier reported earthquake felt in North Dakota was centered at Avonlea, Saskatchewan on August 15, 1909. This shock was felt over an area of 500,000 square miles, throughout the state of North Dakota.

As I noted earlier, no serious earthquakes have ever occurred in North Dakota, but a low-intensity (no measured Mercalli or Richter number) earthquake, centered near Newark in northeast South Dakota (Aberdeen area) on January 29, 1934, rattled dishes in North Dakota. A somewhat more intense earthquake (VI on the Mercalli scale) was centered in northeastern Montana on June 24, 1943 in the area around Homestead, Froid, Medicine Lake, and Reserve. This earthquake, which was felt over much of western North Dakota, was described in newspapers as follows:

> Froid: **"Felt by many; buildings swayed slightly and creaked; a well-constructed granary cracked so severely that wheat spilled out."** The newspaper reported: **"One man north of Brockton was outside when it occurred. He said it felt as though the earth was heaving up and down."**
>
> Homestead: **"Felt by many; faint subterranean sounds heard; houses creaked and chandeliers swayed; basement walls reported cracked."**
>
> Redstone: **"Chandeliers swung; chimneys cracked."**
>
> Reserve: **"Two shocks; thunderous, roaring subterranean sounds; many cracks in plaster; chimneys damaged."**

Another earthquake that occurred between Williston, North Dakota and Plentywood, Montana on October 26, 1946 registered IV on the Mercalli scale. It is described as a "light shock of about 5 seconds duration, felt by many in the vicinity." No damage was reported, but beds swayed and dishes rattled in Williston.

Finally, a 1975 earthquake centered near Morris, Minnesota was felt by some people in southeastern North Dakota. No damage occurred.

So, in summary, North Dakota is located in an area of low earthquake probability. Infrequent, small earthquakes may occur near or within the state, but these are unlikely to cause any serious damage.

COMMENTS

Do you have questions, comments, or suggestions regarding the Newsletter, Oil and Gas Division services or North Dakota Geological Survey services? For additional information on any of the items mentioned in this Newsletter, please contact North Dakota Geological Survey, 1022 East Divide, Bismarck, ND 58501, (701) 224-4109.

CHECKLIST FOR NEW PUBLICATIONS

See page 2 of this Newsletter for descriptions of the publications.

______MS-73 ($5.00)	Mississippian Correlation Cross Section, Southwestern to North-Central North Dakota
______(free)	List of Publications

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Dave Hvinden, Gas Production Auditor

SUPPORT STAFF
Karen Gutenkunst, Administrative Officer

Karen Gutenkunst, Administrative Officer
Rich Baker, Drafting Technician
Donna Bauer, Permit Secretary
Lyn Entzi, Legal Assistant
Linda Harper, File Clerk
Darby Henke, Information Processor Operator
Jim Lindholm, Programmer/Analyst
Karla Lorentzen, Field Secretary
Eula Mailloux, Clerk
Annette Materi, Receptionist
Tracy Perius, Information Processor Operator
Evie Reisenauer, Account Technician