N. D. Geological Survey
Lee C. Gerhard,
State Geologist

GUIDE TO THE GEOLOGY OF Southwestern NORTH DAKOTA

by John P. Bluemle

revised edition 1980

GUIDE TO THE GEOLOGY
OF
SOUTHWESTERN NORTH DAKOTA

Adams, Billings, Bowman, Dunn, Golden Valley, Grant, Hettinger, McKenzie, Mercer, Morton, Oliver, Sioux, Slope, and Stark Counties

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North Dakota Geological Survey

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INTRODUCTION

This publication describes the geology of southwest North Dakota in a nontechnical manner for those with little training in geology. Students, teachers, farmers, and, indeed, anyone interested in the land, should be able to use the booklet as a source of geologic information to explain the variation in rocks, soils, and landforms observable from cars, buses, trains, or planes. The valleys, badlands, hills, and plains take on new meaning when they are viewed with an understanding of their origin and history. The geologic map in the pocket at the back of the booklet shows the distribution and age of the surface rocks of southwest North Dakota*. Several roadlogs have been included to enable the reader to observe certain areas in greater detail.

The North Dakota Geological Survey makes geological educational aids available to North Dakota schools and other organizations. These aids include taped lectures and collections of selected slides, both of which may be borrowed free of charge. Members of the Survey staff are available to give illustrated lectures on arrangement. Rock and mineral collections are available to schools. Numerous technical maps and reports dealing with various aspects of North Dakota geology are also available at nominal costs.

Further information may be obtained from the North Dakota Geological Survey, University Station, Grand Forks, North Dakota 58202.

GEOLOGIC HISTORY

North Dakota is covered by sedimentary rocks, rocks that have been derived from already existing rocks and transported to their present location by erosional processes such as running water, wind, and glaciers. Most of the sedimentary rocks in southwestern North Dakota formed when eroded sediments from other places were washed into the seas that covered the State during much of the past 600 million years. In the same way, topsoil today is washed from the badlands by the Little Missouri River and deposited in the Gulf of Mexico. Such sedimentary rocks are as much as 15,000 feet thick in parts of southwestern North Dakota.

The geologic history of southwestern North Dakota can be reconstructed by studying the rocks exposed in the area and by studying rock fragments and drill cores that have been obtained from the thousands of oil, gas, and water wells that have been drilled.

The oldest rocks beneath southwest North Dakota began as thick sediments–layers of clay, sand, and mud–that built up on the floors of seas for millions, perhaps billions, of years. These sediments gradually hardened into shale, sandstone, and limestone. Then, about a billion years ago, they were transformed by pressure and heat into hard, crystalline metamorphic ("changed") rocks–granite, schist, gneiss, and marble. These ancient rocks, which we refer to as the "Precambrian basement," were then raised above the sea and eroded by streams, wind, and ocean waves, until they were worn down to a smooth surface.

None of the Precambrian rocks can be seen at the surface in North Dakota in the locations in which they formed, but boulders of the same composition are scattered on the surface of the ground throughout that part of North Dakota that was glaciated. These boulders were transported to their present locations from Canada, mainly Ontario and Manitoba, by the glaciers. They can be found in places in southwestern North Dakota within the limit of glaciation (pl. 1).

*Adams, Billings, Bowman, Dunn, Golden Valley, Grant, Hettinger, McKenzie, Mercer, Morton, Oliver, Sioux, Slope, and Stark Counties

About 620 million years ago, southwestern North Dakota again sank beneath the sea and remained submerged for much of the next 550 million years. During that time, thousands of feet of sediment accumulated and hardened into limestone, sandstone, and shale. The sea floor sank as the sediment accumulated. The water, which was probably seldom more than a few hundred feet deep, was alive with a tremendous variety of marine plants and animals, some of whose remains became trapped within the sediments and formed oil. The sea floor did not sink at the same rate everywhere; sinking was greatest below what is now the Killdeer Mountains, where sediments more than three miles thick eventually accumulated. This accumulation of sediment is known as the Williston basin, and it underlies 200,000 square miles of western North Dakota, eastern Montana, northwestern South Dakota, and southern Saskatchewan. Figure 1 shows the Williston basin and related structural features in southwestern North Dakota.

Most of the sediment that can be seen in southwestern North Dakota was deposited in Cretaceous and Paleocene time. During much of Cretaceous time, silt and clay were deposited in shallow seas. This silt and clay was later transformed to shale, which can be seen today in southeastern Sioux County and in western Bowman County (pl. 1). In late Cretaceous time, the sand and silt of the Fox Hills Formation were deposited in the seas that were draining from the State by that time.

The Fox Hills Formation was deposited near the shore of a sea; therefore, the materials that washed into the sea were somewhat coarser than the silt and clay of the underlying formations, which were deposited in deeper water at greater distances from shore. The Hell Creek Formation was deposited as Cretaceous time drew to a close. It consists mainly of sand, silt, and clay deposited by streams flowing on deltas into the same seas in which the Fox Hills and Pierre Formations were being deposited farther east. Figure 2 shows the contact between the Fox Hills and Hell Creek formations in Bowman County. The last dinosaurs died while the Hell Creek Formation was being deposited.

The Cannonball and Ludlow Formation shale and sandstone were deposited at the beginning of Tertiary time, about 75 million years ago, by the only invasion of Tertiary seas into North Dakota. As the Paleocene sea water approached the area, the silt, sand, and shale of the Ludlow Formation were being deposited on land. As the water spread over the area, the marine sandstone and shale of the Cannonball Formation were deposited. These two formations were then covered by the lignite-bearing sediments of the Tongue River and Sentinel Butte Formations.

The Tongue River and Sentinel Butte sediments were deposited during the Paleocene Epoch about 65 million years ago on a flat, sometimes swampy plain, which was similar to parts of the coastal plains of the southeastern United States. It sloped from the newly-risen Rocky Mountains eastward to the sea, which covered part of the eastern interior of North America at that time. The sand was deposited as a series of bars in numerous east-flowing rivers and along the shores of large shallow lakes. Some of the sand was later cemented into sandstone by calcium carbonate that was carried by the groundwater. The silt and clay settled out of backwaters between the individual river channels during times of flood or were deposited in the offshore parts of lakes. The lignite formed where plant debris accumulated in swamps that were not reached by the silty floodwaters. Mammals were rapidly evolving and diversifying during Paleocene time.

Bright-colored clayey and sandy layers of the Golden Valley Formation were deposited toward the end of the Paleocene Epoch and during the first part of the Eocene Epoch, about 60 million years ago. The clay and silt of the lower portion of the formation were deposited in lakes or ponds on river floodplains. The sand of the upper part of the formation was deposited as river point-bar sediment. The clay and silt of the topmost part of the formation were probably deposited from floodwaters in shallow basins on river floodplains; the bentonite beds might be weathered ash that was blown from volcanoes hundreds of miles to the west.

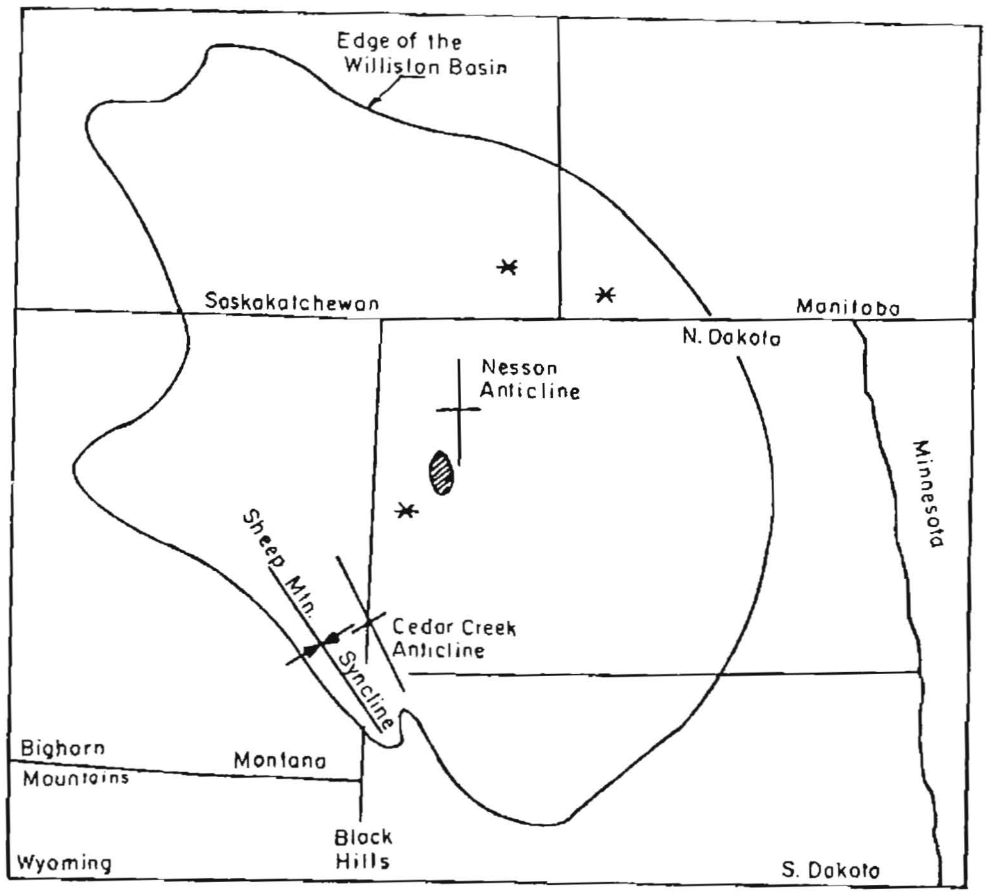


Figure 1. Map of the Williston Basin showing the main structural elements. The shaded area is the deepest part of the basin. Starred locations are astroblems, places that were disturbed when they were struck by large meteors.

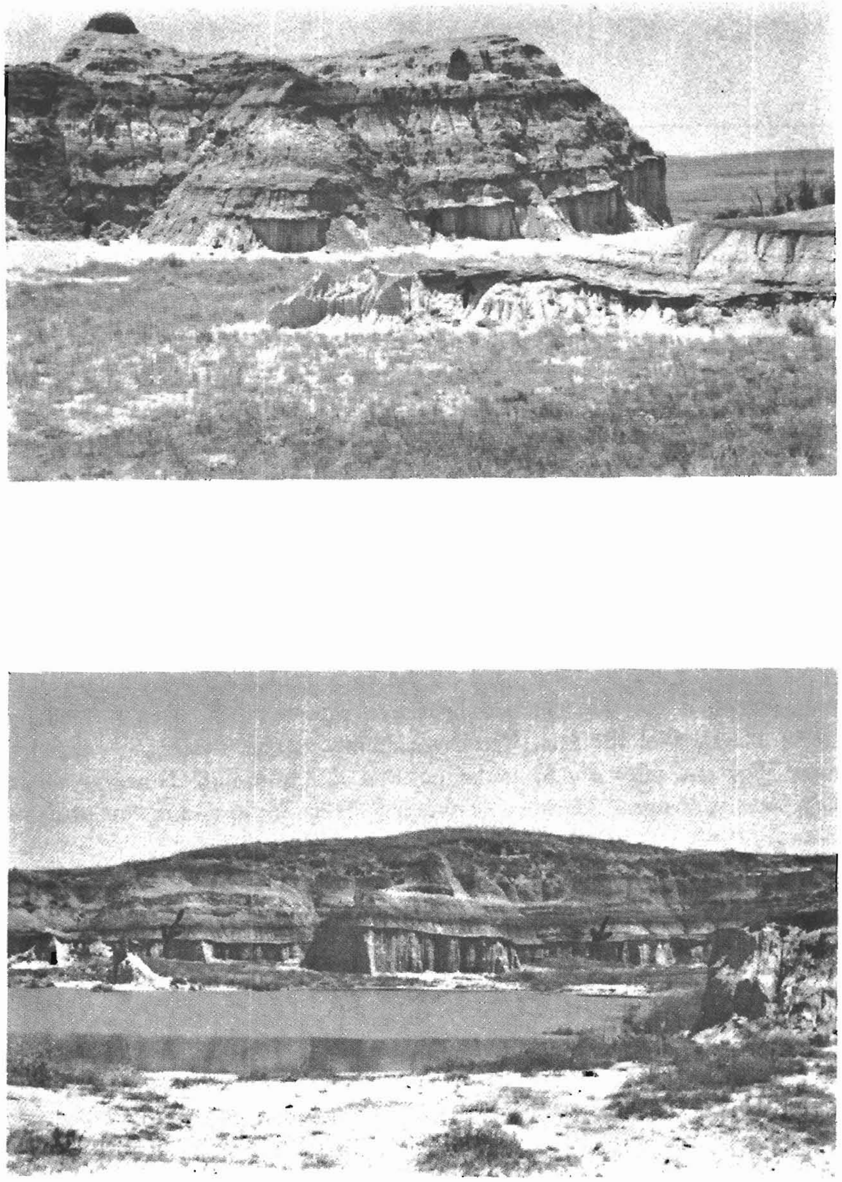


Figure 2. Two photos showing the contact between the Hell Creek and Fox Hills Formations in Bowman County. Arrows indicate the contact. Note the relief on the unconformity that forms the contact. Photo by Charles Frye.

During Eocene time, the climate gradually changed from a warm-temperate one to subtropical, although there was an overall tendency during Tertiary time toward colder climates. After the deposition of the Golden Valley sediments, much of southwestern North Dakota was widely eroded and weathered. Following several million years of erosion, pinkish siltstone, clay, freshwater limestone, volcanic ash from the west, sand, and conglomerate of the White River Formation were deposited in lakes and streams during Oligocene time.

Miocene- or Pliocene-age lake sediments containing considerable volcanic ash that blew into the lakes from the Rocky Mountain area are today preserved on top of the Killdeer Mountains and other scattered areas of southwestern North Dakota. During most of Pliocene time, however, North Dakota was subjected to erosion. Streams flowing over the area left gravel deposits that are preserved today on flat upland surfaces in places. Miocene and Pliocene deposits are not shown on the map because they are restricted to small areas and, where they are found, they are generally thin. By the time the Tertiary Epoch ended, southwestern North Dakota had become a rolling upland (fig. 3).

The Pleistocene Epoch, which began about two to three million years ago, was the beginning of a markedly cooler climate. A great ice sheet inched southward from Canada, across North Dakota, and far to the south, covering a landscape that was largely featureless except for a few scattered buttes. The glaciers advanced several times and, each time they did so, they carried with them vast quantities of rock and soil that they picked up, pulverized, and redeposited as glacial sediment that we now call the Coleharbor Group. The Coleharbor Group consists of several formations of glacial origin. It covers about three-quarters of North Dakota, including parts of McKenzie, Mercer, and Oliver Counties.

When glacial ice first advanced over southwestern North Dakota, the north- and east-flowing streams were blocked and diverted so that the water flowed in a southerly direction along the glacier margin. As a result, the Missouri River valley was formed along the edge of the glacier. The carving of the Little Missouri badlands began when a glacier diverted the Little Missouri River about fifty miles north of Medora, causing it to flow eastward (fig. 4). Prior to the diversion, not only the Little Missouri River, but also the Yellowstone and Missouri Rivers, flowed north into Canada and east to Hudson Bay. As a result of its diversion by the glaciers, the Little Missouri River flowed over a shorter, steeper route than before; and, because of this, the river cut rapidly downward, causing extensive erosion and the carving of the badlands.

The climate slowly moderated and became drier after the end of the ice age. In fact, between about 7,000 years ago and 2,500 years ago, it was both warmer and drier than it is today. As the climate changed, forests that covered the area gave way to prairies with tall grasses. Bison, migrating northward at this time, became plentiful. Sometime toward the end of the ice age, nomadic tribes of primitive men apparently moved into the area. About 2,500 years ago, the climate of southwestern North Dakota became somewhat cooler and wetter again, and it has remained so, with short-term variations, to the present day.

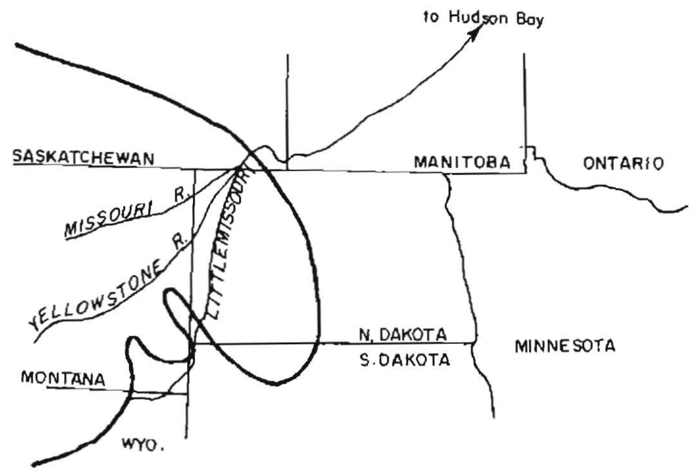
LANDFORMS OF SOUTHWESTERN NORTH DAKOTA

The sediments that can be seen at the surface over most of southwest North Dakota range in age from Late Cretaceous through Paleocene, about 130 million years old to 65 million years old. Patches of sediment that range in age from Eocene to Miocene, about 60 million to 15 million years old, are found in places, particularly on some of the buttes. A thin, discontinuous layer of glacial sediment mantles the older materials in a few places near the Missouri River.

Rolling plains, buttes, and badlands have been carved from the surface sediments into the landscape here today. Even though erosion has continued intermittently ever since the sediments were deposited, the modern landscape dates largely to the ice age. Certain buttes,

PERIOD	EPOCH	AGE (Millions of years)	EVENT OR FORMATION DEPOSITED	BIOLOGICAL EVENTS
QUATERNARY	PLEISTOCENE	0 to 2	Erosion and badlands cutting Glaciation near Missouri River	Human cultures; extinction of many large mammals; early man; increasing herbs; decreasing trees.
TERTIARY	PLIOCENE	2 to 5	Erosion	Abundant mammals; spread of grasslands.
	MIOCENE	5 to 24	Arikaree Fm. in some places	Increase of mammals; development of grasses; reduction of forests.
			EROSION	
	OLIGOCENE	24 to 37	White River Fm. in some places	First modern mammals; worldwide tropical forests.
			EROSION	
	EOCENE	37 to 54	Golden Valley Fm. in some places	Archaic mammals; abundant flowering plants.
			EROSION	
	PALEOCENE	54 to 65	Sentinel Butte Fm. Tongue River Rm.	Evolutionary "explosion" of mammals; modernization of flowery plants; coal deposited.
			EROSION	
LATE CRETACEOUS		65 and older	Hell Creek Fm. Fox Hills Fm. Pierre Fm.	Decrease of reptiles; climax of dinosaurs; early birds; rise of flowering plants; decrease of conifers.

Figure 3. Geological time scale depicting events that have occurred in southwest North Dakota. The formations listed here are all found at the surface.



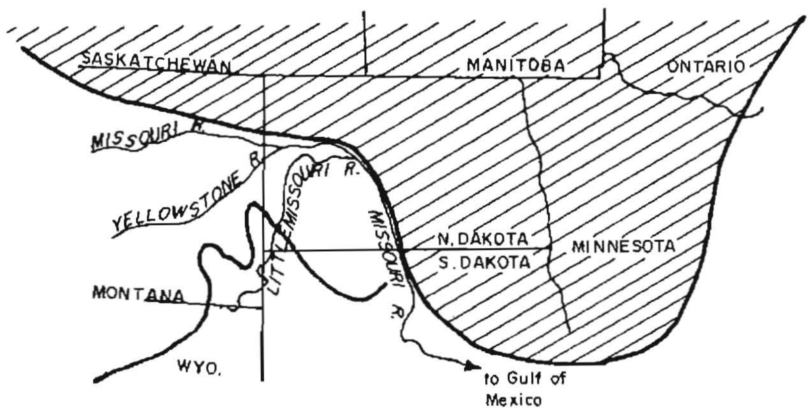


Figure 4. Diagrams illustrating the evolution of drainage in southwestern North Dakota. The upper diagram shows the route of the Little Missouri, Yellowstone, and Missouri Rivers about a million years ago. In North Dakota, the Little Missouri River flowed on sediments of Paleocene age, which had been deposited throughout the shaded area by different streams about 60 million years earlier. The badlands had not yet begun to form at this time.
The lower diagram shows the routes of the same three rivers about 25,000 years ago after the rivers were diverted by a glacier. The new route of the Little Missouri River had a much steeper gradient than did the old one, so the river began to erode the Paleocene sediments, forming the badlands.

such as Bullion Butte, Pretty Butte, Black Butte, Sentinel Butte, and the Killdeer Mountains, were already in existence before the ice age, but they were probably not so prominent then. The Missouri River valley was carved during the ice age when the northeast-trending streams and rivers, such as the Cannonball, Heart, Knife, and Little Missouri were diverted around the edge of the glacier. The present outlet of the Little Missouri River, into the Missouri River in northeastern Dunn County, is much lower in elevation than the pre-glacial stream level. This has caused the Little Missouri River to carve the badlands. In the southern part of the Little Missouri badlands near its headwaters, the river has cut down about 80 feet below its preglacial level (fig. 5). In its lower reaches, in the northern part of the badlands area, the valley floor is about 300 feet below its preglacial level. The eastward course of the river has been cut since the glaciers diverted it. This part of the valley is about 500 feet deep.

The rate of erosion in the badlands has not been constant. Since they were initiated, the badlands and other landforms have undergone many periods of erosion and deposition. During the past few hundred years, the badlands have undergone four separate periods of erosion and three periods of deposition. New gullies have been cut to their present depth since about 1936. In general, erosion tends to be most intense when the climate is dry; for, at such times, the cover of vegetation is thin and offers less protection to the soil.

The erosion that has shaped southwestern North Dakota has been selective in its action. Hard, relatively resistant sandstone and limestone beds have remained as protective caps on buttes and ridges while the softer silt and clay layers have been washed away (fig. 6). Areas covered by grass sod are resistant to erosion (fig. 7). Other materials that are resistant to erosion include layers of reddish scoria, a natural brick that formed when the heat from nearby seams of burning coal baked the adjacent sediments; layers of exceptionally hard pseudoquartzite, which were probably deposited in ancient swamps and later silicified; concretions, which form pedestals as they weather out of the softer surrounding sediment (fig. 8); and, in some places, beds of snail and clam shells and layers of petrified wood.

LIGNITE

Lignite is found throughout southwest North Dakota, especially in areas of Tongue River and Sentinel Butte sediments. It is a soft, low-rank coal that consists of plant fragments. The plants that formed the lignite grew in ancient swamps in a warm and humid climate. The swamps existed along streams that were flowing generally eastward from the newly-formed Rocky Mountains during Paleocene time, about 65 million years ago. As plants died and fell into the swamps, they began to decay due to the action of bacteria. However, before the plants could be completely decomposed, the bacterial action stopped because the bacteria "committed suicide" by filling the stagnant swamp water with their body poisons to such an extent that they died. When the streams changed course, as the Mississippi River does on its delta in the Gulf of Mexico at times, they deposited sand on top of the partially decomposed vegetation, burying it and allowing coal to form.

SCORIA

The reddish layers of scoria, found in many parts of southwestern North Dakota, are composed of sediment that was baked by burning lignite. The scoria commonly contains fragments that look as though they have melted. According to one theory, these fragments were formed when the material overlying a burning coal bed collapsed, plunging it into the "furnace" and heating it to exceptionally high temperatures so that it melted. As a result of such collapsing, spaces are often present in or near beds of scoria. After the scoria cools, the spaces are convenient places in which animals can live. They are especially favored by rattlesnakes for dens.

Figure 5. View over Wind Canyon toward the Little Missouri River in Theodore Roosevelt National Park. Wind and water are rapidly eroding the sediments in this area.

Figure 6. Resistant sandstone bed in Morton County. As the softer underlying sediments are eroded away, the sandstone breaks off and falls down the slope, further protecting it from erosion.

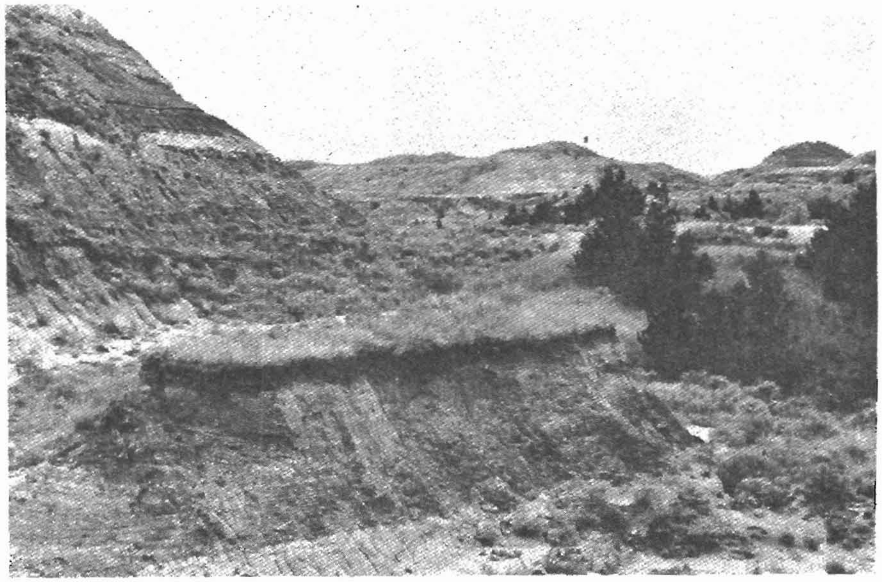


Figure 7. Sod cover protecting underlying sediment.

Figure 8. Concretions in Tongue River Formation acting as "caprock" on pedestals, preventing erosion. Theodore Roosevelt National Park.

The intensity of the reddish color of scoria is governed by the mineral composition and grain size of the material that was baked and by the intensity of the temperature reached during the baking process. The reddish color is due primarily to the presence of the mineral *hematite* (iron oxide, the same as common rust). All of the southwestern North Dakota sediments contain some iron-bearing minerals, although not in concentrations great enough to make them commercially valuable. Since iron is more easily oxidized at high temperatures than at normal temperatures, hematite forms when the sediment is baked.

Range fires may have ignited some lignite beds, while other fires may have been started by lightning. Much of the scoria is now found at elevations where the water table is too high for lignite to burn. This scoria probably formed at a time when the climate was drier and the water table was lower than it is today. This may have happened, for example, during what is known as the "hypsithermal interval" ("hypsithermal" means "maximum temperature"), a warm, dry period of time that lasted from about 7,000 years ago until about 2,500 years ago.

PETRIFIED WOOD

Petrified wood is found in numerous places in southwestern North Dakota. It is especially common in badlands areas where petrified stumps and intact trunks are found (fig. 9). Although all of the area that is now western North Dakota was probably forested during Paleocene time, the preservation of the wood and stumps required that the trees be rapidly buried by sediments so that they escaped decay. This might have happened when a stream changed course or flooded its banks depositing sand or silt on the trees.

After a tree was buried, groundwater began to circulate through it. With the help of bacterial action, the water dissolved out the softer cellulose material of the wood. The water also carried dissolved minerals, among them silica (SiO_2). The silica was deposited in the spaces left by the dissolving out of the plant tissue. This went on for a long time so that the replacement was gradual, a molecule of plant tissue being simultaneously replaced by a molecule of silica. In this way, the original cellular structure of the wood was preserved so that, in many cases, the petrified stumps look exactly like old wood stumps except that they are stone. The petrified wood found in southwest North Dakota is mostly very light brown or cream colored. Petrified wood seems to be more abundant in the Sentinel Butte Formation than in other formations.

CONCRETIONS AND NODULES

Concretions are rock structures that have essentially the same composition as the sediments that contain them, but they are generally more resistant than the surrounding sediments. They are the result of the selective deposition from water of cementing materials in the pores of the sediment. Nodules, like concretions, are also harder than the surrounding sediments, but they are of a different composition than the sediments that contain them. The relative hardness of concretions and nodules makes them important in determining the rate and location of erosion and thereby helps to contribute to the overall shape of the southwestern North Dakota landscape.

All the geologic formations in southwestern North Dakota contain concretions and nodules of all sizes and shapes. Some concretions are nearly spherical (fig. 10). In some badlands areas, the surface is covered by nodules of siderite (ironstone) which, as they weather out of the surrounding materials, form an erosion-resistant layer (fig. 11). Among the more interesting of the various types of concretions are the "logs," (figs. 12 and 13) which are elongate sand bodies that have been cemented, in most cases, by calcium carbonate. The log-like concretions formed when mineral-rich groundwater flowed through

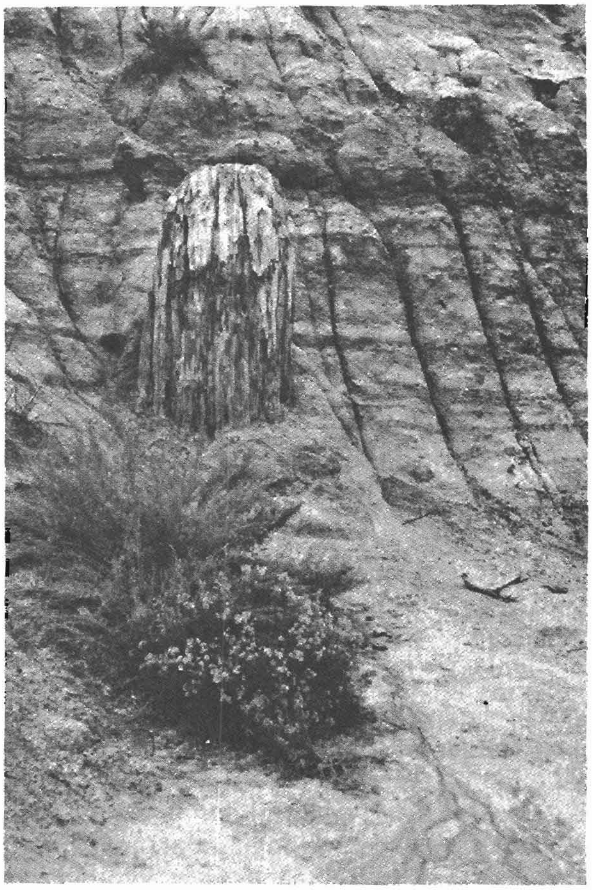


Figure 9. Petrified wood stump in Theodore Roosevelt National Memorial Park.

porous and permeable zones in the subsurface, depositing the minerals in the pores and thereby cementing them to concretions.

PSEUDOQUARTZITE

Many of the southwestern North Dakota ridges and buttes have a cover of pseudoquartzite boulders that help to protect the underlying sediment and minimize erosion. Typical examples of pseudoquartzite-covered hills are Pretty Rock Butte in southwestern Grant County, Rocky Ridge north of Hettinger in Adams County, and numerous others throughout the area.

Pseudoquartzite formed from swamp deposits in Miocene or Pliocene time. It contains numerous petrified plant stems and holes that once contained plant stems. Apparently, fine silt composed mainly of quartz was blown into swamps where it accumulated and eventually solidifed as the swamps dried. Pseudoquartzite is essentially pure, non-crystalline quartz, and it is extremely hard.

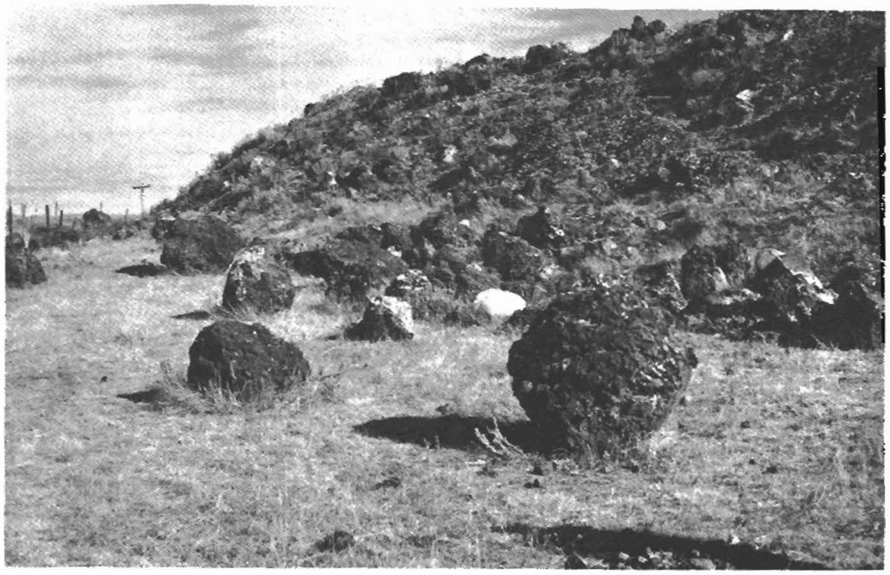


Figure 10. Nearly spherical "scoria" concretions in Sentinel Butte Formation in Mercer County.

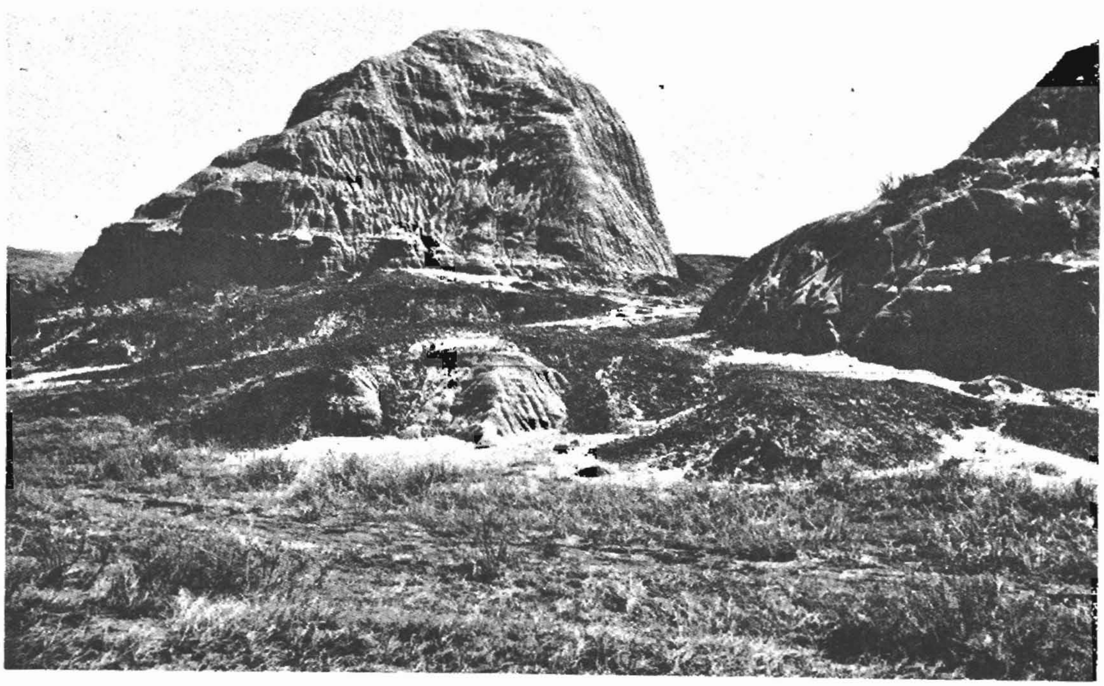


Figure 11.Hell Creek badlands in Slope County, showing siderite (iron carbonate) nodules lying on the surface. Photo by Gerald Groenewold.

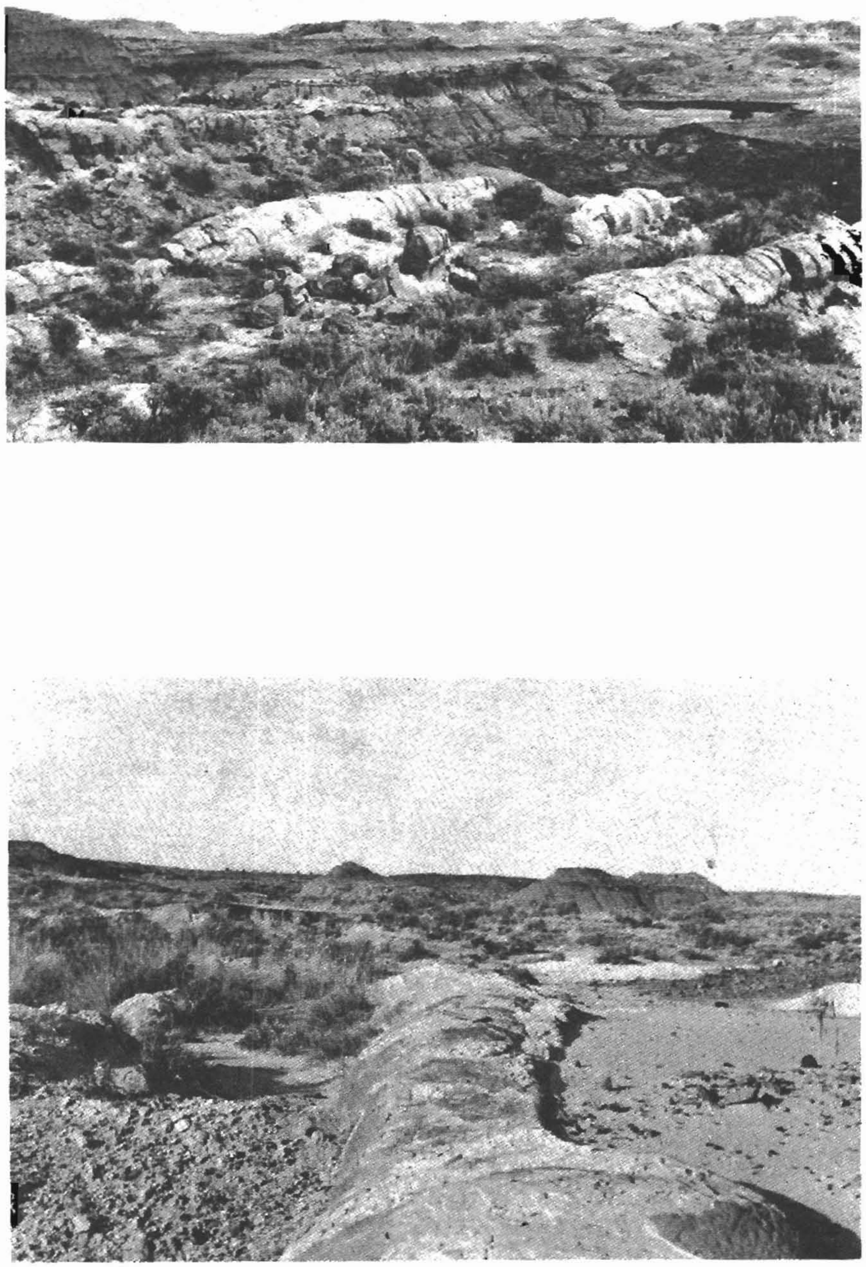


Figure 12. Two photos of log concretions in the Tullock Formation, Slope County. Photos by Charles Frye.

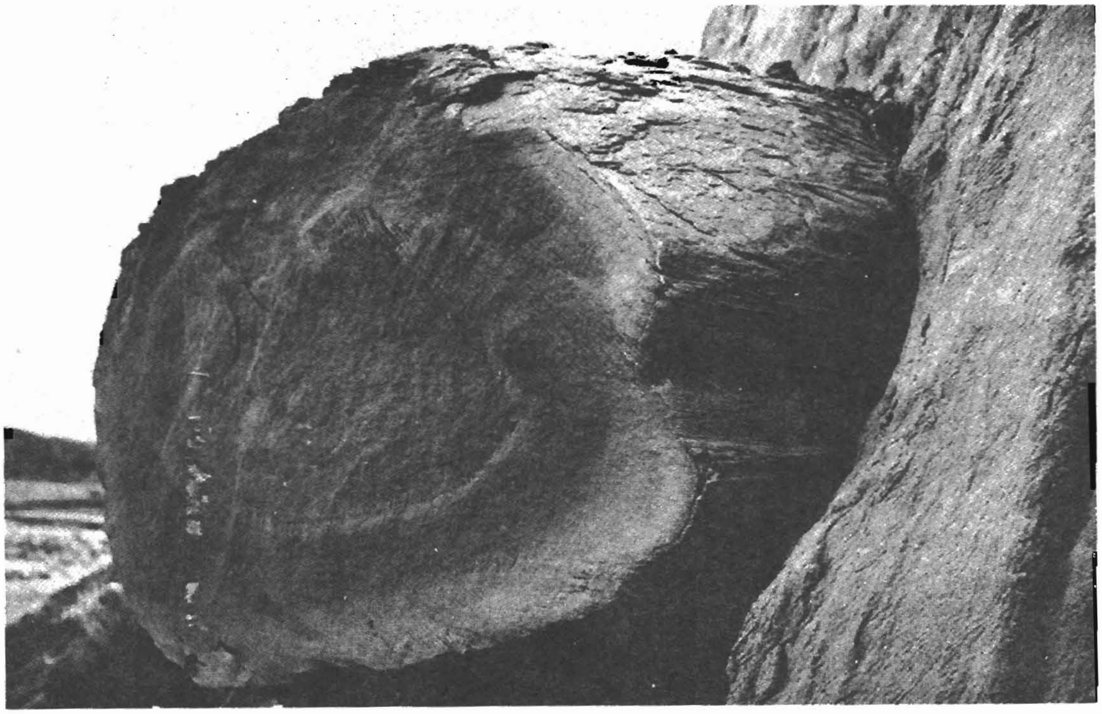


Figure 13. Cross sectional view of log concretion in the Hell Creek Formation, Slope County. Photo by Gerald Groenewold.

FOSSILS

Southwestern North Dakota, with several geologic formations reflecting a diversity of environments, has a proportionately large fossil representation. However, the fossils are abundant in only a few places and the casual observer may not be successful at collecting them. The following discussion is not a "catalog" of fossil localities, but rather a general review of what some of the formations contain.

The Fox Hills Formation contains several clams, snails, and at least one type of cephalopod. The formation is especially fossiliferous in parts of south-central Sioux County, a few miles east of Selfridge where oysters are abundant.

The Hell Creek Formation is characterized by numerous pieces of dinosaur bones. Most badlands exposures of the formation have a few such bone fragments and occasionally an entire bone, or even a skeleton, can be found. Part of a skeleton of the dinosaur *Triceratops* was taken from Hell Creek sediments in Slope County (fig. 14). Fish bones are common near Huff in Morton County and mollusk shells can also be found in places.

The Cannonball Formation commonly contains crab and clam fossils and the Ludlow Formation, which was being deposited on land at the same time the Cannonball Formation was being deposited off shore, contains an abundant fossil assemblage. At one site in Billings County, fossil fish and turtles have been collected from Ludlow sediments. Fossilized crocodiles up to 16 feet long have been found along with fossil champsosaurs, which were similar to crocodiles, but not so large. A few small primate fossils and primitive horse and cow fossils have been found.

The Tongue River and Sentinel Butte Formations contain fossil mollusks, but the most obvious fossil from these two formations is the abundant petrified wood and lignite, which, in a sense, is an accumulation of fossil plant material. It is possible to collect excellent fossil leaves and plant casts from lignite in some places.

Well preserved plant and animal fossils occur in the Golden Valley and White River Formations in some places. At White Butte, south of Dickinson, fossil fish, frogs, reptiles (including four genera of crocodilians), a small bird, and mammals, including rodents, carnivores, pantodonts, perrisodactyls, and artiodactyls, have been collected. The Oligocene

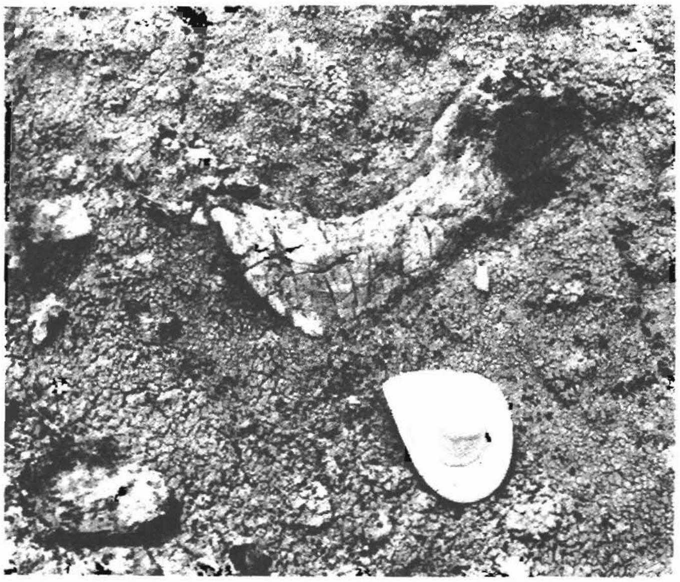


Figure 14. Partially exposed skeleton of the dinosaur Triceratops from Hell Creek Formation sediments in Slope County. This is a nearly-complete skull that is now housed at the University of North Dakota geology department. Photo by Charles Frye.

White River Formation has yielded a few fossils including titanothere bones and a rhinoceros. Fossil beaver and peccary have been found in Miocene age sediment, which is exposed in several locations in southwestern North Dakota.

MINERAL RESOURCES

Mineral production is an important source of income in southwestern North Dakota. Petroleum resources, along with natural gas and coal, account for most of the total mineral value. North Dakota's coal resources, which are extensive, may play an increasing role in energy production in the future.

Oil and Gas

Oil and gas are the remains of living matter that has been reduced by decay to a state in which carbon and hydrogen are the principal elements. These elements are combined in a great number of ways to form molecules of hydrocarbons. Both oil and gas are composed of molecules of hydrocarbons. North Dakota's oil and gas reserves began to accumulate millions of years ago when decaying organic material was covered by sediments deposited in the large, shallow sea that covered western North Dakota. Over millions of years, hydrocarbons from this organic material flowed into relatively porous and permeable reservoir rocks. The hydrocarbons became concentrated when the permeable sediment layers were covered by impermeable layers of sediment that formed traps where the hydrocarbons accumulated.

Petroleum production in North Dakota dates to 1951 when the first producing well was brought in near Tioga in northwestern North Dakota. Petroleum is produced in Billings, Bowman, Dunn, Golden Valley, Hettinger, McKenzie, Slope, and Stark Counties in southwest North Dakota. Production of oil in southwest North Dakota through January 1, 1980, was about 275 million barrels. McKenzie County produced the most, a total of 130 million barrels, although Billings County is currently the leading producing county.

Lignite

Lignite occurs over most of southwest North Dakota (see page 8 of this report for a discussion of the origin of lignite). Lignite is one of the four "ranks" of coal. The other three ranks are anthracite, bituminous, and sub-bituminous coal. The rank of coal is a classification system that considers the heat value, the fixed carbon ratio, and agglomerating characteristics (binding quality). North Dakota lignite is a nonagglomerating coal with a heating value of about 5600 to 7700 Btu's (British thermal units) per pound. Slope, Dunn, and Mercer Counties have the largest strippable lignite reserves, although all the southwestern North Dakota Counties except Sioux have some lignite.

Leonardite

Leonardite is a solid hydrocarbon material derived from the weathering (oxidation) of lignite. It is a soft, earthy, medium-brown, coal-like material associated with virtually all lignite outcrops in southwest North Dakota. It is mined commercially in Adams and Bowman Counties. Leonardite can be used as a soil conditioner, and it has been used as a dispersant, viscosity control in oil-well drilling muds, as a stabilizer for ion-exchange resins in water treatment, and as a source of water-soluble brown stain for wood finishing.

Uranium

The main North Dakota uranium occurrences are found in thin lignite or carbonaceous beds immediately overlying or underlying a sandstone that apparently functioned as an aquifer. The uranium content of the groundwater in these aquifers is generally attributed to groundwater leaching of overlying sediments containing uranium-bearing volcanic ash. The origin of the uranium in the southwestern North Dakota lignite is thus presumed to have been extracted by organic material from groundwater which had taken the metal into solution as it passed downward and laterally.

Significant North Dakota uranium production, which ended in 1967, was limited to the Belfield area. The total production from North Dakota is listed by the U.S. Atomic Energy Commission as 85,138 tons of ore yielding 592,288 pounds of "yellow cake" (U_3O_8). Reserves considered mineable at an 8 dollar per pound U_3O_8 price are carried at 71,000 tons containing 480,000 pounds of U_3O_8. Both production and reserve figures for North Dakota are far less than one percent of the total U.S. production and reserves.

Clay

The clay materials are secondary, forming as alteration products of preexisting rock materials by weathering processes or hydrothermal alteration. Clay deposits may be residual (formed by weathering where they are found) or transported. If the clay, once formed, is removed and transported elsewhere, it may be laid down as a sedimentary clay deposit. Bentonite deposits appear to have formed by the alteration of volcanic ash beds. Nonswelling bentonitic clay beds are found in the White River Formation in Stark, Slope, and Billings Counties.

Light-burning Tertiary clays of the Golden Valley Formation were used in the manufacture of face brick, building tile, and fire brick, with plants located at Dickinson and Hebron. Operations ceased at Dickinson in the late thirties. A sewer pipe plant was opened at Dickinson in the early sixties, but was only operated until 1970. The plant at Hebron is today the oldest (since 1905) and largest brick plant in operation in the State, producing 12 million brick units annually, utilizing about 36,000 tons of clay.

In 1953, a lightweight aggregate plant began operation at Mandan, producing aggregate from shale of the Cannonball Formation. A similar plant, opened in 1954 at Noonan, used clay occurring above a lignite seam in the Tongue River Formation. The latter plant was closed in 1971 because of freight costs. A third lightweight aggregate plant that began operations at Dickinson in 1968, utilizing clay from the Golden Valley Formation, is still in business, producing 100 cubic yards a day during the summer months.

A plant, initially producing kitty litter and floor absorbent material from bentonite and from volcanic ash, was operated during 1971 at Belfield. The success of ceramic plants in North Dakota has been hampered by transportation costs and lack of sufficient markets.

Gem Stones

The gem stones of southwestern North Dakota are principally those formed by the precipitation of silica from cold water solutions. Moss agates are found in the gravels of the Yellowstone and Missouri Rivers in McKenzie County; petrified wood in the Hell Creek, Tongue River, and Sentinel Butte Formations in Billings, Adams, Morton, and Stark Counties; chalcedonic quartz in Stark and Hettinger Counties; agate in the Missouri River drainage throughout the southwest part of the State; and agatized fossil pine cones are recovered from the Hell Creek Formation near the junction of the Cannonball River and Cedar Creek in Grant County. Agate and chalcedony are recovered from glacial gravels in northeast Morton County. In addition, "rosettes" of marcasite crystals are found in the Tertiary coal beds in many places, and rhomboidal gypsum crystals are common in places in the Hell Creek Formation and in the Tertiary Ludlow Formation where they crop out in Morton County. At the current rate of production, the deposits of these gem materials are virtually inexhaustible.

Less well known materials of potential interest to the rock hobbyist occur in the State, and still other materials not yet known to occur or not now exploited might well be searched for. Glassy clinker from burnt coalbeds, similar to obsidian and pitchstone, is apparently little used for gem purposes despite its attractive appearance. Prospecting could also be carried on for hard vitreous clots of coal from the vicinity of coal fires, which could be used like jet. The possibility exists that the bentonite beds in Stark and Bowman Counties, and elsewhere in the southwestern part of the State, may contain opaline quartz, barite concretions, celestite crystals, zeolites, and other gem materials.

North Dakota, having no surface exposures of igneous or metamorphic rocks in which deposits of the more valuable gem stones may have formed, is one of about 15 states each of whose current annual production of gem stones, as estimated over the years by the U.S. Geological Survey and the U.S. Bureau of Mines, has been $1000 or less.

Molybdenum

Molybdenum is a silvery-white metal with an extremely high melting point, approximately 2,620° C. Its primary use is in steel alloys and stainless steel; however, its usage is increasing in the space, nuclear, and electronic industries. It is also used in the paint industry, in the manufacturing of some lubricants, and as a catalyst in petroleum refining.

In North Dakota, molybdenum is associated with uraniferous lignite deposits southwest of the Missouri River. Molybdenum was recovered as a byproduct from the uraniferous lignite from 1964 to 1968. There has been no production of molybdenum in North Dakota since the mining of uraniferous lignite ceased. The last reported production of molybdenum from the State was in 1968 from stockpiled uranium ore. It is expected that, unless it becomes economically attractive to mine the uraniferous lignite again, there will be no further molybdenum production in North Dakota.

Gravel

Gravel is generally scarce in North Dakota southwest of the Missouri River. Terraces along some of the streams constitute the only significant source. Alluvial fan and surface gravels may occur locally in sufficient quantity to be useful. Scoria and sandstone are mined and crushed for road surfacing material in much of the area as a gravel substitute.

REFERENCES

Bluemle, J. P., 1977, The face of North Dakota--the geologic story: North Dakota Geological Survey Educational Series 11, 73 p.

Bluemle, J. P., and Jacob, A. F., 1973, Geology along the south loop road, Theodore Roosevelt National Memorial Park: North Dakota Geological Survey Educational Series 4, Theodore Roosevelt Nature and History Association, Medora, 16 p.

Carlson, C. G., 1973, Geology of Mercer and Oliver Counties, North Dakota: North Dakota Geological Survey Bulletin 56, North Dakota State Water Commission County Ground Water Studies 15, Part I, Geology, 72 p.

Clayton, Lee, 1970, Geologic map of Dunn County, North Dakota: North Dakota Geological Survey Miscellaneous Map 11.

Clayton, Lee, Moran, S. R., and Bluemle, J. P., 1980, Explanatory text to accompany the geologic map of North Dakota: North Dakota Geological Survey Report of Investigation 69.

Clayton, Lee, and others, 1980, Geologic map of North Dakota: U.S. Geological Survey.

Feldmann, R. M., 1972, Stratigraphy and paleoecology of the Fox Hills Formation (Upper Cretaceous) of North Dakota Geological Survey Bulletin 61, 65 p.

Frye, C. I., 1969, Stratigraphy of the Hell Creek Formation in North Dakota: North Dakota Geological Survey Bulletin 54, 65 p.

Holtzman, R. C., 1978, Late Paleocene mammals of the Tongue River Formation, western North Dakota: North Dakota Geological Survey Report of Investigation 65, 88 p.

United States Geological Survey, and others, 1973, Mineral and water resources of North Dakota: North Dakota Geological Survey Bulletin 63, 252 p.

ADAMS COUNTY FIELD TRIP

(total distance about 16 miles)

Distance Between Points (miles)	
	Begin field trip at the east edge of Hettinger on U.S. Highway 12 at the hospital. Drive east.
0.3	Turn north on gravel road.
0.3	STOP 1. Small, light gray exposure of sandstone. By digging in the material in this exposure, you can see that only the uppermost light gray beds continue back into the hill; the light gray sand has washed downward over the remainder of the exposures from this single bed. The lower beds are actually golden in color, as you can see by digging. The white beds you see here belong to the Paleocene-aged Ludlow Formation, which underlies the Tongue River beds.
0.3	The dark bed at this cut is lignite, which weathers to the purplish hues you see here.
0.5	The brownish material exposed in some of the roadcuts is gravel that occurs in this valley.
0.9	Roadcut in the Ludlow Formation. The white materials in the outcrops west of the fence are siliceous rocks that result from weathering of Ludlow Formation sediments. The purplish bands below the siliceous materials are lignite seams. Black shale underlies the lignite beds.
0.8	Roadcut. The white crusty material on the surface in places is salt, the result of upward-moving groundwater. As the water seeps from the roadcut and evaporates, concentrations of salt accumulate on the surface.
0.5	STOP 2. Large roadcut east of the road is in Tongue River Formation sandstone. Wind erosion here is rapidly scouring the sandstone, removing the finer, looser material. Of particular interest are the many concretions, which are being exposed as the wind removes the finer materials. The vertical cylindrical concretions probably formed as accumulations of mineral material on plant stems. The wind does an excellent job of etching the old bedding planes.
0.2	Notice the rectilinear pattern of concretions on the east in the roadcut, which follow the joint pattern in the sandstone.
0.8	Large roadcut west of the road. Notice the highly distorted bedding planes near the upper part of the cut (gray layers in the sandstone). Nearer the base of the cut can be seen several ledge-forming concretions. The roadcut crosses a ridge that is capped by both stream gravel and pseudoquartzite.
0.7	Roadcut exposes a bed of lignite in the Tongue River Formation. The shiny, glass-like particles lying around on the surface are selenite ($CaSO_4$).

0.9

Roadcut through sand beds of Tongue River Formation. Extensive wind erosion on roadcut.

0.1

STOP 3. Rocky Ridge. This rock-covered hill is an excellent example of pseudoquartzite fragments. The presence of pseudoquartzite on the ridge accounts for the existence of the ridge; the hard, erosion-resistant pseudoquartzite protects the underlying sediment while the surrounding sediment is eroded away.

Walk up on the hill and examine the blocks of pseudoquartzite. Abundant petrified plant stems and holes that once contained plant stems are the most common fossils. You may find other fossils by careful examination. Pseudoquartzite apparently formed in Miocene or Pliocene time when fine silt, mainly quartz, possibly windblown, accumulated on the surface, mainly in lower, swampy areas, and hardened into the material you see today. It is extremely hard, as quartz is highly resistant to erosion. Notice the presence of lichens of several types on the pseudoquartzite blocks. Lichens are the only plants capable of extracting nutrients from the hard rock. They help to break off pieces of the rock, thereby initiating the formation of soil from the rock.

Drive west from this corner.

0.6

Rocky Ridge, the same pseudoquartzite-covered ridge of Stop 3, is south of, and parallel to, the road.

2.4

Turn south.

1.6

Ridge on the southeast horizon.

1.0

Hills east of the road. These hills are capped by a channel sandstone, a part of the Tongue River Formation. The resistant sandstone keeps the hill from eroding away. Notice the cross-bedded planes in the sandstone. These bedding structures are typical of those deposited by flowing water.

0.4

Sandstone ridge east of the road.

1.0

Turn east.

1.0

Ridge north of the road. This sandstone ridge may be an old beach that formed in Paleocene time while the Tongue River Formation was being deposited.

0.5

Turn south.

0.9

Gravel pit to the west.

0.1

Turn east at airport.

0.4

Pseudoquartzite capped hill. Road curves southward into Hettinger. End of trip.

BOWMAN COUNTY FIELD TRIP

(total distance about 50 miles)

Distance Between Points (miles)	
	Start trip in Bowman at the junction of U.S. Highways 12 and 85. Drive west on U.S. 12. You will be driving over Tongue River Formation between Bowman and Rhame. Make a mental note of the topography in this area so you will be able to compare it with topography later in the trip.
0.4	The small butte to the north is capped by scoria. Most of the buttes you will see on the trip are capped by either scoria, sandstone, or pseudoquartzite.
1.3	Small roadcut exposes Tongue River Formation siltstone.
5.0	Notice the scoria on top of the buttes north of Griffin.
2.2	Scoria on hill tops south of road.
3.3	Scoria exposures on butte tops north of Rhame.
0.3	Turn south. You are still driving on sediments of the Tongue River Formation.
3.4	Exposure of Tongue River Formation siltstone on both sides of the road. The flat upland in this area is covered by pseudoquartzite, which is broken into fairly small chunks and contains more sand than does the pseudoquartzite to the east in Adams County.
2.5	Turn west on paved road. Tongue River Formation exposed just west of corner.
1.0	Approximate western limit of the Tongue River Formation. You will be driving on Ludlow and Tullock Formation sediments for the next few miles.
1.0	Turn south on gravel road.
1.9	Road curves to the west. Pseudoquartzite boulders in the field. Pseudoquartzite covers these hills, acting as a resistant caprock material.
1.0	STOP 1. East of the road are several small scoria pits. Look at these to see how the baking process has altered the sandstone. In places, the rock appears to have melted, fusing into smooth clinker. The gray, dully shiny boulders over the surface are pseudoquartzite.
0.7	Turn west.
2.0	Turn south.
0.4	Bridge.

0.1

Black marine sand of the Cannonball Formation. The flat area ahead is Hell Creek Formation topography. Compare this with the farmland on the Tongue River Formation a few miles back.

0.3

Black exposures just east of the road are Cannonball Formation lying on Hell Creek Formation, which is at the base of the exposure.

3.6

Badlands to the west are in Hell Creek Formation.

0.8

Corner. STOP 2. The small gully west of the road is an example of Hell Creek Formation rocks. The brownish bed of loose, popcorn-like material is bentonitic shale which swells when it is wet so that when it dries, it shrinks, forming the loose, surface mulch you see here. Bone fragments, mainly dinosaur, are common in this area.
Drive east from this corner.

1.4

Notice the poor soils in this area and the generally poor farmland. This condition is typical of areas over which the Hell Creek Formation is present.

0.5

Lignite bed..

0.8

STOP 3. The hills on either side of the road are sand dunes, probably of relatively recent origin. The sand source was the areas of Hell Creek exposures to the west.
As you drive east, you will be leaving the Hell Creek topography, crossing the Cannonball, Tullock, and Ludlow Formations and returning to the Tongue River Formation.

0.5

Scoria pit south of the road.

1.5

Highway. Turn north.

0.8

Scoria pits and pseudoquartzite east of road.

0.5

Lignite bed exposed in ditches.

2.6

Medicine Pole Hills oilfield. Oil is produced here from rocks of the Red River Formation at a depth of approximately 9,500 to 9,700 feet deep.

1.6

The ridges and hills in this area have a caprock of Tongue River sandstone, probably an old channel deposit.

8.4

Rhame. End of trip.

GRANT COUNTY FIELD TRIP

(total distance about 30 miles)

Distance Between Points (miles)	
	Begin trip ½ mile south of Carson at the junction of Main Street and State Highway 21. Drive east. The underlying sediments here are of the Tongue River Formation sandstone of Paleocene age.
0.6	Turn south on gravel road.
0.5	The buttes to the southwest are capped by resistant sandstone ledges in the Tongue River Formation. These are ancient river deposits that have since become cemented into hard layers. We will see some of these deposits on this field trip.
1.6	Exposure of Tongue River sediment at the curve in the road. The black band at the base of the cut is lignite.
0.4	Rocky ridge to the east. An ancient stream channel deposit of sandstone that caps the hills here results in the ridge, which trends from northwest to southeast.
0.3	STOP 1. Clay outcrop on the west side of the road. This exposure of light-colored clay or mudstone is rich in bentonite, a clay that swells when it is wet. This property causes the loose surface (popcorn-like) mulch. Bentonite is clay that results from the alteration of volcanic ash. The shiny glass-like chips in the clay are selenite, a form of gypsum.
1.6	Sandstone outcrop. Wind erosion has sculpted the sand beds here.
0.1	Railroad crossing.
0.6	Turn east toward Brisbane. Notice the exposures of resistant sandstone just southwest of the corner.
3.0	Cross the railroad tracks and continue to the east.
0.4	Cemetery.
0.5	Turn north.
0.1	STOP 2. Tongue River Formation. Soft sandstone. Numerous coarser-grained concretions have weathered out and litter the surface. The color of the weathered sandstone is brown–gray beneath–this is a result of weathering of the iron minerals contained in the sand.
0.6	STOP 3. This gravel is of glacial origin and much younger than any of the materials we have looked at up to now. It is probably early Wisconsinan or older in age and it was deposited when glacial ice covered the area just to the north. Water flowing from the melting ice carried materials to this location.

Only patches of gravel remain today; much of the gravel has probably been eroded away. Examine the gravel. In addition to cobbles of sandstone and shale, you can see various types of igneous and metamorphic rocks that were transported here by the glacier from Ontario and Manitoba. From the size of the cobbles, what can you infer about the size or velocity of the stream that deposited them?

0.5 Gravel pits to the east. Notice that the pits all occur on the hills. These hills are part of a ridge that marks the old stream course. The topography has been inverted because, when the gravel was deposited, it was in a valley. Everything nearby has since been eroded away.

0.5 Abundant glacial boulders.

0.4 Turn west.

1.0 Turn north.

0.4 STOP 4. Top of ridge. Examine the sandstone outcrops west of the road on the ridge. This sandstone, a stream deposit, is responsible for the existence of the ridge. Notice the large-scale cross-bedding in the sand.

0.8 State Route 21. Turn east.

0.9 Turn north. Cross bridge.

0.4 Railroad tracks. Continue northward.

1.2 Top of ridge. Resistant sandstone. This sandstone is less uniform than the last one you saw. A few large inclusions of siltstone occur in the sandstone. They apparently slid into the stream.

0.6 This hilly area is sand dune topography of recent origin. Notice the loose, uncemented sand along the road.

2.0 Windblown sand to the west. Blowouts.

0.5 Schoolhouse.

0.2 Turn west. Hard, blocky, Tongue River Formation sandstone is exposed along the road.

0.1 Smooth sandstone surface with some iron oxide nodules. This is a windscoured area, a blowout. The gray and brown banding is apparent here; the beds appear to dip to the northwest (notice the exposure across the gully to the southwest).

1.1 Exposure of recent, windblown sand along the road. It is probably only several tens of years old. This sand is darker, due to included organic material, than is the sand of the Tongue River Formation. Notice the dunal topography for the next mile or so.

2.3

Turn south.

0.9

Exposure of light gray sand. This sand contains abundant, nearly spherical sand concretions that are slightly brown in color.

0.1

Sand dunes east of the road.

3.5

Paved road to Carson. End of trip.

MORTON COUNTY FIELD TRIP

(total distance about 42 miles)

Distance Between Points (miles)	
	Begin trip in Mandan at the corner of 6th Ave. E. and Main St. E. Drive south through the underpass on State Route 1806.
0.7	Bridge over the Heart River. The Heart River rises in Billings County and flows through Dickinson. Prior to glaciation, the river flowed northeastward through Burleigh County, but the glacier diverted it and other rivers, forming the Missouri River.
0.3	The area you are driving over is part of the Missouri River floodplain. The floodplain extends to the river on the left.
0.4	Climb off the floodplain.
0.8	The sediment exposed in the road cuts on the right is part of the Cannonball Formation.
0.4	The boulders on the slopes are glacial erratics.
0.9	Missouri River floodplain to the east. The valley through which the Missouri River flows dates to the Pleistocene, when glaciers diverted all the east-flowing streams so that they flowed southward along the margin of the glacier. However, in some places, already existing valleys were used if they were available. It is possible that a preglacial stream flowed northward through this part of the Missouri River valley.
0.6	Missouri River on the left. Notice the many small "steps" on the hillside. These formed as a result of animal activity. First bison, and later cattle, horses, and sheep, tended to follow a single elevation as they walked around the hills. Eventually, the steps developed due to continued compaction by the animals.
0.2	Fort Lincoln State Park.

0.7

The road here is built on a gravel terrace of the Missouri River. The terrace represents a level, a floodplain, at which the river flowed for a time.

0.2

Descend off the terrace to a lower level.

0.5

Railroad overpass. Continue southward over the Missouri River floodplain.

0.3

Notice the abundant glacial erratics in the gully.

0.7

Gravel pit in Missouri River terrace gravel. This gravel is composed of a combination of rocks that were washed out of the glacial sediment and therefore originated to the northeast in Canada, and rocks that were washed in from the west in Montana.

1.5

The road here is built on a gravel terrace. Notice the distinct scarp on the left that separates the terrace from the floodplain below.

0.8

The hillslopes to the west that form the edge of the Missouri River valley have a distinctive vegetation pattern. The trees and shrubs grow best in the small draws and gullies where moisture is most plentiful.

1.4

Bridge over the Little Heart River.

0.7

Gravel pit on the left.

0.7

Hell Creek Formation sediments are exposed in the bluffs to the west with Cannonball Formation sediments at the top of the bluffs.

1.4

The hilly topography on the face of the bluffs to the west has formed as a result of landsliding. The materials in the cliffs slid down as the valley was cut.

1.2

To your left the Missouri River is rapidly eroding into its floodplain.

0.6

Exposure of Hell Creek Formation sediment on the west. The Hell Creek Formation is of Cretaceous age, about 105 million years old.

2.3

STOP 1. Small area of badlands topography. Walk over these badlands, hunting for petrified wood, small pieces of dinosaur bones, and other fossils. Notice the accumulations of ironstone, the dark brown rock on the surface in places. Note how erosion forms caves and "pipes" (holes that open at both the top and bottom).

1.6

Huff. The church here is constructed of field stones, mainly glacial erratics. Turn south (right) onto gravel road at the first corner at the south edge of Huff.

1.1

As you drive southward over the gravel road toward the bluffs, you are traveling over alluvial material, sand and gravel that has washed out of the hills ahead onto the terraces you have been on for the past several miles. Notice the gradual ascent even though you have not yet reached the bluffs.

0.3 Begin climbing bluffs.

0.2 Notice the exposures of coal along the road. These exposures are in Paleocene age Ludlow Formation sediments, mainly sand and shale. The Ludlow is about 20 feet thick here and overlies Cretaceous Hell Creek Formation sediments, which form most of the slope below. The Paleocene Cannonball Formation is exposed near the top of the hill.

0.2 STOP 2. Park your car where the road reaches the upland and walk down the hill, looking at the various beds of material exposed along the road. Just above the coal bed is a layer of carbonaceous shale with leaf fossils. A short search should turn up some fair fossils, which, however, tend to be fragile.
For a good view of the Missouri River valley, climb to the top of the hill west of the road.
End of trip. Return to the highway by driving south, then east back into the valley.

SIOUX COUNTY FIELD TRIP

(total distance about 44 miles)

Distance Between Points (miles)

Begin trip at Fort Yates Post Office. Drive west out of town over glacial and alluvial (stream deposited) material onto a flat Missouri River terrace. The river flowed over this surface at some time in the past 10,000 years, depositing a layer of gravel.

0.9 Gravel pile on the south side of the road. This terrace gravel is about six feet thick and overlies lake sediment that was deposited in a lake that formed when the valley was dammed by glacial ice. Apparently, the river that was dammed to form the lake was a north-flowing one, part of the regional preglacial drainage pattern.

0.9 Turn north on State Route 24. Continue driving over the Missouri River terrace deposits. The bluffs to the west are composed of Fox Hills Formation sandstone.

1.0 The cattails on either side of the road in the ditches indicated a high water table.

0.6 Pelican Inn. Look to the west and notice how the trees are restricted to gullies cut into the Fox Hills bedrock slopes. These gullies are partially filled with washed in (eluvial) material that retains moisture much more efficiently than does the bedrock.

1.2 Climb hill, driving off the low terrace onto Fox Hills Formation bedrock.

0.3 Notice the boulders at the corner on the left. These are erratics that were transported to the area by the glaciers.

0.6

Crest of hill. The hills on the west horizon are composed of Hell Creek Formation bedrock.

1.2

Turn west on paved road. The valley to the right through which Porcupine Creek flows is a melt water trench that carried water along the south edge of the glacier. As much as 200 feet of alluvial fill has been found by test drilling in the valley. At the time the valley was cut by glacial melt water, the Missouri River was not yet in existence and Porcupine Creek continued southeastward across southwestern Emmons County.

0.4

Yarrow (on the north side of the road) is most common on poor soil.

0.6

STOP 1. The roadcut on the left side of the road exposes glacial lake deposits and Fox Hills sandstone. The lake sediment is only a few feet thick and occurs only on the face of the roadcut. Notice the fine banding in the lake sediment. Can you find places where this bedding is contorted due to slumping and sliding that took place when the lake was in existence? Apparently, the lake formed in Porcupine Creek valley when a glacier that advanced somewhat later than the one that formed the valley blocked the valley, causing water to back up, much as Lake Oahe backs up into the valley today. This lake probably dates to the time the Missouri River valley in this area was cut.

1.5

STOP 2. This hilly area is dune topography. What material forms the dunes? Can you find a source for this material? The vegetation on this dunal area is typical of such areas; wild onions, roses, and wolfberry are common.

0.8

Road curves to the west. What plant do you see covering the valley floor? In this area it indicates that the water table is fairly high.

0.6

Gravel road to the right. Continue straight. Notice the change in vegetation as you climb out of Porcupine Creek valley onto the Fox Hills upland. The Fox Hills Formation is exposed in roadcuts for the next three miles.

1.3

STOP 3. Exposure of Fox Hills Formation sandstone. The brown band contains abundant carbonaceous (carbon-rich) material as well as abundant chips of petrified wood. Notice the fault in the band; it results in the carbonaceous zone being offset somewhat.

1.2

Notice the buckbrush (wolfberry) and sage in the valley.

0.6

STOP 4. Here you can see brown, carbonaceous (organic-rich) shale of the lowermost part of the Hell Creek Formation overlying sandstone of the Fox Hills Formation. Dig in both formations. The Hell Creek shale is almost a lignite, although it contains too much extraneous material to burn. You may find a few poorly preserved leaf fossils by careful crosswise splitting of pieces of the shale.

0.4

Notice the brush in the draw. What correlation can you draw between water supply and plant height?

0.1

Exposure of Hell Creek Formation on the right. The Hell Creek deposits form badlands topography wherever erosion is sufficient. Notice the iron and manganese-rich purple and brown debris at the base of the slope.

0.5

Watch for herons in the stream to the south of the road.

2.7

All the rock exposures in this area are of the Hell Creek Formation. South of the road about a mile are the Porcupine Hills, which are covered by a resistant layer within the Cannonball Formation, which overlies the Hell Creek beds. The upper part of the Hell Creek Formation is about 105 million years old and contains abundant dinosaur fossils, particularly in southwestern North Dakota. The overlying Cannonball Formation is only about 65 million years old and it contains no dinosaur fossils.

The land here is generally poor for crops such as wheat, because the underlying Hell Creek Formation tends to form poor soils.

1.0

Notice the pediments (flat erosion surfaces) at the north end of the Porcupine Hills south of the road. What do the naturally-growing lines of trees mark?

1.0

Native prairie on the south side of the road along the stream.

0.3

Junction with State Route 6. Turn north, continuing over the Hell Creek Formation sandstone.

0.5

Road to Shields. Continue to the north.

1.0

Notice the hayfield. What can you infer about water conditions in this area?

0.8

STOP 5. Badlands developed in the Hell Creek Formation. The bare slopes here allow erosion to proceed rapidly. Notice the bands of vegetation that follow moist horizons in the rock. The dark colored debris on the surface is weathered siderite, iron carbonate. Large numbers of concretions can be found and careful searching may turn up some dinosaur bones. Cattle bones are also common so be careful to observe the location in which you find any bones and determine whether they are "in place." If you have a camera, photograph a fossil before removing it.

Petrified wood is common. These fossils help us to understand the environment under which the sediment was deposited in Cretaceous time. The climate was warm and moist, something like that in the Everglades of Florida today. Streams flowing over the area deposited the sand, and dense forests grew in the nearby lagoons.

Notice the "pipes" and "caves," both the result of water erosion. Water rushing down the slopes carves out hollows in the sandstone. These hollows broaden downward as the water flows through them. Tunnels are also common in the gullies and mudflow deposits can be seen in a few places. All these features indicate a rapid rate of erosion in this area. The vegetation in the area is typical of desert badlands: sage, bunch grasses, cacti, and lichens. Notice how erosion is retarded wherever plants are established.

End of trip. Turn around and return to Fort Yates.

STARK COUNTY FIELD TRIP

(total distance about 33 miles)

Distance Between Points (miles)	
	Begin trip by heading south on North Dakota Highway 22 from Villard in Dickinson.
0.1	Railroad underpass.
0.5	Bridge over Heart River.
0.7	Turn west on gravel road.
0.9	Continue west as main road curves southward.
0.1	STOP 1. Clay pit on the north. This clay pit is in Golden Valley Formation sediment of Eocene age. The light colored clay at the top of the Heart River bluff is Golden Valley sediment; the darker shales of the Paleocene Sentinel Butte Formation are exposed below the Golden Valley. The light gray clay was once used in the manufacture of face brick, building tile, and fire brick, with plants located at Dickinson and Hebron. Operations ceased at Dickinson in the late thirties. A sewer pipe plant opened at Dickinson in the early sixties, but was only operated until 1970. It used Golden Valley clay. The broad bends in the river below are meanders characteristic of a stream with a gentle gradient. Here at Dickinson, near the headwaters of the Heart River, the floodplain is much narrower than at Mandan. The hill to the southwest is capped by a relatively hard Golden Valley sandstone, which was once used in constructing many of the basements in older Dickinson homes. Turn around and return to Highway 22.
1.0	Turn south on North Dakota Highway 22. You will be traveling over Golden Valley Formation topography. Numerous small, light-colored exposures of Golden Valley sediment can be seen along the road. Continue southward past the Dickinson airport.
4.0	Dickinson airport. Elevation 2,589 feet.
1.8	The valley of Dry Creek, where the highway crosses it, is in Sentinel Butte Formation sediment. Surrounding higher areas are in Golden Valley Formation sediment.
0.2	Turn west on gravel road. The hills to the south are in the Golden Valley Formation and the gravel road goes up on the Golden Valley Formation in about a half mile.
3.0	Small hill south of the road is made of Golden Valley Formation. In about a half mile you will pass from the Golden Valley into the White River Formation. All the hills on the horizon ahead are White River Formation, which is Oligocene in age.

2.0

Turn north on gravel road. Travel over White River topography for about two miles, then down onto Golden Valley topography.

2.9

Ash Creek.

0.1

Turn west on a gravel road toward White Butte. Road passes onto White River Formation in a short distance.

2.9

STOP 2. White Butte is the isolated butte north of the road. Walk southeast to the butte south of the road. The hard, brown rock scattered over the surface close to the road is silicified lignitic shale weathered from the Golden Valley Formation. As you approach the butte, notice how the white sand cuts downward across the bedding planes into the orange shale. The large gray rubbly blocks are blocks of conglomeratic sandstone that have tumbled down from the top of the butte where they form the cap rock except for a little gray, bentonitic clay on top. The white sand marks the base of the White River Formation, which overlies the Golden Valley Formation. Notice how in some places the white sand cuts well into the yellowish orange layer. The orange layer is an old (Oligocene and older) soil zone that represents a long time of exposure to weathering before the White River sediments were deposited on top of it. The orange color is due to limonite (oxidized iron) staining.

Numerous fossils have been found at this location, and, with some hunting, you may find a few bone fragments. Fossils that have been collected here include fish, frogs, reptiles (including four genera of crocodilians), a small bird, and mammals, including rodents, carnivores, pantodonts, perissodactyls, and artiodactyls.

An eagle's nest is located on a high, isolated rock in the badlands area.

Turn around and drive east.

0.8

Road goes up on to the White River Formation.

1.0

The rim of the hill we are on is dark brown to gray micaceous sandstone, a hard zone high in the Golden Valley Formation. We are near the White River-Golden Valley contact here.

0.2

Hard, resistant sandstone bed beside road to the north.

0.9

Turn north. The bluff of Ash Creek just south of the corner is in the Golden Valley Formation.

2.0

Lignite and lignitic shale of the Sentinel Butte Formation just southeast of corner. Descend on to the Heart River floodplain.

0.7

Bridge over the Heart River. Butte of Golden Valley to the southeast.

0.4

Railroad crossing.

1.2

Old highway 10. Turn east and return to Dickinson. End of trip.

GEOLOGIC ROADLOG FROM BELFIELD TO NEW TOWN

(total distance about 118 miles)

Distance Between Points (miles)	
	Begin trip at the junction of U.S. Highway 85 and Interstate Highway 94 at Belfield. Drive north on Highway 85 over rolling ranchland. The few buttes that occur here are carved from Paleocene Sentinel Butte Formation sediments. Most of the land is grassland; the Little Missouri River badlands begin about six miles west of here.
1.2	Mile marker 77.
1.3	The bright yellow beds in the ditch in this area are in the Eocene Golden Valley Formation.
3.4	Stark-Billings County line. To the west a few miles is a mine where lignite was once mined and burned leaving a uranium-rich ash that was further processed elsewhere to extract the uranium.
2.6	Small exposure of scoria on the east side of the road. The scoria acts as a resistant caprock in many places so that it is commonly seen on top of hills and buttes.
0.2	Cross the easterly-flowing Green River.
0.1	Watch for patches of white on bare places late in summer and during dry periods. These alkali deposits accumulate on the surface as mineral-rich groundwater seeps to the surface and evaporates, leaving the salty residue behind.
0.5	Scoria exposures along the road.
0.3	Small scoria pit west of the road.
0.8	Mile marker 86.
3.5	Small, abandoned lignite strip mine a quarter mile east of the highway. Spoil piles are not obvious on this reclaimed area.
0.5	Mile marker 90.
0.6	St. Demetrius Ukranian Catholic Church.
1.7	The boulders west of the road are pseudoquartzite. Although they are similar in appearance to glacial erratics from a distance, they are not of glacial origin, as this area was not glaciated.
0.9	Pseudoquartzite-covered ridge.
0.9	Mile marker 94.

2.3

Fairfield. The bright yellowish exposures along the road in the Fairfield area are Golden Valley Formation sediments.

2.6

Pseudoquartzite-covered ridge. The resistant pseudoquartzite acts as a caprock and is therefore responsible for keeping the ridge from eroding away.

1.1

Mile marker 100.

4.0

Mile marker 104. The large buttes in the distance to the northeast are the Killdeer Mountains, about 20 miles away. The Killdeer Mountains have a caprock of resistant material of Miocene age, which keeps them from eroding away.

2.7

Billings-McKenzie County line.

1.1

Junction with North Dakota Highway 200. Continue northward.

0.6

Little Missouri River National Grasslands.

0.6

Bright orange beds of Golden Valley Formation to the east.

3.4

Town of Grassy Butte. Grassy Butte is named for one of the neighboring buttes, that has long been a landmark, for among many similarly-shaped elevations in this vicinity, Grassy Butte is the only one not bare of vegetation. The Old Post Office is a log structure, adobe-covered, sod-roofed.

0.8

Mile marker 113. Sentinel Butte Formation sediments are exposed in highway cuts.

0.6

Lignite is exposed in highway cuts.

2.7

Iron-stained sandstone concretions on the east side of the road.

3.8

Mile marker 121. Entering breaks of the Little Missouri River.

1.3

Custer National Forest campground to the west.

1.4

Scenic view. The wall is constructed of pieces of petrified wood and scoria. Notice that some of the pieces of scoria have a melted and fused appearance.

0.3

Notice how the trees follow the draws across the valley. They grow best in the lower, moister areas.

0.4

Lignite seam exposed in the roadcuts.

0.6

Scenic overlook. The horizontal layers in the Sentinel Butte Formation sediments you see here are the result of streams depositing layers of material as they flowed at successively higher levels. The vegetation tends to follow these layers because certain layers, for example, the lignite beds, are more moist than others and plants grow best there.

0.5 Small fault, a displacement in the original layering, can be seen in a cut on the west side of the highway. Notice how the coal seam here ends abruptly against sandstone on the north. The sandstone has dropped relative to the coal.

0.9 Complexly faulted bedrock is exposed in cuts on either side of the highway just south of the bridge. This faulting is probably the result of mudflows or landslides in the Sentinel Butte sediments, perhaps near a river while the soft and unconsolidated materials were still being deposited.

0.2 Bridge over the Little Missouri River. The Little Missouri River has carried about 40 cubic miles of material away from the badlands area since the carving of the badlands began.

0.6 Sentinel Butte beds standing on end just north of the bridge.

0.1 Entrance to North Unit Theodore Roosevelt National Memorial Park.

1.0 Mile marker 128. The bank immediately north of the mile marker sign is subject to recurring landslides. Notice the angles at which the trees grow from the slope.

1.0 Scenic turnout. The inscription on the sign reads as follows:

Badlands Scenery U.S. Highway 85

> This is a typical side canyon, V-shaped with boxed-in shear walls, providing drainage to the Little Missouri River several hundred feet below. Dark green juniper and cedar forests on the north-facing slopes contrast with the sage-covered south slopes.
>
> This observation point is near the southern limit of the vast continental glacier that once moved south across this part of North Dakota. The level skyline visible through the windgap to the south is a remnant of a broad, almost undisturbed landscape that was laid down before the Great Ice Age.

0.7 Scoria pit to the west. In the area from here northward, watch for glacial erratics, boulders that were carried here by the glaciers. The glacier advanced as far south as the present course of the easterly-flowing Little Missouri River, causing it to acquire its present route to the Missouri River. Prior to the time it was diverted by the glacier, the Little Missouri River flowed northward past Williston where it joined another river and flowed on into Canada.

6.9 Bridge over Spring Creek.

3.7 Mile marker 140.

1.2 Bridge over Cherry Creek.

0.6 Watford City.

0.2 Junction of U.S. Highway 85 and North Dakota Highway 23. Continue ahead through Watford City on Route 23.

0.4 Turn east on Route 23.

0.6 Mile marker 1 on North Dakota Highway 23.

0.3 Bridge over Cherry Creek.

2.1 This area has been glaciated, although the evidence of glaciation is not readily apparent in most places. Occasional patches of boulders that were carried to the area by the glaciers are about the only evidence you are likely to see. The large buttes in the area are typical of unglaciated terrain; the ice that covered this area was relatively thin and came early in the ice age. For these reasons, most evidences of glaciation have been removed. As you travel north and east, evidence of glaciation becomes more pronounced.

2.0 Bridge across Cherry Creek.

1.3 Notice the abandoned stream channel of Cherry Creek. This is called a meander scar.

1.2 Bridge across North Fork Creek.

1.9 Bridge across North Fork Creek.

0.9 Bridge across North Fork Creek.

0.4 Bridge across North Fork Creek.

0.1 Watch for patches of white alkali in places.

0.4 Bridge across North Fork Creek.

0.6 Mile marker 12. Scoria-capped buttes can be seen in this area.

1.0 The area to the south of the highway is the Pershing oil field. The wells here produce oil from rocks of Mississippian age about 7,000 feet deep.

3.3 Junction of State Highways 23 and 73 at Johnson's Corner. Turn north on 23. The abundant scoria throughout this area caps some of the buttes, and sandstone layers in the Sentinel Butte Formation form a caprock on other buttes.

4.0 Notice the oil wells along the highway. This area is part of the Camel Butte oil field. Wells here produce from two different depths; Devonian rocks at about 11,000 feet and Mississippian rocks at about 9,000 feet.

0.6

Sandstone-capped butte east of the highway. Notice how the sandstone breaks into large, boulder-sized chunks as it falls down the slope.

1.3

Mile marker 22.

2.8

Keene.

0.9

Glacial erratics become more abundant in the fields north of Keene.

2.6

Highway curves to the east.

2.3

This area is typical glaciated terrain, although the glacial deposits are only a few feet thick. Notice the slightly more hummocky land surface and the closely-spaced hills.

0.6

Mile marker 31.

4.6

Fort Berthold Indian Reservation.

2.6

Junction of State Highways 23 and 22. Continue east on 23.

0.9

Mile marker 45.

0.6

The gravel on the north side of the road is related to an early, higher level of the Missouri River.

0.2

Four Bears Memorial Bridge over Lake Sakakawea and the Missouri River. County line between McKenzie and Mountrail Counties.

0.8

East end of bridge.

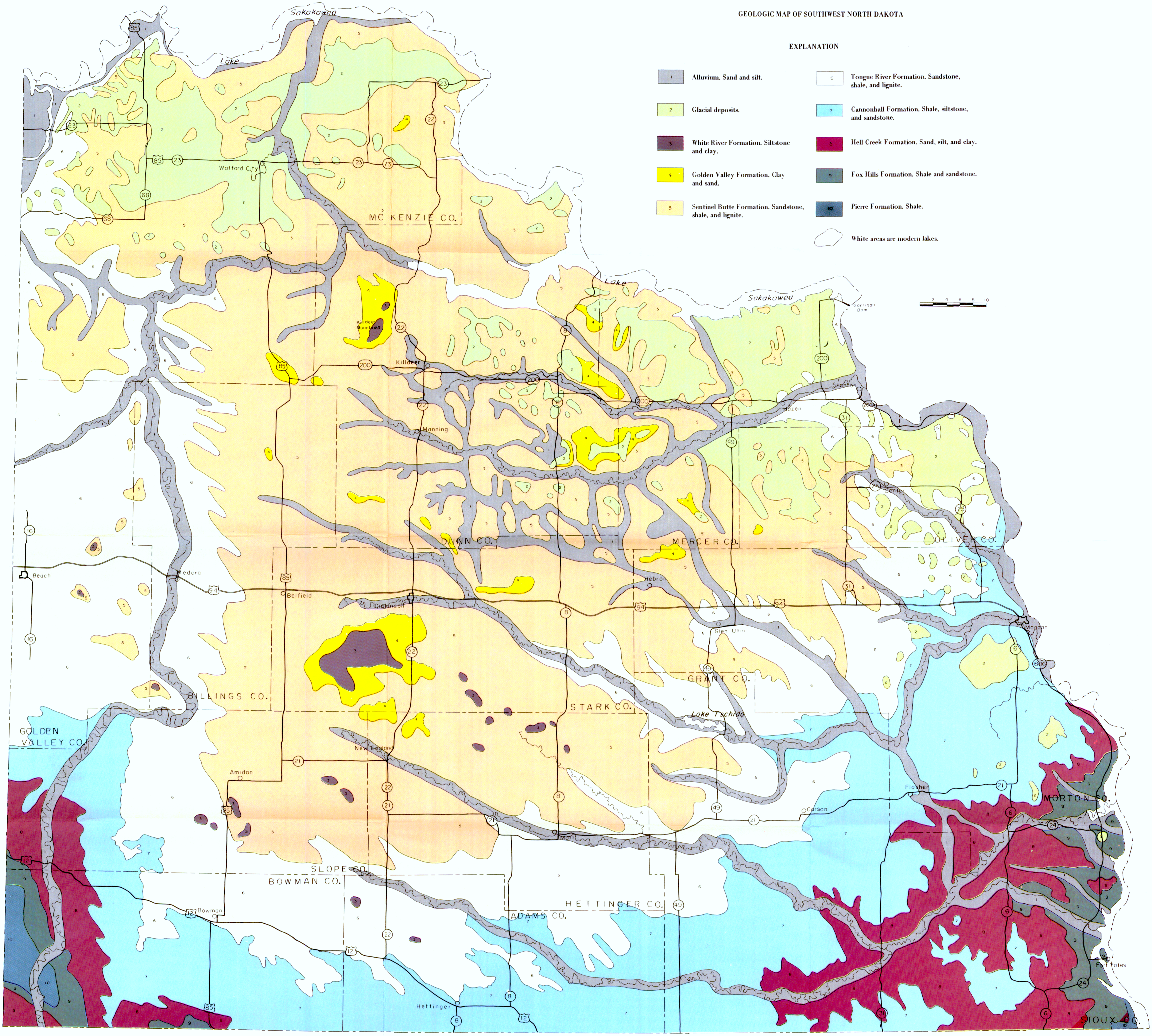
0.5

The road to the north leads to the top of Crow-Flies-High Butte. The view from the top of the butte of the Missouri River valley and Lake Sakakawea is outstanding.

2.1

New Town. New Town was begun in 1950 to replace the towns of Van Hook, Sanish, and Elbowoods, which were all flooded when Garrison Dam was built.

End of roadlog.


GEOLOGIC MAP OF SOUTHWEST NORTH DAKOTA
EXPLANATION
1 Alluvium. Sand and silt.
2 Glacial deposits.
3 White River Formation. Siltstone and clay.
4 Golden Valley Formation. Clay and sand.
5 Sentinel Butte Formation. Sandstone, shale, and lignite.
6 Tongue River Formation. Sandstone, shale, and lignite.
7 Cannonball Formation. Shale, siltstone, and sandstone.
8 Hell Creek Formation. Sand, silt, and clay.
9 Fox Hills Formation. Shale and sandstone.
10 Pierre Formation. Shale.
White areas are modern lakes.
Lake Sakakawea
Garrison Dam
MC KENZIE CO.
DUNN CO.
MERCER CO.
OLIVER CO.
BILLINGS CO.
GOLDEN VALLEY CO.
STARK CO.
GRANT CO.
MORTON CO.
SLOPE CO.
BOWMAN CO.
HETTINGER CO.
ADAMS CO.
SIOUX CO.
Watford City
Killdeer Mountains
Killdeer
Manning
Zap
Hazen
Stanton
Center
Beach
Medora
Belfield
Dickinson
Hebron
Glen Ullin
Mandan
Lake Tschida
New England
Amidon
Flasher
Carson
Mott
Bowman
Hettinger
Fort Yates