North Dakota Geological Survey

WILSON M. LAIRD, *State Geologist*

BULLETIN 45

North Dakota State
Water Commission

MILO W. HOISVEEN, *State Engineer*

COUNTY GROUND WATER STUDIES 6

GEOLOGY AND GROUND WATER RESOURCES

DIVIDE COUNTY, NORTH DAKOTA

PART I
GEOLOGY

By

DAN E. HANSEN

Prepared by the North Dakota Geological Survey
in cooperation with the United States Geological Survey,
North Dakota State Water Commission,
and Divide County Board of Commissioners

GRAND FORKS, NORTH DAKOTA
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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents ground water basic data, and Part III describes the ground water resources.

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THE GEOLOGY OF DIVIDE COUNTY

by Dan E. Hansen

ABSTRACT

Divide County is underlain by 11,500 to 13,600 feet of Paleozoic, Mesozoic, and Cenozoic rocks that dip south toward the center of the Williston basin. The Paleozoic rocks, which overlie Precambrian rocks, are mostly marine carbonates and evaporites that are 5,600 to 7,000 feet thick. The Mesozoic and Cenozoic rocks are generally clastics that are 5,600 to 6,600 feet thick. Most of the 5,100 to 5,200 feet of Mesozoic rocks are marine shales, but continental beds, 500 to 1,450 feet thick, were deposited during the Late Cretaceous and Early Tertiary.

Immediately beneath the glacial drift, the continental, lignite bearing Paleocene Tongue River and Sentinel Butte Formations, which are 0 to 890 feet thick, are found in isolated and small outcrops; most of the outcrops are along the Missouri Plateau escarpment of northeastern Divide County. Overlying the continental beds in places, a few thin deposits of Late Tertiary and Quaternary brown quartzite river gravels were found at the base of the drift. The gravels are associated with the shallow, drift-covered bedrock topography.

Late Tertiary-Quaternary topography in Divide County was formed by the two major drainage systems of the northeastward flowing preglacial Missouri and Yellowstone Rivers. Three sets of topographic levels formed during the incising of these streams have been identified. In descending order they are correlated with the No. 1, No. 2, and No. 3 benches previously identified in northeastern Montana. The preglacial channels of the Missouri and Yellowstone Rivers in Divide County are 550 to 750 feet below the No. 1 bench.

After the benches had been formed, the preglacial drainage systems in Divide County were blocked by glacial drift. Further south, these drainage systems were diverted by a glaciation, which was probably prior to the Wisconsinan. In Divide County, the buried drainage systems are indicated by sags in the glacial drift topography.

The glacial drift, which is the surface formation throughout the county, probably consists of four or five drift sheets. The drift is up to 638 feet thick in the buried preglacial valleys, but the average thickness of the drift is about 175 feet. The glacial drift can be separated into three clastic lithologic groups; these are: (1)

clay and silt, generally lake deposits, (2) sand and gravel, generally outwash deposits, and (3) till, the stony mixture of sand-silt-clay that was deposited in the form of moraines by the glacial ice.

Glacial landforms associated with the surficial drift sheet were deposited in four phases during the northeastward recession of the Late Wisconsinan glacier terminus from Divide County; the phases are, in decreasing age, the (1) Hamlet-Grenora, (2) Smoky Butte-Fertile Valley, (3) Plumer-Alkabo, and (4) Long Creek. The larger landforms associated with the phases on the Missouri Coteau are meltwater channels, dead-ice moraine, end moraine, collapsed lake sediment topography, and collapsed outwash topography; the larger landforms associated with the phases on the Drift Plains are ground moraine, lake plain, outwash plains, meltwater channels, and ice-contact deposits with irregular landforms. Recent clays, silts, and sands occur over the glacial drift as small and isolated veneers. Because of the semiarid climate and interior drainage, sodium sulfate deposits occur in the glacial depressions of southwestern Divide County.

Mineral resources or potential mineral resources of Divide County are deposits of petroleum, lignite, clay, sand and gravel, sodium sulfate, sodium chloride, and possibly potassium chloride. The only mineral resource exploited on a large scale is the petroleum. Production of lignite in Divide County ceased when the large strip mine at Noonan was recently closed and the glacial sands and gravels are mined on the basis of small needs. The petroleum, which has been trapped by a combination of structural and stratigraphic changes, is produced from fragmental limestone beds of the Mississippian Madison; the beds are at depths from 6,377 to 7,956 feet below surface. Large areas of the county are virtually unexplored for petroleum.

INTRODUCTION

Purpose and Scope of Study

This report describes the geology of Divide County, which is located in northwestern North Dakota. The geological investigation is part of a cooperative ground water project sponsored by the North Dakota Geological Survey, the North Dakota State Water Commission, and the Ground Water Branch of the Water Resources Division of the United States Geological Survey. Reports dealing with the ground water basic data and the hydrological studies are published separately as Parts II and III of this Bulletin.

The primary objective of this study was to provide a map of the surficial geology of the county and to derive an understanding of the processes that shaped that geology. Secondary objectives were to study the subsurface geology and to describe the occurrence of mineral resources associated with the surface and subsurface rocks.

Methods of Study

The surficial geology of Divide County was mapped during the 1962 and early 1963 field seasons by Dan E. Hansen and Theodore F. Freers, with aid from C.A. Armstrong. Basic field information was plotted on 1960 county highway maps, scale 1:63,360, prepared by the North Dakota Highway Department. Aerial photo stereo pairs (taken in 1961), scale approximately 1:20,000, obtained from the United States Department of Agriculture were used as an aid in the plotting of the geologic contacts. Topographic maps distributed by the United States Geological Survey, scale 1:24,500, were available for certain parts of the county, and these maps were also used in plotting the lithologic contacts and landforms. Outside of the areas where large scale topographic maps are available, the U.S. Army maps, scale 1:250,000, were used as a guide to interpret the terrain.

The mapping was done along section lines, with transportation by automobile; inaccessible areas were either covered by foot or by cross-country vehicle. The lithologies were determined on these traverses by inspection of roadcuts and samples taken with hand shovel and auger; pebble counts were made and samples collected for laboratory analysis. The colors of the sediments were determined by comparison with the Rock Color Chart (Goddard, and others, 1951).

The glacial subsurface geology was studied by use of mechanical and lithologic logs made during test well drilling, which was completed in 1964. The nonglacial rocks were chiefly studied by use of mechanical and lithologic logs from the files at the North Dakota Geological Survey and by use of published circulars in which the samples from exploratory oil wells are described.

Acknowledgments

The help of the various individuals and agencies involved in this study is appreciated. Dr. Wilson M. Laird, State Geologist, visited the writers in the field and made helpful suggestions. The cooperation of Edward Bradley, former District Geologist, U.S. Geological Survey and his successor, Delbert Brown, is certainly appreciated.

Lithologic descriptions of the test hole cuttings were provided by Larry Froelich and Roger Schmid of the North Dakota State Water Commission. C.A. Armstrong, of the U.S. Geological Survey, provided test hole data and other valuable information. Mr. Samuel J. Tuthill, former student at the University of North Dakota, identified the Pleistocene mollusks that were collected; Mr. Denis L. Delorme, former student at the University of Saskatchewan, identified the ostracods.

Previous Work

REGIONAL STUDIES

The kinds of topography and glacial deposits that occur in Divide County were briefly described by Dawson (1875) in a report about the surficial geology of central North America along the international boundary between Canada and the United States. The generalized description of the surficial geology by Dawson was incorporated into a small part of Chamberlin's (1883, p. 396) report about the moraines of the Missouri Coteau, a range of glacial hills northeast of the Missouri River in North Dakota. The course of the preglacial Missouri River (which is now buried in part by glacial deposits of the Missouri Coteau) was thought by Beekley (1910, p. 323) and Bauer (1915, p. 52-58) to extend from the vicinity of Poplar, Montana, to at least the west edge of Divide County. The statewide groundwater report by Simpson (1929, p. 118-119) included a general description of the geology and topography of the county.

The glacial terrain of Divide County was briefly described by Alden (1932, p. 126-129). In that report Alden used the term Altamont moraine for the Missouri Coteau as he believed the range of hills to be a terminal moraine. The sag in the Missouri Coteau southwest of Crosby was thought by Alden to indicate the preglacial valley of the Yellowstone River. He also believed the sag in the Coteau that extends from Alkabo to Colgan indicated the preglacial valley of the Missouri River.

In an unpublished thesis, Alpha (University of North Dakota, 1935) discussed the geology and ground water of a four county area that included Divide County. Alpha described the Altamont moraine in Divide County. He also outlined the trends of the preglacial Missouri and Yellowstone River valleys in Divide County.

The usage of the term Altamont moraine by Alden (and Alpha) was questioned by Townsend and Jenke(1951 b). Townsend and Jenke believed the term Altamont should not be used on the Missouri Plateau because the type area as defined by Leverett (1932) is a long distance to the southeast and no proof of equivalency on the Missouri Plateau exists. They proposed the name Max moraine be applied to that width of glacial hills in North Dakota commonly referred to as the Missouri Coteau. The term, Max moraine, was also introduced to avoid a certain genetic implication because the glacial hills on the Missouri Plateau had also been thought by Chamberlin (1883) and Alden (1932) to indicate a wide and extremely long terminal moraine. In their comprehensive summary of the North Dakota Pleistocene geology, Lemke and Colton(1958)called the moraine on the Missouri Plateau that has high relief, knobby topography, and few internal lineations dead-ice moraine; since then, most of the till deposits of the Missouri Coteau have been mapped as dead-ice moraine.

The geology in southwestern Divide County was included in a detailed report by Witkind (1959). The results of Witkind's work and the work of several other individuals of the United States Geological Survey, who also mapped geology in Northwestern North Dakota and northeastern Montana during that time, were incorporated by Howard (1960) into a regional report of the Cenozoic geology of northeastern Montana and northwestern North Dakota. In reports previous to the one mentioned above, Howard had discussed the usefullness of caliche in glacial chronology of the area including Divide County (Howard, 1946, p. 1204, 1947a, p. 1194-1195). Howard (1950 and 1956) also studied the composition of the pebbles in the tills of this area. Four drifts and a moraine in northwestern North Dakota were described by Howard, and others, (1946) and Howard (1947b). A map showing the extent of the outwash, end moraines and stagnation moraine in adjacent northeastern Montana was prepared by Colton, and others, (1961). The glacial geological map of North Dakota by Colton, and others, (1963) shows some of the landforms in Divide County. In Saskatchewan, Christiansen (1956) mapped the glacial geology of the Moose Mountain area, which is immediately to the north of Divide County. In the report Christiansen gave a synthesis of Pleistocene history that was illustrated by diagrams showing the position of the ice front in relationship to the more prominent surficial glacial landforms.

The rocks that occur beneath the glacial drift in Divide County and surrounding area have been described in regional reports about the subsurface of the Williston basin; most of this literature is listed in the recent article, "Sedimentary and Tectonic History of North Dakota Part of Williston Basin," by Carlson and Anderson (1965). The article by Carlson and Anderson includes maps showing the areal extent of the Sequences and formations; it also includes a brief description of the rocks.

LOCAL STUDIES

Parts of the surficial geology of Divide County were mapped by personnel of the United States Geological Survey on a scale equivalent to that of this study. These detailed studies were, however, done chiefly to provide geologic data for engineering studies by the Bureau of Reclamation.

The general geology of the 15 minute Noonan quadrangle was mapped by Townsend (1954a). Special attention was directed to the ice-contact features and the outwash-filled channels. The terminology (includes definitions) of the ice-contact features is different, for the most part, than that used in this report. The general geology of the Crosby quadrangle, was also mapped by Townsend (1954b) and in a special section of the report the ground water resources of the quadrangle were discussed by LaRocque. The general geology of the Rival No. 2 (Columbus) quadrangle, just east of Divide County, was mapped by Townsend and Jenke (1951a).

The general geology of the southwestern part of Divide County and adjacent area in northern Williams County were mapped and the reports placed on open-file. The geology of Zahl No. 3 quadrangle was mapped by Gott, Lindvall and Hansen. The report was placed on open-file during 1948 (Lindvall and Hansen, 1948). The general geology of the Zahl No. 4 quadrangle was mapped by Gott, Lindvall, and Hansen and the preliminary report placed on open-file in 1947 (Gott, 1947). The preliminary report of the geology of the Kermit quadrangle by Lindvall and Hansen (1947) was placed on open-file in 1948. In these reports a complete analysis of the glacial landforms in the areas involved was not included.

GEOGRAPHY

Location

Divide County lies in the northwestern corner of North Dakota and is bounded on the north by the 49th parallel and the Province of Saskatchewan, Canada and

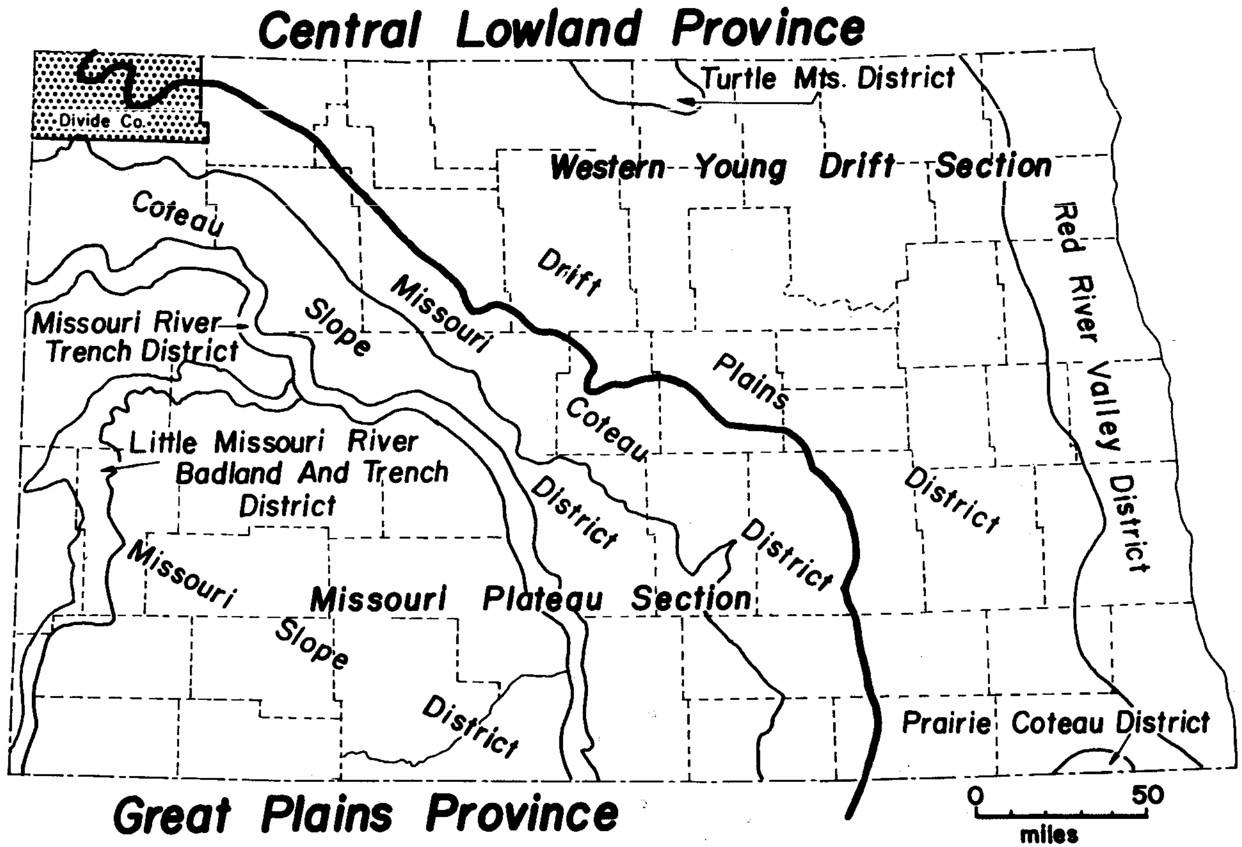


Figure 1. Location of Divide County and the several physiographic subdivisions of North Dakota.

on the west by Montana (fig. 1). In North Dakota the county is bounded on the east by Burke County and on the south by Williams County. The county lies between 48° 37.5' and 49° north latitude and 103° to 104° west longitude. The southern boundary is approximately 33 to 45 miles north of the Missouri River. Divide County is almost rectangular in shape and includes townships 160-164 north and ranges 95-103 west. The total area is 1,303 square miles.

Population, Towns, and Transportation

Divide County had a population of 5,566 people in 1960 (U.S. Bureau of Census, 1960). The largest town in the county is Crosby, the county seat, which had a population of 1,759 in 1960. The other towns in the county and their populations are as follows: Noonan (625), Ambrose (220) and Fortuna (185); Alkabo and Colgan are unincorporated communities. The abandoned communities of Kermit, Stady, Paulson, Fertile and Plumer may still appear on some maps. There are international ports of entry north of the towns of Noonan, Ambrose, and Fortuna.

Two branch-line railroads serve the county. The towns of Crosby and Noonan are served by both the Great Northern and the Minneapolis, St. Paul and Sault Ste. Marie (Soo) Railroads; the Soo Railroad also serves Ambrose, Colgan, Fortuna, and Alkabo. Two hard-surfaced roads, North Dakota State Highway No. 5 and U.S. Highway No. 85, completely cross the county; a segment of North Dakota State Highway No. 40, which is also hard-surfaced, crosses the northeastern part of the county. Several other all weather roads make most of the county accessible by car, and in addition, a high percentage of the section lines have roads and trails that are passable during dry weather. The nearest U.S. airports on scheduled airline flights are at Williston and Minot; Crosby has an airport with grass landing strips and a beacon.

Climate

The climate of Divide County best fits the description by Trewartha (1954, p. 280-288) of the interior continental, dry semiarid or middle latitude steppe climate. On the steppe, temperature variations are relatively rapid day to day, the winters are relatively cold, streams are intermittent, and the greater part of the precipitation falls during the summer. The annual amount of precipitation is quite variable. Thornthwaite, (1948, p. 1) classifies the climate in this area of North America as that of the dry, sub humid and microthermal with a wide temperature range. Records of the temperatures and precipitation have been kept at Crosby for more than 52 years. The temperature extremes during one year have been as great as -47°F to 111°F. The average January temperature is 3.6°F and the July average 67.7°F. The average annual precipitation is 14.09 inches with most of the precipitation failing in the form of rain during the months of May, June, July and August. The growing season is normally 122 days as determined from the earliest and the latest killing frosts in the fall and spring (U.S. Department of Agriculture, 1941, p. 1045).

Native Vegetation

Before settlement by farmers in the early 1900's the dominant native vegetation in the county were the mixed prairie grasses that still occur over most of the grazing areas. Marsh grasses grow in the sloughs and along the streams and lakes; alkaline tolerant plants grow in the areas of high salinity. The most common native shrub in the county is the low shrub, wolfberry (buckbrush); other common native shrubs are the prairie wild rose, the western wild rose, and the buffaloberry. There are few trees in Divide County and of these the greater number have been planted. In southeastern Divide County and along the international boundary north of Crosby groves of aspen and willows, with an occasional cottonwood, grow on the rims of shallow depressions; this growth indicates localized, high water table conditions. Low cactus and dwarf sagebrush are also found throughout the county.

Physiographic Units

Divide County lies partly in the Great Plains province and partly in the Central Lowland province with the division line at the Missouri Plateau escarpment (fig. 1). Both provinces are a part of the Interior Plains major physiographic division (Fenneman, 1946). The subdivisions of the glaciated Missouri Plateau in the county are the Missouri Coteau district and a very small part of the Coteau Slope district. The only subdivision of the Central Lowland province in Divide County is the Drift Plains district.

The Missouri Coteau of Divide County is an area of stony and very hilly (hummocky) moraine, collapsed glacial outwash sediments with hilly topography, collapsed glacial lake sediments with rolling topography, numerous sloughs and small lakes, and nonintegrated drainage. The hilly topography is chiefly due to large scale stagnation near the margins of a continental glacier. Several end moraines are present on the Coteau. Elevations on the Coteau range from slightly less than 2,000 feet above sea level in the bottoms of large kettles to 2,433 feet above sea level at the Writing Rock historical site. The average elevation is about 2,225 feet above sea level (pl. 2, topographic map).

The Drift Plains district in Divide County encompasses the area north of the escarpment of the Missouri Plateau; ground elevations in the district range from 1,850 feet above sea level at the international boundary where Long Creek crosses into Canada to over 2,200 feet above sea level south of the town of Fortuna. The drainage system consists of intermittent and ephemeral streams. The land form is chiefly a relatively flat ground moraine plain, which has a gradual northeast slope. Outwash-filled channels occur on the plain as a system of extinct glacial drainage; a deposit of lake sediments, several ice-contact deposits, and localized outcrops of bedrock also occur on the plain.

Soils

The soils of Divide County are of the Chestnut great soil group, the dark brown loams, clayey loams, and sandy loams of semiarid grassland areas (U.S. Dept. of Agriculture, 1938, p. 979-1001 and 1941, p. 274-279). The soils in Divide County are subdivided by Omodt, and others, (1961) into the Williams-Zahl, Oahe-Sioux, Oahe-Roseglen, and Williams soils on the hilly land of the Missouri Coteau; and the Williams, Roseglen, Williams-Cresbard, Cresbard-Cabour soils on the low, rolling surface of the Drift Plains. The Cresbard-Cabour or alkaline soils occur north of Noonan. This alkaline soil has a claypan subsoil (solentz) and is associated with the nonalkaline Chestnuts.

PRE-QUATERNARY STRATIGRAPHY

Divide County lies on the north flank of the Williston basin, a structural basin containing a thick sequence of sedimentary rocks. The sedimentary rock units that lie above Precambrian rocks were deposited during the Paleozoic, Mesozoic, and Cenozoic Eras (fig. 2). During the time span that includes rocks of Cam-

ERA	SYSTEM	FORMATION	COLUMN	LITHOLOGY	THICKNESS (Feet)	DEPTH TO FM. (Feet)
CENOZOIC	QUATERNARY	Glacial Drift w/ Quartzite Gravel		Clay-Silt, Sand-Gravel, Stony Clay-Silt-Sand: Gravel	0-638 0-37	0 0-488
	TERTIARY	Tongue River–Sentinel Butte		Siltstone, Claystone, Sandstone, Lignite, Shale	0-900	0-560
		Ludlow–Cannonball		Claystone, Siltstone, Sandstone, some Lignite	210-370	200-1,000
MESOZOIC	CRETACEOUS	Hell Creek– Fox Hills		Claystone, Siltstone, Sandstone: Sandstone and Shale	220-312 101-291	550-1,330 750-1,500
		Pierre		Shale	2,000-2,225	953-1,688
		Niobrara — Carlile		Marlstone, Limestone, Shale	346-403	2,960-3,860
		Greenhorn–Belle Fourche		Marlstone, Limestone, Shale	235-297	3,310-4,270
		Mowry–Newcastle		Shale, Sandstone	119-226	3,580-4,580
		Skull Creek		Shale	200-262	3,720-4,740
		Fall River–Lakota		Sandstones	290-510	3,930-4,980
	JURASSIC	Swift		Shale, Sandstone	392-548	4,310-5,220
		Rierdon Piper—Nesson		Shale Limestone, Shale, Sandstone Limestone, Anhydrite	91-108 239-260 230-267	4,688-5,810 4,790-5,920 5,040-6,150
	TRIASSIC (?)	Spearfish		Siltstone, Sandstone	174-360	5,270-6,400
PALEOZOIC	PENNSYLVANIAN	Amsden–Tyler		Dolomite Sandstone, Shale	0-171 0-239	6,240-6,690 6,300-6,870
	MISSISSIPPIAN	Otter–Kibbey		Shale Limestone, Sandstones	0-140 106-310	6,920-7,040 5,590-7,200
		Poplar Interval		Halite, Limestone, Dolomite, Anhydrite	347-514	5,700-7,500
		Ratcliffe Interval		Limestone, Halite, Anhydrite, Dolomite	283-353	6,040-8,000
		Madison Undiffereniated		Limestone	1,023-1,221	6,310-8,340
		Bakken–Three Forks		Shale, Sandstone Siltstone, Dolomite	90-104 163-223	7,640-9,090 7,730-9,205
	DEVONIAN	Birdbear–Duperow		Limestone, Dolomite	98-104 443-506	7,990-9,430 8,090-9,530
		Souris River–Dawson Bay		Dolomite, Limestone	316-370 120-150	8,600-9,970 8,970-10,310
		Prairie		Halite, Anhydrite	322-455	9,090-10,460
		Winnipegosis		Dolomite, Limestone	189-230	9,400-10,920
	SILURIAN	Interlake		Dolomite, Limestone	600-900	9,600-11,150
	ORDOVICIAN	Stonewall–Stony Mountain		Dolomite, Shale	224-252	10,200-12,000
		Red River		Limestone, Dolomite	429-529	10,390-12,100
		Winnipeg		Shale, Sandstone	220-300	10,820-12,700
	CAMBRO–ORDOVICIAN	Deadwood		Sandstone, Limestone	600-800 (?)	11,000-13,000
	PRECAMBRIAN			Unknown	Unknown	11,500-13,600

Figure 2. Stratigraphic column, Divide County, North Dakota.

brian through Cretaceous age, the rock units were deposited chiefly in the marine environment; non-marine rocks were deposited during the Late Cretaceous and Early Tertiary. The total thickness of the sedimentary rocks in southern Divide County may be as much as 13,600 feet, as estimate based on drill hole data and projection of rock units (fig. 3) from wells in adjacent areas. The projection of rock units was necessary because only four of the numerous petroleum exploratory wells drilled in Divide County have penetrated below 10,000 feet, and none of the four wells penetrated Cambro-Ordovician or Precambrian rocks.

Precambrian Rocks

Precambrian rocks are at depths that probably range from 11,500 feet in northwestern Divide County to 13,600 feet in southern Divide County. The composition of the rocks is unknown in the county. Precambrian rock samples from deep wells in nearby Williams County, North Dakota, and Sheridan County, Montana, were identified by Carlson (1960, p. 136 and personal communication) as syenite.

Paleozoic Rocks

CAMBRIAN AND ORDOVICIAN

The Deadwood Formation of Late Cambrian and Early Ordovician age nonconformably overlies the Precambrian in northwestern North Dakota. The depth to the formation in Divide County is based on projection (fig. 3) of the overlying rock units and may range from 11,000 to 13,000 feet. The thickness in Divide County may be from 600 to 800 feet (Carlson, 1960, p. 24). The general increase in thickness is toward the southwest. The lithology of the formation is based on core chip and sample studies of deep wells drilled on the Nesson anticline (Carlson, 1960, p. 24-39). Carlson's study shows that the Deadwood Formation in northwestern North Dakota consists of the three major rock units: (1) a basal "syenite wash" that is overlain by a fine-to medium-grained quartzose sandstone, (2) a glauconitic limestone that is interbedded with white, fine-grained sandstone, and (3) an upper unit that consists of quartzose sandstone and gray and greenish-gray shales.

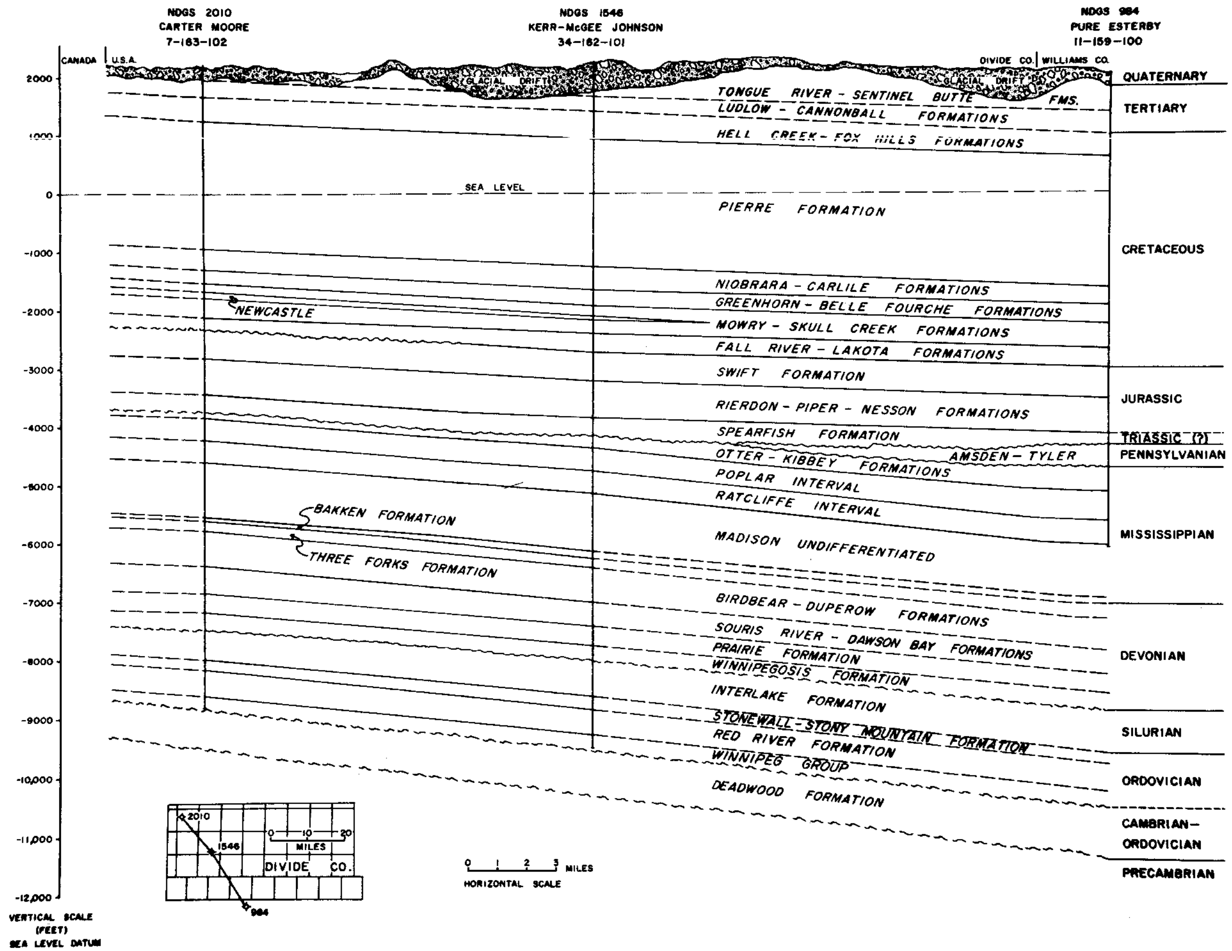


Figure 3. Schematic stratigraphic cross-section, Divide County, North Dakota.

ORDOVICIAN

The Ordovician rocks of Divide County, generally 780 to 970 feet thick, are subdivided into the Winnipeg Group, and Red River and Stony Mountain Formations. The Winnipeg Group, which unconformably overlies the Deadwood Formation, thickens southeastward. It includes three formations that in ascending order are: (1) fine-grained quartzose sandstone, the Black Island, (2) greenish-gray shale, the Icebox, and (3) brownish-gray silty shale, the Roughlock, which is absent because of nondeposition from all but extreme southeastern Divide County.

The Red River Formation overlies the Winnipeg Formation at both a conformable and gradational contact. The Red River Formation thickens to the southeast. The lithology is chiefly a light brownish-gray and yellowish-gray, granular to crystalline limestone and dolomite; thin beds of anhydrite occur in the uppermost part of the formation.

The Stony Mountain Formation also thickens to the southeast in Divide County. The formation consists of two members which are: (1) a lower member, the Stoughton, that consists of gray, fossiliferous shale and limestone beds, and (2) an upper member, the Gunton, that consists of brownish- and yellowish-gray, crystalline limy dolomite and dolomitic limestone beds. A thin bed of anhydrite occurs in the upper part of the Gunton.

ORDOVICIAN AND SILURIAN

The Stonewall Formation of Divide County conformably overlies the Stony Mountain Formation. The thickness increases to the south. The Silurian-Ordovician boundary has been tentatively placed within this formation by Carlson and Eastwood (1962, p. 8-10). The Stonewall Formation consists of anhydrite and gray, crystalline limestone and dolomite beds.

SILURIAN

The Silurian Interlake Formation conformably overlies the Stonewall Formation and thickens from northwest to southeast. The Interlake Formation consists of three intervals (Carlson and Eastwood, 1962, p. 10-13) that are usually identified by mechanical log characteristics coincident for the most part with lithologic changes. The lower interval in Divide County is a light brownish-gray, finely crystalline dolomite; the middle interval is a light yellowish-gray to light brownish-gray, fine and medium crystalline dolomite; and the upper interval is a pinkish-gray to light gray and brownish-gray dolomitic limestone that has both a crystalline and fragmental texture.

DEVONIAN

In northwestern North Dakota rocks of Middle Devonian age lie unconformably above the rocks of the Interlake Formation. The thickness of the Devonian rocks, which includes conformable formations of both Middle and Late Devonian age, ranges from about 1,651 feet to 2,038 feet; the thickening is generally toward the north. The Devonian Formations were first defined by Baillie (1951, p. 575-689) and later described and some units redefined by Sandberg and Hammond (1958, p. 2293-2334).

The Winnipegosis Formation, the basal Devonian rock unit, increases in thickness from north to south. The formation includes a lower unit of interbedded dark-gray, argillaceous limestone and brownish-gray, silty dolomite that is overlain by an upper unit consisting of dense, light gray finely crystalline limestone and a variable thickness of brownish-gray, granular and fragmental limey dolomite. The overlying Prairie Formation increases in thickness to the northeast. The formation consists of a thin basal unit composed of interbedded anhydrite and gray argillaceous limestone of variable thickness, but the main thickness is salt, chiefly halite. Within the salt section, beds that show a high reading on the gamma ray log occur at the same stratigraphic horizon as the potash beds of Saskatchewan.

The younger Dawson Bay Formation also thickens toward the northeast in Divide County. The Dawson Bay Formation in Divide County consists of basal interbedded, gray, argillaceous dolomitic limestones and shales that grade upward into brownish-gray, granular, dolomite and dolomitic limestone; the upper beds also contain anhydrite. Over the Dawson Bay Formation, the Souris River Formation increases in thickness from south to north. The formation in Divide County is a repetitive sequence of cyclic beds that generally consist of (1) gray shales, silty dolomite, and argillaceous limestones (2) brownish-gray, crystalline to fragmental dolomitic limestones and granular to crystalline dolomites, and (3) thin anhydrites.

The lithology of the Duperow Formation is similar to that of the underlying Souris River Formation, but the beds are fewer in number and thicker; the Duperow consists of argillaceous medium dark gray, crystalline and fragmental limestones and beds of anhydrite. The Birdbear Formation consists chiefly of brownish-gray, crystalline and granular, dolomitic limestone and dolomite; anhydrite occurs in the upper part.

The uppermost of the Devonian Rocks, the Three Forks Formation, is chiefly a clastic unit that thickens to the southeast. The Three Forks Formation consists of interbedded greenish-gray and grayish-red shales, reddish silty dolomites, and light gray dolomitic silts. Thin beds of anhydrite occur in the lower half of the formation, inclusions of anhydrite are also found throughout the formation, and thin beds of fine-grained sandstone occur in the upper part.

The Mississippian rocks in Divide County are subdivided into the Bakken Formation, the Madison Group, the Kibbey Formation, and the Otter Formation. The Mississippian rocks, which are about 1,900 to 2,600 feet thick, thicken southward. All the rocks within the system are conformable. The contact between the Bakken Formation and the underlying Devonian Three Forks Formation is disconformable. The Bakken Formation consists of a basal carbonaceous, dark gray fissile shale; an intermediate light gray to gray-brown, fine-grained, calcareous sandstone; and an upper dark gray fissile shale. The overlying Madison Group in North Dakota is subdivided into informal para-time rock units, termed intervals, which are subdivisions based on mechanical log deflections of certain continuous thin clastic beds; the conventional subdivision of the Madison into Charles, Mission Canyon, and Lodgepole Formations is not of practical use to the oil industry in its search for petroleum.

In Divide County the Madison consists of a lower undifferentiated unit, the Ratcliffe interval, and Poplar interval. The Madison undifferentiated includes gray and brownish-gray, argillaceous limestones and light brownish-gray fossiliferous, fragmental to crystalline limestones. The unit thickens southward. The Ratcliffe interval thickens southward, but localized variations in thickness are pronounced. The Ratcliffe includes interbedded, cyclic deposits of anhydrite, light brownish-gray, fragmental limestones and granular, dolomitic limestones, and thin gray shales; the uppermost bed is an anhydrite and halite unit. The Poplar interval also consists of cyclic deposits of thin gray shales, brownish-gray, fragmental limestones and granular dolomitic limestones, and anhydrite and halite, but the number and thickness of the evaporite units is much greater. The total thickness of halite within the interval ranges from 0 to 220 feet. The Poplar interval generally thickens southward, but localized variations are appreciable.

The Kibbey Formation, which overlies the Poplar interval, is chiefly a clastic unit that thins to the north mostly because of two separate intervals of erosion, one pre-Pennsylvanian and the other pre-Jurassic. The Kibbey Formation can be subdivided into three units; their subcrop pattern is shown on figure 4. The lower unit consists of red silt, shale, and fine-grained sandstone; the middle unit is a yellowish-gray, fragmental and crystalline limestone; and the upper unit is a red, fine-to medium-grained sandstone. The overlying Otter Formation also chiefly thins to the north because of the pre-Pennsylvanian and the later pre-Jurassic erosion. The formation is absent in the northern part of the county (fig. 4). The Otter Formation consists of thinly bedded light gray, fragmental limestones and varicolored shales, mostly greenish-gray.

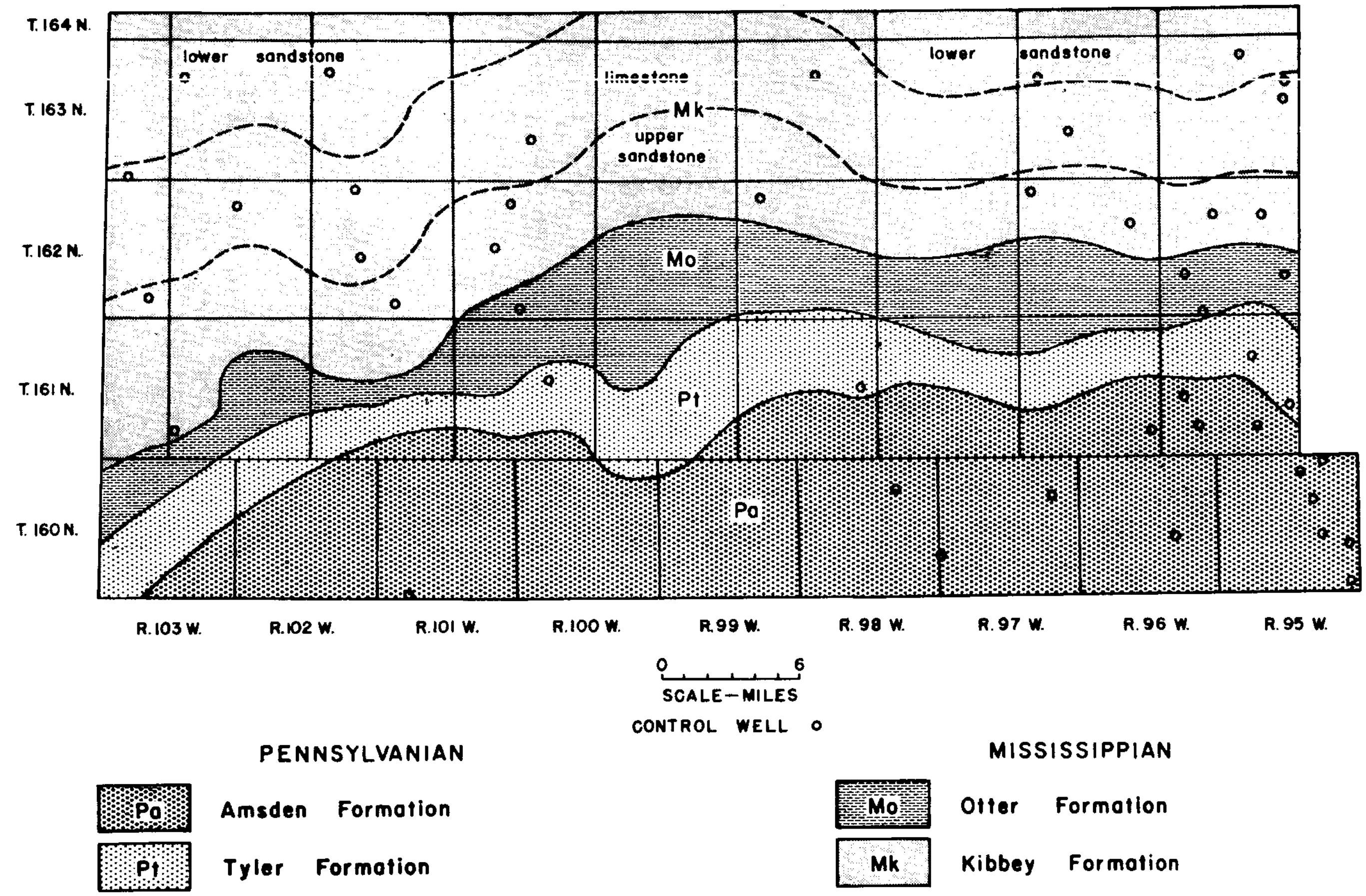


Figure 4. Subcrop map of the upper Mississippian and Pennsylvanian formations.

PENNSYLVANIAN

The Pennsylvanian rocks in Divide County, which overlie the Mississippian rocks unconformably, are subdivided into two formations, the Tyler and the Amsden. Willis (1959, p. 1948) and Foster (1961, p. 89-93) illustrated the regional relationships of the Tyler. The Tyler is absent because of the pre-Jurassic erosion in northern Divide County (fig. 4), but is up to 239 feet thick in southern Divide County. The Tyler Formation in Divide County can be subdivided into two units which are: (1) a lower unit that consists of shale, chiefly dark gray, and an erratic development of gray, quartzose sandstones, and (2) an upper unit that consists of interbedded red and gray shales, and a few thin beds of pinkish-gray and light gray, fine-grained quartzose sandstone. The overlying Amsden Formation, conformable on the Tyler, occurs only in southern Divide County (fig. 4). The Amsden Formation consists of pinkish-gray to light yellowish-gray, crystalline limey dolomite and fragmental, dolomitic limestone.

Mesozoic Rocks

TRIASSIC (?)

According to Dow (1964, p. 127-131), the Spearfish Formation in North Dakota consists of several members of which only one member, the Saude, occurs in Divide County. The Spearfish Formation, unconformably overlying the Paleozoic rocks, consists of interbedded red siltstones, shales, and sandstones. Thickness variations are locally abrupt and reflect the topography of the underlying Paleozoic strata.

JURASSIC

The Jurassic rocks in Divide County, 952 to 1,163 feet thick from southeast to northwest, are divided into a number of conformable formations: the Nesson, Piper, Rierdon, and Swift. The Nesson Formation (Nordquist, 1955, p. 104-106), unconformably overlies the Spearfish Formation. The Nesson Formation consists of three members (Nordquist, 1955) which are: (1) the Poe evaporite, the basal unit of reddish-brown shale and white to pink anhydrite with thin beds of dense, light brownish-gray to light gray limey dolomite, (2) the Picard, a thin reddish-brown and gray shale, and (3) the Kline, the upper unit, that is chiefly a light brownish-gray to yellowish-gray, dense, crystalline, dolomitic limestone with some anhydrite in the basal part and some fragmental and arenaceous limestone in the upper part.

The Piper Formation consists of three members (Nordquist, 1955, p. 99-103), which are: (1) Tampico shale, a heterogeneous sequence of greenish-gray shales and gray to light brownish-gray fragmental and arenaceous limestones overlying a basal red shale, (2) the Firemoon limestone, chiefly a light brownish-gray, fossiliferous, fragmental and crystalline limestone with interbeds of gray shale — some arenaceous limestone and sandstone occur in the basal part, and (3) the Bowes, a sequence of varicolored and variegated shales that are primarily red and brown. The Bowes member contains a few, thin beds of silty, fine-grained sandstone.

Above the Piper Formation, the Rierdon Formation is chiefly a calcareous greenish-gray and light gray shale; red shale occurs at the base of the formation. The overlying Swift Formation consists of three units which are: (1) a basal light greenish-gray to light gray shale with thin beds of fragmental limestone, silt, and quartzose sandstone at its base, (2) a light greenish-gray shale and light gray, glauconitic sandstone unit, and (3) a light gray to light greenish-gray shale that becomes more silty and sandy in the upper part.

CRETACEOUS

The Cretaceous rocks may overlie the Jurassic rocks unconformably in northwestern Divide County, but to the south, toward the center of the Williston basin, there is no evidence of an unconfirmity. The Cretaceous rock units, 3,511 to 4,436 feet thick, are subdivided into three groups, the Dakota, Colorado, and Montana. The Dakota Group, the oldest, includes the Lakota, Fall River, Skull Creek, Newcastle, and Mowry Formations. The Lakota consists of quartzose sandstone, light gray siltstones, light brownish-gray iron-siltstone spherulites, light gray and white clays, and some brown and gray shales. The formation thickens to the south. One of the characteristics of the formation is the erratic occurrence and the great variation in thickness of the sandstones. The Fall River overlies the Lakota Formation disconformably and is a light gray siltstone and quartzose sandstone with gray shales and clays. The contact with the overlying Skull Creek Formation is gradational. The medium and dark gray shales of the Skull Creek, which are thickest in western Divide County, are overlain by the gray quartzose sandstones and shales of the Newcastle Formation. The thickness of the Newcastle ranges from 11 to 100 feet; the greatest thickness is in northwestern Divide County. The overlying Mowry Formation is a medium gray, bentonitic shale that thickens to the west.

Overlying the Dakota group are the several conformable formations of the Colorado Group. All the formations of this group thicken in western Divide County. The oldest, the Belle Fourche, is a dark gray shale with interbedded bentonites. Above the Belle Fourche, the Greenhorn Formation consists of calcareous, dark gray shale, marlstone, and thin beds of limestone and bentonite. The overlying Carlile and Niobrara Formations have a gradational contact that is difficult to pick on the mechanical and lithologic logs. The Carlile is a dark gray, bentonitic shale that is calcareous in the upper part and the Niobrara is a medium to dark gray calcareous shale and marlstone.

Above the Colorado Group, the Montana Group includes the Pierre, Fox Hills, and Hell Creek Formations. The Pierre Formation is a thick shale that changes from a bentonitic, medium to dark gray basal unit to an overlying medium to light gray, massive shale. The formation is thinnest in northeastern Divide County. Lithologic subdivisions of the Pierre are impractical at this time though mechanical logs do show slight changes in characteristics that may be due to changes in lithology.

The Fox Hills Formation, which lies above the Pierre Formation at a gradational and conformable contact, is a marine sandstone and shale sequence that ranges in thickness from 220 to 291 feet in eastern Divide County and from 101 to 238 feet in western Divide County (fig. 5). The nearest outcrops are in the Brockton area of northeastern Montana, about 65 miles southwest of Divide County. The formation consists of three units which are: (1) a basal unit that consists of very fine-to-medium-grained, light gray to brownish-gray sandstone that is 45 to 80 feet thick; (2) a middle unit, generally 50 feet thick, that consists of gray, arenaceous shale in eastern Divide County, but in western Divide County the unit is either a light gray, fine-grained clayey sandstone or an arenaceous claystone; and (3) an upper unit, identified in eastern Divide County, that consists of interbedded gray shales, silts, and very fine-grained sandstones. The sandstones become more massive in the upper part of the unit. The upper unit, 100 to 160 feet thick in eastern Divide County, probably is absent in extreme western Divide County because of erosion.

The Hell Creek Formation, the youngest Cretaceous Formation, unconformably overlies the Fox Hills Formation in western Divide County, but in eastern Divide County the contact is gradational. The thickness of the Hell Creek Formation ranges from 220 feet in eastern Divide County to 312 feet in southwestern Divide County (fig. 6). The nearest outcrops are in the Brockton and Scoby areas of northeastern Montana, about 65 miles southwest and west of Divide County. It is doubtful that the formation crops out in the vicinity of Redstone (about 40 miles west of Divide County) as was shown by Collier (1919, pl. 1); the Redstone area was mapped earlier by Bauer (1914, pl. XVI), and he showed no outcrops of Lance, the old equivalent of the combined Hell Creek - Fox Hills Formations. In Divide County the Hell Creek Formation generally consists of gray and dark brown shales, arenaceous claystones, and brownish sandstones; lignites are absent although much carbonaceous material is found in the forma-

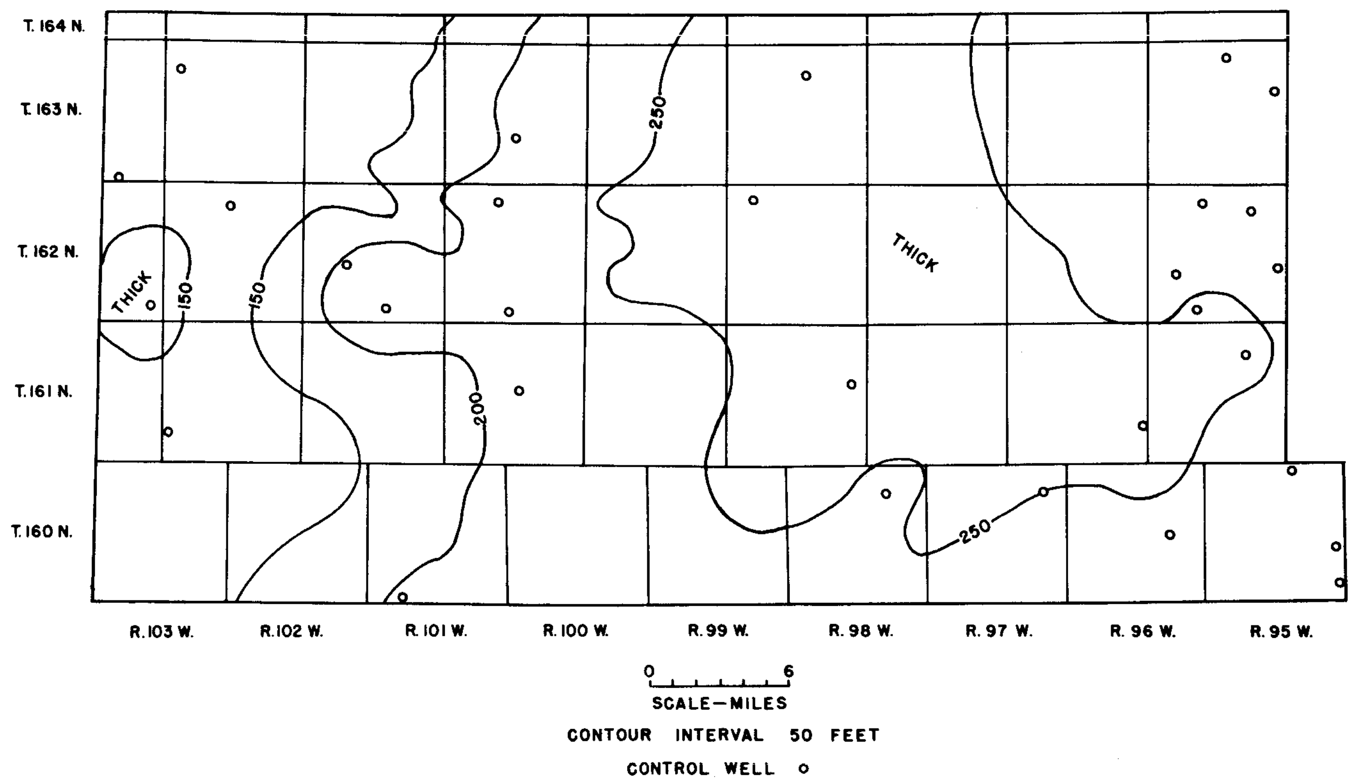


Figure 5. Isopach of the Cretaceous Fox Hills Formation.

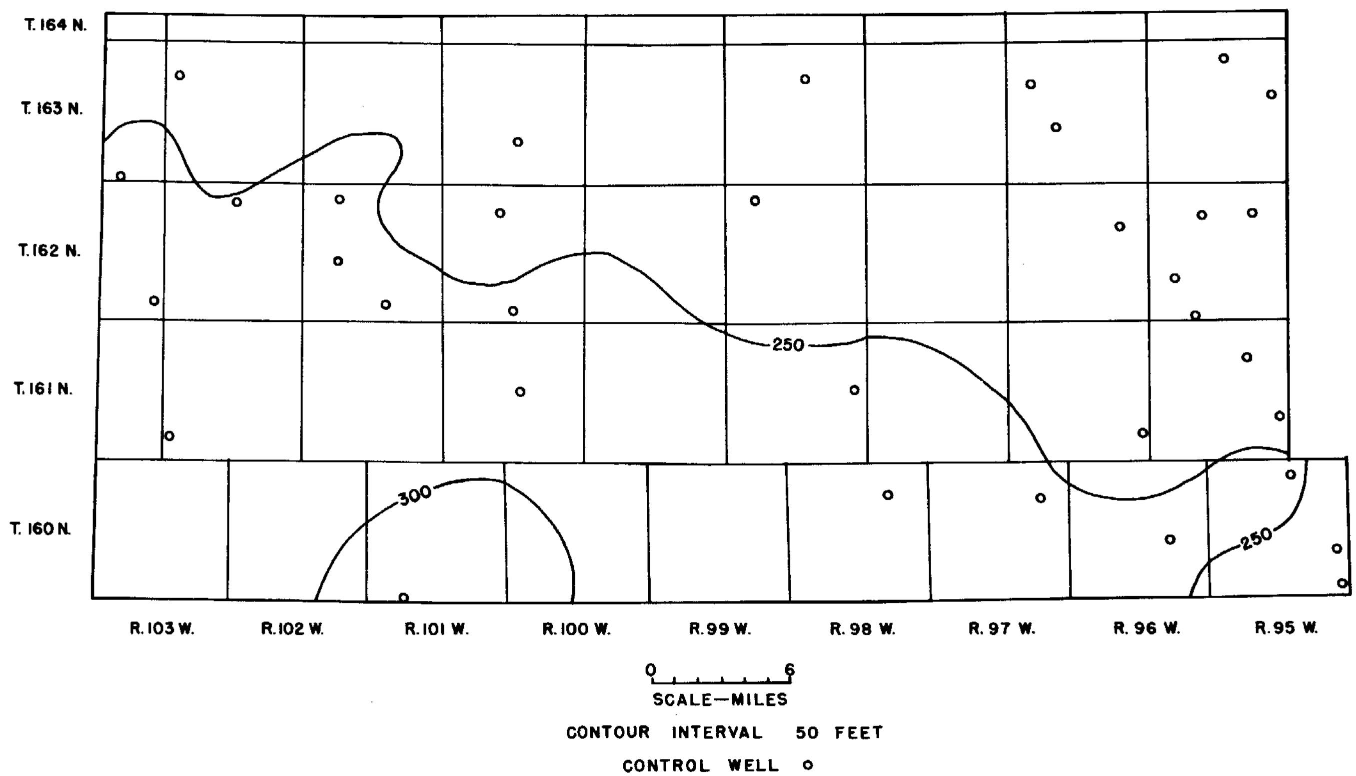


Figure 6. Isopach of the Cretaceous Hell Creek Formation.

tion. The occurrence of the sandstones is erratic except in extreme eastern Divide County where the sandstone beds increase in number and the beds appear to be more continuous.

Cenozoic Rocks

LOWER TERTIARY

The Lower Tertiary rock units are the nonmarine and marine Paleocene Ludlow-Cannonball Formations, undifferentiated, and the nonmarine Paleocene Tongue River-Sentinel Butte Formations, undifferentiated. The Ludlow-Cannonball Formations are not differentiated because they are interfingering formations that are difficult to separate in the subsurface; the Tongue River-Sentinel Butte Formations are not differentiated because little lithologic and no mechanical log data is available for this part of the stratigraphic section in Divide County. The lower Tertiary rocks are generally 200 to 1,130 feet thick; the rocks are thickest in southeastern Divide County.

The Ludlow-Cannonball Formations in Divide County overlie the Hell Creek Formation at a gradational contact. The thickness of the formations (fig. 7) ranges from 210 feet in northcentral Divide County to 370 feet in western Divide County; the thinnest part of the interval is where the formations subcrop beneath the glacial drift in the deeper stream valleys and in the northwest corner of the county. The nearest outcrops of equivalent formations are in the Plentywood and Redstone areas of northeastern Montana; the outcrop areas are about 20 and 40 miles west of Divide County.

The lithology of the nonmarine Ludlow, thickest in western Divide County, is interbedded brownish-gray sandstones and siltstones, greenish-gray and gray bentonitic claystones, brownish-gray shales, and lignites. The lithology of the marine Cannonball, thickest in eastern Divide County, is gray shales, light gray siltstones, and fine-grained, gray and brownish-gray sandstones.

Overlying the Ludlow-Cannonball Formations conformably, the non-marine Tongue River-Sentinel Butte Formations generally lie immediately beneath the glacial drift; isolated exposures are near Alkabo, Writing Rock historical site, Ambrose, and Noonan (pl. 1). The isolated exposures are not large and better exposures are found near Plentywood, Montana, near Estevan, Saskatchewan, and near Hanks, North Dakota. Where the Tongue River-Sentinel Butte Formations are not exposed in Divide County, they may be covered by as much as 560 feet of glacial drift. Maximum thickness of the two formations is almost 900 feet in southeastern Divide County (fig. 8). The Sentinel Butte Formation is limited to the higher preglacial interfluves in southwestern and southeastern

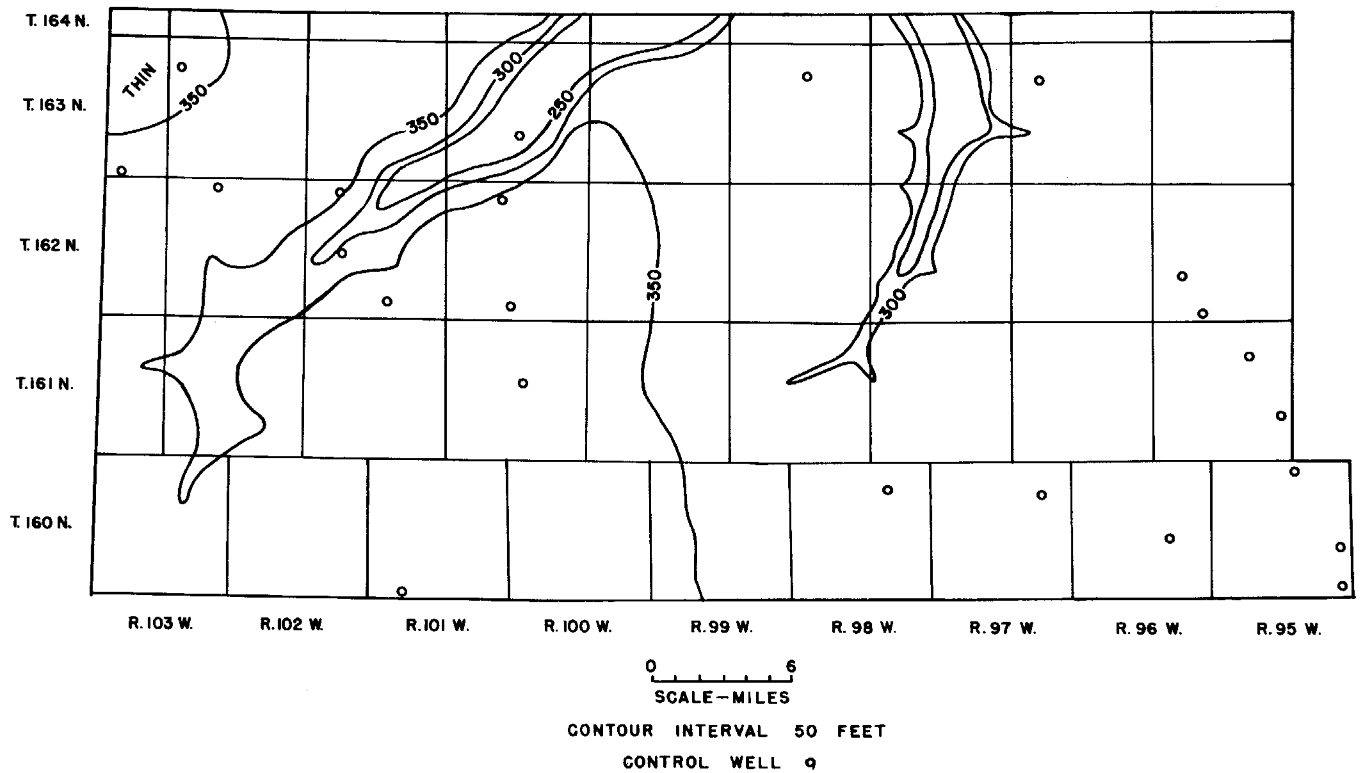


Figure 7. Isopach of the Tertiary Ludlow-Cannonball Formations.

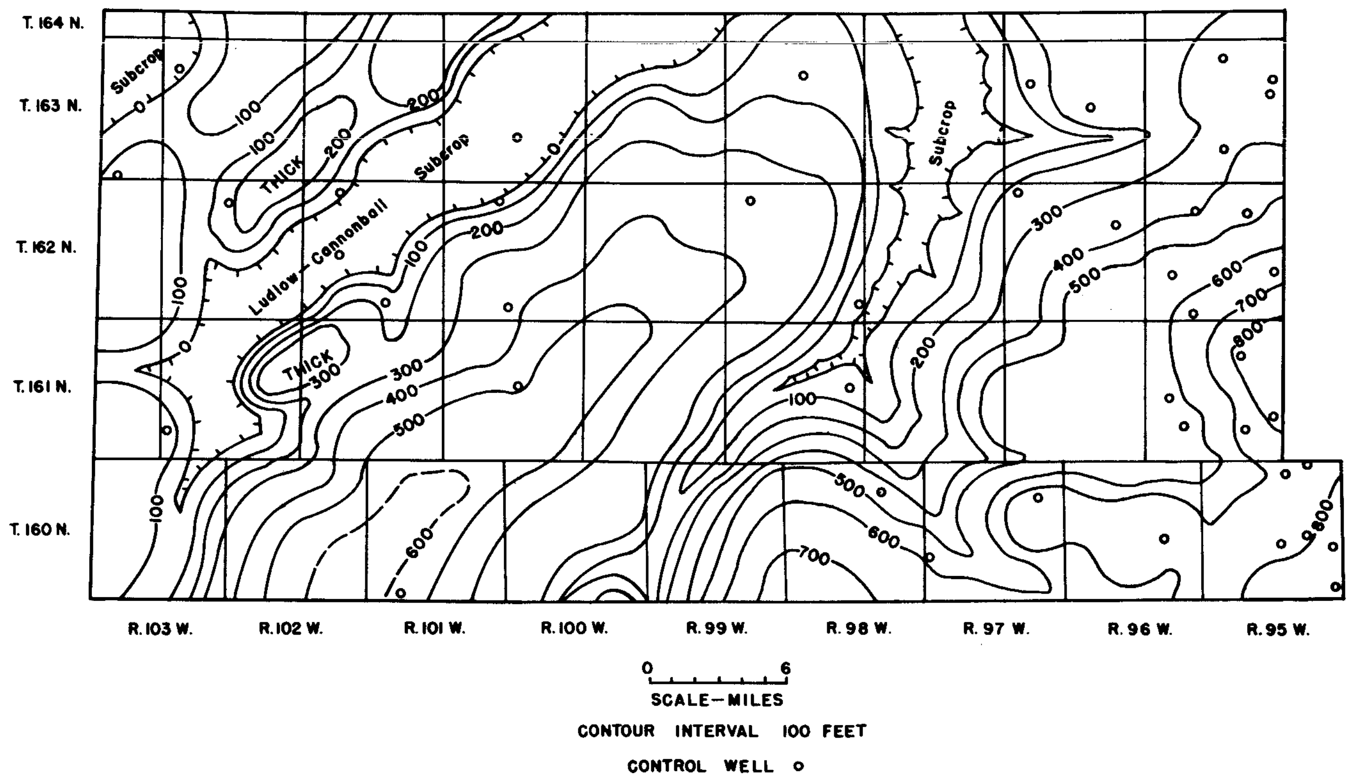


Figure 8. Isopach of the Tertiary Sentinel Butte-Tongue River Formations and subcrop of the Tertiary Ludlow-Cannonball Formations.

Divide County.

The formations consist of interbedded gray, bentonitic claystones and siltstones; friable, yellowish-gray siltstones and sandstones; friable to well-cemented, brownish-gray sandstones; thin beds of greenish-gray claystones and gray limestones; and beds of lignite. Massive sandstones generally occur at the base of the Tongue River Formation; the stratigraphic position of these basal beds can be traced by means of the electric log characteristics. Equivalents of the basal beds of the Tongue River Formation crop out near Plentywood, Montana, where a section of these beds was measured by Bauer (1914, p. 299), and around Big Muddy Lake, Saskatchewan, where the Willow Bunch member of the Ravenscrag Formation, a partial equivalent, was measured, named, and described by McLearn (1930, p. 48-59 and 1931, p. 33). The Willow Bunch member was also described in a report by Frazer, and others, (1935).

STRUCTURE

The sedimentary rocks in Divide County tie on the north side of the Williston basin, an intracratonic basin that had its beginning in Early Paleozoic time. The latest development of the basin took place during the Tertiary, and the outline of the basin (fig. 9), though it is arbitrary, is chiefly the outline after this latest structural deformation.

The southerly dip of the rocks in Divide County is low, however, it does increase with depth. For example, the dip of the Tertiary Tongue River Formation averages about 12 feet per mile, but at greater depth, the dip on the Cretaceous Greenhorn Formation averages about 25 feet per mile and the dip on the Mississippian Ratcliffe interval averages about 50 feet per mile.

The subsurface structures, shown by the contours on the upper surface of the Cretaceous Greenhorn Formation (fig. 10), map as noses that are either in southeast or south trends. The trend of the nose in eastern Divide County is on the north extension of the Nesson anticline. The nose that is continuous from Crosby and south is apparent on all the structure horizons that can be mapped by use of the present well control; the well control is chiefly limited to the Mississippian rocks and above. A gravity map by Hansen (1960) shows a negative anomaly or gravity low on this structural trend. Gravity lows indicate the presence of rocks that are not as dense as the surrounding rocks, and perhaps this structural trend exists because the underlying salt beds of the Devonian Prairie Formation have bulged upward to form an anticline along this trend. The noses in western Divide County are in southeast trends; the strike of the beds is northeast, a change from the general northwest strike of the beds in eastern Divide County.

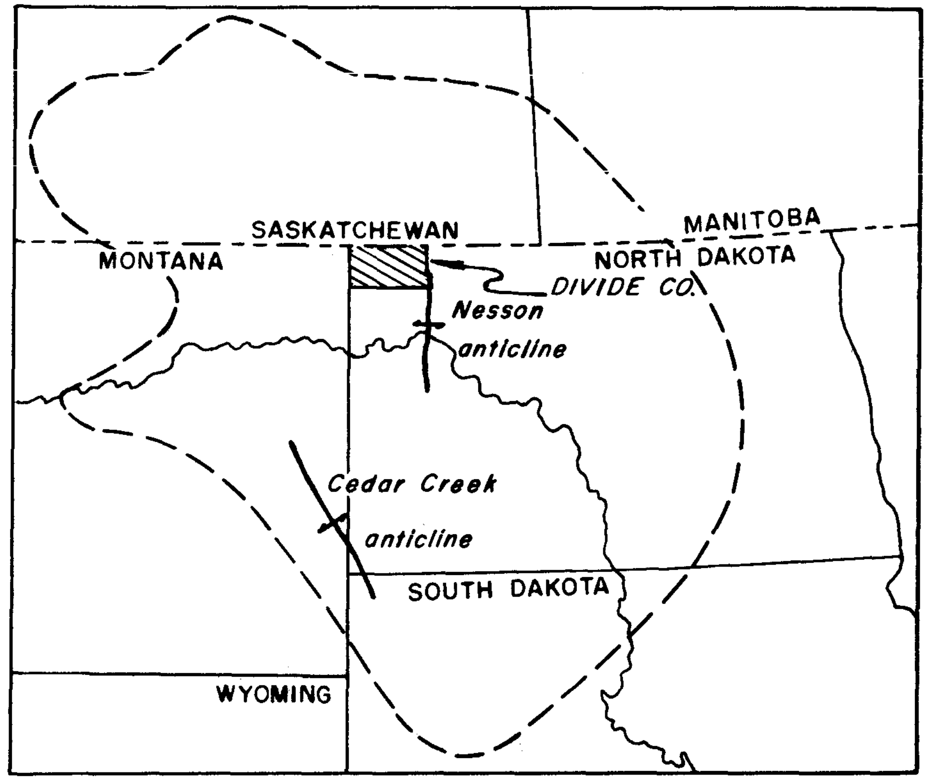


Figure 9. Outline of the Williston basin. The map also shows the location of Divide County and the largest anticlines, the Cedar Creek and Nesson, within the basin.

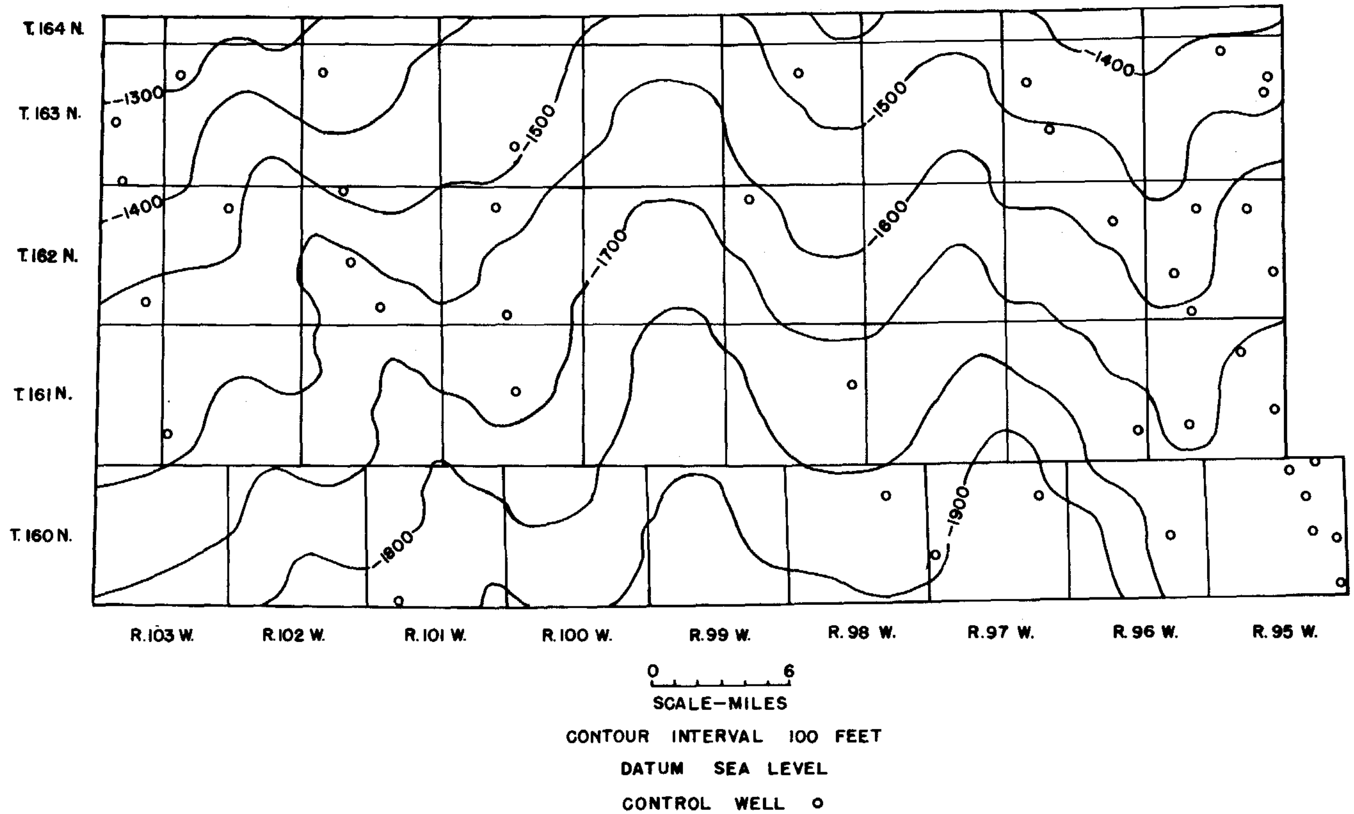


Figure 10. Structure map on the upper surface of the Cretaceous Greenhorn Formation.

QUATERNARY STRATIGRAPHY

Glacial and Non-glacial

UPPER TERTIARY-QUATERNARY

Quartzite gravels

Remnants of brown quartzite gravels, non-glacial in origin, are sparsely exposed in western Divide County. In addition, the same gravels were penetrated in a few of the test wells drilled for this study. In the test wells, the brown quartzite gravels were found to lie beneath the glacial drift and over the bedrock. Although there is some sample contamination or admixture with glacial pebbles, the gravels are similar in composition to the Miocene-Pliocene and Pleistocene brown quartzite gravels of northeastern Montana.

The best exposure of the brown quartzite gravel is north of Alkabo in a roadcut along North Dakota Highway No. 5 in the NW 1/4 SW 1/4, sec. 36, T. 163 N., R. 102 W. In this roadcut, the gravel occurs as a highly tilted bed that is at an elevation of about 2,200 feet above sea level (fig. 28). Poorly exposed brown quartzite gravel also occurs on the slopes south and southwest of the Writing Rock historical site; this gravel is at elevations from 2,200 to 2,300 feet above sea level. The subsurface brown quartzite gravels are found at elevations from 1,642 to 1,921 feet above sea level in western Divide County and from 1,823 to 1,935 feet above sea level in eastern Divide County. The test wells in which the gravels were found are listed in Table I.

The brown quartzite gravels in western Divide County consist chiefly of smooth, well-rounded, brown quartzite pebbles less than 2 inches in diameter (occasionally percussion-market cobbles are found), a few red argillite pebbles, and traces of glacial-derived granitic and limestone pebbles. Sand fills the voids between the pebbles. The thickness of the gravel is from 5 to 37 feet. The brown quartzite gravels in eastern Divide County consist chiefly of smooth, well-rounded, brown quartzite pebbles, chert pebbles, a few andesite pebbles, and a small admixture of glacial granitic and limestone pebbles. The thickness of the gravel is from 1 to 30 feet.

The equivalent brown quartzite gravels of northeastern Montana have been mapped as gravel beds at different topographic levels. Examples of such gravels are the Wiota gravel named by Jensen (1952, p. 45-50), the Cartwright and Crane Creek gravels named by Howard (1960, p. 19-23), and the Flaxville gravel named by Collier and Thom (1918, p. 179-184). The Wiota gravel is associated with landforms adjacent to the valley of the Missouri River; the Cartwright and Crane Creek gravels are associated with landforms adjacent to the valley of the Yellowstone River; and the Flaxville gravel is associated with landforms adjacent to both the Missouri and Yellowstone River valleys.

TABLE 1.

Subsurface occurrence of quartzite gravel in Divide County. The test hole numbers with an * indicate the samples showed definite admixture of glacial gravel with the brownish gravel. The numbers without the * indicate the samples showed a slight admixture of the two different types of gravels.

NDSWCC Test Hole No.	Location	Depth	Surface Elevation (feet)
2244	SW¼ SE¼ SE¼ Sec. 33, T. 163 N., R. 102 W.	175-199	2077
3003*	NW¼ SW¼ NW¼ Sec. 36, T. 160 N., R. 97 W.	288-294	2210
3005	SW¼ SW¼ SW¼ Sec. 18, T. 160 N., R. 102 W.	238-260	2039
3006*	SW¼ NW¼ NW¼ Sec. 19, T. 161 N., R. 102 W.	315-352	2055
3008	NE¼ NE¼ SE¼ Sec. 13, T. 163 N., R. 102 W.	210-236	2113
3011*	NE¼ NE¼ NE¼ Sec. 23, T. 162 N., R. 102 W.	348-358	2076
3020*	NW¼ SW¼ SW¼ Sec. 1, T. 163 N., R. 96 W.	47-48	1870
3022*	NW¼ NW¼ NW¼ Sec. 32, T. 162 N., R. 96 W.	277-298	2186
3023	SW¼ SW¼ SW¼ Sec. 33, T. 163 N., R. 96 W.	88-102	1927
3025	NE¼ NE¼ NE¼ Sec. 5, T. 160 N., R. 103 W.	177-183	2098
3026*	NW¼ NW¼ NW¼ Sec. 2, T. 160 N., R. 103 W.	390-393	2032
3028	NW¼ NE¼ NW¼ Sec. 3, T. 160 N., R. 102 W.	371-383	2117
3032*	SW¼ SW¼ SW¼ Sec. 31, T. 161 N., R. 99 W.	260-270	2195
3035*	SE¼ SW¼ SW¼ Sec. 34, T. 161 N., R. 98 W.	201-229	2100
3080*	NE¼ NE¼ NE¼ Sec. 27, T. 161 N., R. 102 W.	488-505	2130
3081*	SE¼ SW¼ SE¼ Sec. 20, T. 160 N., R. 103 W.	152-162	2044

Bedrock topography

The bedrock topography, immediately below the glacial drift and of Late Tertiary and Quaternary age, has the form as shown on plate 3; this form is an interpretation based on the surface elevations of the bedrock as determined by means of the test hole drilling. The buried topography appears to be similar to that now developed on the soft Tertiary rocks of western North Dakota.

The bedrock topographic map (pl. 3) shows that two large southwest-northeast valleys are continuous across the county. The valley that is continuous from T. 160 N., R. 103 W., to T. 164 N., R. 99 W., contained the northeastward flowing preglacial Missouri River. The valley that is continuous from about T. 160 N., Rs. 99 and 100 W., to T. 164 N., R. 97 W., contained the northeastward flowing preglacial Yellowstone River. Including Divide County, the minimum bedrock elevations in these major preglacial valleys of northwestern North Dakota, southern Saskatchewan, and northeastern Montana indicate a northeastern gradient of the preglacial streams.

In Divide County, the erosional surfaces associated with the development of the preglacial Missouri and Yellowstone River drainage are well hidden by a thick drift cover. In northeastern Montana, however, the preglacial bedrock landforms that are adjacent to the Missouri and Yellowstone Rivers occur at several different topographic levels without a thick glacial cover. The topographic relationships among some of the several landforms in northeastern Montana are illustrated by figure 11, a cross section profile of the Yellowstone River valley above Intake, Montana. In Divide County, the same topographic relationships apply to the preglacial topography. Beginning with the landforms at the higher elevations, the relationships in Divide County and northeastern Montana are as follows:

1. The highest erosional surface in northeastern Montana that can be recognized in northwestern North Dakota is the No. 1 Bench of Alden's report (1932, p. 12-31). This bench is 650 to 900 feet above the bedrock surface in the preglacial channels of the northeastward-flowing preglacial Yellowstone and Missouri Rivers. The bench is covered by a veneer of Flaxville gravel. In Divide County, the erosional surface associated with the No. 1 Bench begins at 2,100 feet above sea level; a plain beginning at this elevation is indicated on the map of the bedrock topography (pl. 3). This plain was partially veneered by a gravel for the brown quartzite gravel exposed in western Divide County is about 2,200 feet above sea level. This gravel is equivalent to the Flaxville gravel.
2. The second highest erosional surface that can be correlated into northwestern North Dakota is the No. 2 Bench of Alden's report (1932, p. 56). In the Yellowstone River valley this bench is veneered by the Cartwright gravel. The bench is about 400 to 500 feet above the bedrock surface of the preglacial

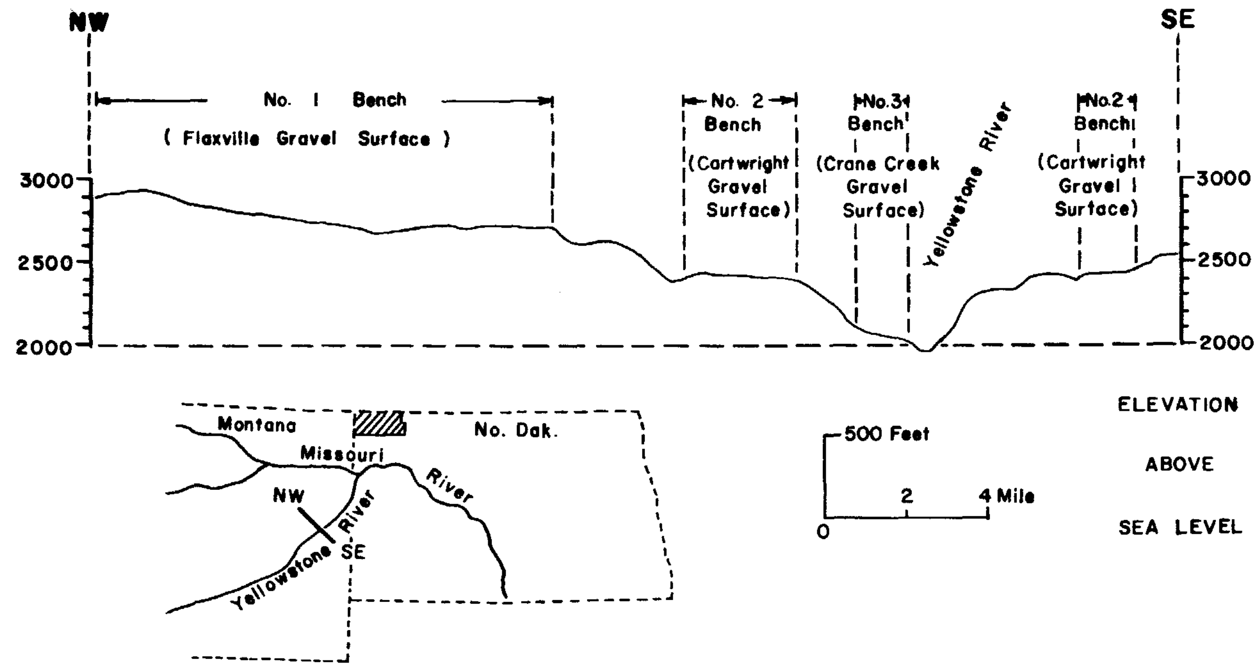


Figure 11. Northwest-southeast cross-section profile of the Yellowstone River valley in northeastern Montana. The profile is from sec. 1, T. 20 N., R. 54 E. to sec. 13, T. 17 N., R. 57 E. and crosses the Yellowstone River near Intake. The numbered benches are used to relate erosional surfaces adjacent to the Yellowstone River valley, northeastern Montana, to erosional surfaces adjacent to the preglacial Yellowstone River valley of Divide County. Names and elevations of the benches and gravels are after Alden (1932) and Howard (1960).

Missouri and Yellowstone channels. In Divide County the erosional surface associated with the No. 2 Bench begins at about 1,800 feet above sea level and extends upward to at least 1,900 feet above sea level; a plain at this altitude is indicated on the map of the bedrock topography in southwestern and northeastern Divide County (pl. 3). A few test holes in eastern Divide County penetrated brownish quartzite gravel at elevations from 1,823 to 1,935 feet above sea level; the gravel is probably equivalent to the Cartwright gravel. In western Divide County a few test holes were drilled through the same kind of gravel at elevations from 1,642 to 1,921 feet above sea level, but no definite surface or surfaces could be associated with the gravel; however, this gravel could be equivalent to Jensen's Wiota gravel, which is at this topographic level and the next lower topographic level.

3. The third highest erosional surface of northeastern Montana is the No. 3 Bench of Alden's report (1932, p. 62-64). In the Yellowstone River valley this bench is veneered by the Crane Creek gravel. The bench is 50 to 150 feet above the bedrock surface of the pre-glacial channels. In Divide County the erosional surface associated with the No. 3 Bench should begin at about 1,500 feet above sea level and should slope upward to at least 1,600 feet above sea level. The test well control is too sparse to denote the surface on the topographic map (pl. 3). In eastern Divide County no brownish gravels were found at this level during the test drilling, but in western Divide County the subsurface brownish gravel found at 1,642 feet above sea level could be from this surface.

In Divide County, several buried northwest-southeast valleys were occupied by tributaries of the two major streams. In southeastern Divide County, the drift-filled valley that is continuous from sec. 13, T. 161 N., R. 98 W., to sec. 25, T. 160 N., R. 97 W., and further to the southeast is one of the larger secondary valleys found during the drilling. The tributary channel in this valley is named the Wildrose Channel. The other tributary channels and their valleys, shown on plate 3, are at this time unnamed because their course as shown is even more speculative. In western Divide County, a large tributary of the preglacial Missouri River may have existed in T. 161 N., R. 103 W.; it may have also been continuous to the northwest in Montana. Further north, the channel in the valley from sec. 33, T. 162 N., R. 102 W., to secs. 4 and 5, T. 164 N., R. 101 W. is either a buried glacial meltwater channel or pre-existing drainage modified by glacial meltwater erosion.

Other bedrock topographic features are the butte-like forms in Tps. 161, 162, 163 N., Rs. 101 and 102 W. These bedrock features now make up a part of the Alkabo end moraine. In addition, the slope on the drift-buried bedrock core of the Missouri Plateau escarpment in northeastern Divide County is less than the slope on the surface equivalent. Deposition of glacial drift has accentuated the height of this slope and the surface prominence of the escarpment is at least partly due to glaciation.

Preglacial drainage history

The two large drainage systems of the preglacial Yellowstone and Missouri Rivers came into existence in Divide County during the Late Tertiary as a consequence of the regional uplift in the northern Rocky Mountains and Plains. In the Late Tertiary and Early Quaternary, the stream systems of northeastern Montana and northwestern North Dakota cut down several times into the underlying rocks in response to different periods of regional uplift, for the existence of planated surfaces, veneered by gravel, at different altitudes means that there were also periods of relative crustal stability.

The pattern of the preglacial streams in northeastern Montana, northwestern North Dakota, and a small part of Saskatchewan is shown in figure 12. The drainage systems ceased to exist in Divide County when the northeastward flowing preglacial Yellowstone and Missouri Rivers were diverted further south by a continental glaciation; this diversion probably occurred prior to the Wisconsinan. For comparison, the pattern of the existing drainage systems is shown in figure 13.

Glacial

QUATERNARY

Glacial Drift

Except for localized bedrock exposures and discontinuous deposits of recent sediments, the glacial drift is the surface formation in Divide County. The total thickness of this glacial drift, 0 to 638 feet, is generally greatest in the buried bedrock valleys (pl. 4).

Where the thickness of the glacial drift is a vertical succession of washed and unwashed units, for example in the deeply buried bedrock valleys, there may have been four or five drift sheets deposited. If this is true, each drift sheet was probably deposited during a glacial substage. Where the thickness is a vertical succession of unwashed drift, however, the subdivision into drift sheets is more speculative. The unwashed drift is alike in composition and color, and the buried oxidized zones, which could mean intervals of weathering and nondeposition between drift sheets, generally occur at random. Despite this, the drift sheet that is associated with the surface topography can be correlated for it has a determinable strati-

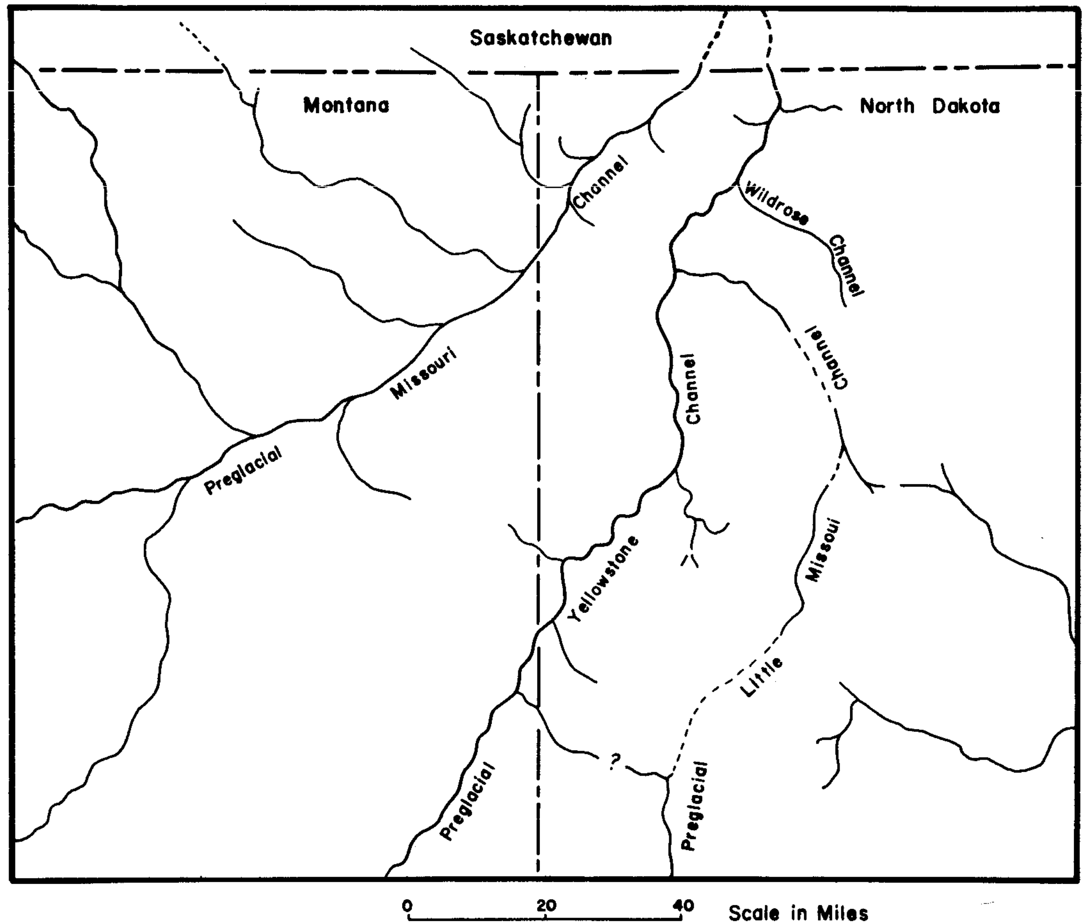


Figure 12. Preglacial drainage systems in northeastern Montana and northwestern North Dakota. That portion of the preglacial Yellowstone and Missouri Rivers in Canada is after Christiansen and Parizek (1961, p. 2).

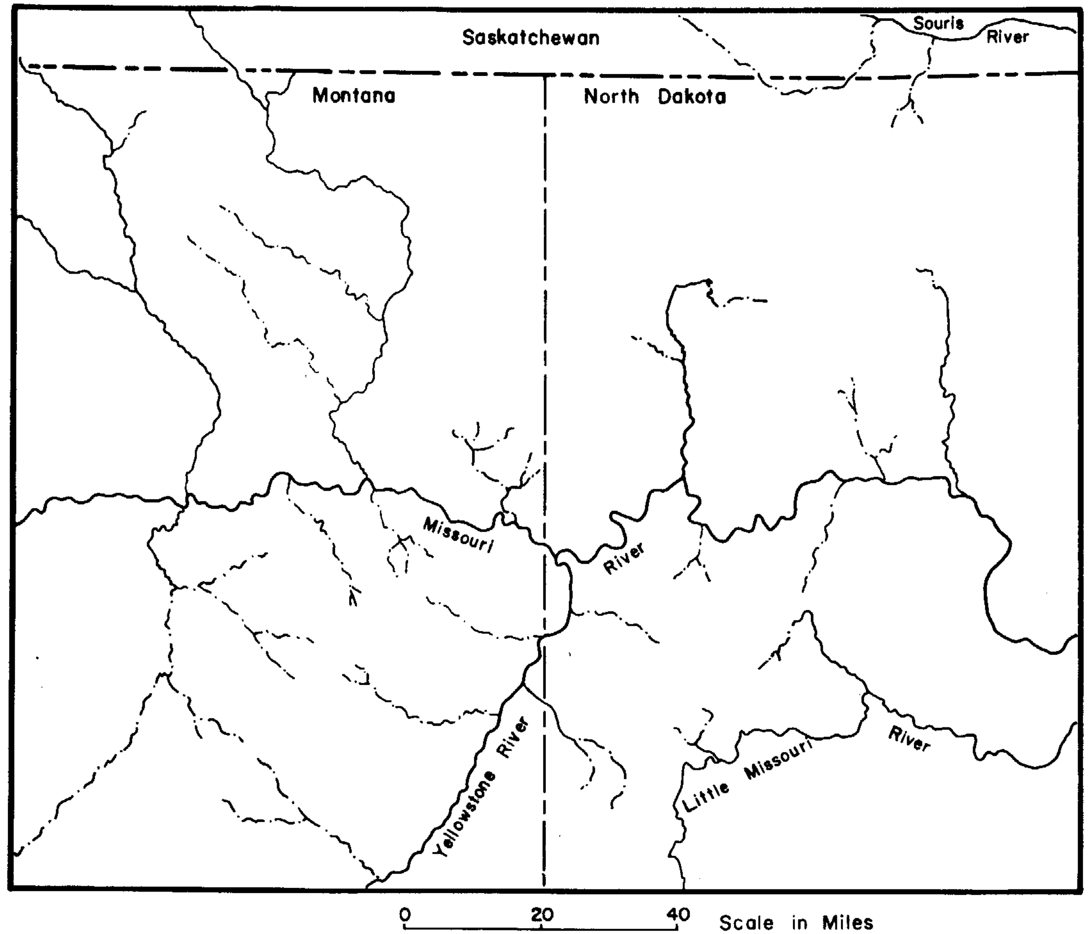


Figure 13. Present drainage systems in northeastern Montana and northwestern North Dakota. This pattern is the result of stream diversion by glaciation.

graphic position above all the washed and unwashed subsurface drift units. Because only one drift sheet can be correlated with some certainty, the deposits of washed and unwashed drift were mapped without reference to time rock subdivisions of the Pleistocene.

The glacial drift is separated into three groups of clastic lithologies (2 washed, 1 unwashed); the separation is based on differences in texture (Wentworth grade scale) and bedding. The lithologic groups are: (1) clay and silt, (2) sand and gravel, and (3) till, an admixture of clay, silt, and sand with stones and pebbles. The till in Divide County is a stony, clay-loam or a stony, sandy mud. The stratigraphic relationships of the lithologic groups are illustrated in several cross sections (figs. 14 and 15 and pl. 5), and areal extent of the surface deposits can be determined from plate 1.

Till — The composition of the till, the most common glacial drift lithology, is the same in the subsurface as at the surface. The surficial till is about 95 percent clay, silt, and sand; the remaining 5 percent is made up chiefly of rock fragments larger than granular size. Laboratory analyses of 54 selected samples of the surficial till show that the ratio average of the clay, silt, and sand fraction (Wentworth grade scale) is 28 percent sand, 35 percent silt, and 37 percent clay (fig. 16 and table II); the maximum deviation of any single sample from the mean of the ratios was less than 8 percent.

Pebble counts were made at several sites in the surficial till. The average of the pebble counts shows that 62 percent are fragments of carbonate rocks, 29 percent of fragments of igneous and metamorphic rocks, and 9 percent are fragments of local bedrock or are miscellaneous types (fig. 17 and tab. III). The cobbles and boulders in the surficial till are chiefly fragments of granite; the other boulders are fragments of carbonate, dark igneous, and metamorphic rocks. The number of surface boulders generally increases from east to west in the county; the number also varies with the type of landform.

Minor inclusions in the surficial and subsurface till include lignite chips, organic material, and "scoria," a local term for the material formed from the baking of overlying beds when lignite burns. Secondary features of the surficial till include accretion of carbonate in a zone immediately below the A horizon of the soil, small nodules of gypsum crystals, alkali concentrations, and limonite deposited around plant roots. The oxidized surficial till is yellowish-gray and light olive gray. The depth of oxidation in the surficial till is generally 20 to 30 feet below surface. A few oxidized zones occur within the succession of subsurface till; they are generally yellowish brown. The unoxidized surficial and subsurface till is mostly olive gray. Both the surficial and subsurface till are compact, but joints in the surficial till are absent or poorly developed. Except alkali, all of the secondary features of the surficial till are common throughout the county.

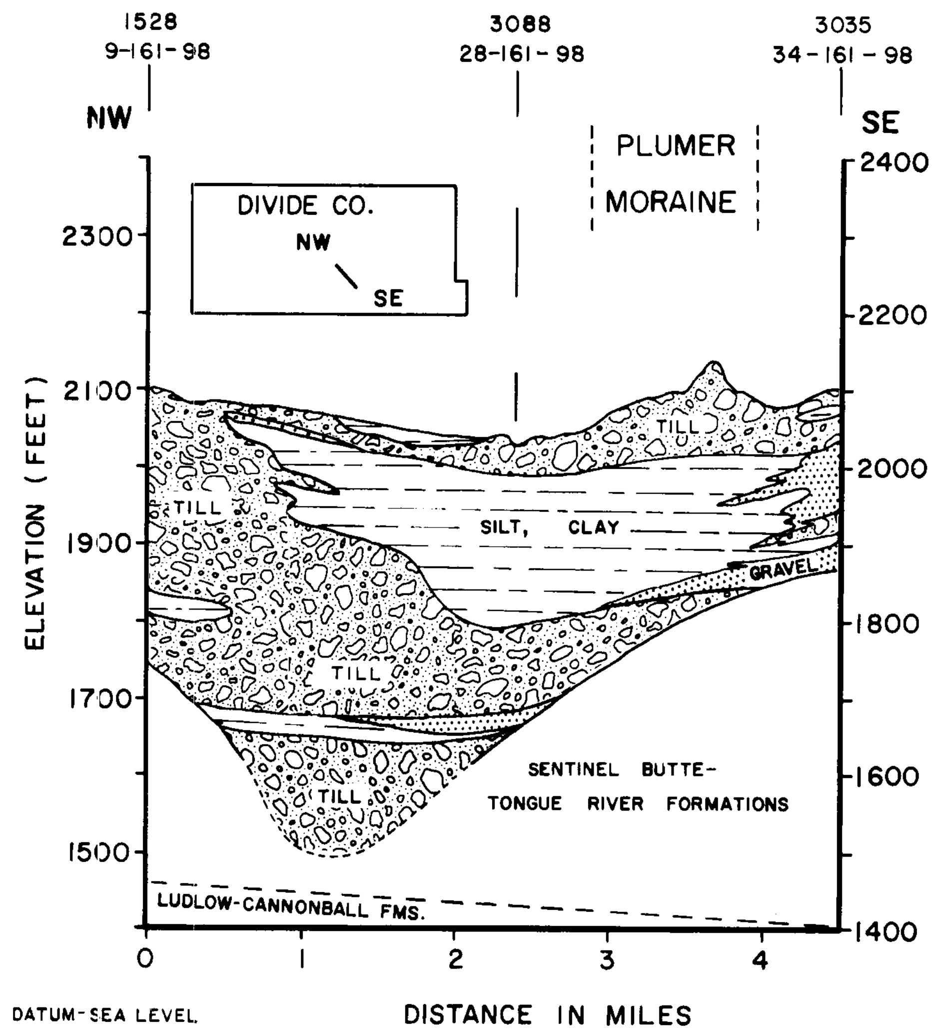


Figure 14. Geologic section across buried valley in south central Divide County. The section shows the lithology of the glacial drift, the surface landforms, and the drift-buried Tertiary formations. The heading above each column is the test well number and the location to section, township, and range.

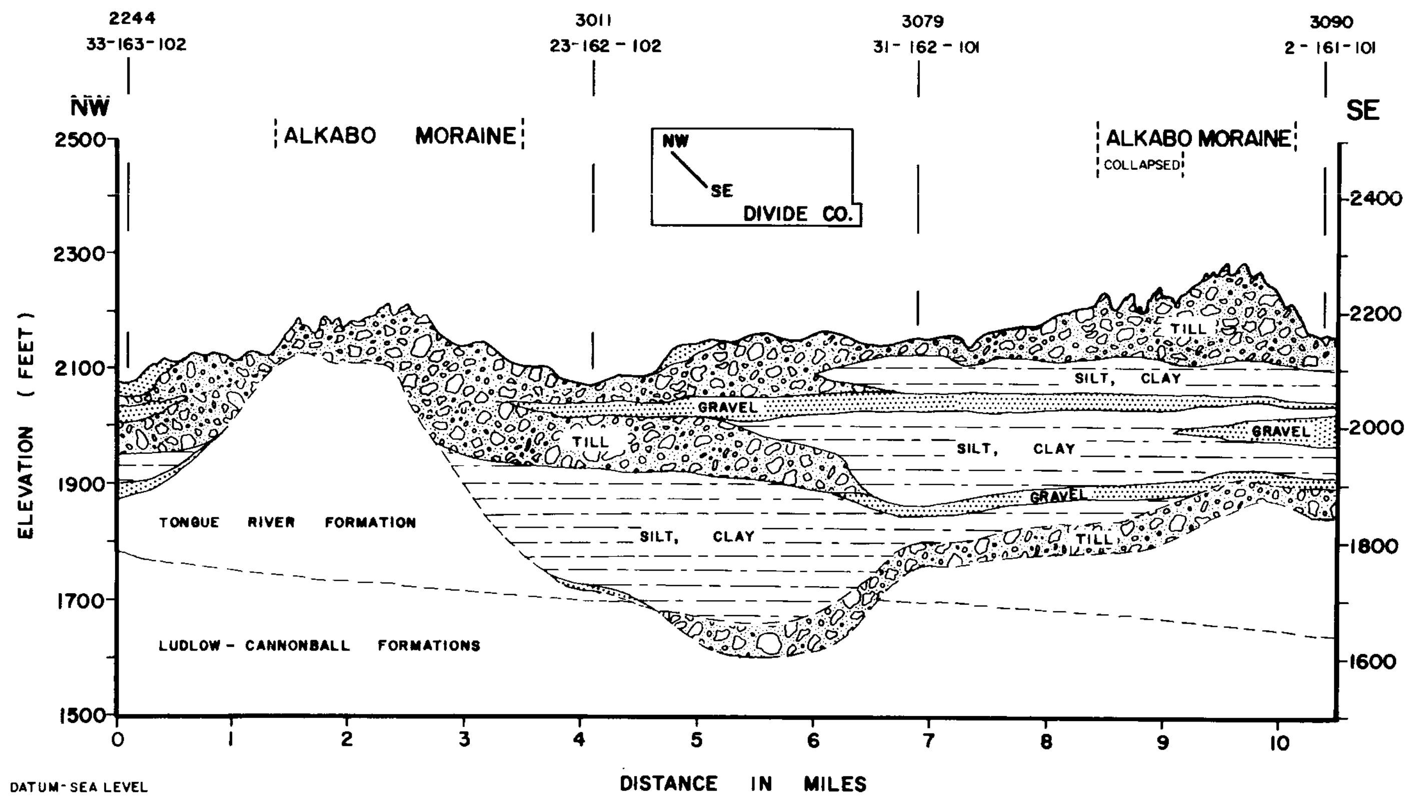


Figure 15. Geologic section across buried valley in western Divide County. The lithology of the drift, the surface landforms, and the drift-buried Tertiary formations are shown on this section. The test well numbers and locations are in the heading above each column.

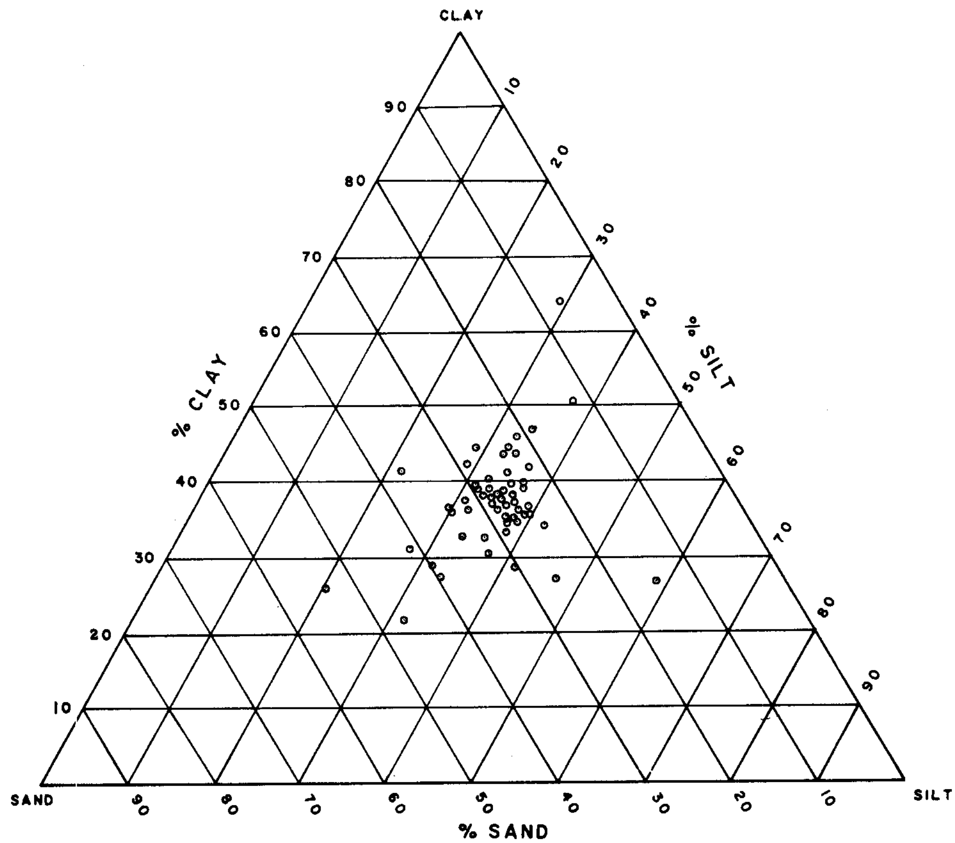


Figure 16. Triangular textural diagram. The graph shows grading of the clay, silt, and sand portion of the surficial till in Divide County. Grain size is based on the Wentworth grade scale.

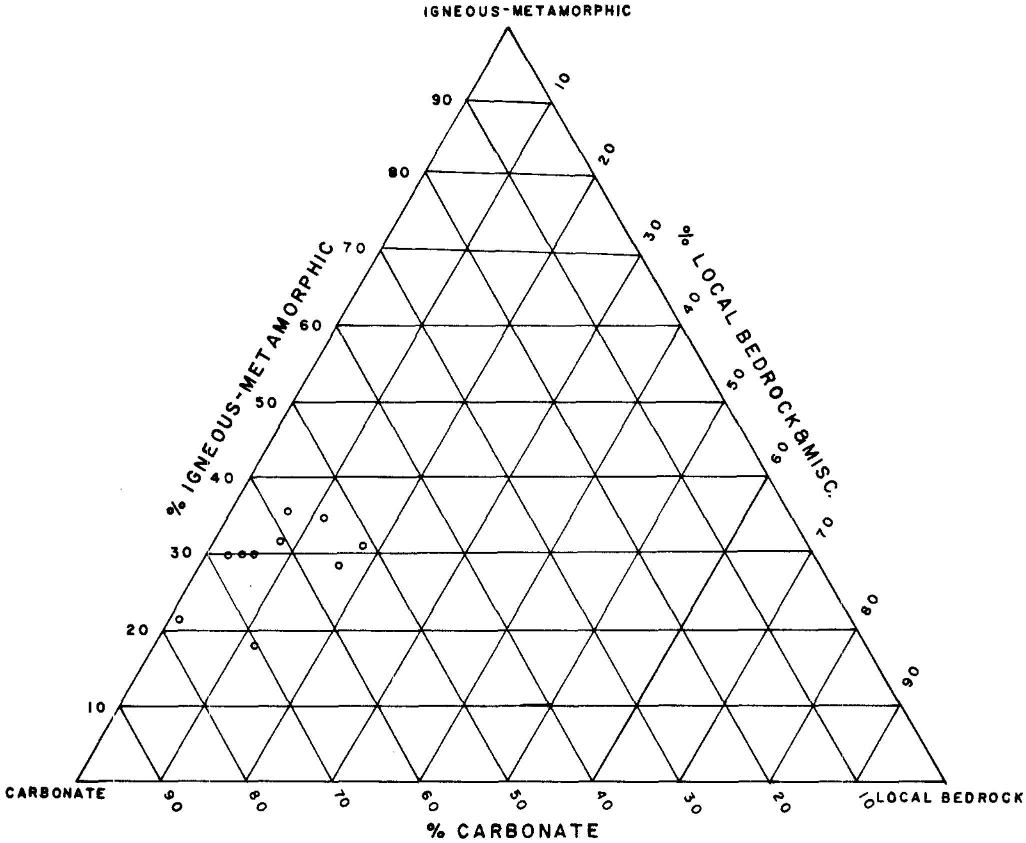


Figure 17. Triangular composition diagram. The graph shows composition of the pebble size fragments in the surficial till of Divide County.

TABLE 2.

Sand-silt-clay ratios in surficial till samples of Divide County

		Percentages		
Location	Landform	Sand	Silt	Clay
SW ¼ SW ¼ sec. 27, T. 164 N., R. 95 W.	ground moraine	29.2	29.0	41.8
NW ¼ SW ¼ sec. 31, T. 164 N., R. 95 W.	ground moraine	28.4	36.0	35.6
SE ¼ SE ¼ sec. 16, T. 163 N., R. 95 W.	ground moraine	27.4	28.7	43.6
SW ¼ NW ¼ sec. 10, T. 162 N., R. 95 W.	ground moraine	32.9	34.5	32.6
NE ¼ NE ¼ sec. 1, T. 162 N., R. 97 W.	ground moraine	28.2	36.5	35.3
SW ¼ SW ¼ sec. 8, T. 163 N., R. 99 W.	ground moraine	27.4	34.6	38.0
NW ¼ NW ¼ sec. 12, T. 163 N., R. 99 W.	ground moraine	19.4	33.6	47.0
SE ¼ NE ¼ sec. 10, T. 162 N., R. 100 W.	ground moraine	24.7	38.9	36.4
SE ¼ SE ¼ sec. 20, T. 161 N., R. 98 W.	end moraine	26.5	35.3	38.2
SW ¼ SW ¼ sec. 3, T. 160 N., R. 99 W.	end moraine	35.4	23.0	41.6
SE ¼ SW ¼ sec. 20, T. 160 N., R. 99 W.	end moraine	28.4	37.9	33.7
SE ¼ SW ¼ sec. 11, T. 160 N., R. 100 W.	end moraine	39.4	33.3	27.3
NW ¼ NW ¼ sec. 11, T. 163 N., R. 101 W.	end moraine	25.5	40.4	34.1
SE ¼ SE ¼ sec. 17, T. 163 N., R. 101 W.	end moraine	21.6	35.5	42.9
SE ¼ SE ¼ sec. 22, T. 162 N., R. 101 W.	end moraine	22.0	33.0	45.0
SW ¼ SW ¼ sec. 36, T. 163 N., R. 102 W.	end moraine	23.9	35.9	40.2
NW ¼ NW ¼ sec. 23, T. 162 N., R. 102 W.	end moraine	53.0	20.9	26.1
SE ¼ SE ¼ sec. 35, T. 162 N., R. 102 W.	end moraine	26.9	33.7	39.4
NW ¼ NW ¼ sec. 12, T. 161 N., R. 102 W.	end moraine	24.3	35.6	40.1
SW ¼ SW ¼ sec. 36, T. 161 N., R. 102 W.	end moraine	14.6	58.4	27.0
NE ¼ NE ¼ sec. 11, T. 160 N., R. 102 W.	end moraine	24.6	32.8	42.6
NW ¼ NW ¼ sec. 34, T. 162 N., R. 95 W.	dead-ice moraine	25.1	41.3	33.6
NW ¼ NW ¼ sec. 22, T. 161 N., R. 95 W.	dead-ice moraine	39.4	31.4	29.2
SE ¼ SE ¼ sec. 9 T. 160 N., R. 95 W.	dead-ice moraine	28.6	33.5	37.9
SE ¼ SE ¼ sec. 19 T. 160 N., R. 95 W.	dead-ice moraine	27.5	34.9	37.6
SW ¼ SW ¼ sec. 35, T. 160 N., R. 95 W.	dead-ice moraine	29.0	34.5	36.5
NE ¼ NE ¼ sec. 27, T. 162 N., R. 96 W.	dead-ice moraine	33.2	30.2	36.6
SE ¼ SE ¼ sec. 10, T. 161 N., R. 96 W.	dead-ice moraine	31.1	38.5	30.4
NW ¼ NW ¼ sec. 18, T. 161 N., R. 96 W.	dead-ice moraine	22.3	33.3	44.4
SW ¼ SW ¼ sec. 24, T. 162 N., R. 97 W.	dead-ice moraine	25.6	46.9	27.5
SW ¼ SW ¼ sec. 20, T. 161 N., R. 97 W.	dead-ice moraine	11.3	37.4	51.3
SE ¼ SE ¼ sec. 36, T. 161 N., R. 97 W.	dead-ice moraine	24.1	37.7	38.2
SE ¼ SE ¼ sec. 22, T. 160 N., R. 97 W.	dead-ice moraine	31.4	31.6	37.0
SW ¼ SW ¼ sec. 11, T. 160 N., R. 98 W.	dead-ice moraine	27.1	32.7	40.2
SW ¼ SW ¼ sec. 35, T. 160 N., R. 98 W.	dead-ice moraine	27.5	35.6	36.9
NW ¼ NW ¼ sec. 36, T. 163 N., R. 99 W.	dead-ice moraine	26.8	36.4	36.8
SE ¼ SE ¼ sec. 14, T. 162 N., R. 99 W.	dead-ice moraine	24.4	39.6	36.0
NW ¼ NW ¼ sec. 12, T. 161 N., R. 99 W.	dead-ice moraine	27.4	36.4	36.2
SW ¼ SW ¼ sec. 25, T. 161 N., R. 99 W.	dead-ice moraine	28.8	38.3	32.9
NW ¼ NW ¼ sec. 36, T. 163 N., R. 100 W.	dead-ice moraine	7.3	29.1	63.6
SW ¼ NW ¼ sec. 8, T. 162 N., R. 100 W.	dead-ice moraine	26.6	38.5	34.9
SE ¼ SE ¼ sec. 14, T. 162 N., R. 100 W.	dead-ice moraine	28.9	32.3	38.8
SE ¼ SE ¼ sec. 2, T. 161 N., R. 100 W.	dead-ice moraine	26.1	38.3	35.6
SE ¼ SE ¼ sec. 35, T. 161 N., R. 100 W.	dead-ice moraine	24.2	36.8	39.0
SW ¼ SW ¼ sec. 21, T. 160 N., R. 100 W.	dead-ice moraine	27.0	37.8	35.2
NW ¼ NE ¼ sec. 9, T. 163 N., R. 101 W.	dead-ice moraine	30.8	37.7	31.5
NE ¼ NE ¼ sec. 22, T. 161 N., R. 101 W.	dead-ice moraine	24.4	34.2	41.4
NW ¼ NW ¼ sec. 8, T. 163 N., R. 102 W.	dead-ice moraine	30.0	41.1	28.9
NW ¼ NW ¼ sec. 6. T. 162 N., R. 102 W.	dead-ice moraine	45.8	32.2	22.0
NW ¼ NW ¼ sec. 7, T. 161 N., R. 102 W.	dead-ice moraine	30.1	31.8	38.1
SW ¼ NW ¼ sec. 22, T. 161 N., R. 102 W.	dead-ice moraine	26.8	38.3	34.9
NW ¼ NW ¼ sec. 6, T. 160 N., R. 102 W.	dead-ice moraine	23.4	33.2	43.4
SW ¼ SW ¼ sec. 28, T. 160 N., R. 102 W.	dead-ice moraine	25.7	36.9	37.4
NE ¼ SE ¼ sec. 22, T. 160 N., R. 103 W.	dead-ice moraine	41.7	27.5	30.8
County average		27.4	35.3	37.1

TABLE 3.

Major pebble types in surficial drift of Divide County

Location	Landform	Number in Sample	Percentages of each rock type: Area Bedrock	Igneous & Metamorphic	Carbonate
NW ¼ NW ¼ sec. 34, T. 162 N., R. 95 W.	Dead-ice moraine	100	10	28	62
SW ¼ SE ¼ sec. 34, T. 161 N., R. 95 W.	Dead-ice moraine	100	4	30	66
SE ¼ SE ¼ sec. 19, T. 160 N., R. 95 W.	Dead-ice moraine	92	12	34	54
NW ¼ NW ¼ sec. 18, T. 161 N., R. 96 W.	Dead-ice moraine	100	17	31	52
SW ¼ SW ¼ sec. 20, T. 161 N., R. 97 W.	Dead-ice moraine	100	14	25	61
SW ¼ SW ¼ sec. 3, T. 160 N., R. 99 W.	End moraine	105	12	17	71
SW ¼ NW ¼ sec. 8, T. 162 N., R. 100 W.	End moraine	101	16	28	56
NW ¼ NW ¼ sec. 14, T. 160 N., R. 100 W.	Collapsed outwash	100	9	30	61
NE ¼ SE ¼ sec. 25, T. 163 N., R. 102 W.	End moraine	117	-	22	78
NE ¼ SE ¼ sec. 23, T. 162 N., R. 102 W.	Disintegration ridge	100	7	35	58
SW ¼ NW ¼ sec. 22, T. 161 N., R. 102 W.	End moraine	100	3	30	67
NE ¼ NE ¼ sec. 25, T. 162 N., R. 103 W.	Collapsed outwash	100	6	30	64
NE ¼ SE ¼ sec. 15, T. 160 N., R. 103 W.	Collapsed outwash	99	7	31	62
Average Percentages			9	29	62

The total thickness of the till is variable but generally the average thickness is about 150 to 200 feet (fig. 18). The maximum measured thickness of 456 feet is from test well 3075, in sec. 35, T. 163 N., R. 101 W.

Sand and gravel – The composition of the sand and gravel is much the same in both the surficial and subsurface deposits although the lower subsurface deposits generally contain more of the brownish quartzite pebbles and fragments of local bedrock. The surficial sand and gravel occurs chiefly as glaciofluvial deposits, which have several different landforms. Generally, the sand and gravel in these deposits varies greatly in grain size, sorting, and type of bedding.

Composition of the sand and gravel particles of surficial deposits varies from chiefly quartz and feldspar grains in the sand fractions to chiefly granitic igneous rock fragments in the cobble and boulder fraction. The constituents of the pebble fraction are chiefly carbonate, igneous, and metamorphic rock fragments; fewer pebbles are quartzite, chert, sandstone, shale and bedrock-concretion fragments (composition of the pebbles is much the same as that in the till). Rarely, cobble-size balls of till, armored by pebbles, occur in the dirty gravels of surficial deposits. Caliche in the surficial deposits is common on the underside of pebbles; staining and accumulation of brown iron oxide is common, expecially in the gravels.

Rounding of the rock particles varies with the grain size and sometimes with the composition. The sand-size fragments are subangular, the pebbles generally subrounded, and the cobble-boulder size fragments are subangular to subrounded. A few of the granitic pebbles and boulders in the surficial deposits are well rounded. The shapes of the rock fragments are generally irregular although the carbonate fragments have a tendency to be tabular and the granitic igneous to be spherical.

The sand and gravel of the surficial ice-contact deposits (pl. 1) is generally dirty sandy gravel. The bedding, though not commonly distinct, is generally steeply inclined and thin to thick. Boulders and cobbles are common in the ice-contact deposits. The sand and gravel of the surficial outwash deposits (pl. 1) is generally gravelly sand or sandy gravel; the bedding, commonly distinct, is generally medium and both cross-bedding and horizontal beds are common.

The average thickness of the sand and gravel at the land surface is 15 to 25 feet; the maximum continuous thickness from land surface was found in test well 3007, sec. 25, T. 162 N., R. 103 W., where 104 feet of sand and gravel was drilled prior to penetrating the underlying till. The maximum total thickness in the wells drilled for this study was found in test hole 3016, in sec. 3, T. 160 N., R. 99 W., where possibly 260 feet of sand and gravel was penetrated; however, the 89 feet at a depth from 308 to 397 feet is probably a gravelly till and maximum total thickness of the sand and gravel is 171 feet. Much of this sand and gravel is a potential source of rather large quantities of ground water. The areas of greater thickness and areal extent of sand and gravel are mostly in (1) T. 160

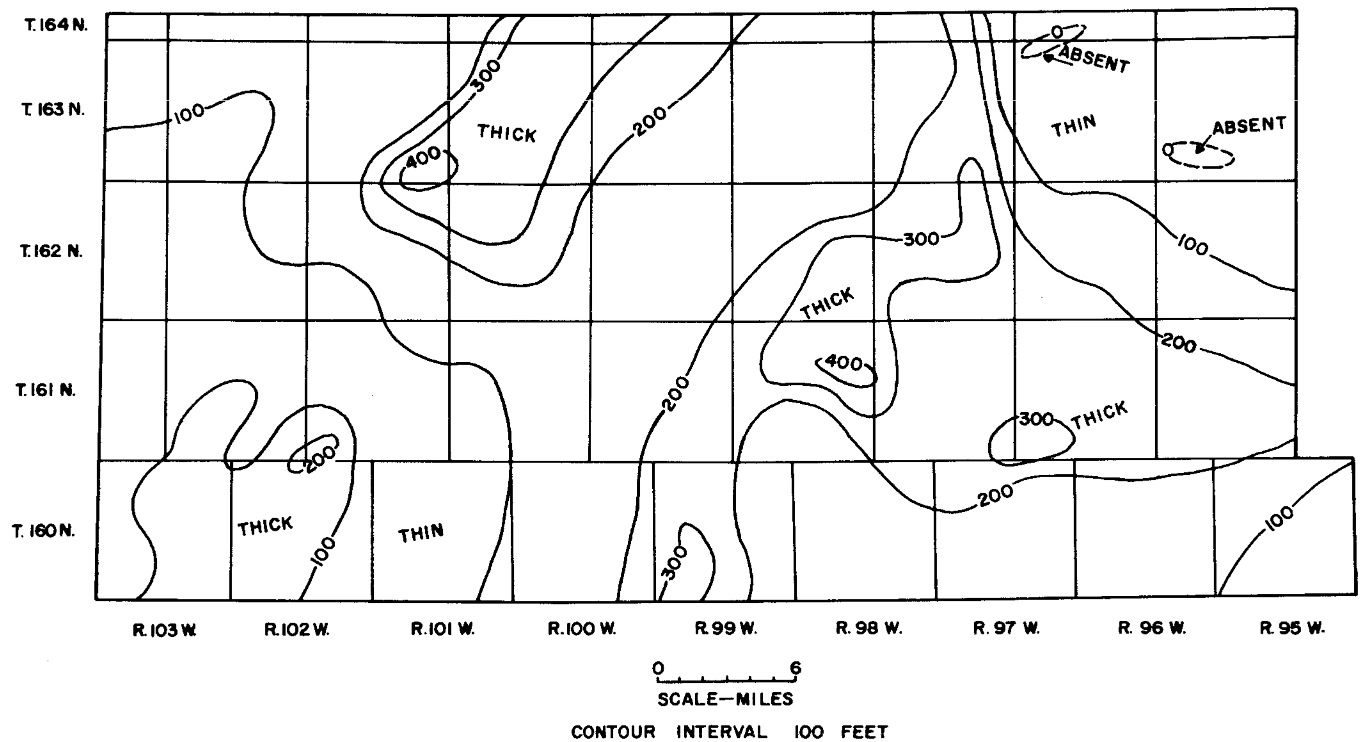


Figure 18. Isopach of the glacial till.

N., R. 103 W., and south half of T. 161 N., R. 102 W., (2) T. 160 N., Rs. 96 and 97 W., (3) T. 163 N., R. 102 W., and (4) Tps. 162 and 163 N., R. 97 W., (see fig. 19).

Clay and silt – The clay and silt found at the land surface occurs as thin lenses of lake deposits that have rolling to hummocky topography (pl. 1). It is found in the subsurface as long, narrow, thick, lenses in the bedrock valleys (fig. 20). The clays are light olive gray, oxidized and olive gray to olive black unoxidized; the silts are yellowish gray oxidized and olive gray unoxidized. The silts and clays are generally laminated and interbedded.

The thickness of the surface clay and silt is generally 0 to 32 feet; the thickness within the subsurface ranges from 0 to 527 feet. The maximum thickness, 527 feet, was found in test well 2248, sec. 9, T. 161 N., R. 102 W.

Fossils – Two fossil sites were found during this study. At one site the fossils are indigenous to the glacial drift, but at the other site the fossils were derived from older sediments. The fossils from the older sediments are mollusks that were obtained out of concretions found in a glacial gravel pit, NW 1/4 SW 1/4 NW 1/4, sec. 9, T. 162 N., R. 101 W., about 3 miles southwest of Fortuna. They were identified by Mr. Rodney Feldmann of the University of North Dakota. According to Mr. Feldmann (personal communications of April 30, 1963) three different species occur in this find. They are: a gastropod, ? piestochilus culbertsoni (Meek and Hayden); a pelecypod, Inoceramus cripsii var. bazabini (Morton), and a gastropod, Haminea cf. H. occidentalis (Meek and Hayden). All the fossils are Upper Cretaceous in age (Cenomanian). The indicated direction of ice flow in this county was from northeast to southwest, and it is therefore assumed the concretions containing the fossils were moved into place after being stripped from the outcrop in Saskatchewan.

The fossils indigenous to the glacial drift were collected at the Mhyre farmsite in the SW 1/4 SW 1/4 SW 1/4, sec. 34. T. 160 N., R. 96 W., about five miles east of Wildrose. This site was the source of a prolific number of fresh-water snails, ostracod carapaces, and stonewart (Chara) zygospore cases. The exposure is at the boundary between sand of collapsed outwash topography and clays and silts of collapsed lake sediment topography. The fossils were seived out of a bulk sample from a two foot bed of yellowish-gray, silty and sandy marl that lies immediately below the thin surface soil zone.

The list of mollusks and comments were provided by S. J. Tuthill (personal communication, April, 1963) and are as follows:

"The following species of mollusks were identified from a 500 ml sample taken from dead-ice features in SW 1/4 SW 1/4 SW 1/4, sec. 34, T. 160 N., R. 96 W.,

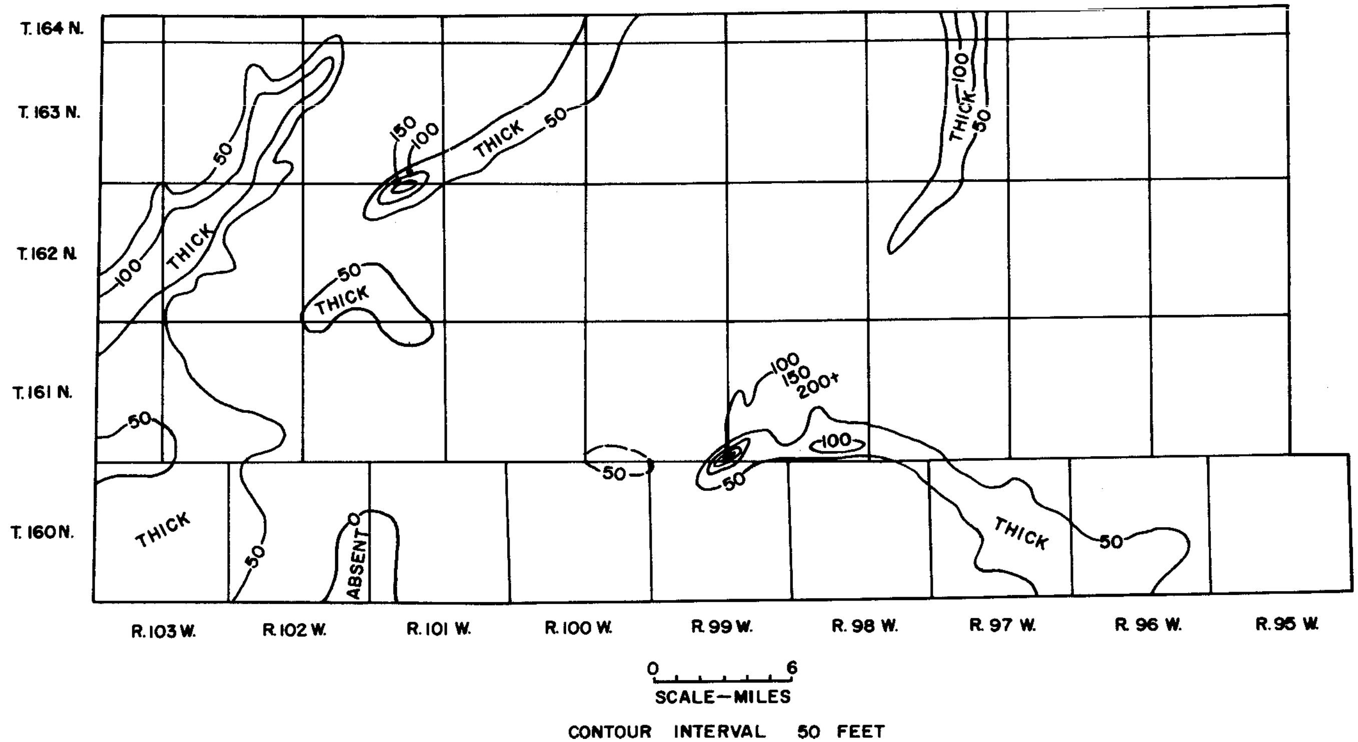


Figure 19. Isopach of the glacial sand and gravel.

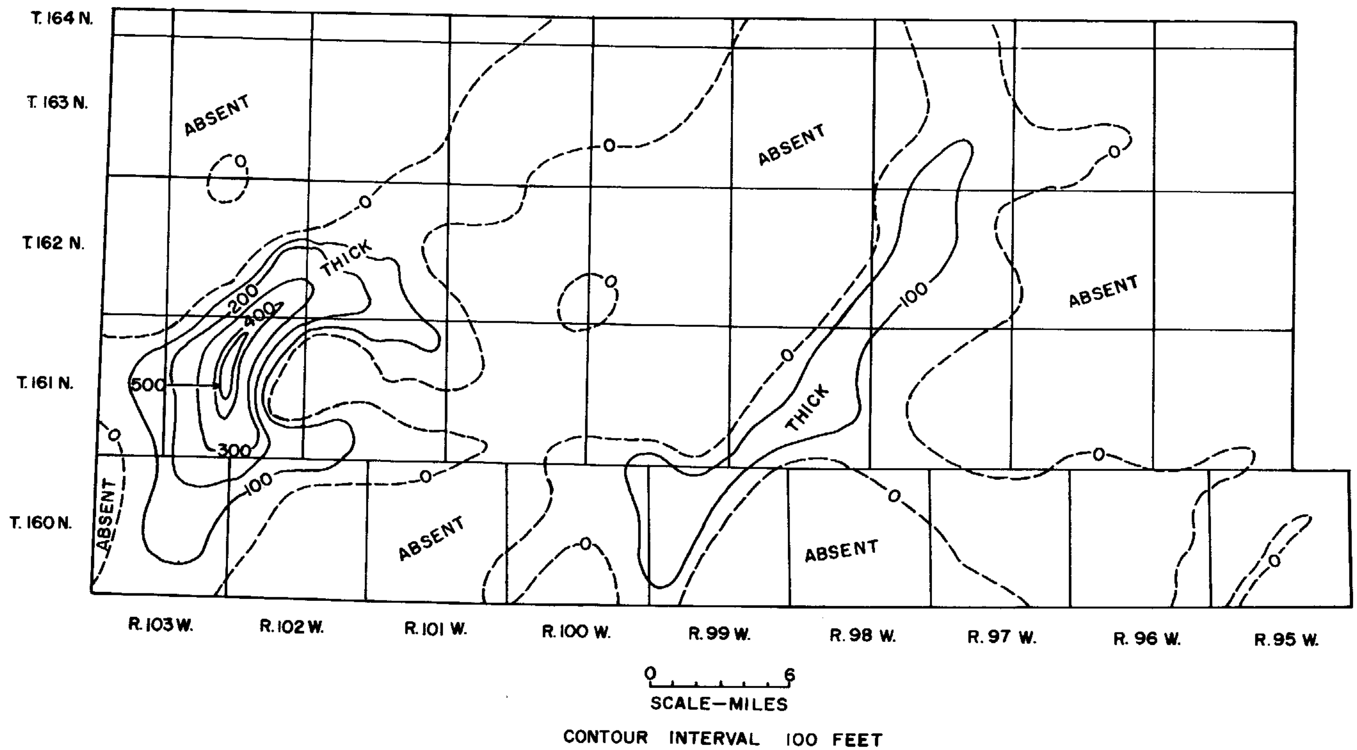


Figure 20. Isopach of the glacial clay and silt.

Divide County, North Dakota, collected October, 1962. The number prefixed by the letters UND indicate the catalogue number under which the specimens are curated in the Department of Geology collection at the University of North Dakota. The number of specimens in each taxon follows the specific name and the percent of the total number of specimens in the molluscan fauna follows:

SYSTEMATIC LIST OF MOLLUSKS

UND 9000 Valvata tricarinata (Say) 1817.	212 specimens	78.5%
UND 9001 Lymnaea humilis (Say) 1822.	7 specimens	2.7%
UND 9002 Gyraulus parvus (Say) 1816.	46 specimens	16.4%
UND 9003 Promenetus exacuous (Say) 1821.	2 specimens	0.9%
UND 9004 Helisoma trivolvis (Say) 1917.	1 specimen	0.5%
UND 9005 Pisidium sp. 4 valves presumably representing 2 individuals		0.9%

In addition to the mollusks the sample contained a great many oogonia probably of the Genus Chara (UND 9006).

The mollusks indicate that the body of water in which they lived was permanent, clear water which warmed seasonally. The present range of Valvata tricarinata is north temperate, therefore the climate of the Missouri Coteau during the time the fossils lived was probably not much different than that which now exists in south-central Canada and the Great Lakes region of the United States. The grain size of the sediments is probably the most reliable indicator of the speed of water movement and suggests that the fossils may have been deposited near the point where a stream entered standing water. The molluscan fauna supports this idea. Valvata can live in slowly moving water, but is more common in lakes. Helisoma trivolvis is rarely found in moving water. Gyraulus parvus, Lymnaea humilis, and Promenetus exacuous are not specific as to habitat preference and can live in bodies of water which dry up during seasons of low rainfall. The dominance of the fauna by the branchiate Valvata tricarinata conclusively proves that the environment in which this fauna lived was a permanent body of water. The presence of pulmonates does not negate this in any way, as they can succeed in permanent water equally well.

The present fauna of the Missouri Coteau district as it is known in southern North Dakota is wholly one of pulmonate gastropods. Thus, while not serving as fossil indices to geologic time, the presence of the branchiate Valvata tricarinata in such striking dominance of the molluscan fauna suggests the animals lived during a time of more humid climatic conditions. Radiocarbon dates from Logan, McIntosh, and Kidder Counties indicate that just such conditions existed in North Dakota between 8,700 and 11,950 C 14 years B.P. I suspect that the present fauna lived at approximately the same time, but conclusive proof would be obtained only from a radiocarbon date taken on the material from this site, as all of the species are presently living in North Dakota."

The ostracods were identified and comments made by D. L. Delorme, University of Saskatchewan (written communications, March 26, 1963 and April 3, 1963). They are as follows:

"The following are the Ostracoda (5 genera, 9 species) obtained from the sample.

Cypridopsis vidua (Muller), 1776
Cyclocypris forbesi Sharpe, 1897
Eucandona neyensis (Getentag & Benson), 1962
Eucandona truncata (Furtos), 1933
Eucandona n. sp.
Ilyocypris gibba (Ramdohr), 1808
Cytherissa lacustris (Sars), 1863
Limnocythere n. spp.

Will you please note that three species from two genera are listed as new species. As far as I can tell, they have not been described before in any published literature, however, I have found these species in Pleistocene, Post-Pleistocene and Recent sediments of Saskatchewan . . . .

The Ostracode fauna can be separated into two environmental groups: (1) lake, (2) fluviatile. The lake fauna is represented by the following species:

Cypridopsis vidua (Muller)
Cyclocypris forbesi Sharpe
Eucandona neyensis (Gutentag & Benson)
Eucandona truncata (Furtos)
Eucandona n. sp.
Cytherissa lacrustris (Sars)
Limnocythere n. spp.

Of the foregoing, it is interesting to note that the first five species listed are common at the present time in lakes depositing marl in north central Saskatchewan. Cypridopsis vidua and Cyclocypris forbesi, although predominately nektonic, are most commonly found among vegetation, most probably Chara. The eucandonids are benthonic, living off the substratum; they also climb vegetation. Eucandona neyensis is most prolific at a depth of about 3.6 meters, however, it will sustain itself at depths ranging from 0.5 to 5 meters. Its temperature range is from 10° to 20° C. with the colder temperature being more favorable. The pH range is from 8.5 to 9.0. The species prefers abundant oxygen. Cytherissa lacustris is generally found in deep cold lakes, however, it is very abundant in

Pleistocene lakes which were supposedly cold but not so deep. The limnocythereans, although not abundant in this section, are benthonic and appreciate an oxidizing environment.

The fluviatile fauna is represented by the following species:

Cypridopsis vidua (Muller)
Cyclocypris forbesi Sharpe
Eucandona neyensis (Gutentag & Benson)
Eucandona truncata (Furtos)
Ilyocypris gibba (Ramodohr)

The first four species listed are commonly found in the backwater regions of streams and rivers. Illyocypris gibba lives in moving water, preferably permanent streams and rivers. The species is very seldom found living in a quiet water environment, however, the remains of the same can be found in lacustrine deposits where a stream has emptied into the lake. The percentage (13%) indicates that the latter is probably not the proper interpretation for the presence of Ilyocypris in this section."

The ostracodes as identified by Mr. Delorme are in the Geological Museum of the University of Saskatchewan and have been assigned the type numbers from GMUS-Ao-83 to GMUS-Ao-100.

Glacial Phases and Associated Landforms

All of the surficial glacial landforms of Divide County were formed when the terminus of the Late Wisconsinan glacier receded northeastward from the county. During the recession, several phases of glaciation occurred. Each of the phases can be identified by geographic position (fig. 21), but they are of the same surficial drift sheet.

On the Missouri Coteau, the phases are generally characterized by the surficial glacial deposits of collapsed outwash topography, end moraine, dead-ice moraine, collapsed lake sediment topography, eskers, linear disintegration ridges, and meltwater channels. Landforms characteristic of the phases on the Drift Plains are ground moraine, outwash plains and meltwater channels, lake plain, kame terraces, and ice-contact deposits that have irregular form.

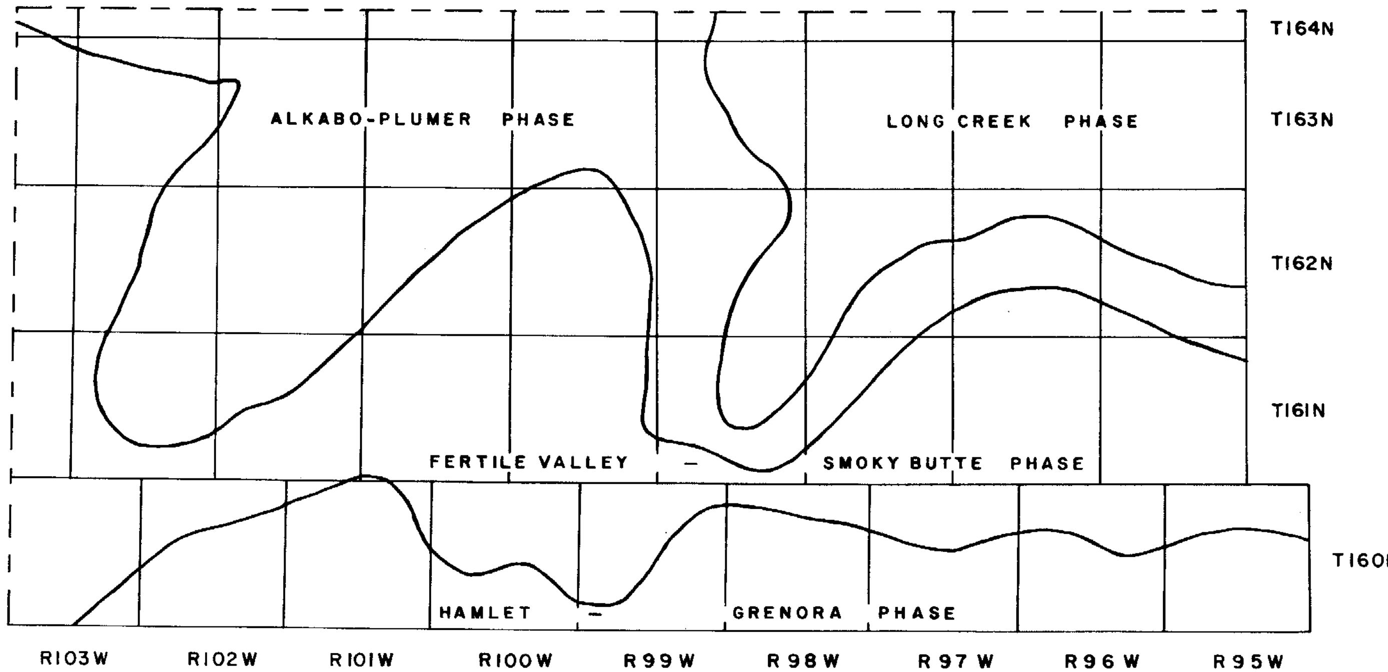


Figure 21. Approximate area and margins of the Late Wisconsinan glacial phases in Divide County.

History

The glacier that advanced southwestward to deposit the drift of the Hamlet-Grenora phase over an earlier Late Wisconsinan drift reached its maximum advance in northern Williams County, North Dakota, and in eastern Sheridan County, Montana. A recessional phase began, but small readvances of the active ice soon resulted in still stand or temporary halt in the recession of the glacier. The margins of the still stand can be mapped chiefly by the geographic positions of small end moraines, collapsed outwash topography, and large marginal meltwater channels. During the slow recession of the active ice front that followed deposition of the end moraines and outwash, large areas of drift-covered glacial ice were left in eastern Sheridan, northern Williams, and southern Divide Counties.

The margin of the ice in eastern Sheridan County extended as far as Medicine Lake and Big Muddy Creek, and meltwater drainage was down the valley of Big Muddy Creek and into the Missouri River. In northern Williams County meltwater streams near the margins of the glacial ice flowed through the large valleys that trend from Grenora to Zahl, Corinth to Appam, and Hamlet to McGregor and beyond to Battleview, Mountrail County. The meltwater from the vicinity of Zahl and Appam drained through the valley of Little Muddy Creek and into the Missouri River. The meltwater from the vicinity of Hamlet and Battleview flowed through the valley of the White Earth River and into the Missouri River.

Glacial Drift

Drift of the Hamlet-Grenora phase covers the southern part of Divide County (fig. 21). The fresh topography and relatively undeveloped soils means the drift is young. It is, however, the oldest part of the surficial drift in Divide County and may be about 12,500 or 13,000 years B.P. because is apparently correlates with Clayton's drift D (Clayton, 1966, p. 18).

Most of the surface associated with the drift of the Hamlet-Grenora phase in Divide County is dead-ice moraine; other landforms are small end moraines, eskers and linear disintegration ridges, collapsed outwash topography, and partly-buried channels. Moraine troughs and closed disintegration ridges occur in the dead-ice moraine. The drift of the Hamlet-Grenora phase ranges in elevations from about 1,980 to 2,200 feet above sea level at the base of the drift and about 2,100 to 2,300 feet above sea level at the surface of the drift. Thickness of the drift ranges from about 34 to 110 feet and averages 80 to 90 feet.

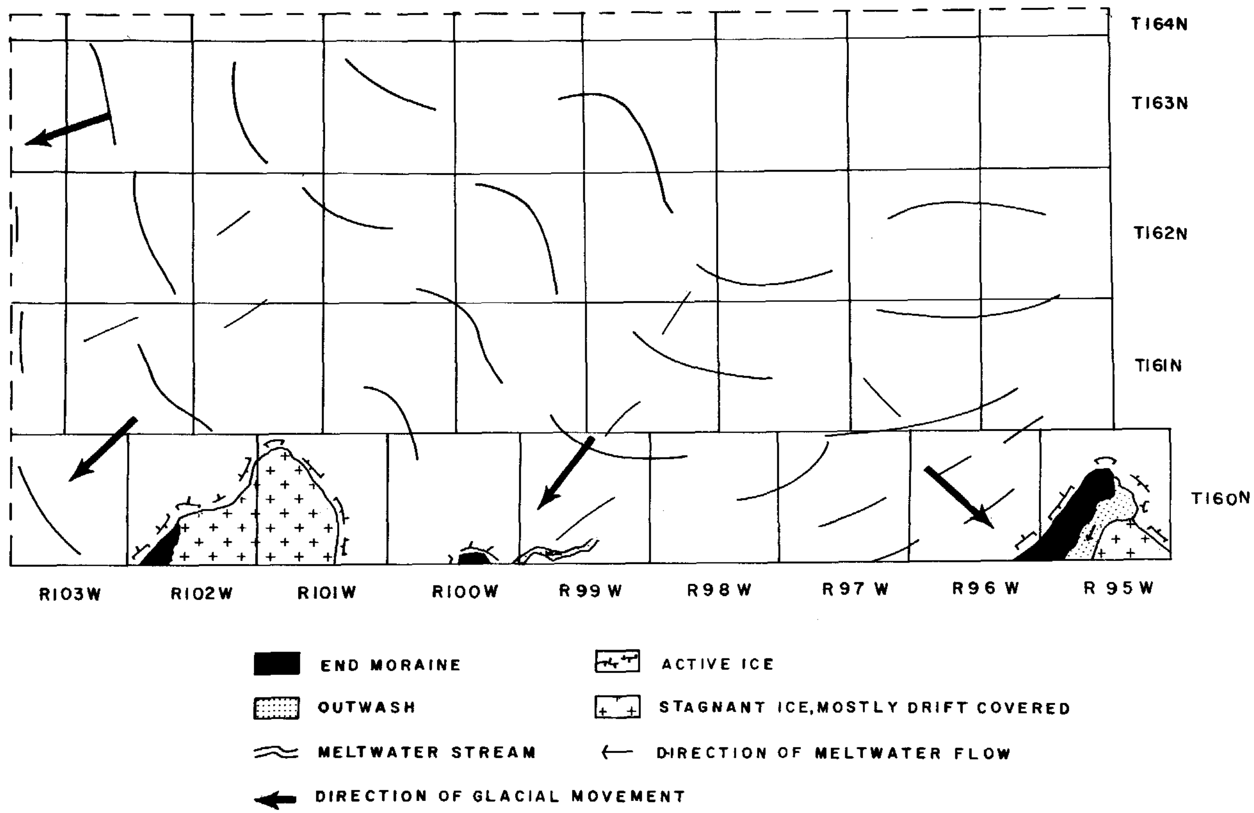


Figure 22. Hamlet-Grenora phase of Late Wisconsinan glaciation. The Hamlet, Appam, and Grenora end moraines were formed during this phase.

Glacial Landforms

End moraine — The accumulations of drift, generally till, that have high constructional relief and overall or internal linearity are end moraines; they were deposited along the active margins of a glacier. The end moraines of the Hamlet-Grenora phase in Divide County are the Hamlet, Appam, and Grenora end moraines (pl. 1 and fig. 22).

The Hamlet end moraine (the post office of Hamlet, Williams County, is on the crest) is a hummocky, northeast-southwest ridge that is rather broad. Internal ridges are few and it is called end moraine because of its overall linearity. The local constructional relief is generally high, 30 to 60 feet, although on the distal margin it may be as low as 10 feet. Local constructional relief, characteristic of glaciated areas, is the difference between maximum and minimum elevations in an area of one-fourth square mile. The moraine is composed chiefly of stony, clayey till although a few ridges and small mounds contain lenses of dirty gravel. Boulders are numerous on the surface of the moraine.

The Appam end moraine, about 2 miles northeast of the post office of Appam, Williams County, is continuous into Divide County for a short distance. The moraine, composed chiefly of stony till, is a high ridge with steep slopes and many smaller superimposed, internal ridges. Local constructional relief on the end moraine in Divide County is generally 20 to 40 feet, but the height of the moraine above the surrounding topography is up to 100 feet.

The Grenora end moraine, about 1.5 miles east of Grenora, Williams County, is continuous into southwestern Divide County for about 2 miles. This northeast-southwest trending end moraine is made up of a band of ridges and knobby hills with sinuous superimposed ridges. The local constructional relief is 20 to 30 feet. The glacial drift is chiefly stony, clayey till and boulders are common on the surface.

Dead-ice moraine — Dead-ice moraine is a hummocky accumulation of glacial drift (chiefly till) that is characterized by abundant knobs and kettles, high constructional relief, and non-integrated drainage. The dead-ice moraine of the Hamlet-Grenora phase in Divide County has a local constructional relief that is generally between 40 and 80 feet. Exceptions to the general range are in the southeast of T. 160 N., R. 95 W., and in sec. 30, T. 160 N., R. 100 W., where the local relief is about 10 feet. Irregular depressions and kettles are numerous and the drainage is non-integrated. The dead-ice moraine is composed chiefly of clayey till and small glaciofluvial and glaciolacustrine deposits; boulders are common.

Associated with the dead-ice moraine are short, closed ridges that are circular, elliptical, and irregular in shape. They have little or no preferred orientation. The features, according to Gravenor and Kupsch (1959, p. 52-54), are closed disintegration ridges.

The circular to irregular, closed disintegration ridges are composed chiefly of till, are generally 50 to 300 feet in diameter, and are 5 to 10 feet high. They are seldom over 15 feet high. A few of the closed disintegration ridges on the dead-ice moraine of the Hamlet-Grenora phase in T. 160 N., R. 98 W., have a maximum diameter of about 500 feet and a maximum height of about 20 feet. If the ridges are nearly circular, they look like doughnuts on the aerial photographs. The ridge surrounds a central depression that usually is above the surrounding ground level. There are many variations in the development of the central depression, and where it is small in circumference and shallow, the form is that of a mound.

The elliptical, closed disintegration ridges are characterized by two saddles in opposite sides of the rim that surrounds the central depression. The elliptical ridges are generally 100 to 500 feet long, are generally 5 to 10 feet high, and are seldom over 20 feet high. The closed ridges are composed chiefly of till but a few contain dirty gravel and clay and silt.

Moraine throughs are narrow linear depressions that contain small, shallow basins and small kettles. The linear depressions are bottomed by till and by clay in the basins and kettles. Moraine troughs are generally parallel to the indicated direction of glacial-ice flow, though some are perpendicular to the flow. Two moraine troughs of the Hamlet-Grenora phase were mapped; one is in the southeast part of T. 160 N., R. 98 W., and the other is in the southwest part of T. 160 N., R. 99 W. (see pl. 1). The two moraine troughs are generally 15 to 40 feet below the surrounding ground level.

Eskers and linear disintegration ridges — Long, sinuous, commonly discontinuous ridges composed chiefly of glaciofluvial drift are eskers. They generally have uneven crests and may be covered on the sides by till. Linear disintegration ridges, mostly composed of till with lenses of sand and gravel, are generally short, straight or arcuate, boulder-covered glacial features that formed along fractures in glacial ice; generally, the ridges are parallel to the direction of ice flow.

The eskers of the Hamlet-Grenora glacial phase are not prominent landforms and do not contain large amounts of well-washed glacial drift. Immediately north of the Appam end moraine, the esker in sec. 34, T. 160 N., R. 100 W., is bifurcated in Divide County (there is a deep depression between two ridges), but to the south in Williams County it is one ridge. The two ridges of the esker in Divide County are 25 to 40 feet high, but not over 125 feet wide. The glacial drift of the esker is chiefly thick-bedded gravelly sand; till covers the sides of the ridges. North of Corinth, Williams County, the esker in secs. 26 and 33, T. 160 N., R. 98 W., consists of several ridges 9 to 17 feet high and less than 150 feet wide. The glacial drift in the ridges is till and gravel; the gravel is dirty, thick bedded, and boulders and cobbles are common. The gravel content of the esker increases southward, and in Williams County the esker is chiefly sandy gravel.

The linear disintegration ridges of the Hamlet-Grenora glacial phase are associated with the outwash near the southern boundary of T. 160 N., R. 99 W., northeast of the Appam end moraine (see pl. 1). They are less than 0.25 of a mile long, less than 135 feet wide, and from 5 to 25 feet high. The glacial drift in the ridges is sandy gravel, gravelly sand, silt, and till. The bedding in the washed drift is faint and thick; it is also highly slumped. Boulders are common on the surface of the ridges and in the gravels.

Collapsed outwash topography – Collapsed outwash topography consists of hummocky accumulations of glaviofluvial drift. Kettles and depressions are abundant and local constructional relief is generally moderate to high; and the relief is similar to that of the dead-ice moraine.

The areas of collapsed outwash topography formed in Divide County during the Hamlet-Grenora glacial phase are small. East of the Hamlet end moraine, the collapsed outwash topography in secs. 15, 22, 23, 27 and 33, T. 160 N., R. 95 W., (pl. 1) has 15 to 25 feet of local constructional relief, contains irregular depressions, and consists of dirty, sandy gravel. The bedding in the outwash is faint and medium to thick and dips moderately.

West of Wildrose, the small area of collapsed outwash topography in secs. 32 and 33, T. 160 N., R. 97 W., is continuous to the south into Williams County for less than 0.2 miles; this collapsed outwash topography has a local constructional relief of 15 to 30 feet. Texture of the outwash is dirty sand and gravelly sand. In addition, the surface of the deposit has been modified by recent wind blown material. Northeast of the Appam end moraine, the collapsed outwash topography in secs. 31, 32, 33 and 34, T. 160 N., R. 99 W., has local constructional relief of 15 to 40 feet. The glaciofluvial material is chiefly sandy gravel and dirty gravel. There are numerous short, bouldery, gravel and till linear disintegration ridges aligned with the trend of this outwash deposit. The outwash is continuous southwest into Williams County where it crosses the Appam end moraine.

Partly-buried channels – Northeast of the Grenora end moraine, the narrow shallow, linear depressions in T. 160 N., Rs. 101 and 102 W., are most noticeable on aerial photograph stereopairs. The till bottomed depressions are mostly 5 to 10 feet deep, although segments are as much as 30 feet deep. Ephemeral streams now occur in some of the depressions. The linear depressions are oriented in north-south and east-west directions and are up to 4 miles long (see pl. 1). The linear depressions could have originated when glacial drift incompletely filled pre-existing glacial meltwater channels. Test well 2249, in sec. 26, T. 160 N., R. 102 W., was drilled in one of the linear depressions; the well penetrated 74 feet of till above bedrock, but no deposits of gravel that could be associated with glaciofluvial deposition were penetrated.

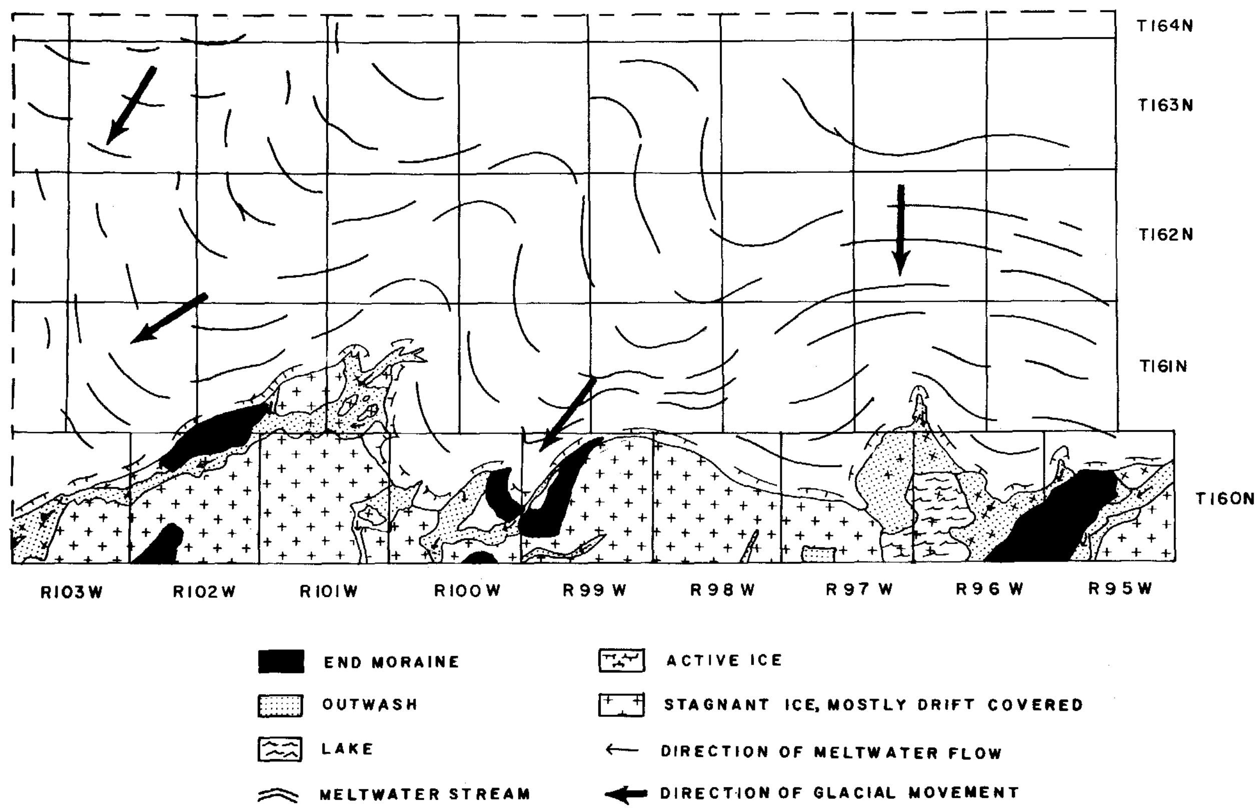


Figure 23. Smoky Butte-Fertile Valley phase of Late Wisconsinan glaciation. The Smoky Butte and Fertile Valley end moraines and adjoining areas of outwash were formed during this phase.

SMOKY BUTTE-FERTILE VALLEY PHASE

History

The Smoky Butte-Fertile Valley phase began when the Late Wisconsinan glacier readvanced against drift-covered dead-ice of the Hamlet-Grenora phase in southern Divide County (fig. 23) and eastern Sheridan County, Montana. The margin of this still stand is determined mostly by the geographic positions of outwash and end morains that were formed over and against the drift-covered dead ice of the previous phase. In southeastern Divide County (fig. 23) the margin of this still stand of the glacier was immediately north of the Hamlet end moraine. Drainage in the vicinity of the Hamlet end moraine was (1) into the large depression northwest of the end moraine, and (2) further east, into a meltwater channel that, near Battleview, joined the valley of the White Earth River. From that junction, the meltwater flowed south through the White Earth River valley and into the Missouri River. In the vicinity of Smoky Butte, where an end moraine of this phase was formed, the meltwater from the ice margin flowed south (around the west side of the Appam end moraine) into the valley of Little Muddy Creek. Through Little Muddy Creek, the meltwater flowed south into the Missouri River. In Southwestern Divide County the margin of the still stand is marked by outwash and an end moraine in Fertile Valley township. In eastern Sheridan County, Montana, the margin of this still stand was in the vicinity of Brush Lake and Clear Lake. Further north, the margin was along the meltwater channel that starts near Comertown. Drainage of the meltwater in southwestern Divide County and eastern Sheridan County was into the area of Medicine Lake. From the Medicine Lake area the meltwater flowed into Big Muddy Creek and south to the Missouri River.

Glacial Drift

The glacial drift of the Smoky Butte-Fertile Valley phase is slightly younger than the drift of the Hamlet-Grenora phase. The drift of the Smoky Butte-Fertile Valley phase may correlate with Clayton's drift E (Clayton, 1966, p. 18), which has an age of about 12,000 years. Deposition of drift was almost continuous between the Hamlet-Grenora and Smoky Butte-Fertile Valley phase; there is no evidence of overlapping drift sheets and there is little difference in the topography associated with the drift of the two phases. Dead-ice moraine is the most prevalent landform of the Smoky Butte-Fertile Valley phase. Other landforms are the Smoky Butte and Fertile Valley end moraines, linear disintegration ridges, collapsed outwash topography, collapsed lake sediment topography, meltwater channel, and kames. The elevations at the surface of the landforms associated with the drift are from about 2,000 feet above sea level in the sags of southwestern and south central Divide County, to about 2,400 feet above sea level in eastern Divide

County. The base of the drift is from about 1,980 to 2,200 feet above sea level. The thickness of the drift ranges from about 40 to 240 feet and probably averages 120 to 130 feet.

Glacial Landforms

End moraine – The Fertile Valley end moraine is a small accumulation of ridged glacial drift in southwestern Divide County; it is about six miles northeast of Grenora. The moraine is named for Fertile Valley township, T. 160 N., Rs. 102 and 103 W. The end moraine, which is about 5 miles long and 2 miles wide, is a band of knobby hills with a few superimposed, internal ridges. Local constructional relief is about 20 to 30 feet, but maximum height of the morainal crest is only about 60 feet above the surrounding terrain. The surficial glacial drift in the end moraine consists chiefly of stony, clayey till. Boulders are abundant on the surface of the moraine. The proximal margin of the moraine slopes westward into the sag associated with the drift-covered preglacial Missouri River valley; the distal margin abuts against the drift-covered preglacial interfluve.

The Smoky Butte end moraine (named for Smoky Butte in secs. 14 and 23, T. 160 N., R. 100 W.) is a narrow and high, arcuate ridge that has a number of aligned and small superimposed ridges. Local constructional relief in the moraine is 10 to 50 feet. The crest of the moraine is up to 200 feet above the surrounding topography. The surficial drift that is associated with the moraine consists of stony and clayey till, silt and clay, and some gravel. Boulders are numerous on the surface of the moraine. In a roadcut exposure at the southwest corner of sec. 3, T. 160 N., R. 99 W., clay, silt, and gravel occur as large tabular blocks in the till of the end moraine. Perhaps this material was derived from ablation drift of the previous Hamlet-Grenora phase for the subsurface deposit of silt, clay, and gravel that underlies the drift of this moraine is at least 75 feet below the surface in this area.

Dead-ice moraine – The dead-ice moraine of the Smoky Butte-Fertile Valley phase is associated with the higher elevations of the Missouri Coteau in eastern and central Divide County. In extreme eastern Divide County, the surface elevations of the dead-ice moraine often exceed 2,400 feet above sea level, but the local constructional relief of 30 to 70 feet is more moderate than that in the areas of dead-ice moraine north of Willow Lake and Smoky Butte. In these areas, local constructional relief of more than 100 feet is common, and the dead-ice moraine is characterized by large knobby hills and depressions. In southwestern Divide County, the dead-ice moraine is at lower elevations, about 2,000 to 2,200 feet above sea level, and the local constructional relief is moderate to high, 20 to 75 feet.

Figure 24. Closed disintegration ridges. This is an aerial photograph of secs. 1, 2, 11, and 12, T. 160 N., R. 95 W., southeastern Divide County. There is an ice-restricted, elevated lake plain (moraine plateau) in the SW 1/4 sec. 1 and collapsed outwash in the SE 1/4 sec. 12.

The drift in the dead-ice moraine of the Smoky Butte-Fertile Valley phase is chiefly till with small amounts of clay, silt, and gravel. It is as much as 200 feet thick in the dead-ice moraine north of the outwash that was deposited behind the Hamlet end moraine. Other areas of similar thickness are under the Fertile Valley end moraine and under the hills that lie to the northwest of the Smoky Butte end moraine.

The closed disintegration ridges associated with the dead-ice moraine of the Smoky Butte-Fertile Valley phase occur in abundance; they appear to be even more abundant where they border bodies of outwash and where local relief is more moderate. For example, closed disintegration ridges are very numerous in T. 161 N., R. 100 W., where the local relief is a moderate 10 to 40 feet and the dead-ice moraine borders collapsed outwash topography. In addition, some of the closed disintegration ridges of this phase in southeastern Divide County are shown by figure 24, an aerial photograph reproduction.

The moraine troughs (linear depressions that contain aligned, closed depressions and kettles) associated with the dead-ice moraine of the Smoky Butte-Fertile Valley phase are southeast of the Alkabo end moraine (pl. 1). The southwest-northeast trending depression in secs. 10 and 16, T. 161 N., R. 100 W., is about 60 to 80 feet below the surrounding terrain; it is about two miles in length. The other moraine troughs southeast of the Alkabo end moraine are more shallow; they are about 30 feet below the surrounding terrain. The linear depression that begins in sec. 11, T. 161 N., R. 101 W., is continuous to the northeast for about seven miles.

Linear disintegration ridges — There are numerous linear disintegration ridges associated with the drift of the Smoky Butte-Fertile Valley phase in Divide County. Most of the ridges occur in sets that are continuous into the outwash of this phase; others occur within the outwash and a few are found to be isolated ridges.

The linear disintegration ridges associated with the outwash immediately northwest of the Hamlet end moraine are in three sets. Generally, the ridges in these sets are less than 0.5 miles long, less than 10 feet high, and less than 100 feet wide. The drift in the set of ridges in secs. 7, 8 and 18, T. 160 N., R. 95 W., is mostly gravelly sand. The drift in the set of ridges that trend southward from secs. 2 to 13, T. 160 N., R. 96 W., is chiefly thick-bedded, dirty, sandy gravel where the ridges are within the outwash, but where the ridges are within till the drift is mostly bouldery till with lenses of dirty, coarse gravel. The drift in the set of ridges in the vicinity of Willow Lake varies from bouldery till and coarse, dirty gravel in secs. 27 and 28, T. 161 N., R. 96 W., to gravelly sand in sec. 5, T. 160 N., R. 96 W.

The linear disintegration ridge that lies on Smoky Butte in sec. 23, T. 160 N., R. 100 W., is a boulder-covered till ridge with constructional relief from 10 to 30 feet. This is a highly elevated till ridge for Smoky Butte is about 200 feet above the surrounding terrain. The ridges associated with the outwash at the distal margin of the Smoky Butte end moraine are generally boulder-covered till and gravel ridges that have local constructional relief from 5 to 20 feet. The set of ridges in secs. 7, 8 and 18, T. 160 N., R. 100 W., which are associated with an isolated outwash, consists of individual ridges in which the drift is stony till and dirty, coarse, thick-bedded gravel. Constructional relief of the ridges in this set ranges from 5 to 30 feet.

Northwest of the Smoky Butte end moraine, the drift in the sets of linear disintegration ridges in Tps. 161 and 162 N., R. 100 W., which are associated with the outwash in front of the Fertile Valley end moraine, generally consists of boulders, stony till, coarse dirty gravel and gravelly sand. The ridges are mostly 3 to 15 feet high and less than 100 feet wide.

Collapsed-outwash topography — The area of collapsed outwash topography that lies in the basin behind the Hamlet end moraine has local constructional relief from 10 to 60 feet. In addition to the numerous irregular depressions throughout the area of outwash, there are many northeast-southwest, narrow ridges 10 to 30 feet high in secs. 1, 2, 11, and 12, T. 160 N., R. 97 W.; the ridges are similar in form to the superimposed ridges of end moraine. The outwash generally consists of sandy gravel and gravelly sand. An exposure in a gravel pit in the NW 1/4 sec. 23, T. 160 N., R. 97 W., shows both thick-bedded, sandy gravel and interstratification of moderately dipping, medium to thick beds of gravel and sand. The exposure of outwash in a gravel pit in NE 1/4 sec. 33, T. 161 N., R. 97 W., shows faint, thick, steeply-dipping beds of sandy gravel. The maximum and average thickness of the outwash is largely unknown, although two wells of this study, test well 3001 in sec. 26, T. 160 N., R. 96 W., and test well 3002 in the NW 1/4 sec. 13, T. 160 N., R. 97 W., were drilled in the outwash. In test well 3001, 17 feet of surface sand, 26 feet of silt, and 10 feet of gravel were drilled prior to penetrating till. In test well 3002 the surface outwash is 20 feet thick; it overlies 31 feet of silt and clay, which lie above 20 feet of outwash gravel. The sequence of sediments probably means the gravel and sand of the outwash intertongues with lake sediments that, one mile further west, border the outwash at the surface.

The areas of collapsed outwash topography at the southwest proximal margin of the Smoky Butte end moraine has local construction relief of 20 to 50 feet. The outwash in this landform is mostly sandy gravel. An exposure in a gravel pit in the NE 1/4 sec. 32, T. 160 N., R. 100 W., showed 24 feet of very thick-bedded, sandy gravel overlying till; in another part of the pit thick, cross-bedded sandy gravel was poorly exposed. No test wells were drilled in this area of outwash, and except in exposures along the contacts bordering till, no other thickness data than that in the gravel pit was available.

West of the Smoky Butte end moraine, the isolated outwash in secs. 17, 18, 19 and 20, T. 160 N., R. 100 W., and in secs. 13, 23, 24, 25 and 26 is in a landform that has moderate local constructional relief of 20 to 40 feet. The outwash is mostly sandy gravel, though sand and clay bottom the large depression in secs. 24 and 25.

The linear southwest trend of collapsed outwash topography immediately south of the distal margin of the Fertile Valley end moraine is continuous from the vicinity of the abandoned post office of Stady, in the SE 1/4 sec. 31, T. 161 N., R. 100 W., southwest to sec. 31, T. 160 N., R. 103 W., and beyond into Montana. This is Witkind's (1959, p. 46) Stady channel, a misnomer of the landform; the outwash may be above the surrounding landforms, below the surrounding landforms, or it may be at the same level as the surrounding landforms. Irregular depressions are common in this collapsed outwash topography. The local constructional relief of the collapsed outwash topography is low, 5 to 15 feet, in the vicinity of Stady, but further southwest it is 10 to 40 feet.

Northeast of Stady, the outwash in this trend of collapsed topography is generally dirty, coarse, thick- and faintly-bedded gravel. Southwest of Stady, the outwash is generally slumped or horizontal- and cross-bedded sandy gravel; the bedding in the sandy gravel is medium to thick and faint to distinct. The thickness of the outwash is from 3 to 6 feet in the exposures northeast of Stady. Southwest of Stady, two test wells drilled during this study penetrated the gravels of this thin surface outwash. In test well 3030, NE 1/4 sec. 3, T. 160 N., R. 101 W., a sandy gravel that is 30 feet thick lies above 13 feet of silt over till; further west, in test well 3081, SE 1/4 sec. 20, T. 160 N., R. 103 W., a sandy gravel that is 8 feet thick overlies till.

Southwest of the Alkabo end moraine, the surface of the isolated outwash in secs. 1, 2, and 11 T. 160 N., R. 103 W., is an undulating plain that is slightly higher than the surrounding topography. The texture of the outwash is sandy gravel. Further north, the isolated area of outwash in secs. 13 and 14, T. 161 N., R. 103 W., is a moderate mound of sand. The surface of this mound of sand has been modified by Recent wind erosion.

Collapsed lake sediment topography — Collapsed lake sediment topography has low to moderate rolling topography, many irregular depressions, and the glacial drift consists mostly of lake sediments. The collapsed lake sediment topography in the basin immediately northwest of the Hamlet end moraine (pl. 1) has an undulating surface and local relief that ranges from 5 to 30 feet; large depressions are common. In this deposit, the lake clays and silts occur as interbedded laminations. The thickness of the lake sediments is 34 feet in test hole 3003, NW 1/4 sec. 36, T. 160 N., R. 97 W.; in addition, lake sediments beneath surface outwash were found in test hole 3002, NW 1/4 sec. 13, T. 160 N., R. 97 W., and in test hole

3001, NW 1/4 sec. 26, T. 160 N., R. 96 W. The clay and silt in test hole 3002 is 31 feet thick. The clay and silt underlie 20 feet of surface outwash sand and overlie 20 feet of outwash gravel. The lake sediments in test well 3001 are 26 feet thick. They lie below 17 feet of surface outwash sand and overlie 10 feet of outwash gravel.

Ice-restricted lake plains — The accumulations of chiefly lake sediments that underlie a plain and that were deposited in an ice-walled lake are ice-restricted lake plains. The lake sediments may or may not lie higher than the surrounding topography. The small ice-restricted lake plains that are associated with the dead-ice moraine of the Smoky Butte-Fertile Valley phase are similar to the moraine plateaus described by Gravenor and Kupsch (1959, p. 51-52). For example, the almost flat area in secs. 33 and 34, T. 161 N., R. 95 W., is roughly circular, less than 0.5 miles in diameter, and unrimmed. The thin glacial drift of the feature is gravelly clay and silt, lenses of sand and gravel, and till. The ice-restricted lake plain is bounded by a steep slope on the south, but in the other directions it does not lie above the surrounding terrain. Another similar ice-restricted lake plain in sec. 1, T. 160 N., R. 95 W., is shown in figure 24. It is higher than the surrounding topography.

Kames — Mounds of chiefly sand and gravel that were deposited in contact with glacial ice are kames. The kames of the Smoky Butte-Fertile Valley phase are low mounds of mostly dirty, sandy, bouldery gravel and till; their form is little different from the numerous knolls of boulder-covered till in the dead-ice moraine. All of the mounds of this phase are in south central Divide County. The low mounds of till and dirty gravel in secs. 4, 5, 7, and 8, T. 160 N., R. 97 W., are not over 15 feet high. The mounds are thickly covered by boulders. The ice contact deposit in sec. 1, T. 160 N., R. 98 W., consists of three very small coalescing mounds of dirty, sandy gravel. The mound of dirty gravel and till in sec. 28, T. 161 N., R. 97 W., is less than 15 feet high. The low mound in sec. 13, T. 160 N., R. 99 W., contains dirty, bouldery gravel.

Meltwater channels — In southeastern Divide County, a gravel-bottomed meltwater channel that served as a drainage for meltwater of the Smoky Butte-Fertile Valley phase and the following Plumer-Alkabo phase is continuous from secs. 13 to 31 and 32, T. 160 N., R. 95 W. This channel, 20 to 40 feet below the surrounding ground level, contains a set of gravel terraces that are eight feet above the channel of the present intermittent stream; this terrace may be remnants of the outwash deposited in the channel during this phase. The gravel in the bottom of the channel becomes coarser toward the source and in sec. 13, where the channel is associated with linear ridges, the gravel consists mostly of cobbles.

Further west in Divide County, the narrow meltwater channel in secs. 23, 25, 26, 35 and 36, T. 160 N., R. 101 W., is 30 to 70 feet deep and bottomed mostly by till. This channel, which is continuous south into Williams County, was a meltwater drain from the area of isolated outwash in secs. 19 and 24, T. 160 N., R. 101 W. The southerly gradient in the channel is in contrast to the present northeasterly slope of the land surface adjacent to the channel.

PLUMER-ALKABO PHASE

History

The Plumer-Alkabo phase began during a halt in the recession of the Late Wisconsinan glacier in northern Divide County and northeastern Sheridan County, Montana. At this time, the active ice front readvanced vigorously southwestward in the vicinity of Alkabo and the Writing Rock historical site. The margin of this still stand is largely determined from the geographic position of outwash and end moraines that were formed over and against drift-covered dead-ice of the previous Smoky Butte-Fertile Valley phase (fig. 25).

In eastern Divide County the dead-ice moraine of this phase is continuous with the dead-ice moraine previously deposited during the Smoky Butte-Fertile Valley phase; therefore, the margin of the still stand in this area is arbitrary. Meltwater of the Plumer-Alkabo phase in eastern Divide County drained down the channel in the southeastern part of the county. Further southeast, in Williams and Mountrail Counties, this channel is continuous to the White Earth valley. In central Divide County the margin of the still stand is marked by a small end moraine. Meltwater drainage in this area was to the southwest in a channel over drift-covered ice of the previous glacial phases. This meltwater flowed south into the valley of Little Muddy Creek. In northwestern Divide County the margin of the still stand is marked both by outwash and end moraine. The glacial drainage in northwestern Divide County and northeastern Sheridan County, Montana, was generally south into Medicine Lake and from there into the valley of Big Muddy Creek.

Glacial Drift

The glacial drift of the Plumer-Alkabo phase is slightly younger than the drift of the Smoky Butte-Fertile Valley phase; the drift of the Plumer-Alkabo phase is probably correlative with Clayton's drift F-G or a late phase of drift E (Clayton, 1966, p. 15 and 16). Deposition of the drift was essentially continuous between the Smoky Butte-Fertile Valley and Plumer-Alkabo phases because there is no evidence of overlapping drift sheets and no difference in the topography of the dead-ice moraine and outwash of the two phases.

The landforms associated with drift of the Plumer-Alkabo phase are the Plumer

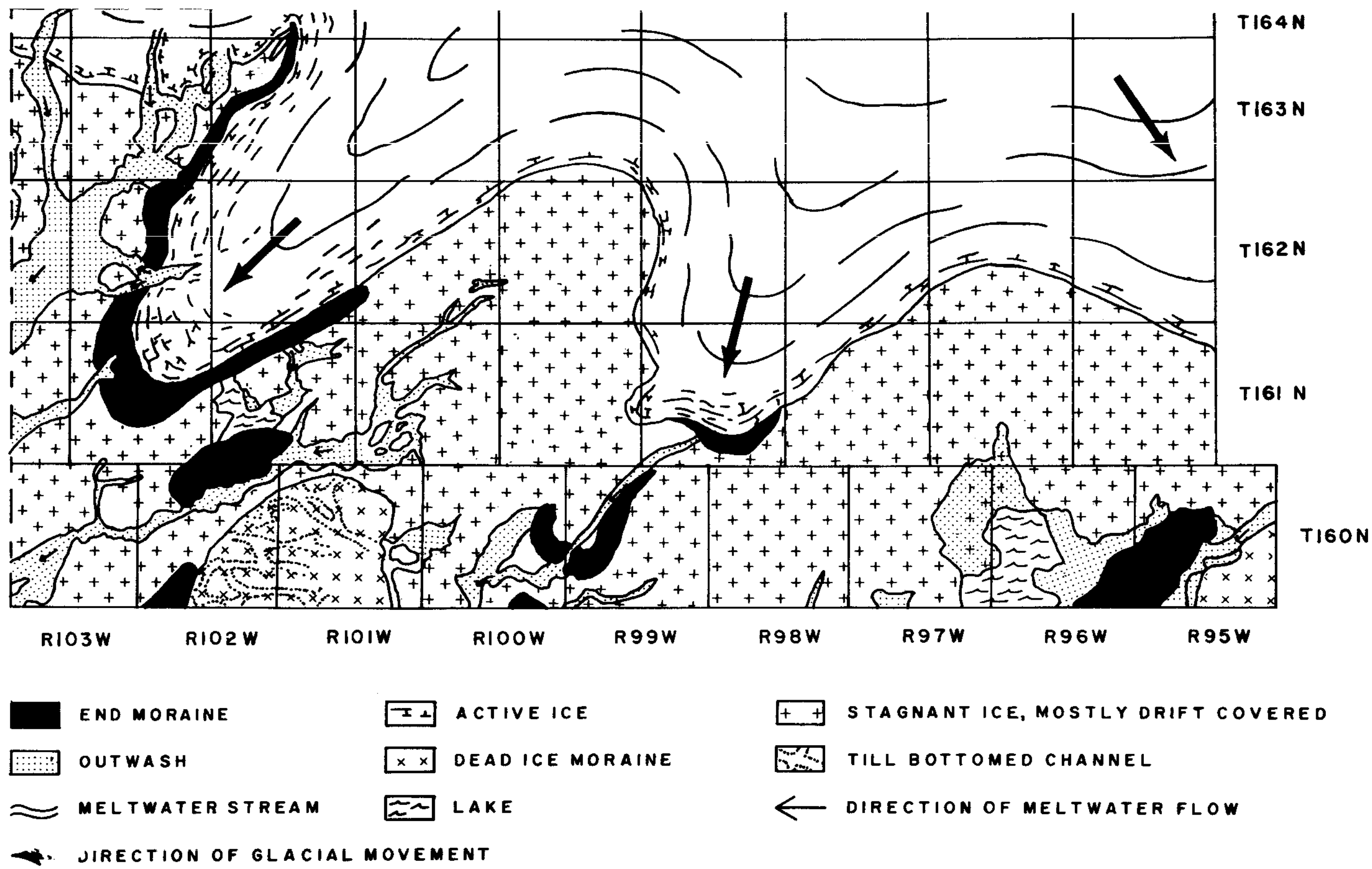


Figure 25. Plumer-Alkabo phase of Late Wisconsinan glaciation. The Alkabo and Plumer end moraines were formed during this phase. Large areas of outwash came into existence in western Divide County. Dead-ice moraine and partly-filled channels formed in southwestern Divide County.

and Alkabo end moraines, dead-ice moraine, esker and linear disintegration ridges, collapsed outwash topography, collapsed lake sediment topography, and ground moraine. The elevations at the surface of the landforms are about 1,900 to 2,300 feet above sea level in eastern Divide County, about 2,040 to 2,200 feet above sea level in south central Divide County, and about 2,100 to slightly more than 2,400 feet above sea level in western Divide County. The base of the drift is from about 1,840 to 1,940 feet above sea level. The thickness of the drift ranges from about 40 to 180 feet and probably averages 60 to 80 feet.

Glacial Landforms

End moraine — The Plumer end moraine, in secs. 26, 27, 28, 34, and 35, T. 161 N., R. 98 W., is an arcuate ridge of glacial drift that rises 40 to 60 feet above the surrounding terrain. The superimposed ridges of the end moraine are 5 to 15 feet high, and the surficial drift is chiefly stony, clayey till. The moraine, named for the township of Plumer, lies in front of the ground moraine in the Drift Plains district.

The Alkabo end moraine, named by Lemke and Colton (1958, fig. 5), is a very conspicuous landform in western Divide County. A high overall trend, numerous superimposed ridges, lobate shape, and steep slopes on the distal margin characterize this end moraine. The moraine is from 100 to 250 feet above the surrounding terrain; the superimposed ridges on the moraine are generally 5 to 30 feet high and a few are continuous for as much as 2 miles. Stony till is the chief lithology of the end moraine, although some of the superimposed ridges consist of large masses of gravel, sand, clay, silt, and till (fig. 26 and 27). Much of the washed drift in the ridges may have been derived from ablation drift of the Smoky Butte-Fertile Valley phase, but there is also a possibility that during the formation of the end moraine the clays found in the vicinity of test well 2248, in the SE 1/4 sec. 9, T. 161 N., R. 102 W., were derived as thrust blocks from the lake sediments of the underlying drift sheet. In this test well clays are continuous from the surface to a depth of about 527 feet.

In the Alkabo end moraine, bedrock is exposed at several places on the distal margin of the moraine. In a road cut exposure along State Highway No. 5 in sec. 35, T. 163 N., R. 102 W., beds of the Tertiary Tongue River Formation and a quartzite gravel have apparent westward dips of 80° (fig. 28). These are abnormally high dips in the bedrock; most of the bedrock in this part of the Williston basin has dips of less than 1°. These abnormal dips are probably due to thrusting or pushing and subsequent slumping of the bedrock during the formation of the end moraine.

Leonard (1925, p. 80) measured apparent bedrock dips of 23°, 33°, and 45° in the now abandoned underground lignite mines in secs. 13 and 14, T. 161 N.,

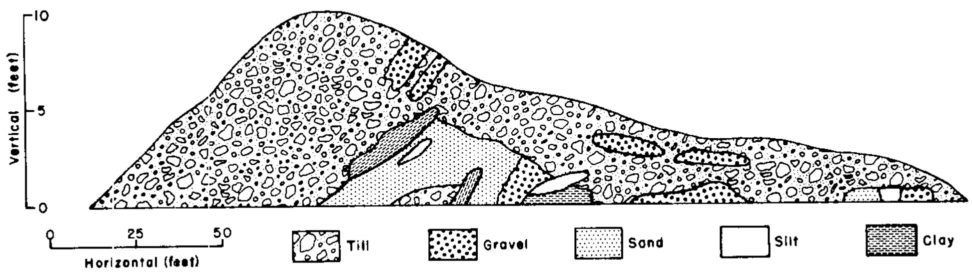


Figure 26. Schematic diagram through a push moraine on the Alkabo end moraine, SW 1/4 NW 1/4 sec. 22, T. 161 N., R. 102 W.

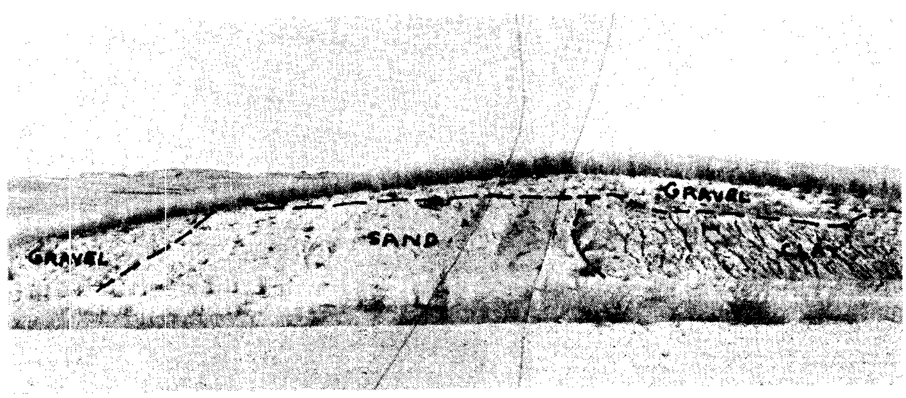


Figure 27. Photographic mosaic of push moraine on the Alkabo end moraine, SW 1/4 SW 1/4 sec. 22, T. 161 N., R. 102 W.

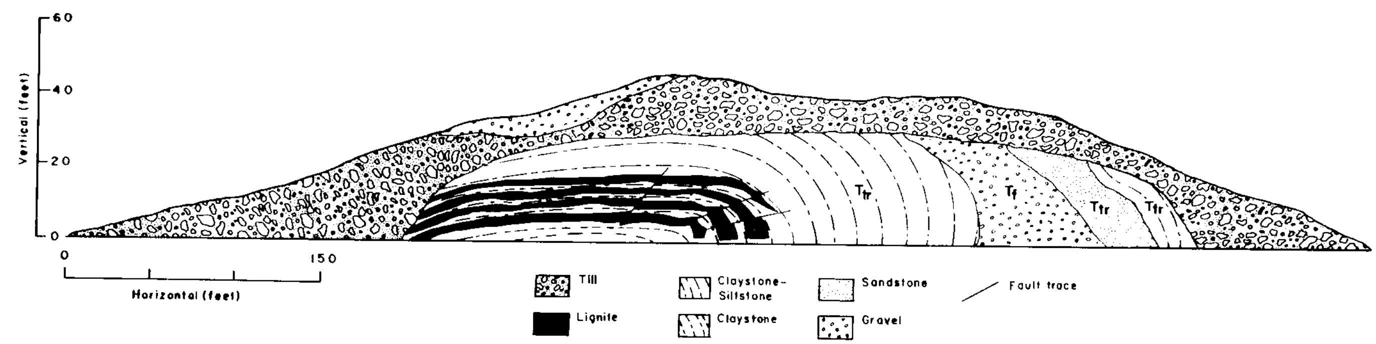


Figure 28. Schematic diagram of bedrock and glacial drift exposed along State Highway No. 5 in sec. 35, T. 163 N., R. 102 W. The beds labeled Ttr are Tertiary Tongue River and the gravel labeled Tf is probably equivalent to the Flaxville gravel.

R. 102 W. Leonard also wrote that some of the coal mine drifts bottomed in clay when the lignite seams were mined out down dip. Kupsch (1962) has also described ice-thrust features that are common along the preglacial valleys transecting the Missouri Coteau in Saskatchewan and Alberta.

Dead-ice moraine — The dead-ice moraine of the Plumer-Alkabo phase has a surface that is generally 2,100 to 2,300 feet above sea level. The local constructional relief of the dead-ice moraine is generally high, although there is a gradual change northward into the lower local constructional relief characteristic of the ground moraine that lies north of the Missouri Plateau escarpment. Because of this gradual change in characteristics of the land forms, the boundary between the dead-ice moraine and the ground moraine as shown on plate 1 is arbitrary. Further, south of Noonan, Crosby, and Ambrose the short valleys of ephemeral streams off the Missouri Plateau escarpment head at a short distance into the dead-ice moraine and some modification of the dead-ice moraine has resulted from stream erosion.

The dead-ice moraine of the Plumer-Alkabo phase in northwestern Divide County is associated with a very bouldery till and numerous closed disintegration ridges. The dead-ice moraine within the loop of the Alkabo end moraine is characterized by a very high local constructional relief that is commonly below the general elevations of the ground moraine off to the northeast. The moraine troughs, which are in the vicinity of the Alkabo end moraine, are the narrow, linear depressions of moderate and high local constructional relief that are either parallel or perpendicular to the movement of the glacial ice in the area (see pl. 1).

Esker and linear disintegration ridges — The small esker in secs. 3 and 4, T. 162 N., R. 102 W., west of the Alkabo end moraine, is continuous over both collapsed outwash topography and dead-ice moraine. The esker is a sinuous, narrow ridge 20 to 40 feet high and about 1.5 miles long; the glacial drift in the ridge is chiefly sandy gravel.

The numerous linear disintegration ridges of the Plumer-Alkabo phase are generally in sets that, from the dead-ice moraine, are continuous into outwash. Within the loop of the Smoky Butte end moraine, the set in secs. 17 and 19, T. 160 N., R. 99 W., consists of narrow ridges that are in a trend over highly collapsed terrain. The ridges, 5 to 40 feet high and thickly covered with boulders, are made up of glacial drift that is generally thick-bedded, dirty, coarse gravel. The glacial drift in the few isolated ridges that are further north in Tps. 161 and 162 N., R. 99 W., and T. 162 N., R. 98 W., is chiefly till with lenses of dirty gravel.

Southeast of the Alkabo end moraine, the set of linear disintegration ridges in secs. 13, 14, 22 and 23, T. 161 N., R. 101 W., consists of short, narrow, boulder covered ridges that are 5 to 10 feet high. The drift in the ridges is chiefly coarse, dirty gravel and bouldery till. To the northeast, a similar set of ridges, 10 to 30 feet high, exist in secs. 15, 16, and 21, T. 162 N., R. 100 W.

North of Fortuna, a set of ridges is continuous from sec. 1 to sec. 28 in T. 163 N., R. 101 W.; in section 14 the ridges are continuous over high topography of the Alkabo end moraine. The drift in the ridges, which are generally low and narrow, is chiefly a dirty, bouldery gravel and till where the ridges are associated with till of the end moraine and dead-ice moraine, but where the ridges are associated with outwash, in section 28 for example, the drift in the ridges is chiefly a sandy, boulder and cobble gravel. In the same area, the drift in the isolated ridges in secs. 10 and 11, T. 163 N., R. 101 W., is chiefly a bouldery till; the ridges are on the high topography of the Alkabo end moraine.

Northwest of the Alkabo end moraine, the glacial drift in the set of low, linear disintegration ridges associated with the dead-ice moraine and the isolated, collapsed outwashed topography in sec. 34, T. 164 N., R. 101 W., and in sec. 4, T. 163 N., R. 101 W., is sandy gravel, coarse and dirty gravel, and bouldery till. The medium to thick beds of the sandy gravel that are exposed in the NW 1/4 sec. 34, T. 164 N., R. 101 W., have steep southwest dips. The other sets of linear disintegration ridges associated with the extensive area of collapsed outwash topography and the dead-ice moraine northwest of the Alkabo end moraine generally consist of short, boulder-covered ridges 5 to 30 feet high. The glacial dirft in these ridges is dirty, thick-bedded, coarse gravel and till. In addition, much of the glacial drift in the short and low ridges of the sets in sec. 31, T. 164 N., R. 101 W., and in secs. 26 and 30, T. 164 N., R. 102 W., is made up of boulders.

Collapsed outwash topography — The linear deposit of highly collapsed outwash that is continuous southwest from the distal margin of the Plumer end moraine in sec. 28, T. 161 N., R. 98 W., to sec. 8, T. 160 N., R. 99 W., consists of thick-bedded, dirty and coarse gravel and sandy gravel. Local constructional relief is 20 to 40 feet and irregular, local depressions are numerous. In two borrow pits, the gravel beds exposed in the SE 1/4 sec. 29, T. 161 N., R. 98 W., are nearly horizontal, but the gravel beds exposed in the NW 1/4 sec. 3, T. 160 N., R. 100 W., dip steeply. The thickness of the outwash was found to be 0 to 10 feet; the thickness was determined only at the contacts with the surrounding till, and at the pit in sec. 3, T. 160 N., R. 100 W., where the 8 feet of exposed gravel was found to be 2 feet above till.

Southeast of the Alkabo end moraine, the isolated area of collapsed outwash topography in secs. 15, 16, 17, 18, 19, 20, 21, and 29, T. 162 N., R. 100 W., has local constructional relief from 20 to 50 feet. The outwash consists of coarse, dirty gravel. The gravel is not much more than a thin veneer over till because outcrops of till are common within the outwash. The isolated deposit of collapsed outwash topography in secs. 10, 15, 19, 20, 21, and 22, T. 161 N., R. 101 W., are associated with glacial lake sediments. The maximum thickness of the outwash, which consists of sandy gravel and coarse, dirty gravel, is unknown. The local constructional relief is from 10 to 40 feet.

The extensive deposits of collapsed outwash that lie mostly west of the Alkabo end moraine and south of the dead-ice moraine deposited during the Plumer-Alkabo phase in northwestern Divide County are continuous into eastern Sheridan County, Montana. In eastern Sheridan County the outwash is continuous southward into the vicinity of Medicine Lake, Montana.

In Divide County, many large and small depressions are associated with this outwash mostly west of the Alkabo end moraine and the local constructional relief ranges from about 5 to 100 feet; generally it is between 20 and 60 feet. An example of low local relief, a part of the outwash west of Miller Lake and about 3 miles southeast of Westby is associated with a plain (pl. 1) that is slightly above the elevations of the surrounding collapsed outwash topography. On the other hand, the high local relief of about 100 feet in secs. 11, 13, and 14, T. 163 N., R. 103 W., is where the outwash is partially in the deep depression that contains the saline McKone Lake. In addition, many of the other large depressions associated with this outwash contain saline lakes. The only fresh water lake associated with the collapsed outwash topography, Skjermo Lake in secs. 11 and 14, T. 163 N., R. 102 W., is completely within the outwash.

The outwash mostly consists of medium-and thick-bedded, sandy gravel and gravelly sand; only in the areas close to the source of sediments, the active ice margin, does the outwash chiefly consist of pebbles, cobbles, and boulders. Where exposed, the bedding of the outwash is faint to distinct. The outwash is thick-bedded where it is coarse gravel and medium- to thick-bedded where it is gravelly sand.

The highly variable thickness of this outwash has been determined from several test holes and surface exposures in gravel pits. The thickness at the surface exposures is 4 feet in the SW 1/4 sec. 35, T. 163 N., R. 101 W., 12 feet in the SW 1/4 sec. 22, T. 163 N., R. 101 W., and 16 feet in the NW 1/4 sec. 9, T. 162 N., R. 101 W.; in addition, the outwash is more than 25 feet thick in the gravel pits in secs. 23, 24, and 26, T. 163 N., R. 102 W. The thickness of the outwash in the test wells ranges from 13 feet in test hole 3009, SW 1/4 sec. 36, T. 163 N., R. 103 W., to as much as 104 feet (at least 54 feet thick) in test well 3007 in the NW 1/4 sec. 25, T. 162 N., R. 103 W. Other test wells and the thickness of this outwash are: (1) test well 3006 in the SW 1/4 sec. 19, T. 161 N., R. 102 W., - 33 feet of surface outwash, (2) test well 2247 in the SW 1/4 sec. 7, T. 162 N., R. 102 W., - 44 feet of surface outwash, (3) test well 2243 in the SE 1/4 sec. 11, T. 163 N., R. 103 W., - 15 feet of surface outwash, (4) test well 3008 in the NE 1/4 sec. 13, T. 163 N., R. 102 W., - 48 feet of surface outwash and (5) test well 2244 in the SW 1/4 sec. 33, T. 163 N., R. 102 W., - 27 feet of surface outwash.

Collapsed lake sediment topography — Southeast of the Alkabo end moraine, the lake clays and silts in secs. 18, 19, 20, 21, 28, 29 and 30, T. 161 N., R. 101 W., are associated with collapsed outwash. Irregular depressions are common within the lake sediments; local constructional relief ranges from 5 to 30 feet. The thickness of this deposit was not determined; the bedding, very faint, is laminated. Areas of similar collapsed lake sediment topography are in secs 14 and 15, T. 162 N., R. 101 W., and in secs. 29 and 32, T. 164 N., R. 102 W.; the lake sediments in sec. 29, T. 164 N., R. 102 W., are south of an ice-restricted lake plain that lies almost entirely in Saskatchewan.

Ground moraine — Ground moraine is an accumulation of drift, chiefly till, deposited by the active ice of a glacier. The surface of the landform is generally a gently undulating to rolling plain. The ground moraine in northern Divide County consists chiefly of till; boulders are not common on the surface. Depressions within the ground moraine are generally small and shallow, and the surface of the landform is almost flat to rolling. In the area of ground moraine east of Fortuna and at the margins with the dead-ice moraine, some of the broad hills are quite high. The surface elevations of the ground moraine are about 1,840 to 2,265 feet above sea level. The drift associated with this ground moraine is about 30 to 100 feet thick; the average thickness is about 40 to 50 feet.

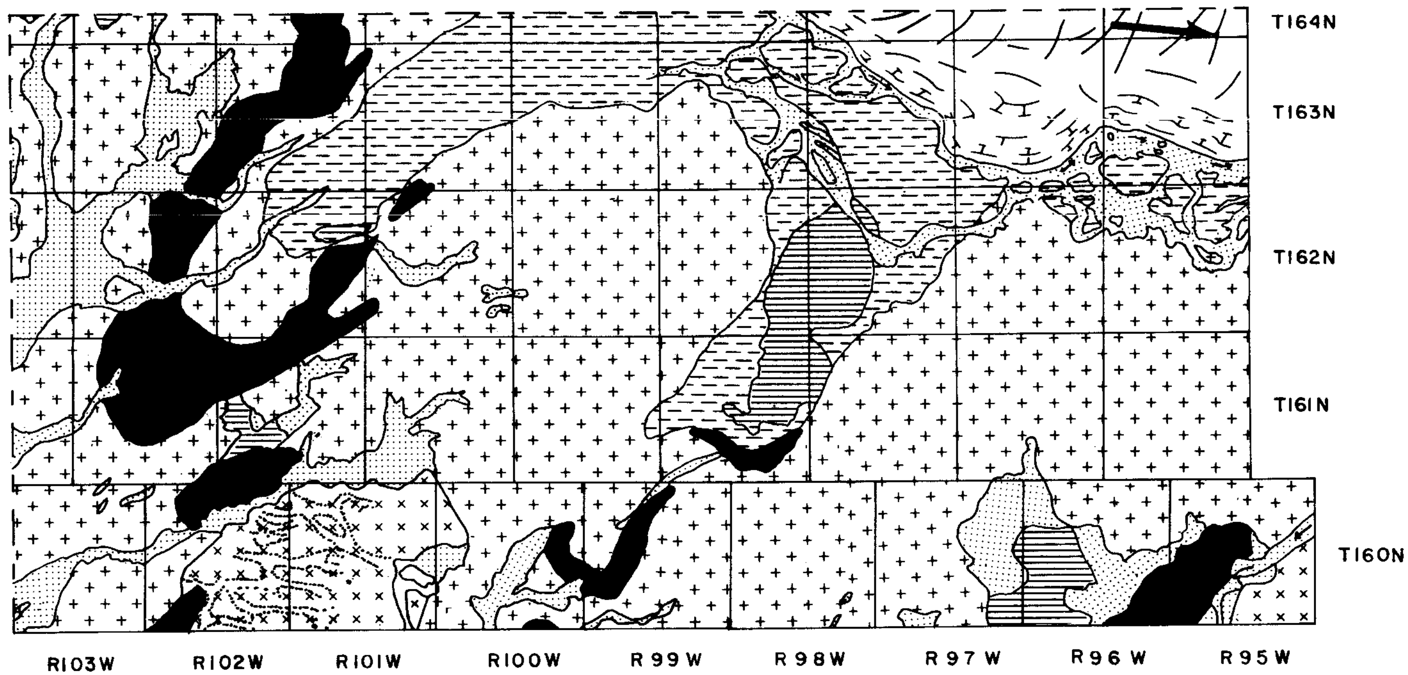
LONG CREEK PHASE

History

The Long Creek phase of glaciation began during a halt in the recession of the Late Wisconsinan glacier in southeastern Saskatchewan and northern Divide County. The margin of the thinning glacier stagnated in northern Divide County; if there was any movement of the thinner glacial ice in northern Divide County, the movement was incidental to the southeastward flow of the main ice mass, which lay off to the northeast. This southeastward flow in southeastern Saskatchewan and to the east of Divide County probably also occurred during most of the preceding Plumer-Alkabo phase.

In northeastern Divide County the margin of the still stand was at a maximum elevation of about 2,150 feet above sea level, but immediately northeast of the Alkabo end moraine the margin was probably temporarily over 2,200 feet above sea level. The margin of the still stand in northeastern Divide County is marked by a lake deposit, a series of ice-contact deposits, and several narrow, coalescing meltwater channels and outwash deposits (fig. 29).

The meltwater drainage was generally to the southeast in a series of shallow ice marginal channels that, during the following northeastward recession of the glacier, formed a part of the Long Creek - Des Lacs glacial drainage. The meltwater channels occupy successive positions that are at lower elevations toward the northeast, the direction of the glacial recession.



END MORAINE

OUTWASH

LAKE BEDS

PARTLY FILLED CHANNELS

ACTIVE ICE

DEAD-ICE MORAINE

MELTWATER STREAM

STAGNANT ICE, MOSTLY DRIFT COVERED

GROUND MORAINE

DIRECTION OF MELTWATER FLOW

DIRECTION OF GLACIAL MOVEMENT

Figure 29. Long Creek phase of Late Wisconsinan glaciation. Outwash plains and outwash-filled meltwater channels were formed during this phase.

Glacial Drift

The glacial drift of the Long Creek phase, slightly younger than the drift of the Plumer-Alkabo phase, is probably equivalent to a part of Clayton's drift H-J (Clayton, 1966, p. 15). Deposition of drift was nearly continuous between the Plumer-Alkabo and Long Creek phases.

The glacial landforms associated with the Long Creek phase are kame terraces, outwash plains and outwash filled meltwater channels, a lake plain, and ice-contact deposits with irregular landforms. Most of the drift deposited during this phase is between 1,840 and 2,050 feet above sea level. The drift is thin; the thickness ranges from 0 to 40 feet and the average thickness is probably 15 to 20 feet.

Glacial Landforms

Lake plain — Southwest of Crosby, the landform in Tps. 161 and 162 N., Rs. 97 and 98 W., is a gently rolling to flat lake plain. Irregular depressions are rare, local relief is not over 5 feet, and the associated lithology is generally clay and silt. Boulders are rare on this lake plain. The lake beds are at surface elevations from 1,960 to 2,080 feet above sea level. They are not more than 30 feet thick; hand-auger holes often penetrated the clay and silt and bottomed in till at depths of less than 6 feet. The clays and silts were deposited as interbedded laminations.

The lake in which the sediments were deposited probably had a brief existence; it was formed when the meltwater from the glacial margin in T. 163 N., Rs. 97 and 98 W., ponded within the sag southwest of Crosby. The lake drained eastward by a meltwater channel that formed parallel to the ice margin; this meltwater channel, held to an elevated position by glacial ice to the north, was eroded into the glacial drift of the Missouri Plateau escarpment in secs. 4, 8, and 9, T. 162 N., R. 96 W.,

Kame terraces — Landforms that are an accumulation of ice-contact stratified drift, chiefly glaciofluvial, deposited between glacial ice and an adjacent valley wall are kame terraces. In Divide County, kame terraces have been deposited near the base of the Missouri Plateau escarpment west of Noonan. The kame terraces in secs. 2, 3, and 4, T. 162 N., R. 96 W., and in secs. 5 and 8, T. 162 N., R. 95 W. are 10 to 30 feet above the adjoining meltwater channels. The glacial drift in the kame terraces is sandy gravel, till, and boulders.

Ice-contact deposits, undifferentiated — Deposited during the Long Creek glacial phase, the ice-contact deposits of generally glaciofluvial drift in northeastern Divide

County are in irregular to linear mounds, which are generally associated with outwash. The irregular to linear mounds range in length from less than 0.1 mile to 1.5 miles, in width from 200 feet to 2,100 feet, and in height from 10 feet to 30 feet. The glacial drift in the ice-contact deposits is generally gravelly sand; silt and clay beds, dirty gravel, boulders, and till are also common in the landforms.

West of Crosby, at an old gravel pit in the NE 1/4 SE 1/4 sec. 30, T. 163 N., R. 97 W., 17 feet of moderately- to steeply- dipping, medium- to thick-bedded, gravelly sand is exposed. Shale pebbles are common in the gravelly sand at the southeast end of the large ice-contact deposit that is continuous from the NE 1/4 sec. 24, T. 163 N., R. 98 W. to the NW 1/4 sec. 29, T. 163 N., R. 97 W., up to 9 feet of highly inclined silt beds and till are exposed along a 560 foot railroad cut. Northwest of Noonan, much of the glacial drift in the ice-contact deposits is gravelly sand or sand; boulders and dirty gravel are common in a few of the landforms. Most of the gravel pits in the Noonan area are in deposits of gravelly sand.

Outwash plains and meltwater channels — The outwash deposited during the Long Creek phase is associated with either a plain at the same surface elevations as the surrounding ground moraine or segments of the narrow outwash deposits are associated with topography characteristic of meltwater channels (see pl. 1). In the meltwater channel segments, the surface of the outwash is from 5 to 40 feet below the surrounding terrain. Most of the channel segments are at elevations from 1,880 to 2,050 feet above sea level, but southeast of Noonan the walls of the short meltwater channels are as high as 2,150 feet above sea level.

The outwash in the narrow channel deposits is generally gravelly sand. In the few exposures, the sand and gravel occur as medium to thick, southeastward-dipping beds that are overlain by thick horizontal beds. Clay and silt beds are also common. The thickness of the outwash north of Noonan was measured in a few locations by Townsend (1954), and was found to be 6 to 40 feet. In the same general area, a few of the test wells drilled during this study penetrated from 2 to 41 feet of washed surface sediments.

The narrow deposits of outwash coalesce north of Noonan into an outwash plain that is continuous across the southern part of T. 163 N., R. 95 W. Local constructional relief on the plain is generally less than 5 feet. The glacial drift is generally sand, but clays and silts are common. The area is poorly drained, and much of the outwash and the surrounding till contain an accumulation of salts. Further north of Noonan, the outwash plain parallel to Long Creek in Tps. 163 and 164 N., R. 96 W., slopes gently into the channel of Long Creek. The surface of the outwash shows relict meander scars, and sand bars rise slightly above the surface.

Non-glacial

Although the glacial landforms in Divide County are fresh, there have been minute changes in the landscape during the Recent Epoch, which began about 5,000 years ago. Most of the changes in landforms have been caused by water erosion and deposition, but wind erosion and deposition have been effective in certain areas.

The more noticeable change in landforms is on the north-facing slope of the Missouri Plateau escarpment in northern Divide County, where ephemeral streams have incised up to 60 feet into the dead-ice moraine and ground moraine associated with the escarpment slope. Though now chiefly downcutting, in the past the ephemeral streams have carried sediments off the escarpment, and where the gradient changes abruptly, have deposited their load, chiefly silts and clays, as a thin veneer on the ground moraine and outwash that lie north of the escarpment. In other areas of the county, the same erosion and deposition has taken place off the steeper slopes of the dead-ice moraine and end moraines. The irregular depressions in the moraines have been catch basins for sheetwash deposits, chiefly clays and silts, and most of the numerous depressions are floored by such Recent deposits. In addition, the deposition of clays and sodium sulphate in the depressions associated with the outwash and dead-ice moraine in western Divide County has continued since deglaciation.

Wind erosion has been more effective in the areas of outwash. The largest areas of landform modification by wind erosion are north of Noonan (see pl. 1), where the surface of the sandy outwash has been blown into low dunes. Now, because of the conservation methods of farming practiced, the areas of low dunes are not generally subject to severe wind erosion.

ECONOMIC GEOLOGY

The most important mineral production in Divide County is petroleum. Other sources, or potential sources, of mineral wealth are sand and gravel deposits, lignite, Glauber's salt from the sodium sulfate lakes, subsurface halite and potash salts, and clay associated with beds of lignite.

SALT

A potential source of mineral wealth are large deposits of salt that occur deep in the subsurface of Divide County. The beds of halite in the upper part of the

Mississippian Madison (Poplar and Ratcliffe intervals) occur at depths from 5,820 to 7,797 feet below surface. The composite thickness of these halite beds is about 300 feet. Halite associated with thinner potash beds of the Devonian Prairie Formation occurs at depths from 9,909 to 10,460 feet below surface. The maximum thickness of the Prairie salt beds drilled to date is 394 feet.

PETROLEUM

The first well drilled to find petroleum in Divide County was the Northwest Oil Company No. 1 well located in the SE 1/4 sec. 27, T. 163 N., R. 95 W., about 1.5 miles north of Noonan. This well, drilled in 1928, was abandoned at a depth of about 2,235 feet. The next phase of exploration began in the county when oil was discovered in northwestern North Dakota during 1951.

Since 1951 and prior to January 1, 1967 there were 94 wells drilled in the county during the search for petroleum; of the wells drilled, 31 are now producing oil. All of the present oil production is from the Mississippian Madison limestone at depths that range from 6,377 to 7,999 feet below surface. There are 6 fields with most of the production coming from the North Tioga and Stoneview fields. Other Madison fields are the Baukol-Noonan, Noonan, Wildrose and Flat Lake East Fields. The Baukol-Noonan, Noonan, Stoneview and North Tioga fields are located in eastern Divide County on the north-south trend of the Nesson anticline. The Wildrose field is on the structural trend that is continuous south from Crosby. The Flat Lake East is an extension of Madison production from northeastern Montana. Production from rocks other than the Madison did exist briefly when Ordovician Red River production was established in the one well-Writing Rock field in 1958, but this well was abandoned in May, 1959.

There are several reasons why more production of petroleum can be expected in Divide County. They are: (1) the established oil production from the Mississippian Madison, (2) the brief oil production from the Ordovician Red River Formation, a formation from which production is firmly established in other parts of the Williston Basin, (3) the oil production from the Devonian and Silurian rocks to the south in Williams County and the occurrence of the same rocks in Divide County, (4) the presence of several structures in the county, and (5) the numerous localized facies changes that take place in several of the formations within the county. Facies changes are most apparent in the Madison and Tyler Formations, where stratigraphic entrapment is more important than structure for the accumulation of petroleum in commercial quantities in many oil fields.

LIGNITE

Lignite has been mined in Divide County from the Tongue River Formation near Noonan and near the Writing Rock historical site south of Alkabo. Large scale lignite mining in the county ceased recently when the reserves of the Baukol-Noonan strip mine in secs. 1, 2, 3, 10, 11 and 13, T. 162 N., R. 95 W., were exhausted. At this mine, over 200,000 short tons of lignite were produced annually. The mines south of Alkabo were underground and have not operated for at least twenty years.

The lignite produced in the Baukol-Noonan mine was from the Noonan bed, which lies at an elevation of about 1,960 feet above sea level; the bed was covered in the stripped area by 3 to 40 feet of overburden. West of the stripped area, the same bed crops out in the ravines along the Missouri Plateau escarpment. The Noonan bed is missing by erosion to the northwest, and to the southeast it is covered by thicker overburden. The stripped area was the most favorable area for lignite production in this northeastern part of the county; immediately south and north of the abandoned strip mine other lignite beds found in test wells are covered by a greater thickness of overburden.

Unless other lignite beds covered by thin overburden can be found in northeastern Divide County, the possibility of future lignite mining in Divide County appears to be remote; however, there are other unexplored areas where the glacial drift cover is less than 100 feet. The areas that are shown on plate 4 are (1) in T. 160 N., R. 95 W., southeastern Divide County (2) in T. 160 N., Rs. 101 and 102 W., southwestern Divide County, and (3) in Tps. 162 and 163 N., R. 103 W., northwestern Divide County. It is possible that relatively shallow Tongue River and Sentinel Butte lignite beds could be found to be mineable in these areas, although that situation is not indicated at this time.

SODIUM SULFATE

Deposits of sodium sulfate in rather large quantities have been known to exist for some time in western Divide County. The largest deposits are found in the following saline lakes: (1) Grenora No. 1 in secs. 10, 15, 16, 21, T. 160 N., R. 103 W., (2) Grenora No. 2 in secs. 28, 29, 32, 33, T. 160 N., R. 103 W., (3) Stady E in secs. 5 and 8, T. 160 N., R. 99 W., (4) Miller in secs. 19, 20, 24, 30, T. 162 N., R. 102 W., (5) North in secs. 7, 8, 17, T. 162 N., R. 102 W., (6) McKone in secs. 14 and 23, T. 163 N., R. 103 W., (7) Westby A in sec. 14, T. 162 N., R. 103 W., (8) Westby B in secs. 3 and 34, Tps. 162 and 163 N., R. 103 W., and (9) Westby C in secs. 3 and 10, T. 162 N., R. 103 W. Reserves in these lakes are given by Binyon (1952, p. 24-28) in short tons of Glauber's salt.

The geologic occurrence of the saline lakes has been discussed by Witkind (1959, p. 71-74) who recognized that deposition ofthe sodium sulfate is associated with restricted ground water circulation in these lake basins. The geologic map (pl. 1) shows that the saline lakes are generally associated with collapsed-outwash topography and dead-ice moraine. Further, the lake basins are generally within larger depressions, are bottomed by clay and till, and are at lower elevations than the outwash. Because this is a region of low rainfall and high evaporation, the lakes are intermittent. The mineralized ground water from the surficial sand and gravel is discharged into the basins; in addition, some mineralized water also percolates into the depression from the surrounding dead-ice moraine, but the importance of till-buried sands and gravels as sources of mineralized water is unknown. Subsequent drying up of the lake leaves sodium sulfate and other salts on the dry lake bed; over the years increments of salt have been built into thick beds of sodium sulfate. The source of the sodium sulfate is the glacial drift.

SAND AND GRAVEL

The sand and gravel deposits of Divide County occur in the following glacial landforms: collapsed-outwash topography, ice-contact deposits undifferentiated, meltwater channels, linear disintegration ridges, kame terraces, and outwash plains. The landforms and the location of the gravel pits are shown on plate 1. The ice-contact deposits— the kame terraces, the undifferentiated forms, and the linear disintegration ridges— are usually poor sources of gravel; the deposits are generally poorly sorted, and the percentages of iron-oxide and claystone pebbles may be higher than that desired. Nevertheless, the ice-contact deposits are often used locally for road surfacing and concrete aggregate. Generally, the outwash associated with collapsed topography is the best source of gravel for all uses; the deposits can be easily washed and screened to make good quality construction gravel. Large reserves of gravel in this kind of outwash are available in northwestern Divide County. The quality of the gravel in the outwash-filled meltwater channels is generally good; unfortunately, deposits are generally small.

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APPENDIX A

Examples of bedrock lithologies and formation tops from shallow test holes.

Partial log of the Northwest Oil Company well that was drilled in the SE 1/4 NW 1/4, sec. 27, T. 163 N., R. 95 W., Divide County. Ground elevation is 1906 feet. This log is from the files of the North Dakota Geological Survey.

Pleistocene -- Glacial Drift	Thickness (feet)	Depth (feet)
Clay, yellow	45	45
Clay, blue	40	85
Tertiary -- Tongue River Formation		
Shale, green	5	90
Shale, blue	10	100
Limestone, thin-bedded	10	110
Sandstone;water	15	125
Shale, blue to gray	40	165
Limestone, thin-bedded	5	170
Lignite	5	175
Shale, brown	25	200
Limestone, gray	20	220
Shale, gray	60	280
Shale, brown	25	305
Lignite	10	315
Shale, gray	5	320
Shale, sandy, gray	50	370
Sandstone; water	10	380
Tertiary -- Ludlow and Cannonball Formations		
Shale, black to gray	40	420
Shale, with pebbles	5	425
Lignite	8	433
Shale, gray	17	450
Shale, black to gray	90	540
Shale, sandy, gray	50	590

Shale, gray	20	610
Shale, sandy, gray	85	695
Sandstone; water and small amount of gas	20	715
Shale, sandy, gray	35	750

Cretaceous -- Hell Creek Formation

Shale, brown	30	780
Shale, gray	125	905
Shale, brown	65	970

Cretaceous -- Fox Hills Formation

Shale, gray	40	1,010
Shale, gray; small amount of gas	10	1,020
Sandstone	15	1,035
Shale, black	5	1,040
Shale, sandy, gray	95	1,135
Shale, black	15	1,150
Sandstone; water and small amount of gas	55	1,205

Cretaceous -- Pierre Formation

Shale, gray	ended log

Log of well drilled by United States Geological Survey. The well was drilled in the SE 1/4 SE 1/4, sec. 15, T. 163 N., R. 96 W., Divide County. Ground elevation is 1906 feet.

Pleistocene -- Glacial Drift	Thickness (feet)	Depth (feet)
Soil	1	1
Clay, brown	5	6
Clay, brown, with gravel	10	16
Clay, gray, with strips of brown clay, with some gravel	9	25
Sand, coarse and fine gravel	26	51
Gravel with boulders, some lignite fragments	4	55

Tertiary -- Tongue River Formation

Clay, sandy, gray and brown	36	91

Clay, sandy, blue, with strips of lignite	10	101
Lignite, with strips of clay	5	106
Clay, sandy, blue and brown, with strips of lignite	31	137
Sandstone, gray, hard	2	139
Sand, fine with strips of gray sandy clay	5	144
Sand, gray compact	6	150
Sand, fine, with strips of gray sandy clay	7	157
Sand, gray, compact with some brown sandy clay	44	201
Lignite, with strips of brown and gray sandy clay	16	217
Sand, gray, compact with strips of lignite, some brown clay	29	246
Lignite with compact gray sand some brown sandy clay	12	258
Clay, sandy, gray, with some green, gray and brown clay	15	271
Sand, gray, compact with strips of lignite	18	289
Clay, sandy, brown (carbonaceous) with strips of lignite	7	296

Tertiary -- Ludlow and Cannonball Formations

Clay, sandy, gray, and green, with strips of lignite	27	323
Lignite, soft	2	325
Clay, sandy, gray, with strips of green sandy clay and some lignite	20	345
Sandstone, thin strips, with dark gray and brown clay	5	350
Sandstone, gray, hard	1	351
Clay, sandy, gray with strips of lignite	69	420
Clay, sandy, gray	5	425
Clay, sandy, brownish gray, with strips of lignite	5	430

Hole filled.

Log of well drilled for the United States Air Force. Location of the drill site was in the SW 1/4 NW 1/4 sec. 36, T. 163 N., R. 102 W., Divide County. Ground elevation is 2330 feet.

Pleistocene -- Glacial Drift	Thickness (feet)	Depth (feet)
Gravel, sand, clay, tan (till)	25	25
Clay, silt, sand, gravel, gray (till)	55	80

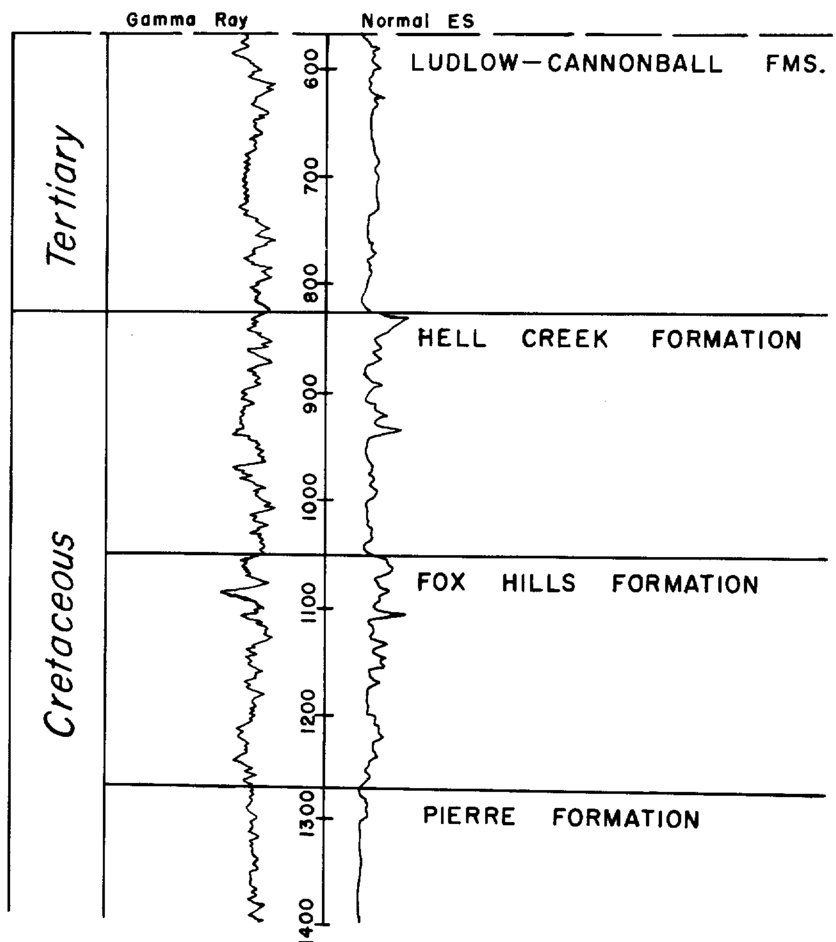
Tertiary -- Tongue River Formation
(beds could have been disturbed by glaciation down to 225 feet)

Clay, sandy, yellow	45	125
Sand, gray	35	160
Clay, silt, gray (carbonaceous material)	15	175
Clay, gray	50	225
Clay, sandy, gray	10	235
Lignite and clay layers	10	245
Shale and clay, gray	20	265
Lignite	5	270
Claystone, sandy, gray	112	382
Sand and clay, tan and gray	18	400

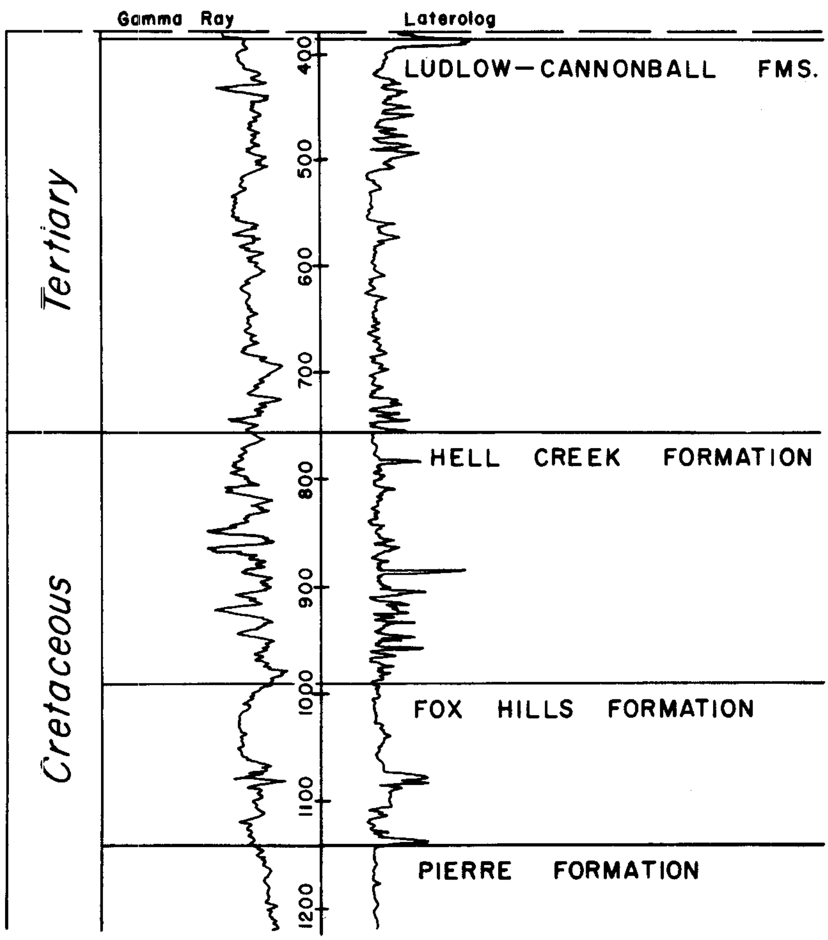
APPENDIX B

Mechanical logs selected to show the log characteristics of the shallow bedrock formations.

NDGS Well No. 321
Argyle Royalty No. 1 Baukol-Noonan
SE 1/4 NE 1/4 sec. 11, T. 162 N., R. 95 W., Divide County
K. B. 2031 feet



NDGS Well No. 3441
Cardinal Petroleum and National Bulk Carriers No. 1 Thon
SE 1/4 SE 1/4 sec. 3, T. 162 N., R. 102 W., Divide County
K. B. 2244 feet



NDGS Well No. 3141
Hunt Petroleum No. 1 L. Rosten
NW1/4 NW1/4 sec. 30, T. 160 N., R. 97 W., Divide County
K. B. 2297 feet