GEOLOGY

of

ROLETTE COUNTY, NORTH DAKOTA

by

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A user-oriented report
describing the geology
of Rolette County

Grand Forks, North Dakota: 1972

The design on the cover represents the entrance to the International Peace Garden, dedicated in 1932 and commemorating 150 years of peace between the United States and Canada. The international boundary passes through the center of the entrance and down the length of the formal garden, built on land donated by the State of North Dakota and the Province of Manitoba. The site in the Turtle Mountains was finally selected for the garden because of its natural beauty, the fact that it is midway between the Atlantic and Pacific Oceans, and is only 35 miles from the spot considered to be the geographic center of the North American continent.

For sale by the North Dakota Geological Survey,
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HOW TO USE THIS REPORT

This report is designed for a wide variety of users: construction engineers, gravel developers, ground-water developers, farmers, soil scientists, conservationists, ecologists, architects, municipal officials, county officers, state or federal administrators, planning board members, geologists, natural historians, and anyone else who might be interested in the geology of the near-surface sediments of Rolette County. Few individuals are likely to be concerned with all the material contained in this report. I have therefore made an attempt to separate this information into useful categories. A certain amount of repetition was necessitated by this organization, but reiteration has been held to a minimum. Abundant cross-references have been added to help you find other sections of this report that may be of interest. An effort has been made to avoid unnecessary technical jargon, and, wherever possible, to use words in the way they are defined in a standard dictionary. Unusual usage and most specialized terms are briefly explained as necessary in the text. Additional explanations of specialized geologic usage can be found in the **Glossary of Geology and Related Sciences, Second Edition with Supplement** (American Geological Institute, 1960).

Plate 1 (*folded and included in the pocket at the back of this report*) is designed as a visual summary of the geologic data and interpretations contained in this report and may be used alone without reference to the text.

The larger map on Plate 1, **Surface Sediments and Landforms**, is a descriptive map showing the distribution of sediment types and geologically significant hillslopes. Units 1 through 15 on that map are explained further in the text in the section **Basic Data**, subsection **Surface Sediments.** Hillslope information is further explained in the section **Basic Data**, subsection **Topography.** Some of the other numbered units on that map are further explained in the text in the section **Special Geomorphic Symbols.**

Users of this report specifically interested in the physical properties of material in Rolette County will find it summarized on the map **Surface Sediments and Landforms** (Pl. 1) and discussed in more detail in the text in the sections **Basic Data** and **Applications.**

The smaller map on Plate 1, **Sediment Origin**, summarizes my interpretations of the origin of the sediments shown on the larger map. An expanded explanation of the alphabetic units (A through Z) shown on this map is given in the text in the section **Sediment Origin.**

Users of this report specifically interested in the geologic history of Rolette County should read the section **Interpreted Quaternary History** before turning to the section **Sediment Origin.**

BASIC DATA

Location

Rolette County contains approximately 942 square miles in north-central North Dakota (Tps. 159-164 N., Rs. 69-73 W.) adjacent to the Canadian border (Fig. 1). The Turtle Mountains form a hilly upland, topographically similar to the Missouri Coteau to the south. The Red River to the east flows across the former site of glacial Lake Agassiz. The Souris River to the west flows across the former site of glacial Lake Souris.

Soils

The word "soil" is used as it is defined by the Soil Survey Staff, United States Department of Agriculture Soil Conservation Service (USDA-SCS) (United States Department of Agriculture Soil Survey Staff, 1960, p. 1-5); it is surface material that differs from underlying sediment as a result of interactions between climate, living organisms, parent material, and relief. Thus soil includes more than earth darkened by humus but does not include all uncemented sediment. For practical purposes soil is that surface material penetrated by roots of perennial plants.

The technical soils terminology used in the rest of this section also follows USDA-SCS usage (United States Department of Agriculture Soil Survey Staff, 1960, 1967, and 1968).

In 1963 the Agricultural Experiment Station, North Dakota State University of Agriculture and Applied Science, published a general soils map of Rolette County (North Dakota State University Department of Soils and United States Department of Agriculture Soil Survey Staff, 1963) at a scale of 1:126,720. According to Patterson, Johnsgard, Sweeney, and Omodt (1968, p. 1) (*this publication is the explanation of the general soil map*) this map was based on a reconnaissance survey made at a rate ranging from about ½ to 2 townships per man per day. Map units are soil associations (not individual soil series) and the smallest areas shown represent approximately 160 acres. Contacts on this map are, in general, less accurately located than are contacts between sediment types on the map **Surface Sediments and Landforms** on Plate 1.

Soils in Rolette County outside the area of the Turtle Mountains are typical North Dakota grassland soils which developed under a native tall-grass vegetation. Soils that developed in ground-water recharge areas that are dry most of the year are Haploborolls (Chernozems). Soils that are dry most of the year, in regional ground-water discharge areas, rich in sodium ions, and have claypan subsoils are Natriborolls (Solodized-Solonetz). In ground-water recharge areas that are in

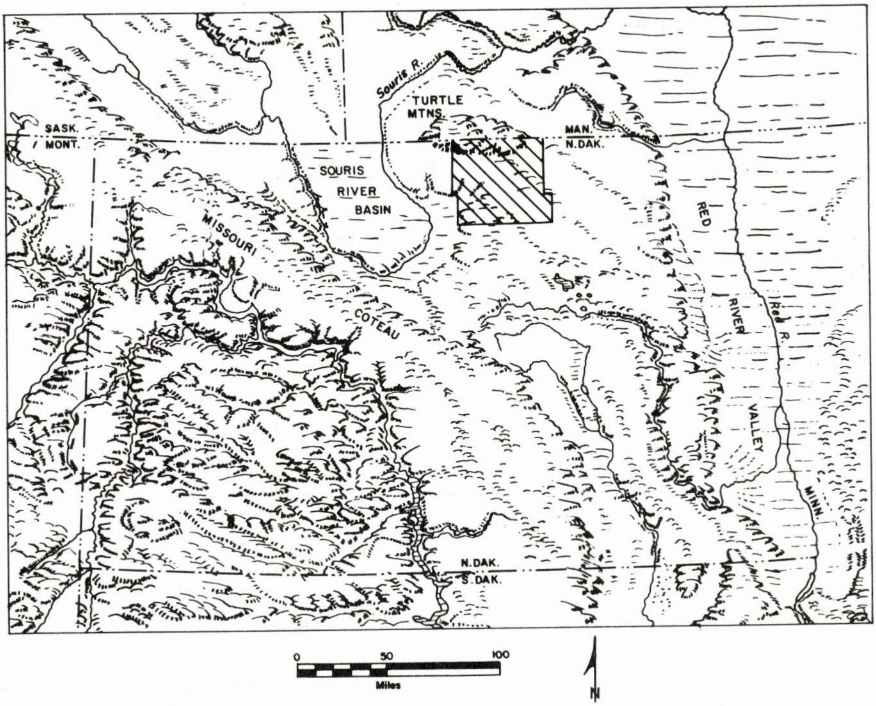


FIGURE 1. Location diagram and physiographic setting of Rolette County.

bottomlands and wetter than those described above, Argiborolls (Planosols), Haplaquolls (Humic Gleys), and Fluvents (Alluvial Soils) occur. Calciaquolls (Calcium Carbonate Solonchaks) occur in ground-water discharge areas.

The Turtle Mountains are high enough to receive significantly more precipitation than the surrounding grasslands and were the only large area in North Dakota forested prior to European settlement. Soils in the Turtle Mountains are mostly Argiborolls (soils transitional between Gray Wooded and Chernozem). Depressions contain more poorly drained soils (Argiborolls, Haplaquolls, and Calciaquolls) like those in prairie depressions, but also contain Histosols (peat). Most peat in the Turtle Mountains occurs in the higher areas west of Rolette County.

Topography

Adequate topographic maps (7½ minute quadrangles, scale 1:24,000, contour interval 5 or 10 feet) are available for only the western half of Rolette County. The following are published United States Geological Survey (USGS) topographic quadrangle maps: Barton, Dunseith, Fonda, Lake Upsilon SW, Lords Lake, Overly, Overly SE, Rolette SW, and Thorn. The following are preliminary, blue-line, USGS topographic quadrangle maps: Dunseith NE, Dunseith NW, Lake Upsilon NE, Lake Upsilon NW, and Lake Upsilon SE. The only topographic coverage of the eastern half of the county is the United States Army Map Service: Devils Lake quadrangle (scale 1:250,000 contour interval 100 feet). Detailed topographic information is available on 1961 aerial photograph stereopairs (scale 1:20,000) obtained from the USDA-SCS.

Most of the county is typically rolling North Dakota prairie, 1500 to 1800 feet above sea level, with the Turtle Mountains, in the northwestern corner of the county, rising 400 to 800 feet higher. Although most areas in Rolette County are below 2300 feet in elevation, a few isolated hills approach 2400 feet. Higher elevations, up to 2545 feet, occur in the western part of the Turtle Mountains in Bottineau County.

Topographic features that I feel are geologically significant are shown on the map **Surface Sediments and Landforms** (Pl. 1). Units 25 through 30 are drawn at the top of slopes. Unit 31 is drawn at the bottom of slopes and outlines the edge of the Turtle Mountains. These slope symbols are located with the same precision as are the contacts between lithologic Units 1 through 15 (*see the following subsection* **Surface Sediments**, *topic* **Field Work**). Solid lines are located with an error probably less than 0.1 mile, dashed lines with an error probably less than 0.2 mile, and dashed lines with question marks may be in error more than 0.2 mile. Use of a dashed line with question marks indicates that the slope could be observed on the ground but that it could not be easily traced on aerial photographs or topographic maps. Units 33 through 44 are ridges or hills rising from a few feet to tens of feet above the surrounding countryside. Many of these units have genetic implications which are discussed in the following section **Special Geomorphic Symbols.**

The average angle of the steepest slopes developed on sediment in recently glaciated areas may have geologic significance (*see the following section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**). I therefore made thousands of visual estimates in the field (measuring random slopes 2 or 3 times a day with a clinometer to maintain accuracy) and show the average angle of the steepest slopes by patterns on the map **Surface Sediments and Landforms** (Pl. 1). Divisions that seem to be geologically significant are: flat, less than 1 degree (approximately 1½ percent); undulating, 1 to 4 degrees (approximately 1½ to 7 percent); rolling, 4 to 7 degrees (approximately

7 to 12 percent); hilly, 7 to 20 degrees (approximately 12 to 36 percent). Significant slopes greater than 20 degrees are shown by scarp symbols, but many scarp symbols mark slopes lower than 20 degrees. All units can contain non-representative slopes.

Users of this slope information should exercise caution. My intent was to obtain a general feeling for the topography, especially that developed on glacier and mudflow sediment, in semi-quantitative terms. This data is less precise than the lithologic data (*see the subsequent subsection* **Surface Sediments**). To reduce the complexity of the final map, most divisions between areas of different slope were adjusted, in the field, to coincide with divisions between areas of different sediment type. Slopes on the flanks of features indicated by Units 33 through 37, 42, and 43 are usually steeper than those indicated for the general surroundings. This is especially important in the area of Unit W on the map **Sediment Origin**, where many branching, sinuous ridges occur that have much steeper sides than the surrounding rolling topography. In the area indicated by Unit W the maximum slope angles characteristic of the topography between isolated ridges is shown because I think that it is geologically most significant (*see discussion in the section* **Sediment Origin**, *topic* **Unit W**).

Surface Sediments

In general geologic usage "sediment" refers to any material transported by and deposited from air, water, or ice (American Geological Institute, 1960, supplement p. 59), and includes material slowly moving down hillslopes under the influence of gravity. The physical character of a sediment, determined by naked-eye observation or with the aid of a low-power magnifier, is generally referred to as the lithology of the sediment. The map **Surface Sediments and Landforms** (Pl. 1) is a lithologic map, and Units 1 through 15 are lithologic units which group together sediments of similar character.

Previous work

Several previously published geologic maps of this and adjacent areas exist, but they are all basically interpretive, genetic maps similar to the map **Sediment Origin** (Pl. 1). In most cases they do not show basic, lithologic information, although a certain amount of lithologic information can be inferred from them. With the exception of Schmid (1964), who modified part of the general soil map (*see the preceding subsection* **Soils**) to make a geologic map of the area around Rolla, all are published at a smaller scale than the map **Surface Sediments and Landforms** (Pl. 1). These maps are by Lemke and Colton (1958) (scale 1:495,000); Flint, Colton, Goldthwait, and Willman (1959) (scale 1:1,750,000); and Colton, Lemke, and Lindvall (1963). Elson (1960 and 1962) (scales 1:253,440 and 1:126,720) has published maps of adjacent areas in Canada that contain a little more lithologic information than the other maps.

Field work

I made observations in available stream banks, road cuts and other excavations. Supplementary data was collected from shallow holes dug with a shovel and a 5-foot hand auger. Therefore most data represents sediment within 4 to 6 feet of the surface. Essentially all information collected is shown on the map **Surface Sediments and Landforms** (Pl. 1).

Field work was done in July and August, 1969. Almost all roads and trails in the county were traveled, either in a truck with a chassis-mounted power winch or on foot. I made traverses at approximately 1 mile intervals and either followed or was reasonably close to every section line in most of the county. Many trails in the Turtle Mountains do not follow section lines, but by following them it was still possible to cover the ground with the same thoroughness. I walked to and hand-augered nearly all features which, as a result of something seen on aerial photographs or topographic maps, I suspected might contain lithologies different from their surroundings. These observations were plotted on aerial photographs (*see the preceding subsection* **Topography**) and transferred to field maps at a scale of 1:63,360.

Sediment textures were estimated by observation and feel in the field. A few random samples were collected to check field estimates and were subjected to sieve and pipette analysis.

Lithologic units

Lithologic contacts (*contacts between Units 1 through 15*) on the map **Surface Sediments and Landforms** (Pl. 1) should be reasonably accurate when used at the published scale. Photographic enlargement of that map is not recommended, as it will tend to give the user a false sense of accuracy. Contacts shown by a solid line (Unit 22) are located with an error probably less than 0.1 mile, those shown by a dashed line (Unit 23), probably less than 0.2 mile, and those shown by a dashed line with question marks (Unit 24) are only approximately located (some may be a few miles in error). In the last case, the contact may be arbitrary and gradational such as many contacts between Unit 6 (sand and silt) and Unit 10 (gravel and sand), or may have been drawn only on the basis of features observed on aerial photographs, topographic maps, or the general soil map.

All lithologic units (1 through 15) may contain up to 15 percent of other lithologies. The Wentworth particle-size scale was used. Where a sediment contained more than one size group, groups are listed in decreasing order of abundance.

For an expanded discussion of the origin of these units, see the subsequent section **Sediment Origin.** Numerical units refer to the map **Surface Sediments and Landforms.** Alphabetic units refer to the map **Sediment Origin.** Both maps are on Plate 1.

Both practical and philosophical problems are involved with the use of the word "**till**" (Harland, Herod, and Krinsley, 1966). The term was originally used in a purely lithologic sense (American Geological Institute, 1960, p. 298) but also has commonly been used by geologists in a genetic sense to refer to glacier-deposited sediment. Complications also exist with the genetic implications (*see the section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**). I prefer to use the term "**diamicton**" (Flint, Sanders, and Rodgers, 1960a and 1960b) when describing the lithology of this sediment because that word is free from genetic implications. This report, however, is written for use by many who are not geologists and who may already be accustomed to using the word "**till**" in a lithologic sense. In order to avoid undesirable confusion in this report, till, the word not enclosed by quotation marks, refers to a lithologic type composed of a slightly stony mixture of sand, silt, and clay in approximately equal proportions (USDA: slightly stony loam or slightly stony clay loam). The stones range from pebble to boulder size. In this report "till," the word enclosed by quotation marks, is used in a purely genetic sense to refer to sediment that has been transported by glaciers and has not been sorted by wind or water. The latter usage will be avoided as much as possible.

Surface silt and sand. A few inches to a few feet of sandy silt to silty sand (USDA: loam, sandy loam, silt loam, loamy sand, sand, and silt) veneers most of the county and is not shown on the map **Surface Sediments and Landforms.** This sediment has been intensely stirred by burrowing animals (mostly worms and rodents) and by plowing and commonly contains clay and scattered pebbles derived from underlying sediments. It was originally transported and deposited by winds.

Organic clay (Unit 1). This unit is tough, black, slightly sandy, slightly silty, clay (USDA: clay) containing several percent organic material. The sediment occurs in ground-water recharge areas in slough (temporary pond) bottoms and was derived from soils developed on adjacent hillslopes. The clay is tough because it has been dry much of the time.

Clay (Unit 2). This unit consists dominantly of clay and silty clay (USDA: clay) deposited as offshore sediment in lakes. It generally includes some offshore clayey silt and nearshore and shoreline silt, sand, gravel, and mudflow sediment that would be shown as Unit 5, 9, 11, 12, or 13 on a more detailed map.

Silt and clay (Units 3 and 4). Lithologies identical to those in Units 2 and 5 are sometimes combined as a distinct map unit because the dominant lake sediment in many places ranges from silty clay to clayey silt (USDA: silty clay, silty clay loam, clay, and silt loam). Silt and clay, undivided, is mapped as Unit 3 unless I hand-augered into underlying till (*as in Unit 12 or 13*), where it is mapped as Unit 4. These units are dominantly composed of offshore lake sediment but include nearshore and shoreline silt, sand, gravel, and mudflow sediment that would be shown as Units 5, 9, 11, 12, or 13 on a more detailed map.

Silt (Unit 5). This unit is dominantly silt and includes some clayey silt and sandy silt (USDA: silt, silt loam, and rarely silty clay loam). The silt-size fragments are largely quartz and feldspar with some limestone, dolomite, and shale. It was not practical to map silt as a separate unit in most of the county and this lithology was usually combined with clay or sand to form Unit 3, 6, or 7. The only large areas that are dominantly silt and shown as Unit 5 occur in the southwest part of the county and were once part of glacial Lake Souris.

Sand and silt (Units 6 and 7). Lithologies identical to those in Units 5 and 9 are combined as a practical map unit for much of the county and contain both stream and lake sediment. Much of the offshore sediment deposited in glacial Lake Souris is a mixture of sand and silt, in many places dominantly fine sand (USDA: sandy loam to silt loam), and is either flat bedded or has high-angle, small-scale, oscillation and current cross-bedding. Stream sediment deposited during the last deglaciation may contain similar lithologies, but is usually coarser, typically sand, silty sand, and clayey sandy silt (USDA: sand, loamy sand, and sandy loam) in overbank (usually flat bedded) and channel (usually lower-flow-regime with high-angle, both small- and large-scale, current cross-bedding and some upper-flow-regime, flat bedded) deposits. This unit usually contains overbank clay and scattered lenses and channels of stream sand and gravel (*as in Units 9, 10, or 11*). The lake and stream deposits interfinger and locally include sediment deposited in deltas. Exposures were not adequate to separate these units on the basis of bedding. *Additional discussion is given in the description of Units D, E, F, G, I, K, L, M, N, and O on Plate 1 and in the section* **Sediment Origin.** Units 6 and 7 also include some similar but older sediment deposited in the Rolette Meltwater Basin and overridden by the Souris River Lobe (*see the discussion of Unit Q on Pl. 1 or in the section* **Sediment Origin**) and has a surface of scattered boulders. Dominantly silt- and sand-sized sediment, undivided, is mapped as Unit 6 unless I hand-augered into underlying till (*as in Unit 12 or 13*), where it is mapped as Unit 7.

Organic silt, sand, and gravel (Unit 8). This sediment is commonly called "alluvium," occurs in valley bottoms now containing perennial or intermittent streams, and consists dominantly of overbank deposits of flat-bedded, organic, sandy, clayey silt (USDA: loam, silt loam, silty clay loam, clay loam, sandy loam, and silty clay) with scattered lenses and channels of lower-flow-regime small- and large-scale cross-bedded sand and upper-flow-regime flat-bedded sand and gravel (*lithologies as in Units 9, 10, and 11*). The overbank deposits contain several percent of organic material, are dark brown, occur in layers a few inches thick, and commonly contain fossils (especially snails, rodents, and bison).

Sand (Unit 9). This unit is dominantly stream-deposited sand, silty sand, and gravelly sand (USDA: sand, loamy sand, sandy loam, and stony sand) in channels and lenses with lower-flow-regime small- and large-scale cross-bedding, and upper-flow-regime flat bedding. Unit 9 may contain some overbank deposits of flat-bedded clayey sandy silt and scattered lenses of sandy gravel and gravel (*as in Unit 11*). This unit usually consists of ice-contact stream deposits outlined by Unit 27, which are commonly called "eskers" (*see Unit 42 and O*). This unit also includes stream sediment deposited on solid ground (*as in Units K, L, M, and N*), well-sorted wind-transported sand (*as in Unit 45*), and similar, older, sediment that has been overridden by the Souris River Lobe (*see discussion of Unit Q*) and has a surface of scattered boulders. The sand-sized particles are largely quartz and feldspar with some limestone, dolomite, and shale, containing small amounts of a wide variety of igneous and metamorphic minerals. In general, shale is less abundant in the southwest part of Rolette County and some deposits are almost shale free.

Gravel and sand (Unit 10). Lithologies identical to those in Units 9 and 11 are combined as a practical map unit for some ice-contact deposits (outlined by Unit 27) and, south of Dunseith and Belcourt, where stream deposits are transitional between Unit 11 (gravel) and Unit 6 (sand and silt, undivided).

Gravel (Unit 11). This unit is dominantly gravel and sandy gravel (USDA: very stony to stony sand, very stony to stony loamy sand, and very stony to stony sandy loam) with upper-flow-regime flat bedding and some lenses and channels of sediment identical to that in Unit 9. The gravel consists of pebbles, cobbles, and boulders of widely varying composition. Most are igneous and metamorphic rock types with some sandstone, limestone, dolomite, and shale. The shale is less abundant in certain deposits (*see the section* **Applications**, *subsection* **Sand and Gravel Resources**) in the southwest part of the county.

Shale-rich till (Unit 12). The problems inherent in the usage of the word "till" and the terminology used in this report is discussed in the introduction of this topic **Lithologic Units.** Unit 12 is a slightly stony mixture of clay, sand, and silt in approximately equal proportions (USDA: slightly stony loam and slightly stony clay loam). Many lithologies are present in the stony fraction (pebbles, cobbles, and boulders). Most are igneous and metamorphic rock types but some shale, limestone, dolomite, sandstone, and lignite occur. This unit is differentiated from Units 13, 14, and 15 by having abundant shale and rare sandstone and lignite fragments in the stony fraction. The sand-size particles are also highly varied in composition, but are dominantly quartz and feldspar with some limestone, dolomite, shale, and a large variety of igneous and metamorphic rock-forming minerals. The silt-size particles are mostly quartz and feldspar with some limestone, dolomite, and shale. The clay-size particles are mostly montmorillonite with some fine-grained calcite, dolomite, quartz, and feldspar. Unit 12 is the dominant unit in the eastern and northern parts of the county. Most of it was deposited by mudflows (*see the section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**).

Shale- and sandstone-rich till (Unit 13). The lithology of Unit 13 is very similar to that of Unit 12, but the characteristic of this unit is that sandstone, lignite, and shale are all common in the stony fraction. The origin of this unit is the same as that of Unit 12.

Thin till over sand (Unit 14). The lithology of Unit 14 is identical to that in Unit 13, but in the area shown as Unit 14 on the map **Surface Sediments and Landforms** it is known to be an approximately 5 to 25 foot blanket over hills of sand and gravelly sand with lithologies like those in Unit 9. *See the discussion of Unit X in the section* **Sediment Origin.**

Stony sand (Unit 15). This unit is composed of slightly stony, slightly clayey, slightly silty to silty sand, and slightly stony, slightly clayey, sandy, silt (USDA: slightly stony sand, slightly stony loamy sand, slightly stony sandy loam, slightly stony sandy clay loam, and may contain some slightly stony silt loam and slightly stony loam) that is very poorly sorted and not bedded. Unit 15 is locally as much as 70 percent sand and usually comes out of the hand auger as easily as clean sand. Sediment shown as this unit has one of two probable origins. Most of it is very sandy "till" (*see the section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**, *discussion of Units Q and R*). Some is either wind-blown silt and sand over stream sand and gravel or just stream sand and gravel that has been so intensely stirred by burrowing animals that the sediment has been mixed and the bedding destroyed. If I could not determine the bedding characteristics of the sediment, it was mapped as Unit 15.

Topography Beneath the Glacial Drift and the Problem of Ice Thrusting

Figure 2 shows the general topography beneath the uncemented Quaternary deposits (mostly glacial drift). It has been modified from a larger map of the state prepared by Bluemle (1971). The northeast-trending valley shown crossing the southern part of the county may be mis-located a number of miles due to inadequacy of the drilling data. Most water wells in the county do not penetrate the entire thickness of glacial drift and never reach the underlying pre-Quaternary sediment. Because oil-well logging commonly excludes Quaternary sediments, the thickness of the glacial drift is not known.

Recent work by others has disclosed that large glacial erratics are fairly common in areas geologically similar to North Dakota. Most reliable data comes from drilling programs of the Saskatchewan Research Council. The Research Council began drilling anomalous pre-Quaternary topographic highs in about 1965 (Moran, S. R., oral communication, June 22, 1970). In the Hudson Bay quadrangle, Saskatchewan, Moran (1969, p. 97) describes a 3-square-mile group of shale blocks, over 100 feet thick, that are glacial erratics. One borehole in this area penetrated 18 feet of drift, 112 feet of shale, and 5 feet of till before encountering underlying shale in place. Moran also reports (1969, p. 87-88) a complex sequence of ice-thrust blocks at Thunder Hill, also in the Hudson Bay quadrangle, that involves repetition of the section to depths of 500 or 600 feet. Figure 3 shows that there is actually a topographic low, not a high, on the pre-Quaternary surface under this 4- by 2-mile hill. Any drilling program ceasing after 20 feet of shale penetration obviously would give data showing this as a topographic high beneath the glacial drift. The thickest erratic so far drilled and identified in Saskatchewan is a 135-foot thick block of shale (Moran, oral communication, April 6, 1970). Moran (1969, p. 97) further states that similar large shale erratics are common throughout Saskatchewan.

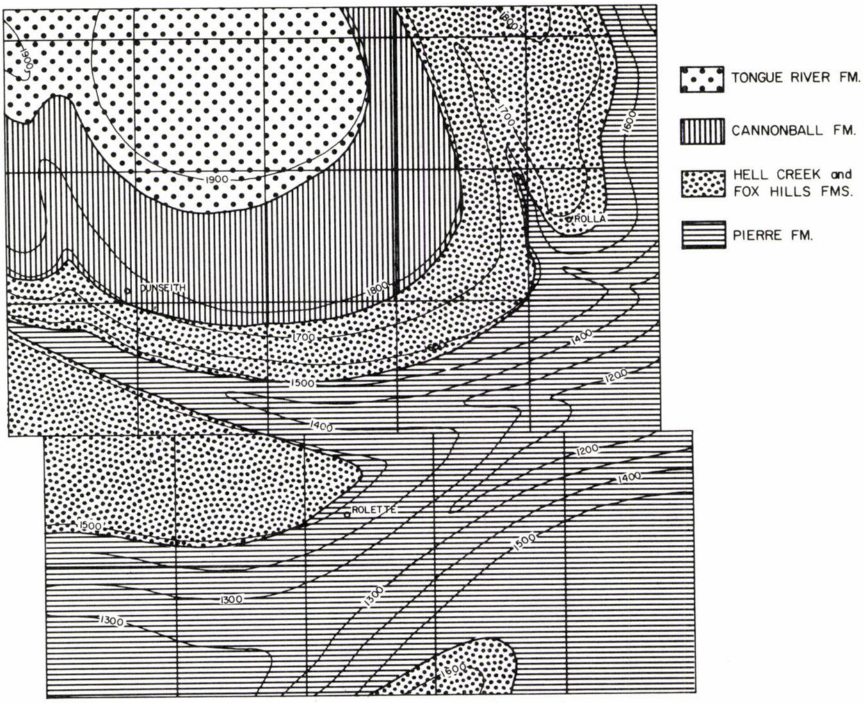


FIGURE 2. Problematical topography on, and geology of, the pre-Quaternary sediments in Rolette County modified from maps by Bluemle (1971); Carlson (1969); and Bannatyne (1966a and 1966b).

The topographic effect of glacier thrusting (probably of both pre-Quaternary sediment and previously deposited drift) is nicely shown on the geomorphic map of the Lancer quadrangle, Saskatchewan (St. Onge, 1967). Byers (1960) and Kupsch (1962, p. 589) discuss ice-thrust blocks of Cretaceous sediment with a minimum thickness of 208 feet in the Dirt Hills, Saskatchewan. Both authors also mention similar occurrences in Europe. A discussion of other similar structures in drift and of the mechanism of glacial thrusting is given by Moran (in preparation). With the data available, it seems that large glacial erratics are not rare, isolated, and unusual features but are fairly common and are to be expected in the glaciated part of North Dakota.

Similar features have been observed or inferred in North Dakota. Bluemle (1967) reports more than 20 feet of shale thrust over till in northwest Cavalier County. Sibley Buttes, which are steeply dipping (up to 60 degrees northeast) blocks of sandstone in Kidder County, can

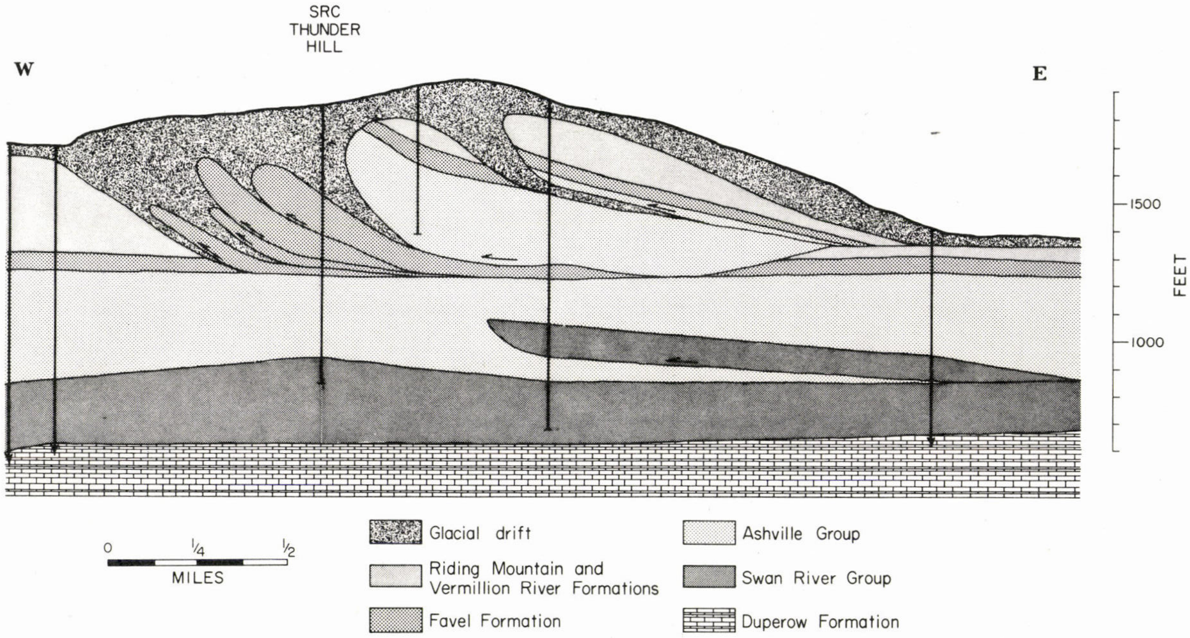


FIGURE 3. Ice-thrust structures at Thunder Hill, Hudson Bay quadrangle, Saskatchewan (from Moran, 1969, p. 92).

be traced, unbroken, for at least 4 miles and form a mile-wide outcrop of unknown thickness. They have similarities to the previously mentioned Dirt Hills in Saskatchewan and it is unlikely that they are in place (Rau, Bakken, Chmelik, and Williams, 1962, p. 18-20; and Clayton and Freers, 1967, p. 14 and 20). Bluemle (1970) postulates that numerous anomalous hills in central North Dakota were formed by glacier thrusting that could involve pre-Quaternary sediment, older glacial drift, or both.

Theoretical work of Mathews and MacKay (1960, p. 34) suggests that glaciers can cause shear failure at depths as great as 200 meters (more than 650 feet). These calculations do not take into account dynamic or topographic effects that could locally increase failure depth. Kupsch (1962, p. 588), based on earlier work by Byers (1960), has estimated that failure took place in the Dirt Hills, Saskatchewan, at a depth of approximately 550 feet. Thus it is possible, although not necessarily probable, that the entire "bedrock" high under the Turtle Mountains is an extremely large glacial erratic. Certainly the northern side was probably highly sheared and overthrust toward the south by glacier action.

I therefore recommend that any drilling program designed to provide data on till thickness and elevations of the surface developed on pre-Quaternary sediment in the glaciated part of North Dakota be extended at least 100 feet into pre-Quaternary sediment ("bedrock"), especially when drilling is initiated on topographic highs. Electric well logs should be routinely run to the bottom of the hole and cuttings and samples in the "bedrock" section should be very carefully studied to pick up any thin till or drift layers that otherwise might be missed. The Saskatchewan Research Council routinely drills at least 50 feet into pre-Quaternary sediment, and where concerned about major "bedrock" thrusting, penetrates at least 100 feet of bedrock or to a marker in the pre-Quaternary sediment (Christiansen, E. A., written communication, July 17, 1970). S. H. Whitaker (oral communication, June 7, 1970) reports that some drilling penetrates more than 200 feet of pre-Quaternary sediment and finds that side-wall sampling is often necessary to confirm the presence of a thin till layer at depth. (Construction and use of an inexpensive side-wall sampler for this purpose is described by Morrison, 1966 and 1969.) In areas of shale bedrock, this practice also provides a good shale base for the calibration of electric well logging.

In areas such as the Turtle Mountains, it would be wise to extend a few drill-holes to a known stratigraphic marker within the pre-Quaternary sediment. At the very least, a critical examination should be made of cuttings and logs of the upper 800 or 1000 feet of "bedrock," looking for thin till or other drift. Morrison (1969, p. 432) states that the side-wall sampler of the Saskatchewan Research Council operates at this depth in a 4½ inch drill hole.

It has only recently been realized that large, ice-thrust blocks of pre-Quaternary sediment occur within the glacial drift and that they can be expected to occur in North Dakota. Previous drilling programs in the state, designed to obtain data on drift thickness, have not adequately taken these factors into account. As a result, many test holes have been too shallow to obtain reliable information. Topographic maps of the surface on the pre-Quaternary sediment in a number of counties in North Dakota have been published in the joint geological and ground-water resource studies of the North Dakota Geological Survey and the North Dakota State Water Commission. For the reasons discussed above, certain areas on those maps are much less accurate than the contouring would indicate. A map more detailed than Figure 2 is not included in this report because drilling support was not available.

Pre-Quaternary Sediment

Figure 2 shows the geology as well as the topography on the surface of the pre-Quaternary sediment beneath the glacial drift. The geology is fitted to the topography by modifying Carlson's (1969) map with data from Bannatyne (1966a and 1966b). The topographic information is not precise (*see discussion in the preceding subsection* **Topography Beneath the Glacial Drift and the Problem of Ice Thrusting**). As a result the reliability of the geologic data is also not precise. Rock types characteristic of pre-Quaternary sediment have been observed in borings from wells in the Turtle Mountains, but it is not known if the rocks were in place or were glacial erratics (*see preceding discussion*).

I found no exposures of pre-Quaternary sediment in place in Rolette County. Several large blocks of sand and sandstone do occur (*see the section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**, *discussion of Unit Z*). The largest erratic, at least 30 feet thick and several tens of feet long, forms the south side of the road cut on State Highway 66, 4 miles west of the town of Rolette (NE corner sec. 23, T. 160 N., R. 72 W.).

Carlson and Anderson (1965) present a general discussion of the pre-Quaternary sedimentary history of North Dakota and Lemke (1960) describes the pre-Quaternary sediments in McHenry and Bottineau Counties. In addition, the Pierre Shale is described by Gill and Cobban (1961); the Fox Hills Formation by Feldmann (1967); the Hell Creek Formation by Frye (1969); the Cannonball Formation by Stanton (1921), Cvancara (1965), and Clayton (in preparation); and the Tongue River Formation by Clayton (in preparation). The three

Cretaceous formations indicated on Figure 3 are an example of deposits that formed during the regression of a shallow sea: marine shales (Pierre Shale) overlain by marine sandstones and beach deposits (Fox Hills Formation), in turn overlain by lagoonal, brackish water, fresh water, and flood plain deposits (Hell Creek Formation) (Frye, 1969, p. 16). The overlying Tertiary formations consist of marine sandstones and shale (Cannonball Formation) overlain by non-marine mudstone, sandstone, and lignite (Tongue River Formation).

Halstead (1959, p. 10) states that only about 100 feet of pre-Quaternary sediment is known to exist above the Riding Mountain Formation (the Canadian equivalent of the upper Pierre Shale) on the flank of the Turtle Mountains in Manitoba, just north of Rolette County. That sediment is a greenish-gray sandstone, weathering yellow-rust, and is quarried for building stone where it is naturally cemented. Halstead assigns this sediment to the Boissevain Formation (Canadian equivalent of the Fox Hills and Hell Creek Formations). He also reports scattered occurrences of lignite-bearing sand, sandstone, and shale of the Turtle Mountain Formation (Canadian equivalent of the Tongue River and Cannonball Formations). None of his data wells penetrated more than 30 feet into these sediments and it is highly probable that some or all of these observations are based on large erratic blocks in glacial drift. Greenlee (1942, p. 20) made the following observation of attempts to quarry the Boissevain Formation on the north side of the Turtle Mountains:

> Information from well drillers indicates that the sandstone does not continue to the north and that its occurrence is local. Drilling on one property may show the sandstone while the neighboring section shows none of it. It is interesting to note here that miners drilling test holes south of Deloraine in the area of their present workings encountered scattered pieces of sandstone hard enough to prevent drilling by jack drills. In other test holes adjacent to, but free of the sandstone, the drills encountered beds of lignite at elevations below the sandstone. . . .

SPECIAL GEOMORPHIC SYMBOLS

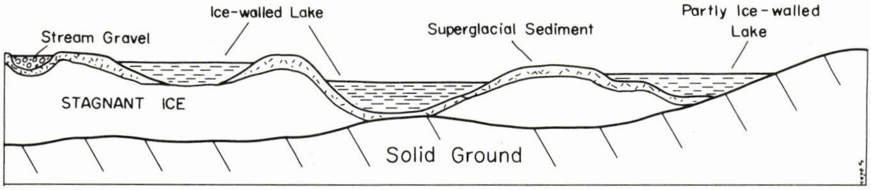
This section is a discussion of those units on the map **Surface Sediments and Landforms** (Pl. 1) that are topographic symbols with genetic implications. Additional general discussion of stagnant-glacier features are by Clayton (1967), Clayton and Cherry (1967), and Parizek (1969).

Slope Symbols

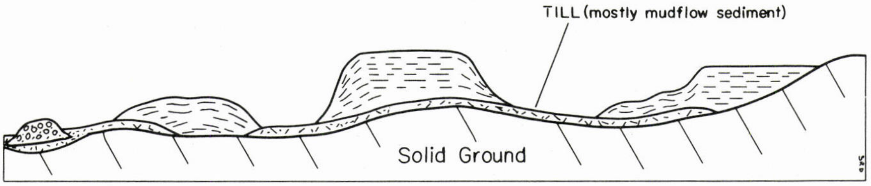
Ice-contact features

Units 26 and 27 are used to mark slope tops that I believe resulted from topographic inversion as shown in Figure 4. Sediment was

Cross-section during melting of stagnant ice



Cross-section after melting of stagnant ice



Map view after melting of stagnant ice

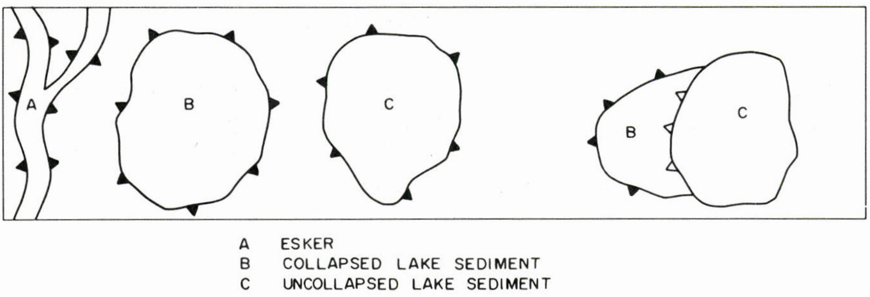


FIGURE 4. Diagram showing the formation of ice-contact features.

deposited in depressions in contact with stagnant glacial ice. After the stagnant glacial ice melted, the sediment remained as topographic highs with margins that slope down-hill toward the pre-existing stagnant ice. The contact is shown as Unit 26 unless the stagnant ice was overlapped and buried by sediment, in which case it is shown as Unit 27. Depressions (sometimes called "kettles") in stream sediment that I think formed similarly by deposition around stagnant ice blocks are also outlined by either Unit 26 or 27. They may contain a lake, pond, or slough (temporary pond). *For a more complete discussion of various features that are indicated by these symbols see the section* **Sediment Origin**, *discussion of Units H, I, L, M, and O.*

Scarps overridden by the last glacial advance

Unit 29 marks the top of slopes that I think existed as major topographic features before ice moved over this area the last time. They were either cut in the pre-Quaternary sediment prior to any glaciation or were developed on or by older glacial drift. Many of the larger slopes in Rolette County probably existed prior to the last ice advance, but use of Unit 29 is restricted to those features that were probably associated with drainage patterns (*see the section* **Interpreted Quaternary History**, *subsection* **History Before the Last Glacial Advance**). Most notable is the large valley extending from the vicinity of Dunseith northward toward Willow Lake in the Turtle Mountains.

Channels cut during the last deglaciation

Unit 28 marks the top of slopes I think were associated with the last deglaciation. Some of these channels do not contain perennial streams, and those that do are usually wider than the modern flood plains. These channels are often referred to as "melt-water channels," but most of the water that flowed in them probably came from rainfall and not melting glaciers. Most of the stagnant ice was covered with an insulating blanket of sediment upon which forests grew and warm-water lakes existed (*see discussion in the section* **Interpreted Quaternary History**). As a result the buried ice took many hundreds of years to melt and contributed water only slowly to the water table. The climate 10,500 to 13,000 years ago was somewhat cooler and moister than it is now, and because of increased rainfall and decreased evaporation the streams were much larger than the present-day streams (*see discussion in the section* **Interpreted Quaternary History**).

Combination of slope symbols

Slope symbols are combined where I think it significant to point out multiple genetic implications. The most important of these combined symbols outline channels that existed prior to the last glaciation. Stagnant ice blocks from the last glaciation remained in these old valleys somewhat longer than on the immediate surroundings. If the stagnant ice blocks were surrounded with or buried under stream or lake sediment, a sinuous series of depressions, tracing the course of the old valley, formed as the buried ice slowly melted. Units 27 and 29 have been combined to outline such features, which are commonly called "kettle chains."

Areas with a freckled appearance on aerial photographs

One minor curiosity encountered during this project was the observation of "freckled" areas (Fig. 5; and Pl. 1, Unit 32) on aerial photographs. The light, circular areas are 30 to 60 feet in diameter, occur on flat or gently undulating surfaces on lake sediment or wave-eroded till, and were extremely difficult to locate on the ground. The ones I located did not seem to be more than a few inches higher, if any, than their surroundings. They appeared to be slightly lighter colored than their surroundings as if more calcium carbonate from the Cca horizon of the soil had been brought to the surface. Clayton (oral communication, September, 1969) reported similar features on till in Burke County in northwestern North Dakota that differed from their surroundings by having a slightly greater number of pebbles on their surface.

Similar features have been reported in Minnesota; these are low mounds, 10 to 130 feet in diameter and 6 to 50 inches high (Ross, Tester, and Breckenridge, 1968, p. 172). Breckenridge and Tester (1961) discovered that Manitoba toads (*Bufo hemiphrys*) used these mounds almost exclusively for hibernation sites, observed that a total of 3276 toads used one large mound the winter of 1961, and estimated that toads could move as much as 85 cubic feet of material per year in one large mound. This report instigated an extensive study of the low mounds by Ross, Tester, and Breckenridge (1968) who state:

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

This seems like a reasonable explanation for the freckled areas in Rolette County.

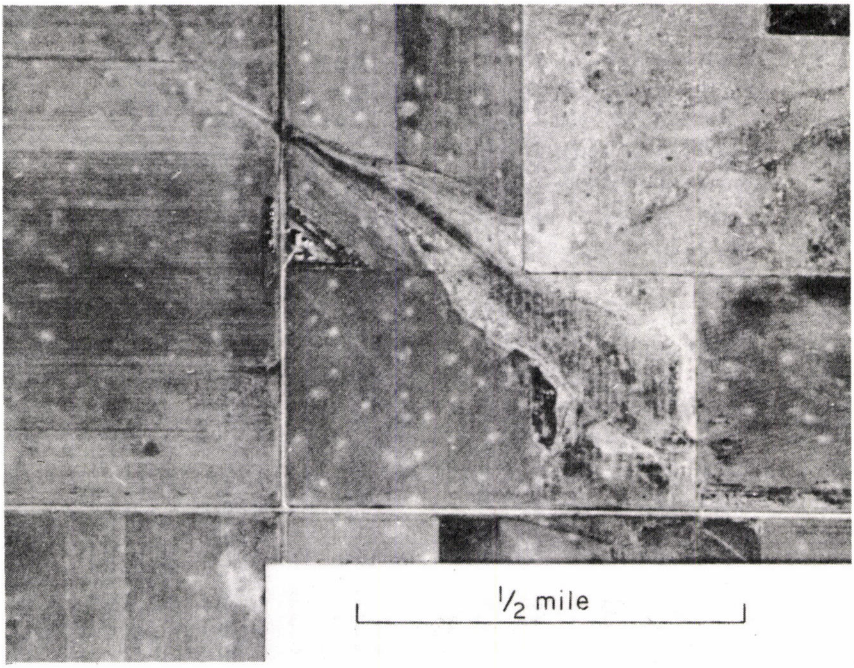


FIGURE 5. Aerial photograph of a "freckled" area. Part of photograph BAG-1BB-3, flown September 16, 1961. Road junction is the SE corner sec. 31, T. 159 N., R. 73 W.

Active Glacier Features

Streamlined hills

Low hills that have been overridden by active glacial ice are often streamlined and elongate parallel to the direction of ice movement (Fig. 6). Most of those in Rolette County are eskers that have been overridden and contain a core of sand and gravel. If they are wide enough, they are shown on the map **Surface Sediments and Landforms** as Unit 33. If they show up as a definite, sharp line on aerial photographs, Units 34 or 35 are used. Unit 34 indicates that the surface lithology is till, Unit 35 indicates that it is sand or gravel. These hills have been called "drumlins," "overridden kames," "drumlinoid hills," "long, linear drumlins," or "fluting."

Stagnant Glacier Features

Stream channel features

Streams flowing in or on top of stagnant glacial ice eroded sinuous, branching, channels that usually filled with sediment. After the

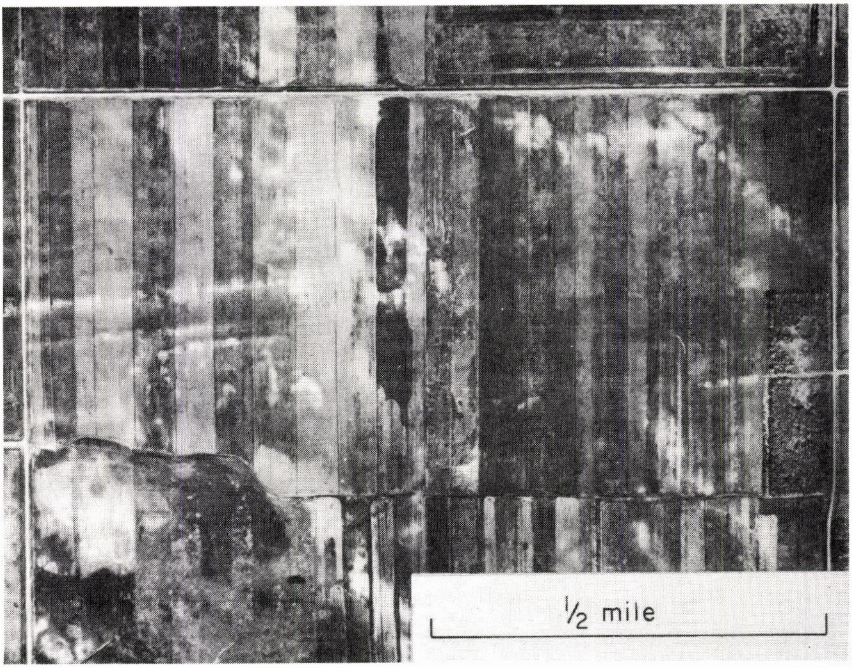


FIGURE 6. Aerial photograph of linear drumlins ("fluting"). Part of photograph BAG-1BB-185, flown September 16, 1961. Road junction in the upper part of the photograph is the NW corner sec. 10, T. 160 N., R. 71 W.

streams disappeared and underlying or enclosing stagnant ice melted, they formed discontinuous ridges or mounds that have been called "eskers" or "kames" (Fig. 7). The sediment that forms these features is usually washed and sorted sand and gravel (*Pl. 1, description of Unit O*), often covered by a veneer of mudflow sediment (usually called "till") that was derived from the blanket of sediment on top of the enclosing or surrounding stagnant ice. In some places the streams flushed nearly all sand and gravel out of the ice-walled channel, which then may have been filled with mudflow sediment. Where eskers formed, the water moving in superglacial streams was mostly derived from the melting ice ("melt-water"). If most of the water in the streams came from rainfall (*see discussion in the preceding subsection* **Channels Cut During the last Deglaciation**), the streams would continue to erode and transport sediment as underlying stagnant ice melted and could have continued after all had melted. Sediment accumulation in the channels was favored if the size and power of the stream decreased as

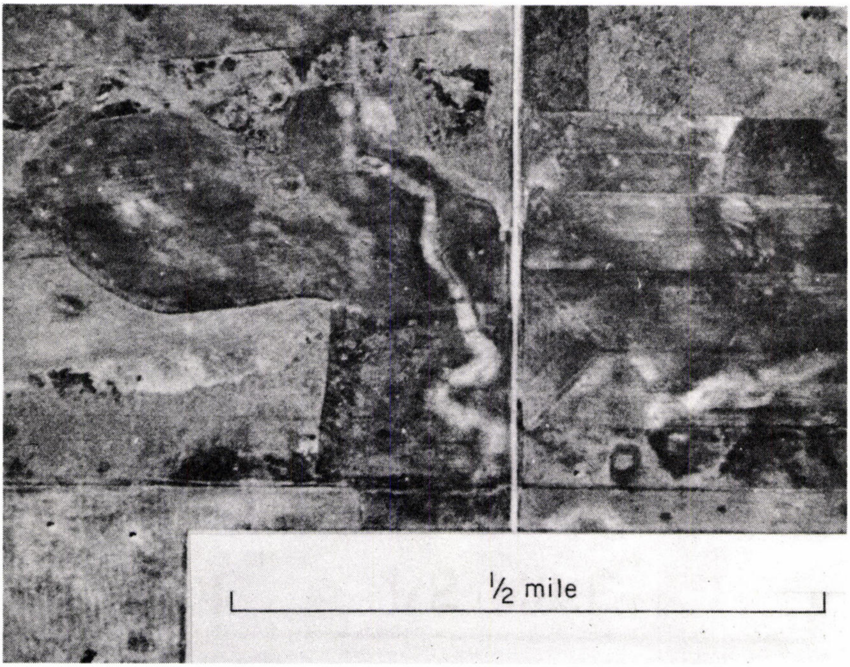


FIGURE 7. Aerial photograph of ice-contact stream sediment ("esker"). Part of photograph BAG-1BB-128, flown September 16, 1961, including the SE¼ sec. 25, T. 160 N., R. 73 W.

the ice melted, which would have happened if most of the water in the streams was derived from the ice itself.

If the channel features are wide enough, they are outlined on the map **Surface Sediments and Landforms** (Pl. 1) by the ice-contact symbol (Unit 26). If they are very narrow, Units 37 or 43 are used. If they are known to be cored with sand or gravel, they are shown as Units 42 or 43. If I was not able to hand-auger through the covering of till, they are shown as Units 36 or 37. The hand-auger was usually stopped by a boulder before I could penetrate five feet. Gravel prospectors should test all these features, even if they are shown as having a covering of till. Most probably have a sand or gravel core. In some instances, as previously discussed, they could be locally all till.

Till ridges

Low, narrow, ridges of till are shown on the map **Surface Sediments and Landforms** (Pl. 1) as Units 38 or 39 if relatively straight

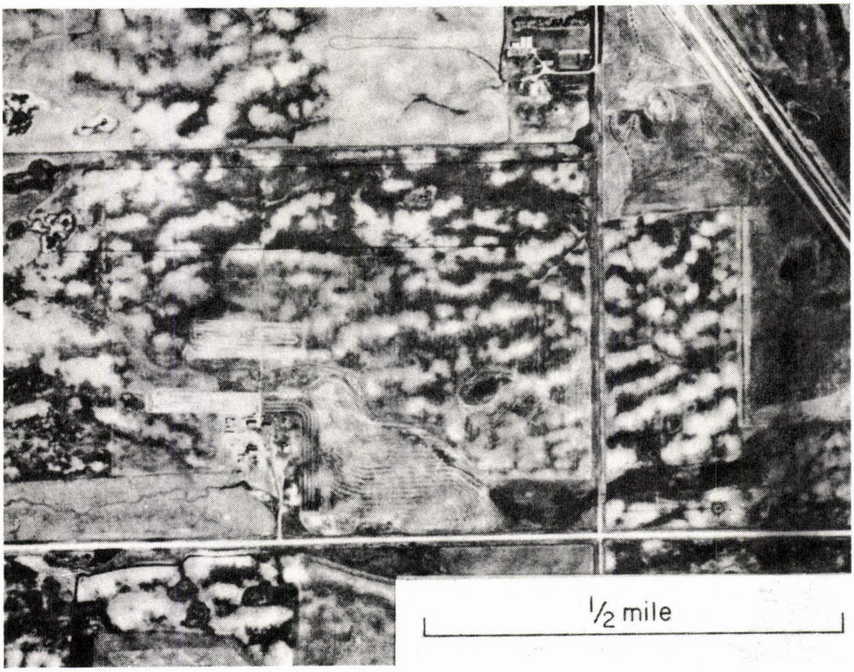


FIGURE 8. **Aerial photograph of linear till ridges ("washboard moraines"). Part of photograph BAG-2BB-84, flown May 25, 1962, including the SE¼ sec. 7, T. 162 N., R. 69 W., just northwest of Rolla.**

or as Units 40 or 41 if circular or subcircular. Various possible origins for these features are discussed by Parizek (1969). For a discussion of the implied relationship between these features, the thickness of superglacial material, and the thickness of stagnant glacial ice, *see the section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**.

Linear till ridges. Most of the linear features in Rolette County (*Pl. 1, Units 38 and 39; and Fig. 8*) are oriented at right angles to the direction of ice movement and many probably originated as superglacial shear ridges (Fig. 9). Crevasses also tend to be oriented at right angles to glacier movement and crevasse fillings, either of material that falls or flows in from above or that is squeezed up from below due to the weight of adjacent ice, can also form low ridges (Fig. 10). These linear till features have been called "washboard moraine," "linear disintegration ridges," "ice-contact ridges," "ice-crack moraine," "crevasse fillings," "ice block ridges," or "till crevasse fillings." Some

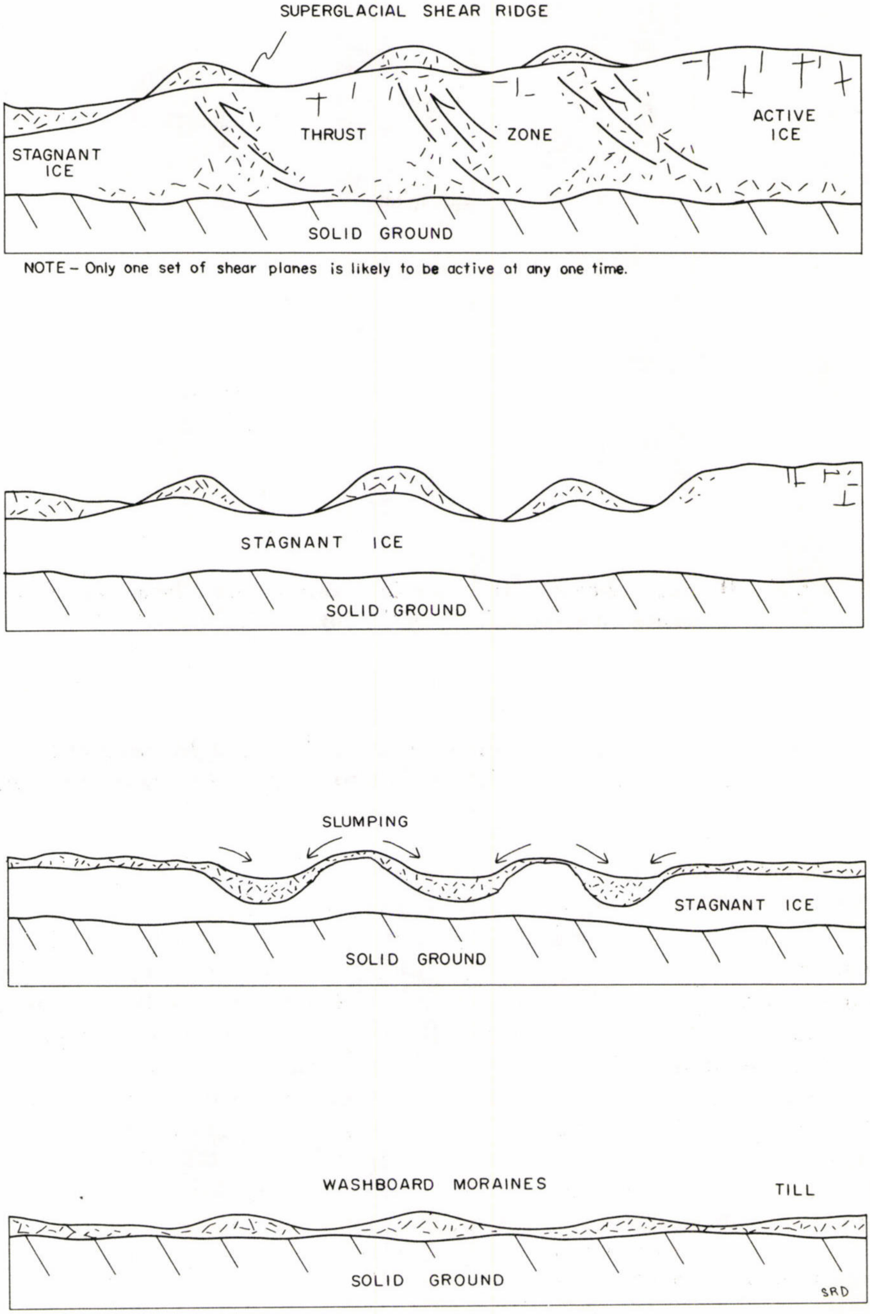


FIGURE 9. Diagram showing how washboard moraines could form from superglacial shear ridges.

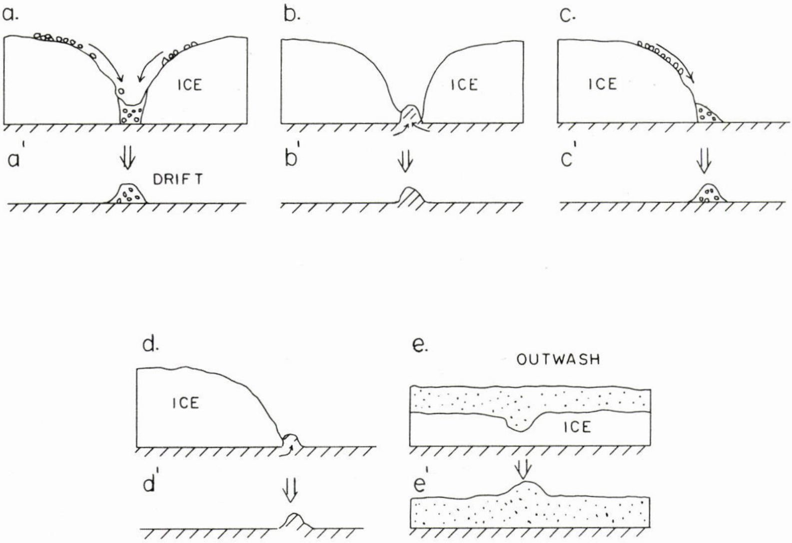


FIGURE 10. Diagram showing five possible origins for linear till ridges ("disintegration ridges") (from Clayton, 1967, Fig. A-3).

features in Rolette County may actually be straight segments of overridden eskers (*see the section* **Sediment Origin**, *discussion of Unit W*).

Circular till ridges. Low circular, subcircular, and semicircular ridges (Fig. 11) are common in the eastern part of the county. Similar features have been called "doughnuts," "rimmed kettles," "closed disintegration ridges," "prairie mounds," "humpies," or "circular disintegration ridges." The ones in Rolette County probably originated by superglacial sediment sliding or flowing into a sinkhole in stagnant ice, subsequent inversion of topography because the sediment insulated the underlying stagnant ice from further melting to form an ice-cored hill, flowage of the sediment blanket down the slopes of the ice-cored hill, and subsequent melting of the ice core (Fig. 12). Clayton (1967, p. 31) has presented theoretical reasons why most of these circular features are about 500 to 600 feet across:

> Beneath a depth of about 150 feet, ice of temperate glaciers tends to become plastic; ice depressions deeper than about 150 or 200 feet are unlikely. If maximum probable ice slopes were about 40 degrees, and maximum depression depth were 200 feet, the average ice depression would have been about 550 feet in diameter. These values are close to the equivalent values for depressions in modern stagnant glaciers.

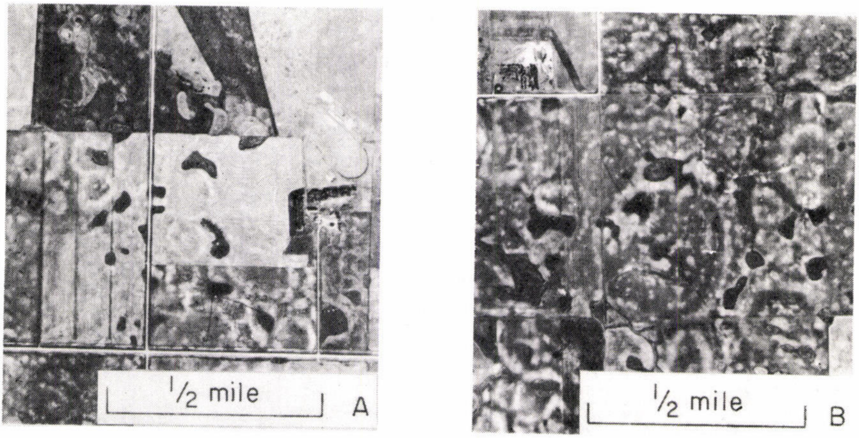


FIGURE 11. Aerial photographs of circular disintegration ridges ("doughnuts"). (A) Doughnuts about 500 feet across, part of photograph BAG-1BB-106, flown September 16, 1961, including the SW¼ sec. 12, T. 160 N., R. 69 W. (B) Large doughnut more than 1000 feet across, part of photograph BAG-1BB-163, flown September 16, 1961, including part of sec. 16, T. 160 N., R. 69 W.

Several dozen circular ridges in Rolette County are larger than this, some reaching diameters of nearly ½ mile (Fig. 11). These may be the largest features yet reported, although Gravenor and Kupsch (1959, p. 52) report some up to 1,000 feet in diameter and Christiansen (1956, Fig. 4) shows a photo of some more than 1,000 feet across at Moose Mountain, Saskatchewan. These unusually large features could have formed as previously described, provided that local events caused the superglacial sediment to become unusually fluid or plastic. An unusually heavy rainfall could have saturated the superglacial debris during the time the material was flowing down the flanks of the ice-cored hills (Fig. 12).

Similar features with larger diameters could form by material sliding or flowing into a hole completely through the stagnant ice (Fig. 13) that had some drainage outlet and did not become an ice-walled lake (Fig. 4). Following the logic presented by Clayton for the probable maximum size of the features formed by topographic inversion as shown in Figure 12, features formed this way should have a minimum diameter of about 500 to 600 feet.

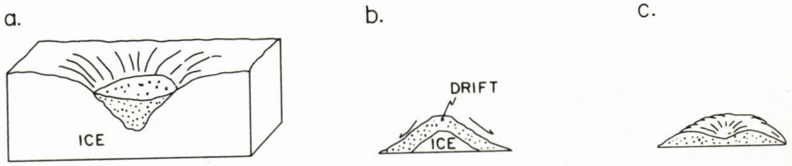


FIGURE 12. Diagram showing three stages in the formation of a circular disintegration ridge ("doughnut") (from Clayton, 1967, Fig. A-2).

It is interesting to note that one closed ridge is distinctly five-sided (Fig. 14), which would suggest that it originated as the filling of pentagonally-arranged crevasses on stagnant ice. Pentagonal or hexagonal stress patterns commonly develop in any contracting sheet (cracks in drying mud and cooling igneous rock are common geologic examples), but it is not clear how contracting stresses could be caused in melting stagnant ice. The explanation of this feature is obscure.

There are local complications and combinations of linear till ridges, closed till ridges, and eskers. This is to be expected because both mudflow and stream sediment will be transported toward the lowest places in the melting stagnant ice.

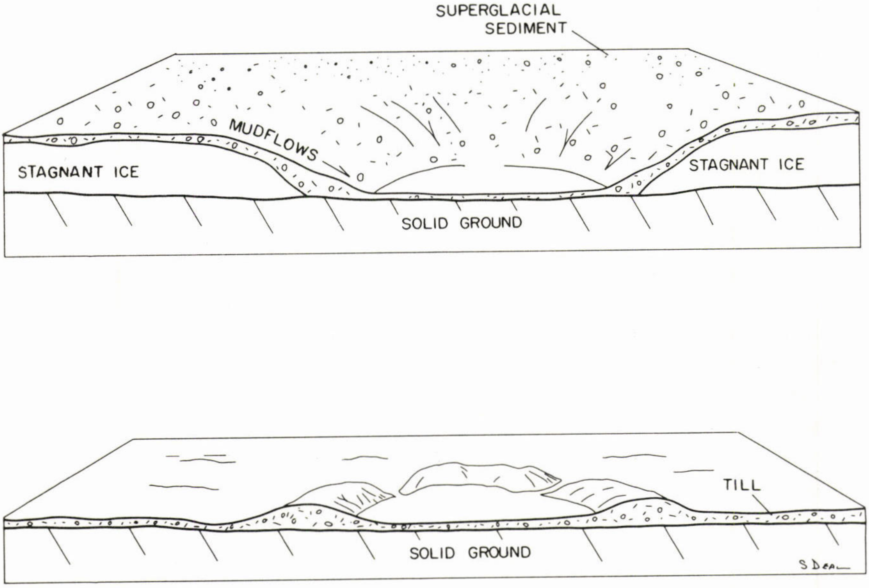


FIGURE 13. Diagram showing how a large circular disintegration ridge ("doughnut") could form.

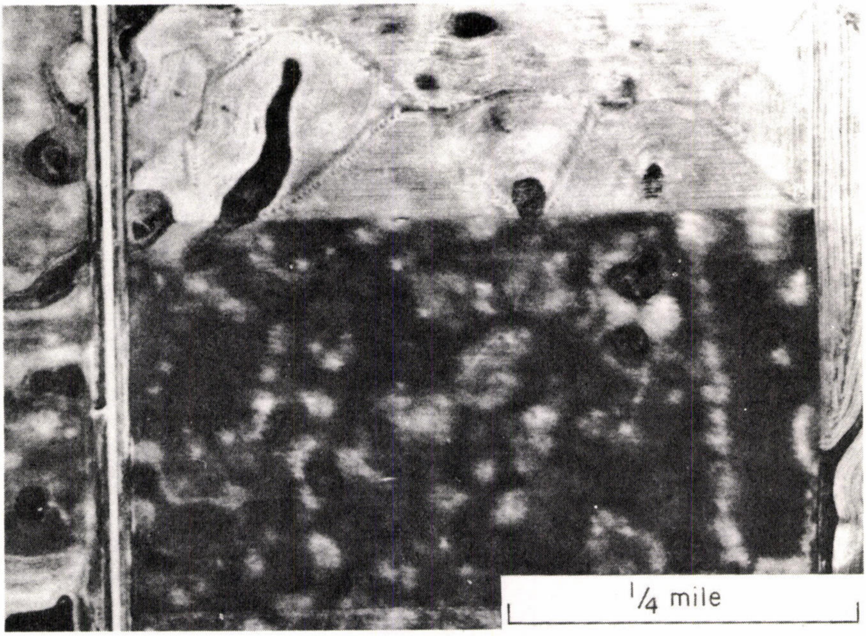


FIGURE 14. Aerial photograph showing a five-sided closed disintegration ridge. Part of photograph BAG-1BB-161, flown September 16, 1961, including the NW¼ sec. 19, T. 160 N., R. 69 W.

INTERPRETED QUATERNARY HISTORY

History Before the Last Glacial Advance

The Quaternary history of Rolette County before the last glacial advance is poorly known. Major topographic elements and significant drainages that existed sometime prior to the last overriding ice sheet are shown in Figure 15. The Turtle Mountains stood as a topographic high, partially cut by a north-south trending valley extending from the vicinity of Dunseith through Willow Lake. The "bedrock" core of the Turtle Mountains was probably a pre-glacial erosional feature, but there is the possibility that it is formed by large erratic blocks transported by an earlier glacial advance (*see the section* **Basic Data**, *subsection* **Topography Beneath the Glacial Drift and the Problem of Ice Thrusting**). A major drainage channel from previous deglaciations and interglacial runoff trended southeasterly from the center of the county.

Evidence for at least two, and possibly five or more, previous glaciations has been found in the vicinity of Rolla. Schmid (1964) reports a test hole drilled two miles west of Rolla that penetrates five sections of till separated by sand or gravel lenses (Fig. 16). He notes

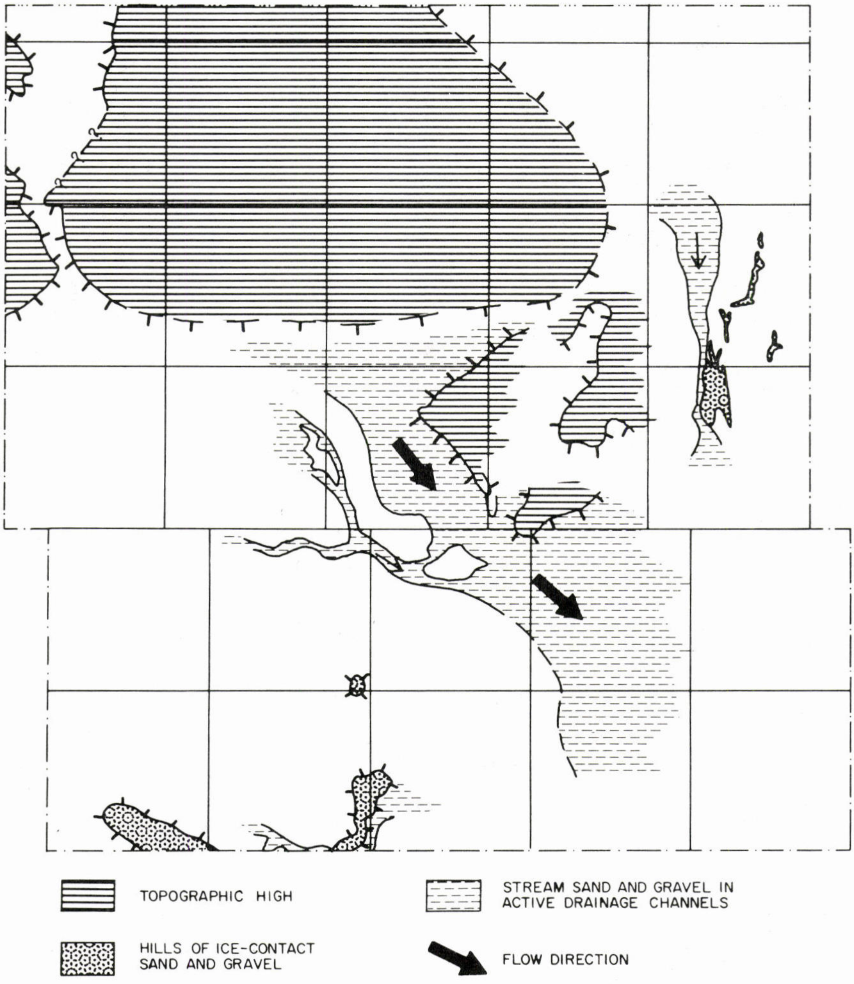


FIGURE 15. **Map showing topographic features developed prior to the last glacial advance.**

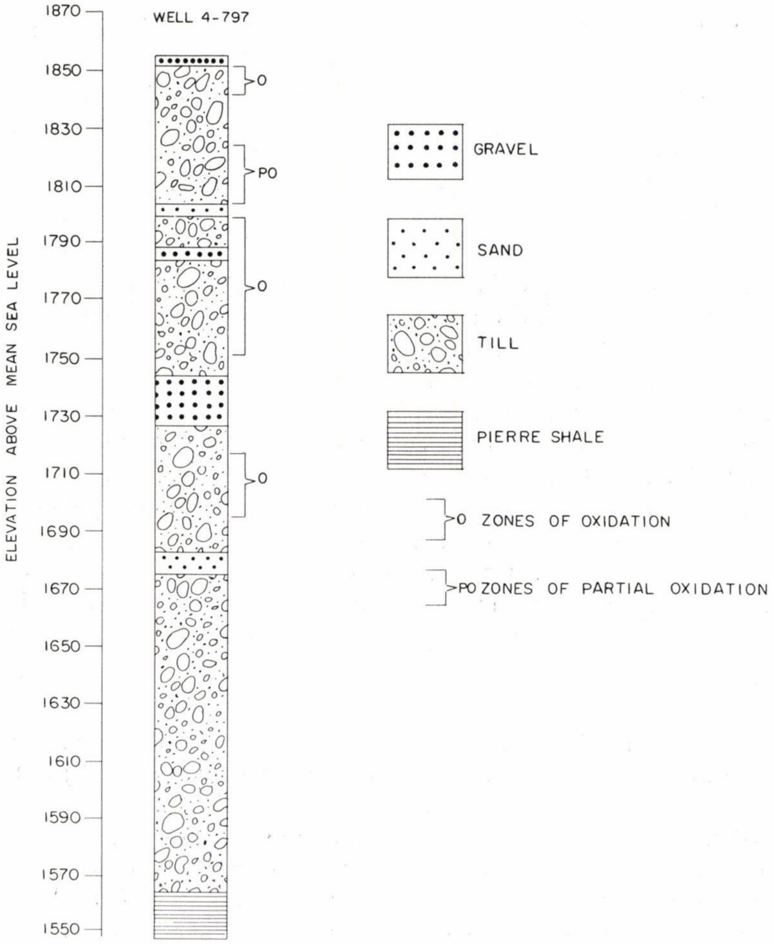


FIGURE 16. Test hole showing multiple tills in the vicinity of Rolla (Schmid, 1964, Fig. 5, well 4-796).

(Schmid, 1964, p. 9) that this is one of several test holes in the area that penetrates two buried zones of oxidized till.

The topography of the area around Rolla is complex, with features developed prior to the last glacial advance "showing through" the uppermost drift (*see the section* **Sediment Origin**, *discussion of Unit W*). I think that during one of the previous glaciations, a stagnant-ice mass terminated just south of Rolla, corresponding approximately to the contact between Units T and W on the map **Sediment Origin.** The evidence for this is a series of till-covered sinuous ridges that trend southward, merge, and then end in a large, low, till-covered hill that seems to thin and spread out to the south. These features could have originated as a stream system on or in stagnant glacial ice that supplied sediment to an outwash plain as shown in Figure 17. I think that the main reason the topography of Units T and W is different (*see the section* **Sediment Origin**) is because the surface sediments in Unit W were deposited over a complex landscape formed by decaying stagnant ice, while the surface sediments in Unit T were deposited over a low-relief surface on outwash sand and gravel. I have no drill data to support this hypothesis, although some of well logs (North Dakota Geological Survey and Works Progress Administration, about 1938), suggest that I might be right. Ground-water prospectors or individuals concerned with waste disposal and possible ground-water contamination should be alert to the possibility that a shallow, buried aquifer may exist in the area (mostly in T. 161 N., R. 69 W.) indicated as stream sediment on Figure 17.

Other prominent hills of sand and gravel that were the result of previous deglaciations occur in the southwest part of the county (Fig. 15). (*See also the section* **Sediment Origin**, *discussion of Unit X.*)

Elson and Halstead (1949, p. 11) report recovery of Black Spruce cones (*Picca mariana*) from beneath 90 feet of drift near Lake William in the Canadian part of the Turtle Mountains. Elson (1955, p. 182 and 275) infers that these must be from a preceding interval of deglaciation and correlates them with a widespread striated boulder pavement in southwestern Manitoba (Elson, 1955, p. 87-97). It does not necessarily follow that because material is buried beneath 90 feet of till it must predate the last glacial advance. Pettyjohn (1967, p. 128) mentions that

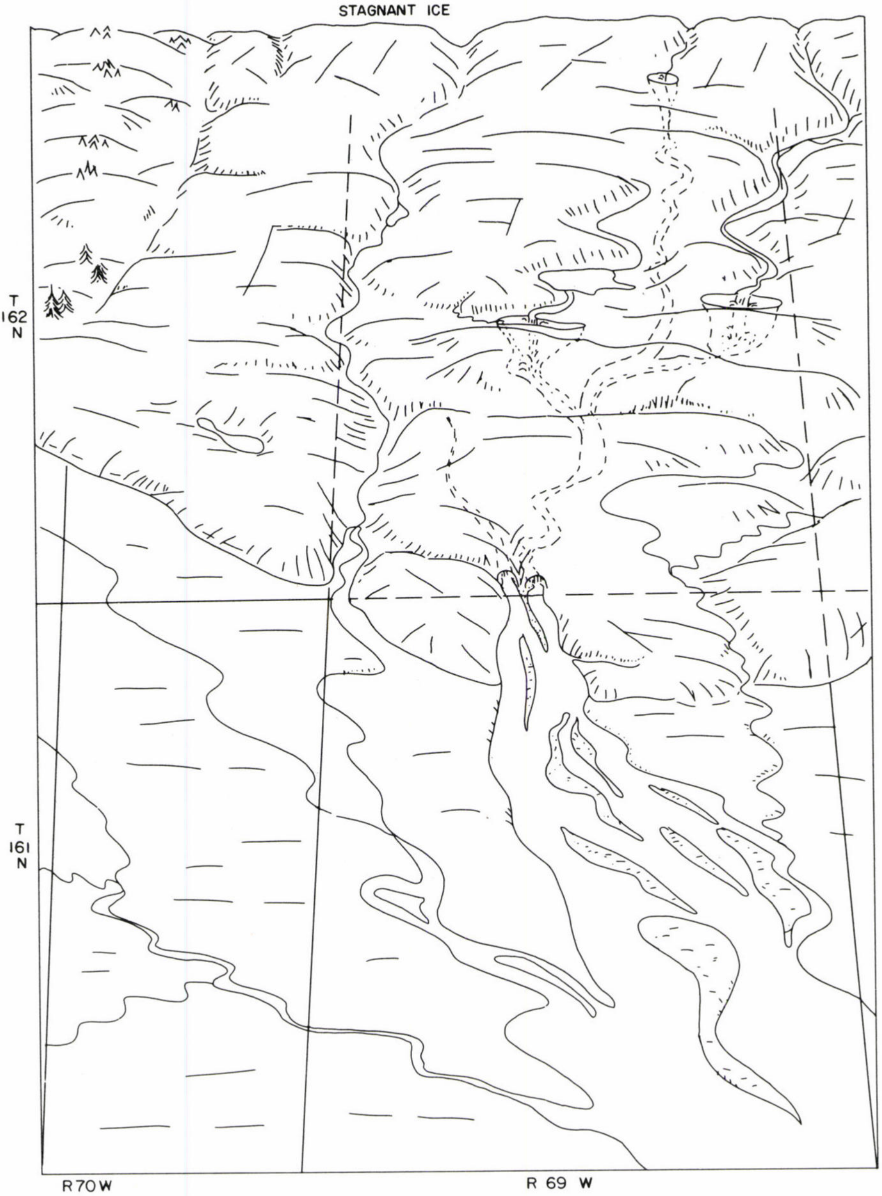


FIGURE 17. Diagrammatic sketch of an inferred esker-outwash complex that existed prior to the last glacial advance east of Rolla.

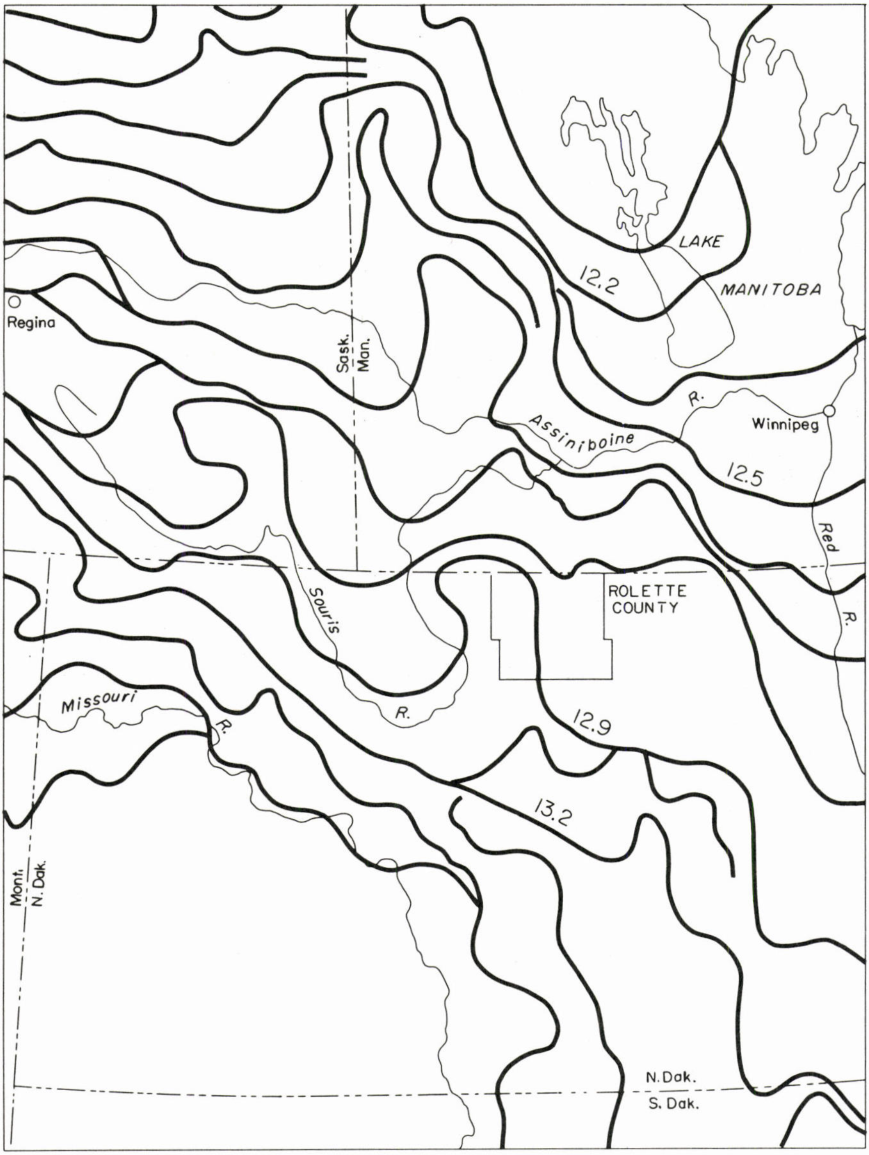


FIGURE 18. Map showing the retreat of Wisconsinan ice in the vicinity of Rolette County (modified from Prest, 1969). Approximate ages of the ice margins are shown in 1000's of radiocarbon years before the present.

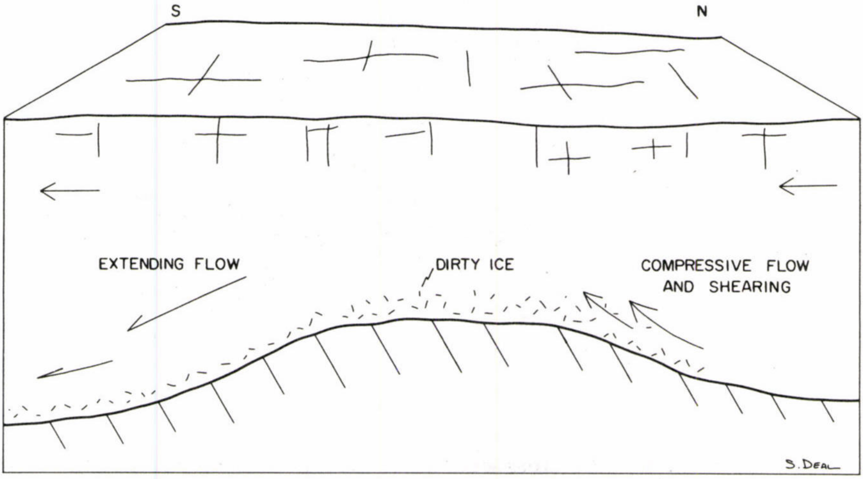


FIGURE 19. Diagrammatic cross-section showing glacial ice overriding a topographic high, such as the Turtle Mountains. Most of the ice at the base of the glacier probably flowed around, not over, such topographic barriers.

wood, white spruce cones, and grass buried beneath 137 feet of till on the Missouri Coteau gave radiocarbon ages of about 10,350 years. This material was probably simply buried by 137 feet of mudflow sediment during the last deglaciation (*see the section* **Sediment Origin**, *subsection* **Glacier and Mudflow Sediment**).

Last Glacial Advance and Deglaciation

During the last glacial advance, ice moved into North Dakota from several major centers of accumulation in northern parts of Saskatchewan, Manitoba, and Ontario. During the retreat of the margin of this ice sheet motion was generally toward the south and southeast (Elson, 1955, p. 275). As the climate changed and the ice margins began to melt faster than ice was being supplied by glacial flow, the margins began to thin and retreat. General positions of ice margins in this area are shown in Figure 18. Flow in the basal part of the ice sheet was diverted around the sides of and over obstructions such as the Turtle Mountains, Moose Mountain, and Riding Mountain (the latter two are in Canada) so that compressive flow conditions caused some debris to be sheared up into overriding ice (Fig. 19). On the lee side of obstructions, extending flow conditions probably moved debris back toward the base of the ice sheet. As deglaciation continued, the

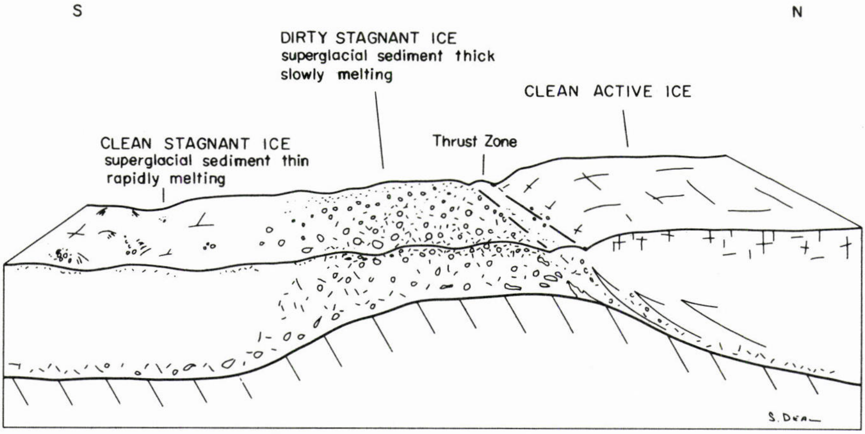


FIGURE 20. **Diagrammatic cross-section of the Turtle Mountains during Phase 1 of the last deglaciation.**

underlying topographic highs were areas of locally early ice stagnation that forced all glacier flow around them.

For convenience in the subsequent discussion, the events of the last deglaciation are divided into four somewhat arbitrary phases.

Phase 1

Stagnation at first resulted in rapid melting of ice over the topographic highs, but because the ice was so dirty, an insulating blanket several feet thick quickly developed, reducing the melting rate. Active ice continued to thrust against stagnant ice (Fig. 20), causing more debris to accumulate. Local rejuvenation occurred as thrusting increased the thickness of the pile of ice and debris. Variations in glacial activity caused shear zones to migrate and also may have rejuvenated formerly stagnant ice from time to time. The end result was the accumulation of a thick blanket of superglacial drift over stagnant ice in the Turtle Mountains. This insulated the buried ice, which melted very slowly. Stagnant ice in the lee of the Turtle Mountains was much cleaner, developed only a thin blanket of superglacial drift, and melted rapidly.

Since the Turtle Mountains rise 600 to 800 feet above their surroundings, and since ice only 200 or 300 feet thick will flow under its own weight, glacial flow continued on either side of the Turtle Mountains. Lemke (1958), in a general discussion of the Souris River

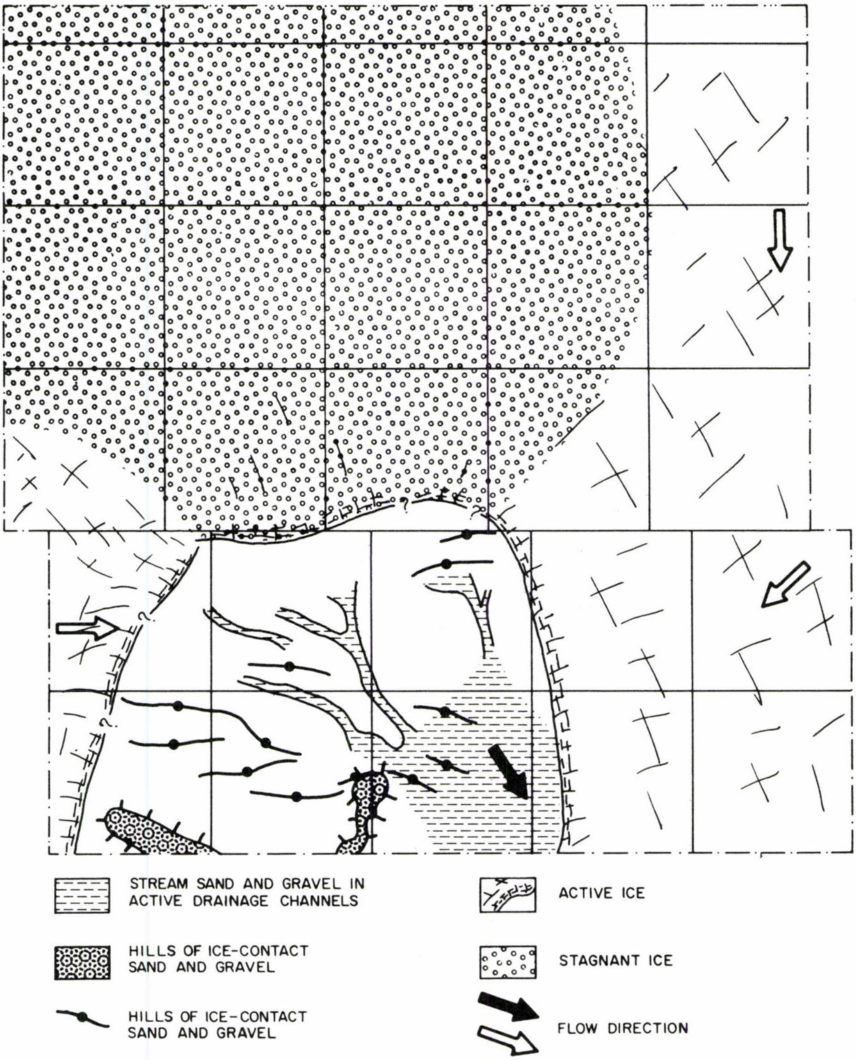


FIGURE 21. Map showing the approximate location of the Rolette Meltwater Basin during Phase 2 of the last deglaciation.

area, has named the glacial flow system to the south and west the Souris River Lobe (which was flowing toward the southeast) and the one to the east the Leeds Lobe (which was flowing toward the south). For a time these glacial flow systems probably merged to form a single moving mass southeast of the nearly stagnant ice in the lee of the Turtle Mountains. Ice immediately south of the Turtle Mountains continued to move as the thickness and movement of the surrounding ice permitted. Stagnation of the ice over the Turtle Mountains probably happened slightly more than 13,000 years ago.

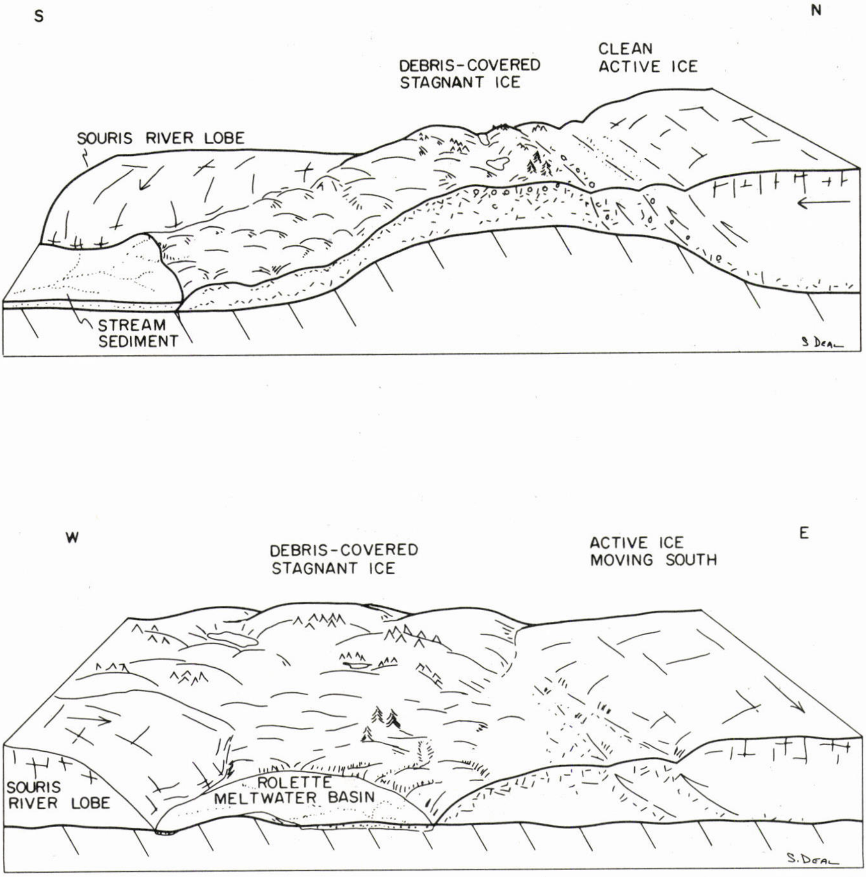


FIGURE 22. **Diagrammatic cross-sections of the Rolette Meltwater Basin during Phase 2 of the last deglaciation.**

Phase 2

Warming encouraged deglaciation and the thinning of the ice sheet continued. When the glacier was reduced to some critical thickness (about 200 feet), movement ceased. This occurred first in Rolette County to the ice immediately downstream (on the south side) of the Turtle Mountains. Movement may have continued for a time on both sides in the main body of the Leeds and Souris River Lobes. The stagnant ice south of the Turtle Mountains was fairly clean and only a thin blanket of superglacial sediment accumulated as it melted. Melting was fairly rapid, the superglacial sediment had a high water content, and mudflows and mass movement were common.

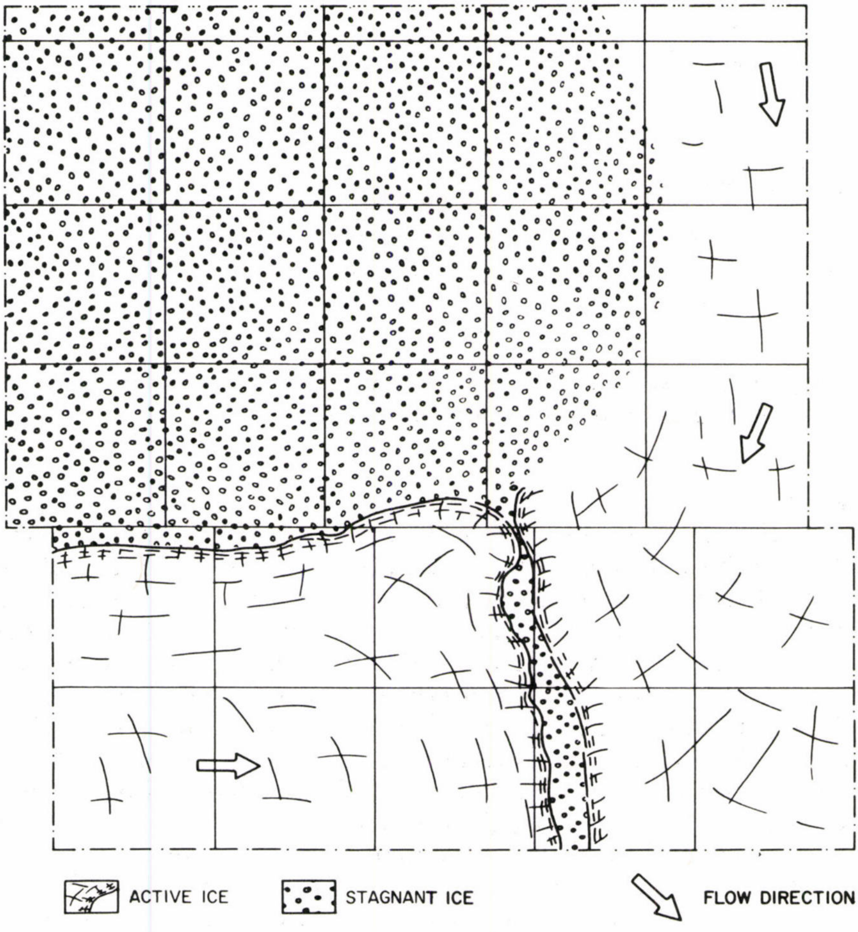


FIGURE 23. Map showing the re-advance of the Souris River Lobe during Phase 3 of the last deglaciation.

Melting of the clean stagnant ice continued until an ice-free area, unknown in extent but at least several townships in size, developed in the southwestern part of the county (Figs. 21 and 22). The town of Rolette is located in this area, which I call the Rolette Meltwater Basin.

Meltwater drained southward through Pierce and Benson Counties and most of the basin was covered with stream sand, gravel, and silt enclosing scattered blocks of stagnant ice. This occurred approximately 13,000 years ago.

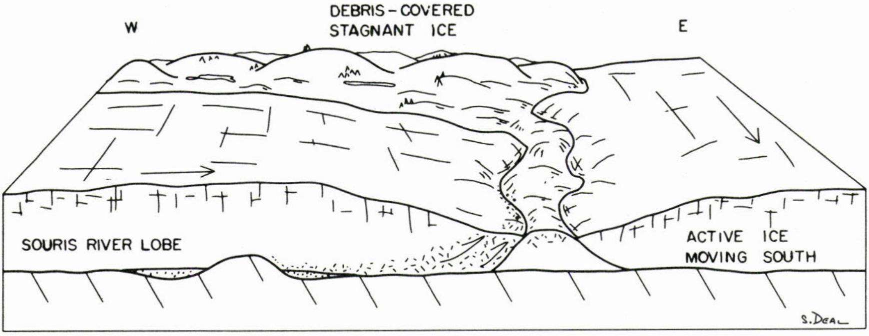


FIGURE 24. Diagrammatic cross-section of the re-advancing Souris River Lobe during Phase 3 of the last deglaciation.

Phase 3

Active ice of the Souris River Lobe advanced to the east across the Rolette Meltwater Basin (Fig. 23 and 24), overriding and streamlining east-trending eskers and eroding the sand and gravel meltwater deposits. It rode up on the stagnant edge of the southward-flowing Leeds Lobe, where intense shearing built a north-south-trending terminal moraine (Pl. 1, Unit R) with an unusual lithology. This terminal moraine, the Rolette End Moraine, is composed in large part of stony sand (Pl. 1, Unit 15) derived from the stream sand, gravel, and silt of the Rolette Meltwater Basin. Since this lithology was clearly derived from the west (*see the section* **Sediment Origin**, *discussion of Unit R*) and is found no farther east than the Rolette End Moraine, it indicates that this advance did indeed terminate in the vicinity of the Rolette End Moraine. Large blocks of sandstone may have been deposited on the northern edge of this active ice advance (*see the section* **Sediment Origin**, *discussion of Unit Z*). *For additional discussion of the various sediments that may be associated with this ice advance, see the section* **Sediment Origin**, *discussion of Units P, Q, R, S, and Z.*

The Rolette Meltwater Basin obviously formed before the ice advanced from west to east to form the Rolette End Moraine. It is possible that sediment in the Rolette Meltwater Basin could have been deposited during the preceding deglaciation or interglacial and not as part of the last deglaciation. If the shallow trenches (*see the section* **Sediment Origin**, *discussion of Units R and Z*) are disintegration trenches, that possibility is unlikely and the Rolette Meltwater Basin formed as part of the last deglaciation.

I think the glacier must have advanced over stream sediment that still contained unmelted, buried ice blocks. The blocks could not have been relatively large or the weight of the overriding active ice would have caused them to flow plastically and become part of the advance. The re-advance of ice across the Rolette Meltwater Basin could have been caused in at least two ways.

There probably was an overall change in the regimen (*which can be thought of as the relationships between rate of melting, rate of glacial flow, and rate of accumulation of snow in the source area of the glacier*) of the Souris River Lobe, with or without any corresponding change in the Leeds Lobe, causing ice to advance in other parts of the Souris River Lobe and probably causing renewed shearing on the northern and western edges of the Turtle Mountains. Lemke (1960, p. 112), discussing the Souris River Lobe in Benson County, noticed a relationship similar to that in Rolette County: "The Souris River lobe appears to have overridden the northwest segments of the end moraines deposited by the Leeds lobe." Lemke (1960, p. 111-112) defines the Martin Moraine as the "interpreted limits of the Souris River Lobe" but goes on to remark that in northeastern Sheridan County the Souris River Lobe extended several townships (Lemke, 1960, Pl. 15) beyond the limits of the Martin Moraine. This might be related to the same re-advance that formed the Rolette End Moraine.

Re-activation of the ice west of the Rolette Meltwater Basin may also have been caused by an advance of the Leeds Lobe in Benson County, blocking the outlet of the basin and causing a lake to form within it. This would have increased the hydrostatic pressure under the Souris River Lobe immediately west of Rolette. The combination of decreased subglacial friction due to more subglacial water and an increased buoyant effect could have caused the eastern extension of the Souris River Lobe across Rolette County without an overall change in regimen.

Phase 3 probably occurred around 12,900 or 13,000 years ago, based on the approximate positions of continental ice margins as shown by Prest (1969).

Phase 4

After the advance that formed the Rolette End Moraine, all glacial ice in Rolette County stagnated. Flow may have continued somewhat longer in the Leeds Lobe in Towner County and along the eastern edge of Rolette County, but by 12,500 years ago the ice margins were several hundred miles northeast of the Turtle Mountains, across the Assiniboine River in Manitoba (Prest,1969).

Melting of the relatively clean ice of the Souris River and Leeds Lobes took place rapidly, most probably melting in a few hundred years. Isolated, buried blocks of stagnant ice that were insulated by a fairly thick sediment blanket existed much longer, as probably did any ice core in the Rolette End Moraine. Water from the Leeds Lobe drained southeast to glacial Lake Agassiz through the Sheyenne River meltwater channel, glacial Devils Lake (a large glacial lake extending from Tilden in Benson County to Stump Lake in Nelson County), and glacial Lake Cando (which covered several townships in southeastern Towner County and northwestern Ramsey County). Some water from the Leeds Lobe also joined water from the Souris River Lobe and flowed southwest into glacial Lake Souris.

During previous deglaciations most meltwater from stagnant ice in southwestern Rolette County probably flowed southeast toward the Sheyenne River drainage (Fig. 15). The Rolette End Moraine now blocked that outlet and meltwater flowed southwest into glacial Lake Souris, which at first drained southeast through the James River and Sheyenne River drainages and later drained northward around the Turtle Mountains and into the Pembina River drainage (Elson, 1958; and Lemke, 1960, p. 115-116).

The thick blanket of superglacial drift on top of stagnant ice in the Turtle Mountains insulated it so that it took several thousand years to melt, contributing water only very slowly to the water table.

Glacial Lake Souris. As with most large glacial lakes, Lake Souris began as a series of small lakes on top of melting, stagnant ice. These small lakes merged as melting continued and formed a large lake, partly on solid ground and partly on buried, stagnant ice. This lake had an ice margin to the north and west. As deglaciation continued the ice margin retreated northward and increased the total amount of area covered by the lake. The retreat of the ice also unblocked lower, more northerly outlets, so the lake level dropped at the same time.

Lemke (1960, p. 115) mentioned two prominent levels of Lake Souris at approximately 1550 and 1510 feet above sea level. Moran and Deal (1970), partly as a result of field work done for this report, identified strandline levels at 1590, 1570, 1550, 1540, 1525, 1510, 1500, 1475, and 1460 feet in Rolette, Pierce, McHenry, and Bottineau Counties. They stated that the three most prominent strandlines are at 1550, 1510, and 1475 feet. Figure 25 shows the sequence of Lake Souris events that occurred in Rolette County.

The first extensive, high level of the lake occurs at about 1600 feet. When forming this strandline, Lake Souris covered a minimum of three townships and was surrounded by a large amount of stagnant ice. Pure ice has a density of 0.917, and it is only necessary to add six percent debris with an average density of 2.4 to make the resulting dirty ice heavier than fresh water, causing it to sink. At this high level the floor of the lake probably contained stagnant ice blocks that were too heavy to float. This lake was undoubtedly ice-walled to the west,

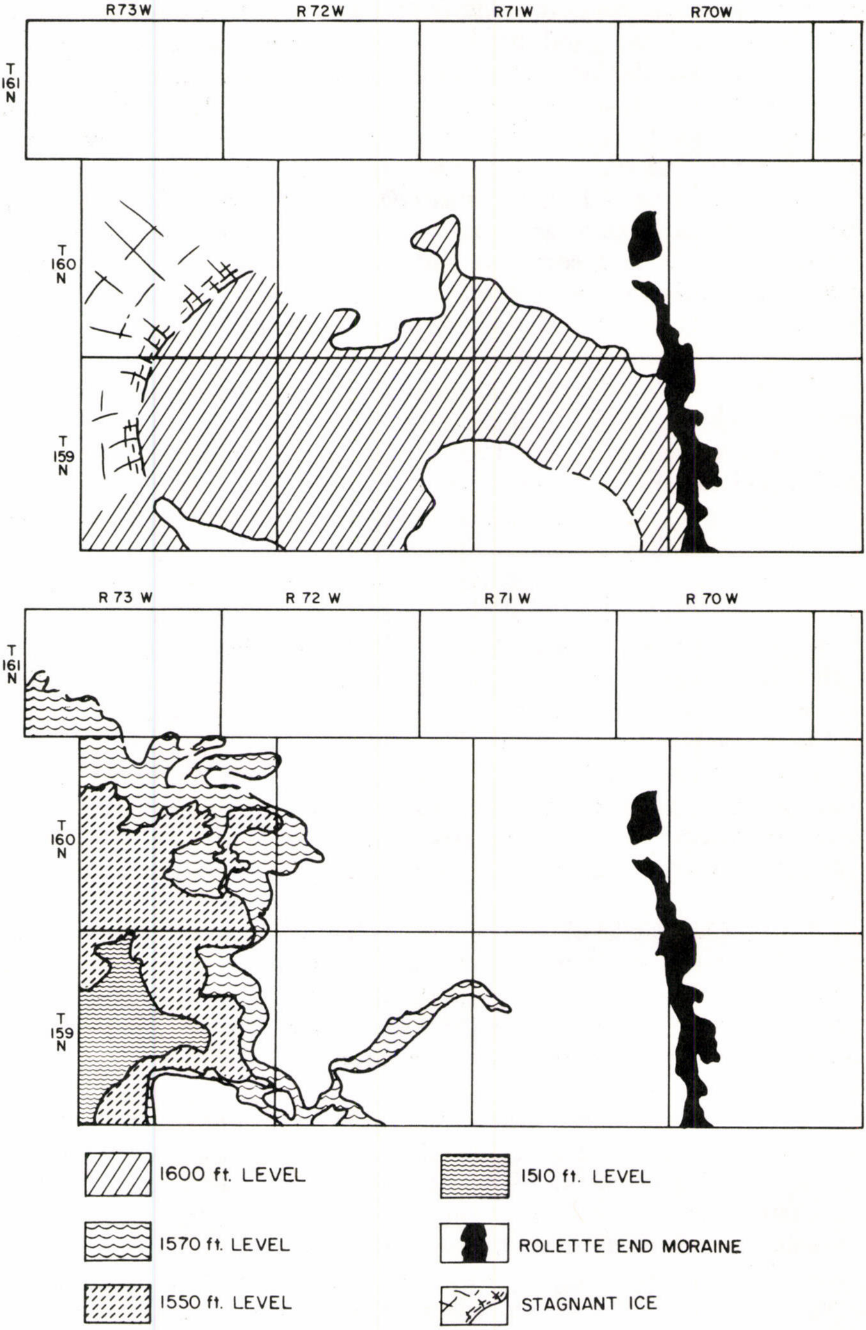


FIGURE 25. **Maps showing the extent of various levels of glacial Lake Souris in Rolette County.**

but it is difficult to determine its extent. Most strandline features (includes both beach and offshore bar features) were developed on stagnant ice that did not melt until after the lake level dropped. As a result, strandline features are irregular, vary in elevation, and are difficult to trace today. At this level the lake extended southward into Pierce County and may or may not be the same body of water reported by Moran and Deal (1970) in southeastern McHenry and southwestern Pierce Counties. If they are not the same lake, they were essentially contemporaneous and soon merged as ice continued to melt. *For a further description of the sediment associated with this high level, see the subsequent section* **Sediment Origin**, *discussion of Units G, K, and L.*

A fairly well marked strandline occurs at approximately 1570 feet. Terrace levels in outwash channels along the present course of Mud Creek and Ox Creek are graded to and terminate at this elevation. There are also indications that the meltwater channel now followed by Ox Creek in T. 159 N., R. 72 W. is a relic from a previous deglaciation and was a drowned valley at this lake level. When forming this strandline the lake connected southward into Pierce County in a number of places and some large, till-covered sand and gravel hills along the Pierce and Rolette County line stood as islands in it. The northern edge of the lake at this level is not precisely located in Rolette County. Strandline features were either developed on stagnant ice or modified by streams flowing into later lower lake levels, or both.

A prominent lake level occurs at approximately 1550 feet. Lemke (1960, p. 115) thought that Lake Souris, when forming this strandline, drained southeast into what is now the North Fork of the Sheyenne River and flowed into glacial Lake Agassiz in what is now the Red River valley.

A strandline at 1525 feet is not evident in Rolette County, but a series of features that appear to be collapsed beaches at this level extend from a point on Willow Creek one mile west of Rolette County to the vicinity of Omemee in Bottineau County. Streams incised their channels through the previously deposited lake sediments in Rolette County.

The lowest shoreline observable in Rolette County is at 1510 feet, but a much more prominent and slightly lower scarp occurs between 1495 and 1510 feet to the west in Bottineau and Pierce Counties. This prominent scarp trends north-south and is 2¼ miles west of the southwest corner of Rolette County. The intervening area may have been mud flats containing stagnant ice blocks at the time Lake Souris was forming the 1510 foot strandline. This elevation marks the time of maximum extent of the lake in North Dakota. It covered approximately 1500 square miles (Moran and Deal, 1970), and flowed southeast into glacial Lake Agassiz through what is now the North Fork of the Sheyenne River (Lemke, 1960, p. 115).

While Lake Souris formed the 1510 foot strandline, ice still blocked northern outlets around the west edge of the Turtle Mountains. When the ice melted in that area the lake dropped below the 1510 foot strandline and emptied into Lake Agassiz by way of what is now the Pembina River. This probably occurred around 12,500 years ago, and by this time all the stagnant ice in Rolette County that was not buried under a thick insulating blanket of sediment had melted. Streams continued to be much larger than the present streams in the area because the climate was wetter than at present.

Elson (1958) outlines the sequence of events that controlled the northern outlets of Lake Souris. If the dates shown by Prest (1969) are reasonably correct, then it is clear that Lake Souris had disappeared from North Dakota by 12,000 years ago.

Turtle Mountains. The Turtle Mountains are similar in many ways to the much better studied Missouri Coteau to the south. (*For an extensive discussion of the Missouri Coteau see Clayton and Freers, 1967.*) Both were places where compressive flow and shearing within the glacier caused an unusual thickness of dirty ice to accumulate. When the glacier stagnated, an insulating blanket of superglacial sediment quickly developed.

The Turtle Mountains are several hundred feet higher than the Missouri Coteau, and it is probable that stagnation took place at about the same time in both areas. I have estimated (*see the preceding discussion* **Phase 1**) that stagnation in the Turtle Mountains may have taken place prior to 13,000 years ago. Clayton (oral communication, June 26, 1970) now feels that stagnation on the Missouri Coteau also took place about 13,000 years ago.

Studies of debris-covered stagnant ice on the Martin River Glacier, Alaska (Clayton, 1967, p. 40-42; and Tuthill, 1969, p. 190-191), show that six feet of superglacial drift is enough to almost completely insulate the buried stagnant ice. Lakes developed on top of the superglacial drift contain relatively warm water derived almost entirely from rainfall and have abundant, normal, aquatic life such as mollusks, fish, waterfowl, beaver, and aquatic plants. This contrasts sharply with the barren, cold lakes on adjacent areas of bare ice. Trees growing on the superglacial drift (average thickness less than 10 to 20 feet) are more than 100 years old. In one case a 100 year-old tree was observed growing on 4½ feet of superglacial drift (J. R. Reid, written communication, August 14, 1970).

I agree with Clayton (1967) and Tuthill (1969), who visualize a similar environment developing quickly on top of stagnant ice on the

Missouri Coteau, where the insulating blanket of superglacial drift reached thicknesses of about 100 feet. Nearly identical conditions formed on the Turtle Mountains as soon as ice stagnated. Clayton (1967, p. 36 and 41) estimated that it took more than 3,000 years for the buried stagnant ice to melt, a figure that seems reasonable for the Turtle Mountains. I therefore visualize a debris-covered stagnant-ice upland, with a surface several hundred feet higher than we see it today, forming on the Turtle Mountains about 13,000 years ago. A forest cover probably developed in a few hundred years and was predominantly spruce, similar to other known late-Wisconsinan forests in South Dakota, North Dakota, Minnesota and Saskatchewan (Moir, 1958; Thompson, 1962; Ritchie and de Vries, 1964; McAndrews, Stewart, and Bright, 1967; McAndrews, 1967; Watts and Bright, 1968; Bickley and Cvancara, 1970; and Bickley, oral communication, June 24, 1970). Superglacial lakes and ponds that formed in the Turtle Mountains were probably similar to those on the Missouri Coteau, which were at first filled with cold, turbid meltwater (Clayton and Cherry, 1967; Royse and Callender, 1967; and Tuthill, 1967 and 1969). As soon as a sufficient thickness of superglacial drift accumulated to stabilize the streams and lakes and isolate them from cold, turbid meltwater, the lakes warmed and large and diverse populations of mollusks were established (Tuthill, 1969, p. 102-104).

I collected mollusks, peat, and wood from two sites in the Turtle Mountains. Both sites are spoil piles from stock-watering dugouts and contained mixed faunas. I collected the fresh-water snails *Gyraulus parvus* (Say), *Helisoma* sp., *Stagnicola palustris* (Muller), *Valvata lewisi* (Currier), and *Valvata tricarinata* (Say); the land snails *Pupilla* sp., *Succinea* sp., and *Vallonia* sp.; and the fingernail clam *Pisidium* sp. from lake sediment at NE¼SW¼NW¼ sec. 24, T. 163 N., R. 72 W. Similar fossils were collected at NE¼SW¼SW¼ sec. 12, T. 163 N., R. 72 W. A detailed paleontological study of assemblages in the Turtle Mountains is needed.

Sediment accumulating in the superglacial lakes further increased the thickness of the insulating blanket over stagnant ice, and ice beneath the lakes may have melted more slowly than that beneath the surrounding areas. Topographic inversions may have taken place several times (*see the subsequent section* **Sediment Origin**, *discussion of Unit I*), and a complex of lakes covering parts of several townships is shown in Figure 26. I think that there are at least three distinct ages of lakes that developed as shown in Figure 27. The relative ages of the many other superglacial lakes that formed in the Turtle Mountains (Pl. 1, Unit I) are not known.

From the paleontological evidence (*see the preceding discussion*) it is clear that the climate between the time ice stagnated

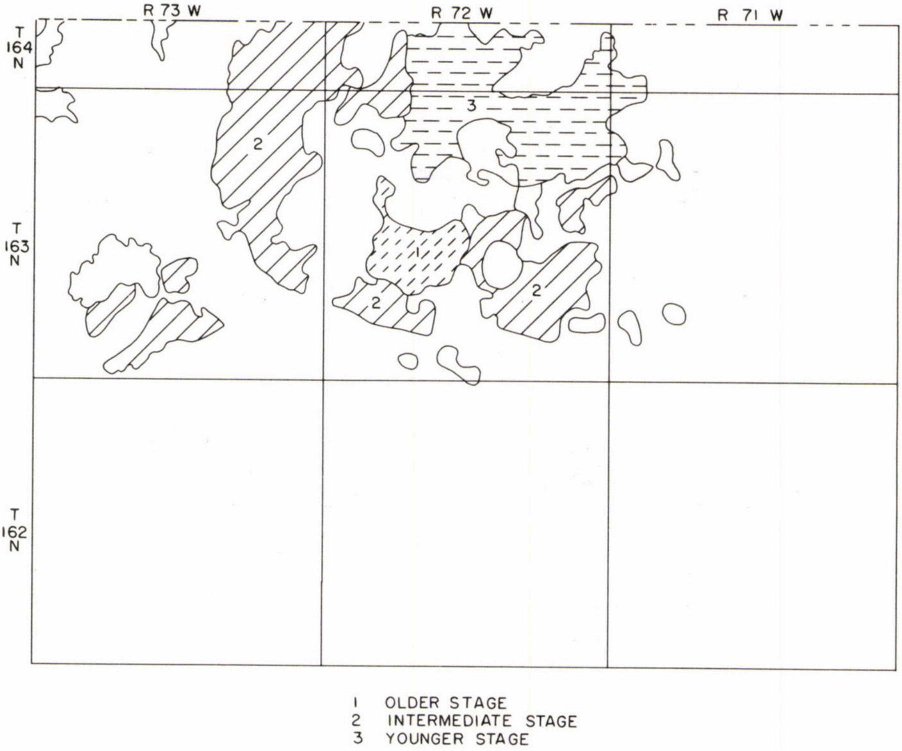


FIGURE 26. Map of the large ice-walled lake complex in the Turtle Mountains.

and about 10,500 years ago was effectively more moist than today. There was either more precipitation, less evaporation, or both. Clayton (1967, p. 35 and 40) concludes that the Missouri Coteau received 5 to 10 inches more precipitation than today and that it was a few degrees cooler. Tuthill (1969, p. 105-106) argues that although it was more humid, the climate was no cooler than today. He feels that the climate in late Wisconsinan time probably had cooler summers and milder winters than we experience today, which would have the same effect on the balance between evaporation and precipitation as an overall decrease in temperature. I tend to agree with Tuthill.

Recent evidence from the Rocky Mountains is starting to indicate a general warming trend about 11,500 years ago (Baker, 1970). This has not yet been substantiated by fossil evidence from the central plains, but does correspond with the rapid, final deglaciation of North America (Prest, 1969). It is widely recognized (*see the previously cited*

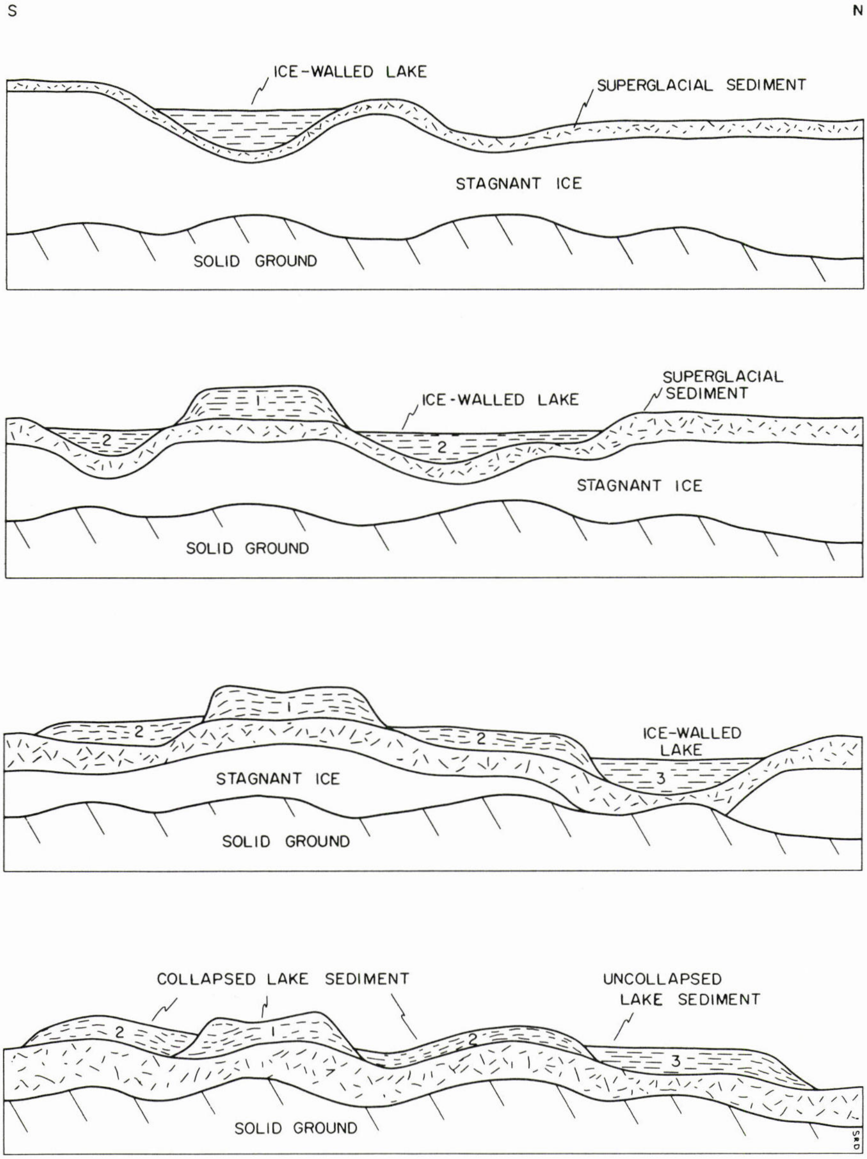


FIGURE 27. Diagrammatic cross-sections showing the development of the ice-walled lake complex in the Turtle Mountains.

paleontological references) that a major warming trend occurred about 10,000 or 10,500 years ago and that this changed the climate from humid to the present subhumid-semiarid climate and terminated forest cover over most of North Dakota. Another warming trend about 8,500 or 9,000 years ago made the climate more arid than it is today and caused the grassland-forest boundary to migrate about 100 miles eastward in Minnesota (*see the subsequent discussion* **Holocene History**). During the humid time (about 10,500 to 13,000 years ago) there was greater effective precipitation and runoff, causing non-glacial stream channels to have meander radii five times as great as the meander radii of the underfit streams flowing in them today (Clayton, 1967, p. 33). This observation holds for the stream channels cut in Units M and N (Pl. 1) in Rolette County.

One of the arguments for the existence of buried, stagnant ice on the Missouri Coteau until about 9,000 years ago hinges on the assumption that if stable basins had formed (by the complete melting of all buried ice) prior to that time, a better integrated drainage than occurs today should exist (Tuthill, 1969, p. 106). A better integrated drainage does exist in the Turtle Mountains, draining southward in Willow Creek and northward in Wakopa Creek. There are three plausible explanations for this: (1) valleys that existed prior to the last glaciation have been rejuvenated; (2) most of the stagnant ice in the Turtle Mountains had completely melted long enough prior to the climate change about 10,000 or 10,500 years ago so that stream channels were established during the time of greater runoff; or (3) the Turtle Mountains, due to their slightly higher elevation, always received enough precipitation to maintain perennial streams. I favor an explanation that combines 1 and 3. I certainly think that Willow Creek follows a drainage developed prior to the last ice advance (*see the preceding subsection* **History Before the Last Glacial Advance**).

Holocene History

Between approximately 10,500 and 8,500 years ago the climate was much like it is today. The warming trend about 10,500 years ago ended the forest cover over most of North Dakota and turned most of the lakes into sloughs (temporary ponds). The Turtle Mountains probably remained forested.

Between approximately 8,500 and 4,500 years ago the regional climate was effectively more arid than today (*see the paleontological references cited in the preceding discussion of the Turtle Mountains*). This could have been caused by less precipitation, warmer temperatures, or both. I visualize North Dakota as having had a climate similar to that experienced during the "Dirty Thirties," from 1928 to 1940. Several feet of wind-blown sand and silt was deposited over most of North Dakota and a veneer of the same material (*see the subsequent section* **Sediment Origin**, *subsection* **Wind-Blown Sediment**) was deposited in Rolette County. Many of the previously existing ponds and lakes turned into sloughs (temporary ponds) and grass cover was reduced outside the Turtle Mountains. As a result, hillslopes became more unstable and more erosion took place even though there was less rainfall (Schumm, 1965). The temporary ponds therefore received coarser, less organic-rich sediment (*see the section* **Sediment Origin**, *discussion of Unit A*).

It is interesting to note that the drought during the "Dirty Thirties" profoundly affected the lakes in the Turtle Mountains. Greenlee (1942, p. 22) did field work in the area in 1939 and 1941 and remarked:

> Glacial lakes found scattered throughout the area are rapidly disappearing. Seasons of light rainfall plus the drain on underground water supplies by numerous artesian wells along the foothills have caused the water levels of such large lakes as Lake Upsilon to drop 10 to 20 feet within the last twenty years. The fish hatchery has been closed, and the future of the area as a fishing summer resort will depend upon an additional supply of water by means of diversion or pumping. It is possible that some of the smaller lakes will some day be drained into a few larger lakes.

I think it is therefore likely that most of the lakes and ponds in the Turtle Mountains turned into sloughs (temporary ponds) during the period between approximately 8,500 and 4,500 years ago, and that they turned into intermittent and permanent lakes and ponds when the present climate was established. Forest cover was reduced and may have completely disappeared from the Turtle Mountains during the more arid interval.

The present climate was probably established about 4,500 or 4,000 years ago.

SEDIMENT ORIGIN

A condensed version of this section is printed on Plate 1 as the explanation of the map **Sediment Origin.** Numeric units refer to the map **Surface Sediments and Landforms** and alphabetic units refer to the map **Sediment Origin.** The alphabetic units are all interpretive and combine purely lithologic units in ways I think are geologically significant. The lithologies they contain are indicated in the explanation of the map **Sediment Origin.** Individual lithologies are discussed briefly on Plate 1 and in more detail in the section **Basic Data**, subsection **Surface Sediments.** This section is written for those users of the map **Sediment Origin** who desire a fuller explanation of my reasons for this grouping of units. I assume that users of this section will have Plate 1 in hand and will make their own cross-references to the lithologic information (*Pl. 1; and in the section* **Basic Data** *in the text*) as necessary for their purposes.

Wind-Blown Sediment

A veneer (a few inches to a few feet) of wind-blown silt and sand was deposited over most parts of Rolette County. Most was deposited between 8,000 and 4,500 years ago, with some additional contributions outside the Turtle Mountains during the "Dirty Thirties" (*see the section* **Interpreted Quaternary History**, *subsection* **Holocene History**). The lithology of this unit is neither shown nor keyed on Plate 1, but is discussed in the section **Basic Data**, subsection **Surface Sediments**, topic **Surface Silt and Sand.** Areas of vegetation-anchored dunes are indicated by Unit 45. This material is usually intensely stirred by burrowing animals, often mixed with the underlying sediment, and has been altered by soil forming processes. It is locally absent or unrecognizable in the Turtle Mountains, but my data is inadequate to determine if the material is generally or locally absent.

Lake Sediment

Modern lake, pond, and slough sediment (Unit A)

It is useful to distinguish between three types of standing water bodies that occur in Rolette County: perennial, intermittent, and temporary.

Perennial lakes and ponds are those which always contain standing water. They occur in local ground-water discharge areas, receive water both from slope runoff and from the water table, and are most abundant in the Turtle Mountains. Sediment deposited in them is dominantly fine grained (silt and clay), unoxidized, and derived from soils and glacial drift on adjacent hillslopes. It contains a few percent organic material, lacustrine fossils (such as fish, microcrustaceans, mollusks, and aquatic plants), fossils washed in from the adjacent forests (such as leaves, needles, wood, and terrestrial snails), and locally contains some peat and bog deposits (but these are more common in the higher parts of the Turtle Mountains west of Rolette County). Perennial lakes are shown on Plate 1 as Unit 46.

Intermittent lakes and ponds normally contain standing water but are dry during periods of little rain. They are also in local ground-water discharge areas and although they receive runoff from adjacent hillslopes during rains and the spring thaw, they receive much of their water from the water table. The sediment in them is similar to that in permanent lakes but lacks fossils of plants and animals that require permanent standing water and tends to be slightly oxidized and slightly tougher than that in perennial lakes and ponds. The summer of 1969 was quite wet, and most intermittent ponds contained water all season and are shown on Plate 1 as Unit 46. In a dry year many more would have been mapped as Unit 1.

Temporary ponds (sloughs) contain water only for a short time after rains and the spring thaw and are in ground-water recharge areas (they lose water to the water table by seepage through the sediment in their bottoms). They contain a few feet of organic clay derived mostly from the A1 horizon of soils on adjacent hillslopes. The sediment is partially oxidized, has been dry part of the time, and is therefore very tough. Temporary ponds are shown on Plate 1 as Unit 1.

Many perennial lakes and ponds existed in Rolette County during deglaciation (*see the preceding section* **Interpreted Quaternary History**), but most became sloughs about 8,500 years ago. Therefore most of the sloughs are underlain by a few feet of lake and pond sediment which in turn is underlain by glacial drift (mostly till).

Shoreline deposits (Unit B)

Sand deposits that may represent strandline features (beaches or bars) of glacial Lake Souris are shown on Plate 1 as Units 44 and B. In most cases exposures were poor and I was not able to conclusively say that these features were strandline deposits even though their location, lithology, and form suggested that they might be. More detailed work may show that some are superglacial stream deposits (such as Unit O) or linear wind deposits (dunes) that fortuitously occur at elevations nearly coinciding with levels of glacial Lake Souris. All occur in the southwestern part of the County and are thought to have formed between 13,000 and 12,000 years ago.

Sediment of ice-marginal Lake Souris (Units D, E, F, and G)

The interpreted history of glacial Lake Souris is discussed in the preceding section **Interpreted Quaternary History**. I think that these deposits formed between 13,000 and 12,000 years ago. Sediments include offshore silt and clay; nearshore and shoreline silt, sand, and gravel; and wave-eroded glacial drift (mostly till). Shoreline and offshore sediment was sometimes deposited around blocks of stagnant ice which, after the lake level dropped, melted to form irregular and pitted surfaces. This was more common with the higher, older deposits. These sediments, from oldest to youngest (highest to lowest), are shown on Plate 1 as Unit G (deposits between 1570 and 1600 feet associated with a lake level of approximately 1600 feet), Unit F (deposits between 1550 and 1570 feet associated with a lake level of approximately 1570 feet), Unit E (deposits between 1510 and 1550 feet associated with lake levels of approximately 1550 and 1525 feet), and Unit D (deposits below a lake level of approximately 1510 feet). All are located in the southwest corner of the county.

Other lake sediment

Other lakes that were not part of glacial Lake Souris and formed during the last deglaciation are lakes that formed on top of and surrounded by stagnant glacial ice (Unit I), lakes that were deposited on solid ground but with a partial shoreline on stagnant ice (Unit H), and lakes that were deposited on solid ground and not in contact with stagnant ice (Unit C). Sediment in these lakes is dominantly offshore silt and clay, but includes some nearshore and shoreline silt, sand, gravel, and mudflow (till) deposits.

Lake sediment deposited on solid ground (Units C and E). Unit C contains those lake deposits that were not formed on top of or in contact with stagnant glacial ice. Water in these lakes came mostly from glacial meltwater between 13,000 and 12,000 years ago. When the stagnant ice either melted or developed an insulating blanket thick enough to retard melting, they became sloughs and probably persisted until the climate changed about 8,500 years ago (*see the section* **Interpreted Quaternary History**). They are not sloughs today, although they may have several smaller sloughs on them.

Unit E is similar to Unit C, except that these lakes were at least partially ice walled. When the stagnant ice melted, a basin no longer existed to form the lake. I have shown a lake in the southeastern part of the county, just north and east of the town of Wolford, in Pierce County, as Unit C. It is not known if this lake had an ice-walled shore to the south or east, and it may have been part of a larger glacial lake in the area now occupied by Hurricane Lake. It is possible that it could also be an old, high level of glacial Lake Cando.

Lake sediment in Unit E includes deposits variously referred to by others as "perched lake plains," "uncollapsed ice-walled lake sediment," "partially ice-walled lake plains," "ice-marginal proglacial lake sediment," "glacier-marginal lake sediment," "elevated lake plains," "ice-restricted lake plains," or "proglacial lake sediment."

Lake sediment deposited on stagnant ice (Unit I). Sediment deposited in lakes on stagnant ice is outlined by the ice-contact symbol (Unit 27) and has undergone collapse (flowing and folding), possibly several times, as the underlying stagnant ice has melted (*see Figs. 4 and 27*). The sediment is dominantly offshore silt and clay but contains some nearshore and shoreline deposits of silt, sand, gravel, and mudflow sediment (till). These deposits rise above their surroundings as hills, and road-cuts in their flanks almost always expose mudflow sediment (till). They make good farmland as they are usually flat to undulating and are free of boulders (Fig. 28).

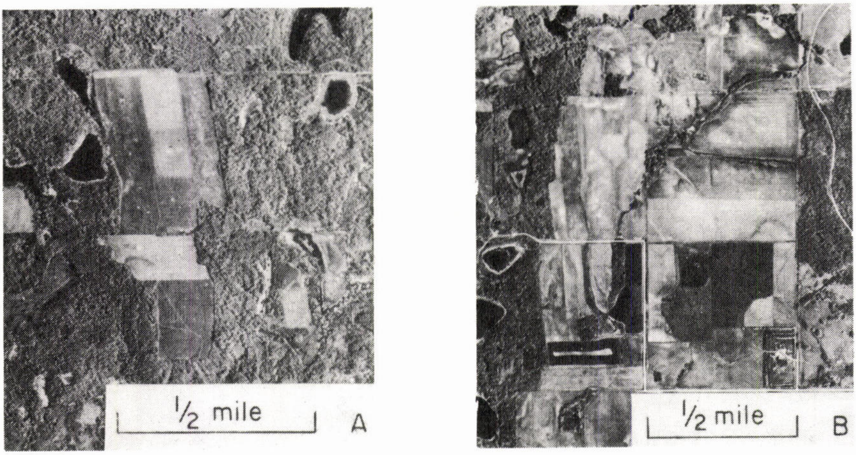


FIGURE 28. Aerial photographs of cleared and cultivated hills formed of ice-walled lake sediment in the Turtle Mountains. (A) Part of photograph BAG-3BB-197, flown May 26, 1962, including the NW¼ sec. 33 and the W½ sec. 28, T. 164 N., R. 73 W. The north edge of the field is the Canadian border. (B) Part of photograph BAG-3BB-195, flown May 26, 1962, including sec. 35, T. 164 N., R. 73 W. Part of the International Peace Garden is shown on the right.

Clayton and Cherry (1967) have distinguished two types of ice-walled lake environments, stable and unstable (Fig. 29). Most of the ice-walled lakes occur in the Turtle Mountains and were stable-environment lakes that developed on top of well-insulated, buried stagnant ice. Most of the water in them was derived from rainfall, not melting of the underlying ice (*see the section* **Interpreted Quaternary History**, *discussion of* **Phase 4**), and as a result they probably contained less sand and more clay than the unstable-environment lakes. They probably contained fairly warm water, abundant aquatic life, were surrounded by forest that was largely spruce, accumulated more sediment than the unstable-environment lakes, and formed between approximately 13,000 and 9,000 years ago.

A few small, unstable-environment lakes, too small to be shown by a color unit (Unit 1 to 15) on Plate 1, occur south of Belcourt and are outlined by Unit 40 (Fig. 30). Larger stable-environment lakes occur in the same vicinity and are outlined by Unit 26. The sediment in the unstable-environment lakes seems to be siltier and sandier than that in the stable-environment lakes in the same vicinity, has sandy "rims," and is generally fairly thin. Water in these lakes was derived mostly from

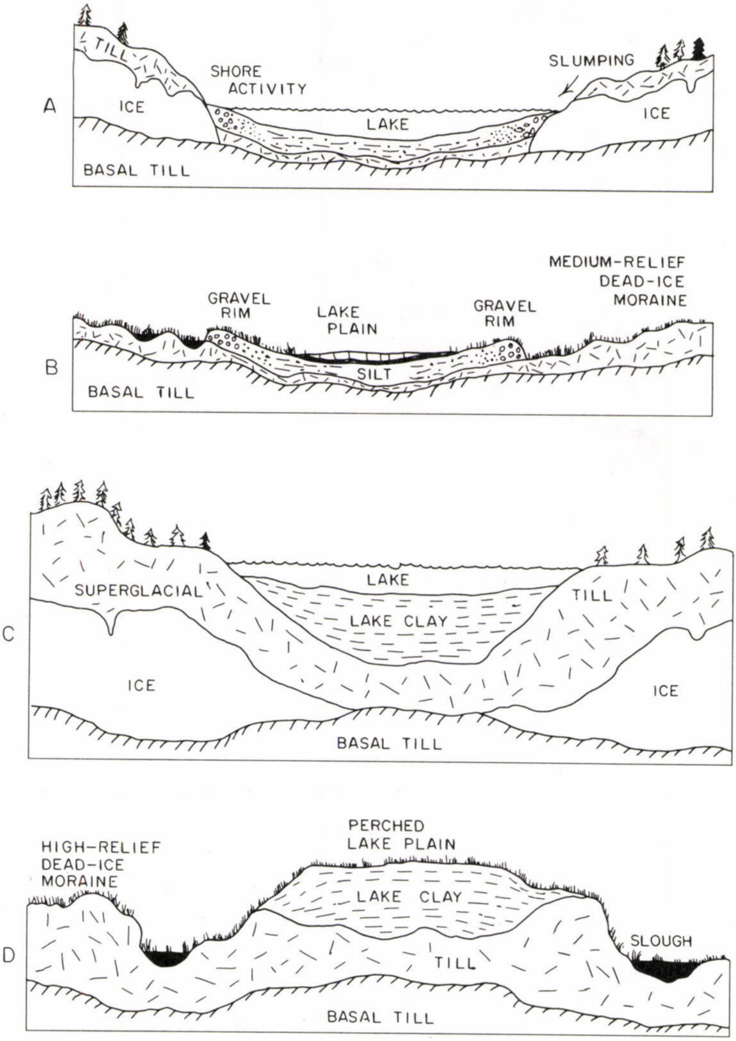


FIGURE 29. Diagrammatic cross-sections showing the formation of ice-walled lakes in unstable (A and B) and stable (C and D) environments (from Clayton and Cherry, 1967).

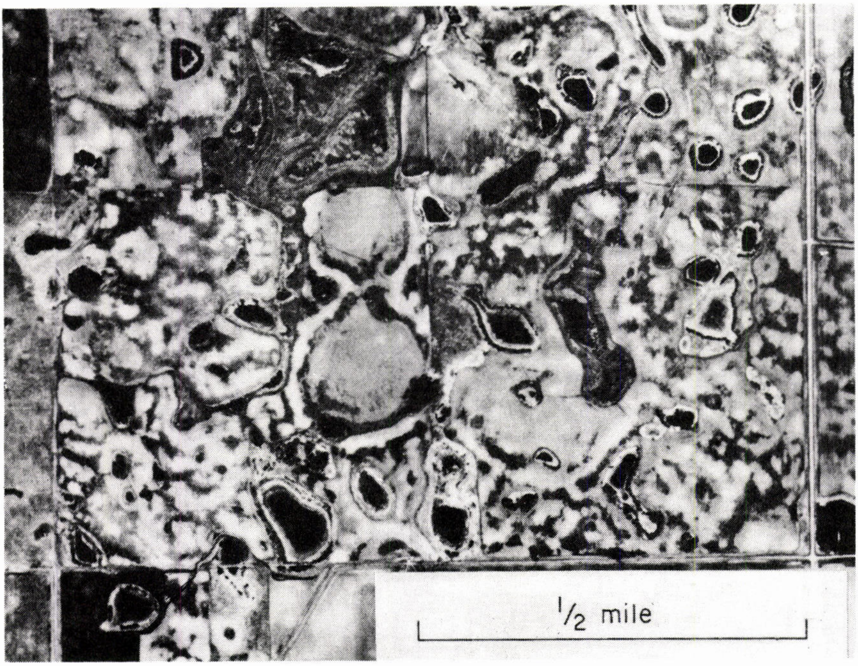


FIGURE 30. Aerial photograph of unstable ice-walled lake sediment. Part of photograph BAG-2BB-43, flown May 25, 1962, including most of sec. 35, T. 162 N., R. 70 W.

melting stagnant ice, was cold, turbid, and relatively free of aquatic life. The unstable-environment lakes formed approximately 13,000 to 12,000 years ago outside the Turtle Mountains.

Lake sediment of Unit I includes deposits variously referred to by others as "ice-restricted lake plains," "ice-walled lake plains," "perched lake plains," "moraine plateaus," "collapsed lake sediment," or "elevated lake plains."

Stream Sediment

Stream sediment includes three major types of deposits: (1) overbank silt, clay, and sand; (2) lower-flow-regime channel deposits; and (3) upper-flow-regime channel deposits. Overbank deposits are sediment laid down by flood waters on stream and river flood plains. This is dominantly flat-bedded silt, sandy silt, and clayey silt, with isolated lenses of clay and silty clay and isolated channels of lower-flow-regime sand. Lower-flow-regime channel deposits are dominantly sand, silty sand, and gravelly sand, with both large- and small-scale, high-angle ripple cross-bedding and both large- and small-scale, high-angle tabular cross-bedding deposited on the downstream avalanche face of bars. It usually includes much flat-bedded sand, silt, and clay. Upper-flow-regime channel deposits are flat-bedded sand and gravel.

Modern stream sediment (Unit J)

Most of the modern stream sediment is overbank silt and sand with some channel deposits. It has been deposited in the last 9,000 years and is distinguished from sediment deposited during the last deglaciation by containing a few percent organic material. Fossils commonly occurring in this sediment include both aquatic and terrestrial mollusk (snail and clam) shells, and rodent and bison bones.

There are three types of streams in Rolette County: perennial, intermittent, and temporary. Perennial streams are gaining streams, receive water from the water table, are in ground-water discharge areas, and flow all year. Temporary streams are losing streams, lose water to the water table, are in ground-water recharge areas, and flow only during and immediately after the spring thaw and heavy rains. Intermittent streams are gaining streams that flow when the water table is high and are losing streams that only flow occasionally (after heavy rains) in the late summer when the water table is low.

Most perennial and intermittent streams are shown on the map **Surface Sediments and Landforms** (Pl. 1), but Unit J is shown only as Unit 8 on the larger map because the occurrences are restricted to narrow bands along streams that are too small to show at the scale of the map **Sediment Origin**. Only the largest temporary streams are shown. Most perennial and intermittent (and some temporary) streams occupy channels, wider than their flood plains, that were cut by runoff between 13,000 and 10,500 years ago when glacial meltwater was available and the climate was effectively more moist (*see the section* **Interpreted Quaternary History**).

Stream sediment deposited during deglaciation

The water flowing in streams during the last deglaciation came from two sources: melting glacial ice and rainfall. Most of the work done by water derived from glacial ice was accomplished in the first few hundred years after stagnation (between approximately 13,000 and 12,000 years ago). After that time the remaining stagnant ice was covered by an insulating blanket of sediment (*see the section* **Interpreted Quaternary History**) and, although much ice still remained, it melted very slowly and contributed water only gradually to the water table. During this time (approximately 12,000 to 10,500 years ago) rainfall was effectively greater than at present and streams, much larger than those presently existing, were common. Water flowing in streams originating mostly from melting glacial ice was cold and very turbid (dirty), and flowed both in channels developed on stagnant glacial ice (Unit O), and in channels on solid ground (Units K and L). Water flowing in streams that formed Units M and N was derived mostly from rainfall.

Stream sediment deposited on solid ground (Units K, L, M, and N). Units K and L are associated with the high, ice-marginal, 1600-foot level of glacial Lake Souris. Both were probably formed by water from melting, stagnant glacial ice. Unit K was deposited in the eastern end of the lake, just west of the Rolette End Moraine. It was probably deposited as a delta but has undergone scouring and erosion after the lake dropped to a lower level. Unit L has a pitted appearance and an upper surface very close to the 1600-foot level. I think it was deposited as a delta around blocks of stagnant ice, which melted to form depressions after the lake level dropped.

Unit M was deposited by streams, derived mostly from rainfall, that flowed into lower levels of glacial Lake Souris. Parts of this unit were deposited around and on top of blocks of stagnant ice which have melted to create a pitted, undulating, or rolling topography. Included in this unit are stream channels that were cut during deglaciation but do not now contain obviously associated sediment. Unit N is similar to Unit M, and is differentiated from it south of the Turtle Mountains where Unit N is distinctly older and stands higher than Unit M. Unit N may have been formed in part by water from melting glacial ice.

These units contain features that have been variously called by others "outwash," "pitted outwash," "collapsed outwash," "proglacial alluvium," "outwash channels," or "meltwater channels."

Stream sediment deposited on stagnant ice (Unit O). Sediment in this unit is dominantly upper-flow-regime sand and gravel deposited in channels cut in stagnant glacial ice. As the stagnant ice melted, flow was reduced in these streams, sediment accumulated and was gradually lowered down to the underlying solid ground (Fig. 4). Gravity faulting displaced the sediment as it settled. Mudflows from the adjacent ice walls often covered the stream sediment with a veneer of till and, if the channel had been flushed of stream sediment before collapse, locally may have filled most of the channel. Most of the sand and gravel is well sorted and bedded, but some is poorly sorted and poorly bedded. These deposits are shown on the map **Surface Sediments and Landforms** as Units 36, 37, 42, and 43.

Fairly continuous, sinuous deposits are commonly called "eskers." Isolated deposits are commonly called "kames."

Glacier and Mudflow Sediment ("Till")

I have commented earlier (*section* **Basic Data**, *subsection* **Surface Sediments**, *topic* **Lithologic Units**) on some problems involved in the use of the word "till," and have pointed out that in this report it is used in a purely lithologic sense when not enclosed by quotation marks but means "glacier-derived sediment not well sorted by wind or water" when enclosed by quotation marks. Till originally referred to an unsorted mixture of sand, silt, clay, and stones (American Geological Institute, 1960, p. 298). This material has also been referred to as "boulder-clay," an unfortunate term in that the sediment has very few boulders and is not mostly clay but, as the hyphen suggests, contains particles that range in size from boulders to clay.

Geologists realized that these deposits were associated with glaciers and the common, genetic, non-lithologic, usage developed. Using "till" to mean "glacier sediment" has never been strictly adhered to in areas of continental glaciation because most of the material was probably deposited by hillslope processes and mudflows, not directly by ice itself. There is obviously sediment near the base of any "till" deposit that was lowered into place without significant rotation or lateral movement as the enclosing stagnant ice melted because striations and lineations remain parallel to the direction the glacier was last moving. Most of the sediment in "till" in North Dakota was sheared into a superglacial position as the ice began to stagnate and quickly formed a blanket of debris over the melting ice. If the blanket was thin, continuing melting caused bare ice walls to develop down which debris fell, rolled, and flowed, depending upon the steepness of the ice wall and the amount of water the sediment contained. Most superglacial debris in North Dakota contained a large quantity of swelling clay (mostly montmorillonite) and therefore had a tendency to flow easily. If the sediment blanket was thick, considerable flowage occurred as underlying stagnant ice slowly melted and changed the direction and steepness of the overlying surface slopes.

Clayton (1967, p. 29-31 and 37-38) has discussed these processes in detail and concluded that the relief on the present landscape (where there is no effect of underlying, buried, pre-last glacial advance topography) is roughly equal to the thickness of the superglacial drift and that most present-day slopes on "till" are closely related to the thickness and plasticity (controlled mostly by mineralogical composition and water content) of the superglacial drift. He has therefore established the following general conclusions (Clayton, oral communication, April 7, 1970): If the present-day local relief is about

5 to 10 feet and average maximum slope angles are between 1 and 4 degrees, the superglacial drift was a few feet to a few tens of feet thick and linear till ridges ("washboard moraines") are common (*see section* **Special Geomorphic Symbols,** *topic* **Linear Till Ridges**). If the local relief is about 20 to 30 feet and average maximum slope angles are between 4 and 7 degrees, the thickness of the superglacial drift was a few tens of feet to several tens of feet and circular till ridges ("doughnuts") are common (*see section* **Special Geomorphic Symbols,** *topic* **Circular Till Ridges**). If local relief is on the order of 100 feet or more and average maximum slope angles are 7 to 20 degrees, then the superglacial drift thickness was several tens of feet to more than 100 feet.

The above analysis is for sediment that is lithologically till, a slightly stony mixture of sand, silt, and clay in approximately equal proportions. Similar relationships hold for superglacial lake and stream deposits in North Dakota, but lake sediment tends to be more plastic, flow more easily, and therefore forms slopes with lower angles. Stream sediment is less plastic and forms steeper slopes.

These relationships seem to hold for Rolette County, with the exception of the area shown as Unit W, where relief is apparently complicated by underlying topography "showing through" the last layer of sediment.

In addition to the fact that very little "till" seems to have been deposited directly by moving ice (and can therefore correctly be called "glacier sediment"), there is "till" present in Rolette County that does not fit the common lithologic definition of till as used in this report. Unit R is obviously "till" but is locally as much as 70 percent sand.

"Till" deposits related to the Souris River Lobe (Units Q, R, and S)

The Souris River Lobe advanced from west to east across the Rolette Meltwater Basin (*see the section* **Interpreted Quaternary History,** *topic* **Phase 3**), picked up a large quantity of sand and silt, and deposited a "till" composed dominantly of stony sand (as in Unit 15). Unit Q is the thin till sheet left in the Rolette Meltwater Basin, Unit R is the Rolette End Moraine, and Unit S are hills streamlined by the ice advance.

Thin "till" (Unit Q). Unit Q is a thin (usually 1½ to 3 feet) blanket of slightly stony sand to slightly stony silt, sand, and clay (Fig. 31; and as in Units 15 and 13). Three striated boulders, all aligned east-west, were found in the base of this "till" in a gravel pit in NE¼SE¼NE¼ sec. 30, T. 159 N., R. 71 W. (Figs. 31 and 32). In many places this unit is intensely stirred by burrowing animals, and is mixed

FIGURE 31. **Photograph of thin (two feet thick) till exposed in a gravel pit south of Rolette. (NE¼ sec. 30, T. 159 N., R. 71 W.)**

with underlying stream sediment and with overlying wind-blown silt and sand. Its presence was usually recognized in the field by scattered boulders (Unit 21) on a topography that otherwise appears to be an "outwash plain" composed of stream and lake sand and silt (as in Unit 6).

When the Souris River Lobe overrode the Rolette Meltwater Basin scattered blocks of unmelted glacial ice remained, buried in the stream sediment deposited in the basin. These buried ice blocks were relatively small, isolated, and must have been surrounded by stream sediment prior to overriding. If they had not been small, isolated, and well contained by relatively incompressible material, the weight of the overriding ice would have caused them to flow plastically and become part of the readvancing ice.

Much of the area overlain by Unit Q has the appearance of a pitted outwash surface (Fig. 32). I think that it formed as shown in Figure 33. The lithology of the unit seems to become progressively more sandy to the east, and more silty and clayey to the west.

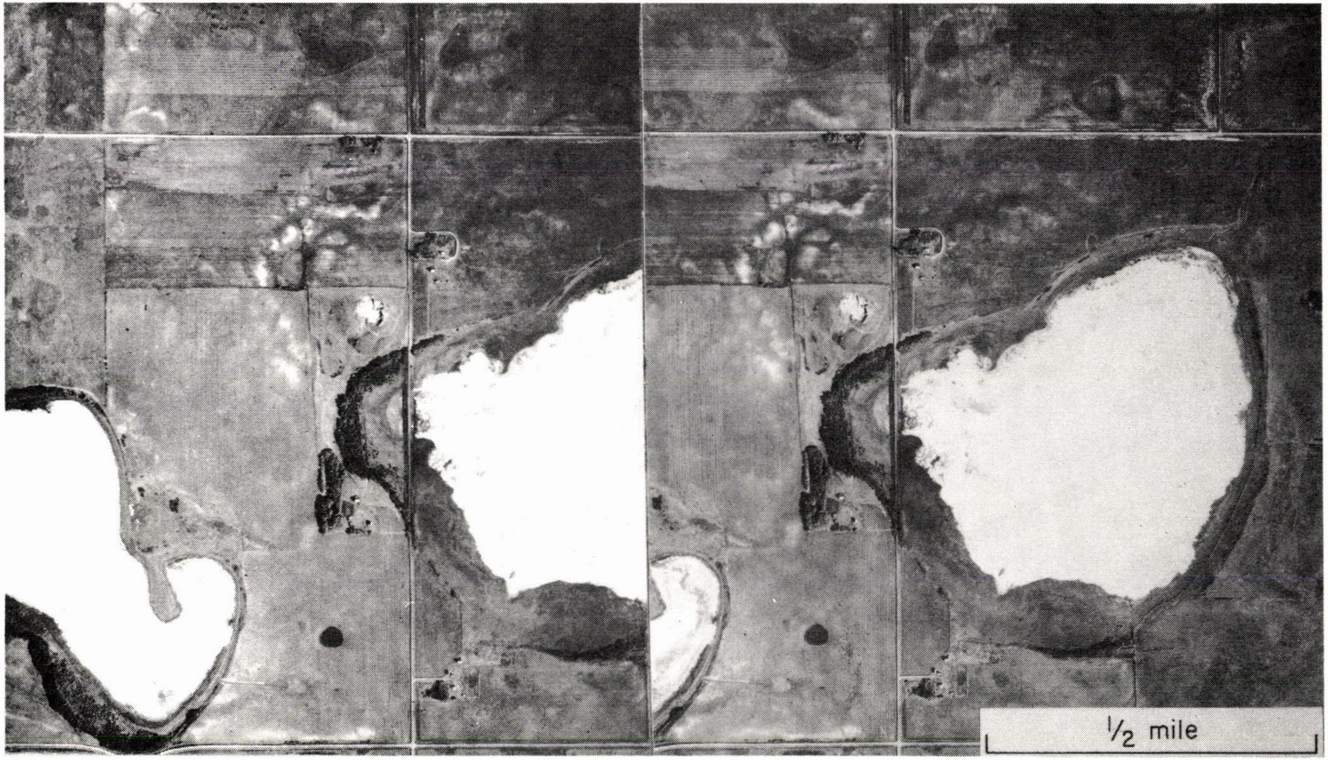


FIGURE 32. Aerial photograph stereoscopic pair of the area around the gravel pit shown in Figure 31, showing part of the area of thin "till" over stream sediment deposited in the Rolette Meltwater Basin. Part of photographs BAG-1BB-14 and 15, flown September 16, 1961.

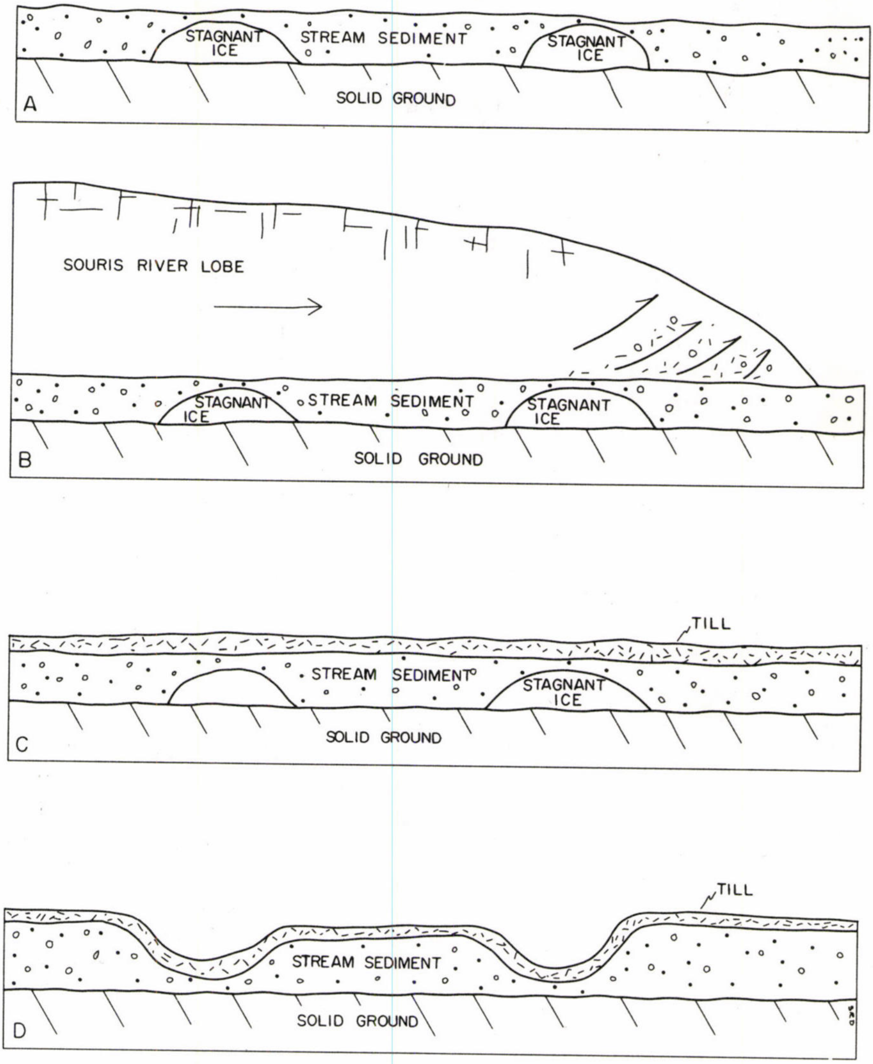


FIGURE 33. Diagram showing the origin of the pitted surface of Unit Q. (A) Stagnant ice buried in stream sediment in the Rolette Meltwater Basin. (B) Overriding by the re-advance of the Souris River Lobe. (C) Melting of the Souris River Lobe. (D) Melting of the buried blocks of stagnant ice.

Rolette End Moraine (Unit R). The Rolette End Moraine is oriented north-south and is a high-relief, hummocky ridge, 20 to 100 feet high, composed of slightly stony to stony, unstratified sand, silty sand, sandy silt, and clayey sandy silt (mostly as in Unit 15). This material was derived from the west as the Souris River Lobe advanced over the Rolette Meltwater Basin because (1) all the lineations in Units Q and S are aligned east-west, and (2) the fairly unusual lithology of these three units becomes progressively more sandy from west to east, as if more and more sand was incorporated in the ice as it crossed the basin. I think this unit is an end moraine because this lithology very abruptly ceases to occur any farther east. "Till" immediately east of this topographic high contains much more clay, commonly contains shale fragments in the stony fraction, and usually does not contain sandstone and lignite in the stony fraction (as in Unit 12).

The Rolette End Moraine (Fig. 34) and the overridden outwash west of it (Unit Q) are cut by numerous, shallow linear trenches. Clayton (1967, p. 33) has observed that linear trenches like these are common in areas where stream sediment was deposited around stagnant glacial ice. He proposed that the trenches originated when stream sediment buried an ice-cored ridge, and calls them "disintegration trenches" (Fig. 35). Sometimes these trenches turn into low ridges as they cross shallow depressions. This has been explained by a similar mechanism by Clayton and Freers (1967, Fig. R-22). During the summer of 1969 many similar features were observed in the unglaciated part of North Dakota and Clayton (1970a and 1970b) now feels that many are trails made by bison migrating up wind.

Many linear depressions in and near the Rolette End Moraine are not oriented parallel to the prevailing wind directions (northwest-southeast) and do not seem to be situated in places where bison would logically make them when avoiding impassable topographic barriers. I think those shown on Figure 34 originated as shear ridges or crevasse fillings that later formed ice-cored ridges which were then buried by stream sediment and overridden by the Souris River Lobe (combine Fig. 35 with Fig. 33). The well-insulated ice cores melted after the Rolette End Moraine was deposited.

Streamlined hills (Unit S). Hills of sand and gravel were overridden, streamlined, and covered with a veneer of till by the re-advance of the Souris River Lobe. They are generally oriented east-west, are conspicuous on aerial photographs, vary from a few hundred yards to several miles in length, and are similar to the "long, linear ridges" described by Lemke (1960, p. 59-66) in McHenry County. Some are distinctly higher at their west end. Two small ones in

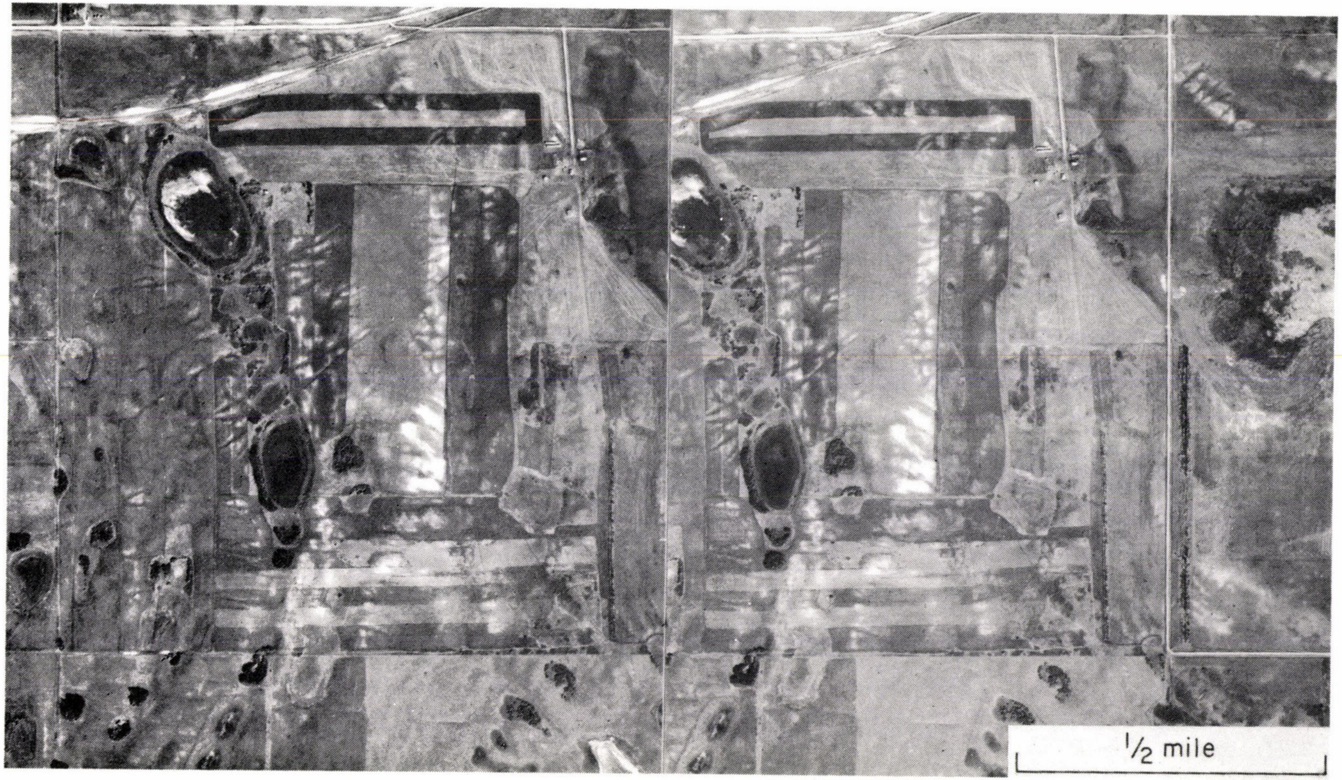


FIGURE 34. Aerial photograph stereoscopic pair of the Rolette End Moraine showing "disintegration trenches." Parts of photographs BAG-1BB-116 and 117, flown September 16, 1961, including sec. 25, T. 160 N., R. 71 W.

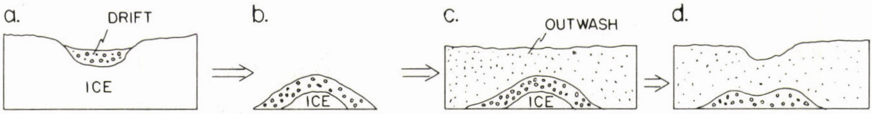


FIGURE 35. Diagram showing the development of disintegration trenches (from Clayton, 1967, Fig. A-3).

the SE¼ of sec. 3, T. 159 N., R. 71 W. have the inverted-spoon shape of a classic drumlin (Shepps and Fairbridge, 1968).

A good exposure of ice-contact stratified sand and gravel in the core of one of these streamlined hills occurs at a quarry 2½ miles south of Rolette (N½SW¼ sec. 4, T. 159 N., R. 71 W.). Stratified gravelly sand is exposed in the core of the double-ridged feature (Fig. 36) in cuts along State Highway 3 about 3½ miles south of the junction with State Highway 66 (NE¼SE¼ sec. 2, T. 159 N., R. 73 W.). Both of these features are covered with a veneer of till. A bison femur (?) was collected from the till over the latter feature, at the driveway to the farm of Leroy Dissette (SE corner NE¼SE¼ sec. 3, T. 159 N., R. 73 W.).

I think the sand and gravel was deposited in eastward-flowing streams during Phase 2 of the last deglaciation (*see the section* **Interpreted Quaternary History**). The unusual double ridge shown in Figure 36 may have initially formed as shown in Figure 37. If the cores of these ridges had not been generally parallel to the direction of the ice advance which later streamlined them, I doubt if they would have formed such long, linear features. It would be difficult to explain the linear ridge 13½ miles long in McHenry County (Lemke, 1960, p. 59) with this reasoning, but there is no necessity for all features with this form to have originated in exactly the same way. It seems obvious that overriding active ice caused the streamlined form.

"Till" deposits in the Turtle Mountains (Units U and V)

The Turtle Mountains are an area of high-relief stagnant-ice moraine with many closed depressions and hilly topography. Most of the sediment was sheared into a superglacial position approximately 15,000 to 13,000 years ago and then redeposited by mudflows during collapse from stagnant ice 13,000 to 9,000 years ago. Most stagnant ice was probably melted by 10,000 years ago.

The sediment is lithologically like that in Unit 12 and is characterized by shale fragments common in the stony fraction.

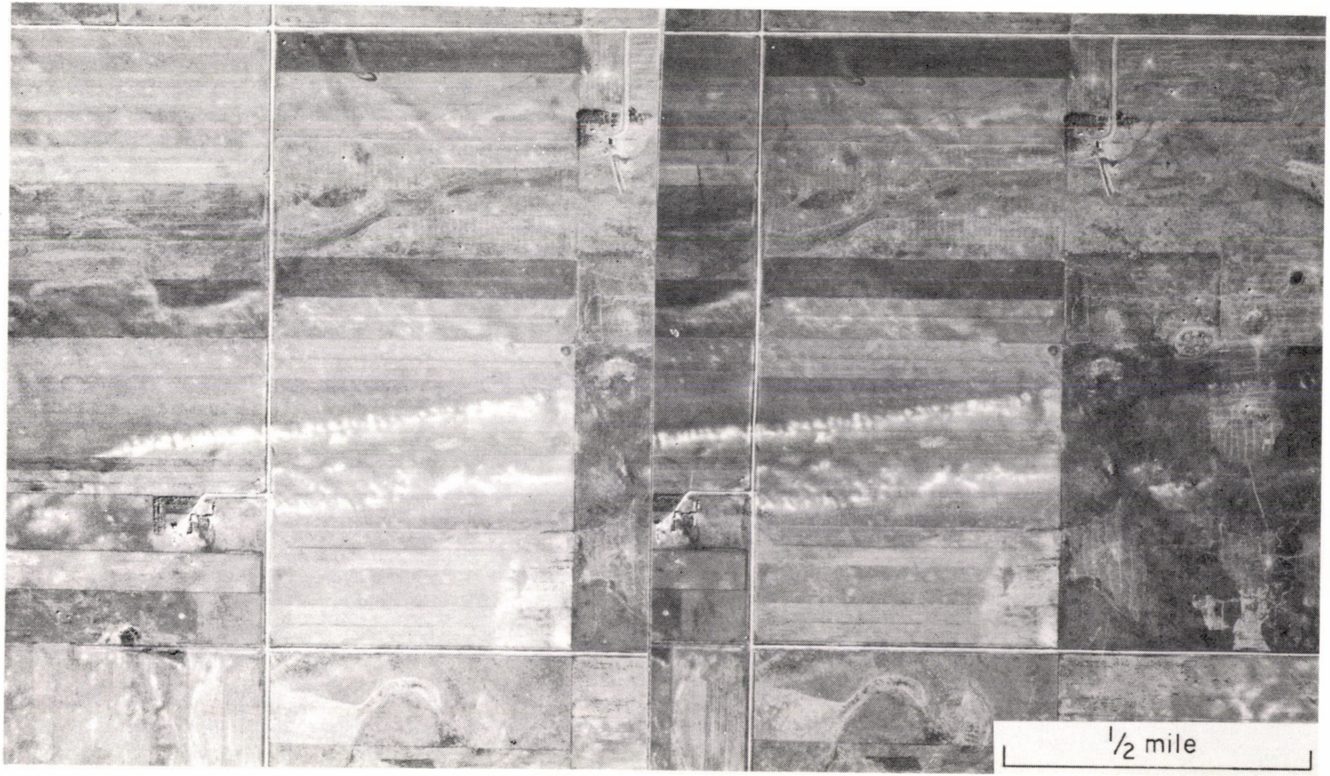


FIGURE 36. Aerial photograph stereoscopic pair showing the double-ridged drumlin south of Fonda. Part of photographs BAG-1BB-75 and 76, flown September 16, 1961, including sec. 2, T. 159 N., R. 73 W.

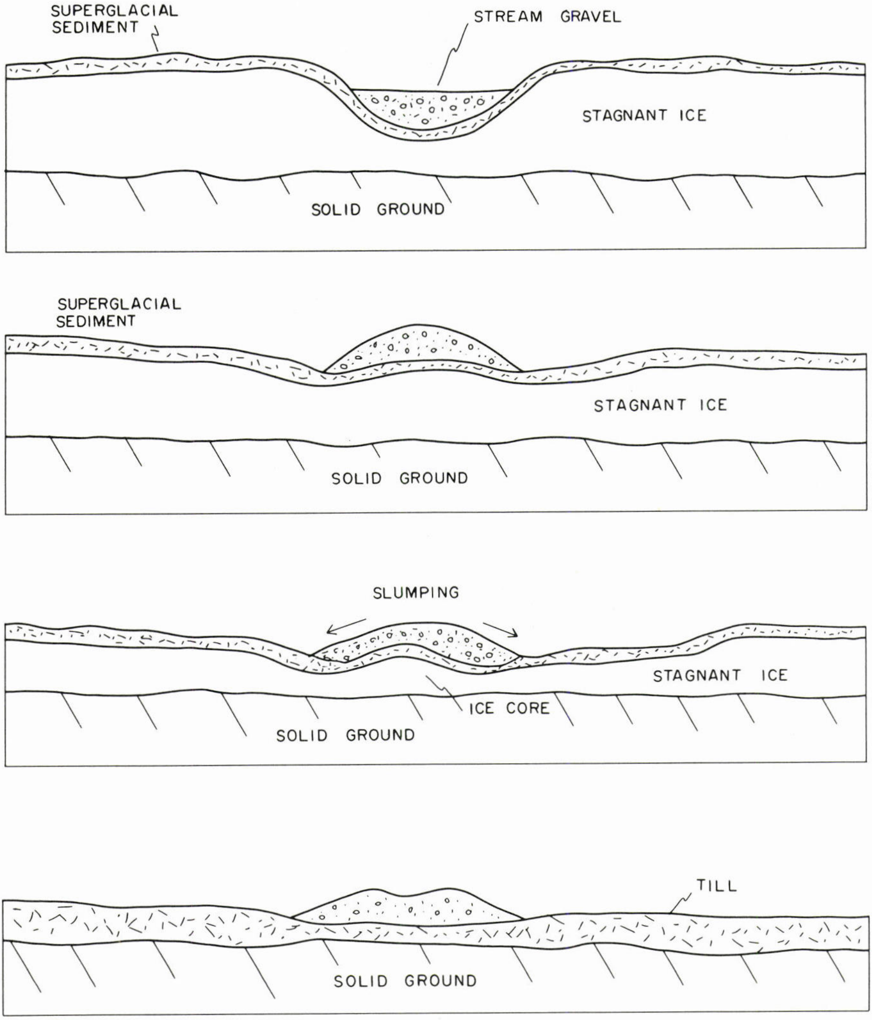


FIGURE 37. Diagram showing a possible origin for the double-ridged feature shown in Figure 36, prior to overriding by the Souris River Lobe.

Sandstone and lignite fragments are rare but become slightly more abundant to locally common on the south side. The area is mapped as Unit U except in the valley of Willow Creek where the topography is lower, has a more compact relief, is thought to be deposited in a valley that existed prior to the last glacial advance (Fig. 15), and is mapped as Unit V.

Limited well data indicate that the drift thickness exceeds 400 feet, but the thickness of any one drift is probably not much greater than 100 feet. The general sequence of events recounted for the last deglaciation has probably occurred a number of times on the Turtle Mountains, and each ice advance deposited a thicker layer of sediment on them than on the surrounding countryside.

"Till" deposits east of the Turtle Mountains (Units T and W)

The lithology of the "till" east of the Turtle Mountains is like that in Unit 12. Shale fragments are common and sandstone and lignite fragments are essentially absent in the stony fraction. The southern part of the area, mapped as Unit T, has low-relief, rolling to undulating topography and contains many circular till ridges (Fig. 11; *see also the section* **Special Geomorphic Symbols**). This is an area of low-relief stagnant-ice moraine that has also been called "ground moraine," "low-relief dead-ice moraine," or "sheet moraine."

The sediment had a past history similar to the sediment deposited in the Turtle Mountains except that compressive flow conditions, necessary to shear debris into a superglacial position, were not common until the glacier began to stagnate. As a result the ice was generally cleaner than that over the Turtle Mountains, superglacial drift thickness was on the order of a few feet to a few tens of feet, and melting of the stagnant ice took place more rapidly. Stagnation probably took place approximately 13,000 to 12,500 years ago and most of the stagnant ice probably melted in a few hundred years. Stagnant ice blocks well insulated by a thick blanket of superglacial sediment may have persisted for several thousand years.

The sediment in the northern area, mapped as Unit W, has a similar lithology and origin but that area has a complex, mixed relief (Fig. 38). Local relief varies from rolling to hilly (*see the section* **Interpreted Quaternary History**, *subsection* **History Before the Last Glacial Advance**). North-south, east-west, northeast-southwest, and northwest-southeast linear trends are apparent on aerial photographs in such complexity that it is difficult to explain them by one glacial advance. That, coupled with the thin mantle of till over the entire landscape, makes me think that many of these features are relics from earlier deglaciations. Some of the features oriented north-south are sinuous, prominent ridges when viewed on the ground, but are not at all

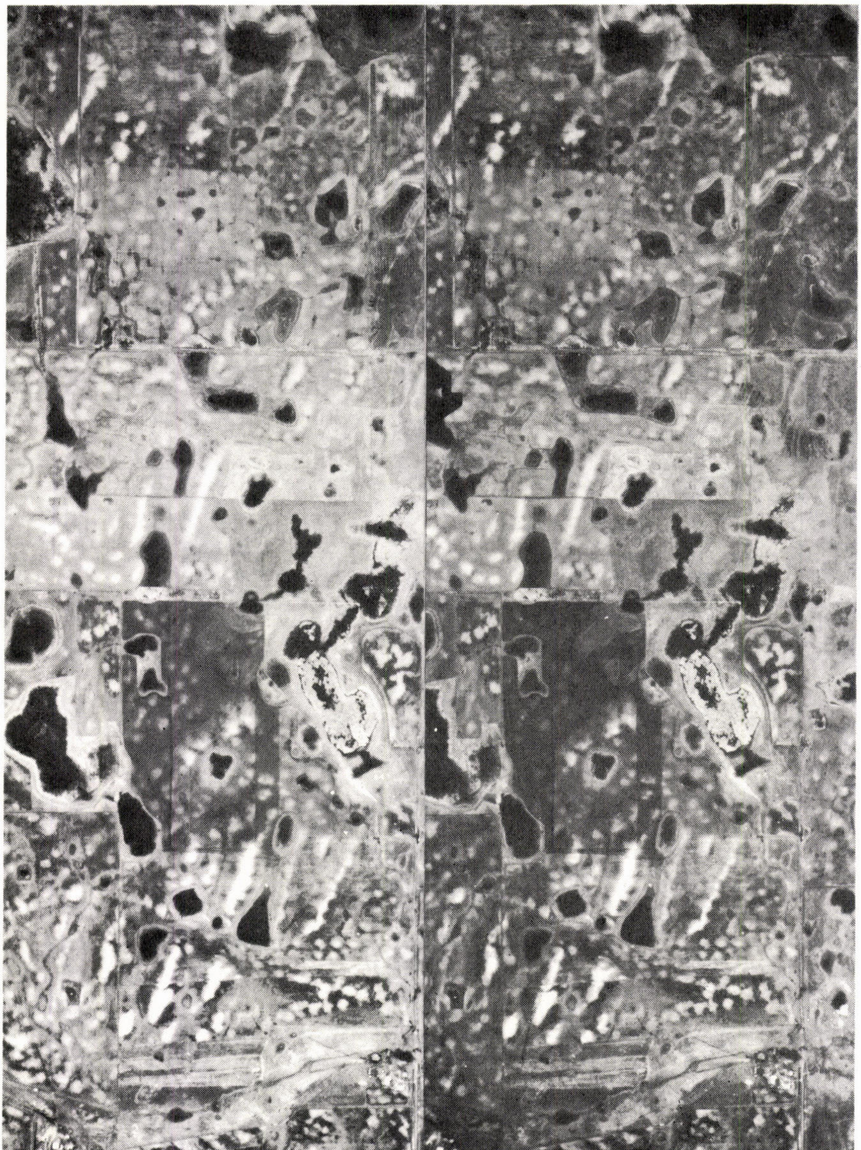


FIGURE 38. Aerial photograph stereoscopic pair showing complex, multi-storied glacial landscape. Topographic features developed prior to the last glacial advance "show through" the till deposited by the last ice advance. Parts of photographs BAG-2BB-118 and 119, flown May 25, 1962, including part of secs. 29 and 32, T. 164 N., R. 69 W. and the Canadian border.

obvious on aerial photographs (Fig. 39) lending support to the idea that they are ice-contact stream deposits ("eskers") that are covered with a blanket of younger superglacial sediment.

Therefore the difference between Units T and W is basically the difference between the topography that underlies the last layer of glacier and mudflow sediment. The area of Unit T is underlain by nearly flat topography, and the area of Unit W is underlain by a topography containing many hills and ridges of ice-contact sand, gravel, and till.

Older "till" deposits south of the Turtle Mountains (Units X, Y, and Z)

"Till" deposits south of the Turtle Mountains that are older than those deposited by the Souris River Lobe are composed dominantly of lithologies like those in Unit 13. The ice that transported this material overrode the Turtle Mountains, and fragments of shale, sandstone, and lignite are all common in the stony fraction. Most of the topography has been modified by either the re-advance of the Souris River Lobe or by stream or wave erosion associated with the later part of the last deglaciation (Lake Souris or Units M and N). These deposits are shown as Unit Y unless they have the special characteristics of Units X or Z.

Thin "till" over sand and gravel hills (Unit X). Several large hills near the Rolette-Pierce county line are veneered with 5 to 25 feet of till. One ridge oriented north-south (Fig. 40) is obviously cored by ice-contact stream sediment that was part of a large north-south-trending esker. Quarry operations expose upper-flow-regime sand and gravel. No good exposures of the till veneer were found, but I suspect that this feature may be covered in part by sediment derived from the Souris River Lobe (as in Unit Q).

The relationship between the till and underlying sand is well exposed in cuts along the south side of the SE¼ sec. 36, T. 159 N., R. 73 W. (Fig. 41). The main bulk of this hill seems to be sand.

A feature characteristic of the topography associated with these exposures is a well-developed but indistinct drainage pattern. I think this drainage pattern developed during an erosion interval prior to the last glacial advance and that the till is draped across this previously established drainage. Equally distinct drainages have not developed on other hills with similar relief and surface sediment in the last 10,000 years, and the drainages on these hills (Figs. 40 and 41) do not appear to be as sharp and distinct on aerial photographs as they should be if they were recent features.

High-relief "till" with large sandstone blocks (Unit Z). Large erratic blocks of bedrock sandstone and sand containing iron

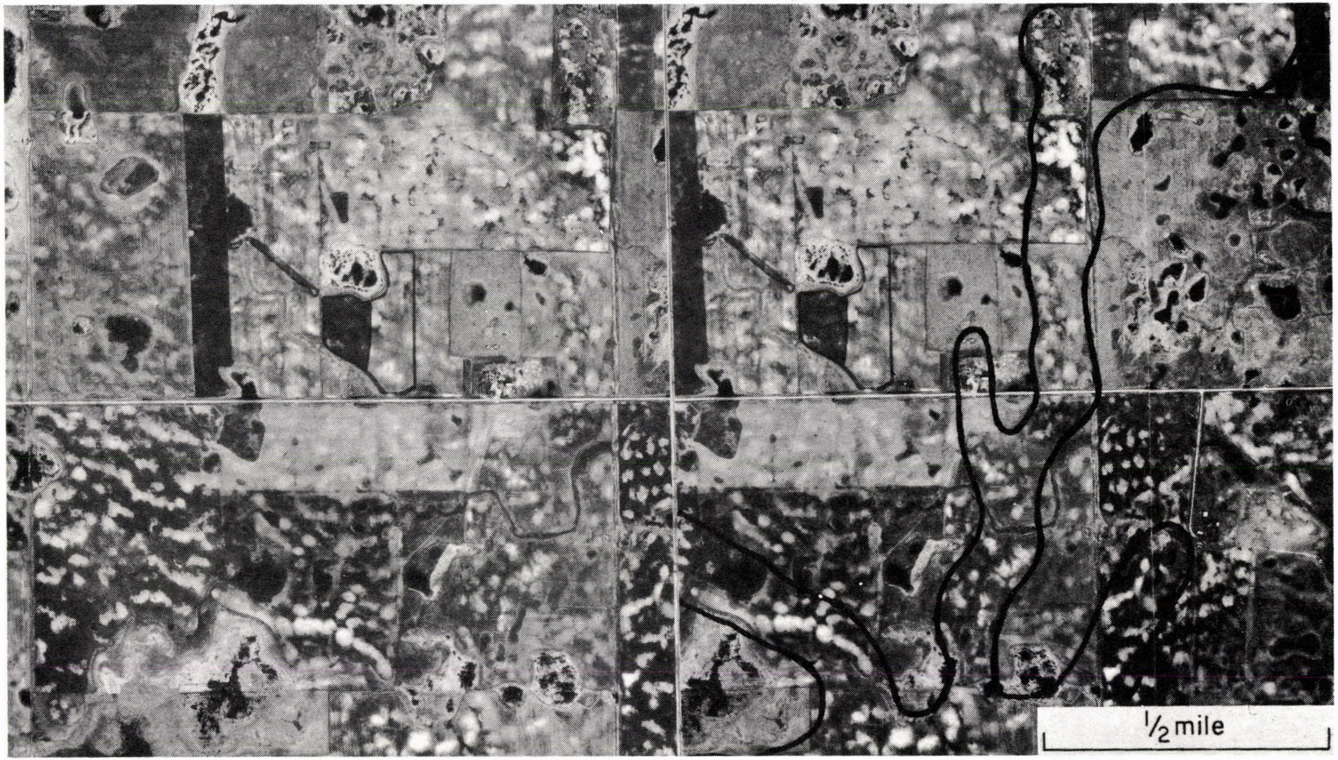


FIGURE 39. Aerial photograph stereoscopic pair of an obscure esker which probably pre-dates the last ice advance. Part of photographs BAG-2BB-71 and 72, flown May 25, 1962, including secs. 15 and 22, T. 162 N., R. 69 W., about 2 miles southeast of Rolla.

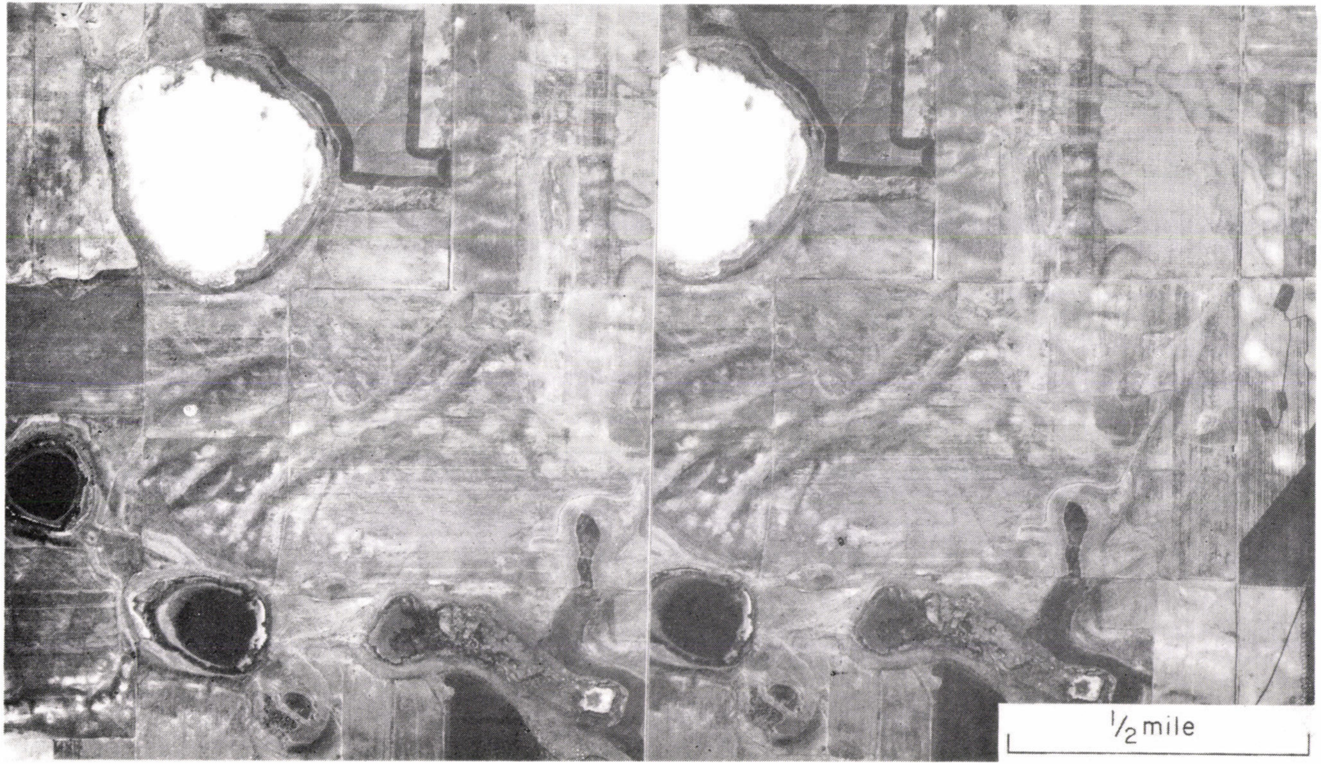


FIGURE 40. Aerial photograph stereoscopic pair of overridden ice-contact stream sediment. Part of photographs BAG-1BB-13 and 14, flown September 16, 1961, including part of sec. 36, T. 159 N., R. 72 W.

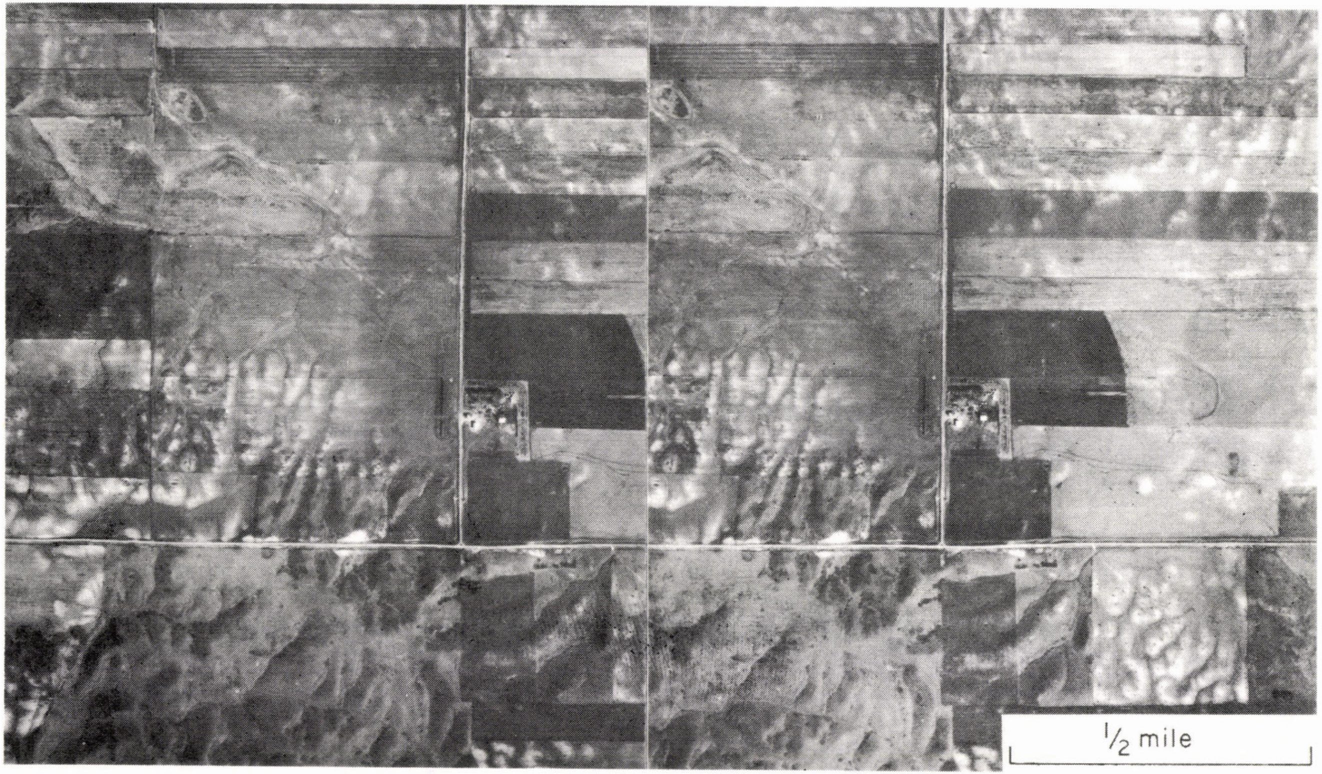


FIGURE 41. Aerial photograph stereoscopic pair of a sand and gravel hill veneered with 5 to 25 feet of till. Part of photographs BAG-1BB-7 and 8, flown September 16, 1961, part of sec. 36, T. 159 N., R. 73 W. is north of the road, which follows the Pierce County line.

concretions occur west and northwest of the town of Rolette. The largest block, at least 30 feet thick, is exposed in the cut along State Highway 66 approximately 4 miles west of Rolette (NW corner of sec. 23, T. 160 N., R. 72 W.). This block was probably derived from the Cretaceous Fox Hills Formation.

Sandstone blocks are also common along the ridge (Fig. 42) in secs. 2, 3, and 4, T. 160 N., R. 72 W.; secs. 31 and 32, T. 161 N., R. 71 W.; and sec. 36, T. 161 N., R. 72 W. This ridge is a rather unusual feature that looks very much like an esker on aerial photographs; is cut by shallow, linear depressions that look like disintegration trenches (*see preceding discussion in this section, topic* **Rolette End Moraine**, *Unit R*); and is dominantly composed of till (20 feet is exposed in the railroad cut in Figure 42, SW¼ sec. 31, T. 161 N., R. 71 W.). The disintegration trenches suggest that this feature might be a moraine deposited on the northern edge of the eastward-moving Souris River Lobe that deposited Unit R. The only additional support for this interpretation is the observation that the streamlined hills (Unit S) occur only immediately south of this feature.

Sand and Gravel of Uncertain Origin (Unit P)

Curved to sinuous ridges (Unit P) in T. 160 and 161 N., R. 70 W. may have formed either as ice-contact stream sediment (as in Unit 0) or as the easternmost part of the Rolette End Moraine (Unit R). Most of these hills are composed of gravelly sand but exposures are inadequate to tell if the deposits are bedded and sorted (as in Unit O) or non-bedded and unsorted (as in Unit R). I favor the hypothesis that these features originated as ice-contact sand and gravel (as in Unit O).

APPLICATIONS

The purpose of this section is to illustrate the types of practical application that can be made from the data provided in the section **Basic Data**. No new data is presented here. The information presented in that section is combined in various ways and the conclusions reached or implied in this section are limited by the accuracy of that data (*see discussion of data accuracy in the section* **Basic Data**). Most of the conclusions are very general because most of the data is of a reconnaissance type. The maps included with this section (Pl. 2) are not intended to be used at any scale larger than that at which they are published, and some of the maps are at best suggestive even at that scale. If your specific interest involves a detailed local problem, this section should help you determine the specific type of local, detailed

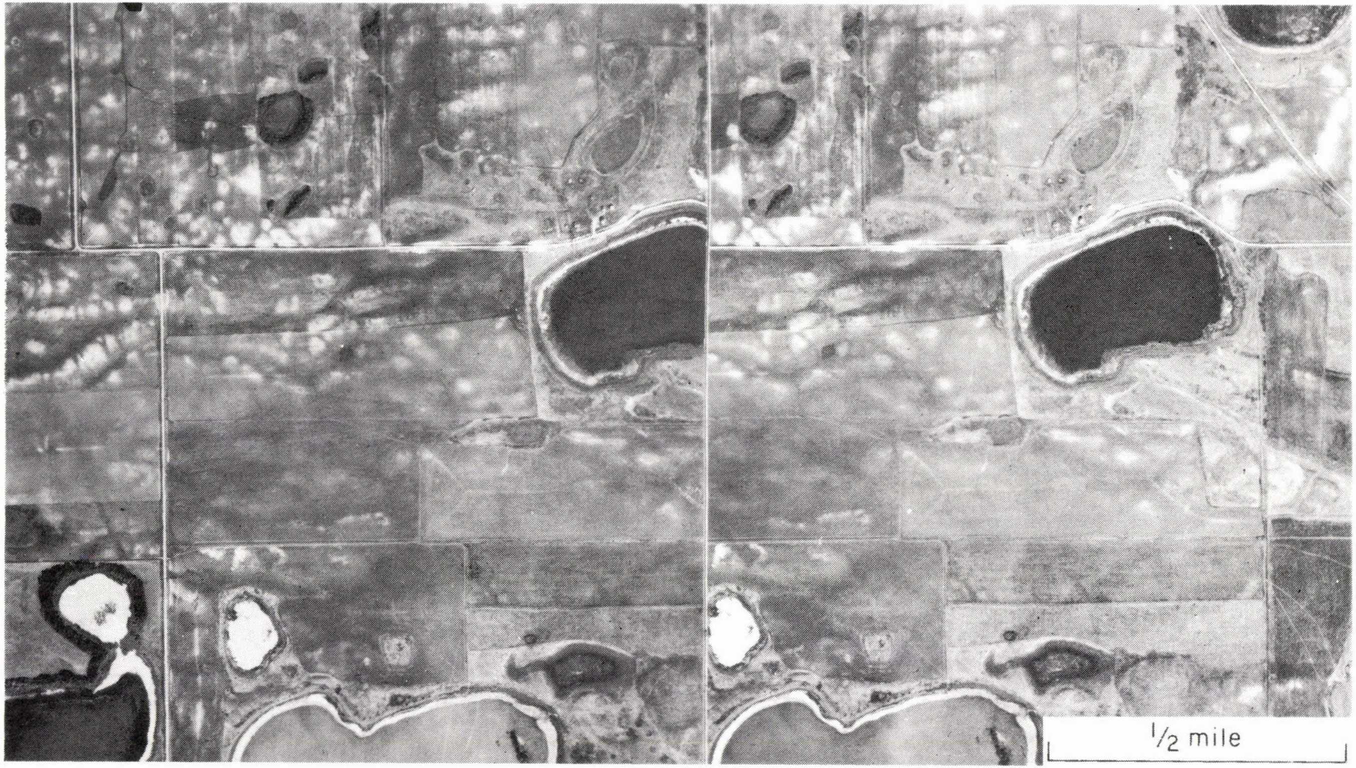


FIGURE 42. Aerial photograph stereoscopic pair of part of Unit Z. Part of photographs BAG-1BB-189 and 190, flown September 16, 1961, the SW corner of sec. 31, T. 161 N., R. 71 W. is about in the center of the photographs.

basic data to request from a soil scientist, geologist, engineer, or well driller to provide a basis for solving your problem.

Water Resources

Water resources of Rolette County can be divided into surface and subsurface resources. Surface resources are limited primarily to stock watering, waterfowl, and recreational use. Subsurface resources are generally adequate in both quantity and quality to provide farm, home, and municipal supplies for human and livestock comsumption, but are not adequate for heavy industrial use.

There has been no extensive, county-wide program of test drilling for ground water in Rolette County. Limited studies have been made for Rolla (Brookhart and Powell, 1961; and Schmidt, 1964), St. John (Brookhart and Powell, 1961; and Froelich, 1967), and Milo (Brookhart and Powell, 1961). These studies have proved invaluable in making the estimates of ground-water quality and quantity contained in this section. An integrated geologic-hydrologic study involving test drilling will be necessary before definite conclusions about the ground-water resources of the county can be drawn. Any such study should first delineate the subsurface stratigraphy of the county by test drilling. All of the holes drilled must be electric logged and sampled so that a geologist can correlate the various stratigraphic units present and delineate the buried land surfaces. These factors strongly control the quantity and quality of ground water. (*See also the recommendations and discussion in the subsection* **Topography Below the Glacial Drift and the Problem of Ice Thrusting.**) Once the detailed stratigraphy is determined by such a program, a geologist and hydrologist can work together to delineate, trace, and evaluate the aquifers that underlie the county.

Until such a detailed drilling and logging program is carried out, it is only possible to make rough estimates of the ground-water resources of Rolette County. The map **Ground-Water Resources** (Pl. 2) was prepared by combining basic data of surface sediments (*map* **Surface Sediments and Landforms** *Pl. 1*), topography developed on the pre-Quaternary sediment beneath the glacial drift (Fig. 2), and the lithology of the pre-Quaternary sediment (Fig. 2). Most of the previous test drilling for ground water in the glacial drift was terminated without providing reliable data on drift thickness. Glacial erratics, tens of feet to several hundred feet thick, of pre-Quaternary sediment can be expected in some parts of Rolette County. Anyone considering a ground-water drilling program should consult the recommendations presented in the preceding discussion in the subsection **Topography Beneath the Glacial Drift and the Problem of Ice Thrusting.** Anyone having a well drilled for domestic or farm water supplies should have a test well drilled to assure adequate quantity and quality before paying for casing or completion.

I have made general estimates of the water quality likely to be found in these aquifers and of the probability of being able to complete a successful well within the areas shown on the map **Ground-Water Resources** by examining the data provided by the North Dakota Geological Survey and Works Progress Administration (about 1938), Brookhart and Powell (1961), Schmidt (1964), and Froelich (1967). These estimates are not highly accurate and are intended only to provide a general guide to the ground-water quality and quantity that can be expected to occur in Rolette County.

Subsurface water occurs in four major settings: (1) surface sand and gravel aquifers, (2) discontinuous shallow aquifers in glacial drift, (3) continuous sand and gravel aquifers in pre-glacial, buried valleys, and (4) fine- to medium-grained sandstone aquifers in pre-Quaternary sediment.

The surface sand and gravel aquifers are the combined Units 9, 10, 11, 14, and 15 from Plate 1. These aquifers are capable of producing hard water in small quantities, generally less than 50 gallons per minute but locally 50 to 100 gallons per minute. Total dissolved salts are usually about 500 parts per million. There is a 95 percent probability that a correctly completed well drilled within this map area will yield water adequate for the average home or farm.

Surface aquifers in the area mapped as sand and silt, undivided (Units 6 and 7) and alluvium (Unit 8) on Plate 1 may be highly variable and are capable of yielding from less than 5 to as much as 100 gallons per minute of hard water having total dissolved salts of about 500 parts per million. These are shown as the same unit on the map **Ground-Water Resources** (Pl. 2) as hills of sand and gravel which may locally produce 50 to 100 gallons per minute of water of similar quality but from greater depths (may be 100 or more feet below the surface).

Discontinuous sand and gravel aquifers, a few inches to many feet thick, may occur throughout the glacial drift. The total drift thickness may be many tens of feet over most of the county and up to several hundred feet over the Turtle Mountains, most of which is till. Where present, these aquifers are capable of producing hard water in quantities generally less than 50 gallons per minute. Total dissolved salts usually range between 300 and 2000 parts per million. In the areas where the surface sediment is till, there is about a 50 percent probability of drilling into a sand or gravel aquifer of this nature. There is 90 percent probability that a correctly completed well in one of these aquifers will yield water adequate for the average farm or home. These comments also apply to the glacial drift that underlies all the other surface sediment in Rolette County.

Areas of drift where shallow, more continuous aquifers are suspected (*see discussion in the section* **Interpreted Quaternary History**, *subsection* **History Before the Last Glacial Advance**) are also indicated on the map **Ground-Water Resources** on Plate 2. This particular map unit is interpretive and is not supported by drilling data.

Continuous sand and gravel units probably exist in pre-glacial valleys buried beneath several hundred feet of glacial drift. Their location is hypothesized from the contour lines on the map of the topography beneath the glacial drift (Fig. 2) and is obviously not accurately located. Since the buried valleys may be mis-located several miles, this information on the map **Ground-Water Resources** (Pl. 2) should be interpreted to mean only that aquifers of this type should exist in the vicinity of the area indicated. Drilling with the expectation of hitting one of these aquifers solely on the basis of information on Plate 2 probably has less than a ten percent chance of being successful. These aquifers are capable of producing hard or soft water in quantities generally ranging between 50 and 500 gallons per minute. Total dissolved salts probably range between 500 and 2000 parts per million.

Fine- to medium-grained sandstone aquifers occur in the bedrock beneath part of Rolette County. This information is derived from Figure 2. There is a 95 percent probability that a correctly completed well drilled in this area on the map **Ground-Water Resources** (Pl. 2) will be successful at a depth less than 600 feet. These aquifers are capable of producing from 10 to 100 gallons per minute of soft water. Total dissolved salts are probably about 2000 parts per million. This highly mineralized water may not be fit for human consumption and is best used for stock and laundering, although brown staining due to high concentrations of colored ions may locally be a problem.

Waste Disposal

The potential for ground-water pollution can be judged from the map **Near-Surface Permeability** (Pl. 2). Permeability is the measure of how easily a fluid will flow through material, so the higher the permeability, the more easily ground water will flow and the greater the probability of contaminating ground water with surface waste. A sewage lagoon is best located in an area of lowest permeability. Septic tanks require leaching fields and will not function properly in areas of very low permeability, but require careful installation and maintenance in areas of high permeability in order to prevent ground-water contamination.

No permeability determinations were made for this report. The map **Near-Surface Permeability** (Pl. 2) was constructed by combining the lithologic units shown on the map **Surface Sediments and Landforms** into units of high, medium, low, and very low permeability according to the general characteristics of sediment as shown by Terzaghi and Peck (1967, p. 55 and 381). There is an 80 percent probability of finding the indicated permeability within the areas shown on that map.

Construction Capabilities

The general types of construction conditions that can be expected in Rolette County are shown on the map **Construction Capabilities** (Pl. 2). There is an 80 percent probability that the conditions indicated will be found within those map areas. Water problems are predicted on the basis of the map **Near-Surface Permeability** (Pl. 2) and topographic location. Engineering properties (foundation conditions, slope stability, frost susceptibility, compressibility, bearing capacity, and so forth) are estimated from general properties of similar sediment as given by Flawn (1970, p. 63-80) and Terzaghi and Peck (1967, p. 29-84).

Sand and Gravel Resources

Sand and gravel is available in various quantity and quality throughout Rolette County, but most contains too much deleterious material (mostly shale, clay, and chert) to be used as high quality concrete aggregate. Some of the till in the southwestern part of the county contains relatively small amounts of shale, and as a result, much of the sand and gravel there contains less shale than the deposits in the rest of the county. Local deposits there may possibly contain material adequate for concrete aggregate. The general types of sand and gravel resources to be expected in the county are shown on the map **Sand and Gravel Resources** (Pl. 2). Sand and gravel prospectors should also critically examine smaller features shown as Units 17, 18, 33, 34, 35, 36, 37, 42, 43, and 44 on the map **Surface Sediments and Landforms** (Pl. 1) and read the discussion in section **Special Geomorphic Symbols**, subsection **Stagnant Glacier Features**, topic **Stream Channel Features.**

Soils

The accuracy of data on Plate 1 may locally be better than that presently available on the general soils map (*see the discussion in the section* **Basic Data**), at least as far as the lithologic data is concerned. **Caution:** Hillslope steepness has been locally adjusted to coincide with lithologic contacts. Users of this report interested in soils can probably refine the information available on the general soils map by using Plate 1 and Bulletin 473 of the Agricultural Experiment Station, North Dakota State University (Patterson, Johnsgard, Sweeney, and Omodt, 1968).

Town Planning

The information presented in this report may be too general to be of much specific use in town planning, but it may still be more helpful than anything else currently available. The three major communities in the northern part of the county, Dunseith, Belcourt, and Rolla, are all located on flat to undulating gravel deposits (Pl. 1). As can be seen from Plate 2, these are areas of good potential water resources, good construction capabilities, high near-surface permeability, and the best sand and gravel resources in the county.

Gravel resources are conveniently located so that if local gravel can be used in construction, hauling costs are kept to a minimum. When communities are small, the noise and dust of gravel operations is usually far enough away from dwellings so as not to be objectionable. Experience has shown (Flawn, 1970, p. 111-114) that as communities grow and residential areas spread out to surround gravel operations, zoning ordinances are passed that drive gravel operators to less economic deposits requiring expensive hauling. By building over and re-zoning the only available sand and gravel deposits many urban areas have caused the price of concrete to go up, construction costs to go up, and the city's bill for municipal projects to be higher. It would be wiser long-range planning to encourage community growth away from, rather than on top of, significant deposits of this type.

Of more immediate concern to communities developed on sand and gravel deposits is the high probability of ground-water pollution due to high near-surface permeability of the sediment. It will be much cheaper to construct adequate sewage lagoons in areas of low, rather than high, permeability. In areas of high permeability, septic tank leaching fields may work so well that a septic tank can cease to function properly, discharge contaminated water to the water table without the owner being aware of the problem, and seriously contaminate local water supplies. Rigorous ordinances regulating septic tank construction and waste disposal would seem to be in order in this situation.

Encouraging construction on river flood plains also would seem to be an error in town planning. Flood plains exist because the river periodically rises and inundates them. This does not necessarily happen every year, but extreme flooding can be expected to occur at intervals. (A good discussion of this problem is available in the North Dakota Geological Survey **Miscellaneous Series 35**, by Harrison, 1968.) Owners and renters of buildings constructed on flood plains can therefore expect that they will be inundated sometime, as there is a 100 percent probability that it will happen. This can commonly be observed at Minot, North Dakota. Wise community planning would prohibit most building construction on flood plains (Units 8 and J on Pl. 1) and restrict their use to recreation, agriculture, parking, storage, or to other open uses.

Farm and Ranch Planning

This report may be able to assist farm and ranch planning by providing additional information on soils, ground-water availability, construction capabilities, and potential pollution problems. This information is provided separately in the preceding subsections.

A major problem of farming in North Dakota is clearing rocks from fields, and I was often asked why some fields were rock-free. These were usually areas of lake plains (Units C, D, E, F, G, H, and I on Pl. 1). Forested hills containing ice-walled lake sediment (Unit I) are common in the Turtle Mountains, and these make relatively rock-free fields when cleared of trees. Rocks are common around the margins of these ice-walled lakes, due to near-shore mudflow sediment, but the centers are normally rock-free. Most of those areas not in school sections have already been cleared and cultivated, but some have not. This is especially true in the Canadian part of the Turtle Mountains, where there are many that are uncultivated.

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Howard (Superintendent, International Peace Garden), the Bureau of Indian Affairs, local officials, and the many residents of Rolette County is greatly appreciated. The town of Rolette provided free camping facilities and showers during much of the field work. At the time of publication the author's address is Department of Geology, Sul Ross State University, Alpine, Texas 79830.

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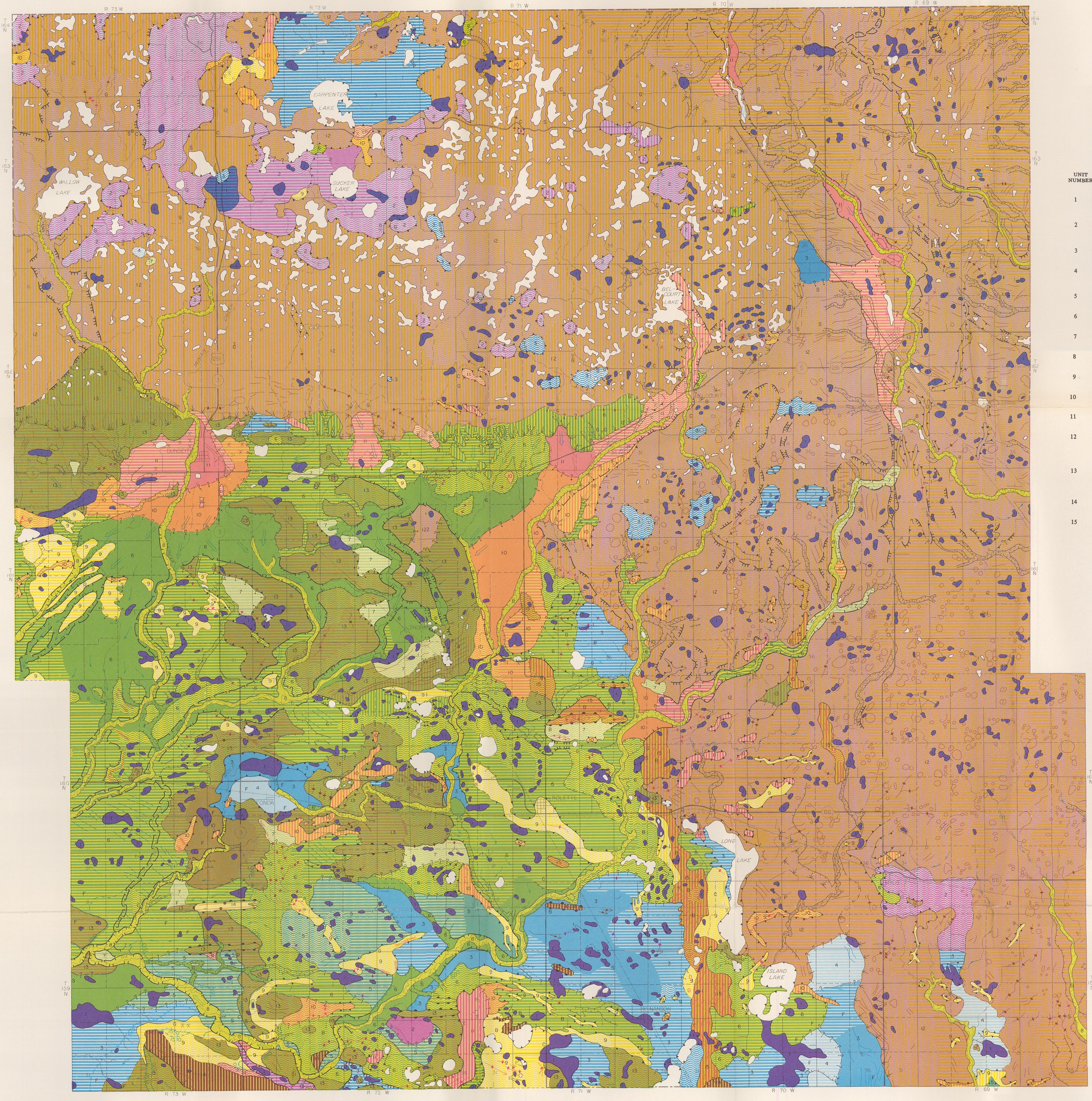


Cartography by S. R. Deal.

GEOLOGIC MAPS OF ROLETTE COUNTY

Dwight E. Deal

1971

SURFACE SEDIMENTS AND LANDFORMS
(A LITHOLOGIC AND GEOMORPHIC MAP)

(Consult the text for a more complete discussion. Color units indicate the lithology of the material beneath the surface soil to a depth of about 5 feet, and can include up to 15 percent other materials. All units may locally have a veneer (a few inches to a few feet) of wind-blown silt and sand that is within the soil profile. For an expanded discussion of origin see the explanation of the map of Sediment Origin. The word till *where not enclosed in quotation marks is used in a purely lithologic, non-genetic, sense.)*

UNIT NUMBER	TOPOGRAPHY				LITHOLOGY	KEY TO THE MAP OF SEDIMENT ORIGIN UNIT
	FLAT <1°	UNDULATING 1°-4°	ROLLING 4°-7°	HILLY >7°		
1	▨	▨			**ORGANIC CLAY:** Temporary pond sediment.	A
2	▨	▨	▨	▨	**CLAY:** Dominantly offshore lake sediment; locally may include some nearshore and shoreline silt, sand, gravel, and mudflow sediment.	C, D, E, G, H, I
3	▨	▨	▨		**SILT AND CLAY:** Sediment as in Units 2 and 5, undivided.	C, F, G, H, I
4	▨	▨	▨		**THIN CLAY AND SILT OVER TILL:** Sediment as in Unit 3 with till (Unit 12) commonly within 5 feet of the surface.	C
5	▨	▨	▨		**SILT:** Dominantly offshore lake sediment; locally may contain some clay or fine sand.	D, G
6	▨	▨	▨	▨	**SAND AND SILT:** Of diverse origin, sediment as in Units 5 and 9, undivided.	D, E, F, G, I, K, L, M, N, O, Q
7		▨	▨		**THIN SAND AND SILT OVER TILL:** Sediment as in Unit 6 with till (as in Unit 12 or 13) commonly within 5 feet of the surface.	E, G, M, N
8	▨				**ORGANIC SILT WITH SOME CLAY, SAND, AND GRAVEL:** Overbank and channel deposits along modern streams.	J
9		▨	▨	▨	**SAND:** Of diverse origin; dominantly stream sediment.	E, F, I, M, N, O, Q
10	▨	▨	▨	▨	**GRAVEL AND SAND:** Sediment as in Units 9 and 11, undivided.	I, M, O, Q
11	▨	▨	▨	▨	**GRAVEL:** Stream sediment.	M, N, O, X
12	▨	▨	▨	▨	**SHALE-RICH TILL:** Slightly stony mixture of clay, silt, and sand in approximately equal proportions (silt is usually dominant); stony fraction contains many lithologies but characteristically contains shale and lacks sandstone and lignite.	P, T, U, V, W
13	▨	▨	▨	▨	**SHALE- AND SANDSTONE-RICH TILL:** Lithologically similar to sediment in Unit 12, but locally may have more sand and less clay; stony fraction characteristically contains sandstone, lignite, and shale.	P, S, V, X, Y, Z
14				▨	**THIN TILL OVER SAND:** 5 to 25 feet of sediment as in Unit 13 over sand and gravelly sand.	S, X
15		▨	▨	▨	**STONY SAND:** Of diverse origin, dominantly glacier sediment; see text for additional discussion.	P, Q, R, S

SPOT OUTCROPS

16	C	**CLAY** (as in Unit 2 or 3): isolated occurrence.
17	S	**SAND** (as in Unit 6 or 9): isolated occurrence.
18	G	**GRAVEL** (as in Unit 10 or 11): isolated occurrence.
19	T	**TILL** (as in Unit 12 or 13): isolated occurrence.
20	P	**PEAT:** isolated occurrence.
21	B	**BOULDERS:** scattered on surface, underlain by sand or silt; see description of Unit Q on the map of Sediment Origin.

LITHOLOGIC CONTACTS

22		<± 0.1 mile reliability
23		<± 0.2 mile reliability
24	? ? ?	Not accurately located in the field; some drawn only on the basis of features observed on topographic maps or aerial photographs; some are gradational (as between Units 6 and 10).

GEOMORPHIC SYMBOLS

SLOPE SYMBOLS: May be combined for slopes that are believed to have a complex origin.

25		**SCARP:** Hatchures point downhill; used for slope tops of unspecified origin and for minor channels; includes both modern channels and some cut more than 10,000 years ago; reliability the same as Units 22, 23, and 24.
26		**SLOPE TOP, ICE-CONTACT FACE:** Arrow heads point down slope and toward the previous location of stagnant glacial ice; reliability the same as Units 22, 23, and 24.
27		**SLOPE TOP, BURIED ICE-CONTACT FACE:** Stagnant glacial ice was buried by sediment; otherwise like Unit 26.
28		**SLOPE TOP, MAJOR DRAINAGE CHANNEL CUT MORE THAN 10,000 YEARS AGO:** Hatchures point downhill.
29		**SLOPE TOP, EXISTING PRIOR TO THE LAST GLACIAL ADVANCE:** Hatchures point downhill.
30	1600	**SLOPE TOP, SHORELINE OF GLACIAL LAKE SOURIS:** Hatchures point down hill; approximate elevation shown in feet; reliability the same as Units 22 and 23.
31		**BOTTOM OF SLOPE:** Arrows point down hill; reliability the same as Units 22 and 23.
32	F	**FRECKLED** appearance on aerial photographs; see discussion in text; may be caused by locally intense activity of burrowing animals.

FEATURES COMPOSED, OR WITH A SURFACE COVERING, OF TILL (as in Units 12, 13, or 15)

33 34 35	13	**STREAMLINED HILL:** Unit 13, 14, or 15 is shown if the hill is large enough to map at this scale; if the hill is too narrow, a line symbol is used; brown indicates surface lithology as in Unit 12 or 13, red indicates surface lithology as in Unit 15; elongate parallel to and arrow pointing in the direction of inferred ice movement.
36 37	12	**ESKER:** Unit 12 or 13 is shown if the hill is large enough to map at this scale; if the esker is too narrow the line symbol is used; a sinuous, sometimes branching, ridge assumed to follow the trace of a former stream developed on or within stagnant glacial ice; normally prominent on aerial photographs.
38 39		**LINEAR TILL RIDGES:** Brown indicates surface lithology as in Unit 12 or 13; red indicates surface lithology as in Unit 15; most either disintegration ridges or washboard moraines; may include some features that are actually eskers; low ridges a few feet high; normally prominent on aerial photographs; may be difficult to see on the ground; normally elongate at right angles to glacier movement.
40 41		**"CIRCULAR" DISINTEGRATION RIDGES:** Surface lithology as in Unit 12 or 13; also called "doughnuts"; low ridges a few feet high; normally prominent on aerial photographs; may be difficult to see on the ground; dashed if covered with a veneer of lake sediment (as in Unit 2).

FEATURES COMPOSED OF SAND OR GRAVEL (as in Units 6, 9, 10, or 11)

42 43	10	**ESKER:** The same as Units 36 and 37 except that they are known to contain stream sediment; see the description of Unit O on the map Sediment Origin; may have a veneer of till.
44	ooooooo	**POSSIBLE SHORELINE DEPOSITS:** May be beach or bar deposits; see discussion of Unit B on the map Sediment Origin.
45	D	**STABILIZED EOLIAN DUNES:** Vegetation-anchored wind-blown sand.

MISCELLANEOUS FEATURES

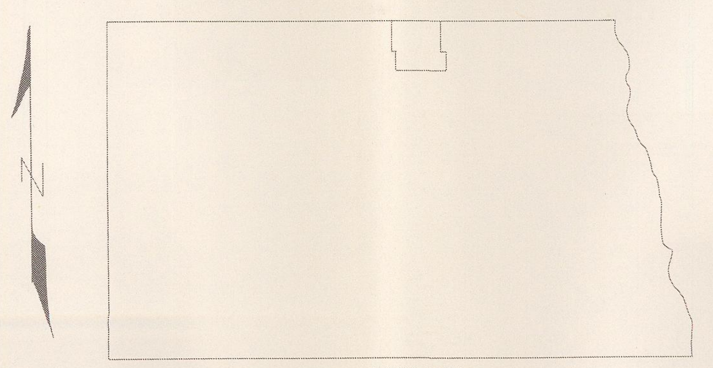
46		**LAKES OR PONDS NORMALLY CONTAINING WATER:** May include some areas that would be shown as Unit 1 in dry years; sediment described in the discussion of Unit A on the map Sediment Origin.
47		**LINEATIONS:** On flat or undulating surfaces that were once beneath the surface of glacial Lake Souris; may be drag marks formed by wind-blown ice floating on the lake, wind-scour (deflation) features, or subglacial lineations caused by the advance of the Souris River lobe.
48		**VERY LOW RIDGES:** On flat or undulating surface of lake sediment; obvious on aerial photographs; very difficult to see on the ground; probably are Units 37, 38, 39 or 43 buried beneath a thin layer of lake sediment (as in Unit 2 or 3).
49		**MAJOR SCOUR MARKS:** Formed by streams during the last deglaciation; see discussion of Unit M on the map Sediment Origin.
50		**MINOR SCOUR MARKS:** Otherwise like Unit 49.

Numbered U. S., State, or County roads

Other graded and drained roads

Dry-weather roads, farm roads, and jeep trails

Gravel pit



INDEX MAP

SEDIMENT ORIGIN
(An interpretive, genetic map)

Consult the text for a more complete discussion. All units may locally have a veneer (a few inches to a few feet thick) of wind-blown silt and sand, most of which was deposited between 4,500 and 8,000 years ago.

LAKE SEDIMENT

DEPOSITED ON		DESCRIPTION AND ORIGIN	KEY TO THE MAP OF SURFACE SEDIMENTS AND LANDFORMS	
SOLID GROUND	GLACIAL ICE		LITHOLOGY	RELIEF
A		**SLOUGH AND POND SEDIMENT:** (*This unit occurs in many areas that are too small to show at this scale and is shown on the map Surface Sediments and Landforms as Units 1 and 46.*): a) Slough (temporary pond) sediment, usually in ground-water recharge areas, partially oxidized, and consisting of material derived from adjacent hillslopes; b) pond sediment, usually a few feet thick, unoxidized, and containing both lacustrine fossils (such as fish, microcrustaceans, and mollusks) and fossils washed in from adjacent forest (such as spruce wood and needles); locally contains peat in the Turtle Mountains. Ponds began to form when glacial ice stagnated (about 13,000 years ago), but stable basins may not have existed until all debris-covered stagnant ice melted (10,000 years ago in the Turtle Mountains, but perhaps as early as 12,500 years ago elsewhere); during this time the climate was cooler and moister than at present; most ponds turned into sloughs (except in the Turtle Mountains) about 10,500 years ago; sediment deposited between 8,500 and 4,500 years ago is coarser and contains less organic material because the climate was drier and hillslopes less stable; thousands of small depressions are not shown on either map.	1, 46	F
B		**SHORELINE DEPOSITS:** Sand bodies in the southwestern part of the map area that may have been reworked or deposited by waves near the edge of glacial Lake Souris between 13,000 and 12,000 years ago. More work might show that some are stream or wind deposits that happen to occur at elevations that nearly coincide with levels of glacial Lake Souris.	44	U, R
C		**LAKE SEDIMENT NOT DEPOSITED ON OR IN CONTACT WITH STAGNANT GLACIAL ICE:** Largely offshore silt and clay but may contain pond sediment similar to that in Unit A as well as nearshore sand and silt; deposited between 13,000 and 12,000 years ago.	2, 3, 4	F, U
D		**SEDIMENT OF ICE-MARGINAL LAKE SOURIS BELOW 1510 FEET IN ELEVATION:** Mostly offshore silt and clay. This unit is restricted to the southwestern part of the map area; associated shoreline features were not formed on stagnant glacial ice; younger than Units E, F, G, K, and L; deposited between 13,000 and 12,000 years ago.	2, 5, 6	F, U
E		**SEDIMENT OF ICE-MARGINAL LAKE SOURIS BETWEEN 1510 AND 1550 FEET IN ELEVATION:** Mostly offshore silt and clay but includes some wave-eroded till. This unit is restricted to the southwestern part of the map area; few (less than 10 percent) shoreline features were formed on stagnant glacial ice; older than Unit D; younger than Units F, G, K, and L; deposited between 13,000 and 12,000 years ago.	2, 6, 7, 9, 13	F, U
F		**SEDIMENT OF ICE-MARGINAL LAKE SOURIS BETWEEN 1550 AND 1570 FEET IN ELEVATION:** Mostly nearshore silt and sand but includes some wave-eroded till. Some (between 10 and 50 percent) shoreline features were formed on stagnant glacial ice; older than Units D and E; younger than Units G, K, and L; deposited between 13,000 and 12,000 years ago.	3, 6, 9, 13	F, U, R
G		**SEDIMENT OF ICE-MARGINAL LAKE SOURIS BETWEEN 1570 and 1600 FEET IN ELEVATION:** Dominantly offshore silt and clay; Units K and L are associated delta and stream sediment. This unit is restricted to the south-central part of the map area; many (50 to 90 percent) of the shoreline features were developed on stagnant glacial ice and are now collapsed; the western margin of the lake was ice-walled and may have been within the southwestern corner of Rolette County; older than Units D, E, and F; deposited between 13,000 and 12,500 years ago.	2, 3, 5, 6, 7	F, U, R
H		**ICE-MARGINAL LAKE SEDIMENT NOT ASSOCIATED WITH LAKE SOURIS:** Dominantly offshore silt and clay but may contain pond sediment similar to that in Unit A as well as nearshore silt and sand. Shorelines were partially on stagnant ice; deposited after stable basins formed by the melting of stagnant glacial ice, 11,000 to 10,000 years ago in the Turtle Mountains, 12,500 to 10,000 years ago elsewhere; also has been called "partially ice-walled lake plains", "ice-marginal proglacial lake sediment", or "perched lake plains".	2, 3	F, U
	I	**LAKE SEDIMENT DEPOSITED ON AND SURROUNDED BY STAGNANT GLACIAL ICE:** Mostly offshore silt and clay becoming siltier and sandier at margins; includes some nearshore sand, gravel, and mudflow sediment derived from enclosing glacial ice. Most of this unit is located in the northern part of the map area; as surrounding ice walls melted, the margins slumped; as underlying glacial ice melted, folding and flow of sediment occurred; if the sediment blanket was thin in relation to the thickness of underlying stagnant ice, hillslope steepness is related to sediment thickness as in collapsed glacial sediment (Units T and U), but slopes are slightly less steep; topography is undulating where there was relatively little stagnant ice beneath the lake sediment and is rolling to hilly where there was considerable variation in the thickness of underlying stagnant ice; formed 13,000 to 10,000 years ago; also called "perched lake plains", "moraine plateaus", "ice-walled lake sediment", or "collapsed lake sediment", depending upon the amount and thickness of stagnant ice that was buried beneath the lake sediment.	2, 3, 6, 9, 10	F, U, R, H

STREAM SEDIMENT

DEPOSITED ON		DESCRIPTION AND ORIGIN	KEY TO THE MAP OF SURFACE SEDIMENTS AND LANDFORMS	
SOLID GROUND	GLACIAL ICE		LITHOLOGY	RELIEF
J		**MODERN STREAM SEDIMENT:** (*This unit occurs along streams in strips that are too narrow to be shown at this scale and is shown on the map Surface Sediments and Landforms as Unit 8*): Dominantly silt and lower-flow-regime channel sand of floodplains; locally contains clay and upper-flow-regime flat-bedded gravel lenses and channels. Commonly contains aquatic and terrestrial mollusk shells and mammal (especially rodent and bison) bones; deposited in the last 10,000 years; commonly called "alluvium".	8	F
K		**SCOURED STREAM SEDIMENT ASSOCIATED WITH THE 1600 FOOT LEVEL OF ICE-MARGINAL LAKE SOURIS:** Dominantly silt and lower-flow-regime channel sand deposited in a deltaic environment; locally includes offshore silt and clay, and rarely, gravelly sand lenses; covered with a thin blanket (up to a few feet thick) of stream sediment (identical to Unit M) that was deposited as the lake level dropped. This unit is restricted to the south-central part of the map area; delta sediment was deposited contemporaneously with Units G and L (the veneer is slightly younger); deposited between 13,000 and 12,500 years ago; commonly called "outwash".	6	F, U
L		**PITTED STREAM SEDIMENT ASSOCIATED WITH THE 1600 FOOT LEVEL OF ICE-MARGINAL LAKE SOURIS:** Dominantly silt and lower-flow-regime channel sand. This unit is restricted to the south-central part of the map area; deposited around numerous blocks of stagnant glacial ice either in a delta or slightly above lake level; the ice blocks melted to form depressions; deposited contemporaneously with Unit G between 13,000 and 12,500 years ago; commonly called "pitted outwash".	6	U, R
M		**STREAM SEDIMENT DEPOSITED DURING THE LAST DEGLACIATION:** Composed of complexly intermixed channels, tongues, lenses, and sheets of gravel, sand, and silt: a) upper-flow-regime channel sediment (largely flat-bedded sandy gravel); b) lower-flow-regime channel sediment (largely high-angle cross-bedded sand); c) overbank silt. This map unit includes some channels that do not contain stream sediment; locally deposited around or upon stagnant ice blocks; some areas have a pitted surface similar to Unit L; 10 to 30 percent occupies channels developed prior to the last deglaciation; water in the streams that formed this unit came mostly from rainfall (the climate was cooler and moister than it is now) and in part from melting glacial ice; deposited 13,000 to 10,500 years ago; also called "outwash", "pitted outwash", "collapsed outwash", "proglacial alluvium", "outwash channels", "proglacial channels", or "meltwater channels".	6, 7, 9, 10, 11 and some areas outlined by Units 25 and 28	F, U, R

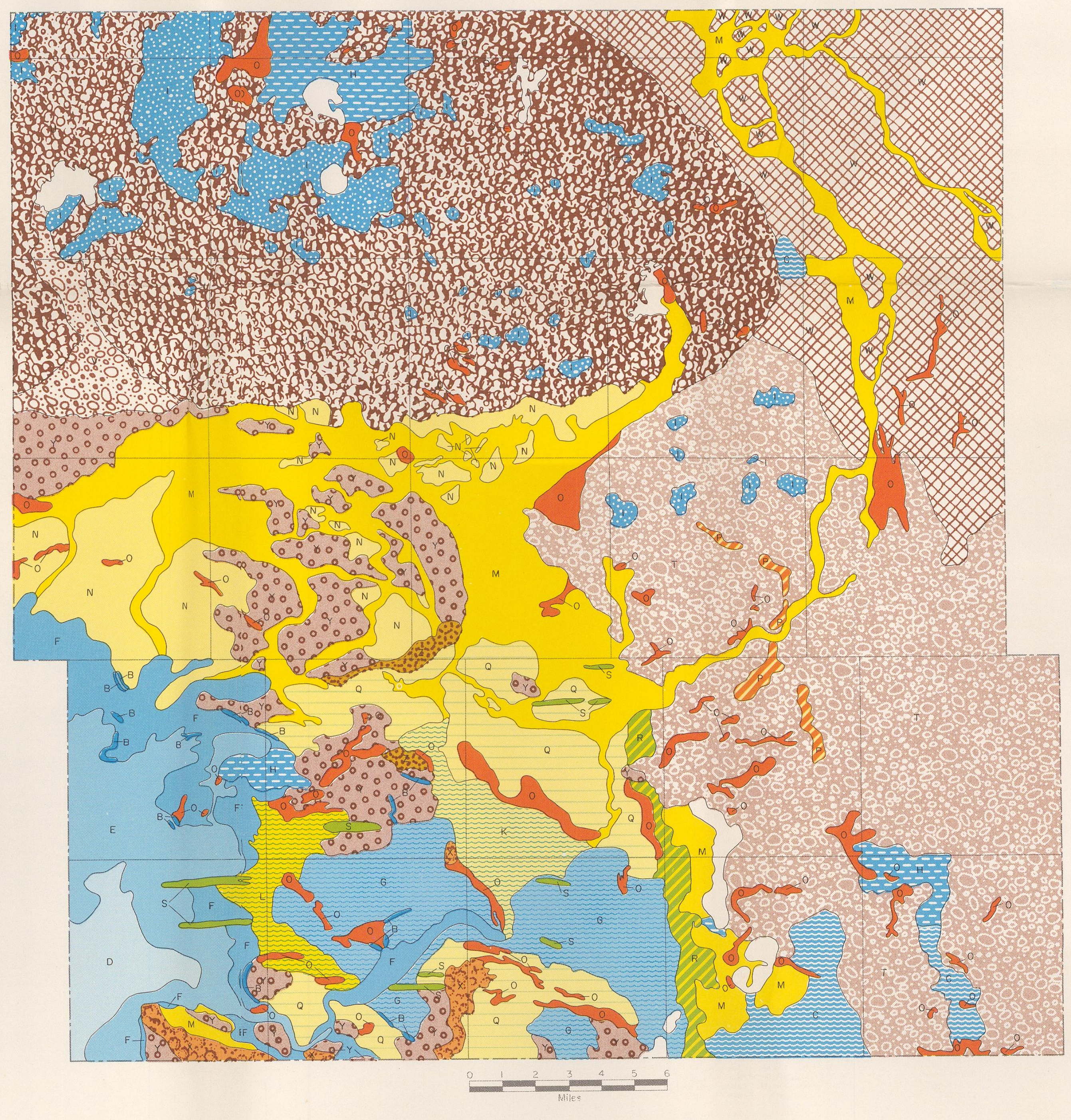
STREAM SEDIMENT

DEPOSITED ON		DESCRIPTION AND ORIGIN	KEY TO THE MAP OF SURFACE SEDIMENTS AND LANDFORMS	
SOLID GROUND	GLACIAL ICE		LITHOLOGY	RELIEF
N		**STREAM SEDIMENT DEPOSITED EARLY IN THE LAST DEGLACIATION:** Identical to Unit M, but differentiated from it south of the Turtle Mountains where this unit stands slightly higher and may have steeper slopes than Unit M; locally crossed by many small channels; formed 13,000 to 12,000 years ago; commonly called "outwash".	6, 7, 9, 11	F, U, R, H
	O	**STREAM SEDIMENT DEPOSITED ON GLACIAL ICE:** Largely upper-flow-regime channel sediment (flat-bedded gravel and sandy gravel) with locally significant deposits of lower-flow-regime channel sediment (mostly high-angle cross-bedded sand); locally includes deposits composed of or veneered with mudflow sediment ("till"). As underlying glacial ice melted, the stream sediment underwent considerable gravity faulting; the thickness of superglacial sediment is related to hillslope steepness as in collapsed glacial sediment (Units T and U), but slopes are considerably steeper; deposited 13,000 to 12,000 years ago; commonly called "collapsed outwash", "kame complex", "kame", or "esker".	6, 9, 10, 11	R, H
	P	**ICE CONTACT SAND AND GRAVEL OF UNCERTAIN ORIGIN:** These deposits belong in either Unit O or R, see text for discussion.	12, 13, 15	R, H

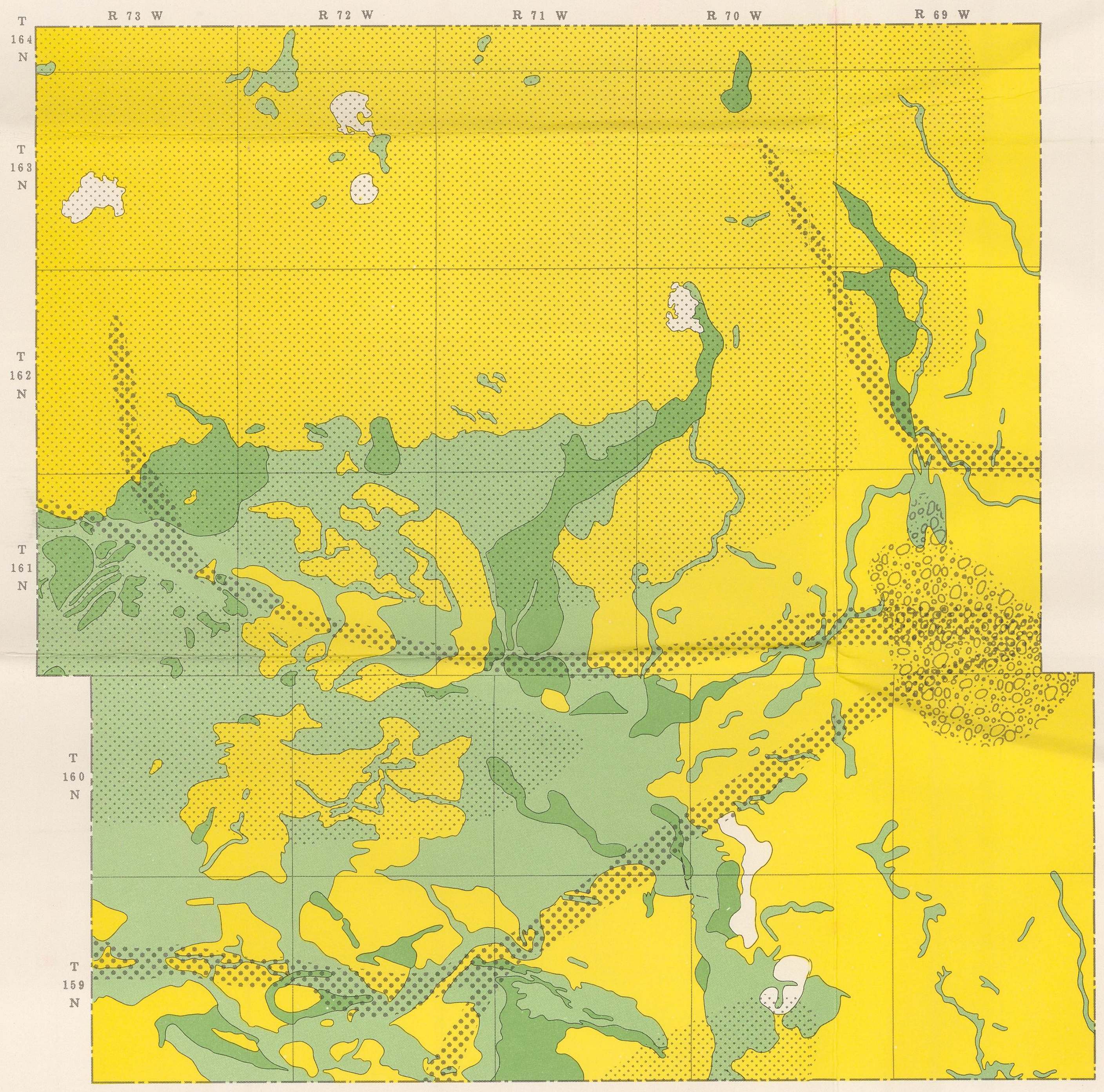
GLACIER AND MUDFLOW SEDIMENT ("TILL")

Glacially transported sediment; the major part of which was sheared into a superglacial position by active ice and then deposited by mudflows as the underlying ice melted; includes a small amount of sediment that was carried at or near the bottom of the glacier and which underwent little or no lateral movement as the enclosing stagnant ice melted. The word "till" is put between quotation marks when this origin is implied.

DEPOSITED ON		DESCRIPTION AND ORIGIN	KEY TO THE MAP OF SURFACE SEDIMENTS AND LANDFORMS	
SOLID GROUND	GLACIAL ICE		LITHOLOGY	RELIEF
Q		**LOW RELIEF "TILL" RELATED TO THE SOURIS RIVER LOBE:** A thin (1 1/2 to 3 feet) blanket of slightly stony, clayey, silt and sand over older stream sediment with lithologies similar to that in Unit M; shale fragments rare in the stony fraction. Striated boulders in base aligned east-west; often expressed as scattered boulders on sand and silt; upper part deposited on stagnant glacial ice and collapsed as underlying ice melted; commonly intensely stirred and mixed by burrowing animals; occurs only west of Unit R in the southern part of the map area; deposited about 13,000 years ago; commonly called "till", "ground moraine", "subglacial moraine", or "low-relief dead-ice moraine".	6, 9, 10, 15	U, R, H
	R	**HIGH RELIEF "TILL" RELATED TO THE SOURIS RIVER LOBE:** Forms a north-south-trending ridge, 20 to 100 feet high, of slightly stony, clayey, silt and sand (locally more than 70 percent sand), marking the approximate eastward limit of the Souris River lobe; shale fragments very rare in the stony fraction. This unit was deposited within and on top of stagnant ice about 13,000 years ago; redeposited by mudflows as the underlying stagnant ice melted 13,000 to 12,000 years ago; commonly called "end moraine", or "high-relief dead-ice moraine".	15	R, H
S		**"TILL" OVER STREAMLINED HILLS, RELATED TO THE SOURIS RIVER LOBE:** Sediment similar to that in Unit Q; over ice-eroded pre-existing hills of gravel, sand, and till. This unit occurs in the southern part of the map area west of Unit R; ice erosion probably took place about 13,000 years ago; commonly called "drumlins", "drumlinoid hills", "long, linear drumlins", "overridden kames", or "fluting".	13, 14, 15	U, R, H
	T	**LOW RELIEF, SHALE-RICH "TILL" EAST OF THE TURTLE MOUNTAINS:** Slightly stony, clayey, silt and sand; shale fragments common, sandstone and lignite fragments rare in the stony fraction. Most of the unit is a relatively thin sheet over pre-existing low-relief topography in the eastern part of the map area; thickness of superglacial sediment was a few feet where topography is flat, a few feet to a few tens of feet where topography is undulating, a few tens of feet to several tens of feet where topography is rolling, and more than several tens of feet where topography is hilly; most hilly topography occurs where this unit blankets older (pre-last ice advance) escarpments; circular disintegration ridges ("doughnuts") are commonly seen on aerial photographs; surface sediment is Late Wisconsinan in age, originally sheared by active ice into superglacial position about 15,000 to 13,000 years ago, then redeposited by mudflows during collapse from stagnant ice, 13,000 to 10,000 years ago; undulating topography has been called "ground moraine" or "low-relief dead-ice moraine"; rolling and hilly topography has been called "ground moraine", "dead-ice moraine", or "end moraine".	12	U, R, H
	U	**HIGH RELIEF, SHALE-RICH "TILL" IN THE TURTLE MOUNTAINS:** Lithology similar to that in Unit T. This unit occurs in the northern part of the map area; hillslope steepness related to thickness of superglacial material as in Unit T, with thickness locally greater than 100 feet where the topography is hilly; total "till" thickness locally exceeds 400 feet but consists of several sheets, each unusually thick because of shearing within active ice caused by the underlying topographic high; lower "tills" are Pleistocene in age; surficial materials are the same age as Unit T; commonly called "high-relief dead-ice moraine".	12	R, H
	V	**MODERATE RELIEF "TILL" IN THE TURTLE MOUNTAINS:** The same as Unit U except that relief is lower and more compact, and sandstone and lignite fragments become more abundant in the southern part; in a topographic low formed before the last glaciation.	12, 13	R, H
	W	**COMPLEX RELIEF, SHALE-RICH "TILL" EAST OF THE TURTLE MOUNTAINS:** The same as Unit T except that underlying topography, developed on older glacier-derived materials, is not flat; older Pleistocene topographic features "show through" the uppermost blanket of sediment; occurs in the northwestern part of the map area.	12	U, R, H
X		**SHALE- AND SANDSTONE-RICH "TILL" OVER SAND AND GRAVEL HILLS:** A thin (5 to 25 feet) blanket draped over hills formed of stream sand and gravel; slightly stony, clayey, silt and sand with shale, sandstone, and lignite fragments all fairly common in the stony fraction; sandstone is usually more abundant than shale. This unit masks, but does not completely obscure, gullies developed on sand and gravel prior to the last glacial advance; underlying deposits are Pleistocene in age; surface sediment was deposited between 15,000 and 11,000 years ago; has been called "kames", "overridden hills", "end moraine", or "sheet moraine".	11, 13, 14	R, H
	Y	**LOW TO MODERATE RELIEF, SHALE- AND SANDSTONE-RICH "TILL":** Lithology as in Unit X and of complex origin. The last sediment blanket is probably thin (a few feet to a few tens of feet) and may have been modified by both wave and stream erosion; surface units may locally differ in age; deposited between 15,000 and 11,000 years ago.	13	F, U, R
	Z	**HIGH RELIEF, SHALE- AND SANDSTONE-RICH "TILL" CONTAINING LARGE SANDSTONE BLOCKS:** Lithology similar to sediment in Unit X but contains abundant, very large (several feet to tens of feet) sandstone blocks. This unit generally has high relief; occurs in the south-central part of the map area. The uppermost part may have been deposited as a moraine between the eastward moving Souris River lobe and stagnant ice between the Souris River lobe and the Turtle Mountains. If so, it would have the same age as Units Q and R. The lower part is a complex of pre-Souris River lobe sediments and is as old as or older than Units U or X.	13	H



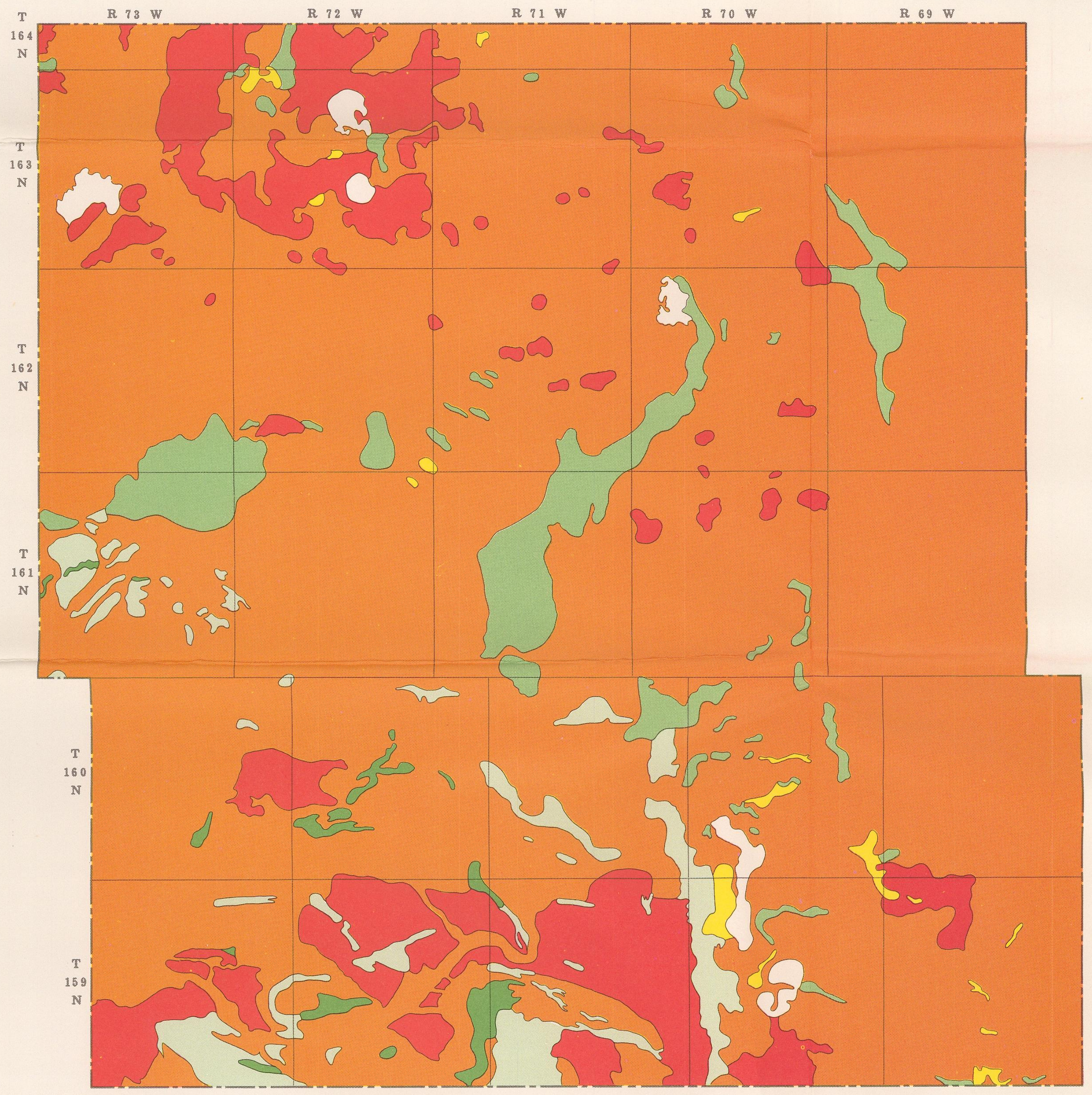
GROUND-WATER RESOURCES



Key to Units on Other Maps	Unit	Type of Aquifer	Production Capability (gal./min.)	Hardness	Approx. Total Dissolved Salts (ppm)	Probability of Drilling into the Indicated Aquifer	Probability of Producing Adequate Water†
Plate 1: 9,10,11,14,15	🟩	Fairly continuous surface sand and gravel.	Generally less than 50, locally 50 to 100	Hard	500	Very high	Very high
Plate 1: 6,7,8	🟩	Surface sand and silt, may be highly variable. Includes sand and gravel hills where the water table may be several to many tens of feet below the surface.	Less than 5 to 100	Hard	500	Variable	Good
Figure 17	▨	Suspected area of shallow, extensive subsurface sand and gravel.	50 to 100	Hard	500	Unknown Possibly very high	
Plate 1:	🟨	Discontinuous subsurface sand and gravel as much as 400 feet beneath the surface; also underlies all areas shown as Units 1, 2, and 3.	Less than 500	Hard	300 to 2,000	Fair	High
Figure 2	▨	Fine to medium grained sandstone as much as 600 feet beneath the surface. Water highly mineralized and most suitable for stock.	10 to 100	Soft	2,000	Very good	High
Figure 2	▨	Continuous sand and gravel in buried valleys as much as 400 feet beneath the surface.	50 to 500	Hard	300 to 500	Very low	Very high

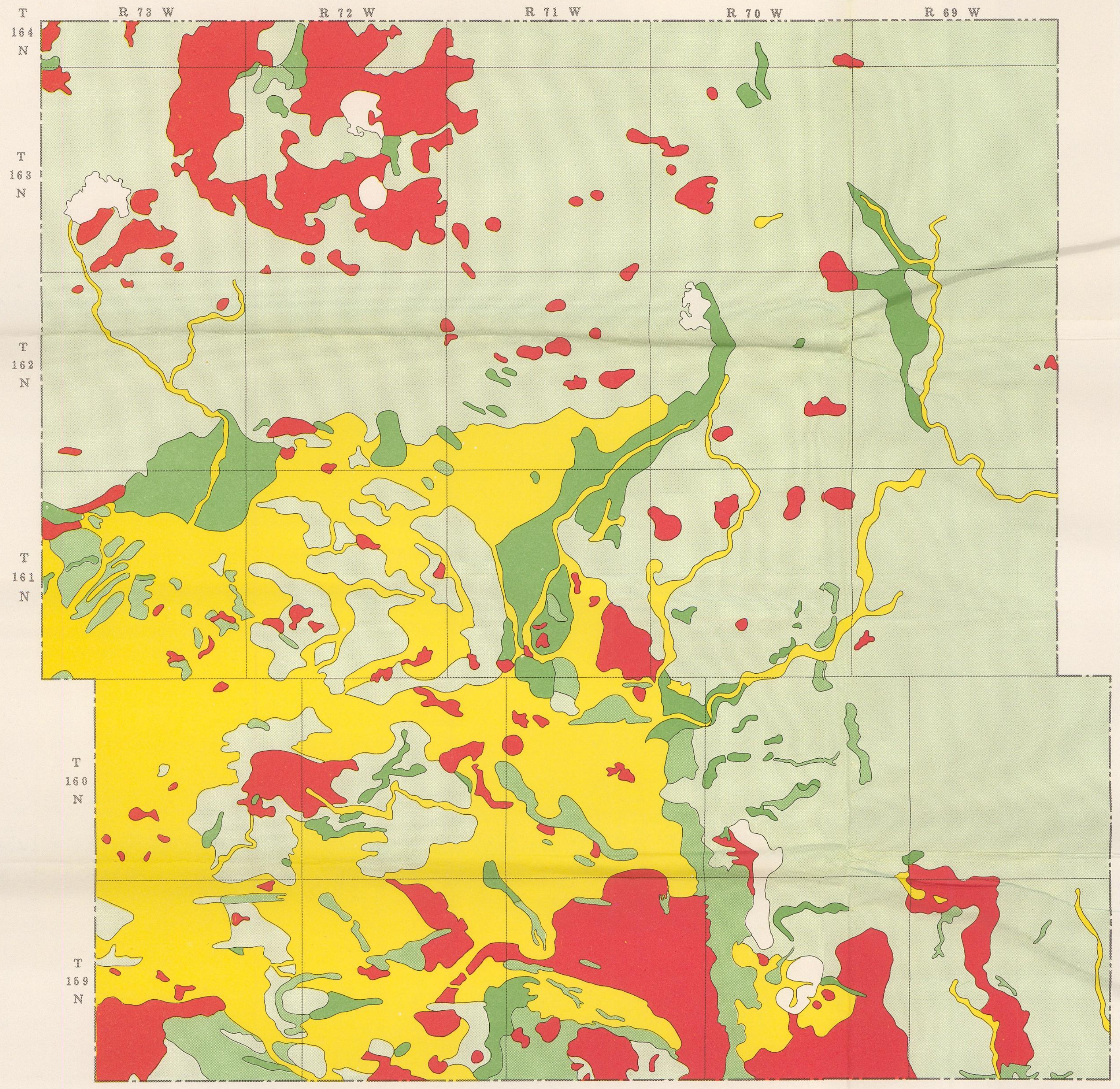
†Assuming the well was completed correctly, supplies water adequate for a small farm or house.

SAND AND GRAVEL RESOURCES



Key to Units on Plate 1	Unit	Resource Characteristics
10,11 in southwest part	🟩	Commercial quantities of high quality gravel with lesser amounts of sand. May contain too much deleterious material (mostly shale, chert, and clay) to qualify as high quality concrete aggregate but is excellent quality for other uses.
10,11 elsewhere, 14	🟩	Commercial quantities of medium to low quality gravel with lesser amounts of sand. May contain as much as 30% shale pebbles.
9 in southwest part, 15	🟩	Small quantities of gravel with considerable sand. Quality in most cases not adequate for high quality concrete aggregate but excellent quality for other uses.
9 elsewhere	🟨	Small quantities of medium to low quality gravel with considerable sand. May contain as much as 30% shale pebbles.
6,7,8,12,13, and some 5	🟧	Small isolated deposits of variable quality capable of producing sand and gravel for individual use. Best prospects on small hills and along streams. See text for discussion of possibly significant local deposits.
1,2,3,4, and some 5	🟥	No surface sand or gravel supplies.

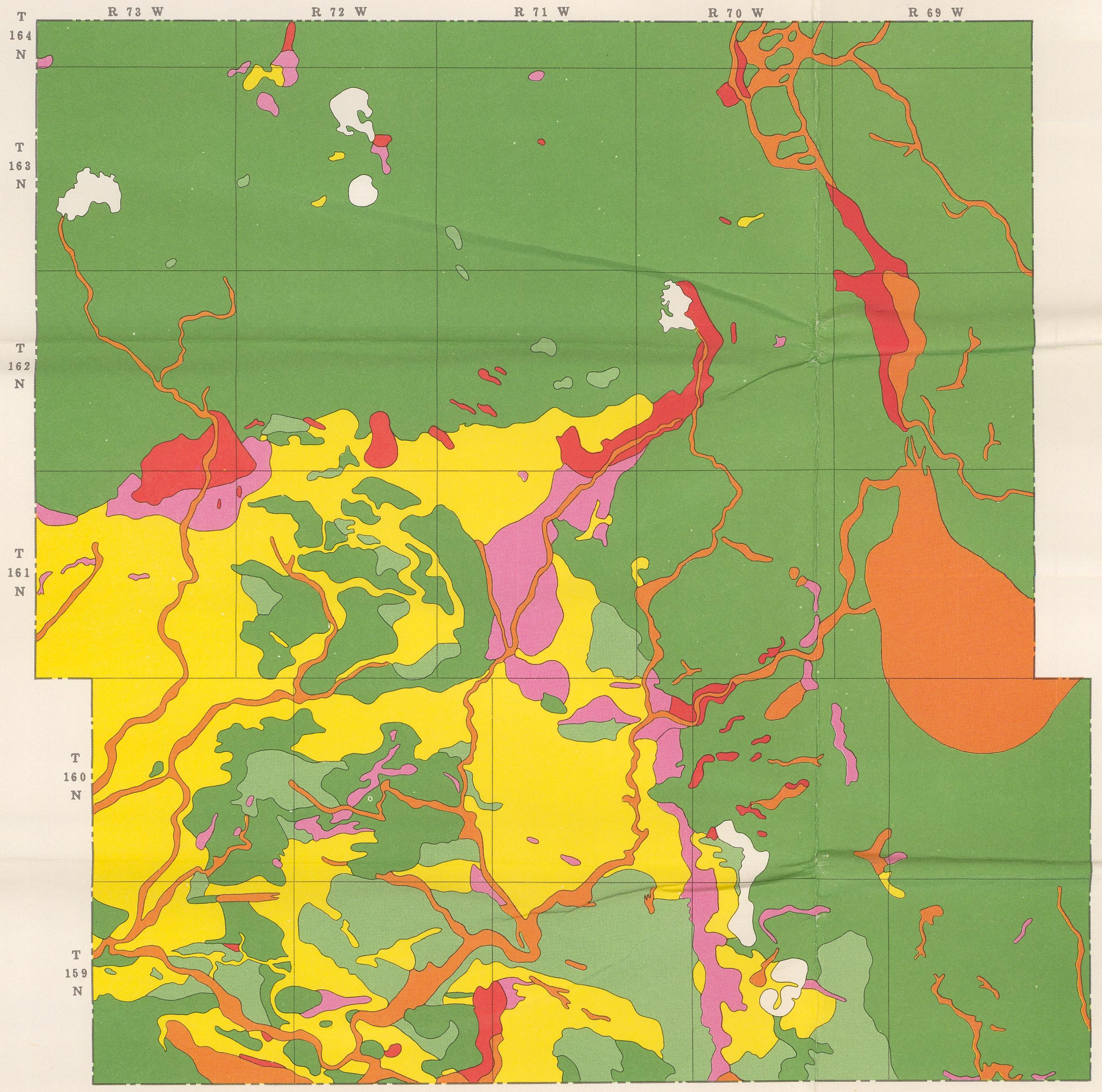
CONSTRUCTION CAPABILITIES



Key to Units on Plate 1	Unit	Water Problems	Permeability	Internal Drainage	Water Table	Foundation Conditions	Bearing Capacity	Compressibility	Slope Stability† Dry	Slope Stability† Wet	Frost Susceptibility
10,11	🟩	Usually none	High	Good	Low	Good	High	Low	Good below 30°	Good below 30°	Low
9,14,15,R,X	🟩	Usually none	High	Good	Low	Good	High	Low	Good below 30°	Good below 30°	Low to moderate
12,13	🟩	Moderate	Low to very low	Poor	High	Good	High	Low	Very good above 30°	Poor	Low to moderate
6,7,8, some 5	🟨	Minor to major	Low to medium	Poor	High	Moderate	High to moderate	Low to moderate	Good below 30°	Fair to poor	High to moderate
1,2,3,4	🟥	Major	Low to very low	Poor	High	Moderate to poor	Low (Medium to high plasticity)	High	Good above 30° for low scarps	Very poor	High to low

†Stability over a period of a few years for shallow excavations where there is no ground-water seepage at the base of the slope.

NEAR-SURFACE PERMEABILITY



Key to Units on Plate 1	Unit	Permeability† (cm/sec)	Potential for Ground-Water Contamination by Degradable Pollutants
11	🟥	High (greater than 10^{-1})	High
10,15	🟪	Medium to high (greater than 10^{-1} to 10^{-3})	High
8,14,36	🟧	Variable High to low (10^{-1} to 10^{-7})	Variable
6,7,9	🟨	Medium to low (10^{-1} to 10^{-5})	Moderate
3,4,5	🟩	Low to very low (10^{-3} to 10^{-7})	Low
1,2,12,13	🟩	Very low (10^{-5} to 10^{-7})	Low

†Laboratory data. Jointed sediments may locally be much higher.

ENGINEERING AND RESOURCE MAPS
of
Rolette County

Dwight E. Deal
1971

Cartography by S. R. Deal.