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The surficial geology of north-central Kidder County, North Dakota

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THE SURFICIAL GEOLOGY OF NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

by

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This thesis submitted by Wallace E. Bakken in partial fulfillment of the requirements for the Degree of Master of Science in the University of North Dakota, is hereby approved by the Committee under whom the work has been done.

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ABSTRACT

Kidder County is situated in central North Dakota within the glaciated Missouri Plateau. Rocks underlying the drift range from Cretaceous (Pierre formation) through Paleocene (Tongue River formation) in age. The Pierre and Fox Hills formations constitute the majority of the pre-Pleistocene surface. Ice-shove deformation, apparently during Cary time, tilted blocks of Fox Hills in the Sibley Buttes into northeastward-dipping positions.

Cary and Mankato subages of Wisconsin age are represented at the surface. Ages are difficult to assign to drift sheets on the basis of lithology or degree of weathering of included tills; but by correlation from South Dakota and crosscutting relationships of moraines, age assignments are suggested. The Sibley Buttes moraine marks a readvance during probable 1st Cary time as indicated by its transection of the Long Lake loop. Small recessional moraines mark positions of stillstand during eastward retreat of 1st Cary ice. Second Cary drift occurs north of Tuttle and Robinson, and outwash to its south indicates melting was the dominant process. Local stagnation formed pitted outwash, especially along the borders of the stagnating ice.

First Mankato deposits are not exposed in the area. Second Mankato deposits are represented in part by the massive, lobe-shaped McPhail Buttes moraine. Glaciofluvial material of 2nd Mankato subage derived from the

northeast has partially buried parts of 2nd Mankato drift in the northeast part of the area.

Recent sediment consists of alluvium and reworked outwash sand.

Preglacial drainage was southeastward into the preglacial Cannonball River which flowed northeastward across the center of the County.

CONTENTS

ILLUSTRATIONS

All Plates Inside Back Cover

INTRODUCTION

Scope and Purpose

The area mapped and described consists of 360 square miles located in Tps. 141 and 142 N., Rs. 70, 71, 72, 73, and 74 W., Kidder County, North Dakota (pl. 1). It is limited by 99° 27' - 100° 07' west longitude and 46° 59' - 47° 08' north latitude and is situated in the eastern portion of Fenneman's (1931) glaciated Missouri Plateau section of the Great Plains province (fig. 1).

The purpose of this study is to outline the Pleistocene history of this area through the description and interpretation of observed glacial features. It is hoped the results will lead to a more thorough understanding of the Pleistocene geology of the state.

Geography

Topographically, the area mapped is a depression in the vicinity of Horsehead Lake and is more or less surrounded by moraines of varying elevations. The topographic map (pl. 2) shows the surface rising slightly to the east and west from the Horsehead Lake area and as a result, drainage is directed into this lake (pl. 3). This is part of a larger internal drainage system occupying parts of Kidder, Logan, and Stutsman counties and including such lakes as Long Lake and Alkaline Lake in southern Kidder County along with Horsehead Lake.

The area mapped is situated on part of a larger area called the Coteau du Missouri, a belt of morainic hills overlying a westward-dipping bedrock escarpment. The Coteau extends to the northwest across North Dakota (fig. 1). Maximum relief in the field area is approximately 300 feet. The lowest elevation (1720± ft.) occurs in the south-central portion and the highest (2020± ft.) on the Sibley Buttes.

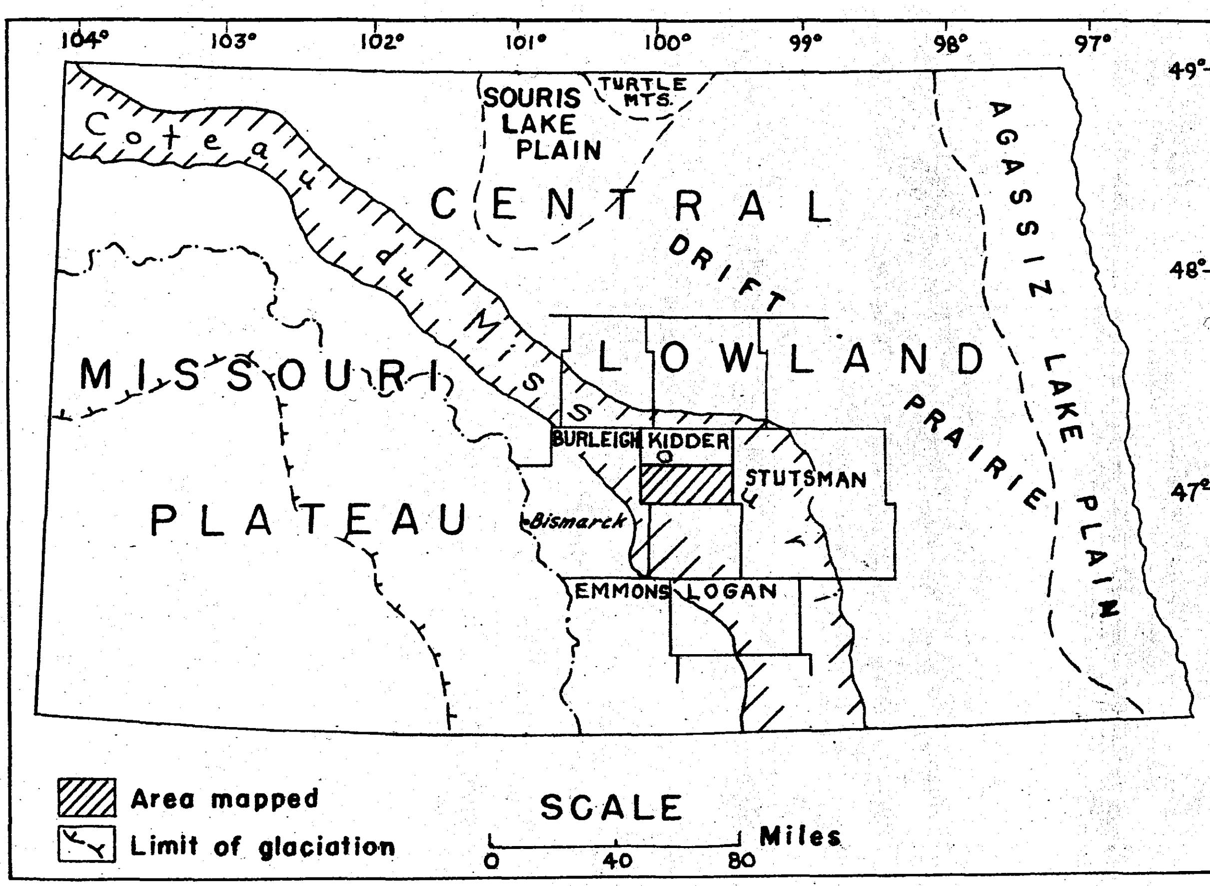

Fig. 1 - Location of area mapped and major physiographic features in North Dakota. Modified from Fenneman (1931) and Lemke and Colton (1958).

Soil

The soil throughout approximately half the area is very sandy, especially on the extensive outwash plain. Soil development on this outwash is locally lighter colored, due to leaching, and more sandy than that in the morainal areas. Soil in the latter areas is clay-rich and extremely slippery when moist. Probably the reason for the concentration of sand in outwash soils is due to the constant reworking by wind action with the finer fraction deposited in the ditches.

The soil section on the outwash plain is poorly developed in contrast with that on the moraines. Wind action has stripped some outwash areas of their loosely consolidated organic material. In general the coarser the outwash the poorer the soil development. Where wind action has been exceptionally severe and during drier years much soil is blown away. Consequently, soil thickness to some degree is greater in lower areas between hills and thinner on hilltops and steep slopes. Local areas, especially along streams, also have thicker soil sections.

Climate

The area is characterized by cold winter temperatures and warm summers. Summer temperatures reach 100° F. and winter temperatures as low as -30° F. The humidity is low and the air dry nearly all year. Often during the winter, warm, dry, descending "chinook" winds flow eastward from the Rocky Mountains and cause winter temperatures to be 20° to 30° above normal. Prevailing winds are from the north and northeast. Annual precipitation is about 18 inches. Precipitation was below normal during the summer (1959) the area was mapped, hence most of the kettle depressions were dry and mapping was facilitated.

Culture

North-central Kidder County is traversed by numerous county highways and two state highways (North Dakota #3 and #36). U. S. Interstate #94 (formerly U. S. #10), the main east-west highway across North Dakota, passes 9 miles south of the field area. The area is 50 miles from Bismarck, North Dakota.

A branch line of the Northern Pacific Railroad passes through the villages of Pettibone, Lake Williams, Robinson, and Tuttle twice daily. Each of these villages has populations under 500 with Tuttle being the largest.

Approximately half the area mapped is tillable. The outwash plain with its sandy soil is suited to grain farming with the major crops being wheat and corn. Considerable sheep and cattle grazing is done in the rougher morainal areas. The chief recreational area is Cherry Lake where boating and fishing have become common in recent years.

Gravel and sand are important resources in the area and numerous pits have been opened and are being mined. Plate 4 shows the location of these pits as well as the United States Geological Survey test hole locations.

Terminology

During glacial mapping, various problems are encountered concerning whether to map strictly on the basis of topography or to map and interpret features genetically. This problem was resolved in this mapping project by setting definitions for each type of glacial deposit and topographic form. This was necessary not only so mapping techniques would be standardized, but also in order that interpretations by other workers (Cox, Williams, Chmelik, 1960) would follow a uniform pattern. Each feature was therefore mapped and interpreted on a genetic basis in this report. The major problems were encountered where the bedrock influenced glacial deposition and the location of moraines. A glossary is included in Appendix 1 which gives the writer's definitions of glacial terms as used in this paper.

The term stagnation moraine, which some geologists consider synonymous with ablation moraine and which the writer believes is actually "dead-ice moraine" (Lemke and Colton, 1958), has only recently been applied to glacial mapping. These writers consider "dead-ice moraine" as being characterized by high local relief, devoid of apparent trends. Most earlier workers referred to "dead-ice moraine" merely as drift deposited by stagnant or stagnating ice. The term stagnation moraine is herein used as an accumulation of drift devoid of linear trends and characterized by numerous "knobs and kettles". Relief ranges from 20 to 100 feet. Drift thickness in stagnation moraine is dependent on the amount of debris contained in the ice sheet. Stagnation moraine is commonly spoken of as consisting of "knob and kettle" topography, "knob and sag" topography, and "hill and kettle" topography. The genetic implications of the term stagnation moraine warrant its being adopted and used by glacial geologists.

According to Flint (1929, p. 285), Cook (1924) was the first to attempt to predict the areal limits of stagnation. It is questionable how great an area a stagnant ice sheet would cover; however, ice thickness would probably be the predominant limiting factor. Charlesworth (1957, p. 1147) estimates the average width of stagnation at from 20 to 120 kilometers. His stagnation hypotheses follows that of other writers in describing the ice border of a stagnating ice sheet as ragged with the outer edge shrinking back and leaving disconnected fragments of ice which later become buried and eventually melt.

Charlesworth (1957, p. 1150) cites the following as evidence of stagnation: abundant eskers, marginal deposits with undisturbed stratification, knolled topography, and the absence of looped recessional moraines. However, Charlesworth makes special note that "the absence of recessional moraines does not necessarily imply stagnation." Cook (1924) working in the Hudson Valley of New York used the following additional criteria as evidence of the overall inactiveness of a stagnating ice sheet: irregularity of the frontal line, thin ice occupying valleys, pitted outwash plains, and the absence of traceable lines of drainage. Salisbury (1902), Fuller (1904), and Clapp (1904) all conclude on the basis of the presence of many of the above mentioned features, that the glacial topography of various portions of northeastern United States was the result of ice melting in place and not by ice retreat. Flint (1928, p. 416) notes that crevasse fillings and pitted areas of drift indicate stagnant ice at the time of their deposition.

Various theories have been proposed to account for stagnant ice. Cook (1924) believed that stagnation was probably the result of subsidence of the crust caused by the weight of the ice sheet. This theory is, however, rejected by many geologists in the light of postglacial uplift in northeast United States.

The writer suggests that climate, rather than subsidence, is probably a more important factor causing stagnation of ice. A warming of the climate would cause rapid melting and a general thinning of the ice sheet. As a result, ice blocks would become detached from the main ice body, become buried, and eventually melt and form depressions on the drift surface. Topography probably controls local stagnation. On relatively smooth topography, ice movement would probably be relatively uniform as long as supply and wastage remained more or less constant; however, if the supply and wastage continued to be constant, but the ice moved over a badland-type topography, a relative slowing with subsequent stagnation would be expected. Topographic control of ice applies well to Kidder County where the topography was probably of the badland-type. In addition, the escarpment along the northeast side of the Missouri Plateau was ideally situated for initiating ice stagnation. The topography and regional dip to the west were such that ice, advancing on this escarpment, became slowed down and/or conditions may have been favorable for the ice to just push over the crest of the escarpment and then stagnate; thereby forming the Coteau du Missouri. It is probably to stagnation moraine that Simpson (1932, p. 15) refers when he mentions the drift on the Coteau du Missouri as consisting of "... irregular ridges and confused groups of hills."

End moraine is considered as any ridge-like accumulation of drift of constructional origin formed along the front of a glacier and marking the terminal position of a major readvance and/or pause of the ice. The method of mapping end moraine and the problem of which features to include in end moraine and which to exclude is ever present. Many smaller areas of other morainal types are situated within the end moraine complexes and in such cases the whole is mapped as end moraine, provided regional interpretation is not affected. For instance, if a patch of "knob and kettle" topography should occur in an area of end moraine, it would hardly warrant separate mapping. Such an occurrence of knob and kettle topography within end moraine does not have a direct bearing on the overall Pleistocene interpretation, but it does show that conditions were favorable for local detachment and separation of ice blocks. In addition, small, isolated remnants of till are often noted in outwash areas, but all of these are not mapped since again, they are not considered significant to the regional interpretation.

Related to end moraines in the field area is the problem of mapping bedrock highs. This is encountered in the Sibley Buttes moraine where Fox Hills sandstone (Cretaceous) crops out. Flint (1955, p. 116) encountered this same problem in mapping some areas of eastern South Dakota where this same sandstone crops out or is covered by a thin mantle of drift. Whether a linear ridge covered with a thin veneer of drift should be mapped as a bedrock high or as end moraine must often be based on additional evidence. Such evidence might consist of the outwash patterns or the relationship of the feature in question to older or younger moraines in the area. In this area, evidence suggests that the ice stopped along the Sibley Buttes bedrock high, so the location of the bedrock high influenced ice movement and morainal deposition. Additional evidence for this interpretation is discussed below. Areas of bedrock highs are indicated on the geologic map (pl. 1) by crosshatching superimposed on the morainal designation. A general relationship between bedrock highs and topographic form can be obtained by comparing the geologic map with the map showing topography on the pre-Pleistocene surface (pl. 7).

Recessional moraine is any ice-built ridge or series of ridges composed of drift which generally shows linear or arcuate trends. This feature is formed during minor pauses in the retreat of the glacier. Usually their identification must be based on evidence other than that obtained from the moraine itself, such as their occurrence between two large end moraines. The crests of the individual ridges within the recessional moraines are shown by black lines on plate 1. "Washboard moraine" is a special type of recessional moraine. Genetically, it is the same except its ridges exhibit very even spacing with the overall aspect resembling the surface of a washboard, hence the name.

Ground moraine is any accumulation of drift characterized by swell and swale topography. Gentle slopes (less than 3°) and relief of approximately 20 feet or less are characteristic. Ground moraine is outlined on the basis of topography as well as lithology. Topographically, ground moraine is often indistinguishable from an outwash plain; consequently where the two are in contact, choosing the boundary is difficult and must be done largely on the basis of the presence or absence of boulders and the general lithology of the drift. The lithologies of ground and end moraine deposits are similar, but their topographic expression is different enough to necessitate separate mapping.

Some ground moraine forms through lodgment of debris as the glacier advances over an area. Other ground moraine forms when debris is lowered from the surface (ablation) of the ice during ice retreat (Flint, 1955, p. 112). The writer believes this latter method constitutes the method of formation of the majority of ground moraine. This is based on the theory that debris must have been continually let down on to the ground surface as the ice receded.

Previous Work

The Pleistocene geology of north-central Kidder County has never been done in detail; although its drift constitutes part of the morainal complex extending along the Coteau du Missouri commonly referred to as the Altamont moraine. The Altamont moraine was named by Chamberlin (1883) after Altamont, South Dakota, where the feature is typically located. Todd (1896) traced the Altamont moraine as far north as the 47th parallel. Later, Campbell, and others, (1916) traced the Altamont moraine further northward and correlated it with the morainal complex extending through Long Lake and northwestward between the villages of Sterling and Driscoll in eastern Burleigh County, North Dakota. Supposedly, the early workers believed the Altamont moraine extended from South Dakota northward to northwestern North Dakota and on into Canada. However, Townsend and Jenks (1951) have suggested the Altamont in South Dakota may be of different age than that in North Dakota and they proposed the term Max moraine for the series of morainic hills extending from the Bismarck, North Dakota area northwestward into Canada. The Altamont moraine in its type locality is a terminal moraine; however, it is not known whether the moraine northwest of the Bismarck area and in the Max, North Dakota vicinity is terminal or drift on a bedrock high. Townsend and Jenks (1951) therefore believe that, until more evidence is obtained for either interpretation, the moraine should be given "a name without genetic implications, i.e. Max moraine." This writer will follow Townsend and Jenks's (1951) terminology.

Leonard (1912, p. 59) mentions the Altamont (Max) moraine as varying from 6 to 20 miles in width and marking the western edge of Wisconsin drift in North Dakota. He (1923-24) was one of the first to comment specifically on part of the area mapped when he mentioned the outwash plain developed south of the villages of Tuttle, Robinson, and Pettibone. Rasmussen (1945, p. 2) also mentioned the outwash deposits around Robinson, Lake Williams, and Pettibone and thought they were deposited by a receding ice mass. The closest detailed mapping to the area under consideration is that of Paulson (1952). He mapped in the Streeter area, 20 miles southeast of the field area, in parts of Stutsman, Kidder, and Logan counties.

Bedrock beneath the drift north of Steele, North Dakota, and pre-glacial drainage across the Altamont (Max) moraine are discussed by Wilder (1902) and Todd (1896), respectively. The bedrock topography of the Kidder County area is shown in a general way by Horberg and Anderson (1956) who state that bedrock has had an important influence on ice movement throughout central United States.

The thickness of drift in North Dakota has been contoured by Randich (1958, unpublished senior thesis). This was based on United States Geological Survey test holes drilled throughout the state. The writer's contour map of the drift in the area brings part of Randich's work up to date in that additional well data is used in this later compilation.

Hansen's (1956) geologic map of North Dakota shows the distribution of bedrock beneath the drift in the state. The Fox Hills - Pierre contact in the Horsehead Lake area has been placed approximately 7 miles east of Hansen's contact. This was done on the basis of information obtained from United States Geological Survey test hole logs.

The most recent published work pertaining to the field area is that by Lemke and Colton (1958) in which they summarize the Pleistocene geology of the state. In their paper, numerous maps show the major moraines in the area, but no detailed history is discussed. The United States Geological Survey has also compiled a large scale glacial map of North Dakota which is soon to be published. This map is based largely on work done on aerial photographs and reconnaissance surveys as well as published material.

The most recent work in the region is that by Clayton (1960, unpublished report) concerning the tills exposed in the county. His work consists of hydrometer analyses of numerous till samples chosen at random from moraines throughout the county. Approximately 6 of these were from the area mapped. The results of these analyses, complemented by field observations, led Clayton to place most of the drift in the map area as Cary in subage. He also concluded that the mechanical analyses of the tills is insignificant in indicating ages of the moraines.

Field and Laboratory Work

The interpretations and conclusions herein presented are those based on field work conducted during June, July, and August of 1959, for the North Dakota Geological Survey. The area mapped was revisited in October to measure specific sections and take pictures. Contacts were placed on aerial photographs (scale: 1" 1 mi.) based on field observations. The base map used was the highway map of Kidder County (scale: 1" 1 mi.) published by the North Dakota State Highway Department in 1958. The majority of roads in the area were passable during dry weather, thereby making field work by auto practicable. The automobile odometer was used for computing many horizontal distances and locating specific features.

Linearity of various glacial features, which otherwise would not have been evident from the ground, showed well on aerial photographs. A vertical sketchmaster was used to transfer material from photographs to the base map. In particular, "washboard moraine" (see p. 9) was difficult to see in the field, but on aerial photographs these trends were conspicuous. Topographic maps were unavailable for the majority of the field area, but parts of the southern border of the area were covered by the following U. S. Geological Survey topographic quadrangle maps: Driscoll, Steele NW, Steele NE, Tappen N, Tappen NE, and Crystal Springs.

The map (pl. 5) showing the outcrops of Fox Hills sandstone in the Sibley Buttes was constructed using aerial photographs and then transferring the data to a map by use of a sketchmaster. It is beyond the scope of this paper to discuss the structure of the Fox Hills sandstone in the Sibley Buttes to any degree of detail; however, it is recommended these "buttes" be mapped and studied in greater detail.

Numerous spot elevations were taken using a Paulin aneroid altimeter. United States Coast and Geodetic Survey benchmarks located in western Stutsman County were used as reference points for the altimeter survey. The topographic sketch map was constructed using altimeter data in conjunction with elevations obtained from United States Department of Interior maps (New Rockford, McClusky, and Jamestown). These maps are on a 1 :250,000 scale and contoured on a 100 foot interval. The Abney hand level was used for relative elevations and for measuring stratigraphic sections.

Samples of drift were collected throughout the area. Some of these were obtained by use of a hand auger, especially where roadcuts did not expose any drift. Since the area is predominantly outwash, the majority of samples consisted of this type of drift. Outwash samples pertinent to the interpretation of the area were sieved and histograms of these appear throughout the paper. Till samples collected from the moraines were studied in the laboratory during the winter of 1959-60. Till colors were compared with those in the Goddard, and others, (1948) Rock Color chart. Colors are designated in the text by a number from this chart such as 5Y 5/2 which indicates the shade of the primary color. Hydrometer analyses were performed on ten till samples and the results of these appear in figures 13, 17, and 22. These analyses were conducted in hopes of finding significant differences in lithologies of the tills. Some differences were noted by the writer between tills of the various end moraines; however, movements and ages of the ice lobes were largely inferred from the trends of the moraines and the areal extent and form of their outwash masses -- not by the mechanical analyses of the tills.

Pebble counts were conducted on the tills in the morainal areas wherever roadcuts would allow. The procedure consisted of selecting a roadcut with a good backslope, the surface of which was moderately covered with pebbles greater than one-fourth inch in diameter. An area estimated to contain from 100 to 150 pebbles was marked off with a rock hammer. Particles greater than one-fourth inch, but smaller than cobble size were collected and sorted into twelve groups. The results obtained were of insignificant value to the interpretation of the Pleistocene history of the area.

Test wells have been drilled at scattered points throughout the region by the United States Geological Survey. These were drilled primarily in topographically lower areas, usually ground moraine, stagnation moraine or outwash areas. Logs of these wells were obtained from the U. S. Geological Survey Ground Water Branch in Grand Forks and cross sections compiled from them across significant areas.

Acknowledgments

The writer is grateful to Dr. Wilson M. Laird, State Geologist of North Dakota for the opportunity of mapping and interpreting the geology of this area, financial aid, and for critically reading the manuscript. The writer is especially indebted to Dr. Jon L. Rau, now geologist with the United States Geological Survey at Columbus, Ohio, but at the time of this study a geologist with the North Dakota Geological Survey, for his assistance in the field and helpful comments during discussions of the many major problems encountered during mapping. Consultations with James Chmelik, Barrett Williams, and Lee Clayton proved valuable in understanding regional aspects of the glacial history in areas immediately north and south of the field area. Thanks also are due to Mr. Joseph Brookhart, district geologist, Ground Water Branch, United States Geological Survey, Grand Forks, for use of Kidder County well logs. Dr. F. D. Holland, Jr. and Dr. Mark Rich read and criticized the manuscript.

PRE-PLEISTOCENE ROCKS

Stratigraphic Sequence and Lithology

The sequence and lithology of rocks units directly underlying the drift in this area is shown in figure 2.

SYSTEM	SERIES	GROUP	FORMATION	THICKNESS -FEET-	LITHOLOGY
TERTIARY	Paleocene	Ft. Union	Tongue River	0-1100	light & dark sh & ss with lignite.
			Cannonball	0-360	light gray ss, slst, & clay.
CRETACEOUS	Upper		Hell Creek	0-575	gray, bentonitic ss & sh with lignitic sh.
		Montana	Fox Hills	0-320	light, shaly, bentonitic ss & sandy sh.
			Pierre	0-2300	medium to light gray sh with bentonite.
		Colorado	Niobrara	0-500	medium to light gray, calcareous sh.

Fig. 2. Stratigraphic column of bedrock units directly underlying drift in north-central, Kidder County, North Dakota. Modified from unpublished N. Dak. Geological Survey Stratigraphic Chart (1960).

The areal extent of these units is shown by the pre-Pleistocene paleogeologic map (pl. 6). The Fox Hills and Pierre formations occupy the majority of the area and will be considered the most in reference to bedrock topography and its influence on ice movement. The type of bedrock probably had much to do with the lithology of the earlier, now buried drift deposits, and the writer believes most till is locally derived through upward movement along shear planes within the ice. It is not known how much of the exposed drift is reworked earlier drift and how much is material brought upward from the bedrock by ice movement.

Cretaceous Strata

Fox Hills sandstone crops out in two localities in the area. The most conspicuous of these is located southwest of Horsehead Lake and is known as the Sibley Buttes. The Fox Hills formation is variable in lithology, but generally consists of medium-gray to gray-brown, fine-grained, friable sandstone. It is often iron-stained which causes variations in the general gray color. The formation is easily weathered. In some exposures it is massive; elsewhere is splits into brittle plates, some as thin as one-fourth inch. Locally the sandstone exhibits small concretions from one-fourth to 1 inch in diameter. The erosional resistancy of these concretions is probably due to relatively greater concentrations of iron. These concretions are most abundant in a ditch out of the area mapped (SW portion, sec. 6, T. 140 N., R. 72 W.). In parts of this same ditch, the formation is very crumbly and could be confused with the sandy till which overlies it in places.

The other known outcrop of Fox Hills in the area occurs in a roadcut along North Dakota State highway #3, south of Tuttle, North Dakota. The section at this locality is shown in figure 3.

Additional evidence that bedrock is close to the surface in this area are the Fox Hills outcrops along U. S. highway #10, east of Steele as well as north of Robinson, both outside the area. Indirect evidence of bedrock such as faint dendritic drainage patterns and butte shapes in some moraines are present throughout much of the area. The location of end moraines was partially influenced by these bedrock highs. Tertiary beds crop out north of the village of Tuttle, outside the area.

Roadcut (west side) - SW¼ NW¼ sec. 33, T. 141 N., R. 73 W., 10.5 mi. S. of Tuttle on North Dakota #3.

(Exposed in 1959)

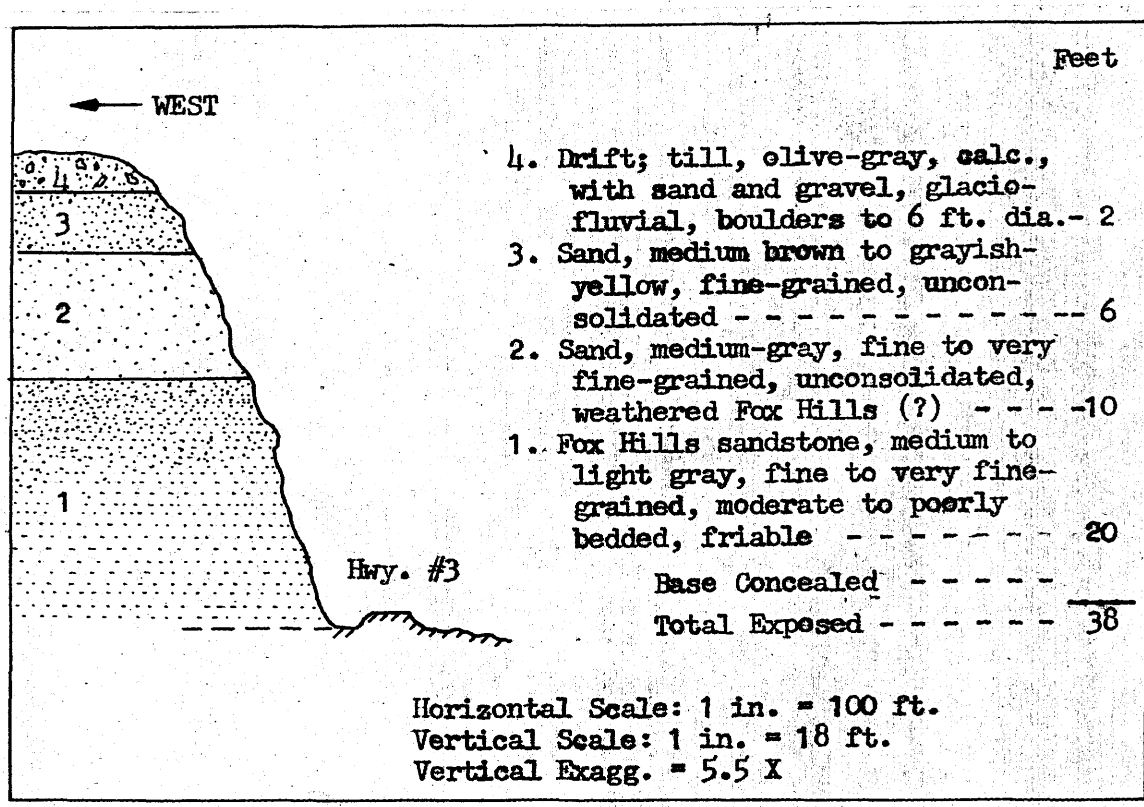

Fig. 3. Roadcut section exposing Fox Hills sandstone. Roadcut slope is slightly exaggerated.

Sibley Buttes Structure

The Sibley Buttes are a series of ridge-like hills of Fox Hills sandstone located in parts of secs. 25, 26, 35, and 36, T. 141 N., R. 73 W.; secs. 30, 31, and 32, T. 141 N., R. 72 W.; sec. 1, T. 140 N., R. 73 W. and sec. 6, T. 140 N., R. 72 W. These "buttes" trend northwest-southeast and are conspicuous on topographic maps and aerial photographs. A photograph of the Sibley Buttes is shown in figure 4.

Fig. 4. Sibley Buttes (looking north).

The Sibley Buttes rise approximately 275 feet above the drift surface to the northeast and about 200 feet above the drift to the southwest. A northeast-southwest topographic profile (fig. 5) shows these relationships.

Approximately 15 strikes and dips were recorded on Fox Hills outcrops throughout the Sibley Buttes. Plate 5 shows the outcrops of Fox Hills as compiled from aerial photographs. The area in which the dips and strikes were taken is outlined. The outcrops generally occur at or near the tops of ridges and are all at approximately the same elevation. They are topographically expressed as ridges striking northwest-southeast and dipping at various angles to the northeast. Whether the position of these sandstone blocks is due to subsurface faulting or to some type of ice-shove phenomenon is the problem to be considered.

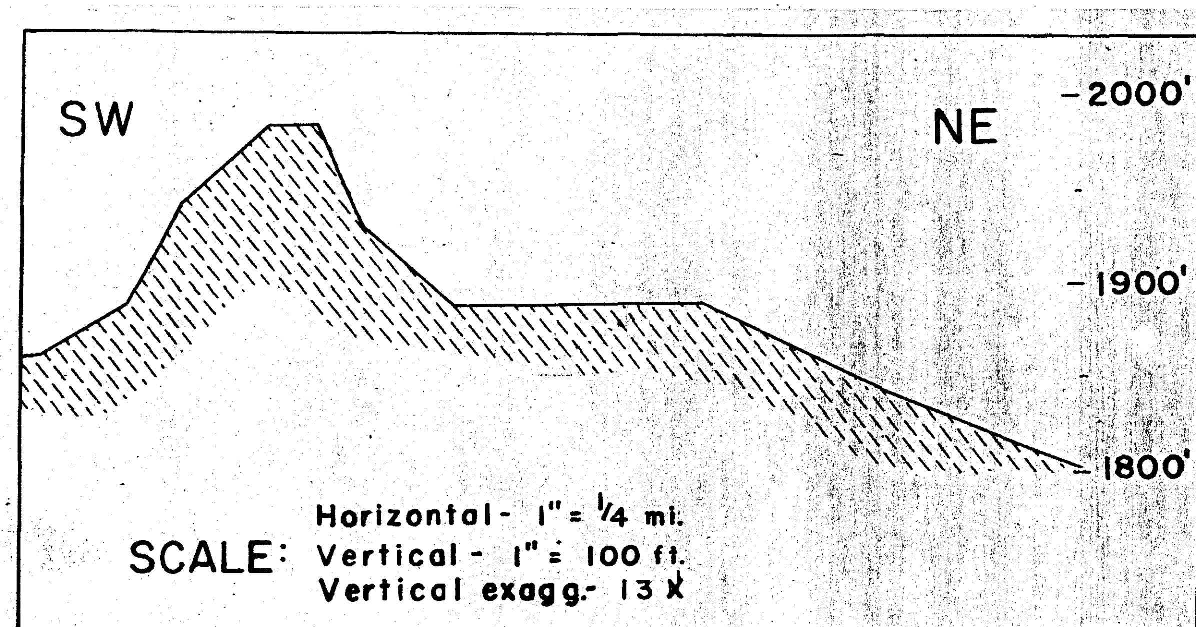

Fig. 5. Profile of the Sibley Buttes. From the SW corner to NE corner, sec. 31, T. 141 N., R. 72 W. Distal slope to left.

The strikes measured ranged from N. 14 W. to N. 84 W. The beds dip 18° to 90° to the northeast with most beds dipping from 18° to 44°. Regionally, the Fox Hills formation dips slightly southeastward. An outcrop of undisturbed Fox Hills is present outside the area mapped in the ditch at the east end of the Sibley Buttes (NW¼ sec. 6, T. 140 N., R. 72 W.). Outcrops also occur throughout the southern part of the county. As shown in plate 5, the strikes and dips are variable, even within one outcropping ridge. In general, the strikes align with the general trend of the Sibley Buttes proper. Some of the outcropping ridges are traceable up to 1000± feet, but then end at the edge of a gully; however, on the opposite side of the valley, the same trend can be followed again. This suggests the ridges formerly extended directly across these valleys. Many ridges are arcuate in plan view and appear to have been forceably wrapped around an abutment of some type. Whether or not this curving is a consequence of the lobate shape of the ice front is not known.

At outcrop X (pl. 5), located in sec. 1, T. 140 N., R. 73 W., blocks of Fox Hills (one of boulder size about 6 feet in long dimension) have apparently been shoved or otherwise displaced to the southwest off the main ridge (fig. 6).

This is indicated by their position in relation to the main ridge and general appearance, although post-glacial erosion is also a possible explanation for their present topographic expression. At X, the bedrock strikes N. 30 W. and dips approximately 30° to the northeast. This outcrop is on the west side of a ridge which trends approximately S. 50 E., hence the strike of the sandstone blocks is not in alignment with the trend of the ridge proper. Blocks of bedrock along the west side of this ridge give the appearance of a cuesta-like structure. The blocks occur in ridges, one of which is indicated by the dashed line in figure 6. The blocks appear to have dropped to the northeast and/or been uplifted to the southwest, probably by rotation on a nearly northwest-southeast axis. A small ridge (X'), west-southwest of ridge X has the same strike for part of its trend, but at the north end it veers away to the northwest as shown in figure 6. These same relationships are present throughout other parts of the Sibley Buttes but to a lesser degree.

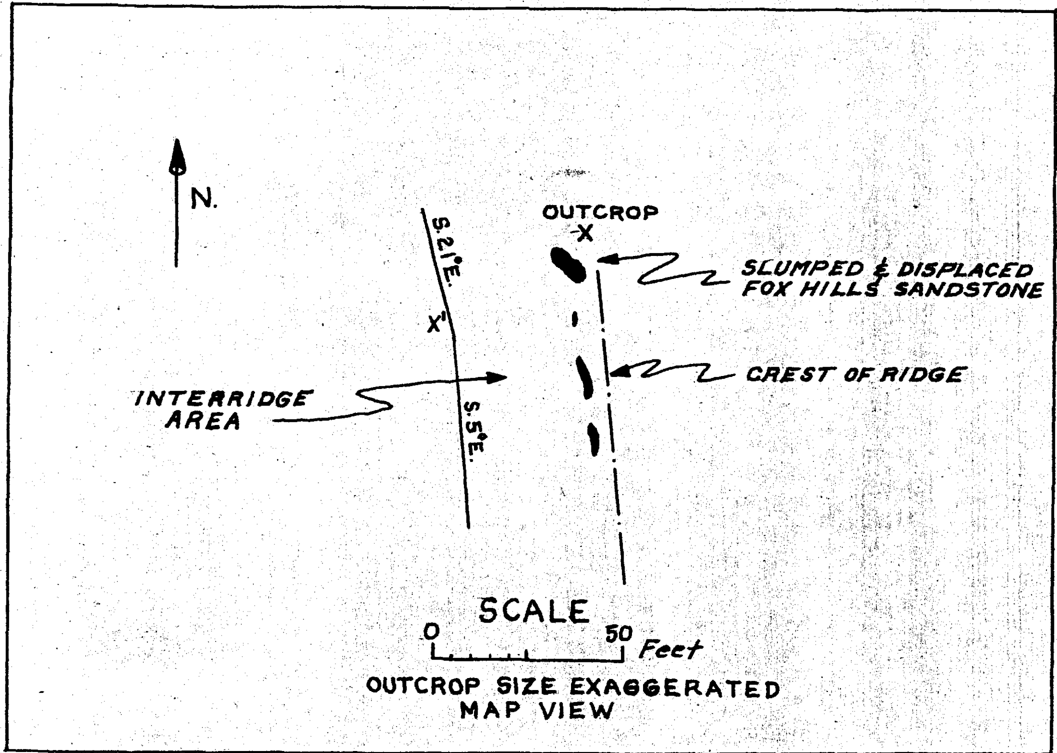

Fig. 6. Relationship in map view of sandstone blocks to ridges in the Sibley Buttes.

The ridge on which outcrop B (sec. 32, T. 141 N., R. 72 W.) (pl. 5) is located is somewhat convex to the south whereas the two ridges to the south of it each exhibit convexity in opposite directions — one is convex to the north, the other convex to the south.

The problem in the Sibley Buttes is to ascertain what caused these blocks of sandstone to be displaced and distorted into masses which have arcuate trends and moderate to steep northeasterly dips. Study of moraines and outwash relationships indicate that glaciers passed over the area from north and northeasterly direction. Before considering the Sibley Buttes problem from the standpoint of an ice-shove origin, it is necessary to reconstruct the preglacial topography on the premise that ice movement and direction of movement was to some degree, topographically controlled. The map showing preglacial topography (pl. 7) was constructed using data obtained from logs of 34 United States Geological Survey wells.

The Sibley Buttes, prior to glaciation, were no doubt a single bedrock high or series of discontinuous buttes. The area was probably topographically similar to the present-day Badlands of western North Dakota, although probably on a more subdued scale. United States Geological Survey test hole log #1145 (sec. 29, T. 141 N., R. 72 W.), located $1\frac{1}{2}$ miles northeast of the Sibley Buttes, indicates Fox Hills sandstone at about 245 feet below the surface (see fig. 7). The ground surface in this area is approximately 275 feet below the top of the Sibley Buttes; this plus the 245 feet to bedrock on the northeast side of the "Buttes" indicates approximately 520 feet of relief on the preglacial Fox Hills surface. The log of another test hole (#1146; sec. 16, T. 141 N., R. 72 W.) drilled about 4 miles north-northeast of the Sibley Buttes shows bedrock at only 175 feet. From this it appears the bedrock surface may be lowest immediately adjacent to the "buttes" themselves. The bedrock topographic map (pl. 7) shows these relationships well.

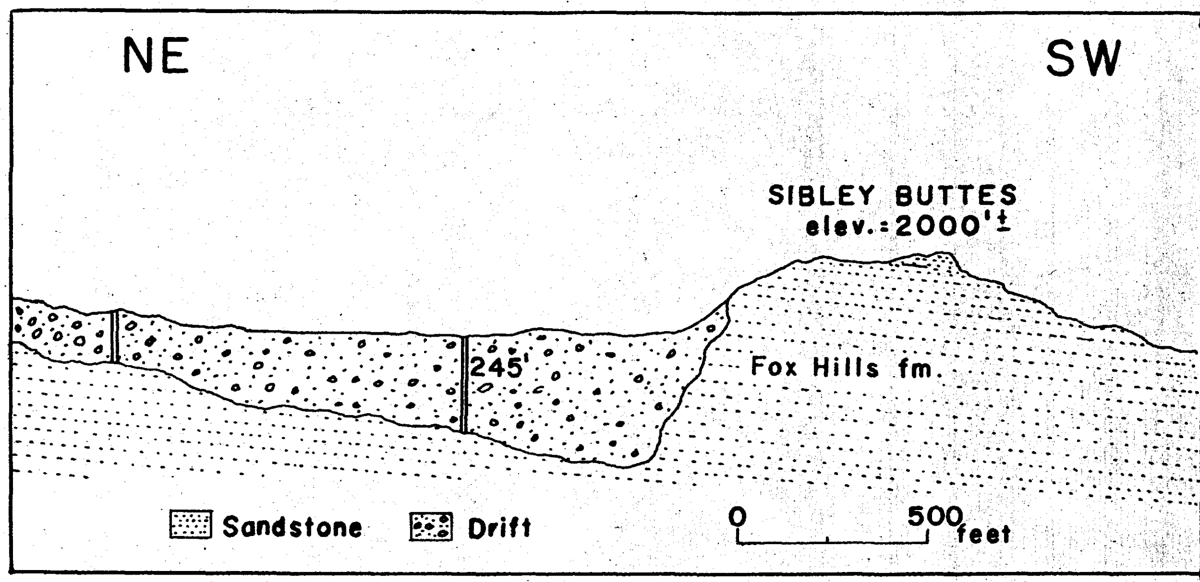

Fig. 7. Inferred preglacial topography northeast of the Sibley Buttes. Data from U. S. Geological Survey test hole logs.

The absence of Fox Hills in a well (Prairie Oil and Gas well #2, Kidder County, North Dakota) drilled immediately south of the Sibley Buttes (SW¼ SW¼ sec. 2, T. 140 N., R. 73 W.) is peculiar. Laird (1941, p. 23) shows this well as having penetrated 56 feet of drift followed by Pierre shale. This might be explained by a stream channel cut through the Fox Hills sandstone into the underlying Pierre formation. Basal gravel in the drift section of this well suggests this possibility. Possibly, due to the friable and sandy nature of the Fox Hills formation, this sandstone may have been logged with the 56 feet of drift.

The relatively few holes drilled in the area, especially in the immediate vicinity of the Sibley Buttes, are inadequate for an accurate interpretation of either the bedrock topography or the Sibley Buttes structure. The preglacial surface must therefore be inferred from both the scant well data and from the present-day topography.

Mechanics of Movement

The most logical explanation of origin for the Sibley Buttes structure is that the Fox Hills sandstone was shoved southwestward by the advancing ice. To deform the sandstone by ice-shove, the advancing ice mass would have had to exert pressure against the northeast side of the "buttes". That the ice could have done this is shown by the low in the preglacial topography on the northeast side of the Sibley Buttes. This preglacial low can be seen on the preglacial topography map (pl. 7), the isopachous map of the drift (pl. 8), and diagrammatically in figure 7. Figure 8 on the following page shows the writer's interpretation of the sequence leading to deformation of the Sibley Buttes. Figure 8A shows the preglacial topography prior to glaciation. Later (fig. 8B), probably during Cary time, ice located on the southwest side of the "buttes" and left from a previous glacial advance, acted as a buttress to any force exerted from the northeast or east. As the glacier forced its way southwestward and came in contact with the "buttes", the latter were pushed against the ice buttress. Unable to move any direction but upwards, the end result (fig. 8C), after subsequent recession of the ice, was a series of "blocks" dipping northeastward and occurring in ridge-like forms in plan view. The arcuate trends and variations in dips and strikes of the individual ridges were probably caused by differential movement of the ice around the bedrock high resulting in rotation and

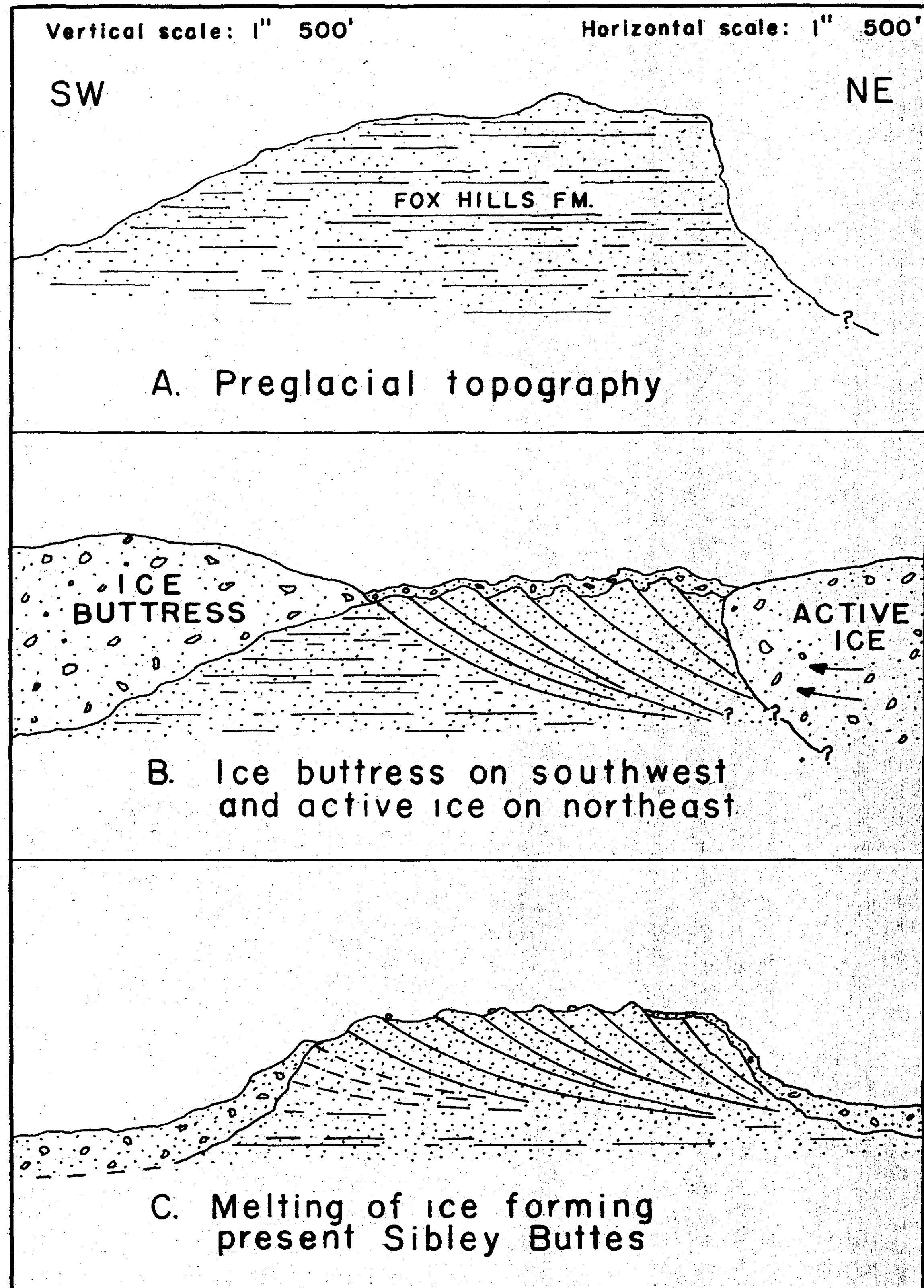

Fig. 6. Cross sections showing stages in proposed method of bedrock deformation in the Sibley Buttes.

buckling of some of the sandstone blocks. Local variations in sandstone composition may have aided in breaking the rock into blocks.

That ice actually passed over the top of the Sibley Buttes is shown by the presence of granitic, glacial erratics (some up to 10 feet in diameter) on the top of the "buttes". The till cover is absent or very thin. Because of the friable nature of the Fox Hills formation, no striae were formed on its surface; or, if inscribed, were not retained to the present time.

The same ice advance that deposited the Cherry Lake moraine (herein proposed for that recessional moraine located in the east-central portion of T. 141 N., R. 73 W. — directly north of the Sibley Buttes) also abutted against the Sibley Buttes. It may have been during this time that arcuate trends were imparted to the ridges since the curving trends of the Cherry Lake moraine and the trend of the Sibley Buttes ridges tend to complement one another. Possibly the Sibley Buttes bedrock may extend northward beneath the Cherry Lake moraine although no outcrops have been found in the latter to verify such an interpretation.

Faulting due to deep-seated movements is a possible origin for the Sibley Buttes structure. Fisher (1952, p. 32) mentions the presence of an east-west fault in central Kidder County with beds dipping to the northeast. It is possible he is referring to the Sibley Buttes. He attributes the fault to northeast-southwest trending Precambrian structures in conjunction with crossfaulting. Hansen (1954, p. 17) also mentions the Sibley Buttes structure and suggests that if the feature is of deep-seated origin, this may be supporting evidence for Townsend and Jenks's (1951) suggestion that the entire Max moraine may be of structural origin.

The possibility of faulting followed by ice-shove cannot be ruled out. This explanation would necessitate very local conditions of crustal movement probably through differential uplifting and downwarping. The weight of glacial ice may have reactivated movement along former lines of crustal weakness in the fault system suggested by Fisher (1952). More mapping and study must be done before a fault origin can be either accepted or ruled out.

Conclusions

Evidence seems to favor an ice-shove origin for the Sibley Buttes structure with glacier pressures working in conjunction with topographic irregularities. The horizontal Fox Hills sandstone in the ditch at the east end of the Sibley Buttes, approximately 200 feet below the tilted blocks, is the best evidence for a glacial origin. It seems reasonable that these beds in the ditch should be deformed if the Sibley Buttes structure is other than ice-shove in origin. As Flint (1955, p. 91) explains: "... the shear caused by an overriding glacier can deform incompetent sedimentary layers, creating complex structures and conspicuous ridges that resemble end moraine." This seems to fit the Sibley Buttes structure and topography perfectly.

A slump origin for the Sibley Buttes is possible, but there is no apparent direct evidence to support such an origin. The low in the pre-glacial topography on the northeast side of the "buttes" suggests the possibility of undercutting by streams. Such undercutting would probably cause some local slumping, but the writer doubts if slumping on any greater scale is easily explained. It seems that slumping would have displaced the sandstone blocks into more erratic positions than exist in the Sibley Buttes.

PRE-WISCONSIN GLACIAL DEPOSITS

Leonard (1916, p. 532) suggested that three drift sheets may be present in the state; the late Wisconsin east of the Altamont (Max) moraine, the early Wisconsin west of the moraine and north of the Missouri River, and the Kansan, west and south of the Missouri River. However, recent work by Lemke and Colton (1958, p. 41) indicates there is no direct evidence of pre-Wisconsin glaciation in North Dakota. Flint (1955) in South Dakota, places the Illinoin drift border west of the Missouri River. Assuring this interpretation is correct, it would seem that at least a part of eastern North Dakota was affected by Illinoin ice; however, whether this ice sheet reached as far west as Kidder County is not known.

Apparently, any direct evidence for pre-Wisconsin glaciation in North Dakota will have to come from well data probably through radiocarbon dating.

PHYSICAL GEOLOGY OF THE WISCONSIN STAGE

Glacial Markings

No glacial striae were observed on outcrops in the area. The easy erodability of the Fox Hills sandstone and Pierre shale would erase any evidence of glacial movement in the way of striations. Boulders and cobbles, generally carbonates or granitic rocks, show smoothed and rounded surfaces caused by glacial abrasion. These are most prevalent in end moraine deposits.

Thickness of Drift

Plate 8 is an isopachous map of the glacial drift over the area compiled from information obtained from United States Geological Survey well logs with most information and control in the central portion of the area. The control is directly related to the roughness of the topography in that test wells are primarily drilled in flatter outwash and ground moraine areas and not in the rougher end moraine topography. United States Geological Survey test hole #1125, located approximately 2 miles west of the village of Pettibone (sec. 4, T. 141 N., R. 70 W.) shows the thickest section of drift (352 feet).

The isopach lines of the drift tend to follow the contours on the bedrock topography (compare pl. 7 and 8). This seems reasonable, since after each glacial advance and retreat, the preglacial topography is leveled and former lows tend to be filled and have thicker accumulations of drift.

Topographically higher areas such as end moraines do not necessarily have thicker sections of drift. The Sibley Buttes moraine (herein proposed for that end moraine trending nearly east-west along the southwest portion of the area — pl. 1) trends west of the Sibley Buttes proper and is an example of a bedrock-controlled end moraine. As discussed later, this feature is actually a ridge of mesas and buttes along which the ice stopped thereby forming an end moraine. No test wells have been drilled on the Sibley Buttes moraine, but examination of roadcuts shows the drift might be no more than 25 feet thick on the higher portions of the trend. Intermittent thinning and thickening occurs along its trend because the original topography was relatively dissected.

STRATIGRAPHY OF THE WISCONSIN DEPOSITS

Stratigraphic Subdivision

The classification of Wisconsin drift deposits used in this paper is that of Flint (1955) with some modifications (fig. 9). It is essentially Leighton's (1933) original four-fold classification.

Epoch	Age	Subage	Significant Readvance
PLEISTOCENE	Wisconsin	VALDERS	
		Two Creeks Interstadial	
		MANKATO	Second Mankato
			First Mankato
		Interstadial	
		CARY	
		Interstadial	
		TAZEWELL	
		Interstadial	
		IOWAN	
		Interstadial	
		FARMDALE	

Fig. 9. Classification of Wisconsin age and relation to drift sheets in north-central Kidder County, North Dakota. Modified after Flint, 1955 and Leighton, 1957.

Frye and Willman (1960) have suggested a somewhat revised classification of the Wisconsinan stage (Frye and Willman, 1960), but as yet this classification is only applicable to a local area (Lake Michigan glacial lobe).

Differentiation of Drift Sheets

Relative age differentiation of the various drift sheets on the basis of lithology, color, or degree of weathering of their tills is virtually impossible in this area. Flint (1955) encountered the same problem in working out glacial age relationships in eastern South Dakota, especially in differentiating Cary drift from that of other substages of the Wisconsin. Differences in depth of weathering from one till sheet to another during the relatively short period of Wisconsin time is not to be expected. Also the climate of the area was probably not conducive to rapid weathering. Lithologic changes from one till sheet to another are indistinguishable because the ice passed over essentially the same bedrock and/or drift during each readvance. Topography of the drift is a criterion for relative age determination in that older drift surfaces generally have a more subdued topography. Pebble counts are commonly used for distinguishing different till sheets, but the results of pebble counts in the area mapped were inconclusive. The average composition of pebbles in tills of major moraines in the area is shown in figure 10.

The most successful method in this area for distinguishing relative ages of various drift sheets is by observation of morainal trends or alignments in relation to other trends, as well as the pattern of the outwash bodies.

ROCK TYPE	Sibley Buttes Moraine	McPhail Buttes Moraine	Robinson Moraine	Cherry Lake Moraine
Leucocratic rock	25.2	21.0	18.0	38.0
Melanocratic rock	9.1	16.5	23.0	19.0
Foliated Metamorphic	1.2	—	—	—
Quartzite	5.4	1.2	—	—
Shale	4.4	1.8	7.0	5.0
Sandstone	2.7	—	—	—
Limestone & Dolomite	45.8	56.0	50.0	37.0
Chert	2.5	1.8	1.0	—
Iron Concretion	3.2	0.6	—	—
Miscellaneous	0.5	1.1	1.0	1.0

Fig. 10 Average percentage composition of pebbles in tills of major moraines.

Regional Stratigraphic Relations and Correlations of Wisconsin Deposits

In South Dakota and Minnesota the stratigraphic sequence has been established by correlation from the type areas. This is done generally on the basis of depth of leaching, interglacial loess deposits, degree of dissection of the drift surface, lithologic differences of the drift, and trends of the end moraines. Age assignments for drift in the area mapped are based largely on correlation northward from South Dakota where Flint (1955) has mapped the Pleistocene geology.

The end moraine of Flint's (1955) D-1 Mankato advance is shown by Lemke and Colton (1958) to be correlative with the Streeter moraine (as used by Paulson, 1952) in Logan and McIntosh Counties, North Dakota. Lemke and

Colton (1958) correlate Flint's (1955) 1st Mankato advance in South Dakota with numerous unnamed moraines along the front of the Coteau du Missouri in North Dakota and designate Flint's (1955) 1st Mankato drift as post-Tazewell---pre-Two Creeks drift.

In South Dakota, Flint (1955) shows Cary drift overridden by 1st Mankato ice. The Cary drift disappears beneath Mankato drift in southeastern Walworth County and reappears in Logan County, North Dakota, approximately 80 miles to the north.

Flint (1955, p. 118 - 119) does suggest that his A series (1st Mankato) of moraines may be correlative with the Altamont (Max) moraine and his B series (2nd Mankato) correlative with the Cary moraine. This is based on the greater massiveness of the Altamont in relation to the Cary moraine and accordingly in South Dakota, the A series is more massive than the B series. According to Lemke and Colton (1958, p. 49), Flint's B series approximately correlates with the Cary moraine in southwestern Minnesota.

Local Stratigraphic Relations and Correlations of Wisconsin Deposits

Clayton (1960, unpublished report), in studying the tills of Kidder County by use of hydrometer analyses and morainal trends, concludes that the tills show no significant differences in size of particles. He correlates Flint's (1955) 1st Mankato advance with the moraines in southeastern Kidder County (see pl. 10) where it overlies drift of Cary substage. He also correlates Flint's (1955) 2nd Mankato advance with the moraines situated along the eastern border of Kidder County represented in the area mapped by end and stagnation moraine. This is along the morainal trend which

Campbell, and others, (1916, p. 46) call the Gary moraine. The latter writers show the "Gary" moraine as ending immediately south of Chase Lake in west-central Stutsman County, North Dakota.

According to Clayton (1960) drift of the 2nd Mankato advance overlies 1st Mankato drift in southeastern Kidder County, but northward from here, 1st Mankato drift disappears eastward beneath younger drift and 2nd Mankato drift is in direct contact with Cary drift as shown in plate 10. Previous to this study, no drift of Cary subage was known north of Walworth County, South Dakota; in fact, Lemke and Colton (1958) state that no drift of Cary subage is known at the surface in North Dakota. Rather, they refer to that drift shown as Cary in Kidder County, as post-Tazewell — pre-Two Creeks in subage.

Mapping end moraines and outwash patterns seem to be the most reliable methods for differentiating drift sheets in the Kidder County area. Dating of drift sheets in the area is based on the following evidence:

1. The writer's mapping of end moraine trends and outwash patterns.

2. Flint's (1955) and Clayton's correlations of Cary and Mankato drift sheets northward from South Dakota (pl. 10).

3. Clayton's (1960) study showed no significant differences in particle size of the tills.

On these bases, only Cary and Mankato subages of the Wisconsin age are represented in the area.

The outer margin of Cary drift as used in this paper can be seen on plate 10 as passing immediately west of the area mapped and between the villages of Sterling and Driscoll. The outer margin is herein referred to as the Cary Maximum. In the discussion to follow, drift left by significant readvances of Cary ice within the area mapped will be designated chronologically as 1st Cary drift and 2nd Cary drift, largely for the sake of reference. These relationships are shown on plate 9.

The outer margin of Mankato drift as used in this paper (pl. 10) passes through the extreme eastern portion of the area and consists of the McPhail Buttes moraine (herein proposed for that end moraine located in parts of Tps. 140 and 141 N., and Rs. 70 and 71 W.), till associated with this end moraine and outwash to the north of the moraine. Based on its massiveness and correlation with moraines southward into South Dakota, the McPhail Buttes moraine is assigned a 2nd Mankato subage.

Each drift sheet mentioned above (Cary and Mankato) is discussed under the following headings: 1st Cary drift, 2nd Cary drift, 1st Mankato drift (not exposed in this area), and 2nd Mankato drift. The physical characteristics and interrelationships of each subage are covered separately under each subage heading. The order and method of organization and presentation is applicable only on the basis that these age assignments by correlation from South Dakota are correct.

First Cary Drift

The oldest drift exposed in the area consists of drift associated with the 1st Cary advance. This is expressed topographically by the Sibley Buttes end moraine shown on plate 1.

Relation to Older Drift

The Sibley Buttes moraine marks the outer edge of a Cary readvance. The moraine extends from the area of the Sibley Buttes, outlined on plate 1, west-northwestward out of the area mapped. The inferred position of 1st Cary ice at its maximum is shown in plate 9. The linearity of this moraine is a clue that the underlying bedrock is in a ridge-like form. As shown in figure 11, the Long Lake loop (Todd, 1896) is transected at its north end by the Sibley Buttes moraine.

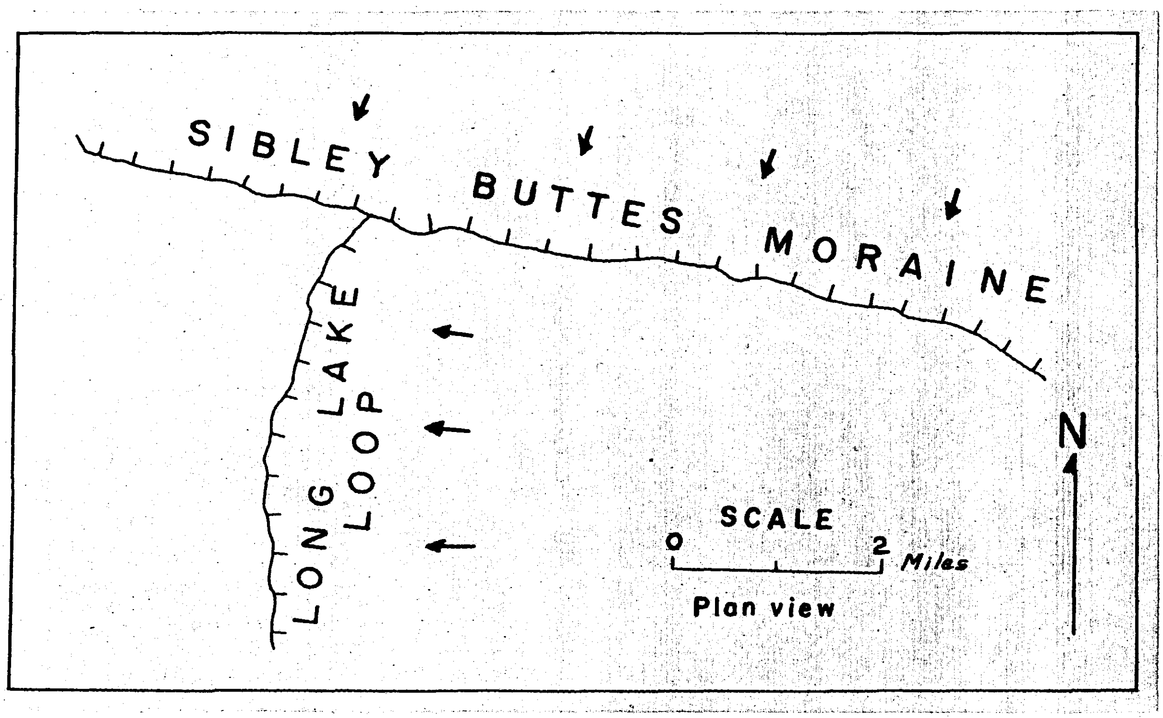

Fig. 11. Diagrammatic relationship between the Long Lake loop and the Sibley Buttes moraine.

The subdued topography of the Long Lake loop compared with the boulder-strewn, rugged topography of the Sibley Buttes moraine is striking. Part of the ruggedness of the Sibley Buttes moraine is due to bedrock influence. The lack of conformity of their trends and differences in topographic expression indicate the Sibley Buttes moraine to be a deposit of a younger advance. Williams (1960) believes the relationship of the two moraines is one of interlobation; therefore the same age.

Lithology of Drift

Till of 1st Cary subage is generally a light, olive-gray (5Y-5/2), clay-rich type (fig. 12). Leaching is insignificant, but locally the till is iron-stained. The greatest thickness exposed in Kidder County is 5 feet; however, westward in Burleigh County, a roadcut 20 feet deep exposed only till.

Fig. 12. Exposure of till in the Sibley Buttes moraine. Location: sec. 27, T. 141 N., R. 74 W.

The material making up the till is nearly all locally derived from underlying bedrock except for granite, limestone, and dolomite erratics brought in from Canada. Mechanical analyses of tills from this moraine are shown in figure 13. Samples studied and plotted showed a grouping on a triangular diagram (fig. 14). Silt content is uniform (about 30 per cent); however, the sand and clay contents range over limits of 20 per cent.

Topographic Expression

End Moraine

The Sibley Buttes moraine comprises the greater percentage of 1st Cary drift exposed at the surface. This moraine appears as a distinct, continuous ridge, especially when viewed from the north. The general relief is approximately 150 feet with local relief of 40 feet. It is steeper on its north side (proximal side) and more gradual sloping on its south side (distal side) as shown by the profile in figure 15 and photograph (fig. 16). Fox Hills sandstone crops out in various places along its trend. The steep-sided gullies along the proximal side of the moraine suggest these may reflect the original dissected preglacial Fox Hills topography mantled with a thin veneer of drift.

The steeper, proximal side of the Sibley Buttes moraine is bounded for the most part by outwash derived from a later ice advance from the north. Along parts of its northern border, it passes gradually into ground moraine, also of 1st Cary subage. Along its distal side, end moraine gradually merges into ground moraine except where the former truncates the older Long Lake loop. The contact between the Sibley Buttes moraine and the ground moraine on its south side is difficult to place.

On the distal side of the Sibley Buttes moraine, where one would expect to find outwash, none is present, except in local areas. This probably

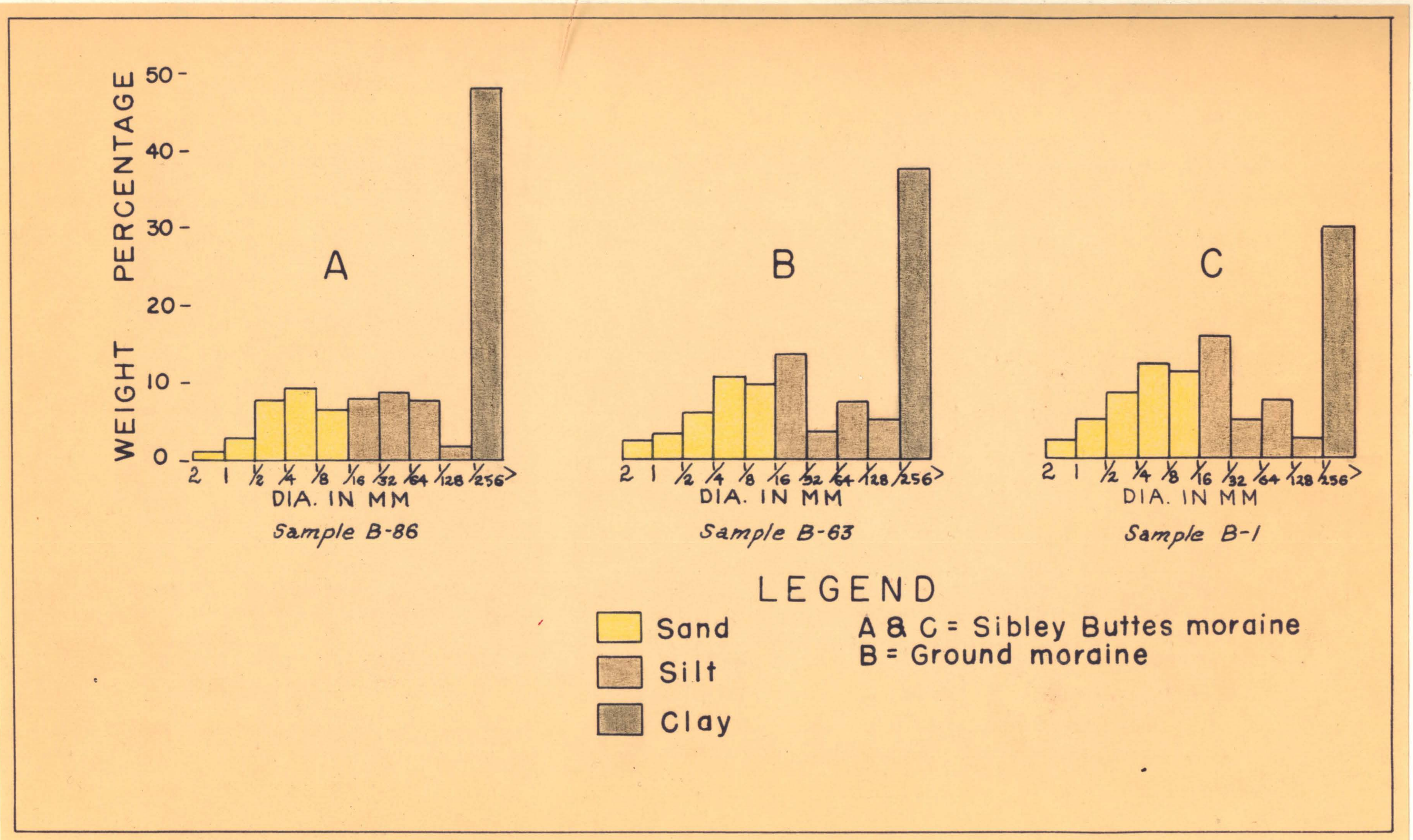

Fig. 13. Histograms showing frequency of grain sizes smaller than granules in till samples of 1st Cary subage.

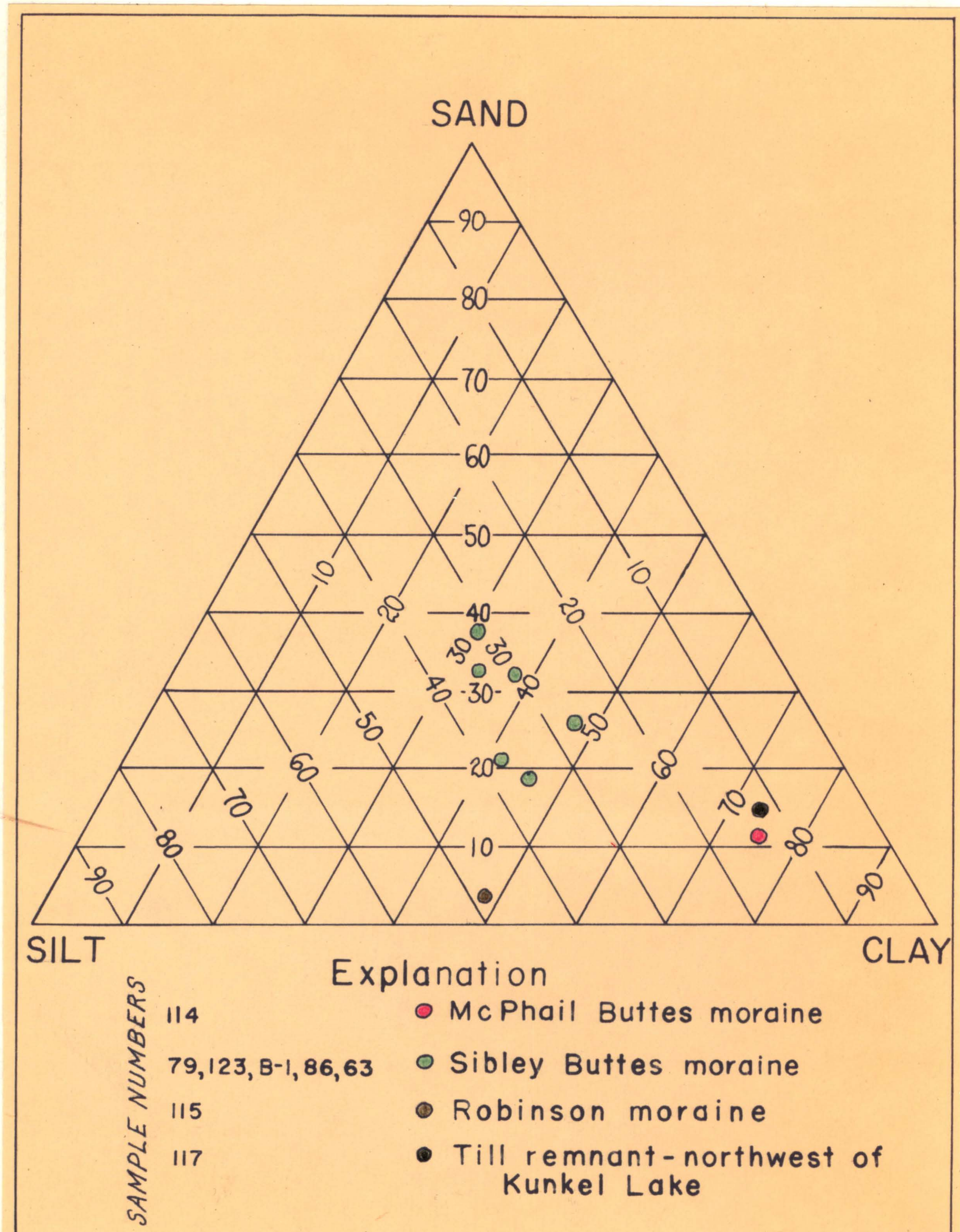

Fig. 14. Size analyses of representative till samples from moraines in north-central Kidder County, North Dakota.

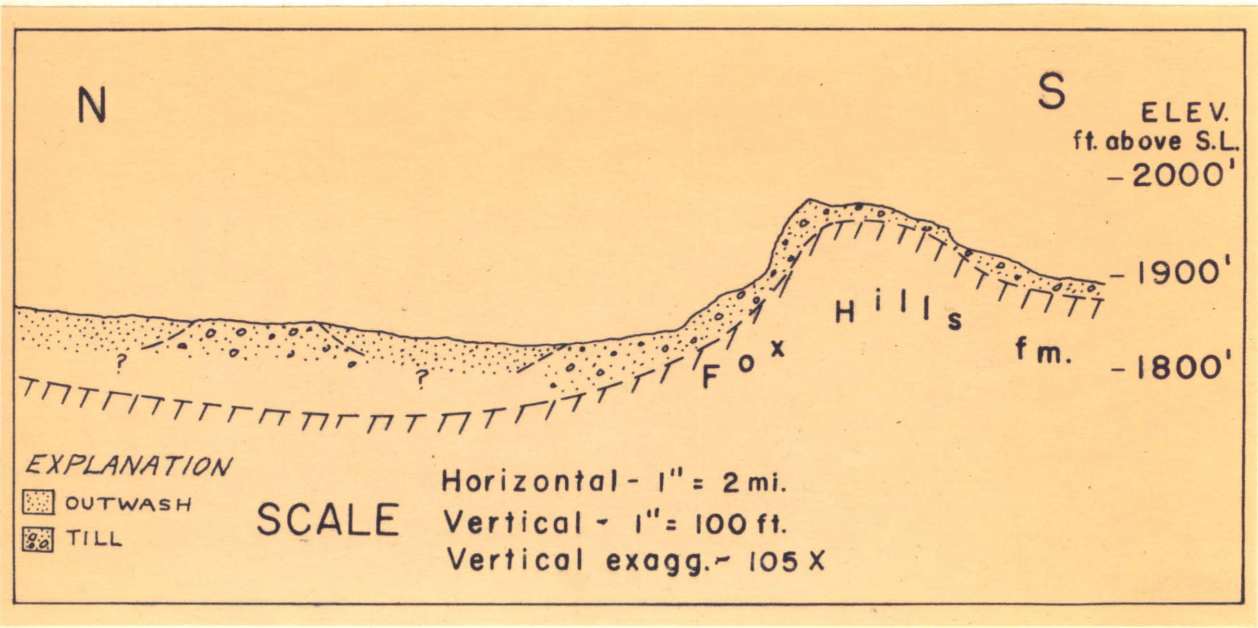

Fig. 15. Profile across the Sibley Buttes moraine. From NE corner, sec. 10, T. 142 N., R. 74 W. to SE corner, sec. 6, T. 140 N., R. 74 W.

Fig. 16. Sibley Buttes moraine in background. Looking southwest from NE¼ sec. 17, T. 141 N., R. 73 W. at proximal slope. Ground moraine in foreground.

indicates a deficiency in drift along the ice front and within 1st Cary ice. Any southward-flowing meltwater must have carried only small amounts of sand and gravel and probably in distinct subglacial channels which today are not evidenced at the surface because of ablation and slumping. An alternative theory is that meltwater flowed northward beneath the 1st Cary ice sheet. Ice advancing upon the bedrock high (in the present position of the Sibley Buttes moraine) became slowed down and forward motion was balanced by melting. Since the topography beneath the ice front sloped northward, meltwater probably flowed beneath the ice. Younger outwash and ground moraine deposited during retreat of this ice sheet has possibly buried outwash of "Sibley Buttes" time.

Many gravel knolls are associated with the drift of the Sibley Buttes moraine. These are local features formed by small englacial and subglacial streams issuing from points within the ice sheet. Patches of coarse gravel of ice-contact origin are located in the south portion, sec. 34, T. 141 N., R. 73 W. These are probably genetically related to the kettle chain located approximately 1 mile west of sec. 34.

Recessional Moraine

Recessional moraines formed during retreat of 1st Cary ice, are present in the west-central portion of the area. These moraines, seen today as a series of discontinuous patches, were probably originally connected and formed during minor halts as the ice sheet retreated eastward. Some outwash-mantled recessional moraines occur in secs. 10, 11, 14, 15, and 22, T. 142 N., R. 74 W. and on aerial photographs the northeast-southwest trends (shown on pl. 1) of the morainic ridges show through the overlying blanket of outwash. When noted on aerial photographs, it is not possible to tell whether these trends are mantled with outwash or not; and only by field observation can such be determined. The thickness of outwash covering this series of recessional moraines is unknown, but it is presumed to be thickest to the north, towards the outwash source area; since along this northern portion of the area, meltwater streams deposited their greatest volumes of bedload material.

The majority of till deposited by retreating 1st Cary ice is buried by outwash from younger ice sheets. A relatively thin sheet of ice must have existed over the recessional moraines in the west-central portion of the area. Such a sheet of ice is necessary to preserve the ridged pattern of the recessional moraines as we see them today. Probably the recessional moraines were buried in proglacial lake waters which eventually froze. Waters flowing off the receding ice front deposited sand and gravel on the frozen mass. Subsequent melting of the underlying ice "let down" the outwash, whereupon it took the shape of the underlying surface. Had not a protective ice sheet been present, meltwater would deposit outwash between the ridges resulting in a level outwash surface.

The linear, northwest-southeast trending patch of till situated in parts of secs. 1, 2, 11, and 12, T. 141 N., R. 74 W., and secs. 7, 8, and 17, T. 141 N., R. 73 W. tends to parallel parts of the recessional moraine to the west and also the Sibley Buttes moraine to the southwest (see pl. 1). It is probably a younger recessional moraine laid down during further retreat of 1st Cary ice. It also has been partially buried by outwash. Till in this moraine contains some white, flat, dolomitic erratics similar to those in the till in one area of the Sibley Buttes moraine (sec. 16, T. 141 N., R. 74 W.). Another till area approximately one square mile in size located in parts of secs. 26, 27, 34, and 35, T. 142 N., R. 74 W. is also part of the drift left by 1st Cary ice.

The foremost example of recessional moraine in the area is the Cherry Lake moraine located in secs. 11, 12, 13, 14, 15, 22, 23, 24, 25, and 26, T. 141 N., R. 73 W. This moraine has distinct arcuate trends convex to the west indicating ice movement from the east. The arcuate trends of the individual ridges show well on aerial photographs, especially in secs. 13, 14, and 23. The trends curve towards the southeast at their south ends and tend to align with the west-northwest——east-southeast trend of the Sibley Buttes.

The Cherry Lake moraine is steeper on its distal (west) side. A cross section of this moraine showing its relation to ground moraine on the west and outwash on the east is shown in plate 11. The moraine is approximately 100 feet above the outwash surface on its east and ground moraine on its west side. Drift is at least 20 feet thick in one roadcut across the moraine; however, the exact thickness over the main portion of the moraine is unknown, since no roads traverse its highest portion and no test holes have penetrated it. Coarse gravel and sand occur within parts of the moraine and were deposited by glacial streams ending in ponded water. The till-outwash contact on the east side of the Cherry Lake moraine is not difficult to map. Boulders, which in this case indicate the presence of till, mark the till-outwash contact. Although some meltwater no doubt flowed west from the site of this moraine, considerable glaciofluvial material might have left by east-flowing subglacial channels while ice still occupied the area. Evidence for this consists of a strip of coarse outwash extending north-south along the east side of the moraine. The outwash becomes progressively finer towards Horsehead Lake. The slope of the land beneath the ice was probably to the east at the time of deposition of the moraine; therefore, the meltwater flowed in that direction. This indicates the present position of the Cherry Lake moraine may mark the position of a bedrock high. Younger outwash from the north has partially buried this moraine on its north side.

United States Geological Survey test hole #1146 located along the west side of Horsehead Lake indicates 40 feet of clay in part of its section. This suggests a glacial lake may have been dammed up in the area, perhaps during deposition of the Cherry Lake moraine. A less likely interpretation is that the clay section marks a till deposit devoid of coarse fractions. From study of well logs, it appears that outwash east of the Cherry Lake moraine overlies till of 1st Cary subage; therefore, the till is probably the same age as that making up the Cherry Lake moraine (see cross section, pl. 11).

Two small patches of till situated at the south end of Horsehead Lake in parts of secs. 26, 27, and 35, T. 141 N., R. 72 W. are deposits of retreating 1st Cary ice. These till patches are in an area which has a relief of about 60 feet. A gravelly knoll is present on the northwestern-most of the two till patches. The outwash surrounding these till remnants is relatively thin, especially on the east and southeast sides. In the NW corner, sec. 31, T. 141 N., R. 71 W. (United States Geological Survey test hole #1016) till is only 15 feet from the surface. In the SW corner, sec. 24, T. 141 N., R. 72 W. (test hole #1017) till occurs within 7 feet of the surface. In both localities the till is overlain by outwash.

Ground Moraine

The only ground moraine at the surface in the area is that associated with Cary ice. It is located along the proximal side of the Sibley Buttes moraine as shown on plate 1. The local relief does not exceed 20 feet and slopes are gentle. Boulders are locally sparse, but this may only appear so, since such areas, due to their relative flatness, are usually farmed; consequently the rocks have been removed by man. Ground moraine, since its surface is characteristically flat, is not subjected to as great erosion as end moraine; hence boulders may not be exposed as readily as in end moraine areas.

Ground moraine west of the Cherry Lake moraine is partially buried by outwash on its north side. Cross section A-A' (pl. 12) indicates evidence for this interpretation. A section of till extends through all the well sections beneath the outwash layer.

Outwash

The only exposed outwash of 1st Cary subage, other than that east of the Cherry Lake moraine, is found southwestward out of the area. Outwash of 1st Cary time is scant and probably flowed north and south of the ice front which occupied the present position of the Sibley Buttes moraine.

Locally, clay-rich lacustrine material is interbedded with till indicating the former presence of subglacial or proglacial lakes. Besides the lacustrine sediments in a test hole along the east side of the Cherry Lake moraine, other test hole logs indicate "clay" in their sections; however, those may or may not record old glacial lake deposits, since some other so-called "clays" are known to be till.

Second Cary Drift

Second Cary drift consists of stagnation moraine bordering the northern portion of the area as well as the outwash derived from this stagnant ice sheet and located south of the stagnation moraine. The inferred frontal position of the ice at this time is shown in plate 9. Nearly the entire southern drift border is marked by topographic features characteristic of stagnant ice including pitted outwash plains, esker-like ridges, and other ice-contact stratified deposits. These features indicate the ice sheet had become thinned and was breaking into separate ice blocks which eventually were buried by outwash.

Relation to Older Drift

The relation of the 2nd Cary morainal deposits to those of 1st Cary time is striking. The entire drift sheet of 2nd Cary time is bordered on its distal side by very coarse and sometimes pitted outwash, whereas the distal border of the 1st Cary advance has little outwash.

Lithology of Drift

Till of 2nd Cary time is not megascopically distinguishable from that of earlier Cary deposits. Again, it is a light, olive-gray (5Y-5/2), tenacious, moderately oxidized and very calcareous variety of till. Maximum drift thickness observed is approximately 15 feet. Representative histograms of 2nd Cary till are shown in figure 17.

Topographic Expression

Stagnation Moraine

No special name has been applied to the area of stagnation moraine bordering the northern portion of the area; however, for ease of reference the part of this till sheet centered around the village of Robinson will hereafter be referred to as the Robinson moraine. It is predominantly an area of "knob and kettle" topography and extends pronglike southward for three miles where it is surrounded on three sides by outwash. Local relief on the Robinson moraine itself is 50 feet, but the regional relief in relation to the surrounding outwash plain is slight with the surface of the moraine no more than 15 feet above the general elevation of the outwash area.

Interfingering of outwash with till occurs along the southern edge of the Robinson moraine; and as one proceeds north-south across the till-outwash contact, a dozen or more changes from sand to till to sand, etc., occur within half a mile. Were it not for the roadcuts, which give an indication of the lithology, it would be difficult to place the till-outwash contact, since topographically there is no change. In addition, the outwash does not coarsen towards the Robinson moraine. This suggests the moraine is slightly older than the outwash which surrounds and partially buries it.

Stagnation moraine of 2nd Cary subage occurs at irregular intervals along the northern border of the area between the Robinson moraine and the Burleigh County line, and throughout the greater portion of the northern quarter of Kidder County mapped by Chmelik (1960).

Fig. 17. Histograms showing frequencies of grain sizes smaller than granules in till samples of 2nd Cary subage.

Recessional Moraine

The only recessional moraine of 2nd Cary time in the area is located in secs. 4 and 5, T. 142 N., R. 74 W. It is partly surrounded by, and in contact with, outwash and stagnation moraine. Maximum local relief is approximately 20 feet. It is topographically similar to the surrounding area which consists of rolling, sometimes pitted outwash plains and "knob and kettle" areas of stagnation moraine. The northeast-southwest trending ridges of this moraine indicate the ice of 2nd Cary time was locally active from the northwest.

Ground Moraine

Ground moraine of 2nd Cary time is present in patches east and west of the village of Tuttle. These areas have relief similar to the ground moraine associated with 1st Cary deposits. The ground moraine on either side of Tuttle marks an area which was not occupied by stagnant ice, but rather was passed over by an evenly retreating part of the ice mass.

Outwash

Second Cary outwash covers about one-third of the area mapped. It is variable in texture depending upon its relationship to the source area. In general, coarser outwash is found closer to the distal border of the 2nd Cary drift sheet.

Meltwater, flowing from the stagnant ice during 2nd Cary time, discharged from various positions along the ice border. A massive outwash plain of sand and gravel was formed to the south as the various meltwater streams coalesced. This coalescence and shifting of meltwater channels from side to side caused successive layers of sand and gravel to be spread over the area. As glaciofluvial material was spread southward, the coarser and heavier sediment was laid down first. This is shown when traversing North Dakota State highway #36 westward from Tuttle to the Kidder County-Burleigh County line. This road parallels the Northern Pacific Railroad tracks and this track bed has cuts up to 20 feet deep which expose medium to well-rounded gravel and sand with abundant cobbles up to 7 inches in diameter. The road and railroad alike essentially parallel the front of the stagnant ice sheet of 2nd Cary time. Outwash from this railroad cut (SW corner, sec. 2, T. 142 N., R. 74 W.) was sampled and its histogram is shown in figure 18F along with histograms of other 2nd Cary outwash. A photograph of this same outwash is shown in figure 19. The deposit is moderate to well sorted, slightly stratified and loosely compacted. Its coarseness indicates discharge was excessive at the time of deposition.

Southward from this railroad cut, grain size of outwash decreases until, in the area approximately 5 miles south, it consists of fine to medium-grained sand. The outwash plain in the area 5 to 6 miles southwest of Tuttle is exceptionally level with local relief no more than 3 feet. (fig. 20). Some outwash derived from 2nd Cary ice was carried nearly 8 miles south to the proximal side of the Sibley Buttes moraine; hence, as can be seen in plate 1, the entire area between Tuttle and the Sibley Buttes moraine is a vast outwash plain. Areas closer to the Sibley Buttes moraine were probably final settling places for the finer fractions of sand and silt washed out of the stagnant ice from the north. Outwash thickness south and southwest of Tuttle is unknown. Evidence that this outwash plain is built

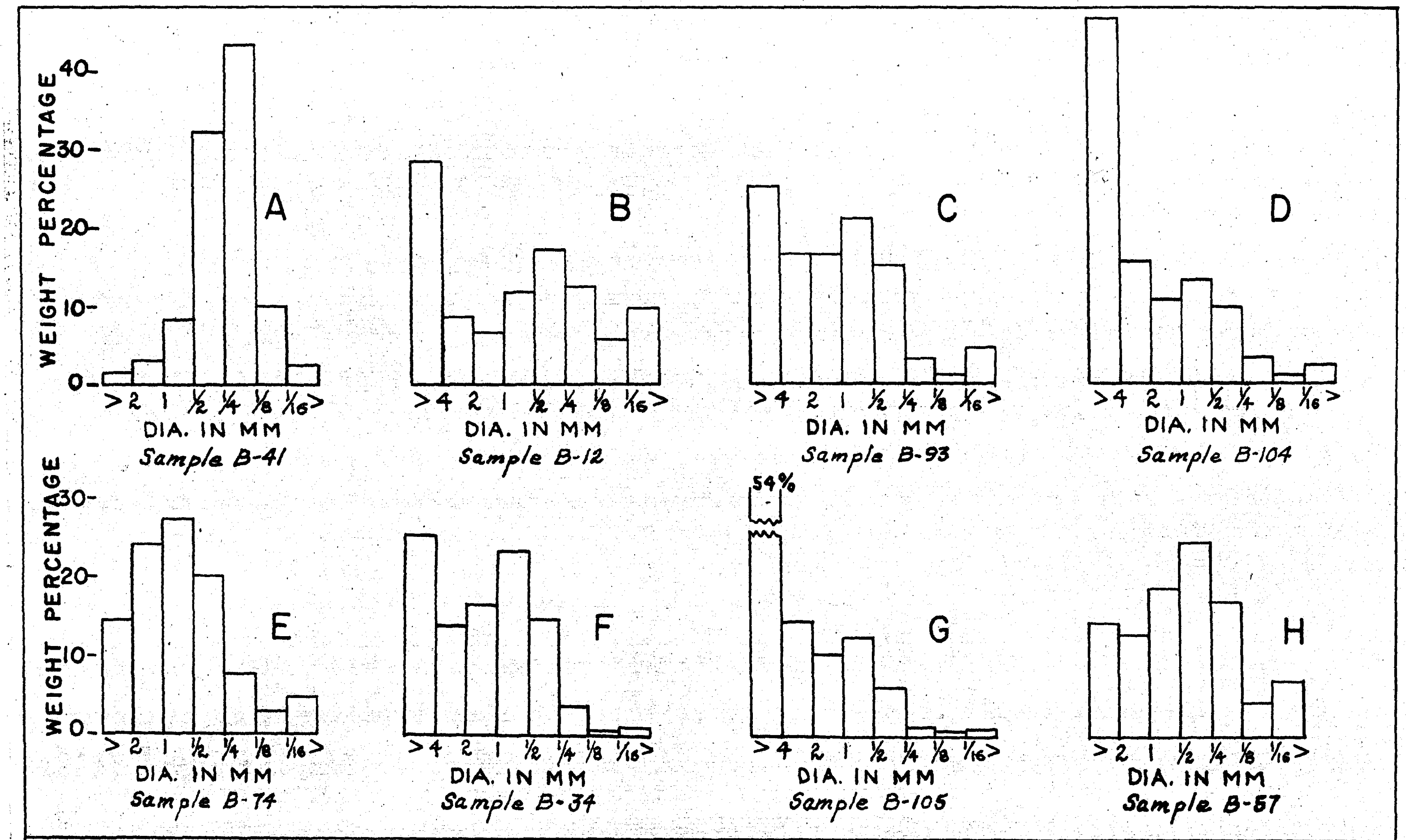

Fig. 13. Histograms of representative outwash samples of 2nd Cary substage.

Fig. 19. Outwash of 2nd Cary subage (one-fourth mile west of Tuttle). Note extreme coarseness of material. Cut is about 7 feet deep.

Fig. 20. Outwash plain south of Tuttle. Looking north from top of Sibley Buttes moraine.

largely of material derived from the north is three-fold: 1) the outwash plain slopes gradually southward, 2) the material decreases in grain size southward, and 3) strata dip 3° to 4° to the south in the SW¼ NW¼ sec. 26, T. 142 N., R. 74 W. Other areas also show southward-dipping strata.

Outwash adjoining the eastern end of the recessional moraine located in secs. 16, 17, and part of 18, T. 142 N., R. 74 W. is probably related to the meltwater channel which extends from the north at this point. The strata in a gravel pit located in the SW¼ NW¼ sec. 16, T. 142 N., R. 74 W. dip southwestward 20° to 25°. The relatively steep dips of the strata may be due to ice-contact slumping. The section consists of 2 feet of medium to coarse gravel with cobbles up to 100 millimeters in diameter. This is underlain by 8 feet of slightly finer grained sand and gravel. In places, the upper 2 feet of drift has the appearance of till or "dirty outwash"; however, this is probably due to recent wind-blown silt intermixed with the upper 2 feet of outwash. Rounded shale pebbles up to 40 millimeters in diameter are abundant. The entire section is calcareous.

Approximately one-half mile southeast of the above location, a roadcut shows very coarse gravel of which 70 to 80 percent is large pebble through cobble size. The strata appear to dip southwestward at 17°. This is in general agreement with the stratification in the pit to the northwest.

Not all areas of outwash exhibited stratification as distinct as those exposures mentioned above. Stratification is generally lacking in the majority of roadcuts indicating deposition occurred under relatively uniform conditions or else the rate of deposition was too rapid for stratification to develop. Considerable shale is interstratified with the outwash sands. One example is that located two-tenths mile west of the NE corner, sec. 8, T. 141 N., R. 73 W. where the soil cover is underlain by 6 inches of very shaly outwash. This is underlain by coarse sand and gravel largely devoid of shale. The sequence indicates a different source area for the two units.

Outwash of 2nd Cary subage has partially buried some areas of 1st Cary drift. One instance is that located in parts of secs. 26, 27, 34, and 35, T. 142 N., R. 74 W. as well as the recessional moraine located in parts of secs. 16, 17, and 18, T. 142 N., R. 74 W. In the last mentioned area, 1st Cary ground moraine is still considerably higher than the surrounding outwash plain, probably 50 to 75 feet. This contrasts to the till-outwash elevation relationships around the Robinson moraine mentioned previously.

Ice-Contact Features

The 2nd Cary ice sheet was relatively thin over a large area as indicated by the pitted nature of the outwash along the south edge of the stagnation moraine, especially between Tuttle and the Burleigh County line. The area of sec. 24; S½ sec. 13; north portion, sec. 25; and the east portion, secs. 23 and 26, T. 142 N., R. 74 W. and the W½ sec. 19, T. 142 N., R. 73 W. comprise the larger part of a pitted outwash plain. Its material consists of a very coarse gravel intermixed with coarse-grained sands. A few ice-rafted boulders are scattered on the surface. The surface shows general accordance of summits with the only irregularities being kettles scattered between the knolls. Possibly some of the irregularities are due to settling after frozen gravel and sand had thawed. Ice blocks which melted to form this pitted plain may have been part of the same ice sheet that formed the collapsed area associated with the kettle chain south of Tuttle. This feature is discussed in more detail below.

Another area of pitted outwash and till associated with 2nd Cary time is located in the W½ sec. 5, T. 142 N., R. 74 W. It consists of coarse gravels and sands and is mapped as part of the stagnation moraine which adjoins it because of its close association with the till of this moraine.

Varying degrees of pitting occur throughout most of the area covered by outwash of 2nd Cary subage. This is related to the stagnant nature of the ice and the fact that most of the meltwater channels which deposited the glaciofluvial material also carried blocks of ice out onto the outwash plain where they were buried and eventually melted.

Ice-marginal drift is evident throughout other parts of the area. Often this occurs as massive, slumped deposits of stratified drift near the head of the original outwash source. Such deposits consist predominantly of gravel and sand. Topographically, such areas remain at approximately the same elevation as the adjacent morainal areas; therefore, no simple relationship exists between their topographic expression and lithology. A good example of this occurs in the NE¼, T. 141 N., R. 71 W. in the Kunkel Lake area. Another such occurrence is in the SW¼ sec. 20, T. 142 N., R. 73 W. and crossing southward to the SW corner, sec. 20, T. 142 N., R. 73 W.

Kettles are found largely in stratified drift, usually close to the former ice margin. The fact that most kettles occur in chains, sometimes indicates a relationship to preglacial valleys in which the ice persisted longer than elsewhere. A series of kettles is present in the form of a "chain" extending east-west from a point 1 mile south of Tuttle. It occupies parts of sec. 12, T. 142 N., R. 74 W. and secs. 7, 15, 16, 17, and 18, T. 142 N., R. 73 W. It becomes indistinct about 4 miles southeast of Tuttle where it passes into present-day drainage. The kettle chain is surrounded by outwash except on its west end where it heads in stagnation moraine. Its maximum relief is about 60 feet. Local residents report that Clear Lake, one of the lakes in this kettle chain, is 40 to 50 feet deep.

The lithology and structures relative to the origin of this kettle chain are best seen in a gravel pit located approximately 1 mile south of Tuttle (NW¼ SE¼ sec. 12, T. 142 N., R. 74 W.). In this pit, 3 to 4 feet of light to medium gray, sandy till overlie gravel and sand with the latter exhibiting slumped and disrupted bedding. The overlying till is up to 4 feet thick and locally absent. Dips of the strata are erratic due to slumping.

The position of this kettle chain probably marks the location of a preglacial valley. Apparently a lobe of ice existed in this valley and the surrounding area for an indeterminate length of time. Eventually the ice retreated, but blocks of ice remained in the lower parts of the valley. During further melting, the valley acted as a meltwater channel for water flowing east; and, as water flowed on top of the ice-filled depressions, blocks of ice were buried by sand and gravel. Subsequent melting caused ice-contact slumping and formation of collapse structures along the valley banks. This created ideal conditions for the formation of small, angular unconformities caused by slumping alternating with periods of deposition. This sequence of events occurred numerous times as shown by the numerous unconformities.

Another kettle chain is located along the east side of Horsehead Lake (pl. 1). In this series over half a dozen nearly circular lakes are in general north-south alignment for over three miles. The kettle chain exhibits a slight convexity to the west and occurs in an area of fine to medium-grained outwash. The relief is approximately 75 feet. The closest United States Geological Survey test hole is located at the south end of the kettle chain (SW corner, sec. 24, T. 141 N., R. 72 W.). Its log shows 3 feet of soil, 4 feet of outwash, 22 feet of till, and 150 feet of alternating outwash and till. Locations of other kettle chains are shown on plate 1.

The sinuous ridge located in sec. 6, and part of sec. 7, T. 141 N., R. 73 W. is probably an esker; although admittedly there is not enough information available to say the feature is not some other type of ice-contact deposit such as a crevasse filling. Both eskers and crevasse fillings may be sinuous and be composed of fine sand as is this deposit. For lack of definite information, the sinuous ridge herein described will be referred to as an esker-like ridge. This ridge, shown in figure 21, is about 25 feet wide at the base and trends north-south for about one-fifth mile before becoming indistinct. A roadcut across this ridge (one-tenth mile west, SE corner, sec. 6, T. 141 N., R. 73 W.) exposes 14 feet of very clayey till overlain by 6 feet of gravel and sand with rounded shale pebbles. The till is light-olive gray with dolomite cobbles and fragments of boulders scattered on its surface. The contact zone is interlensing and the gravel and sand are loosely compacted. No stratification or slumping is evident. This ice-contact feature formed when the retreating border of 1st Cary ice

Fig. 21. View looking north along esker south of Tuttle

was situated near the present position of the esker. Meltwater flowed in a subglacial or englacial stream and headed northward, probably paralleling present-day drainage.

Another esker-like deposit, somewhat smaller than the one mentioned above, is located in the NE corner, sec. 24, and the SE corner, sec. 13, T. 142 N., R. 74 W. It is situated within a pitted outwash plain and is genetically related to this plain. A recently opened gravel pit shows strata dipping southwestward. The main portion of the esker trends N. 45 E. and is approximately three-fourths mile long and 100 feet wide at the base. Another ridge branches off at nearly right angles and extends west-northwest for approximately one-fourth mile. This branching arrangement could be a crevasse filling at right angles to the esker proper. The section as measured in a gravel pit in this esker is shown on the following page.

Two-tenths mile west of NE corner, sec. 24, T. 142 N., R. 74 W.

	Feet
Sand and gravel, medium-brown, 30 to 40 percent of clastics pebble size and coarser, faint stratification inclined to the southwest	1.0
Silt, medium to dark gray, clayey, pebble-free	0.5
Sand and gravel, same as upper 1 ft.	5.0
Base Concealed	___
Total Exposed	6.5

Boulders 2 to 3 feet in long diameter are scattered throughout this pit indicating ice rafting occurred. Some slumped bedding is evident.

There are other smaller esker-like ridges evident on aerial photographs of the area, especially immediately south and southeast of Tuttle. A peculiar and interesting type of ridge occurs in secs. 29 and 32, T. 142 N., R. 73 W. On aerial photographs the feature appears as two parallel ridges. The first impression is that water flowed between these ridges. They probably mark the former position of meltwater channels with natural levees bordering their sides. It is the natural levees which are seen as parallel ridges. The area has since been partially smoothed by wind action causing the ridges to be less distinct than might be expected. Where ridges do not occur in parallel sets, they too may be associated with former meltwater channels. Material from one of these ridges consisted of loosely compacted, medium-brown sand and gravel with some boulders present on the surface. No slumped bedding is present, but the roadcuts through the ridges are not deep enough to make a thorough investigation.

Faintly varved clays occur in the outwash plain in a roadcut located one-tenth mile south of the NW corner, sec. 7, T. 142 N., R. 74 W. This roadcut consists of 3 feet of fine to medium-grained sand (glaciofluvial) underlain by $3\frac{1}{2}$ feet of yellow-brown clay showing alternating light and dark laminations. The dark layers are three-fourths inch thick and the light beds 6 inches thick. This sequence is underlain by yellow-brown, silty clay which grades downward into fine-grained sand. These varved clays indicate the presence of one of many small, local, ice-marginal lakes which existed along the distal side of the stagnating 2nd Cary ice. Some of these lakes persisted long than others depending on various climatic factors. Some were dammed by ice blocks and, depending on the rate of melting, lacustrine sediments accumulated in the ponded areas.

Second Mankato Drift

Relation to Older Drift

The drift of 2nd Mankato subage consists of till and minor amounts of outwash associated with the McPhail Buttes moraine as well as smaller till sheets in the eastern portion of the field area. Besides being topographically similar, Mankato and Cary drifts exhibit tills of essentially identical lithologies and depths of leaching.

The approximate position of the 2nd Mankato drift border is shown in plate 9. The outer margin of 2nd Mankato ice in the area is marked by the massive McPhail Buttes moraine. It is an end moraine in the truest sense of the word. Its interlobate relationship with the Crystal Springs moraine (Williams, 1960) located to the south indicates the ice front was lobate during their deposition. Traced southward, the McPhail Buttes moraine correlates with the Crystal Springs moraine and joins the Streeter moraine (as used by Simpson, 1952) in Logan and McIntosh counties before passing into South Dakota.

The McPhail Buttes moraine is lobate and convex westward in contrast to the linear trending, older Sibley Buttes moraine. The difference in form between the topographies of the two moraines is due to the influence of bedrock on the latter moraine. The names of both end moraines, because of the word "butte", imply bedrock; however, none was found in the McPhail Buttes moraine; although its geomorphology is suggestive of bedrock, especially when viewed from the south. The interlobate relationship of the McPhail Buttes moraine and the Crystal Springs moraine may be related to a bedrock high. Often bedrock highs will split ice sheets with individual lobes flowing around each side of the bedrock. Often, at the same time, the ice is slowed or stopped with subsequent deposition of an interlobate moraine.

Lithology of Drift

Till of 2nd Mankato subage is megascopically indistinguishable from that of Cary subage. It is essentially the same clay-rich type (fig. 22) found in other till sheets in the area. The color is light, olive-gray (5Y-6/1). The greatest thickness observed in a roadcut is 12 feet. Boulders are abundant on drift of 2nd Mankato subage. In South Dakota, Flint (1955) was unable to differentiate Cary from Mankato till on the basis of mechanical analysis or physical appearance.

As shown in figure 14, the clay content is lower in tills from the Sibley Buttes moraine and in drift located along the northern portion of the

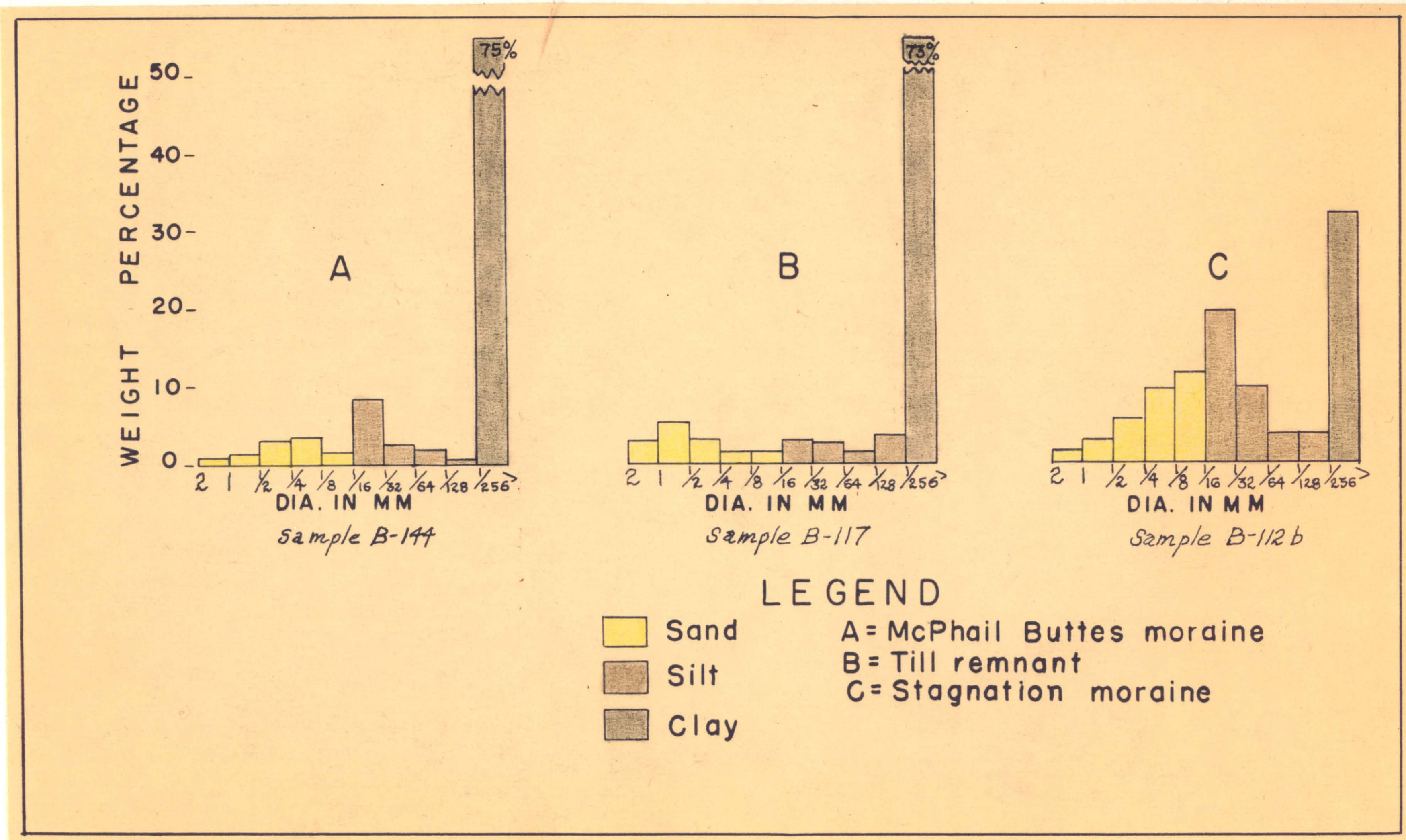

Fig. 22. Histograms showing frequency of grain sizes smaller than granules in till samples of 2nd Mankato subage.

area than that in the McPhail Buttes moraine and in the till remnant located northwest of the McPhail Buttes moraine. On the basis of lithologic similarity of tills and relative geographic positions, this till remnant is believed correlative with the McPhail Buttes moraine (2nd Mankato subage). Plate 9 shows the probable line of connection of these two features. It should be noticed (fig. 14) that these 2nd Mankato tills have a greater clay content than the 1st Cary till of the Sibley Buttes moraine. Clayton's (1960) more complete work, however, showed no significant differences in grain sizes of the tills throughout the county; and the variance between the writer's and Clayton's results may be due to the greater number of samples analyzed by the latter.

Topographic Expression

End Moraine

The McPhail Buttes end moraine has a general relief of approximately 100 feet with local relief of 60 feet. It consists of a continuous curving ridge along its outer edge behind which is an area of stagnation moraine (see pl. 1). The relationships between the end and stagnation moraine are distinct, both on aerial photographs and in the field. The surface of stagnation moraine is generally 75 feet below the crest of the highest ridge in the end moraine proper. The distal slope of the McPhail Buttes moraine is somewhat steeper than the proximal slope (see profile, fig. 23). The area of stagnation moraine has local relief of 50 feet with its surface characterized by stagnation features. These features (mostly knob and kettle topography) were formed as the 2nd Mankato lobe, which previously built the McPhail Buttes moraine, stagnated.

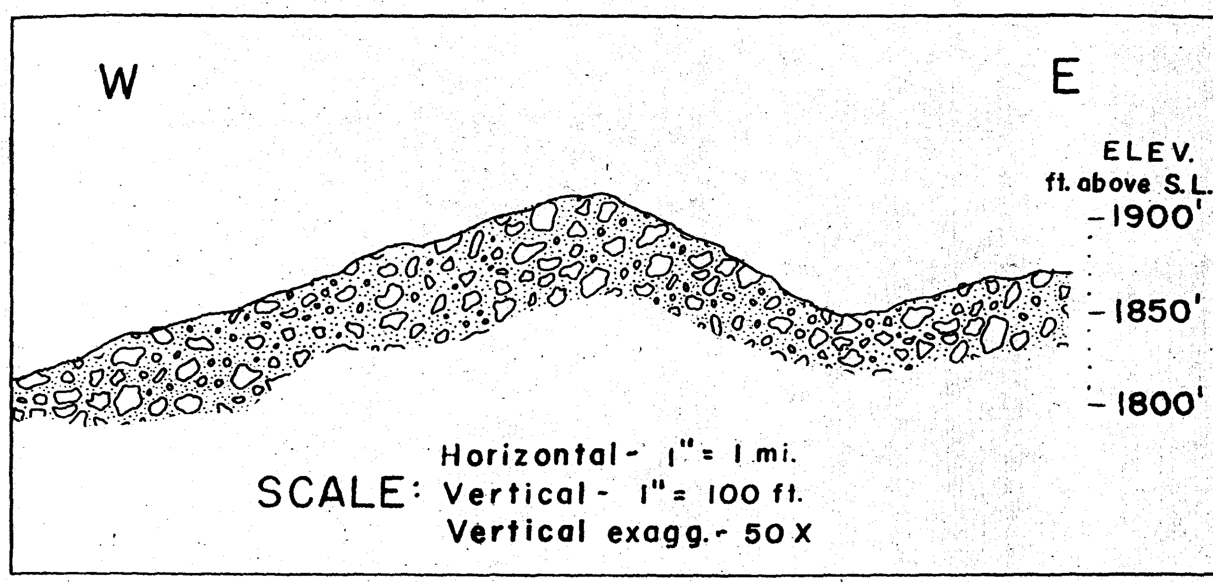

Fig. 23. Profile across McPhail Buttes moraine. From sec. 22, T. 141 N., R. 71 W. to NE corner, sec. 24, T. 141 N., R. 70 W. Distal slope to west.

The area of stagnation moraine located in parts of secs. 25, 35, and 36, T. 142 N., R. 70 W. and secs. 1 and 2, T. 141 N., R. 70 W. is apparently part of the stagnation moraine located behind the McPhail Buttes moraine. This till sheet projects into eastern Kidder County about 1½ miles and is peculiar in that it has local relief of only 25 feet with its overall surface about equal to or slightly lower than the outwash plain which surrounds it on the north, west, and south sides. It is approximately at the same elevation as the stagnation moraine behind the McPhail Buttes moraine. This leads the writer to believe the two areas were formerly connected. Possibly the outwash now separating the two areas has buried part of the intervening area of till.

The small remnant of clayey till located in parts of secs. 27, 28, and 33, T. 142 N., R. 71 W., approximately halfway between Kunkel Lake and the village of Robinson, is probably a remnant of moraine left by 2nd Mankato ice. This till sheet is not any higher than the surrounding outwash plain, hence this moraine is partially buried by outwash.

Outwash

Most of the stratified drift derived from the ice of 2nd Mankato subage occurs along the southern and western sides of the McPhail Buttes moraine. The outwash generally becomes coarser as the morainal front is approached from the south. Outwash from post-2nd Mankato maximum pulsations has partially buried some 2nd Mankato drift. The fine-grained outwash along the north side of the McPhail Buttes moraine is derived from areas north and northeast.

The majority of outwash in the western two-thirds of the area is derived from the north, but approximately eastward from the Robinson moraine, the direction of outwash coarsening is towards the east indicating a shift in source area. Sand in a roadcut located four-tenths of a mile east of the village of Lake Williams on North Dakota highway #36 shows strata dipping westward at about 10°

Outwash in a gravel pit located half a mile south of Pettibone displays excellent cross stratification of both torrential and scour and fill types. The upper 8 feet of medium and coarse gravel has beds dipping west at approximately 2° . This further confirms the eastern source for this outwash. The scour and fill cross stratification is near the base of the 13 foot deep pit. The entire cut of this pit was channel sampled and found to be predominantly granule-sized material. Its histogram (sample B-120), along with other 2nd Mankato outwash samples is shown in figure 24. Occasional rounded pebbles of Pierre shale occur in the outwash, but their frequency is not as great as in other outwash areas to the west.

The characteristic feature of most outwash deposited during melting of 2nd Mankato ice is the pitting it displays mostly along the northeast border of the area and specifically around Sink Lake. What may possibly be an old remnant of a previous drift surface and what is now observed as a pitted outwash plain is located in parts of secs. 10 and 15, T. 142 N., R. 71 W., near Sink Lake. This remnant is in the form of a relatively flat-topped knoll situated about 75 feet above the surrounding outwash plain. The knoll is composed of material ranging from pebble gravel through fine sand with medium-grained sand being the predominant size (fig. 24, sample B-111). Rounded shale pebbles up to 25 millimeters in diameter are present on top of the knoll. A slough adjoins this feature on its immediate west and is about 75 feet below the top of the knoll. The relationship between the slough or kettle and the knoll is an indication of the thickness of the former ice sheet. Apparently the entire area around the knoll was once covered by an ice mass upon which was deposited glaciofluvial material. As the buried ice melted, sand and gravel was let down as a sheet-like covering (see fig. 25A, B). In places, the ice was thicker and in such areas a sag occurs in the present topography such as X in figure 25B. The difference in elevation between the bottom of the present-day adjoining sag and the top of the flat-topped knoll to its east is a rough index to the former thickness of the ice in this locale. Assuming this

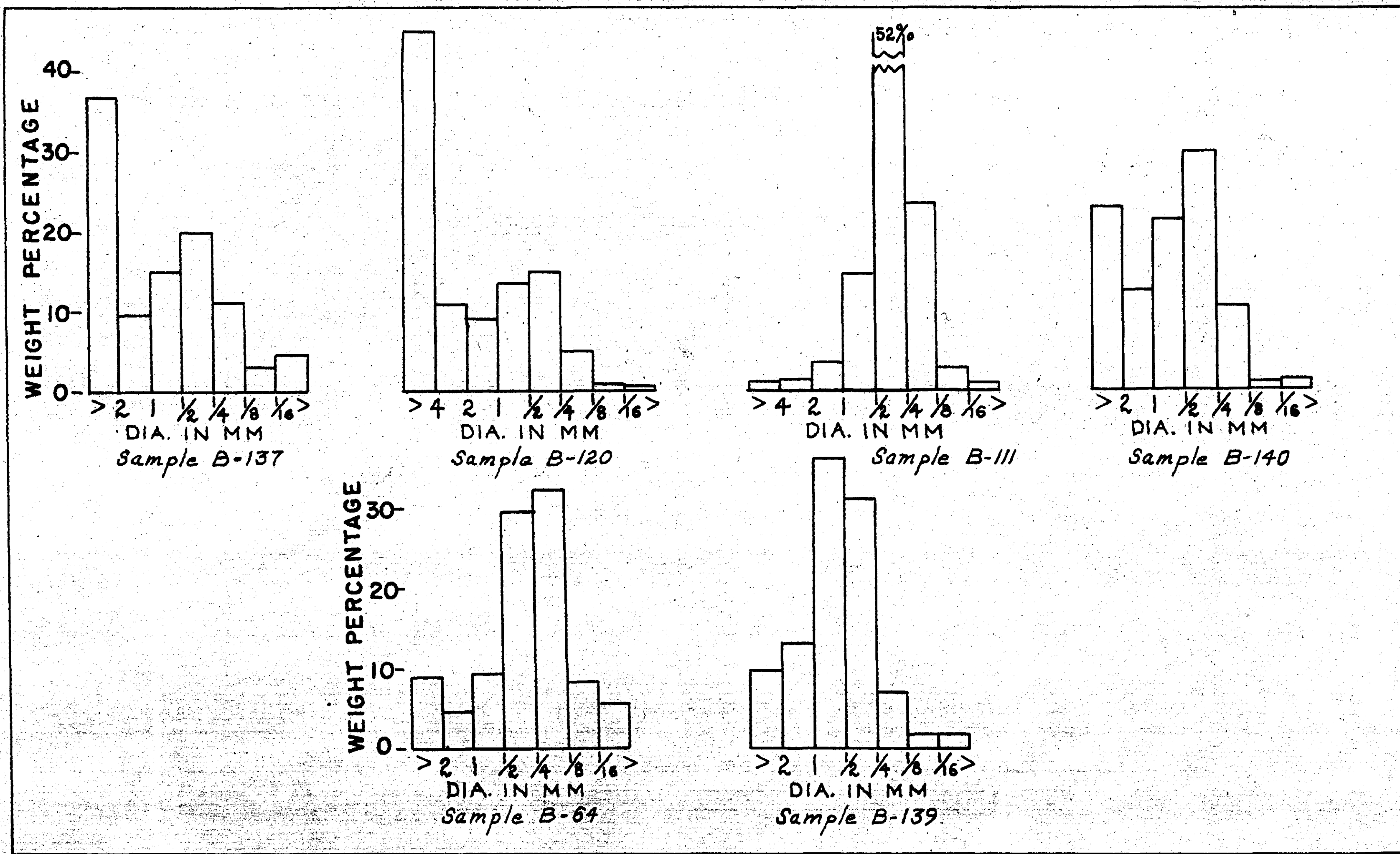

Fig. 24. Histograms of representative outwash samples of 2nd Mankato subages.

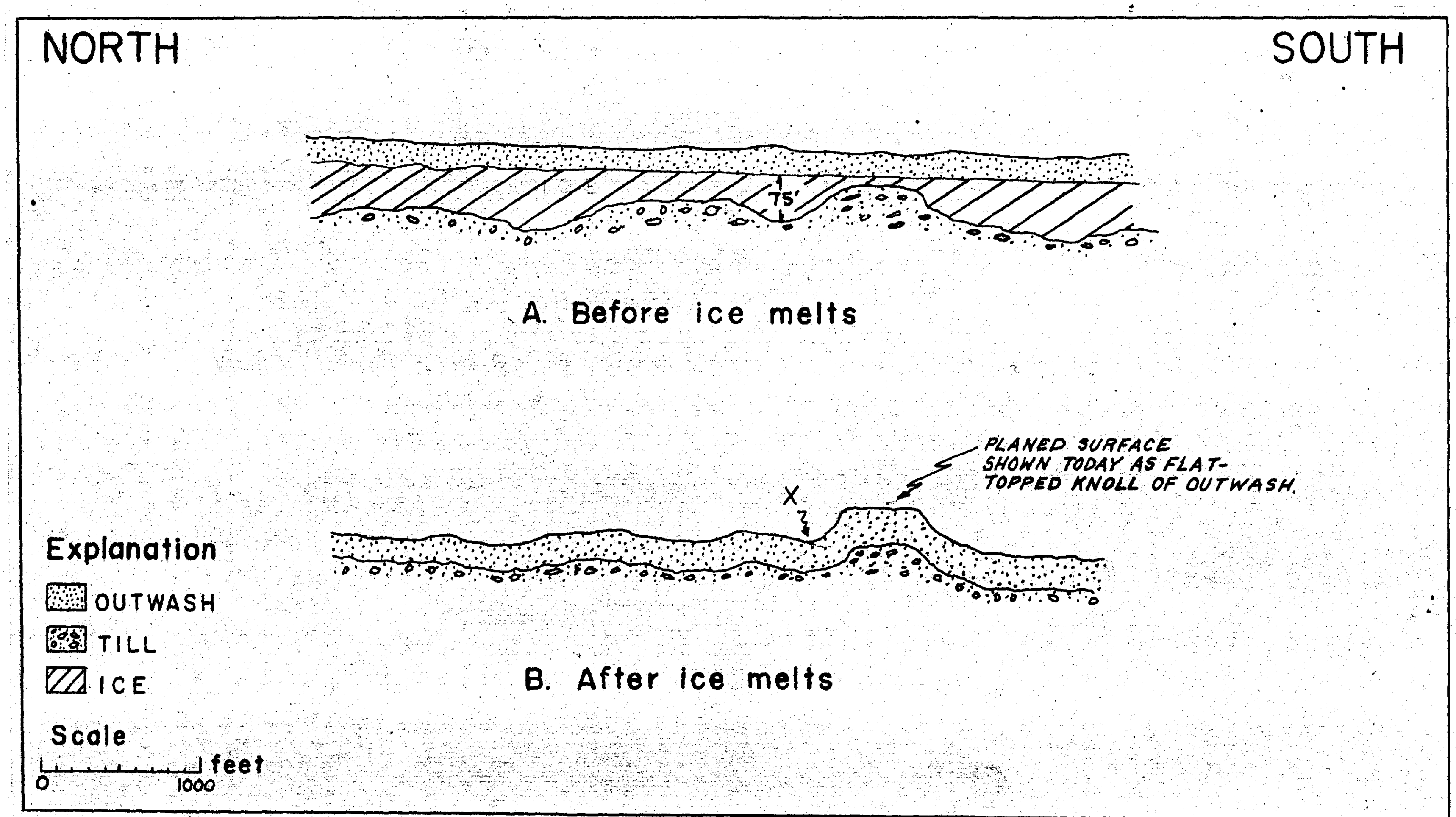

Fig. 25. Cross sections showing proposed method for origin of pitted outwash plain in the Sink Lake area.

method of formation, the ice was apparently about 75 feet thick.

Rasmussen (1945) suggests the youngest outwash in the Pettibone-Lake Williams-Robinson area was deposited within and around ice-covered or ice-filled kettle holes of the preceding moraine with part of the original relief subsequently destroyed by planation and filling under the ice.

Recent Deposits

The most recent deposits in the area are alluvium and eolian sands. Nearly half the surface of the area is sand or gravel occurring as a more or less continuous unit; therefore, considerable sand movement occurs, especially when the wind is able to sweep long distances. Even a moderate wind is capable of moving sand grains along the ground over the very sandy areas. Many ditches are filled with recent wind-blown silt and sand, and on windy days excessive drifting occurs across the farmed areas.

Deflation is a dominant process in local portions of the area. There are some areas, especially in the Sibley Buttes and McPhail Buttes moraines, where finer sediments are eroded leaving boulders and large cobbles as lag. The boulders often occur in ridges and in some cases are partially reburied by recent wind-blown silt trapped by vegetation.

Eolian sand occurs along the east side of Horsehead Lake as shown on plate 1. This area does not possess distinct dune topography, but is merely rolling topography of fine-grained, well rounded, quartz sand with maximum relief of 10 feet. The surface has a dark, gray-black soil up to half a foot thick. Closer to the lake, the eolian sand is intermixed with clay and silt and where it has dried on the surface, the mixture is hard and white.

Based on the presence of other white deposits around lakes in North Dakota, this material is probably sodium sulfate (Glauber's salt). It apparently precipitated from the lake waters when water level was higher, generally during the spring of the year. Winds often carry this powdered sodium sulfate in suspension and form white clouds over the area.

Evidence for the eolian nature of the sands east of Horsehead Lake, besides the well rounded sand grains, is that no rounded Pierre shale pebbles are present; whereas to the east, shale pebbles up to 40 millimeters in diameter are abundant. Also, near the southern edge of this sand area (SE¼ NE¼ sec. 23, T. 141 N., R. 72 W.), an exposure of sand and gravel contains moderate amounts of shale pebbles.

Alluvium is negligible in the area and is mapped along with outwash. Silt and clay deposits are present along many of the lakes. There are also minor amounts of alluvium along channels of the intermittent streams.

DRAINAGE HISTORY

Existing Drainage

Plate 3 shows the recent drainage in the area. Primary drainage from the west into Horsehead Lake passes through Cherry Lake, reportedly from an area as far west as Wing in Burleigh County about 20 miles west of the area. Intermittent streams from morainal areas to the north and northwest also flow into Horsehead Lake. Many larger streams heading in the end, stagnation, and recessional moraines flow out at the base of these moraines and usually end in lakes. In addition, many small lakes on the outwash plain serve as centers for local drainage accumulation. There is virtually no surface interconnection of drainage in the eastern half of the area, especially in areas of stagnation moraine.

Evidence of Preglacial Drainage

Primary evidence for former drainage is deduced from cross sections drawn from United States Geological Survey test hole logs. These cross sections indicate a preglacial valley lying between the Sibley Buttes moraine and the area north of the village of Tuttle (see pl. 12). This valley, herein designated the Tuttle Valley, contained an east-flowing tributary (the Tuttle branch) to the preglacial Cannonball River. The configuration of the valley probably remained much the same throughout each glacial advance and retreat because of bedrock highs on its north and south sides. This valley is reflected in the present topography. Its configuration probably influenced the direction of ice movement during Cary time.

Figure 26 shows the preglacial drainage across the area, as well as the inferred direction of the preglacial Cannonball River. It appears that east-flowing tributaries joined the Cannonball River southeast of Horsehead Lake. From here the preglacial Cannonball flowed eastward beneath the present site of either the Crystal Springs or McPhail Buttes moraine. This is based on the assumption that the ice lobe which deposited either of these moraines followed the valley of the preglacial Cannonball in its southeastward advance. The 39 feet of gravel overlying bedrock in United States Geological Survey test hole #1118 may mark the site of the preglacial Cannonball or a major tributary thereof (see pl. 13). The bedrock in this well, located in the NW¼ sec. 5, T. 140 N., R. 71 W., is 120 feet lower than that in well #1016, three miles to the northwest in the NW corner, sec. 31, T. 141 N., R. 72 W. Bedrock in well #1119 (2 miles north of well #1118) is 175 feet higher than that in well #1118, hence there is a gradient between these two wells of approximately 90 feet per mile.

At approximately the 110 foot depth in test hole #1118, south of Kunkel Lake, 10 feet of coarse gravel is overlain by 55 feet of sand with interbedded lignite. The stream responsible for this gravel must have had a source area somewhere to the north over coal-bearing Tertiary beds; and it may mark a channel deposit of a meltwater stream. Kettle chains, such as that east of Horsehead Lake may mark the location of parts of preglacial valleys with streams tributary to the preglacial Cannonball.

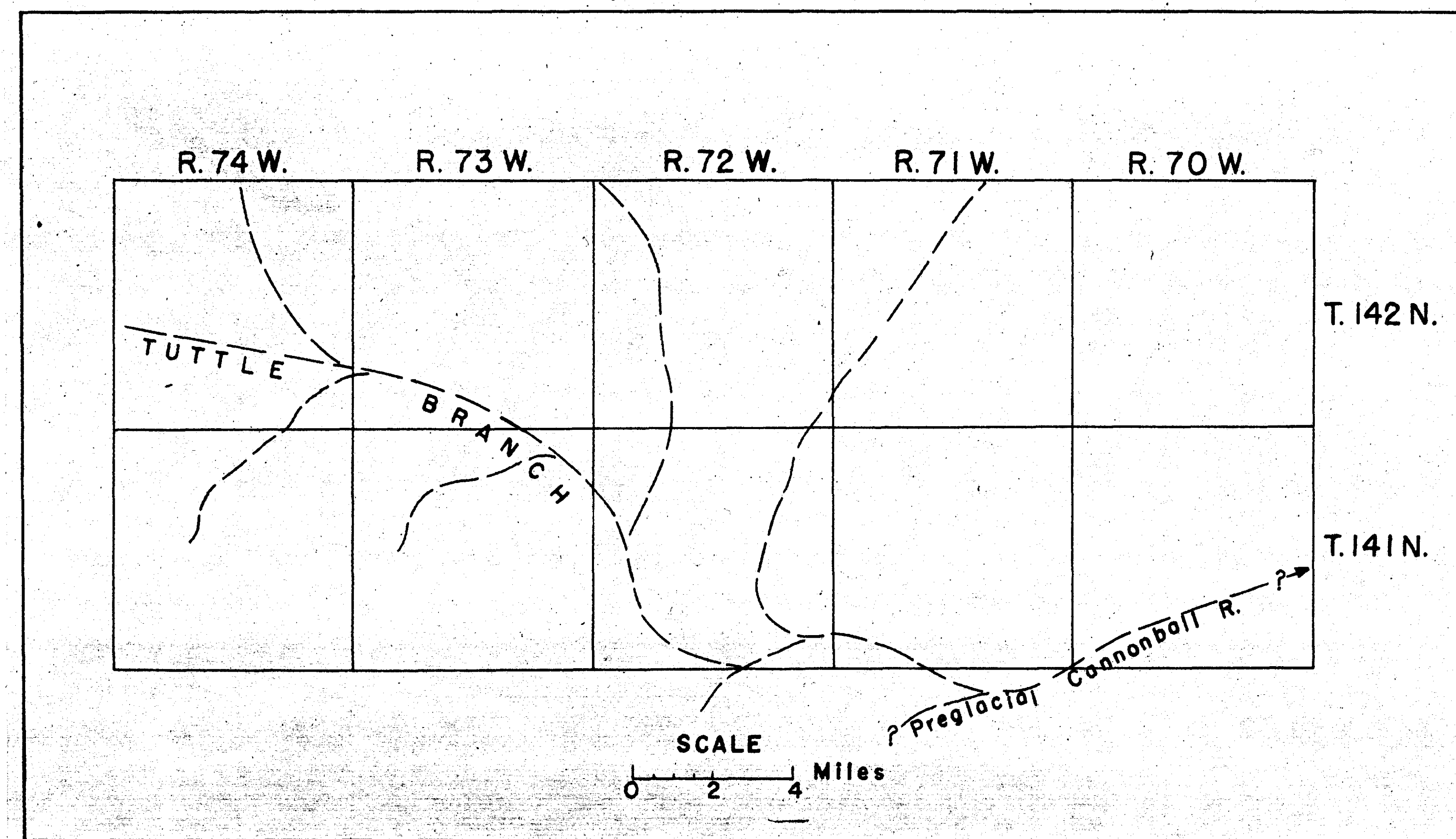

Fig. 26. Preglacial drainage across north-central Kidder County (interpreted from U. S. Geological Survey test hole data).

Other alternatives for preglacial drainage other than that shown in figure 26 have been proposed. Todd (1896, p. 57) stated the preglacial Cannonball flowed into Devils Lake, northeast of the area, via the Long Lake area. Additional drill holes are needed for a better understanding of the preglacial drainage in this area.

SYNTHESIS OF PLEISTOCENE HISTORY

Pre-Wisconsin Glacial Ages

There is no direct evidence in the area for Pleistocene drift of pre-Cary age; however, deposits of earlier Pleistocene drift occur south and southwest of the area, and ice of these times may have deposited drift in north-central Kidder County. No pre-Cary drift could be recognized by the writer, however, in the course of his subsurface studies. Since Tazewell and Iowan (?) glacial deposits occur in North Dakota southwest of the area mapped, it is likely that these ice sheets once covered this area.

Wisconsin Glacial Age

Following retreat of Iowan (?) ice eastward for an unknown distance, Tazewell ice passed over the area and built a terminal moraine west of the area. Following another cycle of retreat and advance, the Cary terminal moraine was built just west of the area. Subsequently, the Long Lake loop was formed during a minor readvance (or pause of the glacier during retreat from the Cary Maximum position) of Cary ice.

The first event of Cary time in the area (shown by surface glacial deposits) was the readvance of Cary ice from an easterly direction. This was during 1st Cary time. The glacier during this time probably followed an old preglacial valley or major east-flowing tributary to the preglacial Cannonball River. The area had previously been overridden by ice of earlier

Wisconsin subages, but the degree of valley filling by these advances is unknown. The 1st Cary ice sheet was probably thinner than that during Cary Maximum, hence it tended to follow lows in the topography. As 1st Cary ice progressed westward, it overrode and destroyed younger moraines that may have been present; and, at its maximum, truncated and overrode part of the Long Lake loop, an older Cary end or recessional moraine. The Sibley Buttes moraine was deposited near the southern border of 1st Cary ice along a series of discontinuous buttes and mesas of Fox Hills sandstone. The bedrock trend probably influenced ice movements of this advance and acted as a barrier to further southward movement of ice; consequently, the till of the Sibley Buttes moraine is relatively thin along its entire trend. The same situation may be present north of Tuttle out of the area mapped where bedrock highs of Tertiary formations crop out. Probably ice of 1st Cary time also deformed the Fox Hills sandstone in the Sibley Buttes to some extent.

Along its outer margin in Burleigh County, 1st Cary ice must have been thin and stagnant with many blocks of ice becoming detached from the main ice sheet. Warmer climate caused 1st Cary ice to retreat eastward and as a result, recessional moraines formed at points of more or less standstill and/or slight readvance. The series of discontinuous moraines making up the prominent recessional moraine located in the west-central area indicates the retreating ice stood still for short periods before making slight retreats eastward. A series of lakes, convex westward, mark the position of a melt-water channel which probably flowed around the front of the retreating 1st Cary ice lobe. During further eastward retreat, meltwater accumulated in ice-marginal lakes along the ice front and formed local lacustrine deposits.

Climate continued to be unfavorable for the existence of ice and further retreat occurred. During this time ground moraine was deposited, indicated today west of the Cherry Lake moraine. A period during which glacial melting more or less equaled glacial flowage followed, and deposition of the Cherry Lake moraine occurred. By this time the main ice sheet of 1st Cary subage was centered more to the deeper, south side of the Tuttle preglacial valley. Minor pulsations of the ice at this time may have caused the major ice-shove deformation in the Sibley Buttes. Some outwash apparently flowed eastward beneath the ice during this time. Slight retreats from the Cherry Lake position followed and were eventually even enough so drift was laid down evenly, eastward out of the area. The only till remnants of 1st Cary subage at the surface east of the Sibley Buttes moraine are those located south of Horsehead Lake.

Second Cary ice originated to the north and by the time it reached the northern part of the area, the ice had thinned and become generally stagnant. The entire ice frontal zone during 2nd Cary time was characterized by stagnant ice. Upon the front portions of this thin, ice sheet, southward flowing melt-water streams deposited glaciofluvial material. Related to these streams were sinuous ridges which apparently formed in parallel sets on either side of the meltwater channels. These features also suggest stagnant ice. Locally, ice blocks were buried, melted, and formed areas of pitted outwash. In the case of the Robinson moraine, a lobe of ice probably occupied a low in the pre-2nd Cary topography, so the ice which deposited this moraine projected lobe-like, further south than the rest of 2nd Cary ice. The outer ice border during 2nd Cary time was very irregular as evidenced by the amount and variety of ice-contact drift along the border.

Outwash flowed southward off 2nd Cary ice and covered a considerable portion of the area, burying and partially burying many moraines of the earlier Cary advance (1st Cary subage). The great amount of outwash suggests melting was the major process during this time. Local pulsations of 2nd Cary ice are indicated by the recessional moraine in secs. 4 and 5, T. 142 N., R. 74 W.

Ice of 1st Mankato time probably never reached this area; however, drift from this ice was deposited further south. If 1st Mankato drift existed in this area its front was buried and overlapped by later ice advances.

Stagnant ice may still have been present along the northern border of the area when a reactivation of ice occurred from the east and the 2nd Mankato ice advanced and deposited the McPhail Buttes moraine. The massiveness of the McPhail Buttes moraine indicates that during the time of deposition of this moraine probably the glacier was heavily laden with debris. In such case, the ice need not have stayed in this position for more than a relatively short time before receding. An alternative is that the ice was deficient in debris in which case the glacier would have had to remain in the position of the McPhail Buttes moraine for a relatively longer time than had the ice been heavily charged with material. A variety of combinations between the amount of debris in the ice and time are possible to the formation of a massive end moraine.

Outwash flowed south and west off the ice front during 2nd Mankato time. Retreat of 2nd Mankato ice occurred and stagnation moraine was formed behind the McPhail Buttes moraine and for some distance eastward into

Stutsman County. Second Mankato outwash buried much 2nd Mankato and less amounts of 2nd Cary drift; namely parts of the McPhail Buttes moraine and Robinson moraine respectively. Thinning of 2nd Mankato ice and further retreat caused cessation of meltwater flowage. Further alteration of topography was minor consisting primarily of melting of buried ice blocks and formation of pitted outwash plains. Presence of pitted outwash in the northeast part of the area again suggests that ice extended beyond the morainal front only a short time before formation of the moraine east and north of it.

The present-day topography in the area is not greatly different from that immediately after the ice receded. End moraines have been only slightly subdued by deflation and fluvial action. Probably the greatest topographic changes have occurred on the outwash plain. Here, sand and silt, have been moved by deflation and the general tendency has been toward leveling the area. In general, the drainage is better developed on the outwash plain than on the moraines.

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APPENDIX I. GLOSSARY

The definitions given below are those of the writer unless otherwise specified. They are stated in the sense that the writer used them in the field during the mapping of the area under study.

Ablation - wastage of a glacier by surface melting, evaporation, sublimation and calving (Flint, 1955, p. 24).

Active ice - moving ice or ice at standstill due to supply equalizing wastage.

Age - time unit corresponding to stage.

Alluvium - postglacial material usually less than sand size; commonly deposited in recent valley floors by modern fluvial action.

Boulder - a rounded rock fragment greater than 256 mm in diameter.

Clay - an accumulation of clastic rock or mineral particles generally less than 1/256 mm in diameter.

Cobble - a rounded rock fragment ranging from 64 to 256 mm in diameter.

Distal - the side of the moraine away from the source of ice; opposite to proximal.

Drift - deposits formed by glacial deposition or erosion.

End moraine - a ridge-like accumulation of drift formed along the outer border of an ice sheet marking the position of a major standstill of ice. The ice front remains stationary due to balance of wastage with supply.

Englacial - within or beneath the surface of the glacier; that area intermediate between subglacial and superglacial.

Eolian sand - unconsolidated, generally sand size material, usually composed of quartz, accumulated through wind action.

Esker - a sinuous ridge of glaciofluvial material usually formed at right angles to ice movement. It generally is stratified and contains slumped bedding.

Gravel - unconsolidated, generally rounded rock particles greater than 2 mm in diameter; may be either a pebble, cobble, or boulder gravel.

Ground moraine - an accumulation of drift characterized by swell and swale topography with slopes generally less than 2° and relief less than 20 feet.

Histogram - a vertical bar graph representing the size composition of a sediment with the area of the bars proportional to the quantity of material in each class. The width of bars is determined by the class limits (Pettijohn, 1957, p. 30).

Ice-contact deposits - an inclusive term for kames, crevasse fillings, eskers and other ice marginal, collapsed, and stratified drift.

Inactive ice - non-moving ice which has become detached from the main glacier.

Kettle - a depression formed in drift by burial and subsequent melting of a block of ice.

Kettle chain - a group of kettles occurring in a linear or curving pattern.

Lacustrine - lake deposits; usually silts and clays.

Leucocratic - refers to light-colored igneous rocks (Am. Geol. Inst. Glossary, 1957, p. 167).

Lobe - a projection of glacial ice ahead of the main ice body and shown in plan view by a u-shaped moraine.

Lodgment - plastering of glacial debris beneath the base of the ice sheet.

Melanocratic - refers to dark-colored igneous rocks (Am. Geol. Inst. Glossary, 1957, p. 181).

Meltwater channel - a channel in which glacial meltwater flowed off the ice sheet.

Moraine - a deposit of glacial drift exhibiting "a constructional topographic expression ... and having been built by the direct action of glacial ice" (Flint, 1955, p. 111).

Outwash - silt, sand or gravel (or combinations of these) washed out of the drift and deposited by proglacial streams usually along the front of a moraine.

Pebble - a rounded rock fragment ranging from 4 to 64 mm in diameter.

Proximal - the side of the moraine towards the source of ice; opposite to distal.

Recessional moraine - a ridge-like accumulation of glacial drift marking minor standstills during ice retreat.

Sand - unconsolidated sediment consisting of rock or mineral fragments less than 2 mm and greater than 1/16 mm in diameter (Pettijohn, 1957, p. 20). Sand in the area mapped is composed predominantly of quartz.

Silt - unconsolidated sediment consisting of rock or mineral fragments between 1/16 and 1/256 mm in diameter (Pettijohn, 1957, p. 20).

Spillway - an abandoned, glacial outlet channel marking the outflow location of a glacial lake.

Stage - the largest time-rock subdivision of an epoch.

Stagnation moraine - an accumulation of glacial drift characterized by hummocky topography. It is indicative of relatively thin, stagnant, inactive ice.

Striation - a fine line inscribed in bedrock generally by material imbedded in the base of a moving glacier.

Subage - time unit corresponding to substage.

Subglacial - pertaining to beneath the glacier.

Substage - the largest time-rock subdivision of a stage.

Superglacial - pertaining to the surface of the glacier.

Terminal moraine - a ridge-like accumulation of drift marking the position of farthest advance of a particular ice sheet.

Till - unsorted and unstratified glacial drift composed of clay to boulder-size particles.

Varve - a pair of strata, usually light and dark, marking an annual accumulation of sediment and commonly indicating lacustrine conditions.

Washboard moraine - moraine consisting of a closely spaced series of moraines resembling the surface of a washboard.

GEOLOGIC MAP OF NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

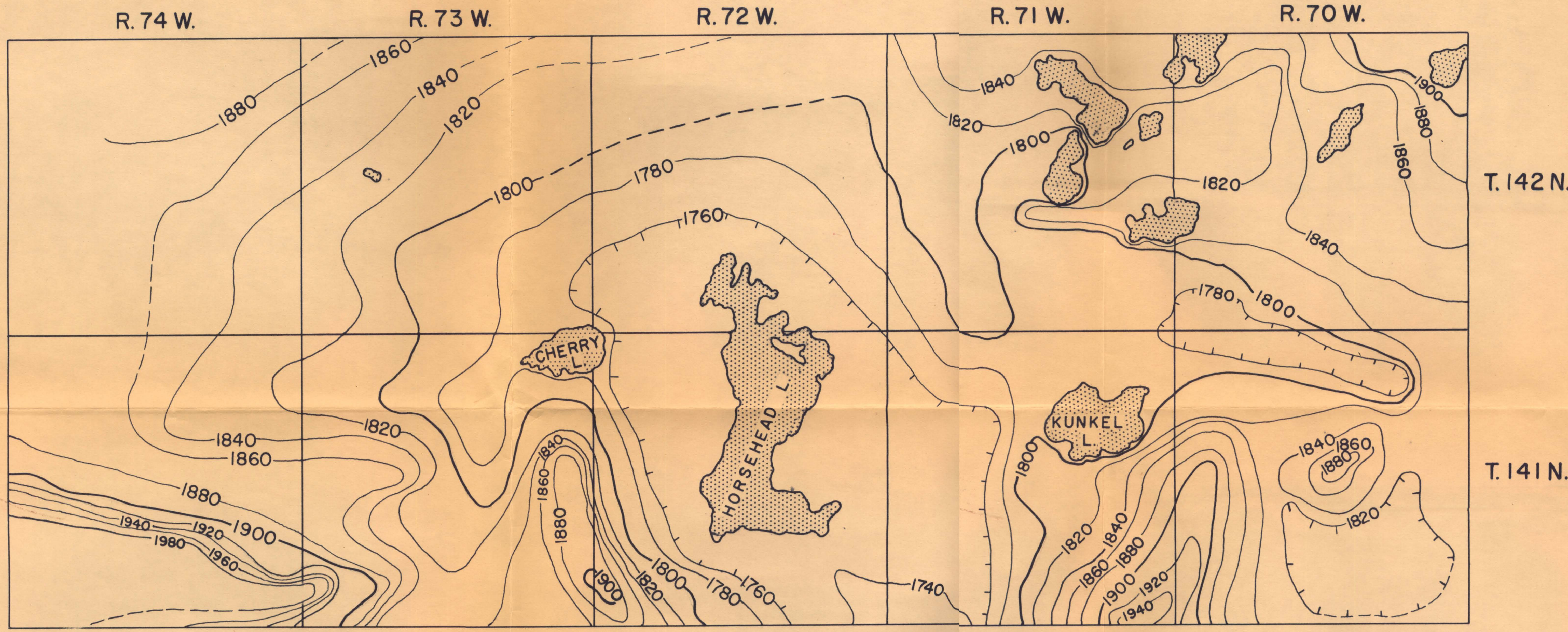
SCALE

1 0 1 2 3 Miles

EXPLANATION

- E.M. END MORAINE
- RECESSIONAL MORAINE
- G.M. GROUND MORAINE
- S.M. STAGNATION MORAINE
- OTW OUTWASH
- E.S. EOLIAN SAND
- E ESKER
- KC KETTLE CHAIN
- TRENDS IN DRIFT
- BEDROCK HIGHS
- FOX HILLS FM. (Kfh)

Plate 1



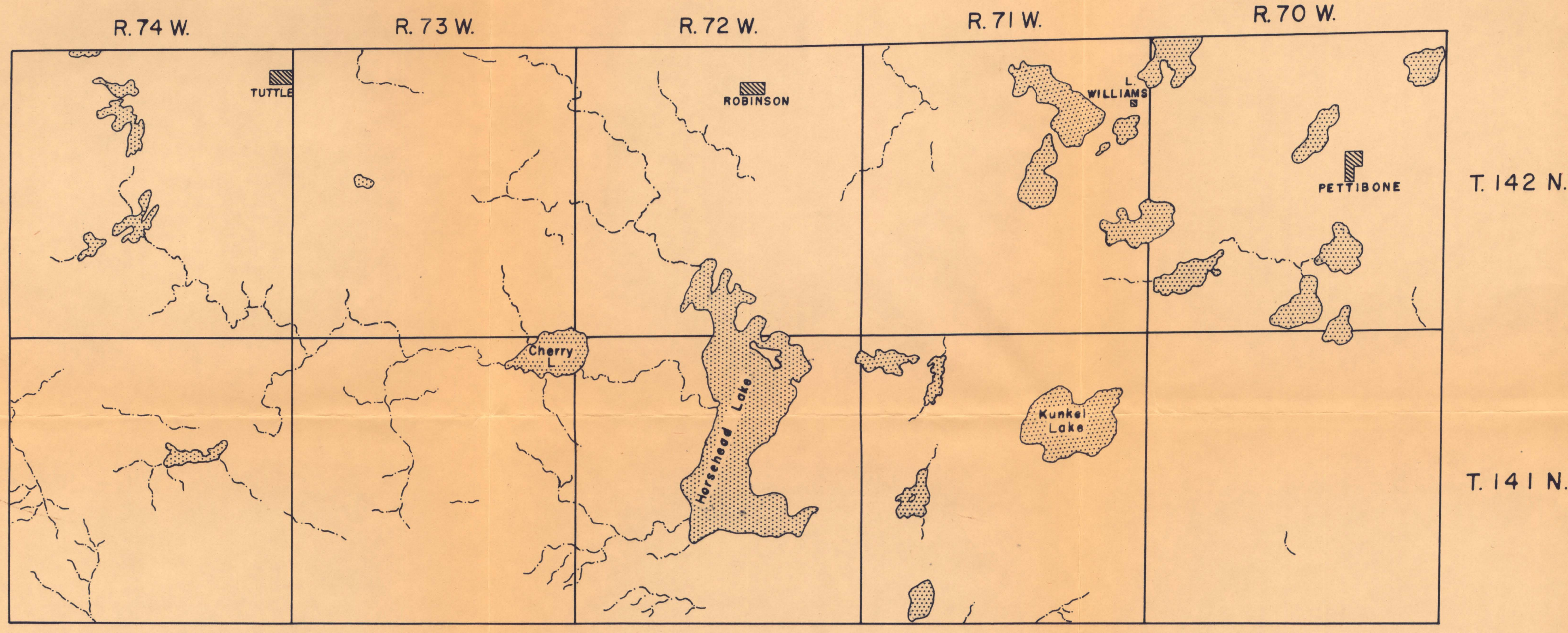
TOPOGRAPHIC SKETCH MAP OF NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

SCALE

2 0 2 4 Miles

DATUM - Sea Level
Contour Interval = 20 ft.

Plate 2

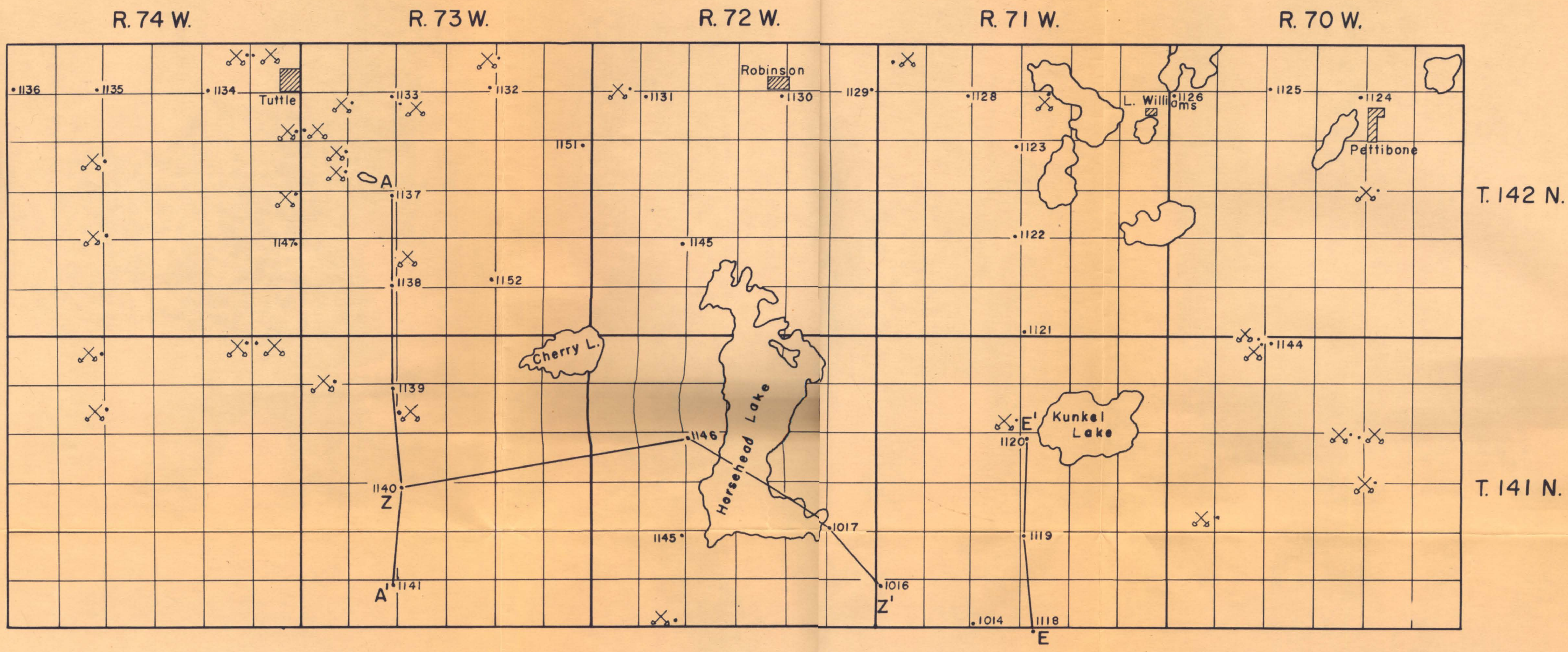


RECENT DRAINAGE IN NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

SCALE

2 0 2 4 Miles

Plate 3



LOCATION OF SAND & GRAVEL PITS, U.S.G.S. TEST HOLES & LINES OF CROSS SECTION NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

Scale

2 0 2 4 Miles

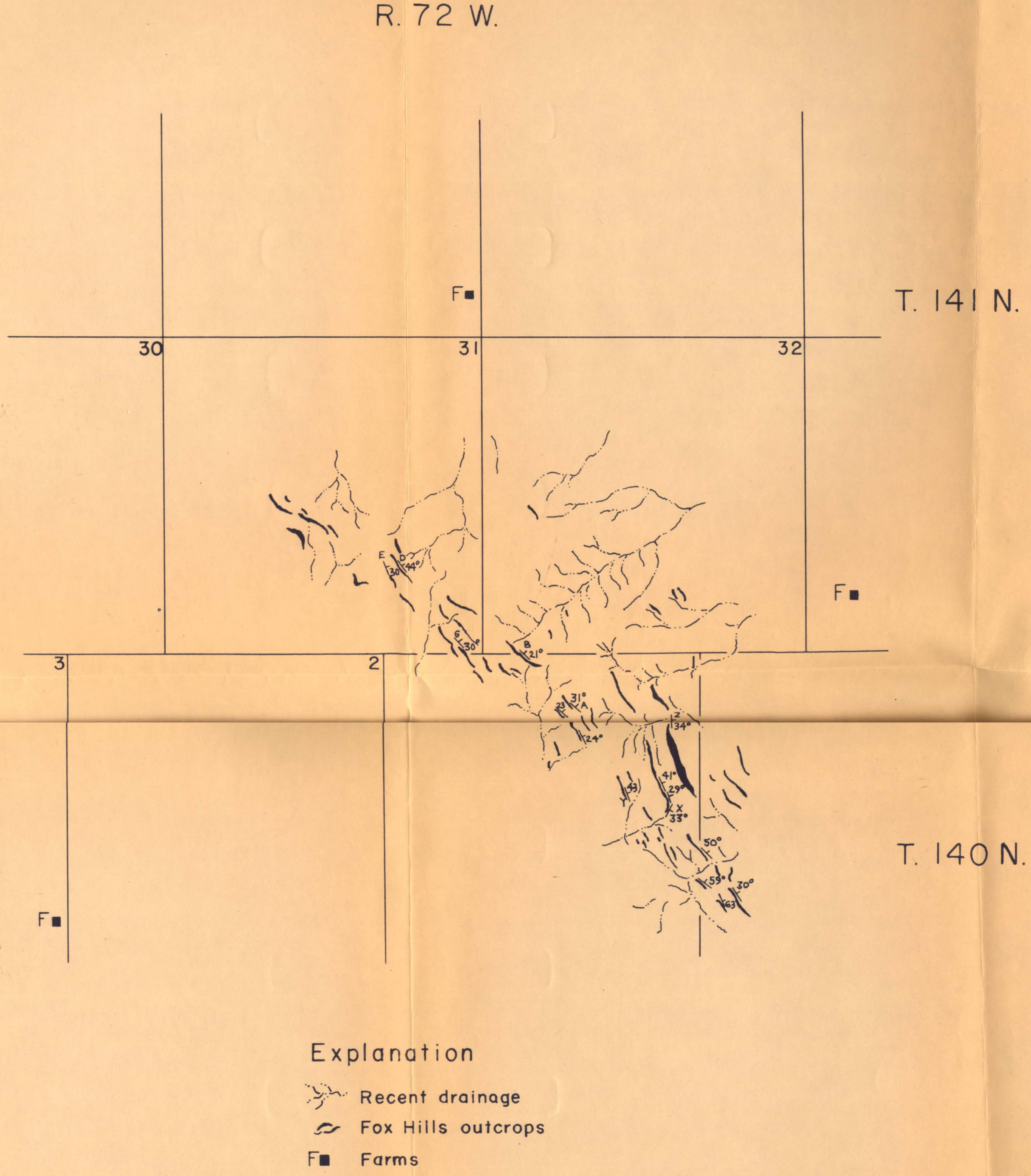
Explanation

• 1138 – U.S.G.S. test hole

Surface pit (sand & gravel)

Lines of section

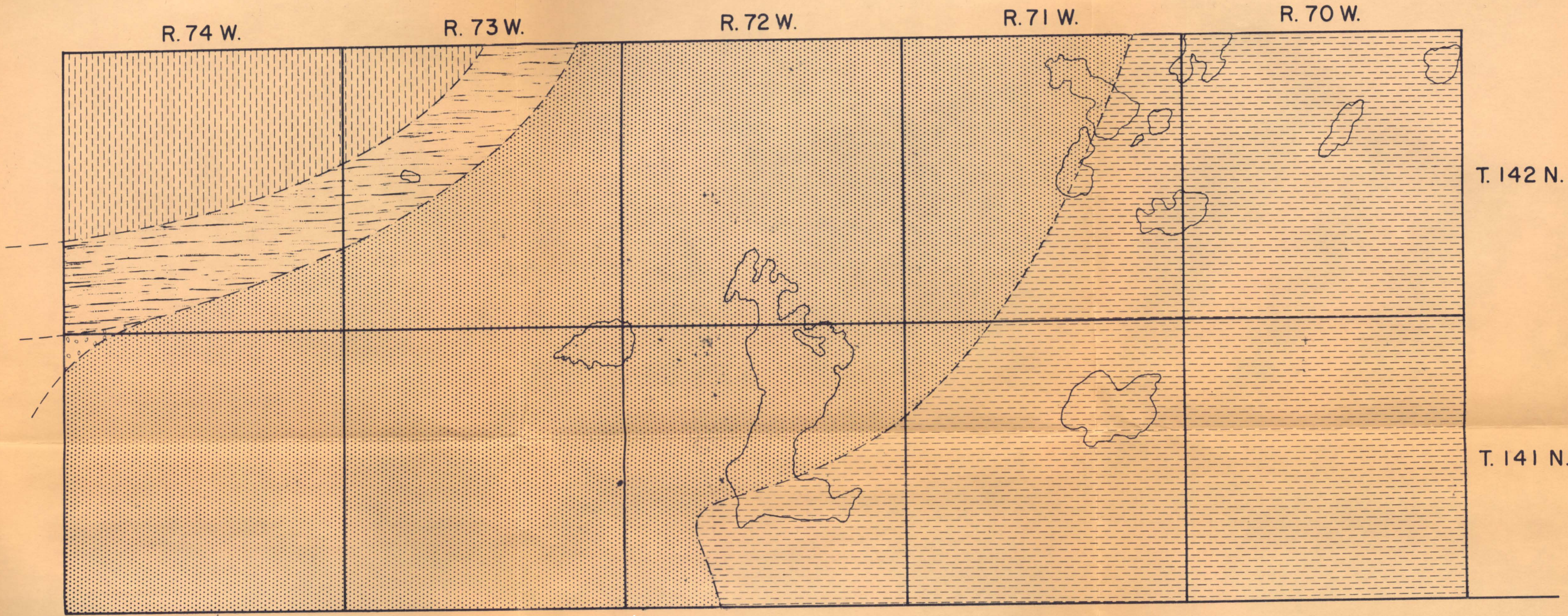
Plate 4



OUTCROPS OF FOX HILLS FORMATION IN THE SIBLEY BUTTES

SCALE

0 ½ 1 Miles



EXPLANATION

CRETACEOUS | PALEOCENE

- Tongue River fm.
- Cannonball fm.
- Hell Creek fm.
- Fox Hills fm.
- Pierre fm.

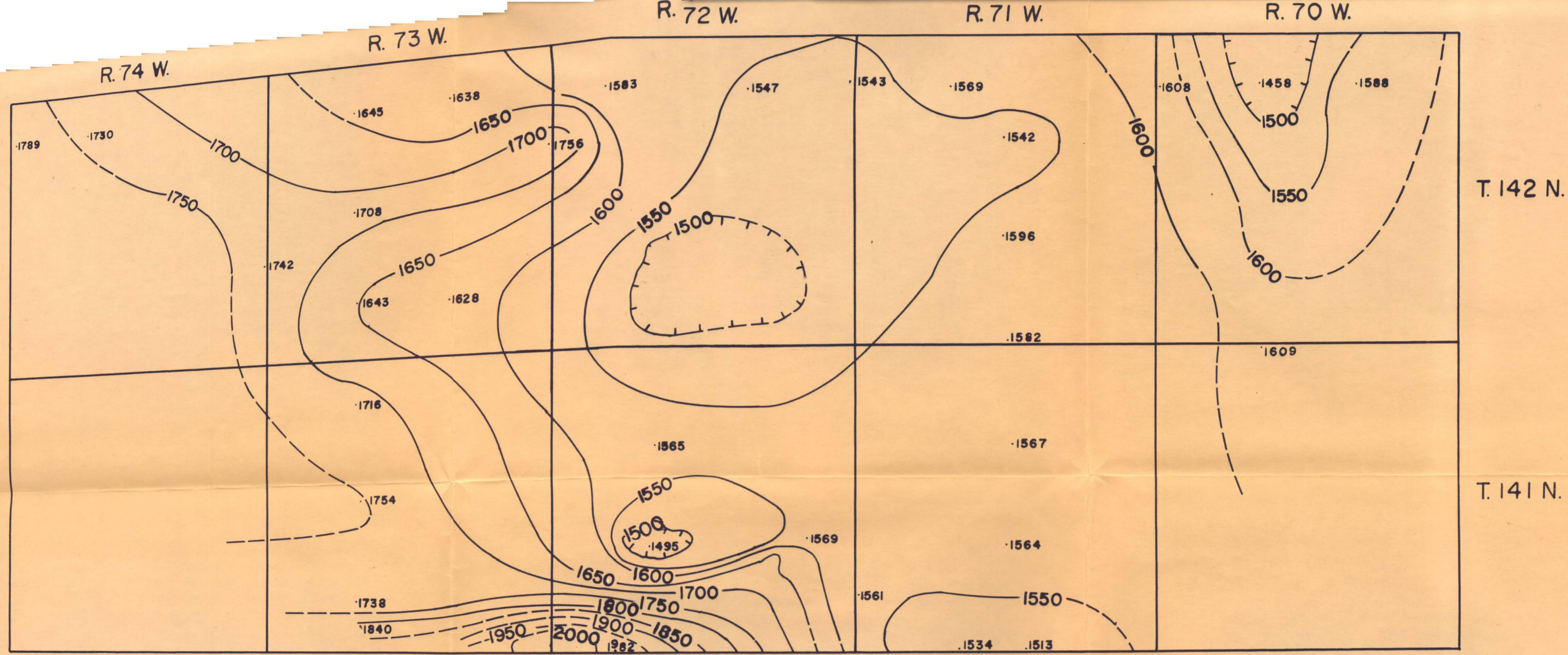
PRE-PLEISTOCENE PALEOGEOLOGIC MAP OF NORTH-CENTRAL KIDDER CO., N. DAK.

SCALE

2 0 2 4 MILES

Modified after - Hansen, 1956.

Plate 6



TOPOGRAPHIC MAP OF PRE-PLEISTOCENE SURFACE NORTH CENTRAL KIDDER CO., N. DAK.

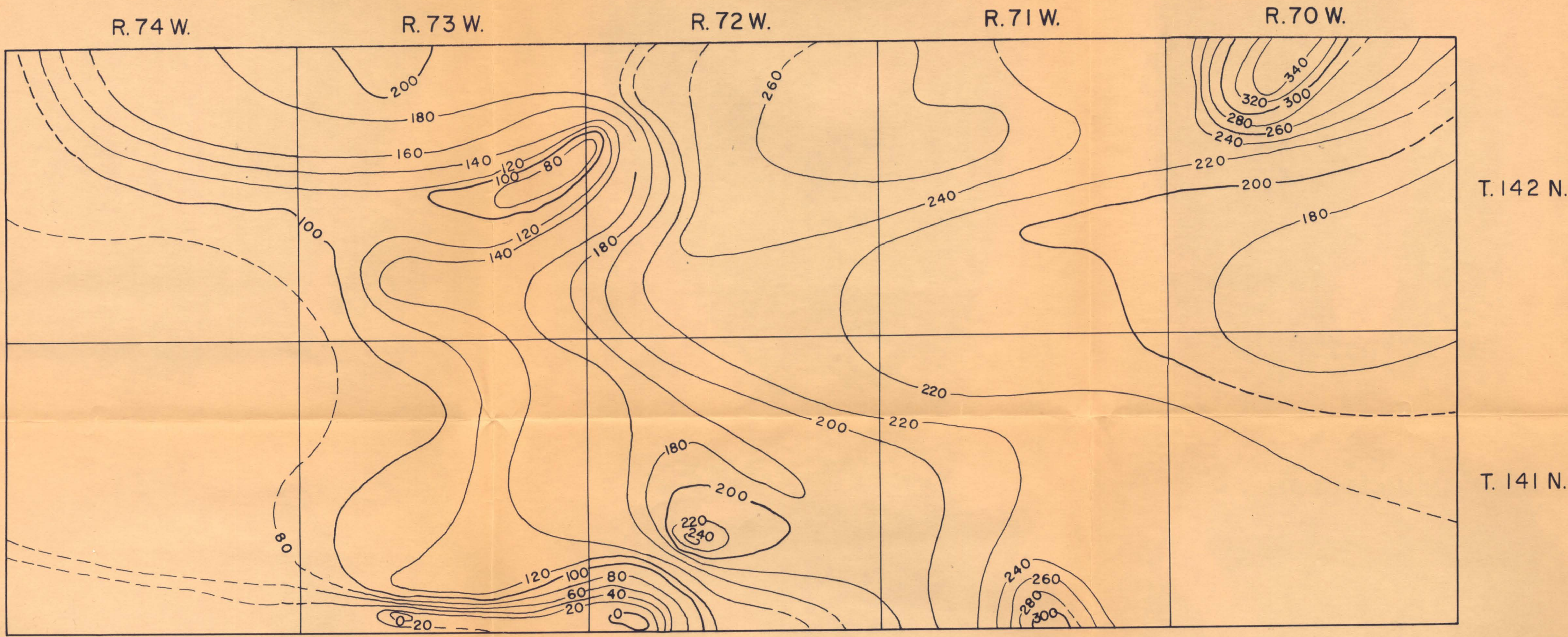
SCALE

2 0 2 4 MILES

Contour Interval - 50 feet

DATUM - Sea Level

Plate 7



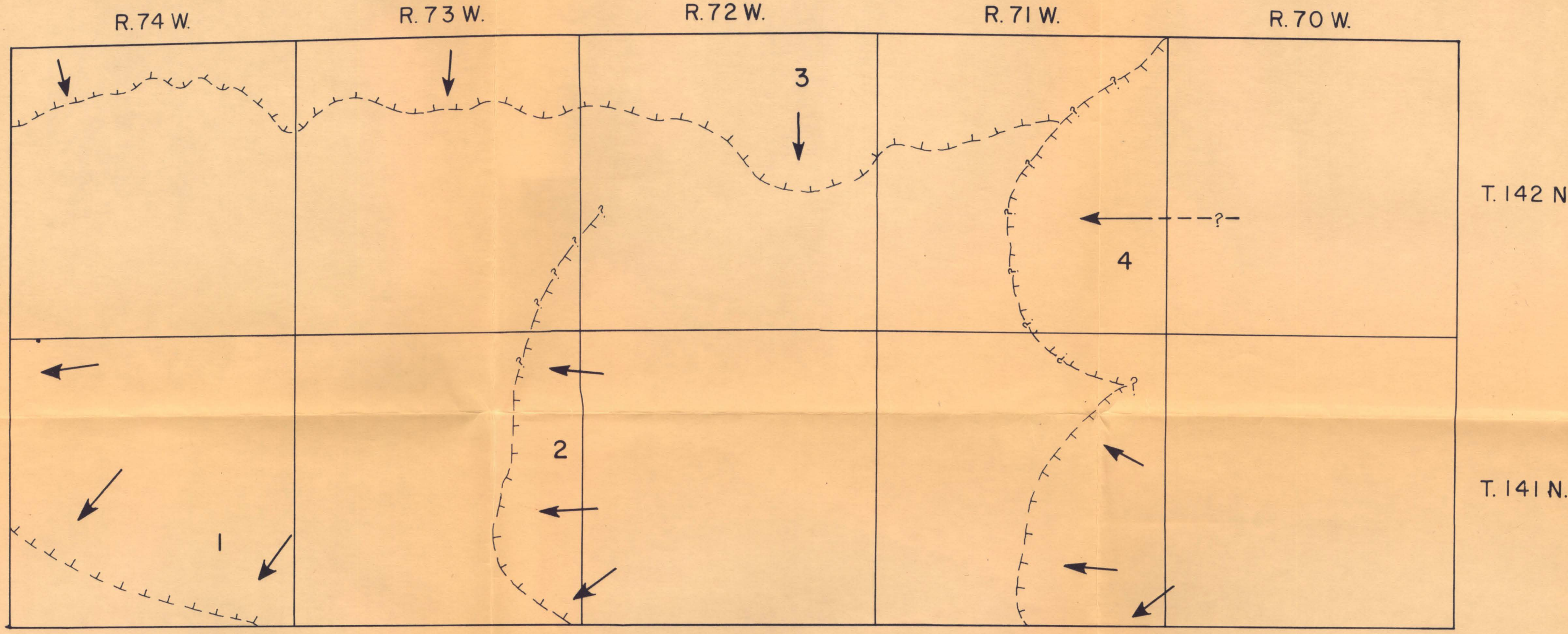
ISOPACHOUS MAP OF DRIFT
NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

SCALE

2 0 2 4 Miles

Contour Interval = 20 ft.

Plate 8



PROBABLE EXTENT OF CARY & MANKATO ICE–NORTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

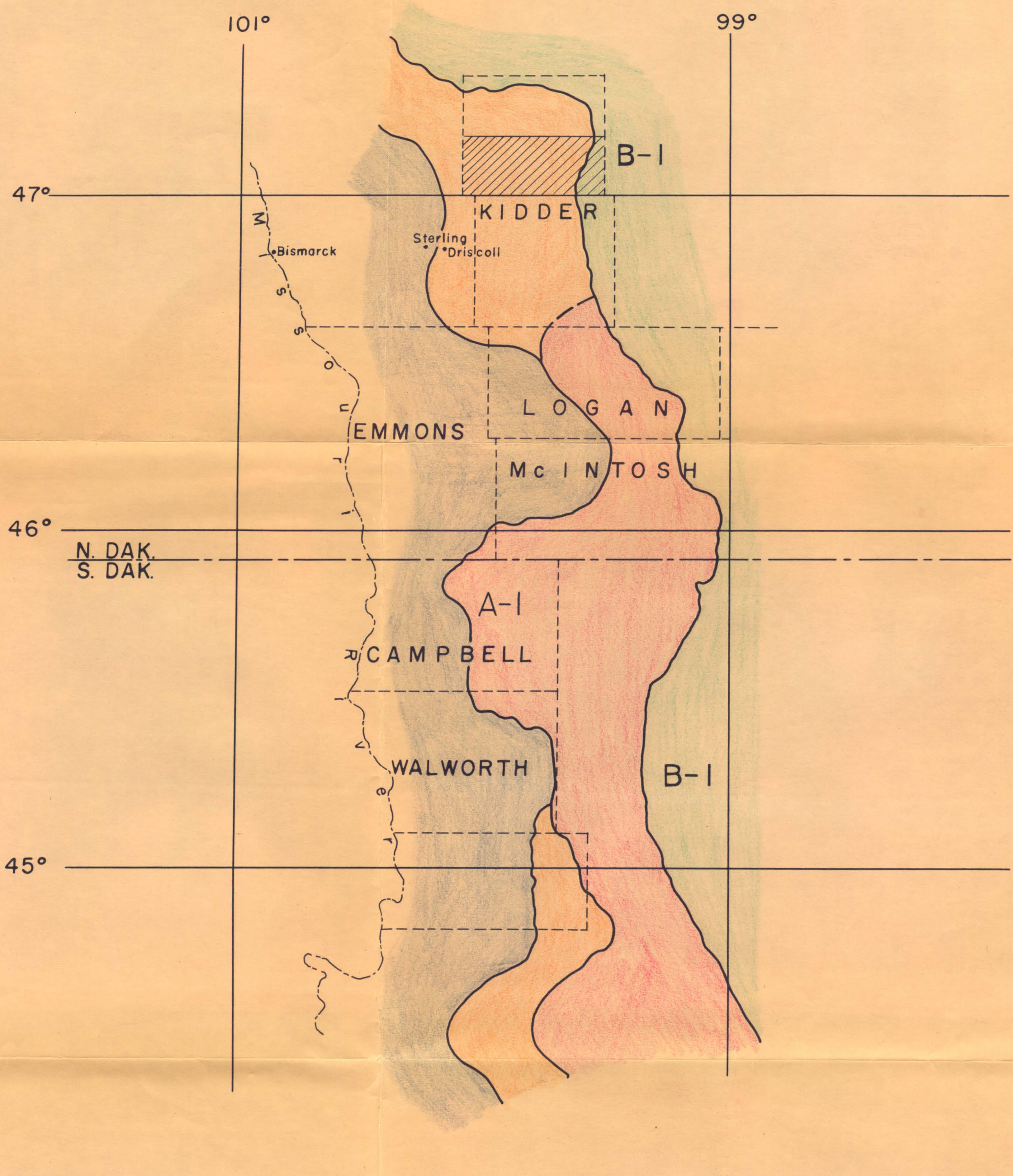
SCALE

2 0 2 4 Miles

LEGEND

- 4 APPROXIMATE POSITION OF ICE FRONT DURING DEPOSITION OF McPHAIL BUTTES MORAINE
- 3 APPROXIMATE POSITION OF ICE FRONT DURING DEPOSITION OF 2nd CARY DRIFT
- 2 APPROXIMATE POSITION OF ICE FRONT DURING DEPOSITION OF CHERRY LAKE MORAINE & DEFORMATION OF SIBLEY BUTTES
- 1 APPROXIMATE POSITION OF ICE FRONT DURING DEPOSITION OF SIBLEY BUTTES MORAINE
- INFERRED DIRECTION OF ICE MOVEMENT

Plate 9



CORRELATION OF CARY & MANKATO DRIFT MAXIMA- SOUTH DAKOTA TO KIDDER COUNTY, NORTH DAKOTA

EXPLANATION

- 2ND MANKATO DRIFT
- 1ST MANKATO DRIFT
- CARY DRIFT
- TAZEWELL DRIFT

SCALE

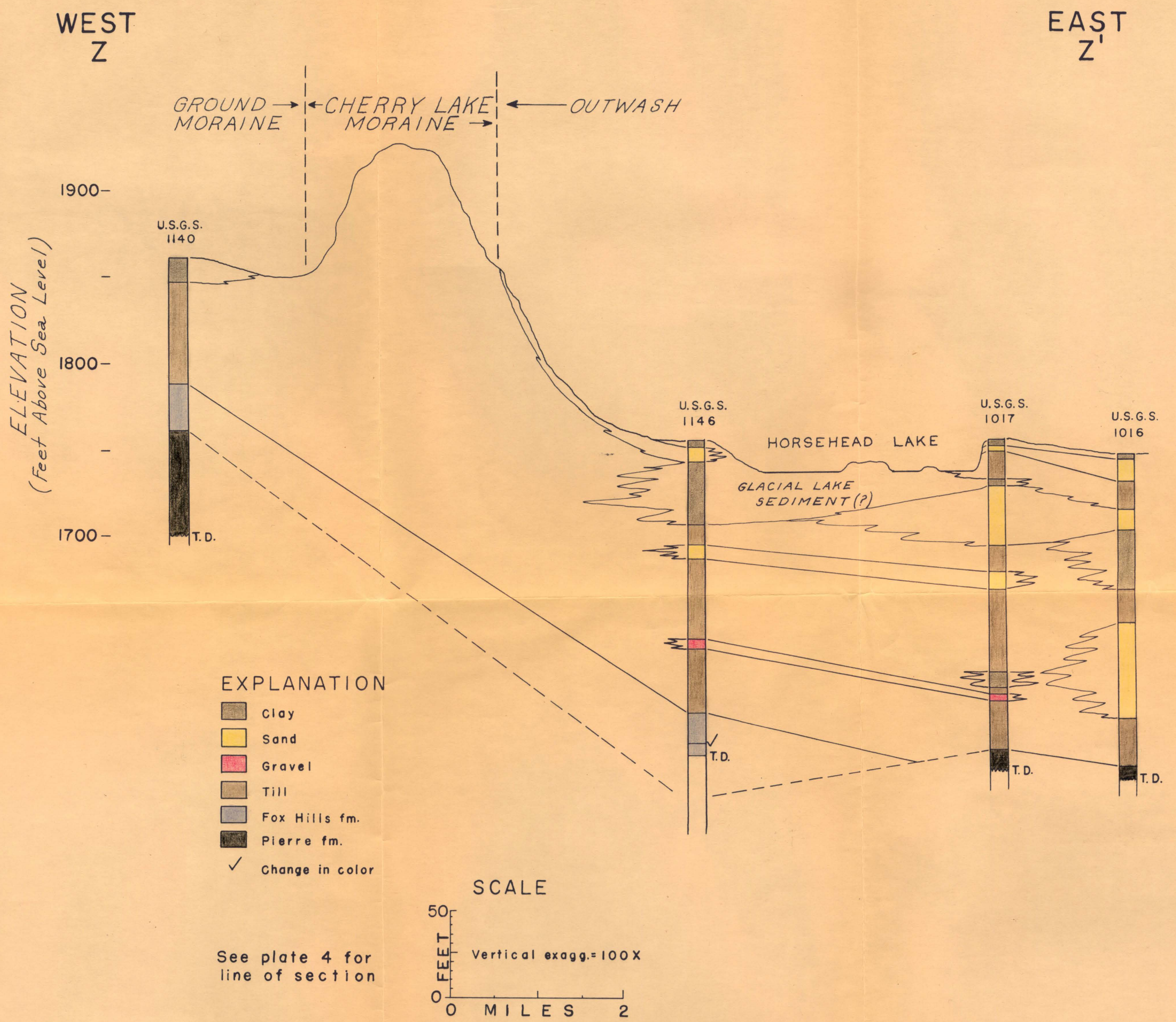
0 20 40 Miles

AREA MAPPED

A-1 First Mankato advance and maximum extent of Mankato subage (Flint, 1955).

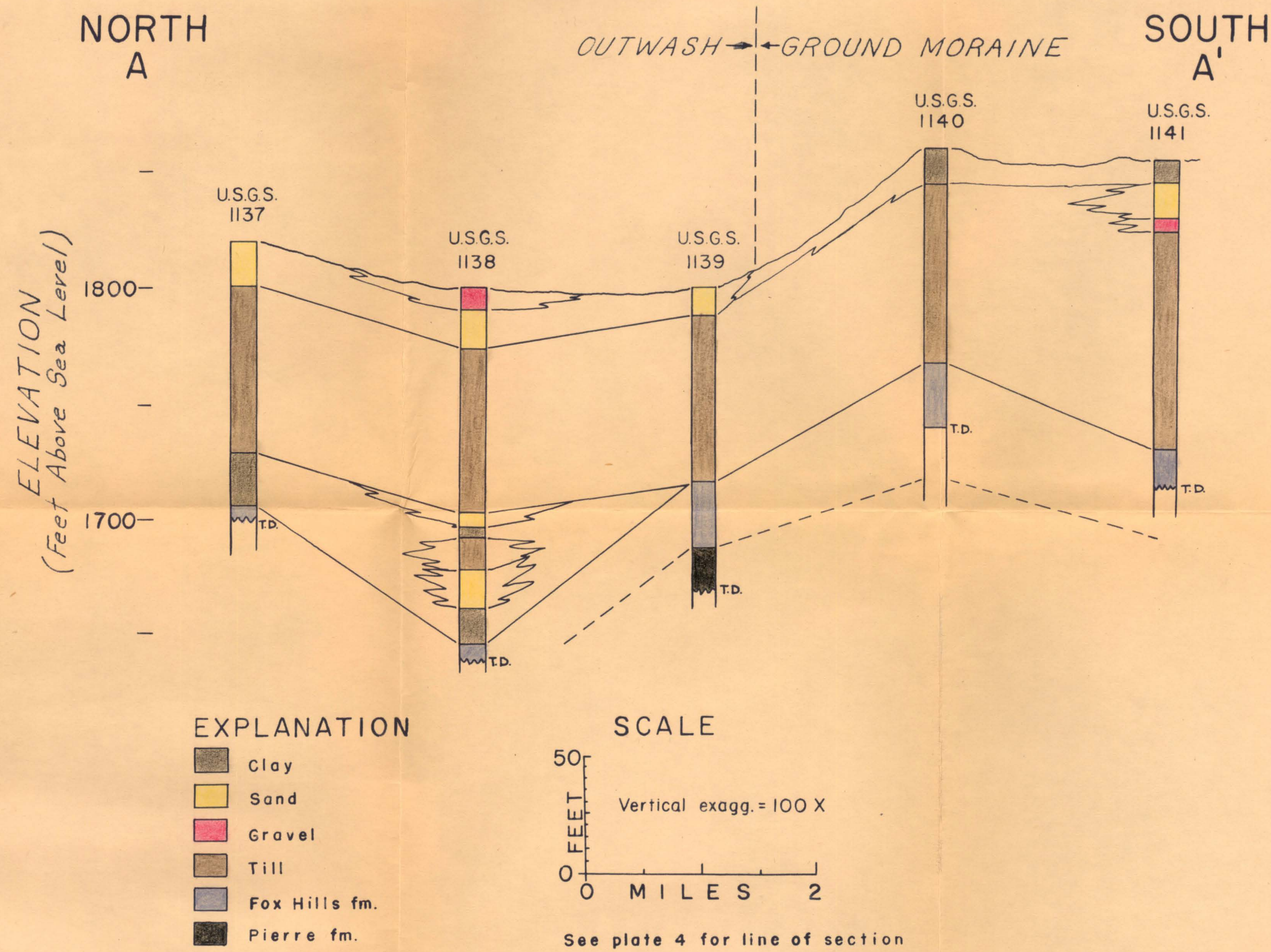
B-1 Second major advance following shrinkage of unknown extent (Flint, 1955).

Modified after: Flint (1955), Lemke & Colton (1958), & Clayton (1960)



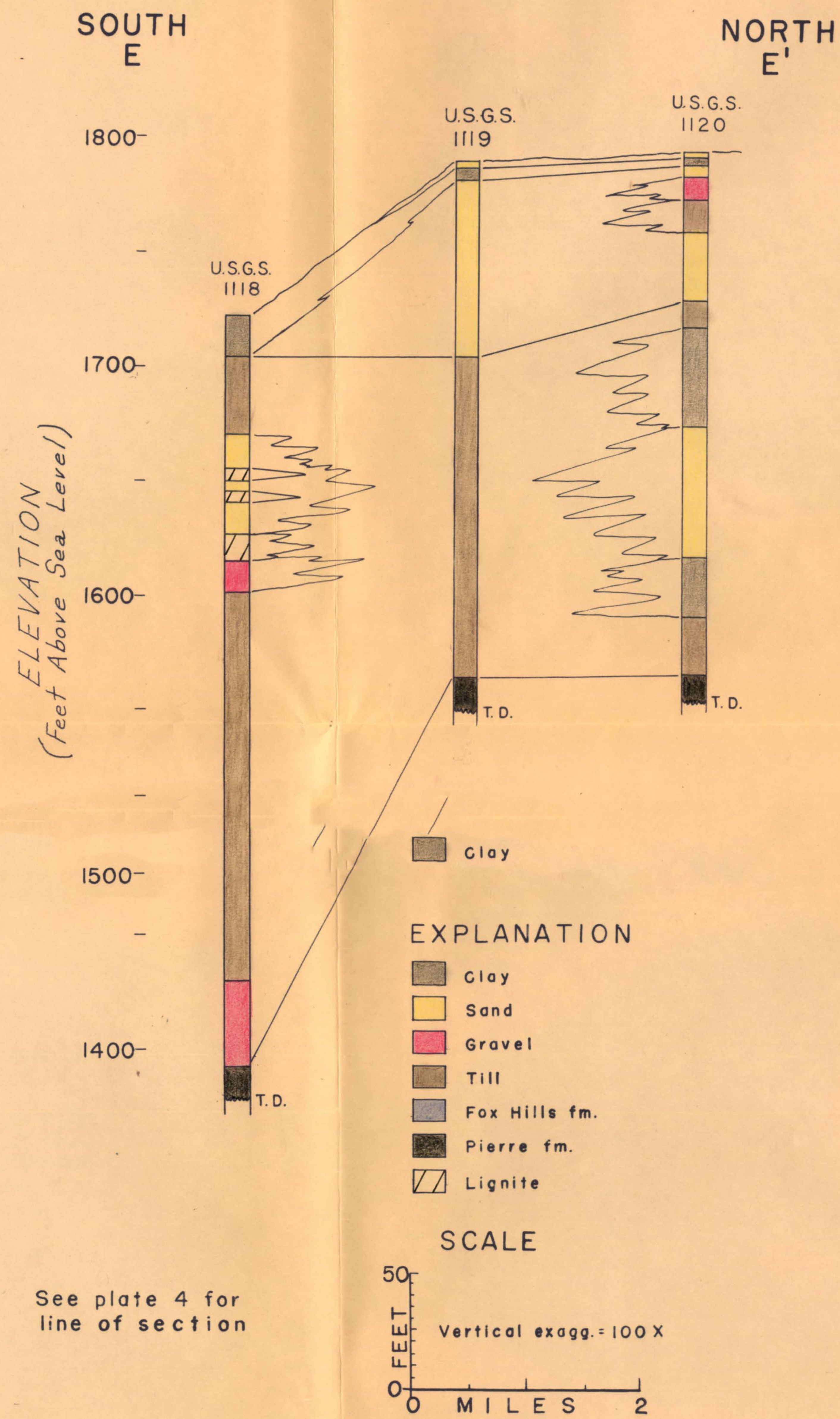
CROSS SECTION Z-Z'
CHERRY LAKE MORAINE

Plate 11



CROSS SECTION A-A'— TUTTLE TO SIBLEY BUTTES

Plate 12



CROSS SECTION E-E' - PROBABLE PREGLACIAL CANNONBALL RIVER (or tributary thereof)

PLATE 13