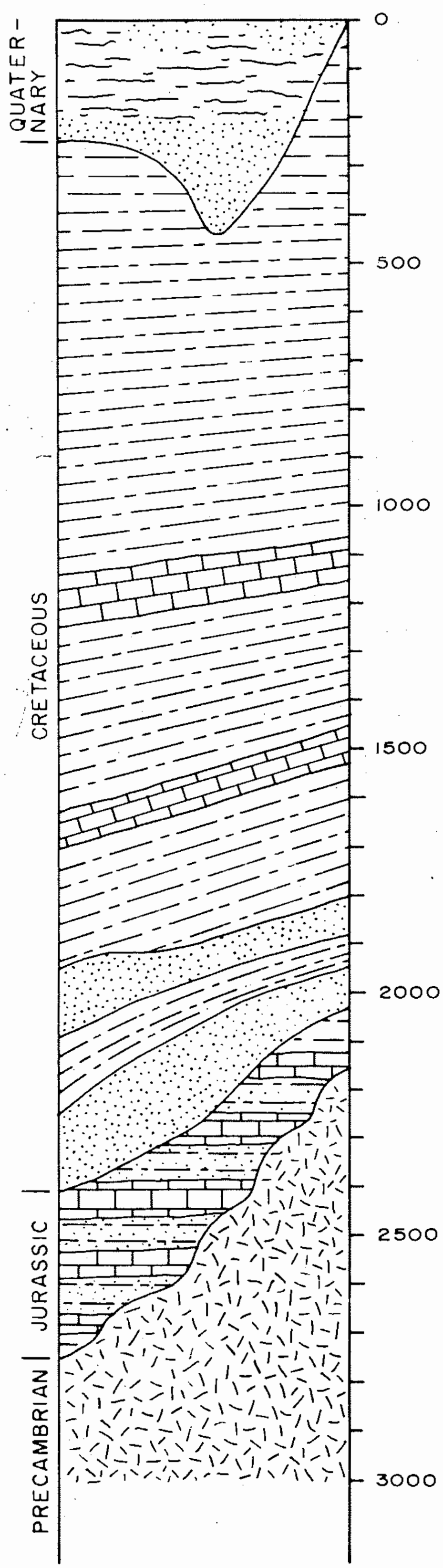

GEOLOGY AND WATER RESOURCES OF CAMPBELL COUNTY SOUTH DAKOTA

Part I – Geology

by Lynn S. Hedges,
South Dakota Geological Survey

Bulletin 20
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STATE OF SOUTH DAKOTA
Richard Kneip, Governor

SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

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PART I: GEOLOGY

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Prepared in cooperation with the
United States Geological Survey,
Oahe Conservancy Sub-District
and Campbell County

Science Center
University of South Dakota
Vermillion, South Dakota
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ABSTRACT

Campbell County includes an area of approximately 763 square miles in north-central South Dakota in the Coteau du Missouri, a division of the Great Plains physiographic province. Outstanding geomorphic features in the county are the north-south trending Missouri River trench which lies along the western boundary of the county, and the broad linear low areas marking the former courses of eastward-flowing rivers which were present prior to the formation of the Missouri River.

Pre-Pleistocene rocks range in age from Precambrian through Late Cretaceous. All of the rocks from Precambrian through much of the Cretaceous are found in the subsurface and their presence and description are inferred mainly by extrapolation of subsurface data from surrounding counties. Limestones and dolomites of Paleozoic age which are about 1500 feet thick, overlie the Precambrian rocks. Sediments of Cretaceous age, about 2500 feet thick, overlie the Paleozoic rocks and consist chiefly of sandstone and shale with some limestone and marl. Cretaceous rocks present in the subsurface are, oldest to youngest: Inyan Kara Group, Skull Creek Formation, Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Marl and most of the Pierre Shale. The Virgin Creek, Mobridge, and Elk Butte Members of Pierre Shale and the Fox Hills Formation of Cretaceous age are exposed along the Missouri River trench and the uplands in the northwest part of the county.

Surficial deposits of glacial drift, as much as 475 feet thick, mantle the bedrock formations except along the walls of the Missouri River trench. Several deep bedrock channels contain sediments that consist of outwash and a complex outwash-alluvium deposit of pre-late Wisconsin age, glacial till, and the Pollock Formation. The Pollock Formation is a new name proposed for proglacial late Wisconsin lacustrine deposits in the Mound City Channel and the Ancient Grand Channel.

Loess-covered drift in the western one-third of the county, formerly correlated with the Iowan and Tazewell undifferentiated drift, has been tentatively correlated with the late Wisconsin stage.

Extensive areas of collapsed outwash and the presence of ice-walled lake plains, ice-walled gravel plains, and collapsed lake plains indicate the former presence of superglacial drift and subsequent deposition as stagnation drift.

The Artas, Herreid, and Bowdle moraines are tentatively correlated with the Zeeland, Venturia–Burnstad, and Streeter end moraines in North Dakota.

Natural resources of economic value include large reserves of both surface and ground water and large volumes of sand and gravel. Known natural resources which may have potential economic value are boulders, which could be used for rip-rap, and clay although a thorough investigation of the clay would be required to evaluate its potential. Present evidence indicates no significant metallic or fossil fuel resources in Campbell County.

INTRODUCTION

LOCATION AND SIZE OF THE AREA

Campbell County includes approximately 763 square miles in extreme north-central South Dakota. The north boundary is the South Dakota-North Dakota state line. The Missouri River separates Campbell County from Corson County in the west. Walworth County is to the south and McPherson County to the east (fig.1).

PURPOSE OF THE INVESTIGATION

This report contains the results of a cooperative study of the hydrology and geology of Campbell County conducted by the South Dakota Geological Survey and the United States Geological Survey. It is the fourth in a series of county studies (fig. 1) which are being undertaken to determine the mineral and water resources available for future development, and to establish the basic geologic and hydrologic framework upon which future development and management decisions can be based. The study was initiated at the request of the Campbell County Commissioners. Funds for the study were available through the South Dakota Geological Survey, the United States Geological Survey, Campbell County, and the Oahe Conservancy Sub-District.

The results of this investigation will be published as Parts I, II, and III of South Dakota Geological Survey Bulletin 20. Part I, presented here, is the geologic report; Part II contains the hydrology and water-resource potential; and Part III contains a compilation of all basic data collected during this investigation.

Supplementary non-technical reports concerning the glacial aquifers (Hedges and Koch, 1967) and the sand and gravel potential (Hedges, 1969), have been published.

PREVIOUS INVESTIGATION

The first geologic description of the area including Campbell County was made by Chamberlin, (1883) as part of a reconnaissance study concerning the drift border of the "Second Glacial Epoch." Much of Chamberlin's work in this area was based on studies already in progress by J. E. Todd in North Dakota and South Dakota that were later published by Todd (1885, 1894, and 1896). Following Chamberlin's work were regional studies concerning the geology, artesian water, and structure including work in the Campbell County area (Darton, 1896, 1909, 1918). Flint (1955) made a reconnaissance study of the Pleistocene deposits of eastern South Dakota including Campbell County. An additional study worthy of note is a brief study of the shallow ground-water supply at Mound City conducted by Lee (1956).

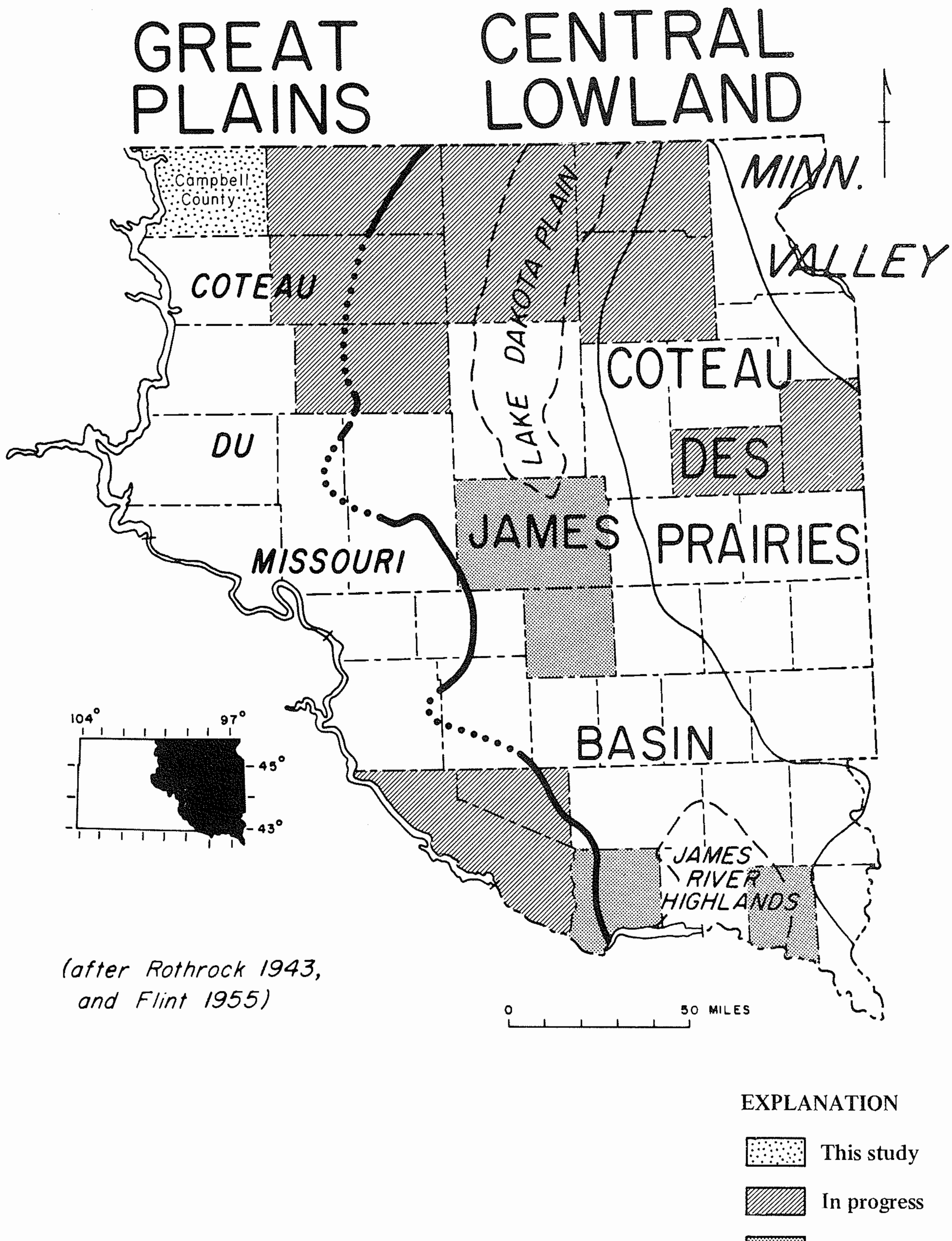


Figure 1. Map of eastern South Dakota showing location of physiographic divisions and location of county water resource studies.

METHOD OF INVESTIGATION

The data for this report were obtained during the summers of 1964, 1965, and 1966. The geology was mapped on vertical air photos by standard methods and later transferred to a base map, scale 1 inch to 1 mile, prepared by the South Dakota Department of Highways. A number of test holes as much as 475 feet deep were drilledd for subsurface information by the South Dakota Geological Survey and the United States Geological Survey. Most cuttings from these test holes were examined and described in the field, but several sets of cuttings received further study in the laboratory. Electric logs are available at the South Dakota Geological Survey for many of the rotary test holes which helped in subsurface correlation. Supplementary data were obtained from records of private well drillers, railroad test holes and wells, U. S. Bureau of Reclamation test holes, and from oil tests in nearby areas. All data in this report are located according to the standard legal method of land subdivision. Location of all test holes for which geologic and hydrologic information are available is shown on figure 2, Part II of this report (Hedges and Koch, 1970).

ACKNOWLEDGMENTS

The field work and preparation of this report were performed under the supervision of Duncan J. McGregor, State Geologist. Valuable advice and criticism were obtained from many members of the South Dakota Geological Survey staff. Special thanks go to Merlin J. Tipton, Associate State Geologist of the South Dakota Geological Survey, and Neil C. Koch, geologist for the United States Geological Survey, for discussion during field trips and office conferences. The test drilling program for the South Dakota Geological Survey was greatly enhanced through the services of Drill Supervisor Lloyd Helseth and drillers, Robert Stach and Dwight Brinkley. Thanks are also due to the many other people who performed services during various phases of this project.

The residents of Campbell County, members of the Oahe Conservancy Sub-District, the Board of County Commissioners, and Michael Madden, County Extension agent, are gratefully acknowledged for their cooperation throughout this project.

DRAINAGE

Since construction of the Oahe Dam on the Missouri River and subsequent formation of the Oahe Reservoir, Spring Creek remains the only significant stream in the county. Its headwaters are in north-central McPherson County, and it flows west through the northern one-third of Campbell County to man-made Lake Poccasse which overflows into the Oahe Reservoir. Springs along the lower reaches of the stream supply a nearly perennial flow of water. Olson Creek and Blue Blanket Creek in the western part of the county also carry run-off water, but only during periods of precipitation or snow melt. Other run-off is collected by undrained depressions in the glacial drift.

TOPOGRAPHY

The Missouri River trench is the most outstanding topographic feature in Campbell County. Cutting to an average depth of 500 feet into the Fox Hills Formation and the Pierre Shale, the trench has been partially refilled with about 100 feet of sandy alluvium. From the mouth of Spring Creek northward into North Dakota the trench is 2 to 3 miles wide, where as south of the mouth of Spring Creek the trench is three-fourths to one and one-half miles wide. Several square miles of nearly level terraces, composed of outwash and alluvium, occur near the mouth of Spring Creek and north of the mouth of the Grand River (pl. 1).

From the Missouri River trench to the collapsed outwash plains 6 to 10 miles to the east, the dissected bedrock has a thin cover of drift making the existing topography less rugged than the buried bedrock topography; however it still retains the essential characteristics of the older bedrock topography. A broad nearly continuous collapsed outwash plain (pl. 1) lies in the topographic sag along the courses of the Ancient Grand Channel and the Mound City Channel (pl. 2).

Topography over the rest of the county is characteristic of hummocky glacial terrain associated with stagnation drift having relief ranging from 10 to 100 feet.

STRATIGRAPHY

PRE-PLEISTOCENE DEPOSITS

There are no deep wells or oil tests in Campbell County which completely penetrate the bedrock formations. There are several deep water wells, but these penetrate only about one-half the sedimentary sequence and drilling records for these wells are inadequate or missing. Because of this lack of information, bedrock data presented in this section is mainly based on logs of the Peppers No. 1 State oil test 12 miles south of Campbell County in central Walworth County. This well bottomed in Precambrian granite at a depth of 3914 feet. The electric log of the Peppers No. 1 State oil test (pl. 3) includes all but the upper 400 feet of the entire sedimentary sequence present in this area. All of the formations present in the Peppers No. 1 State oil test are undoubtedly represented in Campbell County, although they may be somewhat thicker in Campbell County. There may also be additional bedrock units underlying Campbell County which are not present in this oil test.

The nomenclature of the Paleozoic rocks follows Schoon (1967). Similarly, the nomenclature of the Dakota Formation, Skull Creek Formation, and Inyan Kara Group for central South Dakota follows Schoon (1965). Both sets of nomenclature are currently accepted by the South Dakota Geological Survey. Nomenclature for the rest of the bedrock is that proposed for the South Dakota Geological Survey by Agnew and Tychsen (1965).

PRECAMBRIAN ROCKS

The Peppers No. 1 State oil test in Walworth County terminated in basement rock at a depth exceeding 3900 feet. The basement rock is a pink biotite granite. This information combined with knowledge of the general distribution of granitic rocks in South Dakota makes it likely that the basement rock in Campbell County is also granitic.

A granite from the Pray No. 1 Kranzler oil test in Walworth County has a Rb-Sr date of 1.69 B.Y. (Goldich and others, 1966).

Ages for other granitic rocks in South Dakota range from 1.97 B. Y. (K-Ar57B, Goldich and others, 1961) on a sample from northeast South Dakota to an age of 2.5 B.Y. on a granite gneiss from the Black Hills in western South Dakota (Zartman, Norton, and Stern, 1964).

A preliminary map of the Precambrian surface of South Dakota (Steece, 1961) shows a uniform slope from about 1800 feet below sea level in the southeast part of the county to about 3500 feet below sea level in the northwest part of the county. The average slope of the Precambrian surface is thus about 57 feet per mile into the Williston Basin.

PALEOZOIC ROCKS

Paleozoic rocks in Campbell County consist of over 1500 feet of limestone, dolomitic limestone, and dolomite. However, thin sandstone and shale units may also be present throughout much of the section. Thickness, age and general lithologic description of the individual formations are shown graphically on plate 3. The Permian to Cretaceous rock sequence, lying between the Hayden Formation and the Inyan Kara Group (pl. 3), is a red clay that may be highly weathered Paleozoic sediments or a deposit post-dating the Paleozoic rocks.

SUBSURFACE CRETACEOUS ROCKS

In the Peppers No. 1 State oil test in Walworth County (pl. 3) the only mesozoic sediments recognized are Cretaceous in age. There is a strong probability that some older Mesozoic sediments are present in Campbell County (Robert A. Schoon, personal communication) although their thickness and correlation are unknown.

The Cretaceous rocks present in the subsurface in Campbell County are, oldest to youngest, the Inyan Kara Group, Skull Creek Shale, Dakota Formation, Graneous Shale, Greenhorn Limestone, Carlile Shale, Niobrara Marl, and the lower members of the Pierre Shale. The age, thickness and lithologic description of these units are graphically shown in plate 3.

The complex history of nomenclature and problems of correlation with the Dakota-Skull Creek-Inyan Kara Group is explained by Schoon (1965). Throughout central South Dakota including Campbell County, the earlier interpretations correlated what is now considered the Skull Creek Shale and the Inyan Kara Group to the Morrison Formation and Sundance Formation respectively, both of Jurassic age. The Dakota Formation was correlated with the entire Dakota Group of central South Dakota as defined by Agnew and Tychsen (1965). In general, the remainder of the subsurface Cretaceous rocks, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Marl and the Pierre Shale create very little difficulty in regional correlation.

The lower members of the Pierre Shale which are not exposed in the Campbell County area are, oldest to youngest, Sharon Springs, Gregory, Crow Creek, DeGrey and Verendrye Members. Crandall (1958) discussed the nomenclature and lithologies of these members in the outcrop areas around Pierre, South Dakota.

EXPOSED CRETACEOUS ROCKS

Cretaceous rocks exposed in Campbell County are the Virgin Creek, Mobridge and Elk Butte Members of the Pierre Shale, and the Trail City and Timber Lake Members of the Fox Hills Formation. The distribution of these rocks in Campbell County as shown on plate 1 has been taken from the Pollock geologic quadrangle (Baldwin, 1951), and the Mobridge geologic quadrangle (Baker, 1952) with only minor changes. See figure 2 for location of mapped geologic quadrangles in the vicinity of Campbell County.

Pierre Shale

History of the nomenclature for the Pierre Shale along the Missouri River valley in South Dakota is admirably discussed by Crandall (1958), and the terminology adopted by him is followed in this report. Because the present report has placed emphasis mainly on the surficial Pleistocene deposits, the following discussion about the members of the Pierre Shale is but a brief resume of previous work.

Virgin Creek Member

The Virgin Creek Member of the Pierre Shale (Searight, 1937) is designated as those beds between the Verendrye zone including all the noncalcareous beds to the base of the Mobridge Member. Two units are generally present in this member near Mobridge in Walworth County: an upper dark-gray bentonitic clay about 60 feet thick, and a lower dark-gray siliceous bentonitic clay with numerous thin bentonite beds. The lower unit is about 90 feet thick. In the Pierre area the Virgin Creek ranges in thickness from 120 to 230 feet (Crandall, 1958, p. 15).

In Campbell County the Virgin Creek crops out as a narrow band along the Missouri River. At present, water of the Oahe Reservoir nearly covers the entire outcrop of the Virgin Creek (see pl. 1).

Mobridge Member

The Mobridge Member of the Pierre Shale (Searight, 1937, p. 44) was named from exposures

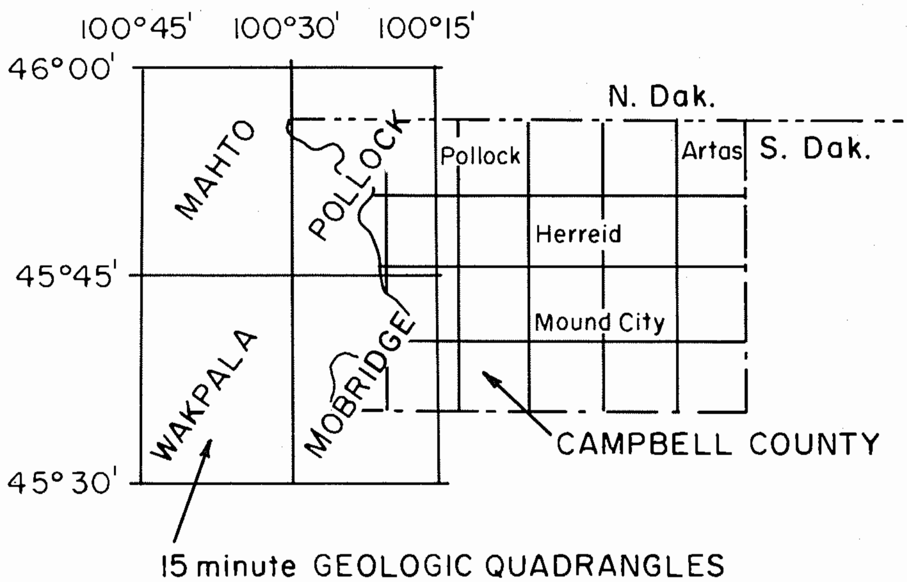


Figure 2. Index map showing location of geologic quadrangles in Campbell County and surrounding area.

above the west end of the highway bridge across the Missouri River at Mobridge, Walworth County. It is defined as a series of highly calcareous shale, marl and chalk beds. Thickness at the type section measured by Searight is 137 feet. However, Baldwin (1950, unpublished manuscript) indicated that the total thickness of the Mobridge Member is closer to 200 feet. No attempt was made in the present study to refine the work of the earlier studies.

Rothrock (1947) recognized four distinct zones in the Mobridge: a crab zone (lower), baculite zone, marl zone, and a banded zone (upper). Baldwin (1950, unpublished manuscript) recognized these four zones in the Pollock quadrangle in Campbell County.

In Campbell County the Mobridge Member crops out as a narrow band along the Missouri River with most exposures south of the mouth of Spring Creek. North of Spring Creek the water of the Oahe Reservoir covers most of this member (see pl. 1).

Elk Butte Member

The Elk Butte Member of the Pierre Shale was named by Searight (1937) for exposures west of Wakpala in eastern Corson County along U. S. Highway 12. The Elk Butte is a flaky weathering, bluish-gray clay. Ironstone concretions, selenite, and bentonite beds are present but not abundant. About 25 feet above the highest calcareous beds of the Mobridge is a bentonite seam containing 3 to 4 inch diameter barite rosettes which are useful for mapping structure. Weathering reduces the clay of the Elk Butte Member to small flakes which are easily transported by wind. As a result, blowouts are common in exposures of Elk Butte. Thickness of the Elk Butte reported at the type section is 270 feet. No complete sections of Elk Butte are present in Campbell County but across the Missouri River at a section near the abandoned Kenel–Pollock Ferry, Baldwin (1950, unpublished manuscript) measured 162 feet of Elk Butte Member with neither upper nor lower contact visible. At the same section, Gries (1942, p. 41) reported 242 feet of Elk Butte, but Baldwin (1950, unpublished manuscript) says that Gries ". . . evidently included some of the lower part of the Fox Hills in his measurement." In Campbell County the Elk Butte Member crops out extensively along the Missouri River (pl. 1). However, because of weathering the upper and lower contacts are hidden under talus.

Fox Hills Formation

The Fox Hills Formation was named by Meek and Hayden (1861, p. 427) for exposures near Fox Hills between the Cheyenne and Moreau Rivers about 50 miles southwest of Campbell County. Since about 1900, four lithologic units of the Fox Hills have been mentioned in the literature. It was not until 1956, however, that all four units were formalized as members. The four named members are, from oldest to youngest, Trail City, Timber Lake, Bullhead and Colgate Members.

Waage (1961) discussed the Fox Hills Formation and the relationship of the four members in and around its type area in central South Dakota. Later Waage (1968) proposed dropping the names Bullhead and Colgate Members and including them as the Bullhead lithofacies and Colgate lithofacies of the new Iron Lightning Member. Only the lower two members, the Trail City and Timber Lake Members are present in Campbell County.

Trail City Member

The Trail City Member was named by Morgan and Petsch (1945, p. 13) for exposures around Trail City in northeast Dewey County. The Trail City is described as sandy brown or buff clay near the base, becoming more sandy in its upper part. In its type area, the Trail City Member ranges from about 50 to 90 feet in thickness. Baldwin (1950, unpublished manuscript) described yellow sulfate veins, streaks and pellets in the lowest Trail City beds and when present used them as markers in helping to define the Elk Butte–Fox Hills contact. According to Waage (1961), unpublished chemical tests showed the yellow nodular material to be composed chiefly of jarosite. He further stated that the jarosite layer in the Trail City Member is neither continuous nor is it the only jarosite layer present in the Trail City; thus the jarosite layer cannot be used to trace the contact between the Fox Hills and Pierre Shale Formations. In the Pollock quadrangle (Baldwin, 1951), which includes part of Campbell County, no jarosite beds were observed although just west of Mobridge the writer observed abundant jarosite just above the Elk Butte–Trail City contact.

In Campbell County the Trail City Member consists of gray silty clay, silt, and sandy silt with fossiliferous concretions. No complete section of this member is exposed but Baldwin (1950, unpublished manuscript) reported between 50 to 90 feet of Trail City. In the present study the Trail City Member has been included with the overlying Timber Lake Member, and the two members have been mapped as Fox Hills undifferentiated, as Baldwin (1951) and Baker (1952) have done.

Timber Lake Member

The Timber Lake Member was named by Morgan and Petsch (1945, p. 15) for exposures in and around the town of Timber Lake, Dewey County. The Timber Lake Member is chiefly a fine-to-medium grained, dirty, greenish-gray sand which upon weathering turns to various shades of yellow-brown. The sand is glauconitic and contains calcareous concretions. Locally much of the sand is cemented.

Very little data is presented by Morgan and Petsch (1945) concerning the thickness of the Timber Lake Member. Waage (1961) stated that the sand unit changes in thickness from as little as 30 feet in the southwest portion of the type area to as much as 200 feet in the northeast portion of the type area. He attributes part of this variation in thickness to gradation and intertonguing with the overlying Bullhead Member. Baldwin (1950, unpublished manuscript) reported 87 feet of the Timber Lake Member on Oak Creek, a mile east of McLaughlin, but neither the bottom nor top contact was seen by him. He also reported more than 100 feet of the Timber Lake Member at the Kenel–Pollock Ferry section. In Campbell County the lower slopes of the Fox Hills Formation are covered and the upper part of the Fox Hills Formation is incomplete or, if present, is covered with glacial drift as that complete thicknesses of the Fox Hills could not be measured. One section of the Fox Hills in SW¼SW¼NW¼SE¼ sec. 2, T. 128 N., R. 79 W. exposed 32 feet of friable sand with interbedded sandstone and sandy limestone ledges one inch to one foot thick. Undoubtedly thicker sections of the Timber Lake Member are present in Campbell County, but they are not exposed. With the use of topographic maps and isolated outcrops, the Fox Hills in Campbell County is estimated to be about 200 feet thick of which the Trail City Member and Timber Lake Member each comprise about 100 feet.

Sandstone of the Timber Lake Member forms the steep-sided bluffs adjacent to the uplands north and south of Pollock and caps the bedrock outlier 4 miles west of Pollock. Although not confirmed, a buried bedrock ridge 4 miles southwest of Mound City is thought to be a resistant ridge of Timber Lake sandstone with a thin cover of glacial drift.

ABSENCE OF DEPOSITS OF TERTIARY AGE

Tertiary deposits are not known to exist in north-central South Dakota, east of the Missouri River, and no evidence of Tertiary deposits was found during the mapping of Campbell County.

In the Wakpala and Mahto quadrangles just west of Campbell County (fig. 2) across the Missouri River, there are a number of buttes and mesas capped by hard silica-cemented sandstone that ranges from 3 to 10 feet in thickness. No index fossils have been found in this sandstone so the age is not known. Stratigraphic and elevation data in the area suggest that the upper 100 feet or so of rocks capping these buttes may be post-Fox Hills Formation and could be in part Hell Creek Formation (Baldwin, 1950, unpublished manuscript). Baldwin later stated (written communication to Baldwin from C. L. Baker, South Dakota Geological Survey files) that the caprock may be Miocene in age and could correlate with the Bijou quartzite, a part of the Ogallala Formation of south-central South Dakota.

PLEISTOCENE DEPOSITS

TERMINOLOGY

In the midwestern United States, four glaciations have been recognized; from oldest to youngest these are: the Nebraskan, Kansan, Illinoian, and Wisconsin. These glaciations are separated by the Aftonian, Yarmouth, and Sangamon Interglaciations, respectively. In South Dakota glacial deposits from all the glaciations and deposits representing each interglaciation have been tentatively identified (Lemke and others, 1965). The only pre-Wisconsin glacial deposits known and identified in South Dakota are located in the southeastern part of the state.

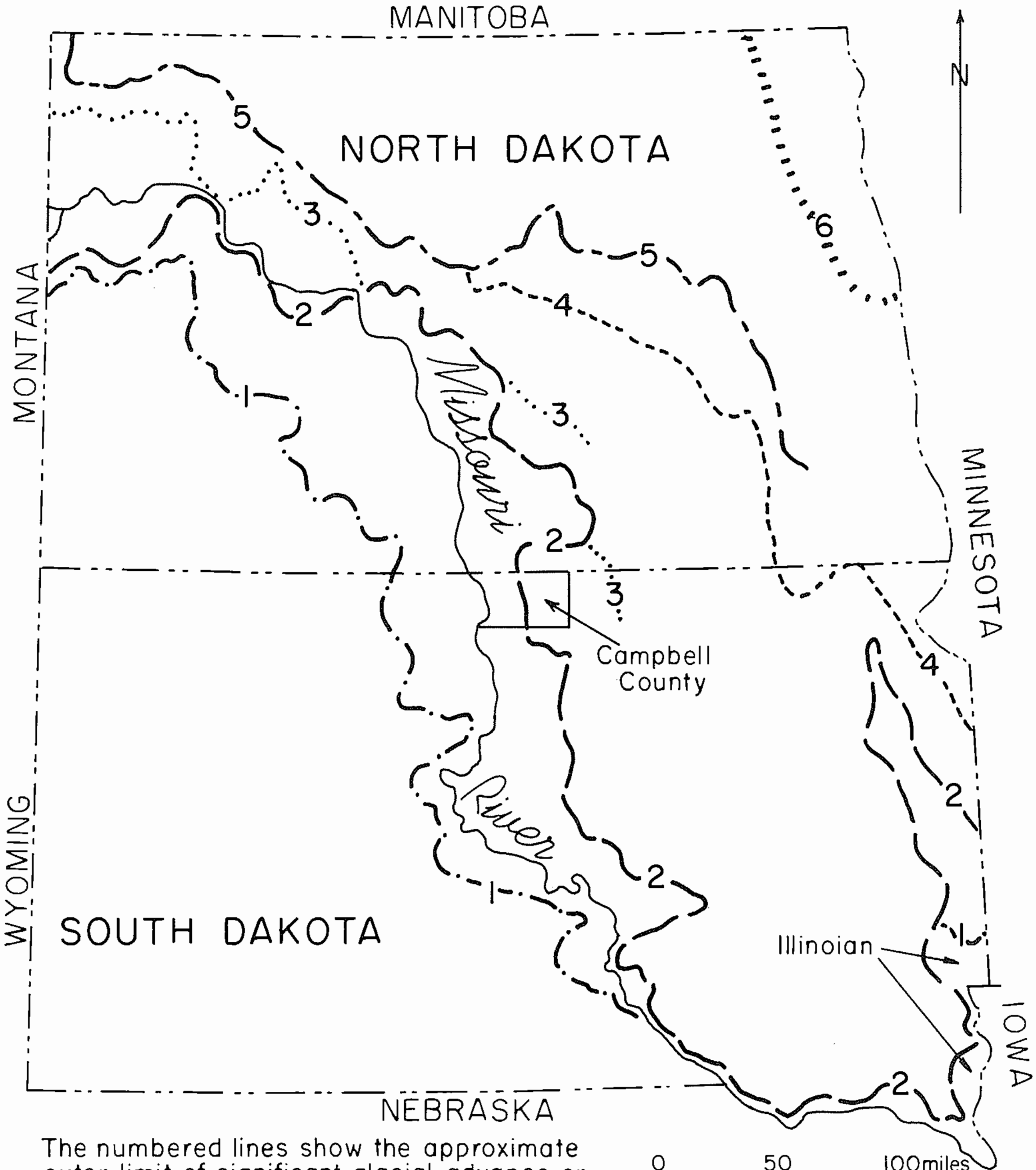
Flint (1955) mapped the Pleistocene deposits in South Dakota and used the following classification of Leighton (1933) for the Wisconsin Stage:

Wisconsin glacial stage
- Mankato substage
- Cary–Mankato interval
- Cary substage
- Tazewell–Cary interval
- Tazewell substage
- Iowan–Tazewell interval
- Iowan substage

The work of Flint (1955) offered the first attempt at the synthesis of the Wisconsin deposits in South Dakota and provided tentative regional correlation. The classification that he used soon became outdated because of C–14 dating methods, particularly with reference to South Dakota. This lack of correlation illustrates the danger of stretching a classification good for one region to another region.

The method now used for the classification of Wisconsin deposits in this state by the South Dakota Geological Survey is that of numbering each ice advance in sequence from oldest to youngest (fig. 3), and in the text showing the tentative correlation of these advances with other published classifications. The discussion of the various ice advances by Lemke and others (1965) correlates advance one with early Wisconsin; i.e., Iowan and Tazewell, undifferentiated, of Flint (1955). Succeeding advances were assigned to the late Wisconsin; i.e., Cary and Mankato of Flint (1955). Mapping done by the writer in Campbell County has modified the relative positions of some of the advances compared to those shown by Flint (1955) and Lemke and others (1965). This topic will be discussed later in this report. Table 1 shows the classification of Pleistocene glaciation now used in South Dakota and the writer's interpretation of the correlation with classifications from other areas.

Because of widespread use of radiocarbon dating, recent detailed surface and subsurface mapping studies, definition of previously unknown deposits, and subsequent redefinition of known deposits, nomenclature and classification of deposits of Wisconsin age in the United States is in a constant state of revision. The stratigraphic record for the Wisconsin Stage is fairly complete and well documented in the Great Lakes region of the United States near the heart of the glacial advances. In the areas near the margins of the continental glacial advances, however, the stratigraphic record is generally less complete. The geographic position of South Dakota is at the southwestern margin of the Wisconsin ice sheet. For this reason and possibly due



The numbered lines show the approximate outer limit of significant glacial advance or readvance of Wisconsin age, not necessarily of stadial rank. Numbered from oldest to youngest.
(Modified from Lemke and others, 1965)

Figure 3. Boundaries of Wisconsin ice advances in North Dakota and South Dakota.

Table I. Pleistocene classification in South Dakota and other areas.

Radiocarbon Years (B.P.)	Frye and Willman, 1960		* Flint, 1955		Lemke, and others, 1965, and this paper	
0	RECENT		RECENT		RECENT	
	WISCONSINAN	VALDERAN				
10,000		TWO CREEKAN	WISCONSIN	MANKATO	WISCONSIN	- - ? - - - - - ? - - LATE
		WOOD-FORDIAN		CARY		
				TAZEWELL		EARLY
20,000				IOWAN		
		FARMDALIAN	SANGAMON			
30,000		ALTONIAN				

* The classification used by Flint was first proposed by Leighton (1933) in naming subdivisions of the Wisconsin glacial age.

to the lack of information, deposits making up the stratigraphic record of the Wisconsin Stage is incomplete in South Dakota as compared to some other areas. Because the stratigraphic record for South Dakota is probably inherently different from other areas for the Wisconsin Stage, the adoption of a classification framework for South Dakota based on deposits and dates from other regions would be relatively meaningless. Thus, the South Dakota Geological Survey has adopted a classification for Wisconsion deposits (Lemke and others, 1965) as explained in the previous paragraph. A comprehensive review of Pleistocene classifications can be obtained from Wright and Frye (1965) and the Wisconsin classification in particular is summarized in Frye and others (1968).

According to Lemke and others (1965) each Wisconsin advance may or may not have stadial rank. It may be a slight readvance with little regional significance, or it may simply mark a temporary halt during deglaciation, or it may mark the zone of drift accumulation between stagnant ice and active ice.

The distribution of the surficial Pleistocene deposits in Campbell County is shown on plate 1. Table 2 is a generalized stratigraphic section of the Pleistocene deposits present in Campbell County.

PRE-LATE WISCONSIN DEPOSITS

Ancient Grand Channel valley-fill

The oldest known Pleistocene deposit in Campbell County is a buried sequence of outwash and alluvium as much as 40 feet thick, hereafter informally referred to as the Ancient Grand Channel valley-fill. This deposit is the basal sediment in a deep channel system cut into the Pierre Shale and is restricted to the deepest parts of the Ancient Grand Channel and its tributary, the Mound City Channel (see pl. 2 for location of these channels). Where present, this deposit always lies on the Pierre Shale and is overlain by the Pollock Formation or late Wisconsin glacial drift.

The Ancient Grand Channel valley-fill ranges in thickness from a feather edge to a known maximum of 216 feet in test hole 39 (cross section D-D', pl. 4). Most other test holes in this general area have penetrated nearly 200 feet of valley-fill, but the normal range in thickness is from 50 to 100 feet. This deposit consists of a basal outwash sand and gravel unit and an overlying complex outwash-alluvium unit.

The basal outwash sand and gravel unit of the Ancient Grand Channel valley-fill, loosely referred to as the "basal unit", has a maximum thickness of about 90 feet, averages about 35 feet, and is always found in direct contact with the Pierre Shale. The basal unit is primarily a clean, sandy, medium to coarse gravel with cobbles and boulders, although clay-filled zones are occasionally present. The outwash is composed of igneous and metamorphic rocks, limestone, dolomite, shale, sandstone, and abundant large fragments of coal. In a reverse circulation rotary hole drilled for an irrigation well near Pollock, the writer observed chunks of coal as much as 4 to 5 inches in diameter that were brought up from this horizon. The four following characteristics of the basal unit have not been observed for any other outwash deposits in the County, and thus serve to be diagnostic of the basal unit: 1) abundant large coal fragments, 2) relatively low shale pebble content, 3) more abundant sandstone fragments, and 4) lower stratigraphic position.

The complex outwash-alluvium unit, hereafter referred to as the "complex unit", of the Ancient Grand Channel valley-fill is known only in the subsurface. It has a maximum thickness greater than 200 feet (see cross sections D–D', E–E', pl. 4) and consists primarily of laminated very fine to fine sand, interbedded with sand and gravel, silty sand, and clayey sand. A characteristic of the complex unit as revealed in test hole cuttings is that dark manganese dioxide stain is present throughout. This dark coloration is particularly pronounced in the upper part, and is thought to represent a period of oxidation of this unit as a result of sub-aerial exposure. Staining such as this is common in exposed younger but similar sediments along the Missouri River. The black staining is significant because in Campbell County it allows identification and correlation of the buried valley-fill, part of which could not be easily differentiated from otherwise similar fine-grained buried outwash deposits. Exact origin of the complex unit is uncertain. The finer portions may be mostly stream alluvium derived primarily from glacial drift; whereas, coarse fraction may be alluvium or outwash. The entire complex unit is lithologically and texturally similar to present Missouri River floodplain and terrace deposits.

One or both units of the Ancient Grand Channel valley-fill is present throughout the buried channel system in the County (see cross section, pl. 4). Where the complex unit is thick the basal unit thins or is absent. Conversely, where the basal unit is well-developed the overlying complex unit is thin or absent. The significance of this relationship is not understood at the present time.

Age of the Ancient Grand Channel valley-fill is unknown. The only conclusions about its age that can be determined at this time is that the valley-fill is pre-late Wisconsin as indicated by the following lines of evidence: (1) these deposits pre-date or are contemporaneous with formation of the Missouri River trench which itself is no younger than early Wisconsin; (2) the valley-fill deposits underlie known late Wisconsin deposits (see cross sections, pl. 4), and (3) black sand in the complex outwash-alluvium unit is interpreted as representing a weathering interval which would have to pre-date the last Wisconsin. Presently the Ancient Grand Channel valley-fill cannot be correlated with any other known deposit.

Table 2. Generalized geologic section of the Pleistocene deposits in Campbell County.

EPOCH	DEPOSIT	THICKNESS (feet)	DESCRIPTION
Recent	Alluvium	0–15	Mostly dark colored clay and silty clay containing various amounts of sand and gravel.
Recent and Pleistocene	Sand Dunes	0–25	Fine to medium well-sorted quartzose sand; dune topography and blow-outs locally present.
Recent and Pleistocene	Colluvium	0–12	Silt and clayey sandy silt; derived primarily from loess; or dark pebbly, sandy clay derived mostly from till.
Recent and Pleistocene	Loess	0–15	
Pleistocene, Wisconsin, Late Wisconsin	Loess	0–15	Yellow wind-blown silt; much of terrace loess definitely Recent in age but upland loess probably mostly Pleistocene in age.
Pleistocene, Wisconsin, Late Wisconsin	Undifferentiated Glacial Drift: Surface Outwash	0–100	Poorly-sorted to well-sorted sand and gravel; upper part mainly gravelly; lower part mainly well-sorted fine to very fine sand.
Pleistocene, Wisconsin, Late Wisconsin	Undifferentiated Glacial Drift: Till	0–300	Dark-gray pebbly sandy clay; locally, includes sand and gravel lenses; high shale-pebble content in till and sand and gravel lenses; averages about 100 feet thick.
Pleistocene, Wisconsin ?, Pre-Late Wisconsin	Pollock Formation	0–170	Laminated silty gray clay to nearly massive gray clay; contains very fine sandy zones; weathers to yellow, compact sticky clay where exposed.
Pleistocene, Wisconsin ?, Pre-Late Wisconsin	Undifferentiated Drift ?: Till	0–120	Dark-gray pebbly sandy clay with high shale-pebble content; differentiated only where it is beneath the Pollock Formation.
Pleistocene, Wisconsin ?, Pre-Late Wisconsin	Undifferentiated Drift ?: Outwash	0–30	Sand and gravel ranging to silty clay; highly variable lithology; usually lies near base of till.
Pleistocene, Wisconsin ?, Pre-Late Wisconsin	Ancient Grand Channel valley fill	0–216	Coarse coal-rich gravel, averaging 40 feet thick, overlain by as much as 176 feet of laminated fine to very fine sand interbedded with sand and gravel and gravelly clay; laminated black fine sand.

Glacial Deposits

The only known glacial deposits in Campbell County, other than those mentioned above, which may be pre-late Wisconsin in age, is the undifferentiated glacial drift underlying the Pollock Formation and overlying the Ancient Grand Channel valley-fill (see cross sections, pl. 4). This undifferentiated glacial drift consists mainly of till with associated fine to coarse outwash sediments. The maximum thickness of the undifferentiated glacial drift found between the Ancient Grand Channel valley-fill and the Pollock Formation is 150 feet.

The till from the glacial drift cannot be distinguished from other tills in the county on the basis of rotary drill samples, and there are no known surface exposures of these deposits for comparison, unless the loess covered till in the western part of Campbell County is pre-late Wisconsin and correlates with the buried glacial deposits. Evidence presented in a later section of this report indicates that such a correlation is unlikely.

In the eastern part of the county the thick glacial drift overlying the Ancient Grand Channel valley-fill (see pl. 4) may contain deposits equivalent to the inferred pre-late Wisconsin glacial deposits; however, there are no means of differentiation at the present time.

The only valid reason for assigning the buried glacial deposits to a pre-late Wisconsin age is their stratigraphic position below the Pollock Formation which is inferred to be a proglacial late Wisconsin lacustrine deposit. Thus, by inference, any till below the Pollock Formation would probably belong to an earlier ice advance.

If the glacial deposits underlying the Pollock Formation is pre-late Wisconsin it could be Illinoian or early Wisconsin age. It may be equivalent to the Napolean Drift in Logan and McIntosh Counties, North Dakota, which has been dated as older than 38,000 years before present (Clayton, 1962, p. 59).

LATE WISCONSIN DEPOSITS

Pollock Formation

Test drilling in Campbell County has revealed the presence of an extensive late Pleistocene formation not previously recognized as a formal stratigraphic unit. This report recognizes the formation as a formal rock unit and proposes the name Pollock Formation to apply to this rock unit.

General Occurrence

In Campbell County the Pollock Formation is restricted within the boundaries of the Mound City Channel and the Ancient Grand Channel west of the range line between Ranges 75 and 76 West (fig. 4). Although thin surface exposures of this formation are present north of Pollock, South Dakota, the bulk of the unit is buried in places by as much as 150 feet of glacial drift. For this reason the Pollock Formation is designated a subsurface rock unit.

Designation of Type Section

The type section of the Pollock Formation is from a test hole drilled by the South Dakota Geological Survey located in the NE¼NE¼NE¼NE¼ sec. 13, T. 128 N., R. 78 W., about 3 miles northeast of Pollock, Campbell County, South Dakota (fig. 4). This test hole was chosen as the type section because: (1) it contained one of the thicker sequences of the formation, (2) there was good sample recovery from this test hole, (3) this test hole had an electric log made, and (4) it was the closest test hole to the outcrop area which also met the above requirements. The formation description is based on rotary drill cuttings collected at 10-foot intervals and electric logs obtained from many test holes penetrating this formation. The lack of detailed information about the formation at its type section is off-set by the many test holes partially or completely penetrating the unit, thus attesting to its wide distribution, continuity, and gross uniformity of lithology. Samples, lithologic logs and electric logs from many test holes including the type section are on file at the South Dakota Geological Survey, Akeley Science Center, Vermillion, South Dakota.

Description

At its type section the Pollock Formation consists of 148 feet of uniformly bedded clay and silty clay. Unweathered material is medium-to dark-gray. Near the middle and bottom of the unit, light-gray, very fine sand laminae are readily visible interbedded with medium-to dark-gray silt or silty-clay laminae. Weathered portions of this deposit are yellow and mostly massive. In exposures and from drill-cuttings, the weathered portions are very similar in appearance to weathered Pierre Shale, especially the Mobridge Member. No mega-fossils have been observed in the drill cuttings or exposures. Possible micro-fossil content of the formation has not been studied. Figure 5 shows the lithologic and electric logs at the type section of the Pollock Formation. These logs are typical of the formation throughout its extent.

Stratigraphic Relationship

The Pollock Formation is part of a complex system of cut and fill deposits occupying the Ancient Grand Channel and the Mound City Channel. This complex system of cut and fill deposits consists of both units of the Ancient Grand Channel valley-fill previously described, outwash, till, alluvium, and glacio-lacustrine deposits. Stratigraphically it overlies glacial drift of pre-late Wisconsin (?) age, and underlies till and outwash of late Wisconsin age. In many places, however, the base of the Pollock Formation is in direct contact with the Ancient Grand Channel valley-fill; or less frequently, it is in contact with the Pierre Shale on the channel margins (pl. 4).

The relationship of the Pollock Formation to the Missouri River alluvium (now water covered) is not known because there are no drill records available

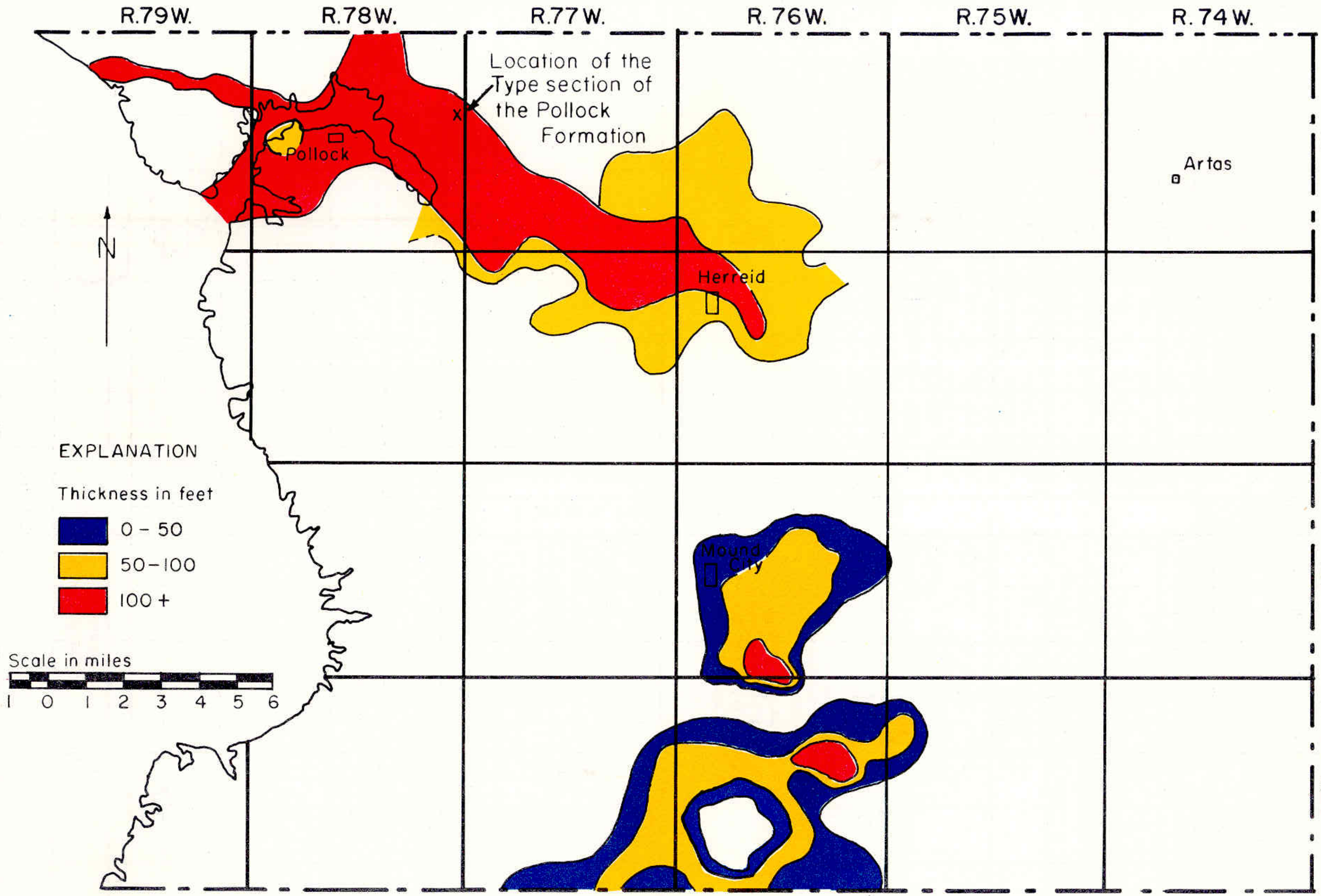


Figure 4. Distribution, thickness, and location of the type section of the Pollock Formation.

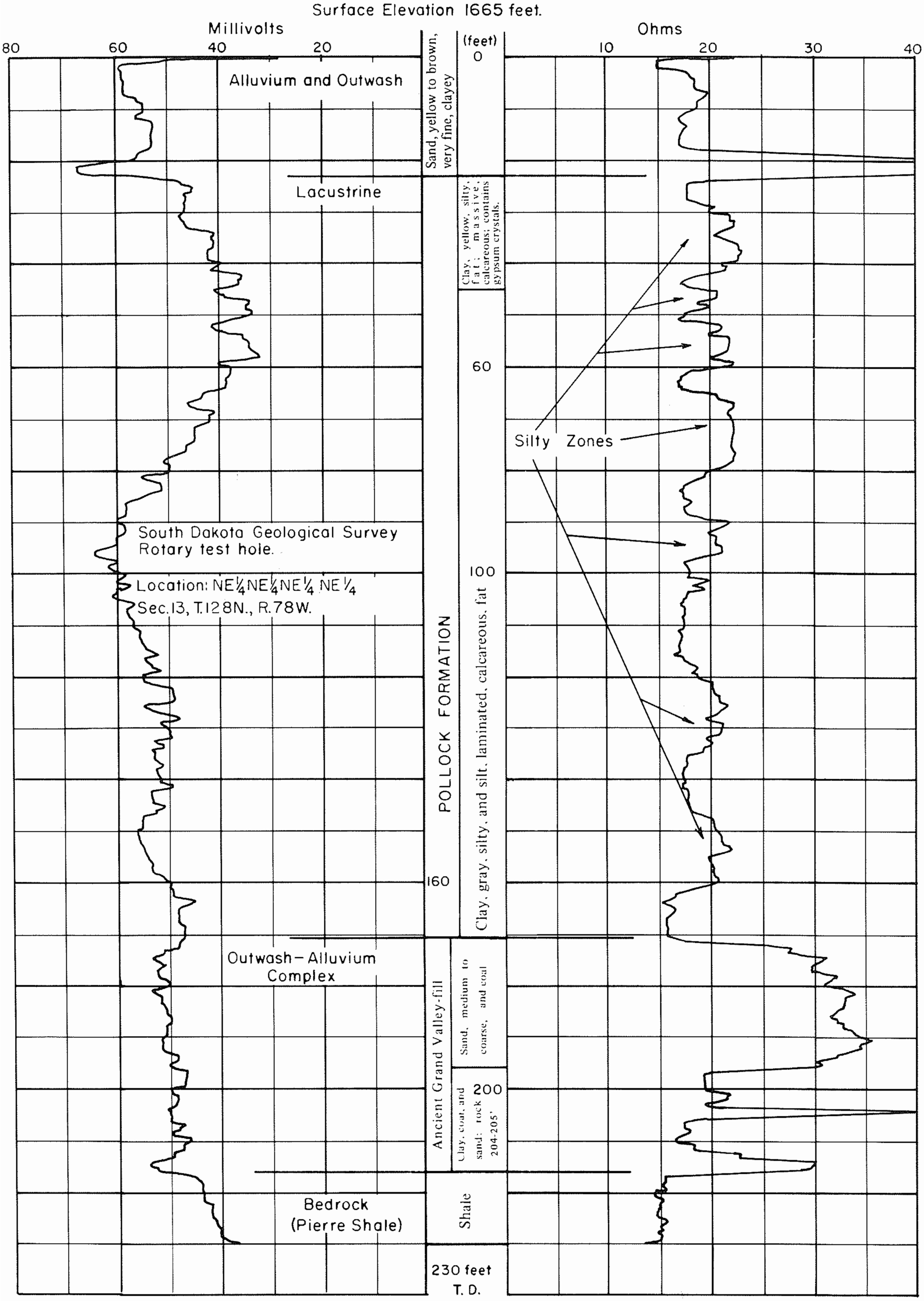


Figure 5. Mechanical and lithologic logs of the type section of the Pollock Formation.

from the Missouri River floodplain in the vicinity west of Pollock. The water-covered floodplain elevation is about 1575 feet. The general elevation of the top of the Pollock Formation is about 1700 feet and the general elevation of the base is about 1500 feet. Therefore, on the basis of elevation alone it would be possible for the Missouri River trench to contain as much as 75 feet of the Pollock Formation.

Thickness and Distribution

The Pollock Formation is shown as three separate areas on figure 4. The northern area is separated from the central area by till and associated deposits in the Mound City Channel. Test drilling revealed no connection of the formation between the two areas. The central area is separated from the southern area by the bedrock high which occurs between the Mound City Channel and the Ancient Grand Channel (see pl. 2). The southern part of the formation contains a bedrock high (see pl. 2) which also resulted in non-deposition of the formation. The southern portion of the formation joins similar type of deposition in Walworth County over a broad area about 11 miles wide which indicates that the formation is probably extensive in Walworth County.

Thickness of the Pollock Formation varies from zero at the margins to about 150 feet thick in the vicinity of the type locality (fig. 4). The northern segment of the formation is more uniform in thickness, averaging about 100 feet thick. The southern segments locally exceed 100 feet in thickness but average only about 50 feet thick.

Age

Age of the Pollock Formation is tentatively placed as late Wisconsin. This age designation is based on the preliminary interpretation of the Pollock Formation as sediments deposited in a proglacial lake associated with the advance of the late Wisconsin ice. Furthermore, there are no known significant stratigraphic breaks separating the Pollock Formation from the late Wisconsin till, outwash, or loess.

A significant factor in age determination of the Pollock Formation rests with the determination of the age of the thick till overlying the formation in the Mound City Channel northwest of Pollock (see cross section A-A', pl. 4). Following the age designation used by Flint (1955), glacial drift in this part of the county would be Tazewell (early Wisconsin) or older. If this till is in fact early Wisconsin as mapped by Flint, then the Pollock Formation would certainly be at least as old as early Wisconsin and could be pre-Wisconsin age. With the use of subsurface information, loess distribution and interpretation of local and regional topographic details in the late Wisconsin drift, the writer intends to show strong evidence favoring a late Wisconsin age for all the drift in Campbell County which Flint (1955) mapped as early Wisconsin.

Correlation

The first mention in the literature of anything which might relate to the Pollock Formation was by Todd (1885, p. 389) who made references to an extensive proglacial lake which was dammed in the valley of the Grand River by the expanding Bois Cache ice lobe (a sub-lobe of the James lobe). Todd mentioned this lake again (Todd, 1894, p. 119, and 1896, p. 32), and named this hypothetical body of water Lake Arikaree (Todd, 1908, p. 40). This lake, according to Todd, extended at least as far north as Bismarck, North Dakota, and several miles west up the valley of Ancient Grand River. These first references were used to explain the high level bouldery ridges and glacial erratics west of the present Missouri River as ice rafted debris. However, at this time there was no reference to a glacial lake deposit in the valley proper.

On the Pollock geologic quadrangle, Baldwin (1951) mapped "lake beds" and described them as "thin-bedded silt and clay-forming terraces" along the Missouri River near the mouth of Spring Creek. In the unpublished manuscript accompanying the map, Baldwin did not mention specifically that these lake beds were deposited in Lake Arikaree although it may be assumed that this was his intention.

At present it seems unlikely that the "lake beds" of Baldwin bear any relationship to the Pollock Formation. First of all, the Pollock Formation can not be physically traced by drill holes from its known occurrence southwest of Pollock to the terrace south of the mouth of Spring Creek. Second, the "lake beds" of Baldwin mapped on the terrace differ lithologically from the Pollock Formation. The following stratigraphic sections include the "lake beds" of Baldwin:

CAMPBELL COUNTY STRATIGRAPHIC SECTION C-7

Located on Missouri River terrace about 1 mile south of mouth of Spring Creek along bluff north of small tributary in SW¼SW¼NW¼NW¼ sec. 1, T. 127 N., R. 79 W.

3. Loess, yellow	*4 feet*
2. Silt and sandy silt, laminated, clayey in part; interbedded with sand and gravel. At the base is 2 feet of till-like pebbly clay which contained articulated fossil leg bone, probably Bison, and occasional gastropod. (This unit is probably the "lake beds" of Baldwin, 1951)	*16 feet*
1. Shale, medium gray-brown, calcareous, limestone layer 10 inches thick. Probably Mobridge Member of Pierre Shale. (Lower part of section to water level covered with slump material).	*7 feet*
Total	*27 feet*

CAMPBELL COUNTY STRATIGRAPHIC SECTION C-8

Located on Missouri River terrace about 1¼ miles south of the mouth of Spring Creek along south bluff of small tributary in SW¼SW¼SE¼NE¼ sec. 2, T. 127 N., R. 79 W. (about one-fourth mile southwest of stratigraphic section C–7).

6. Loess, basal 18 inches medium brown, grading upwards to yellow to dark modern soil; upper 12 inches leached	*6 feet*
5. Silt, upper 6 inches dark, basal 1 foot medium brown grading to yellow; no structure evident; calcareous	*4 feet*
4. Silt, clayey, and fine sand, laminated; upper 6 inches dark colored, lighter below; calcareous	*5 feet*
3. Silt, sandy, and fine sand; upper 8 inches dark brown to black, lower 10 inches medium gray; occasional gastropod; non-calcareous	*1.5 feet*
2. Sand, red and gray mottled, medium, well sorted; contains a few pebbles	*4 feet*
1. Shale, medium-gray, calcareous. Probably Mobridge Member of Pierre Shale	*20 feet*
Total	*39.5 feet*

**Units 3 and 4 above are certainly part of Baldwin's (1951) "lake beds" and perhaps he included units 2 and 5.*

Those terrace deposits described above are thin, directly overlie bedrock, contain sand zones, gravelly clay, and dark horizons which probably are alluvial in nature. The whole terrace sequence appears to be a loess covered alluvial-outwash complex, none of which is characteristic of the Pollock Formation.

On the Mobridge geologic quadrangle, Baker (1952) mapped extensive lake-bed sediments which he said (Baker, 1958) were caused by "A lobe of the glacial ice sheet pushed up the old Moreau–Grand drainage, ponding the streams and producing from them glacial meltwater Lake Arikaree." This concept of glacial Lake Arikaree is essentially the same as Todd (1908). The area mapped as "lake beds" does contain a bedded, fine-grained deposit. Reconnaissance in the area indicates that these deposits are probably not as extensive as mapped by Baker and include some till. The exposures visited in the Mobridge–Glenham area are laminated as opposed to the more massive bedded Pollock Formation; they contained small fragments of reworked material, and are not uniform in color like the Pollock Formation. It is possible that this area represents a different facies of the Pollock Formation. Other possibilities are that the "lake beds" are the fine-grained equivalent of a collapsed outwash, or they are locally derived alluvial or colluvial deposits. Whether the "lake beds" of Baker are actually part of the Pollock Formation or not will have to be determined by detailed surficial mapping supplemented with test drilling.

Flint (1955, p. 121) mentions some "... parallel-bedded lacustrine facies" deposits near Pollock, and suggests that they may be the result of "... a blockade of some kind in the Missouri trench." Within 2 miles from the town of Pollock the Pollock Formation is exposed; fine-grained outwash sediments are also present within this distance. The lack of a specific location and incomplete material description makes it impossible to determine which deposit Flint was describing.

Glacial Drift Undifferentiated

Thickness and Distribution

Glacial drift covers all of Campbell County except for a narrow band along the Missouri River at the western border of the county and a narrow strip north of Pollock (pl. 1). In the western one-third of the county the drift is masked by a cover of loess as much as 15 feet thick. Thickness of the late Wisconsin drift is unknown because the tills (if more than one is present) can not be distinguished from each other in test hole samples. The maximum thickness of the glacial drift is unknown. Test Hole 50 (cross section E–E', pl. 4) penetrated 475 feet of Pleistocene deposits and still did not reach bedrock. As much as 335 feet of these deposits could be late Wisconsin. This figure is supported by logs of other test holes drilled in the southeastern part of the county into sediments in the Ancient Grand Channel. These logs indicate 300 feet of drift with no significant stratigraphic breaks. The drift gradually thins westward and northward, except over the bedrock channels, from an average thickness of about 200 feet in the southeast to about 40 or 50 feet to the north and west (pl. 4). In the eastern two-thirds of the county excluding the area of bedrock channels, the late Wisconsin drift consists primarily of till, and till also comprises the bulk of the drift in the western one-third of the county. In the central part of the county over the bedrock channels, the late Wisconsin drift consists primarily of the Pollock Formation and outwash deposits not contained within the Pollock Formation, (see cross sections, pl. 4).

Lithology

A lithologic analysis was not made on the tills and outwash in Campbell County. However, lithologic analysis of correlative Wisconsin tills in Logan and McIntosh Counties, North Dakota, indicate that the various tills encountered there could not be differentiated by this method (Clayton, 1962, p. 55). Clayton found the various tills to contain about equal amounts of clay, silt, and sand with about 5 percent pebbles, cobbles and boulders. Pebble counts from the various tills in North Dakota showed about 55 percent local rocks (shale, siltstone, and sandstone), 25 percent limestone and dolomite, and about 20 percent igneous and metamorphic rocks. Various types of outwash were found to have about the same composition as the till. General field observations indicated that the till and outwash in Campbell County are lithologically and texturally similar to the tills found in the adjacent part of North Dakota.

Correlation and Age

Drift underlying the loess in the western part of Campbell County and till exposed at the surface throughout the rest of the county, is part of a single drift sheet. This drift sheet correlates with all or parts of what has been called the Zeeland Drift and the Burnstad Drift in North Dakota (Clayton, 1962). It should be pointed out that these two drifts in North Dakota are not used in a strict litho-stratigraphic sense. Clayton (1962, p. 53) defines those drift sheets as morphostratigraphic units which, in North Dakota, are part of a single drift sheet comprising the upper Wisconsin glacial deposits. Also the drift sheets have been dated by the radiocarbon C-14 method as between 11,650 $\pm$ 310 and 9,000 $\pm$ 300 years before present (Clayton, 1962, p. 68). The Zeeland Drift could be slightly older than this in terms of radiocarbon years, but would still belong to the late Wisconsin.

Extensive outwash deposits and non-loess covered till in the eastern part of the county (pl. 1) were called Mankato by Flint (1955). Loess-covered drift in the western part of the county, which in this report is called late Wisconsin, was correlated with the Iowan or Tazewell (or early Wisconsin) by Flint (1955).

Major criteria used by Flint to distinguish between Iowan-Tazewell deposits and Cary-Mankato deposits (early Wisconsin and late Wisconsin respectively are: (1) older drift is usually loess covered, (2) older drift has a partially or completely integrated drainage net, and (3) older deposits have less constructional topography. It is felt that these criteria are not valid, at least in Campbell County because: (1) Along the Missouri River in South Dakota the presence of a loess cover overlying late Wisconsin deposits is not uncommon (Christensen, 1967, and Christensen, in preparation; Simpson, 1960; Hedges, in preparation). In the Pierre area Crandall (1958) mapped up to 30 feet of loess, much of which is late Wisconsin in age. (2) Partially integrated drainage in the western part of the county is the result of thin drift overlying a highly dissected bedrock terrain, rather than due to longer exposure to erosional processes (see cross sections, pl. 4). In T. 125 N., R. 78 W., there is an area of non-integrated drainage. Drift in this area is generally from 50 to over 100 feet thick as compared to generally less than 50 feet where the drainage is more integrated. (3) In an area of early Wisconsin drift (Tazewell-Iowan of Flint) located in T. 125 N., R. 78 W., in western Campbell County (pl. 5), there is an area encompassing several square miles of low to medium relief constructional topography which, in appearance, has the same constructional topographic features as are characteristic of late Wisconsin drift.

Any discussion and explanation about the correlation and age of the loess covered drift and the non-loess covered drift must be compatible with the following facts:

(1) There is a sharp break between the loess-covered till and outwash except for a few square miles in the north-central part of the county near the intersection of Highways 10 and 83 north of Pollock. In this area the loess gradually thins eastward to scattered patches and finally disappears about 2 miles east of Highway 83. This relationship is graphically illustrated in figure 6.

(2) Outwash is completely loess-free westward to the mouth of Spring Creek while the adjacent uplands are loess-covered. Thus loess accumulation on the uplands had to have occurred before or during the depositon of the outwash.

(3) Loess-covered till mentioned in number (1) above is within the late Wisconsin border according to both Flint's (1955) interpretation and the present interpretation. There are no stratigraphic breaks within the upland loess sequence nor is there any abrupt change of thickness of loess at the supposed boundary between early Wisconsin and late Wisconsin deposits. This strongly suggests that the loess was deposited as a continual blanket-like deposit in a relatively short time. This also means the loess must be no older than late Wisconsin since its eastern margin overlies late Wisconsin drift.

(4) Within the late Wisconsin drift border there is about 140 feet of drift underlying loess and directly overlying the Pollock Formation. This same relationship is true in the Mound City Channel northwest of Pollock (see fig. 6).

(5) The Pollock Formation has already been identified as a proglacial lake deposit, and its location with respect to the maximum probable ice borders of both Flint (1955) and the present writer, suggests that the ice should have overridden the area now occupied by the Pollock Formation. Thus, if the Pollock Formation is a proglacial lake deposit of the early Wisconsin of Flint, it is probable that two different age tills should overlie the formation. Evidence provided though subsurface studies indicates the presence of only one till overlying the formation. Furthermore, throughout much of its extent there is no till overlying the Pollock Formation.

The sequence of events which would be compatible with the known and assumed facts listed above is as follows: The late Wisconsin ice advanced westward up the Ancient Grand Channel and ponded meltwater and non-glacial river water from the west. This created a proglacial lake in which sediments of the Pollock Formation were deposited. Further advancement by the ice partially covered the Pollock Formation with drift, even as far west as the channel northwest of Pollock. At this time the ice extended to the Missouri River throughout the County except for possible small high buttes in the west-central and northwest parts. Ice encroaching on the adjacent highlands was relatively free of englacial and superglacial drift as established by the scarcity of features associated with superglacial drift in the equivalent Zeeland drift in North Dakota (Clayton,

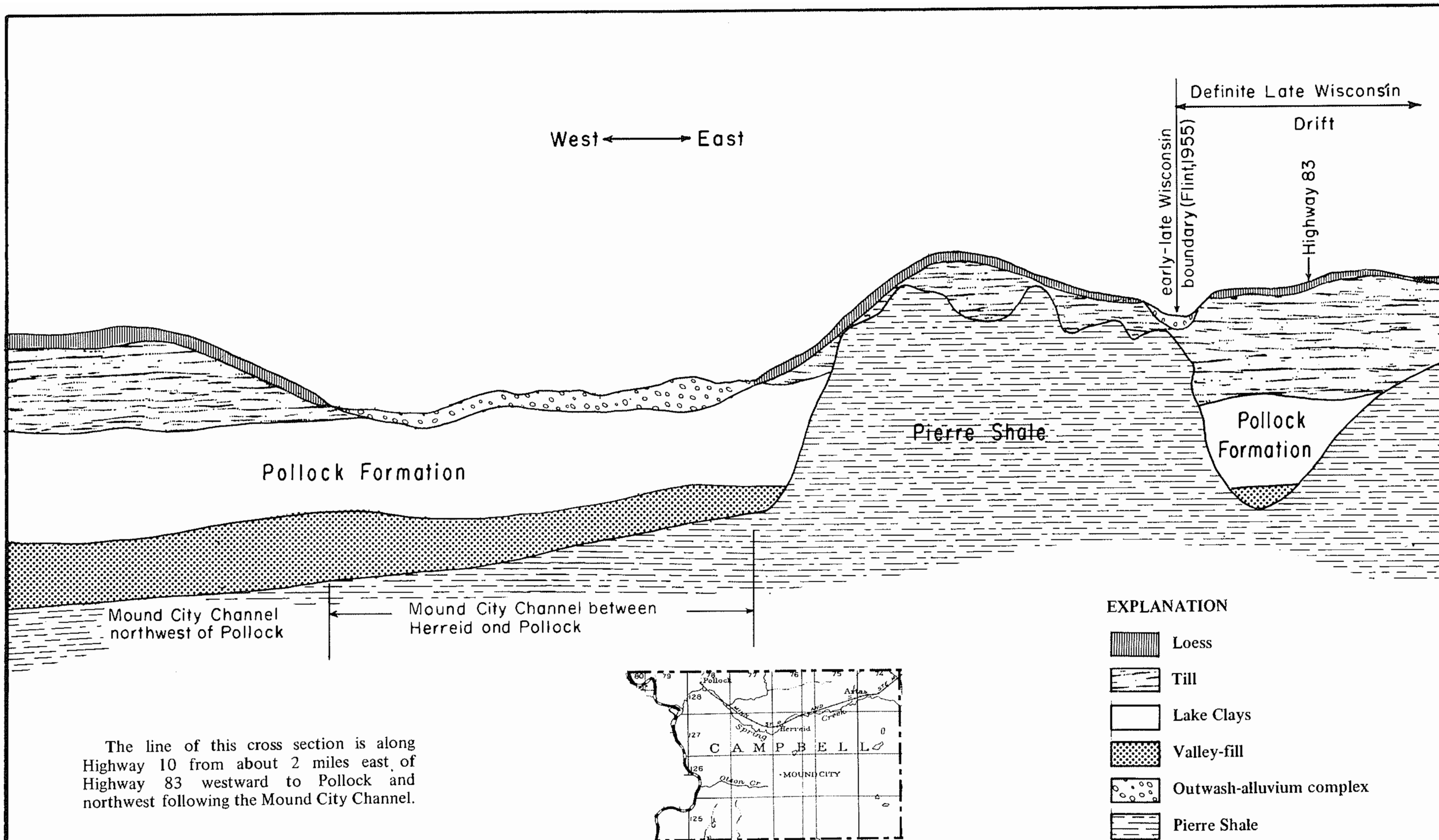


Figure 6. Diagrammatic cross section in northwestern Campbell County showing stratigraphic relationship of the Pleistocene deposits.

1962), and the equivalent drift north of the Herreid end moraine (see pl. 5) in Campbell County. Thus, ice on the high bedrock areas melted quite rapidly leaving these areas free of ice while active ice, or drift covered stagnant ice, remained farther back from the border and in the lower elevations. Upland loess was deposited during the time this area first became ice free, the deposition probably continued while the adjacent ice-filled valleys were receiving outwash. The area to the east still had much drift covered ice and perhaps some active ice while the loess deposition was in progress. If any loess was deposited east of its present extent, it was in an actively forming outwash or on superglacial drift. Thus, any loess that might have been deposited on drift-covered ice would have been washed away or incorporated into the drift as the ice melted.

Outwash

Outwash deposits in Campbell County consist of proglacial sand and gravel deposits, small lenses of outwash incorporated within the till, and various volumes of ice-contact outwash deposits. Many various textural details and landforms are exhibited by the different types of outwash. As a stratigraphic unit these deposits are part of the late Wisconsin drift sheet which was just discussed. However, because of their great extent and potential economic value as both aquifers and aggregate resource, they are discussed in more detail.

Proglacial outwash and outwash lenses are mostly buried beneath till or other deposits. For the most part these deposits consist of sand and gravel although nearly all textural variations do occur. General distribution and occurrence of these deposits are graphically illustrated in the cross sections on plate 4, and are described in detail in the written logs (Hedges and Koch, 1970).

Nearly all the outwash exposed at the surface in Campbell County is in the form of ice-contact deposits. Extensive, nearly continuous deposits of collapsed outwash extend from the mouth of Spring Creek east to Herreid, then southward through Mound City to the southern border of the county (pl. 5). From this point the collapsed outwash extends southward into Walworth County and northeastward from Herreid via Salt Lake and into McPherson County, (pl. 5). This outwash varies from about one-half mile to more than 6 miles in width and averages about 4 miles wide. Surface outwash extending eastward from Herreid along Spring Creek averages about 1 mile in width and is mostly non-collapsed.

Outwash near the mouth of Spring Creek and in that area between Mound City and Herreid is generally fine-grained, consisting mostly of clayey silt or silty-fine sand. Throughout much of the rest of the area the surface outwash generally consists of some combination of sand, or sand and gravel mixed.

Thickness of the outwash varies from a thin veneer of 1 or 2 feet to a maximum of about 100 feet. Usually the upper 10 to 20 feet contains the coarser material. In some areas the upper coarser outwash overlies a narrow thick deposit of very uniform sand which occurs as a channel deposit cut into till or the Pollock Formation. A good illustration of this deposit is seen in cross section G–G' (pl. 4, hole 74 and 75). This deposit is usually quite distinctive because of its uniform texture, greater thickness, and light-to dark-mottled coloration. It is informally referred to here and in the test hole logs (Hedges and Koch, 1970) as the "salt and pepper" sand.

For more details about the outwash deposits, reference is made to Hedges (1969). For the origin of the outwash deposits, relative age relations, geomorphic expression, and relationship to late Wisconsin geologic history the reader should refer to the section "Development of Landforms" and "Geologic History" elsewhere in this report.

Loess

On the uplands of western Campbell County there is a nearly continuous blanket-like deposit of loess generally overlying till. The loess is primarily silt or clayey silt, and all exposures are completely oxidized. The modern soil is leached to a maximum depth of about 24 inches in areas of good surface drainage. None of the exposures examined contained any buried soils or any other evidence of a stratigraphic break within the loess section.

Thickness of the loess varies from a maximum of about 15 feet close to the Missouri River and gradually thins to a feather edge about 12 to 15 miles to the east. In areas where steep slopes are present and loess cover is thin, the loess is re-worked and may contain much clay, some pebbles, and may exhibit bedding. This occurrence is especially prevalent along the eastern margin of the uplands where the steep loess-covered slopes are adjacent to the outwash.

It is thought that the loess represents one continuous blanket-like deposit of late Wisconsin age and probably accumulated under conditions already explained earlier in this report.

RECENT DEPOSITS

COLLUVIUM

Colluvium as used in this report includes a variety of deposits located primarily on slopes or at the foot of slopes, and may include material which has moved downslope under the influence of gravity or running water. It may also locally include patches of till and fine-grained outwash material which has not been reworked.

Colluvium is composed of clay, silt, or sandy silt and is known to be at least 12 feet thick. Much of it occurs marginal to the loess-covered till in the western one-third of the county where silt intermixed with pebbles and sand is a common slope deposit. Other areas, such as the large colluvial plain 3 miles northeast of Pollock (pl. 1) are primarily pebbly, silty clay derived mostly from till.

Some of the basal colluvium may date from the later part of the late Wisconsin. However, differentiation of ages has not been attempted.

SAND DUNES

Sand dunes are present on the lower terrace northwest of Pollock (pl. 1) overlying the outwash-alluvium terrace complex. Dune topography with relief of 8 feet is developed in about a 1 square mile area. Thickness of this eolian sand is unknown but it is thought to be about as thick as the maximum dune relief. Sand was derived from either the underlying outwash-alluvium terrace complex or it was blown up onto the terrace from the adjacent Missouri River floodplain.

Another area of sand dunes is present 3 miles east of Sand Lake in the south-central part of the county (pl. 1). Dunes here are composed of fine to medium, well-sorted sand and cover about a 3 square mile area. Relief in the dune area is as much as 25 feet and blow-outs with 15 to 20 feet of sand exposed are common. Dunes are located along the eastern boundary of the outwash which indicates that the prevailing wind direction was from the west at the time of deposition. The sand dunes overlap the distal slope of the Bowdle end moraine. Wind-blown sand 1 to 3 feet thick is present surrounding the dune area but apparently is not thick enough to develop dune topography.

Sand which now forms the dunes probably started accumulating during the later part of the late Wisconsin. Some of the dune areas are presently active and have probably been active throughout the Recent.

ALLUVIUM

Alluvium is present along Spring Creek and its tributaries, along other smaller unnamed streams, in sloughs, and in other low areas receiving periodic run-off (pl. 1). Alluvium is composed primarily of dark-colored clay with various amounts of silt, sand and pebbles present, and was deposited by water. Alluvium in the larger mapped areas is 5 to 10 feet thick with a maximum thickness of 15 feet. Many smaller unmapped areas contain alluvial deposits 1 to 5 feet thick.

LOESS

Much of the loess overlying the terrace deposits along the Missouri River is thought to be Recent. The loess on the terraces has a maximum thickness of about 7 feet as opposed to about 15 feet on the uplands. The modern soil is very poorly developed. Poorly developed buried soils may also be present. Along the terrace south of the mouth of Spring Creek, Indian artifacts and other campsite debris are found cropping out in the loess 3 or 4 feet below the modern soil. Similar deposits elsewhere along the Missouri River in South Dakota are known to be only a few hundred years old. These occurrences attest to the youthfulness of at least 50 percent of the loess on the terraces. Age of the loess underlying the artifact layer is unknown. However, a lack of well-developed buried soils and relative thinness of terrace loess as compared to upland loess suggests that the whole sequence may belong to the later part of the Recent.

STRUCTURE

Campbell County is situated near the southeast margin of the Williston Basin. Precambrian basement rocks slope northwest towards the center of the basin with an average dip of about 57 feet per mile (Steece, 1961). These rocks control the structural features of the overlying sedimentary rocks.

The structure map of South Dakota (Petsch, 1953) drawn on top of the Cretaceous Greenhorn Limestone shows a uniform northwesterly dip of about 13 feet per mile and has about the same strike as the slope of the Precambrian surface. A structure contour map on top of the siliceous unit of the Virgin Creek Member of the Pierre Shale shows a general northwesterly dip of about 10 feet per mile (Rothrock, 1947). This area is southwest of Campbell County but includes a small portion of the western part of the County. The detail of this latter map shows many small flexures and folds and one fairly prominent shoulder projecting northwest from Mobridge. Local dips associated with this fold are of the magnitude of 50 to 60 feet per mile. Rothrock named this structure the Snake Creek Anticline. He attributes the sharp bends of the Grand River, Snake and Claymore Creeks in this area to the structural control of the Snake Creek Anticline.

More detailed surface and subsurface mapping will undoubtedly reveal local structural features not indicated from present data.

DEVELOPMENT OF LANDFORMS

Present topography of Campbell County is the result of pre-glacial landforms and their modification by glaciation. The general elements of the pre-glacial landforms are still very much in evidence today although they are somewhat modified by glaciation. Conversely, the pre-glacial landforms have had a very direct influence on the glacial modification as it was occurring. Fortunately, geologic mapping and test drilling has provided the information needed to describe the various landforms and their interrelationship. Non-glacial landforms discussed below are essentially those in which the major elements are more related to the pre-glacial topography than to subsequent alteration by glaciation. Glacial landforms are those which owe their origin primarily to construction by glacier activity.

NON-GLACIAL LANDFORMS

PRE-GLACIAL TOPOGRAPHY

Pre-glacial surface in Campbell County was formed by eastward flowing streams and their tributaries eroding deep channels through the sandstone and shale bedrock before the Missouri River was formed (Flint, 1955, p. 139-143). The major elements of this drainage net for Campbell County and adjacent areas is shown by Flint (1955, pl. 7). The present study in Campbell County confirms Flint's interpretation of the pre-glacial drainage and introduces only minor modifications of detail.

The bedrock map of Campbell County (pl. 2) shows contours on the bedrock surface. In Campbell County the bedrock topography is characterized by sloping dissected shale uplands with resistant sandstone-capped buttes present in the western part. This dissected upland surface is generally between 1600 and 1900 feet in elevation whereas the tops of the buttes exceed 2100 feet in elevation. Major bedrock channels, the Ancient Grand Channel and the Mound City Channel, are incised more than 300 feet below the adjacent shale uplands. The lowest bedrock elevation recorded in the county is 1390 feet in a test hole northwest of Pollock near the Missouri River trench, making total bedrock relief in the county more than 700 feet.

ANCIENT GRAND CHANNEL

The Ancient Grand Channel enters the south central part of Campbell County, and trends slightly northeast through the southeastern part of the county (pl. 2). A westward extension of the subsurface channel lies below Blue Blanket Lake, Glenham, and Mobridge, all in Walworth County; then it follows the course of the Missouri River northward to the mouth of the present Grand River. The eastward extend of the Ancient Grand Channel outside of Campbell County is unknown due to the increasing thickness of glacial drift. However, the channel probably turns nearly southward as shown by Flint (1955, pl. 7), and eventually joins a similar buried channel related to the Moreau River.

MOUND CITY CHANNEL

The Mound City Channel (pl. 2) enters Campbell County and South Dakota via the course of the present Missouri. After a distance of about 5 miles it changes abruptly to a southeasterly course for about 12 miles. Near Herreid it turns southward for about 6 miles before bifurcating. One segment of the channel continues straight south to its junction with the Ancient Grand Channel. The other segment swings eastward and joins the Ancient Grand Channel near the Campbell-McPherson County line. At the eastern border of the county a bedrock high splits the channel into two segments. The size, shape, and significance of this feature is unknown due to lack of subsurface information in counties to the east.

Isolated segments of the Mound City Channel and some of its tributaries may owe some of their development to glacial activity. As the ice spread westward from the James lobe, the major drainages were eventually dammed by ice. Ponded water evidently overflowed across low divides and quickly cut new channels in the weak underlying shale. Examples of such possible diversion channels are: 1) the north-south segment of the Mound City Channel south of Mound City, and 2) the deep, narrow channel northwest of Pollock (pl. 2).

These channels are now filled with 200 to 500 feet of glacial deposits (cross sections, pl. 4). Western segments (except in the narrow channel northwest of Pollock) contain very little till. Most of the valley-fill consists of 200 to 300 feet of sediment comprised of an outwash-alluvium complex called the Ancient Grand Channel valley-fill, a glacial complex named the Pollock Formation, and sand and gravel outwash. Eastern segments of the channels contain 300 to 500 feet of sediment. The lower 200 feet is the outwash-alluvium complex of the Ancient Grand Channel valley-fill, and the upper 200 to 300 feet is glacial drift; mostly till (cross sections D, E, F, and G, pl. 4).

AGE OF THE CHANNELS

The Ancient Grand Channel antedates the diversion of the present Missouri River (Flint, 1955). Results of the present study in Campbell County corroborates Flint's conclusion about the relative age of the Ancient Grand Channel. The Mound City Channel is a tributary to the Ancient Grand Channel and apparently part of the same drainage system. It would therefore also antedate the formation of the Missouri River trench.

The age of the Missouri River trench is uncertain at present. Warren (1951) and Flint (1955) agree on a probable Illinoian age for formation of the trench while White (1964) suggests that the trench is no older than early Wisconsin. Since the Ancient Grand Channel and its tributaries antedate the formation of the Missouri River trench, they are at least older than early Wisconsin and may be older than Illinoinan.

STREAM-ERODED BEDROCK TOPOGRAPHY

Stream-eroded bedrock topography is characterized by a nearly complete lack of glacial deposits and lack of evidence of glacial control in formation of the present topography. Stream eroded topography in Campbell County is restricted to a narrow zone 1 to 4 miles wide along the Missouri River and a narrow zone along the northwest border of the county (pl. 5). Local slopes are steep and maximum relief in the area is 400 feet. The drainage is completely integrated and very dense. Bedrock is mostly shale with small patches of sandstone present in the northwest corner of the county.

Although the area of the stream-eroded bedrock topgraphy was probably once covered with glacial deposits, erosion during the rapid downcutting by the Missouri River and its tributaries has removed nearly all traces of glacial deposition and exposed the bedrock deposits. Large and small scale mass-movement processes have been active throughout most of this area since retreat of the ice.

GLACIALLY-MODIFIED, STREAM-ERODED TOPOGRAPHY

Glacially-modified, stream-eroded topography is characterized by thin glacial deposits or other evidence of glacial modification (pl. 5). The drainage is nearly everywhere integrated, although slopes are less, local relief is less, and density of drainages is much less than in the stream-eroded bedrock topography. A blanket-like deposit of loess-covered till 10 to 50 feet thick covers most of the area. Many small patches of bedrock are exposed in the drainages. Test-hole information and bedrock outcrop patterns indicate that nearly all the drainages are related to former bedrock drainages.

GLACIAL LANDFORMS

REGIONAL BEDROCK CONTROL OF ICE MOVEMENT

The Ancient Grand Channel and similar channels cut by the Ancient Moreau and Cheyenne Rivers to the south (Flint, 1955, pl. 7), join in Edmunds County and trend eastward to the west edge of Brown County where they turn north joining the James Lowland. This channel system carved out a regional bedrock valley which has persisted as a "low area" during the various glacial advances, serving as a funnel for a sublobe of ice stemming from the main James lobe. This means that whereas the main thrust of the James lobe was to the south and west, flow direction of the sublobe was to the west and northwest up the Ancient Grand Channel. As shown by the distribution of end moraines, the ice encroached upon the surrounding highlands. Todd (1885) recognized the configuration of this lobe of ice and referred to it as the Bois Cache lobe. The Zeeland end moraine in North Dakota is recognized by Clayton (1962) as marking the northern extent of what Todd called the Bois Cache lobe. Along its course in McIntosh County, North Dakota, the predominant direction of ice flow was nearly straight north. Figure 7 shows the approximate outer boundaries of the various late Wisconsin ice phases in Campbell County and surrounding areas. The term "phase" as used in this report refers to each recognizable active ice margin and all the drift and landform developments between it and the next younger recognizable margin. Figure 7 clearly shows the orderly step by step recession of the late Wisconsin ice sheet in the north-central South Dakota and south-central North Dakota area, and the relation of the Bois Cache sublobe to the James lobe.

Of major importance in determining the glacial sequence in the north-central South Dakota area is the "hinge-line" just west of Leola, in McPherson County, South Dakota, shown as a former divide by Flint (1955, pl. 7). This high bedrock area and its northwestward extension was the fulcrum point of the Bois Cache sublobe. Ice expanding in this area was impeded by the Missouri Coteau, a bedrock escarpment along its western margin, although the ice eventually overrode the escarpment and expanded onto the uplands to the northwest. However, progressive backward stagnation of the ice margin impeded the flow of ice and created a massive pile up of drift around Long Lake in McPherson County now marked by the large areas of collapsed drift in that area (Flint, 1955, pl. 1). Detailed mapping presently underway in this hinge-line area in McPherson County will help to determine the relationship of end moraines between North Dakota and South Dakota (Christensen, in preparation).

More local bedrock control of ice movement is shown by the splitting of the Bois Cache sublobe into still smaller sub-lobes. One of these smaller lobes of ice flowed northwest to the Missouri River along the course of Spring Creek; the other flowed southwest through the Blue Blanket Lake area at least to the town of Glenham in Walworth County, and probably as far southwest as the Missouri River at Mobridge.

STAGNATION DRIFT

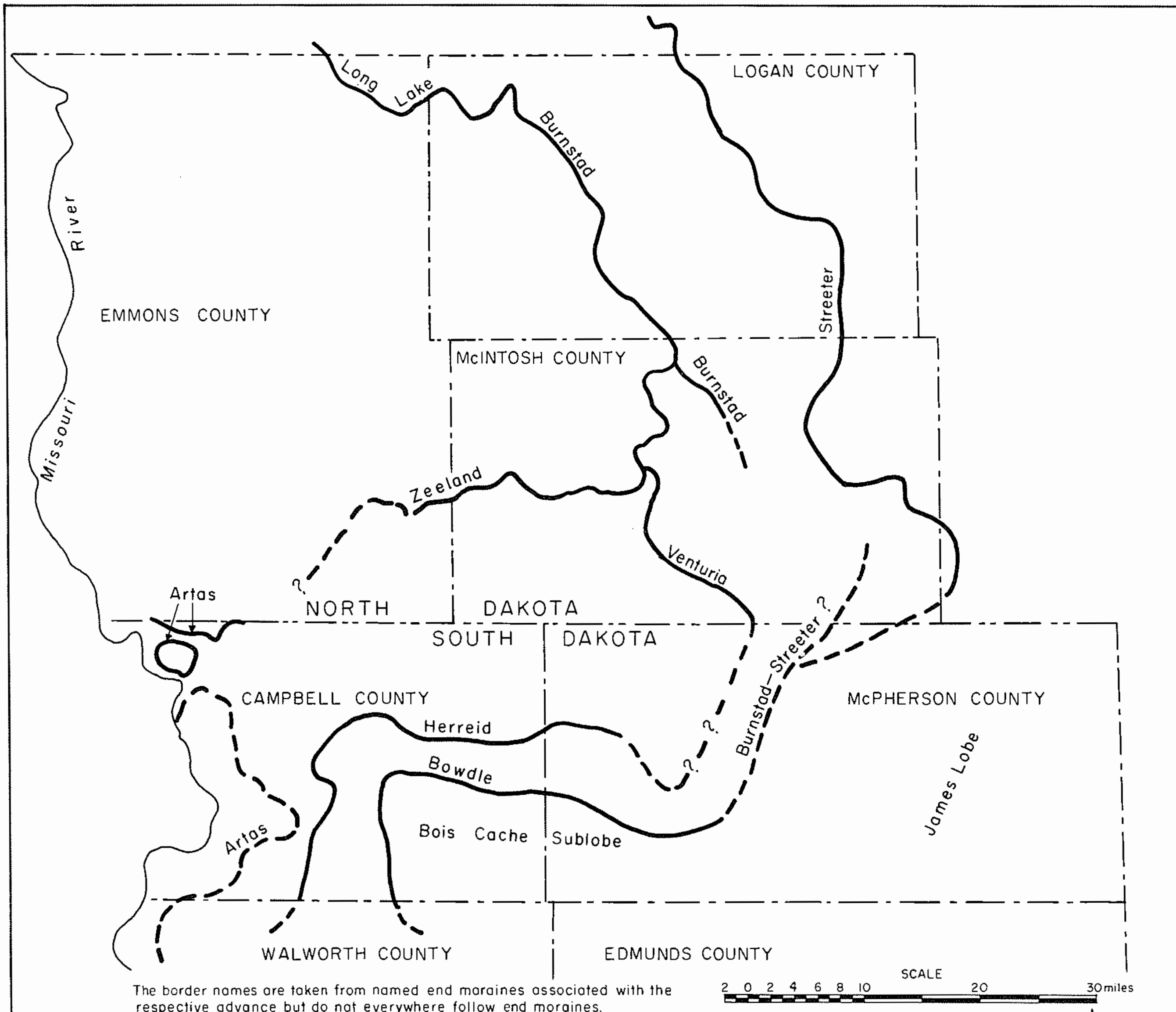
Terminology

Stagnation drift is composed primarily of till which was deposited under conditons of large-scale glacial stagnation. If there were significant amounts of superglacial or englacial debris, characteristic landforms such as ice walled lake plains and outwash plains, or collapse features such as contorted bedding, doughnuts, collapsed outwash, and collapsed lake plains, should be present.

Occurrence of stagnation drift on the Missouri Coteau in North Dakota and Canada has been known for a number of years (Townsend and Jenke, 1951; Christiansen, 1956; Colton and Lemke, 1957; Bayrock, 1958; Gravenor and Kupsch, 1959; Clayton, 1962; Winters, 1963). Stagnation drift is now known to be a widespread landform unit on the Missouri Coteau in South Dakota. Its presence on at least the northern part of the Coteau des Prairies in South Dakota is also well established (F. V. Steece, oral communication).

Accumulation of superglacial drift and subsequent formation of stagnation drift from a continental glacier is the result of a combination of many factors. An excerpt from Clayton (1967, p. 26) adequately summarizes the important points:

> The active ice rapidly thinned during the general deglaciation near the close of the ice age. Where the thin ice flowed over the Missouri Escarpment onto the Missouri Coteau, it experienced compressive flow and intensive marginal thrusting, which dragged great quantities of subglacial drift up into the ice. As the ice melted, the till was concentrated on its surface, forming a nearly continuous blanket of superglacial till several tens of feet thick over most of the Coteau. This drift blacket insulated the ice, causing it to melt very slowly. A nearly continuous



The border names are taken from named end moraines associated with the respective advance but do not everywhere follow end moraines.

Figure 7. Outer boundaries of Late Wisconsin ice phases in parts of South Dakota and North Dakota.
(North Dakota borders from Clayton, 1962, and Colton, Lemke, and Lindvall, 1963.)

> sheet of stagnant ice, initially a few hundred feet thick, covered almost the entire Coteau. Much of this ice persisted for at least 3000 years, until 9000 B.P.
>
> The superglacial drift blanket was irregularly distributed, and, as a result, the ice melted irregularly, and the topography on the stagnant ice became hilly and pitted with irregular depressions. The superglacial till was water-saturated and was highly plastic or fluid; it slid or flowed down the ice slopes and accumulated in depressions. Mudflows were common. The thick drift in the depressions caused the underlying ice to melt more slowly, and the newly exposed ice melted more rapidly, resulting in continual inversions of the superglacial topography.

The term "stagnation drift" is the same as various other terms applied to similar glacial landforms, such as: dead-ice moraine, ablation moraine, hummocky moraine, disintegration moraine and hummocky stagnation moraine. These terms have all been used in areas where there was apparently relatively large amounts of superglacial or englacial drift associated with the stagnant ice. This same concept applies to the Coteau areas in northern South Dakota; however, farther south along the Coteau evidence indicates that large-scale stagnation did occur although it was generally not accompanied by large amounts of superglacial and englacial drift. For this reason the term "stagnation drift" is proposed for use in South Dakota and applies to regional deposits of glacial drift associated with stagnant ice, regardless of whether the ice contained large amounts of drift.

Description and Origin

Stagnation drift in Campbell County is represented by landforms which indicate a relative abundance of superglacial or englacial debris associated with the ice that stagnated.

Stagnation drift is characterized by closely spaced hills and depressions with local relief as much as 100 feet. Areas of higher relief have a definite hummocky topography while the areas of lower relief are less hummocky and may approach a swell and swale type of topography. Slope angles in stagnation drift are relatively steep.

Although the stagnation drift in Campbell County was formed by the same processes and at approximately the same time as the same deposits nearby in North Dakota and in McPherson County, South Dakota, fewer stagnation features are present and their topographic expression is more subdued. Ice entering Campbell County was a sub-lobe of the main James lobe, and was probably somewhat thinner, and subjected to less compressive force, than occurred along the margin of the main James lobe in North Dakota and the "hinge-line" area in McPherson County, South Dakota.

Distribution

All the area in Campbell County mapped as stagnation drift (pl. 5) contains one or more of the features identified as being associated with stagnation drift. That drift mapped as glacially-modified, stream-eroded topography may be stagnation drift, end moraine, or ground moraine. No features associated with stagnation drift have been found in this area. However, if these features were present they would be difficult to identify because: (1) the drift is generally thin, thus, any landform associated with stagnation drift would probably be subdued and any deposit associated with stagnation drift would probably be thin, and (2) the whole area has a loess cover as much as 15 feet thick which would partially or completely mask any landform or deposit recognizable as being associated with stagnation drift.

END MORAINES

Definition of end moraines as used in this report refers to an area of primarily constructional glacial topography that is judged by the writer to be the result of deposition at or near the margin of active ice. The most important factor in recognizing end moraine is linearity, in the overall pattern or in small-scale features. Small-scaled features are lacking in Campbell County.

Distribution of end moraines in Campbell County illustrates a close relationship to the bedrock topography. End moraines are, in general, parallel to the broad valley walls and interfluves of the major bedrock drainages, with only minor deviations from this pattern. Where the course of end moraines cross bedrock valleys the characteristic ridge disappears and stagnation drift or collapsed outwash is present. Local variations in end moraine topography are due to local ice conditions not necessarily controlled by bedrock.

The margin of each ice phase as illustrated in figure 7 is not continuously marked by the presence of end moraine, although the major trends are indicated by prominent end moraines.

Artas End Moraine

The end moraine present in north central Campbell County is here named the Artas end moraine for the town of Artas near its southeast boundary (pl. 5). This moraine is probably correlative with the Zeeland end moraine (Clayton, 1962) in North Dakota (see fig. 7), although actual mapping of this moraine from the McIntosh-Emmons County border (in North Dakota) westward and south to South Dakota is yet to be accomplished. As pointed out by Clayton (1962, p. 26), these moraines are equivalent, at least in part, to the northern part of Todd's (1896, p. 21-22) "Blue Blanket loop of the First, Outer, or Altamont moraine." The term "Altamont moraine" originates in northeastern South Dakota where a well-defined end moraine is present. However, tracing this moraine from the Des Moines lobe on the east side of the Prairie Coteau to moraines in the James lobe on the west side of the Coteau has never been satisfactorily demonstrated. Furthermore, as pointed out by Clayton (1962) and this report, segments of end moraines called "Altamont" by Todd in south central North Dakota and north central South Dakota are actually separate distinct end moraines. Correlation of this moraine is further complicated by the identification of the Bemis end moraine in the Des Moines lobe (Leverett, 1932, p. 57), as being outer-most late Wisconsin according to terminology used in this report. Thus, the Artas end moraine may be equivalent to the Bemis end moraine.

Position of the Artas end moraine was controlled by ice moving northwesterly upstream in a bedrock valley in McPherson and Campbell Counties. This ice spread out radially northward onto a bedrock highland with a thin narrow lobe extending westward to the Missouri River in a bedrock low along the present course of Spring Creek. In South Dakota and northward several miles into North Dakota, the end moraine trends north-south and then loops eastward probably joining the westward mapped extend of the Zeeland end moraine (see fig. 7). Several small knobs and ridges at the State boundary just east of Highway 83 are oriented north-south. Loess and colluvium covered drift in the bedrock channel northwest of Pollock is thought to be part of the Artas end moraine. Interpretation of this till as end moraine is based on drill hole information which shows as much as 135 feet of till overlying other sediments (cross section A-A', pl. 4).

The Artas end moraine is actually at a slightly lower elevation than the stagnation moraine to the south and east due to its location over a "low" in the bedrock topography. It is recognized as end moraine because the drift is thicker and more completely masks the underlying bedrock topography than areas of thinner drift. Drainage on this moraine is mostly non-integrated (except on slopes adjacent to major drainages) and sloughs are numerous. Local relief is higher than on the adjacent stagnation drift.

Herreid End Moraine

The end moraine trending east-west through east-central Campbell County and terminating 1 mile east of the town of Herreid (pl. 5) is here named the Herreid end moraine. The Herreid end moraine is a low, rather inconspicuous ridge 1 to 3 miles wide. No small scale lineations are present within the moraine, but a slightly denser population of sloughs marks its course on aerial photos. Local relief on the Herreid moraine is about 40 feet. At its western end the moraine drops into the Mound City Channel near Herreid. The low relief stagnation drift in the valley 2 miles southwest of Herreid (pl. 5) may be the collapsed equivalent of the Herreid moraine. To the east the Herreid moraine is broken where the collapse trench (explained later) trends north-south through the moraine.

The Herreid end moraine is part of what Todd (1896) called the Second, Inner, or Gary moraine and is what Flint (1955, fig. 31) called "A-5", or possibly it correlates with the Venturia end moraine (Clayton, 1962) in McIntosh County, North Dakota. This later correlation has been strengthened by recent detailed mapping in the Long Lake area (Cleo M. Christensen, in preparation).

Bowdle End Moraine

The end moraine in southeast Campbell County is here named the Bowdle end moraine, named for its prominent occurrence near the town of Bowdle, South Dakota. The "Bowdle Hills" (Todd, 1896, p. 24) have long been a known landmark in eastern South Dakota.

The northern limb of the Bowdle moraine trends east-west where it enters Campbell County and is essentially parallel to the course of the Artas and Herreid moraines (pl. 5). Its course continues west for about 11 miles before looping southwest across the course of the Ancient Grand River Channel. At this point the ice flow was less restricted allowing a slight expansion towards the southwest down the course of the Ancient Grand River. This radial sector of the moraine is a prominent narrow ridge 1 mile wide. Near the south-central part of Campbell County the moraine curves back towards the east to the extreme southeast corner of the county where it trends southeast toward Bowdle.

The Bowdle end moraine is a massive, prominent ridge 2 to 4 miles wide with local relief approaching a maximum of 100 feet. On the northern limb of the moraine in McPherson County its presence is less conspicuous where the moraine is partly in the topographic low area associated with the Ancient Grand River valley.

The Bowdle end moraine was recognized by Todd (1896, p. 33) who called it the "Second or Gary moraine." However, part of this moraine in North Dakota was referred to by Todd as the "First or outer Altamont." Also, part of the moraine Todd referred to is actually stagnation drift. This, plus the complications already mentioned concerning the term "Altamont" are the reasons for renaming this the Bowdle moraine.

There is little doubt that the Bowdle moraine correlates with the Burnstad-Streeter moraine complex of North Dakota. Recent mapping in McPherson County indicates the Bowdle moraine may be equivalent to the Streeter moraine of Clayton, (1962) [Cleo M. Christensen, in preparation].

ICE-WALLED OUTWASH PLAIN

One well developed ice-walled outwash plain is present in the high relief stagnation drift in T. 126 N., R. 74 W. in southeast Campbell County (see pl. 5). This feature is a flat-topped hill over 1 mile long, one-fourth to one-half mile wide, rising about 70 feet above the surrounding depressions. Well developed ice-contact faces are present on the north and south sides and the west end has been slightly collapsed. A recent road-cut through the west end of the plain exposed about 40 feet of sand and gravel.

ICE-WALLED LAKE PLAIN

A small but distinct ice-walled lake plain about 50 feet above the surrounding end moraine and stagnation drift, is present on the north edge of the Herreid end moraine in T. 127 N., R. 74 W. in eastern Campbell County (pl. 5). Its upper surface is nearly flat. An auger test hole on top of the lake plain penetrated more than 50 feet of sand and clayey silt. Although small in area (about one-fifth square mile), it is an excellent example of the form of an ice-walled lake plain. Numerous ice-walled lake plains up to 12 square miles in area have been mapped in North Dakota (Clayton, 1962; Winters, 1963; Clayton and Freers, 1967).

COLLAPSED OUTWASH

Collapsed outwash is outwash sand and gravel which was deposited on stagnant glacial ice and subsequently let down or "collapsed" as the underlying ice melted. It is characterized by an undulating topography with higher local relief than an outwash plain or valley train. Small patches of collapsed outwash within stagnation drift are difficult to recognize and delineate because the adjacent topography is often very similar.

A large, nearly continuous collapsed outwash plain is present in Campbell County overlying the Ancient Grand Channel and the Mound City Channel (pl. 5). For convenience, the major area of collapsed outwash can be divided into three segments, informally referred to as the Spring Creek outwash, the Blue Blanket outwash, and the Salt Lake outwash (fig. 8). The Spring Creek outwash includes valley train deposits in the eastern one-half of the county; the relationship of the valley-train deposits will be discussed in a later section of the report. The Blue Blanket outwash and Salt Lake outwash, both collapsed, are part of the Selby Aquifer of Koch (1970).

Spring Creek outwash

The collapsed portion of the Spring Creek outwash (fig. 8) was deposited on stagnant ice trapped in the pre-diversion Mound City Channel. It grades westward from a well-sorted, medium gravel at Herreid to a silty, clayey sand near the mouth of Spring Creek southwest of Pollock. For a distance of about 5 miles west of Herreid local relief in the outwash is as much as 70 feet. Westward beyond this area local relief diminishes to a maximum of about 20 feet. In the area of maximum relief depressions are more numerous and larger than in the area of lesser relief.

At the north edge of Herreid and westward for about 4 miles to just north of Spring Creek is a poorly defined ice-contact face which has been partially collapsed. The area north of this ice-contact face is that area with the higher relief and more numerous large depressions. This ice-contact face probably represents the maximum northward extension of active ice during the formation of the Herreid end moraine and temporarily controlled westward flow of meltwater and sediments. Slightly later the meltwater was restricted to the present course of Spring Creek and was confined on the south by the stagnation drift in the Mound City Channel about 2 miles southwest of Herreid.

Blue Blanket outwash

The Blue Blanket outwash was deposited on stagnant ice trapped in the Mound City Channel and the Ancient Grand Channel. Much of the fine-grained material along the western part of the Blue Blanket outwash may be collapsed outwash. Much of the collapsed Blue Blanket outwash between Herreid and Mound City is also fine-grained material. Along the eastern margin of the outwash where it joins the high relief stagnation drift the outwash is dominantly gravel; whereas the central part of the Blue Blanket outwash is primarily coarse sand to fine gravel. Local relief on most of the Blue Blanket outwash is about 20 feet. This outwash extends into Walworth County, probably as far as Mobridge; however, the detailed relationship of this part of the outwash to the outwash in Campbell County is uncertain at this time.

Geomorphic relationship, drainage relationships, and inferred geologic history suggest that the Spring Creek and Blue Blanket outwashes were deposited as separate outwash bodies although deposition could have been comtemporaneous and movement of meltwater between the two areas might have occurred on a limited scale.

Salt Lake outwash

The Salt Lake outwash was deposited on stagnant ice trapped in the eastward extension of the Ancient Grand Channel. During and after the formation of the Bowdle moraine a regional basin area existed in the ice surface along the course of the Ancient Grand Channel. This basin became the drainage-way for part of the meltwater associated with the formation of the Bowdle moraine and younger (?) moraines. Much of the meltwater and sediments flowed southwest through Blue Blanket Lake in Walworth County, finally discharging into the Missouri River. Some of the meltwater and outwash sediments probably flowed northward forming the Blue Blanket outwash. Probably little of the water and sediment from the Salt Lake area ever reached the Spring Creek drainage.

Sediments in the Salt Lake outwash grade westward from medium-sized gravel to coarse, gravelly sand. The topography changes westward from a slightly pitted outwash plain with maximum local relief of 40 feet to an undulating outwash plain with local relief of about 20 feet.

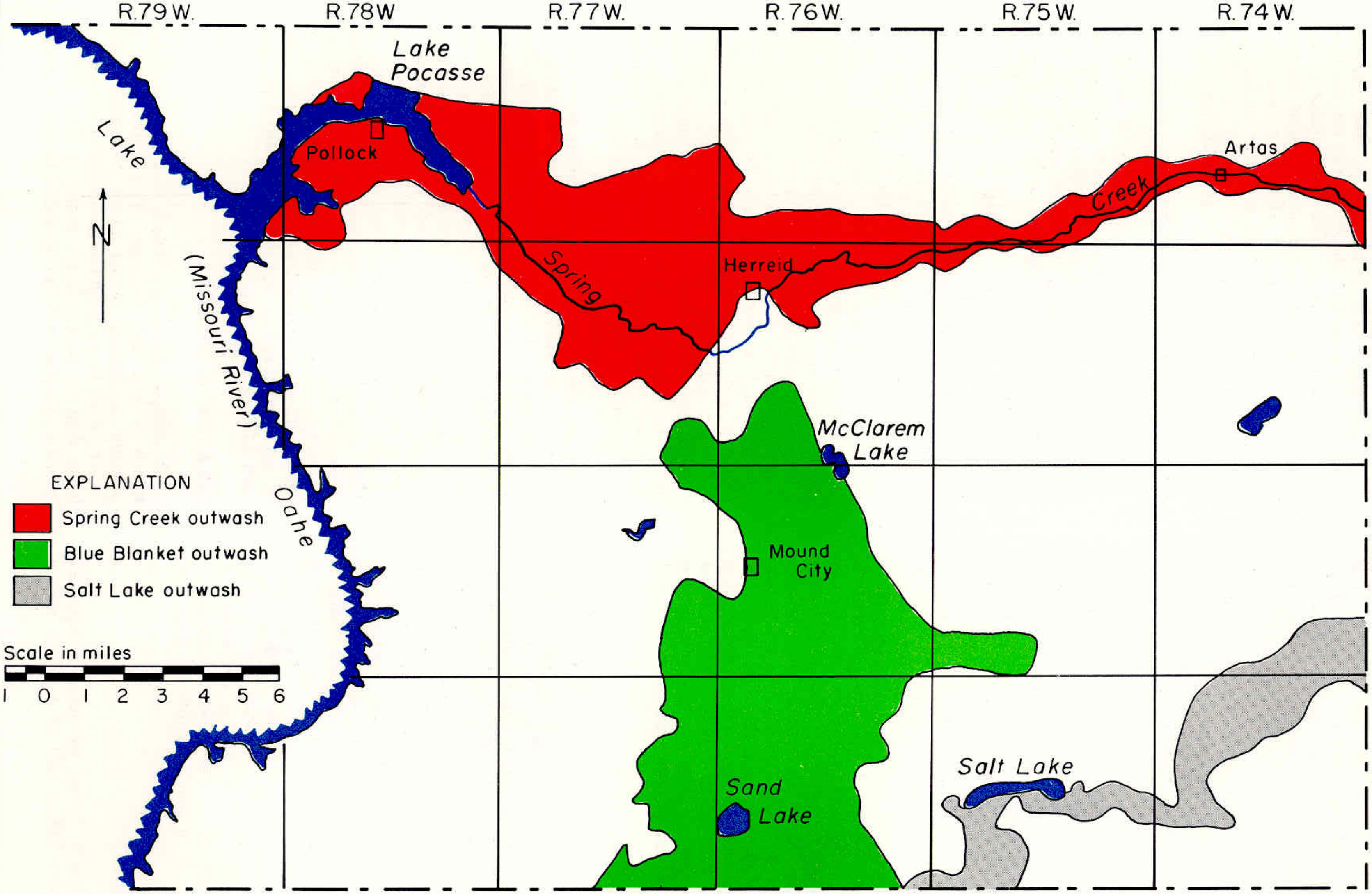


Figure 8. Extent of the Spring Creek outwash, Blue Blanket outwash, and the Salt Lake outwash.

COLLAPSED LAKE PLAIN

Collapsed lake sediments are formed from deposition of silt and clay in lakes on stagnant glacial ice with subsequent melting and letting-down of the superglacial deposits. The resulting topography is similar to collapsed outwash topography or stagnation drift.

Two small areas of collapsed lake plain are present in northeast Campbell County (pl. 5). The sediments are thin (less than 10 feet thick) and the topography is only slightly undulating, similar to the low relief stagnation drift surrounding the deposit. These features suggest a relatively small lake which has not been let-down or collapsed a great amount. An interesting point to note is the alignment of these areas with the ice-walled lake plain in Campbell County and the collapsed lake plain one-half mile south of Zeeland in McIntosh County, North Dakota (Clayton, 1962; pl. 1). These features are all aligned northward from the distal edge of the Herreid end moraine suggesting that meltwater flowing from the Herreid moraine was first trapped in a depression in stagnant ice where the ice-walled lake plain is now located. The water then flowed northward over the stagnant ice and was trapped in a lake basin on top of stagnant ice in an area now represented by the collapsed lake plain topography in Campbell County South Dakota, and McIntosh County, North Dakota. It is not known whether the lake was continuous from the Herreid moraine to Zeeland, North Dakota, or whether the now isolated deposits collected in small individual basins. The area near Spring Creek has undergone considerable erosion and it is possible that some of the lake sediments have been removed.

VALLEY TRAIN OUTWASH

Valley train outwash deposits consist of sediments which are deposited by meltwater flowing in a pre-existing valley. A valley train outwash at Herreid and 4 miles eastward (pl. 5) is slightly undulating, having local relief of about 10 feet and has a few shallow closed depressions. The sediment is primarily a well-sorted, medium gravel. Farther east the valley train is flat with no closed depressions and the sediments generally are not as well sorted as those to the west. The topography of the valley train outwash in the first 4 miles east of Herreid suggest that it may be due to collapse. However, because the change in topography to the east is subtle and gradational as contrasted with the abrupt topographic change to the west, this part of the outwash has been included with the valley train deposits. Absence of collapsed outwash in the Spring Creek drainage east of Herreid is explained by the lack of a deep bedrock channel to trap ice and by the presence of thin ice with little superglacial drift.

KAME TERRACES

A kame terrace is formed by outwash deposited between ice and a hill or side of a valley. Such a terrace is present on the north edge of Mound City (pl. 5). This terrace is an elevated mound or hill of ice-contact sand and gravel which was trapped between the highland to the west, and the ice that formed the Herreid moraine. The kame terrace on the north edge of Mound City is mostly coarse sand to fine gravel where exposed. Exposure was not extensive enough to determine internal structure or thickness although topographic evidence would indicate a maximum thickness of about 20 feet.

ICE-DISINTEGRATION RIDGES

Ice-disintegration ridges are circular to elongate ridges of till or outwash material formed in association with disintegrating stagnant ice. Their formation involves filling of holes or cracks in the ice with superglacial or englacial debris and later deposited as a ridge as the underlying or surrounding ice melts. An alternative method of formation is through a squeezing action of the ice on water-saturated subglacial material. For a more detailed account of the origin of these features see (Gravenor and Kupsch, 1959, p. 52-54; Clayton and Freers, 1967, p. 31, 32; and Bik, 1967, p. 83-94).

Several prominent hills or ridges have been mapped as disintegration ridges in Campbell County (pl. 5). A circular disintegration ridge located on the north edge of the Bowdle end moraine in east-central Campbell County is similar in form to the "prairie mounds" of Gravenor (1955); the "doughnuts" of Gravenor and Kupsch (1959), and Stalker (1960a); and "rim ridges of plains plateau" by Stalker (1960b). Origin of these landforms is uncertain at present. Theories range from formation by association with stagnant glacial ice to periglacial phenomenon. A recent comprehensive discussion on this subject is provided by Bik (1967).

Kames are a special type of disintegration ridge which is a mound-like hill of ice-contact outwash material. As pointed out by Clayton (1962, p. 40), stagnation drift may contain many isolated hills of sand and gravel which are about the same size and shape as adjacent hills or till. Therefore, he restricts the definition of kames to those hills of ice-contact outwash which are "prominent" or "conspicuous." Following this definition several kames have been identified 2 to 4 miles southwest of Herreid (pl. 5). The kames are ovate to circular in plan, as much as one-eighth square miles in area, and as much as 30 feet high. Sand is the predominant material comprising these kames. Other less conspicuous hills of sand and gravel in the stagnation drift have not been differentiated.

COLLAPSE TRENCHES

A collapse trench is defined as a non-erosional trench with closed drainage. It is formed by a partially or wholly buried block of stagnant ice melting from beneath till producing a trench which is lower than the surrounding topography. The mass of buried ice is apparently not related to former bedrock channels although it could be related to a former meltwater channel cut into till.

The largest collapse trench in eastern Campbell County (pl.5), T. 127 N., R. 74 W., consists of two segments that are quite different in appearance. Part of the trench north of the Herreid end moraine starts as a small gully rapidly deepening and widening to the south. It is similar in appearance to the disintegration trench of Clayton (1962, p. 42) although larger, and is formed in till rather than outwash. At the Herreid end moraine and to the south, the trench is more of a broad sag containing a series of small lakes and sloughs, similar to the partly buried channels of Clayton (1962, p. 42), kettle chains of Flint (1955, p. 68), and partially buried drainages of Hedges (1968, p. 22). The low sag continues southward toward the Bowdle end moraine and gradually becomes less conspicuous. A line of sloughs extending to the Bowdle end moraine could be related to the collapse trench but since the sloughs are not connected they are not included as part of the trench. It does not continue southward through the Bowdle end moraine. The smaller collapse trench in T. 127 N., R. 75 W, (pl. 5) is similar to the northern segment of the larger trench and it does not extend through the Herreid moraine as does the larger trench.

Form and position of the trench in relation to the end moraines and stagnation moraine suggests that it was formed by melting and subsequent collapse of a buried block of ice covered with till.

LAKE PLAINS

Two lake plains are present in Campbell County. The lake plain 2 miles southwest of Sand Lake (pl. 5) is a low, flat area which is in the northern extension of the Blue Blanket Lake basin in Walworth County. The sediments of the lake plain 2 miles north of Pollock are part of the Pollock Formation. Thin surficial deposits of outwash, colluvium, and alluvium locally overlie this formation. Topography of this area is irregular due to erosion by Spring Creek and its tributaries.

MISSOURI RIVER TERRACES

The Missouri River terraces are flat or sloping surfaces along the present Missouri River. They are composed of a complex sequence of deposits which may include lacustrine facies, till, fine-to coarse-outwash material, loess, sand dunes and colluvium. Most of the outwash material was deposited as alluvium or a combination of outwash and alluvium. These terraces represent former deposits of the outwash-alluvium complex which have been left as erosional remnants as the Missouri River down-cut to its present floodplain level.

There are two terrace levels in Campbell County. The lower terrace is essentially flat at about 1650 feet elevation, or 100 feet above the modern floodplains (now water-covered). Its outer edge is scalloped by recent erosion. Surface of the upper terrace slopes from 1650 feet elevation to about 1700 feet where it joins the uplands.

GEOLOGIC HISTORY

PRE-PLEISTOCENE

Prior to the Paleozic Period, about 550 million years ago, a structural low began to form in the locality of the present Williston Basin. The sea slowly encroached upon the area and shallow-water, near shore, clastic deposits of the Late Cambrian and Early Ordovician Periods were deposited. Deep basin carbonate sediments were deposited during the rest of Ordovician as the sea continued to advance. During the Silurian and Devonian Periods the sea was relatively stable and while the central part of the basin continually received deposits the older sediments along the margins were being eroded.

During the Mississippian Period the seas again expanded and deposited a thick carbonate sequence. Upper-most Mississippian rocks are probably missing in Campbell County which indicates non-deposition or erosion at the end of the Mississippian Period.

Encroaching Pennsylvanian seas eventually became restricted and sandstone, limestone and anhydrite deposits were formed. The Permain Period was probably one of non-deposition or erosion in Campbell County while the sea became more restricted and then again transgressed elsewhere in the basin.

Absence of Triassic or Jurassic sediments in the county indicates non-deposition or erosion. The Mesozoic Era is well represented by Cretaceous sediments characteristic of deltaic and shallow, off-shore deposits. The Dakota-Inyan Kara sandstone sequence indicates a transgressive deltaic sequence; and the overlying shales, marls, and limestones were deposited in a relatively stable off-shore enviornment.

Any Tertiary rocks that may have existed in the county have been eroded away. During much of the Tertiary Period the Cretaceous sediments were probably being eroded also.

PLEISTOCENE

There is virtually no known evidence of the early Pleistocene events in the Campbell County area. Before diversion of the Missouri River the eastward flowing streams in western South Dakota continued their generally easterly course into east-central South Dakota. The Mound City Channel and the Ancient Grand Channel in Campbell County was part of this easterly flowing drainage system. Warren (1951) and Flint (1955) agree that diversion was by Illinoian ice while White (1964) indicates that the diversion was probably during early Wisconsin. The present study has failed to yield any new evidence concerning a diversion date for the Missouri River trench. An older date for the Missouri River is precluded by evidence cited by Flint (1955, p. 134), and additional evidence from J. C. Harksen, vertebrate paleontologist with the South Dakota Geological Survey (personal communication), which indicates the presence of pre-diversion, high level drainage basins of Kansan and Yarmouth age close to, or crossing the present Missouri River in an easterly direction. However, an age younger than Illinoian cannot be precluded.

The oldest known Pleistocene deposit in Campbell County is the Anicent Grand Channel valley-fill which consists of a basal Illinoian or early Wisconsin outwash (depending on diversion date) underlying a complex outwash-alluvium deposit which is only slightly younger or the same age. The valley-fill is older than late Wisconsin because of its difference in lithology from late Wisconsin deposits and because the black sand of the outwash-alluvium complex is interpreted as manganese dioxide from sub-aerial weathering which could only have occurred during the Sangamon interglacial or the early-late Wisconsin interval.

Formation of the Missouri River trench is illustrated in figure 9. Advancing ice dammed up meltwater from the glacier and water from the east-flowing rivers. A thick sequence of clay and silty clay, now named the Pollock Formation, was deposited in the temporary lake. This ice then over-rode the Pollock Formation and deposited till on top of it in the Mound City Channel northwest of Pollock and north of Herreid. The time of this blockade is uncertain; however, some evidence has been shown which suggests it may have occurred during earliest late Wisconsin time.

It is not known with certainty whether the ice completely melted away, or whether the ice receded to a position shown in figure 10 at the time of formation of the Artas end moraine. In either event, the western one-third of the county was free of ice and was undoubtedly receiving deposits of loess during earliest late Wisconsin.

During the early stages of formation of the Artas end moraine the ice was active, even in the Mound City Channel west of Herreid. Later, the ice in the Mound City Channel stagnated and the Herreid end moraine formed (fig. 11). During the early stages of the Herreid moraine, stagnant ice with little or no drift cover was present to the north and thin lake sediments were deposited. Stagnant ice was present in the Mound City Channel west of Herreid, and much of the water run-off and sediments were carried over the ice. Coarser sand and gravel was deposited on the ice while most of the finer material was carried to the Missouri River. As determined by regional correlation of end moraines and radiocarbon dates in North Dakota, the Herreid end moraine was probably formed about 12,000 years before present.

By the time of formation of the Bowdle end moraine (fig. 12), the stagnant ice north of the Herreid end moraine was mostly melted and stagnant ice was present in the Mound City Channel south of Herreid. Sediment size, grading relationships and distribution of end moraines suggest that most of the Blue Blanket outwash was derived from meltwater associated with the ice that formed the Bowdle moraine and later stagnated. Most of the Spring Creek outwash was deposited from meltwater confined to the Spring Creek drainage and thus was derived mainly from the ice that deposited the Herreid end moraine in Campbell County, and ice associated with formation of the Herreid and Bowdle end moraines in McPherson County. Most of the sediments from the Bowdle end moraine in Campbell County were deposited in the Blue Blanket outwash although some of the water may have overflowed into the Spring Creek drainage. By the time the ice that formed the Bowdle end moraine stagnated, most of the Spring Creek and Blue Blanket outwashes had been deposited in Campbell County.

After formation of the Bowdle end moraine, the ice stagnated (fig. 13) and the "low" in the ice over the eastward extension of the Ancient Grand Channel carried meltwater and sediments forming the Salt Lake outwash. By this time active ice was not present in Campbell County. The stagnant ice covered with superglacial drift melted more slowly as the superglacial drift accumulated. A continual inversion of topography progressed until eventually all the ice melted, leaving the hummocky stagnation drift.

Nearby in North Dakota the drift-covered stagnant ice was re-populated by plants and animals. Evidence of re-population has been reported in McPherson County (C. M. Christensen, personal communication) although such evidence has not been found in Campbell County.

Clayton (1962) shows evidence that indicates the equivalent stagnant ice existed in nearby North Dakota for a period of 2,000 to 3,000 years, or about 12,000 years before present to about 9,000 years before present. More data is needed before conclusions can be made about Campbell County.

RECENT

During Recent time, only minor changes have occurred in Campbell County. Locally, gullies have been eroded and elsewhere only minor erosion has occurred which has resulted in small amounts of alluvium in sloughs and along streams. Along the Missouri River trench mass movement processes are still active and continually modify the existing topography. Most of the soils have been formed during the Recent age.

ECONOMIC GEOLOGY

WATER

Water is probably the single most important mineral commodity to the people of Campbell County. Fortunately, the county has an abundant supply of water available, either in surface water from the Oahe Reservoir or as ground water. The major drawback to either of these supplies is their uneven distribution throughout the county.

The availability and occurrence of ground water is directly related to and controlled by the geology of the water-bearing materials. This is one of the main reasons for the detailed description and discussion of the geologic units and glacial landforms. With this basic geologic framework established the future development and management of the water resources of the county can be accommodated in a more systematic and economical manner. The water

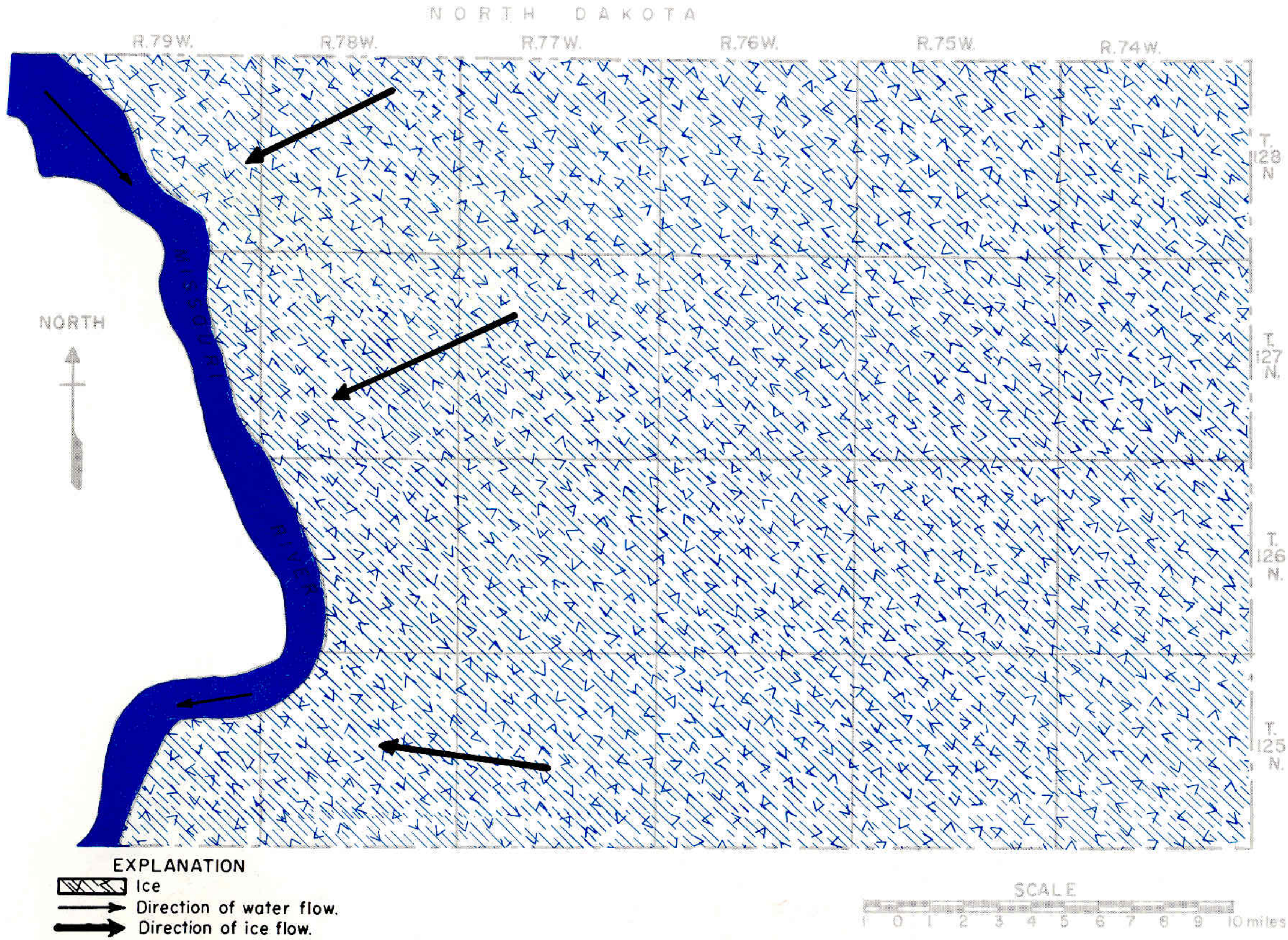


Figure 9. Formation of the Missouri River trench.

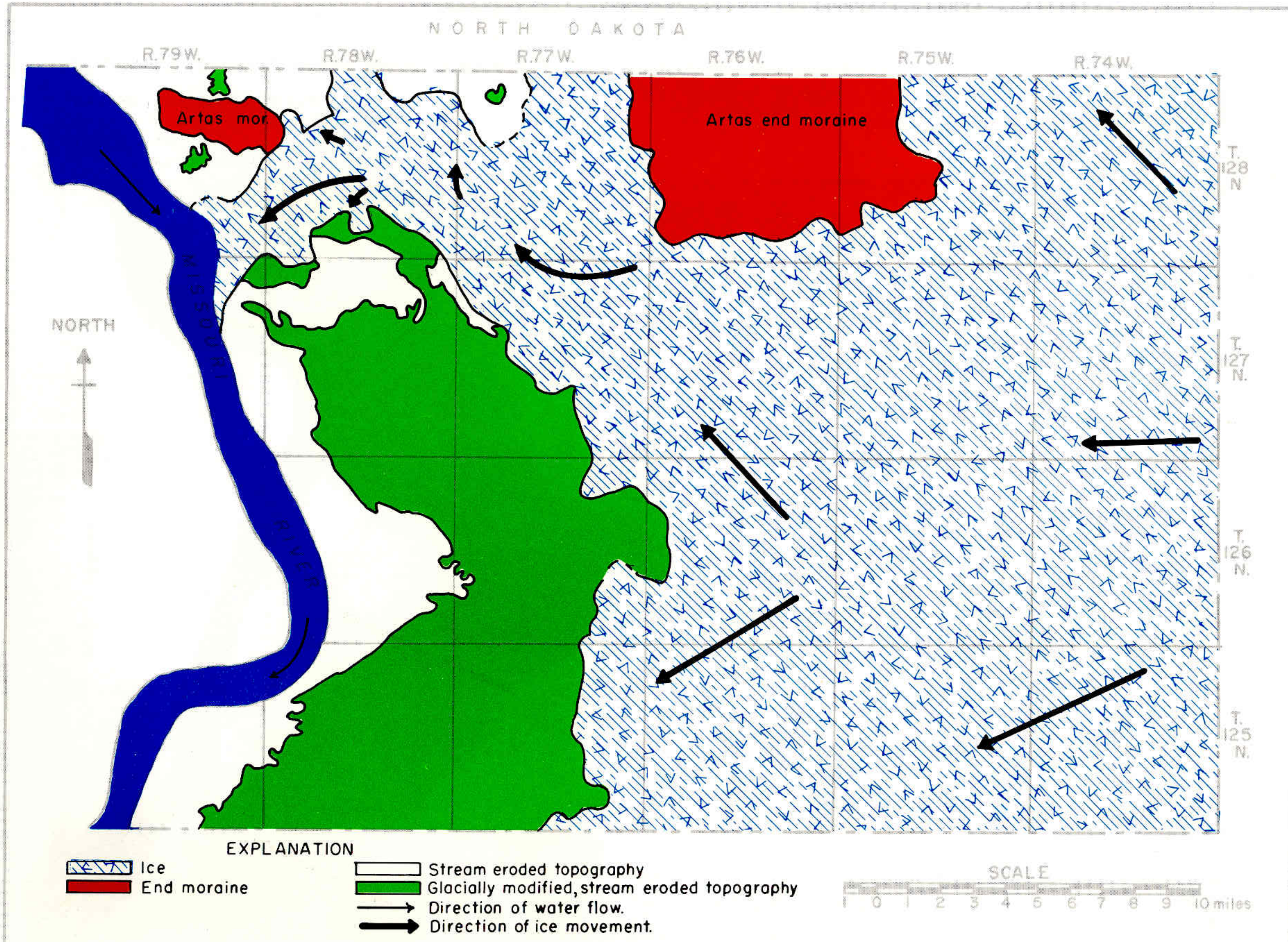


Figure 10. Formation of the Artas end moraine.

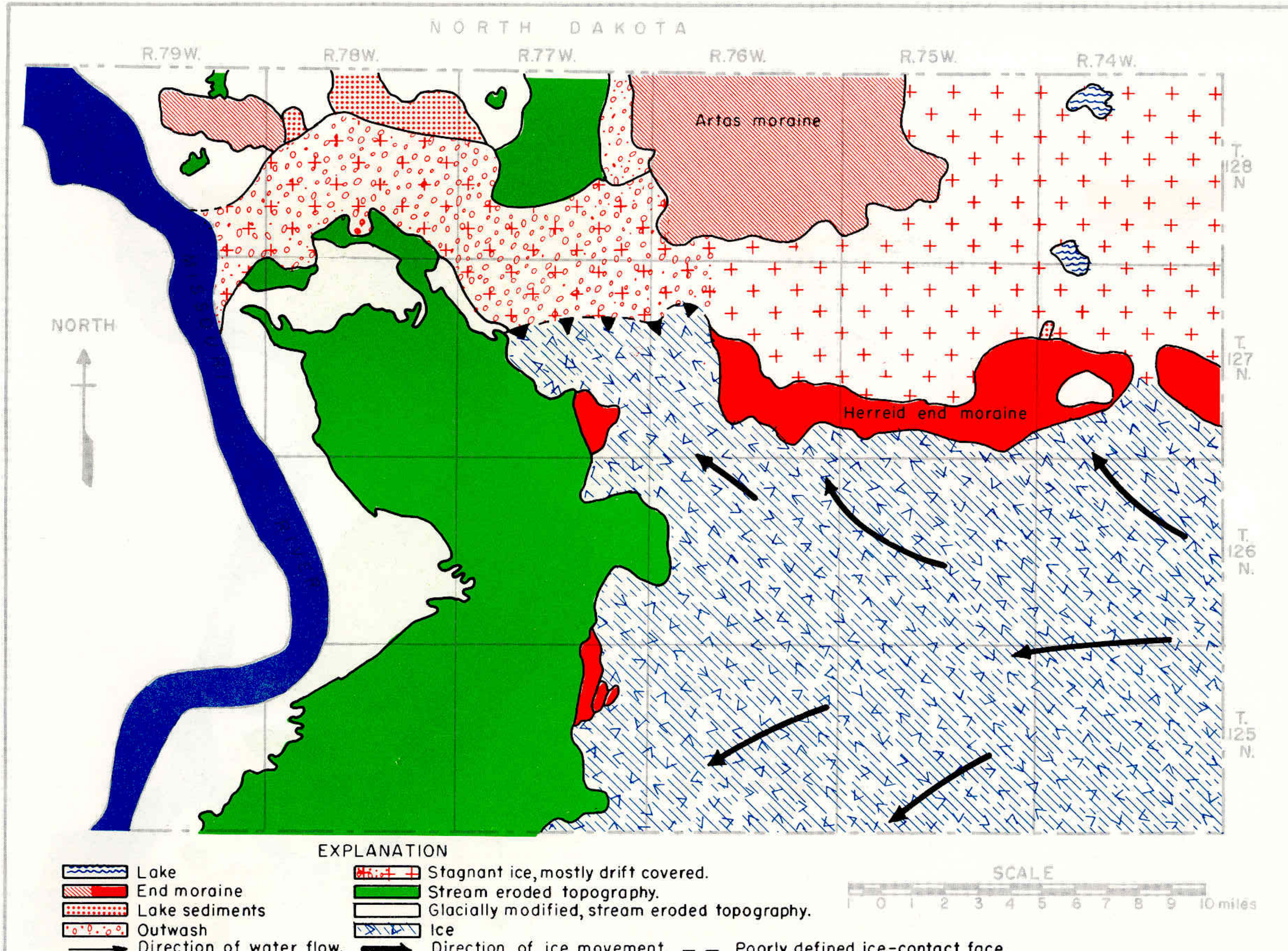


Figure 11. Formation of the Herreid end moraine.

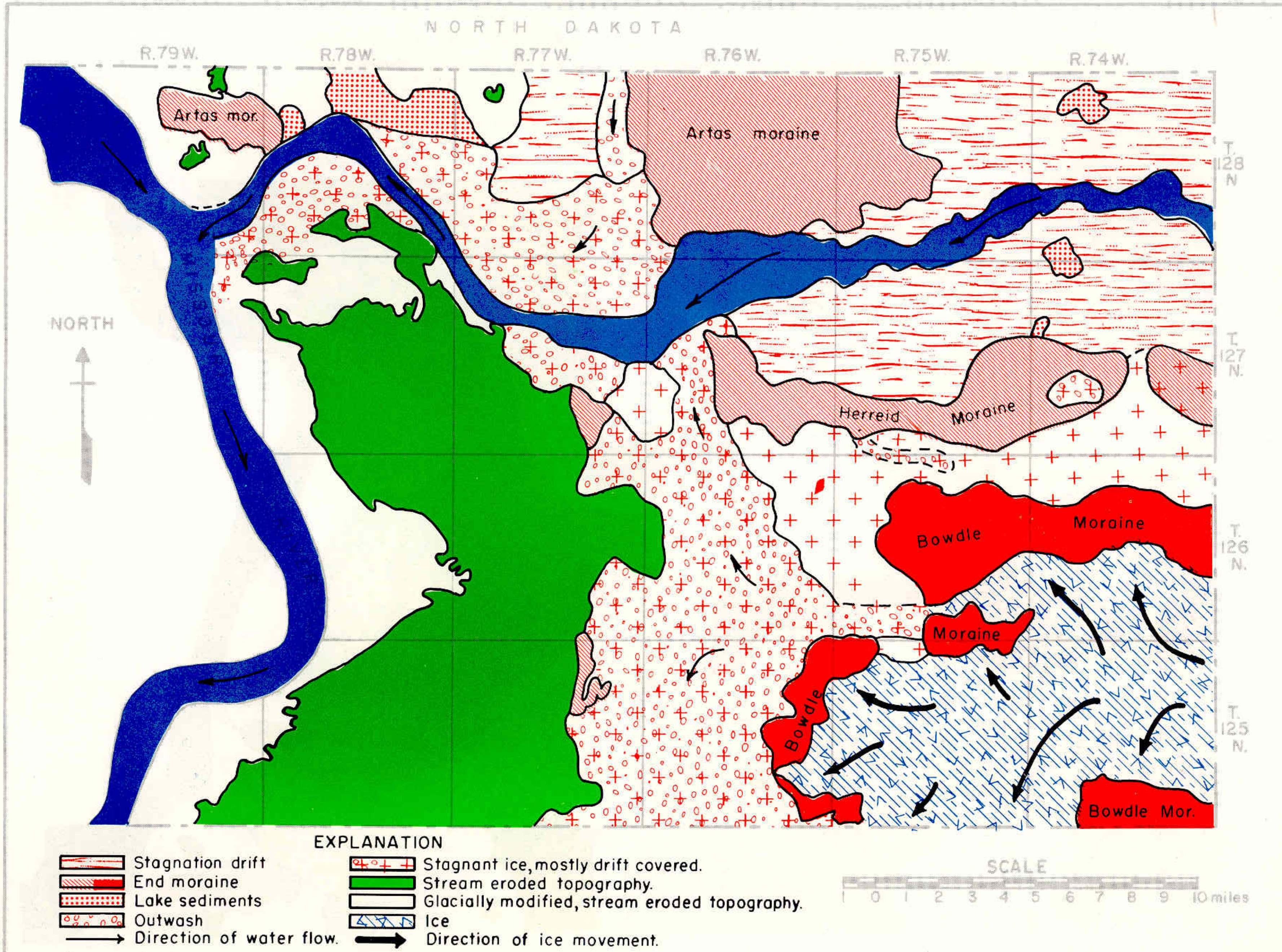


Figure 12. Formation of the Bowdle end moraine.

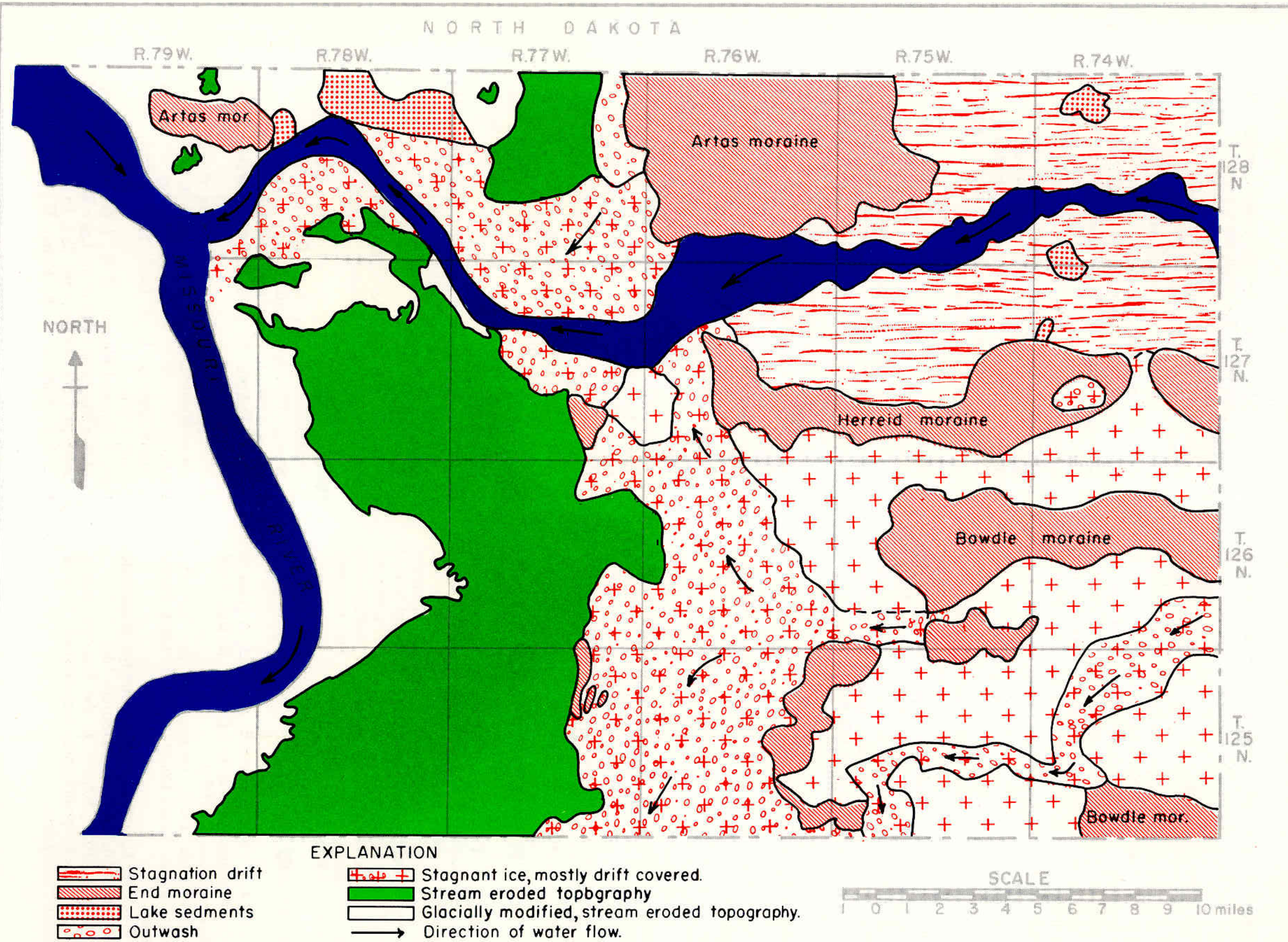


Figure 13. After retreat of active ice from Campbell County.

resources of Campbell County are described in detail in Part II of this report (Koch, 1970).

SAND AND GRAVEL

Campbell County has an abundant supply of sand and gravel available. The major problems related to development of this resources is its uneven distribution and quality restrictions for certain specifications. A discussion of all geologic data pertaining to sand and gravel resources is found in Hedges (1969).

OIL AND GAS

Several oil tests have been made in north-central South Dakota and south-central North Dakota, but no tests have been made in Campbell County. None of the tests produced commercial quantities of oil or gas. In view of the near absence of stratigraphic data in the county at the present time the presence or absence of oil in the county will have to await further investigation.

BOULDERS AND CLAY

The eastern one-half of the county is covered with stagnation drift or end moraine, both of which generally contain abundant boulders. Where abundant, these boulders could be used for rip-rap. The southern two-thirds of the eastern half of the county contain the most boulders. The industrial quality of the clay fraction of the various formations has not been investigated. Those formations having a high enough clay content to warrant further investigation are the Pierre Shale, Pollock Formation, and the glacial till.

MAGNETOMETER SURVEY

Campbell County has been included in the State-wide magnetometer survey the results of which have recently been published by Petsch (1967). The map indicates a vertical magnetic intensity difference between a reading of 42 gammas in the west-central part of the county to 573 gammas in the northeast part of the county. In the absence of stratigraphic data no geologic interpretation of the magnetic variance is attempted.

REFERENCES CITED

Agnew, A. F., and Tychsen, P. C., 1965, A guide to the stratigraphy of South Dakota: S. Dak. Geol. Survey, Bull. 14, 195 p.

Baker, C. L., 1952, Geology of the Mobridge quadrangle, South Dakota: S. Dak. Geol. Survey map.

------, 1958, Surface of the Mobridge quadrangle, unpublished, S. Dak. Geol. Survey files.

Baldwin, B., 1950, Report on the Wakpala, Mahto, and Pollock quadrangles, unpublished, S. Dak. Geol. Survey files.

------, 1951, Geology of the Pollock quadrangle, South Dakota: S. Dak. Geol. Survey map.

Bayrock, L. A., 1958, Glacial geology, Galahad-Hardisty district, Alberta: Alberta Research Council Prelim. Rept. 57-3, 35 p.

Bik, J. J., 1967, On the periglacial origin of prairie mounds: *in* glacial geology of the Missouri Coteau and adjacent areas, Lee Clayton, and Theodore F. Freers, Chief editors, North Dakota Geol. Survey, Misc. series 30, p. 83-94.

Chamberlin, T. C., 1883, Preliminary paper on the terminal moraine of the second glacial epoch: U. S. Geol. Survey, 3rd Ann. Rept., p. 291-402.

Christensen, C. M., 1967, Geology and hydrology of Clay County, South Dakota, Part I, Geology: S. Dak. Geol. Survey, Bull. 19, 86 p.

------, in preparation, Geology and water resources of Bon Homme County, South Dakota, Part I, Geology: S. Dak. Geol. Survey, Bull. 21.

------, in prepartion, Geology and water resources in McPherson, Edmunds, and Faulk Counties, South Dakota, Part I, Geology: S. Dak. Geol. Survey, Bull. 27.

Christiansen, E. A., 1956, Glacial geology of Moose Mountain area, Saskatchewan: Saskatchewan Dept. of Mineral Resources, Rept. 21, 35 p.

Clayton, Lee, 1962, Glacial geology of Logan and McIntosh Counties, North Dakota: N. Dak. Geol. Survey, Bull. 37, 84 p.

------, 1967, Stagnant-glacier features of the Missouri Coteau in North Dakota: *in* Glacial geology of the Missouri Coteau and adjacent areas, Lee Clayton, and Theodore F. Freers, Chief editors, N. Dak. Geol. Survey, Misc. series 30, p. 25-46.

Clayton, Lee, and Freers, T. F., 1967, Glacial geology of the Missouri Coteau and adjacent areas: N. Dak. Geol. Survey, Misc. series 30, 170 p.

Colton, R. B., and Lemke, R. W., 1957, Glacial map of North Dakota: U. S. Geol. Survey (unpublished).

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U. S. Geol. Survey Misc. Geologic Investigations Map I-331.

Crandall, D. R., 1958, Geology of the Pierre area, South Dakota: U. S. Geol. Survey, Prof. Paper 307, 83 p.

Darton, N. H., 1896, Preliminary report of artesian waters of a portion of the Dakotas: U. S. Geol. Survey, 17th Ann. Rept., pt. 2, p. 603-694.

------, 1909, Geology and underground waters of South Dakota: U. S. Geol. Survey, Water-Supply Paper 227.

------, 1918, The structure of parts of the central Great Plains: U. S. Geol. Survey, Bull. 691.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U. S. Geol. Survey, Prof. Paper 262, 173 p.

Frye, J. C., and Willman, H. B., 1960, Classification of the Wisconsin stage in the Lake Michigan glacial lobe; Ill. Geol. Survey, Circ. 285, 16 p.

Frye, J. C., Willman, H. B., Rubin, M., and Black, R.

F., 1968, Definition of Wisconsin Stage: U. S. Geol. Survey, Bull. 1274-E, 22 p.

Goldich, S. S., and others, 1961, The Precambrian geology and geochronology of Minnesota: Minn. Geol. Survey, Bull. 41, 193 p.

Goldich, S. S., Lidiak, E. G., Hedge, C. E., Walthall, F. G., 1966, Geochronology of the Mid-continent region, United States: J. Geophys. Res., v. 71, no. 22, p. 5389-5408.

Gravenor, C. P., 1955, The origin and significance of prairie mounds: Am. Jour. Sci., v. 253, p. 475-481.

Gravenor, C. P., and Kupsch, W. O., 1959, Ice-disintegration features in western Canada: Jour. Geology, v. 67, p. 48-64.

Gries, J. P., 1942, Economic possibilities of the Pierre Shale: S. Dak. Geol. Survey, Rept. Inv. 43.

Hedges, L. S., 1968, Geology and water resources of Beadle County, South Dakota: Pt. I, Geology: S. Dak. Geol. Survey, Bull. 18, 66 p.

------, 1969, Sand and gravel deposits in Campbell County, South Dakota: S. Dak. Geol. Survey, Circular 38.

------, in preparation, Geology and water resources of Charles Mix and Douglas Counties, South Dakota, Pt. I, Geology: S. Dak. Geol. Survey, Bull. 22.

Hedges, L. S., and Koch, N. C., 1967, Glacial aquifers in Campbell County, South Dakota: S. Dak. Geol. Survey, Water Information Circular 2.

------, 1970, Geology and water resources of Campbell County, South Dakota: Pt. III: Basic Data: S. Dak. Geol. Survey, Bull. 20.

Koch, N. C., 1970, Geology and water resources of Campbell County, South Dakota: Pt. II, Water Resources: S. Dak. Geol. Survey, Bull. 20.

Lee, K. Y., 1956, The water supply at Mound City, Campbell County, South Dakota: S. Dak. Geol. Survey, 15 p.

Leighton, M. M., 1933, The naming of subdivisions of the Wisconsin glacial age: Science, new ser. v. 77, p. 168.

Lemke, R. W., Larid, W. M., Tipton, M. J., and Lindvall, R. M., 1965, Quaternary geology of Northern Great Plains: *in* the Quaternary of the United States: Review volume, 7th Congress, Internat. Assoc. Quat. Research, U. S. A., 1965, H. E. Wright, and D. G. Frey, Editors, Princeton Univ. Press, p. 15-27.

Leverett, F., 1932, Quaternary geology of Minnesota and parts of adjacent states: U. S. Geol. Survey, Prof. Paper 161.

Meek, F. B., and Hayden, F. V., 1861, Description of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska . .; with some remarks on the rocks from which they were obtained: Philadelphia Acad. Nat. Sci. Proc., v. 13, pp. 415-447.

Morgan, R. E., and Petsch, B. C., 1945, A geological survey in Dewey and Corson Counties, South Dakota: S. Dak. Geol. Survey, Rept. Inv. 49.

Petsch, B. C., 1953, Structure map of South Dakota, Greenhorn datum: S. Dak. Geol. Survey.

------, 1967, Vertical-intensity magnetic map of South Dakota: S. Dak. Geol. Survey Mineral Resource Investigations Map 4 and text.

Rothrock, E. P., 1943, A geology of South Dakota, Pt. I: The Surface: S. Dak. Geol. Survey, Bull. 13, 88 p.

------, 1947, Geology of the Missouri Valley and vicinity near Mobridge: S. Dak. Geol. Survey, Rept. Inv. 54.

Schoon, R. A., 1965, Dakota Formation of South Dakota: S. Dak. Acad. Sci. Proc., v. 44, p. 72-79.

------, 1967, Stratigraphic cross section of Paleozoic rocks of South Dakota: *in* Stratigraphic cross section of Paleozoic rocks, Oklahoma to Saskatchewan, published by Am. Assoc. Pet. Geologists, Tulsa, Okla., p. 10-12.

Searight, W. V., 1937, Lithologic stratigraphy of the Pierre formation in the Missouri Valley in South Dakota: S. Dak. Geol. Survey, Rept. Inv. 27.

Simpson, H. E., 1960, Geology of the Yankton area South Dakota and Nebraska: U. S. Geol. Survey, Prof. Paper 328.

Stalker, A. M., 1960a, Ice-Pressed drift forms and associated deposits in Alberta: Geol. Survey of Canada, Bull. 57, p. 38.

------, 1960b, Surficial geology of the Red Deer-Steetler map-area, Alberta: Canada Geol. Survey, mem. 306, 140 p.

Steece, F. V., 1961, Preliminary map of the Precambrian surface of South Dakota: Mineral Resources Map No. 2; S. Dak. Geol. Survey.

Todd, J. E., 1885, The Missouri Coteau and its moraines: Am. Assoc. Adv. Sci, Proc. 33, 1884, p. 381-393.

------, 1894, A preliminary report on the geology of South Dakota: S. Dak. Geol. Survey, Bull. 1.

------, 1896, The moraines of the Missouri Coteau and their attendant deposits: U. S. Geol. Survey, Bull. 144, 71 p.

------, 1908, Preliminary report on the geology of the northwest-central portion of South Dakota: S. Dak. Geol. Survey, Bull. 4, p. 13-76.

Townsend, R. C., and Jenke, A. L., 1951, The problem of the origin of the Max moraine of North Dakota and Canada: Am. Jour. Sci., v. 249, p. 842-858.

Waage, K. M., 1961, The Fox Hills Formation; in its type area, central South Dakota: Wyo. Geol. Assoc. Guidebook, Simposium on Lake Cretaceous Rocks of Wyoming, pp. 229-240.

------, 1968, The type Fox Hills Formation, Cretaceous (Maestrichtain), South Dakota: Pt. I: Stratigraphy and paleoenvironments: Peabody Musuem of Natural History, Yale University, Bull. 27.

Warren, C. R., 1951, Probably Illinoian age of part of the Missouri River: Geol. Soc. America, Bull., v. 60, p. 1926.

White, E. M., 1964, Post-Illinoian age for Missouri River in South Dakota proposed from relationship to a White River terrace: Am. Jour. Sci., v. 262, Apr., p. 494-496.

Winters, H. A., 1963, Geology and ground water resources of Stutsman County, North Dakota: N. Dak. Geol. Survey, Bull. 41, 84 p.

Wright, H. E., and Frey, D. G. (editors), 1965, The Quaternary of the United States: A review volume for the VII Congress of the International Association for Quaternary Research, Princeton University Press, Princeton, N. J., 1965.

Zartmarn, R. E., Norton J. J., and Stern, T. W., 1964, Ancient granite gneiss in the Black Hills, South Dakota: Science, v. 145, p. 479-481.

APPENDIX A

List of locations for test holes and well logs used in cross sections on plate 4. Numbers correspond to test hole and well log numbers on plate 4 and 5.

1. SWSWSESE sec. 5, T. 128 N., R. 79 W.
2. NENENE sec. 8, T. 128 N., R. 79 W.
3. SWSWNENE sec. 8, T. 128 N., R. 79 W.
4. SWSENWNW sec. 10, T. 128 N., R. 79 W.
5. NWNWSWNW sec. 11, T. 128 N., R. 79 W.
6. SWNWNWSW sec. 12, T. 128 N., R. 79 W.
7. SWSWSWSW sec. 12, T. 128 N., R. 79 W.
8. SWSWSWSW sec. 7, T. 128 N., R. 78 W.
9. SESWSWSE sec. 5, T. 127 N., R. 77 W.
10. NWNWNWNW sec. 9, T. 127 N., R. 77 W.
11. SWSWSWSW sec. 3, T. 127 N., R. 77 W.
12. SESESESE sec. 3, T. 127 N., R. 77 W.
13. SESESESE sec. 2, T. 127 N., R. 77 W.
14. NWNWNWNW sec. 7, T. 127 N., R. 76 W.
15. SWSWSWSW sec. 5, T. 127 N., R. 76 W.
16. NWNWNWNW sec. 9, T. 127 N., R. 76 W.
17. NENENENE sec. 9, T. 127 N., R. 76 W.
18. SWSWSWSW sec. 2, T. 127 N., R. 76 W.
19. SWSWSWSW sec. 6, T. 127 N., R. 75 W.
20. NENENENE sec. 9, T. 127 N., R. 75 W.
21. SESESESE sec. 3, T. 127 N., R. 75 W.
22. SWSWSWSW sec. 34, T. 128 N., R. 74 W.
23. SWSWSWSW sec. 31, T. 128 N., R. 73 W.
24. SESESESE sec. 32, T. 127 N., R. 77 W.
25. NWNWNWNW sec. 2, T. 126 N., R. 77 W.
26. SESESESE sec. 35, T. 127 N., R. 77 W.
27. NENENENE sec. 1, T. 126 N., R. 77 W.
28. NWNWNWNW sec. 5, T. 126 N., R. 76 W.
29. SESESESE sec. 32, T. 127 N., R. 76 W.
30. SWSWSWSW sec. 33, T. 127 N., R. 76 W.
31. SWSWSWSW sec. 35, T. 127 N., R. 76 W.
32. SWSWSWSW sec. 31, T. 127 N., R. 75 W.
33. NENENENE sec. 4, T. 126 N., R. 75 W.
34. NENWNWNW sec. 3, T. 126 N., R. 75 W.
35. SESESESE sec. 36, T. 127 N., R. 75 W.
36. NENENENE sec. 4, T. 126 N., R. 74 W.
37. SESESESE sec. 36, T. 127 N., R. 74 W.
38. NWNWNWNW sec. 10, T. 126 N., R. 76 W.
39. NENENESE sec. 12, T. 126 N., R. 76 W.
40. SESESESE sec. 9, T. 126 N., R. 75 W.
41. SESESESE sec. 12, T. 126 N., R. 75 W.
42. NENENENE sec. 20, T. 126 N., R. 76 W.
43. SWSWSWSW sec. 15, T. 126 N., R. 76 W.
44. SWSWSWSW sec. 14, T. 126 N., R. 76 W.
45. SESESESE sec. 13, T. 126 N., R. 76 W.
46. NWNWNWNE sec. 20, T. 126 N., R. 75 W.
47. NENENENE sec. 20, T. 126 N., R. 75 W.
48. NENENENE sec. 24, T. 126 N., R. 75 W.
49. SWNWNWNW sec. 22, T. 126 N., R. 74 W.
50. SESESESE sec. 13, T. 126 N., R. 74 W.
51. SWSWSWSW sec. 36, T. 126 N., R. 78 W.
52. SESESESE sec. 31, T. 126 N., R. 77 W.
53. SWSWSWSW sec. 34, T. 126 N., R. 77 W.
54. SESESESE sec. 35, T. 126 N., R. 77 W.
55. SESESESE sec. 36, T. 126 N., R. 77 W.
56. NENENENE sec. 6, T. 125 N., R. 76 W.
57. NWNWNWNW sec. 4, T. 125 N., R. 76 W.
58. NWNWNENW sec. 4, T. 125 N., R. 76 W.
59. NWNWNWNW sec. 2, T. 125 N., R. 76 W.
60. SESESENE sec. 1, T. 125 N., R. 76 W.
61. SWSWSWNW sec. 3, T. 125 N., R. 75 W.
62. SWSWSWNW sec. 6, T. 125 N., R. 74 W.
63. SWSWSWSW sec. 34, T. 126 N., R. 74 W.
64. SESESESE sec. 36, T. 126 N., R. 74 W.
65. SESESESE sec. 9, T. 125 N., R. 78 W.
66. SWSWSWSW sec. 11, T. 125 N., R. 78 W.
67. SESESESE sec. 12, T. 125 N., R. 78 W.
68. SESESESE sec. 8, T. 125 N., R. 77 W.
69. NWNWNWNE sec. 15, T. 125 N., R. 77 W.
70. SESESESE sec. 11, T. 125 N., R. 77 W.
71. NENENENE sec. 13, T. 125 N., R. 77 W.
72. NWNWNWNE sec. 18, T. 125 N., R. 76 W.
73. SWSWSWSW sec. 8, T. 125 N., R. 76 W.

74. NWNWNWNE sec. 17, T. 125 N., R. 76 W.
75. SESESESE sec. 8, T. 125 N., R. 76 W.
76. NENENENE sec. 16, T. 125 N., R. 76 W.
77. NENENENE sec. 15, T. 125 N., R. 76 W.
78. NENENENE sec. 14, T. 125 N., R. 76 W.
79. SWSWSWSW sec. 7, T. 125 N., R. 75 W.
80. NWNWNWNW sec. 15, T. 125 N., R. 75 W.
81. SWSWSWSW sec. 7, T. 125 N., R. 74 W.
82. NENENENE sec. 16, T. 125 N., R. 74 W.
83. SWSWSWSW sec. 7, T. 125 N., R. 73 W.
84. SESESESE sec. 34, T. 125 N., R. 79 W.
85. NENENENE sec. 2, T. 124 N., R. 79 W.
86. SWSWSWSW sec. 33, T. 125 N., R. 78 W.
87. SESESESE sec. 34, T. 125 N., R. 78 W.
88. SWSWSWSW sec. 31, T. 125 N., R. 77 W.
89. SWSWSWSW sec. 32, T. 125 N., R. 77 W.
90. SESESESW sec. 32, T. 125 N., R. 77 W.
91. SESESESE sec. 32, T. 125 N., R. 77 W.
92. SESESESE sec. 33, T. 125 N., R. 77 W.
93. SWSWSWSW sec. 35, T. 125 N., R. 77 W.
94. SESESESE sec. 35, T. 125 N., R. 77 W.
95. SWSWSWSW sec. 31, T. 125 N., R. 76 W.
96. SESESESE sec. 31, T. 125 N., R. 76 W.
97. SESESESE sec. 32, T. 125 N., R. 76 W.
98. SWSWSWSW sec. 33, T. 125 N., R. 76 W.
99. SWSWSWSW sec. 34, T. 125 N., R. 76 W.
100. SWSWSWSW sec. 35, T. 125 N., R. 76 W.
101. SESESESW sec. 36, T. 125 N., R. 76 W.
102. SWSWSWSW sec. 31, T. 125 N., R. 75 W.
103. SESESESW sec. 32, T. 125 N., R. 75 W.
104. SWSWSWSW sec. 33, T. 125 N., R. 75 W.
105. SESESESE sec. 31, T. 125 N., R. 74 W.
106. NWNWNWNE sec. 4, T. 124 N., R. 74 W.