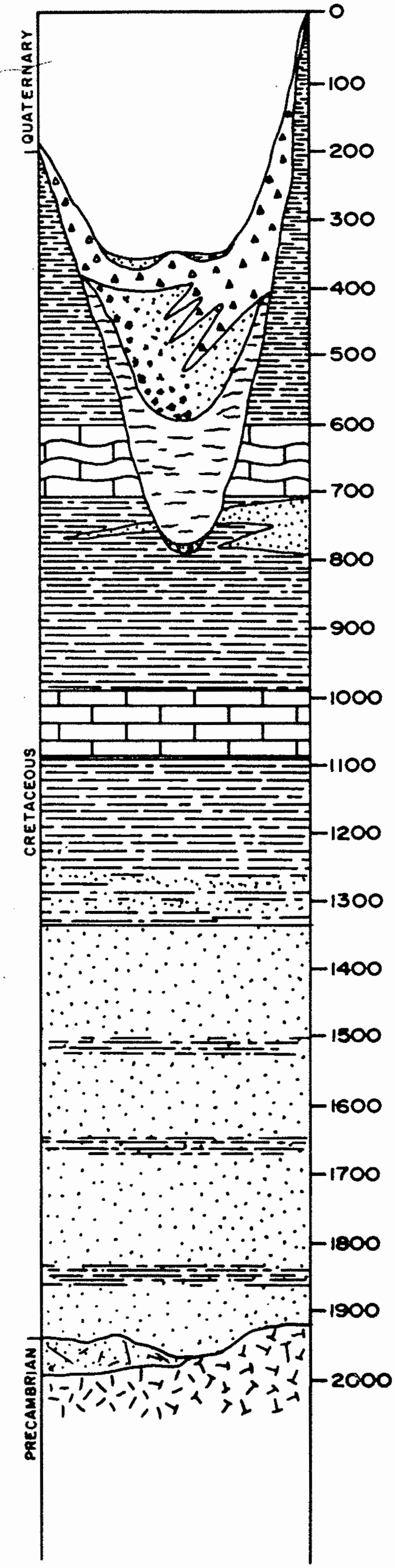

GEOLOGY AND WATER RESOURCES OF BEADLE COUNTY SOUTH DAKOTA

Part I: Geology

by

Lynn S. Hedges,

South Dakota Geological Survey

Prepared in cooperation with the

United States Geological Survey

Bulletin 18

South Dakota Geological Survey

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STATE OF SOUTH DAKOTA
Nils Boe, Governor

SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

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Science Center
University of South Dakota
Vermillion, South Dakota
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ABSTRACT

Beadle County occupies 1,260 square miles in east-central South Dakota, in the James Basin division of the Central Lowland physiographic province; the extreme southwest corner is in the Coteau du Missouri section of the Great Plains physiographic province. Drainage is controlled by the James River which flows essentially north-south through the eastern third of the county. However, much of the area has internal drainage to small closed depressions.

Pleistocene glacial and lacustrine deposits of pre-Wisconsin(?) age, glacial deposits of early and late Wisconsin age and Recent sediments make up the surficial deposits of Beadle County. A thin basal glacial deposit and overlying lacustrine sequence as much as 400 feet thick may be pre-Wisconsin in age. Early Wisconsin deposits underlie much of the county and form extensive bodies of buried outwash in deeply incised former bedrock drainage channels. Late Wisconsin glacial drift with an average thickness of 35 feet occurs at the surface over most of the county. Evidence suggests that the late Wisconsin ice margin halted four times in Beadle County during the period of deglaciation. Late Wisconsin glacial meltwater was dammed up by drift and ice and the first deposits of glacial Lake Dakota were laid down in north-central Beadle County. Lake Dakota was eventually drained southward cutting the James River trench. Recent water and wind action has only slightly modified the landscape since the retreat of the glaciers.

Cretaceous sedimentary rocks overlie Precambrian granitic rocks and the Sioux Quartzite. The Cretaceous sediments are as much as 1,400 feet thick and include the Pierre Shale, Niobrara Marl, Carlile Shale, Greenhorn Limestone, Graneros Shale and the Dakota Group. The Pierre Shale crops out in the southwestern and eastern parts of the county.

Ground water and sand and gravel comprise the major mineral resources of the county.

INTRODUCTION

Purpose and Scope

This report is the result of a detailed study of the geology of Beadle County, South Dakota. The study was initiated in 1961 as part of a comprehensive ground-water study for the county in cooperation with the United States Geological Survey.

The detailed geologic study was conducted to determine the geologic history of the area, to determine the natural resources and to learn the geologic factors that control the occurrence, quantity and quality of ground water.

The study is published in three parts: Part I contains the geology; Part II, the water resources; and Part III, the basic data.

Location and Extent

Beadle County is located in east-central South Dakota and is bordered on the north by Spink and Clark Counties; on the east by Kingsbury and Clark Counties; on the south by Sanborn and Jerauld Counties; and on the west by Hand County (fig. 1). The county is 42 miles long from east to west, and 30 miles wide from north to south, and has an area of 1,260 square miles.

Field Work and Acknowledgments

Geologic mapping was done during the summers of 1961, 1962, and 1963 by traversing the county and adjoining areas by automobile and inspecting natural and man-made exposures. Information was plotted on U. S. Army high-altitude (approximately 1:63,360) air photos and then transferred to a base map of approximately the same scale obtained from the South Dakota Department of Highways.

During 1962 and 1963 several days were spent in the field with Lewis Howells and Jerry Stephens of the U. S. Geological Survey, who were conducting hydrologic studies.

More than 400 test holes were drilled for this study by the State Geological Survey, the U. S. Geological Survey and contract drilling by commercial well drillers. In addition to the test holes drilled for this project, numerous logs are available of test holes and wells made by the U. S. Bureau of Reclamation, the U. S. Corps of Engineers, the South Dakota Water Resources Commission, the South Dakota Department of Highways and private well drillers.

Elevations were determined from published standard U. S. Geological Survey $7\frac{1}{2}$ minute quadrangle maps and unpublished U. S. Bureau of Reclamation reconnaissance topographic maps. Where these maps were unavailable, elevation determinations were made by running level lines to data points, or by altimeter.

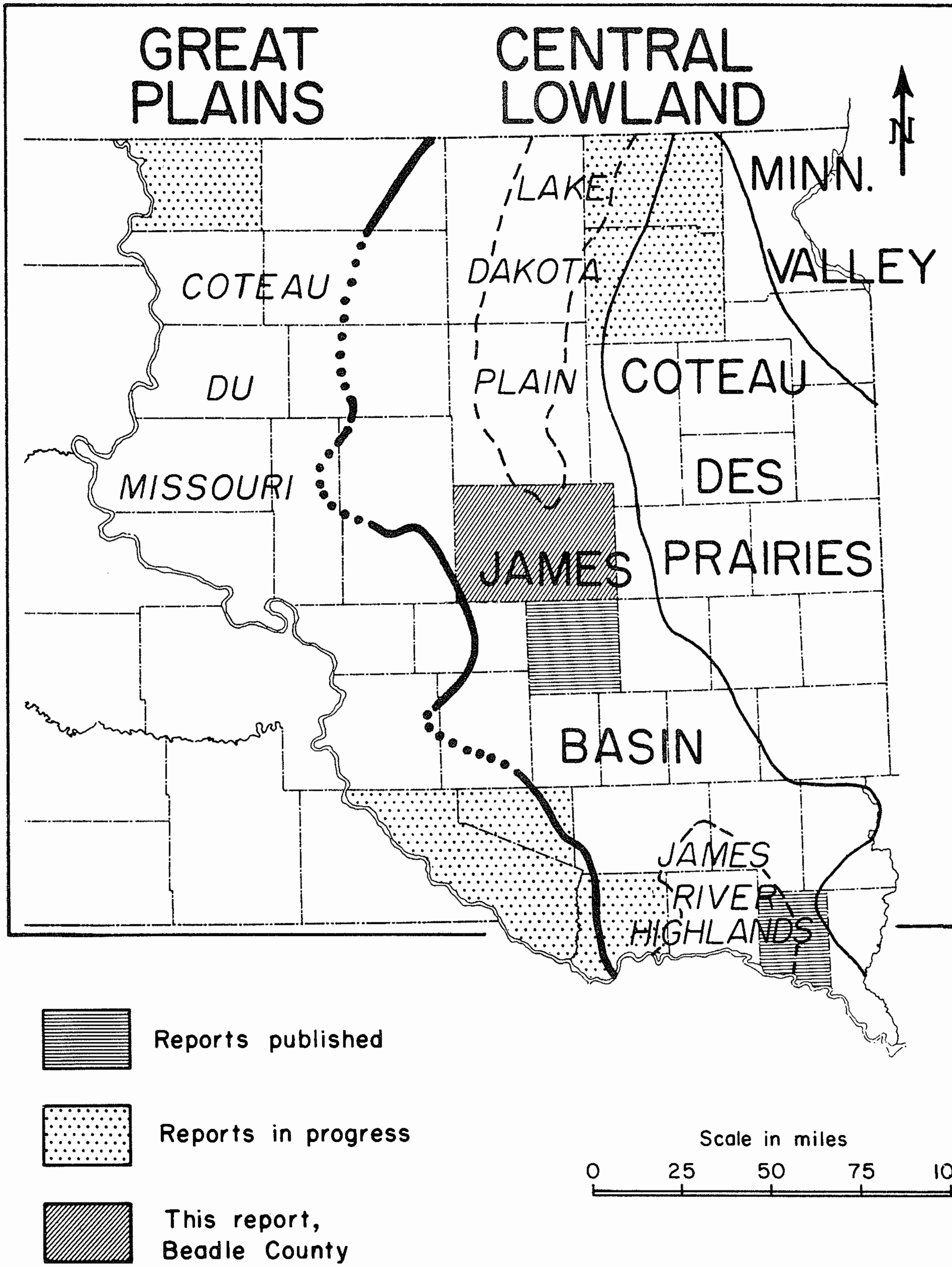

Figure 1. Index map of eastern South Dakota showing physiographic divisions and location of county ground-water studies. *(after Rothrock 1943 and Flint 1955)*

Several people have contributed to the geologic mapping of Beadle County although the present author takes responsibility for the published map and geologic interpretations. The geologic mapping was started in 1961 by Ian Walker and was assisted by Mark McDermott. By the end of the 1961 field season, Walker had mapped 15 and one-half of the 35 townships in the county. The present writer reviewed this geologic mapping and integrated it with the geology mapped during 1962 and 1963.

The writer was assisted in the field during 1962 by Mark McDermott and during 1963 by Steve Pottratz and Allan Wood. Field consultation and joint mapping with Fred V. Steece of about 72 square miles in southwestern Beadle County was also conducted in 1962. Helpful comments from Merlin J. Tipton, Assistant State Geologist, and Fred V. Steece, Geologist, during the planning, mapping and writing stages of this report are also appreciated. Acknowledgment is due the U. S. Geological Survey personnel in Huron, South Dakota, for their comments throughout the project and for their assistance in editing this report.

The writer also wishes to thank Meyer Rubin, U. S. Geological Survey, Washington, D. C., for making radiocarbon dates.

Keith Osberg and Ben Hasz, well drillers, also contributed substantially to the project by making available well logs and samples from Beadle County and adjacent areas.

Richard Bruce, Highway Geologist, also deserves thanks for test hole information and other data made available during his aggregate research study which covered portions of Beadle County (Bruce and Lundberg, 1964).

The residents of Beadle County allowed access to private land and extended courtesies and provided information pertinent to this report.

Previous Investigations

Prior to this investigation, the geology of Beadle County had not been studied in detail but had been included in many regional and state-wide studies. Chamberlin (1883) described the moraines of eastern South Dakota. Todd (1896) described the moraines and glacial features between the Missouri and James Rivers. Todd (1904a, b; 1909) published three geologic folios which described the glacial geology of three areas, each including parts of Beadle County. Todd and Hall (1904) published a paper in which they described the water resources and geology of the lower portion of the James Valley which included parts of Beadle County and was a compilation based on much of the literature already cited. Darton (1909) included Beadle County in his general report on the geology and underground-water resources of South Dakota. Rothrock and Petsch (1935) discussed the geology and ground-water conditions around Huron. Sayre (1936) included a general geologic study of Beadle County in his investigation of water resources and dam sites in the James River valley. Rothrock (1946) made a reconnaissance study of the surface geology of part of the James Basin which included a portion of Beadle County. Erickson (1954) included Beadle County in the study of artesian conditions in east-central South Dakota. Flint (1955) made a reconnaissance study of the Pleistocene geology of eastern South Dakota. Tipton (1960) and Walker (1961) contributed more knowledge about the geology and ground-water conditions around Huron.

Climate

The climate of Beadle County is continental temperate with large daily and seasonal fluctuations in temperature, characterized by long, cold winters and short, hot summers.

The average monthly temperature and precipitation at the U. S. Weather Bureau Station at Huron for the period 1931 to 1961 are listed in table 1. The mean annual temperature during this period was 45.5 degrees Fahrenheit and the average annual precipitation was 17.33 inches. Precipitation occurs mostly as rain during late spring and summer.

Well-Numbering System

Wells and test holes in this report are numbered in accordance with the U. S. Bureau of Land Management's system of land subdivision. The first numeral of a well designation indicates the township; the second, the range; and the third, the section. Lowercase letters following the section number indicate the position of the well within the section; the first letter indicates the 160-acre tract; the second, the 40-acre tract; the third, the 10-acre tract; and the fourth, the $2\frac{1}{2}$-acre tract. The letters a, b, c, and d are assigned to the tracts in a counterclockwise direction beginning in the northeast corner of each tract. For example, well 110-60-3dadd is in the $SE\frac{1}{4}SE\frac{1}{4}NE\frac{1}{4}SE\frac{1}{4}$ sec. 3, T. 110 N., R. 60 W., (fig. 2). If two or more wells are located within the same tract, consecutive numbers beginning with 1 are added as suffixes to designate the order in which the wells are listed (such as 110-60-3$dadd_1$).

PHYSIOGRAPHY

The map showing the physiography of eastern South Dakota (fig. 1) shows most of Beadle County lying within the Central Lowland province with about 7 square miles in the southwestern corner located in the Great Plains province. The Coteau du Missouri section of the Great Plains province is represented by a highland in the southwest part of the county. The Central Lowland province is divided into the Coteau des Prairies section and James Basin section; a part of the latter is designated the Lake Dakota plain.

Total relief in Beadle County is about 630 feet. The lowest elevation is the floor of the James River trench at the Sanborn County line at about 1,220 feet. The highest point is on the Coteau du Missouri at an elevation exceeding 1,850 feet.

The James River is the master stream for Beadle County. The tributaries east of the James River are usually deeply incised throughout much of their course, whereas many of the streams west of the James River have

Table 1.--Temperature and precipitation data
for Beadle County, South Dakota.

Temperature and precipitation averages from 1931 to 1961 at the U. S.
Weather Bureau station in Huron, South Dakota.

	Average monthly temperature (degrees F.)	Average monthly precipitation (inches)
January	13.5	0.48
February	17.1	0.60
March	29.7	1.11
April	46.0	1.84
May	58.0	2.36
June	68.1	3.14
July	75.5	1.81
August	73.3	2.07
September	62.4	1.53
October	49.8	1.15
November	32.2	0.68
December	20.3	0.56
	45.5 degrees F. (mean annual)	17.33 inches (total precipitation)

U. S. Dept. of Commerce, Climatological Data, S. Dak., 1963-1964.

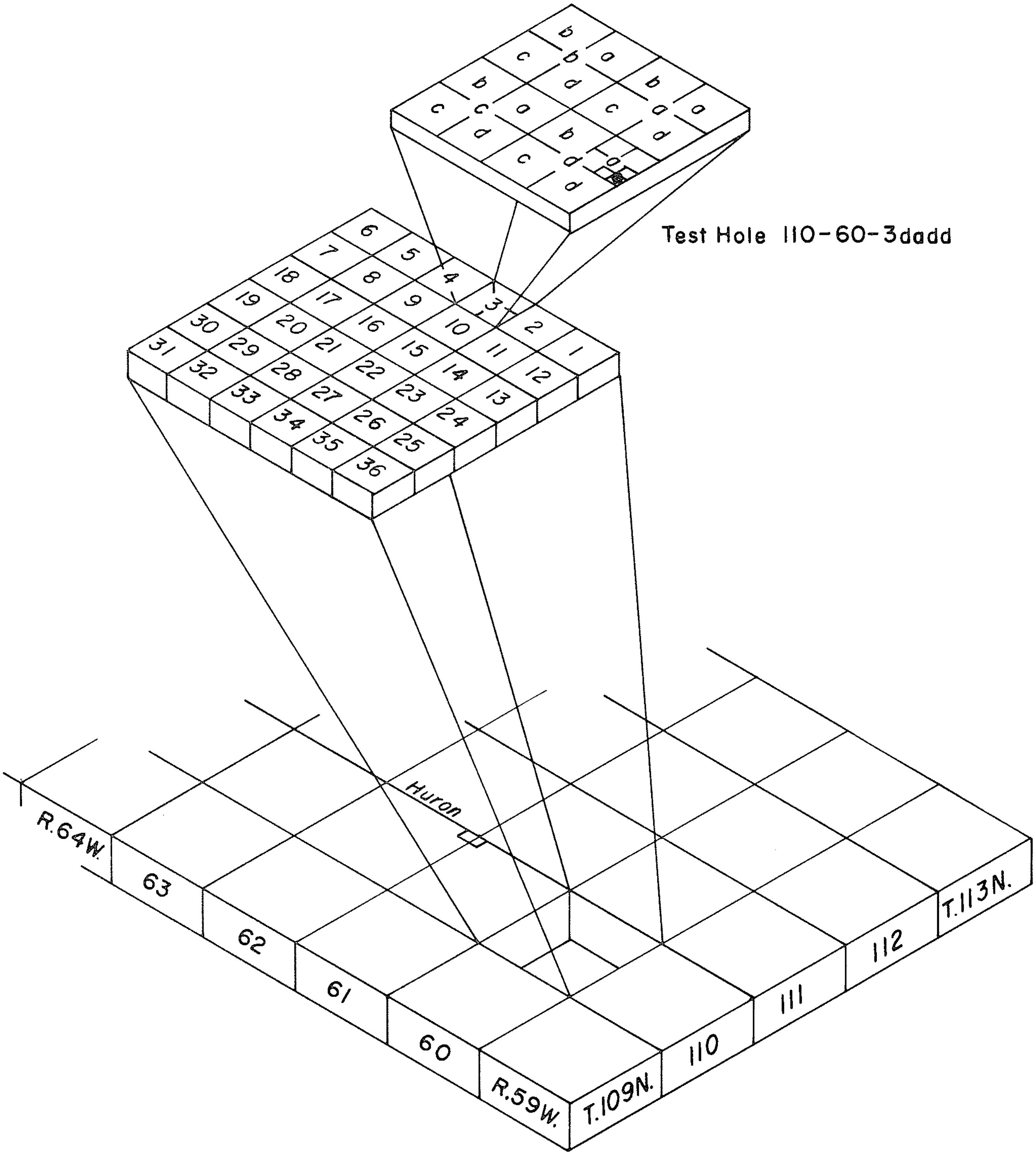

Figure 2. Diagram showing well-numbering system.

broad shallow valleys which deepen and become incised as the James River is approached.

Coteau du Missouri

The Coteau du Missouri forms an abrupt northeast facing escarpment rising 350 feet above the James Basin. The escarpment is a smooth slope except where dissected by many small streams and where an occasional knob occurs. The escarpment is a bedrock highland thinly veneered with glacial drift whereas the surface of the coteau is covered with as much as 120 feet of glacial drift. A knob and kettle topography, characteristic of youthful glacial terrain, masks the underlying bedrock topography on the surface of the coteau.

James Basin

The James Basin in South Dakota is a lowland of low to moderate relief trending north-south between the Coteau du Missouri and the Coteau des Prairies. The basin is 50 to 75 miles wide and 250 miles long in South Dakota (Rothrock, 1943, p. 24).

The floor of the basin in Beadle County is nearly flat to rolling east of the James River with maximum local relief of 25 feet (excluding the Lake Byron channel and stream valleys). West of the James River the floor of the basin gradually becomes more rugged. Near the western edge of the county the topography is characterized by knobs and depressions with local relief as much as 75 feet.

To the east and west of the James River the basin floor gradually gains altitude to about the 1,500 foot topographic contour which roughly defines the limits of the James Basin. In southwest Beadle County this basin terminates abruptly against the prominent escarpment of the Coteau du Missouri at an elevation of about 1,500 feet. About 6 to 12 miles east of Beadle County the basin merges gradually with the west slope of the Coteau des Prairies, which at this latitude forms no prominent westward facing escarpment.

Lake Dakota Plain

The Lake Dakota plain is a part of the James Basin with about 70 square miles present in north-central Beadle County. The plain was formed by glacial Lake Dakota which existed late in the Pleistocene Epoch and once extended from about 4 miles northeast of Huron to about 25 miles into North Dakota. This plain is a broad, flat, slightly dissected area most of which lies east of the James River in Beadle County and is underlain with till, fine sand and silts, and some fine gravel. In Beadle County the elevation of the Lake Dakota plain ranges from 1,290 to 1,310 feet, which is about the maximum range in elevation for its entire length.

GLACIAL LANDFORMS AND ASSOCIATED DEPOSITS

Studies involving glacial stratigraphy, especially those dealing with the younger Pleistocene glacial deposits often cannot be detailed enough for mapping purposes when a strict rock-stratigraphic concept is employed. In order to work out the detailed glacial history of an area, a study of the origin of glacial landforms and their associated deposits must be utilized. Likewise, the lithology of the deposits associated with the landforms may or may not be significant in determining the origin and interpretation of particular landforms. Thus, the following discussion concerns itself with the glacial landforms and associated deposits which are found in Beadle County.

Undifferentiated glacial deposits are termed "drift"; this refers to any material deposited by or from a glacier. Drift can be subdivided into two broad types: (1) till, which is a heterogeneous mixture of boulders, cobbles, gravel, sand, silt and clay, commonly referred to as "boulder-clay"; and (2) stratified drift, which is a glaciofluvial sediment that exhibits some degree of sorting by glacial meltwaters. A third type of material which may be considered part of glacial drift is glaciolacustrine sediment or glacial lake sediment.

Those portions of Beadle County which have been included on previous geologic maps (Todd, 1904a, b; 1909; and Rothrock, 1946) show less end moraine than either Flint (1955) or the present writer. Two reasons are thought to be mainly responsible for this discrepancy: (1) differing concepts of the definition of the term end moraine; and (2) the availability of detailed topographic maps and air photos to the later workers.

Detailed topographic maps and air photos used in conjunction with field observation have shown many glacial geomorphic features which are important in determining the late Pleistocene geologic history of Beadle County. Among these geomorphic features are a group of linear elements (end moraine) which offer a variety of topographic expression. The change from one form to another is most often subtle and gradational, although in broad aspect the change is real and easily distinguished. For this reason, a detailed description of end moraine is included in this section of the report.

End Moraine

End moraine is composed mostly of till but may contain small to significant amounts of stratified drift intercalated within or on the till. The historical development of the term end moraine has been adequately presented by Flint (1955, p. 112) and the following quotation is his definition of the term:

> "An end moraine is a ridgelike accumulation of drift built along any part of the margin of a glacier. Its topography is primarily constructional." (Flint, 1957, p. 131)

This definition allows a wide variety of topographic forms to be included as end moraine and still fall within the general definition of the term. The most important factor in recognizing end moraine is linearity either in overall or internal linear patterns.

The end moraine in Beadle County is divided into five types on the basis of form and inferred method of origin: (1) smooth ridge, (2) hummocky ridge, (3) end-moraine complex, (4) minor moraines, and (5) hummocky uplands. The first three listed are often laterally gradational to one of the other two types making it difficult at times to place an individual end moraine into a precise classification. However, where these features can be recognized and classified they are important in determining the history of the area.

Smooth Ridge

The smooth-ridge type of end moraine has been described by Flint (1955, p. 113):

> "...the long, rather straight, smooth ridge, 10 feet to 100 feet or more in height and commonly half a mile to two miles in width. This type of ridge has little topographic variation in detail; ordinarily it is no more than a broad smooth swell."

It seems likely that an end moraine of this type would be formed in an area of thin, active ice under fluctuating climatic conditions. This set of conditions would create a rapid fluctuation of the ice margin in a relatively narrow sector and allow a thickening of the till throughout the sector in which the ice margin was fluctuating. Eventually this would result in a ridge which would act as a further impediment to the flow of ice and would tend to restrict marginal fluctuations. The actual fluctuation then would occur in a narrow sector immediately adjacent to the ice margin. The resulting ridge would be an accumulation of lodgement till mixed with material let down at the margin of the ice.

One end moraine of the type just described is found in Beadle County. It is located northwest of Huron and trends northwest from sec. 9, T. 111 N., R. 61 W. to sec. 3, T. 113 N., R. 63 W., a distance of about 18 miles. The trend of this moraine is indicated on plate 1 by the heavy line in this area. The end moraine is 1 to 2 miles wide and is a broad smooth swell which appears flat in topographic detail and has only a few closed depressions. On the surface of the ridge the only conspicuous relief is where present drainages are incised. The southern boundary of the end moraine is an outwash plain which is at a general elevation of about 1,280 feet. The boundary between the outwash plain and the end moraine is a distinct escarpment along much of its course, rising 10 to 35 feet to a maximum elevation of 1,325 feet southeast of Hitchcock. The northeast boundary is gradational into the ground moraine and the Lake Dakota plain at an elevation of 1,290 to 1,310 feet.

Hummocky Ridge

As defined by Flint (1955), the hummocky-ridge type of end moraine is linear in gross aspect but contains few or no internal lineations. This type of ridge consists of a jumbled mass of knolls and closed depressions. The ridge may be 100 feet high and several miles wide.

End moraines of this type are built when the margin of the glacier is wasting at nearly the same rate the ice is advancing or when a restriction halts the lateral movement of ice and continual piling up of debris occurs in a narrow sector.

Several discontinuous ridges in Beadle County are end moraines fitting this description, but in a much subdued form, and they are gradational with the third type of end moraine described (see following section).

The heavy lines representing end-moraine crests on plate 1, except on the smooth ridge, indicate the areas which most closely resemble the hummocky-ridge type of end moraine. At best, this type of end moraine is poorly represented and the heavy lines are not meant to illustrate single continuous ridges.

One such discontinuous ridge is present just west of Hitchcock and trends southeast nearly to Broadland (pl. 1, heavy line). This ridge has more constructional topography than the smooth-ridge type end moraine, although in this area the ridge is mantled with eolian sand.

Another discontinuous hummocky-ridge type of end moraine enters Beadle County from Sanborn County in the southwestern part of T. 109 N., R. 62 W., and trends northwest along Cain Creek (pl. 1, heavy line). This ridge is over 1 mile wide and has a maximum height of 40 feet. Upon entering Beadle County the ridge becomes less distinct and is gradational with end-moraine complex (see following section).

The boundaries between the hummocky-ridge type end moraine and the end-moraine complex (see following section) are not indicated because the two are somewhat gradational and would require extremely detailed mapping to delineate the boundaries.

End-Moraine Complex

The third type of end moraine is an end-moraine complex. This type of end moraine is an undulating lowland ("low" in respect to end-moraine ridges) of low relief which in plan view over a large area contains drainage depressions and intervening ridges in arcuate, subparallel arrangement. The local relief in this type end moraine is 15 feet.

The end-moraine complex probably formed while the ice margin was retreating. During recession, the ice margin must have periodically halted just long enough to form the ridges and then retreated, leaving the subaligned depressions which are so characteristic of this type topography. It is the arcuate linearity of the depressions which impart the "grain" to this topography.

Nearly all of the end moraine in Beadle County east of the James River consists of end-moraine complex. West of the James River the end-moraine complex comprises the undulating topography between the hummocky ridge end moraines. The end-moraine complex type of topography is illustrated on the eastern half of photo 1, and it shows the subaligned depressions and arcuate drainage patterns.

Minor Moraines

A minor moraine consists of a broad swell which is traceable generally less than a mile. Minor moraines usually are found in groups or clusters and as many as 20 may be present in a square mile. Each minor moraine may rise 5 to 10 feet above the intervening depression, although on topographic maps with contours as closely spaced as 5 feet the pattern is barely discernible. The linear pattern would probably go undetected in the field without the aid of air photos or detailed topographic maps. In marked contrast with the end-moraine complex topography previously described, ridges are the dominant features of minor moraines rather than depressions.

The minor moraines herein described are similar to the "swell and swale" topography described by Gwynne (1942, p. 202) in Iowa and the minor moraines of Gwynne (1951) in South Dakota and Minnesota; washboard moraines (Elson, 1957; Lemke, 1960; Winters, 1960; Christiansen, 1961), washboard ridges (Gravenor and Kupsch, 1959), and minor end moraines or minor recessional ridges (Christiansen, 1956).

Gwynne (1951) concludes that the minor moraines were formed by lodgement at or near the margin of the ice, although in areas of low relief a "pushing process" may have been more important than lodgement. Elson (1957) believes that washboard moraines are formed by lodgement till where plastic ice was thrust over or against dead ice at the margin of a glacier. Gravenor and Kupsch (1959, p. 55) attribute the formation of washboard moraines to squeezing along thrust planes in the ice parallel to the periphery of the ice sheet, although ultimate preservation is due to stagnation. Hoppe (1957) points out that in some instances washboard moraines are situated transverse to the general direction of ice flow, and fabric studies of the till in some areas show that movement of the material in the ridges was independent of the direction of ice movement. In North Dakota similar ridges have been noted by Lemke (1960) and other workers. The interpretation of these features in North Dakota is that they are recessional moraines marking cyclic pauses of the ice front during deglaciation.

In summary, most authors agree that the minor moraines usually are oriented parallel to the former ice margin and are probably formed during ice recessional stages. Not all writers agree, however, on the mechanics of their formation.

The minor moraines in Beadle County are found about 3 miles northeast of Huron and encompass about 4 square miles (photo 1). This area contains a series of slightly arcuate, subparallel ridges generally 5 to 10 feet in height, which are oriented northwest-southeast and number up to 20 per square mile. The northeastern border of the minor moraines terminates at the edge of a small, ice-marginal (?) meltwater channel. The northwestern border of the minor moraines terminates near the James River trench. Southward the minor moraines gradually become less conspicuous until finally they merge into the end-moraine complex.

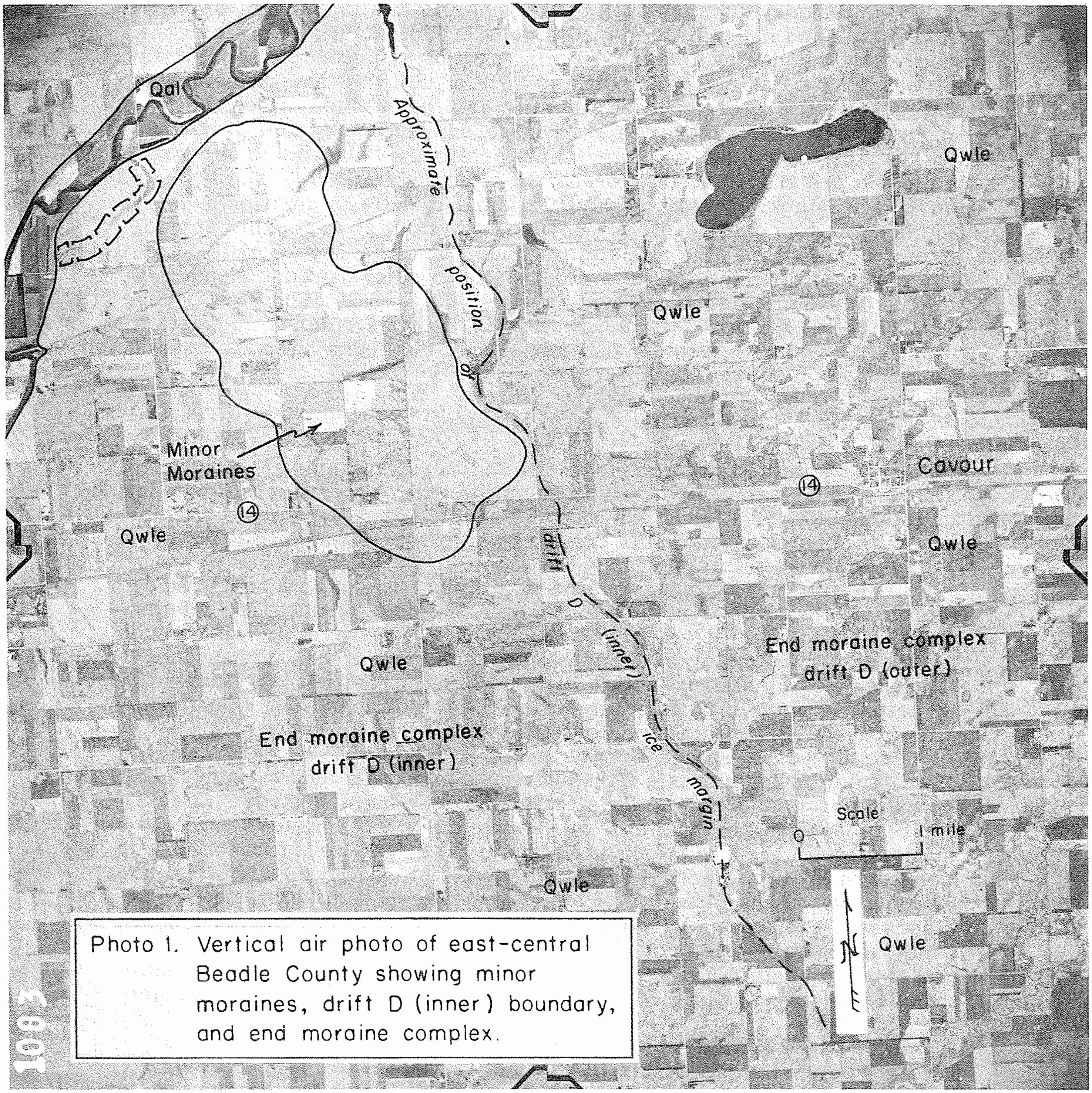

Photo 1. Vertical air photo of east-central Beadle County showing minor moraines, drift D (inner) boundary, and end moraine complex.

Hummocky Uplands

The hummocky-uplands type of end moraine is a prominent, areally restricted, and irregularly shaped highland. Although the origin of the hummocky uplands as true end moraine may be questionable, their massive dominance over the surrounding terrain justifies their classification and description. One such end moraine is present 2 miles south of Wessington. This moraine is a steep-sided, hummocky upland rising abruptly 80 feet above the surrounding surface. A shallow rotary test hole near the summit of this hummocky upland showed 5 feet of reworked shale overlying 30 feet of pebbly, yellow clay-till. A detailed map of the bedrock topography (pl. 2) shows a bedrock high under this upland, thus suggesting that the formation of these features may be at least partially bedrock controlled. Other end moraines of this description, although smaller in magnitude, were found in secs. 23, 24, 25, and 26, T. 111 N., R. 65 W. The arcuate distribution of the three uplands suggests that they may be an ice-marginal feature. Thus, they have been included under the section on end moraine.

Ground Moraine

Ground moraine is composed of till and may contain small amounts of stratified drift intercalated within or on the till. Ground moraine as defined by Flint (1957, p. 131) is "...moraine having low relief devoid of transverse linear elements." This definition enjoys preference in the literature and is followed in this paper.

The definition of ground moraine just given implies no specific mode of deposition. This is desirable because the exact mechanics of deposition of ground moraine usually is not apparent. However, three methods are thought to be mainly responsible for deposition of ground moraine: (1) lodgement or "plastering on" of drift contained in the base of flowing ice, (2) letting down of drift from the surface of the ice, and (3) deposition of drift from the ice margin as it retreats at a nearly uniform rate.

In southwestern Beadle County in T. 110 N., R. 65 W., and small parts of adjoining townships is a 24-square mile area of ground moraine (pl. 1). This area of ground moraine is situated between Sand and Silver Creeks and extends from the Beadle-Hand County line about 8 miles southeast to the junction of the two creeks mentioned. The local relief on the ground moraine is about 15 feet. Many of the areas of maximum relief are linear features parallel to direction of ice movement. These features will be discussed later in this section of the paper under eskers and flutings.

Ground moraine also covers more than five townships in north-central and extreme eastern Beadle County (pl. 1). Local relief is seldom more than 15 feet, except in the Lake Byron channel and where drainages are incised.

Although the ground-moraine surface is relatively smooth, it is not level. Regional slope toward the axis of the James Basin accounts for more than 200 feet change in elevation along the north Beadle County line from an elevation less than 1,300 feet near the James River trench to the northeastern corner of the county, which is slightly over 1,500 feet. Much of the ground-moraine surface in north-central Beadle County is thinly mantled with lacustrine deposits. Near the James River trench the ground-moraine surface has been partially dissected by late Pleistocene melt-waters.

Flutings

Flutings include a family of streamlined, molded forms characterized by ridges and grooves that impart a fluted pattern to be the ground surface (Flint, 1957, p. 66). Features similar to the fluted surface in Beadle County have been reported by Steece, Tipton, and Agnew (1960) near Trent in southeastern South Dakota, but they are present on older glacial drift.

Lemke (1958) described linear drumlins near Velva, North Dakota, that are nearly identical in form and composition to the flutings found in southwest Beadle County. He also made an extensive survey of the literature on this subject and the reader is referred to this publication for additional references. Lemke concluded that the linear ridges in North Dakota are drumlins formed during the advance of the last ice sheet to occupy the Velva area and that their lineation is parallel to the direction of the last ice movement. Lemke further concluded:

> "...that the larger partly stratified drumlins were formed by glacier ice advancing over stratified deposits, eroding and shaping the deposits into ridges and then plastering a layer of till over the deposits."

He was not so definite about the mechanics of formation for the smaller drumlins.

An alternate hypothesis to the formation of the ridges is that they may be ice-pressed ridges as described by Stalker (1960). Although most of the ridges described by Stalker are composed chiefly of till, the squeezing process which formed the till ridges could with equal ease form ridges from stratified drift; the only difference would be the size of the ridge formed. Stalker (1960, p. 21) stated that, "...under favorable conditions with ice 200 feet thick, assuming an ice density of 0.8 and a till density of 2.0, a ridge about 80 feet high could be constructed." The problem with the ice-pressing theory is in finding a mechanism for producing the long, straight, parallel tunnels or crevasses in the base of the ice into which the ridge material has been squeezed.

Still another possible origin of the ridges is crevasse fillings. The major drawbacks of this theory are: (1) finding a mechanism to produce the necessary long, straight, parallel crevasses, and (2) in areas where crevasse fillings have been studied, the crevasse fillings transect each other.

Reed, Galvin and Miller (1962) studied the form, orientation, and spacing of drumlins. Among their conclusions was the suggestion that drumlin formation is the result of both erosion and deposition and that it is preferable to consider drumlins as "ice-molded forms." They further concluded that the dynamics of the ice was more important in considering drumlin formation than is the type of material involved.

The flutings in Beadle County are present in T. 110 N., R. 65 W. (photo 2). They are narrow, somewhat discontinuous, parallel and very slightly arcuate ridges rising about 10 feet above the general land surface. On one or both sides of a particular ridge, a linear, narrow depression makes the total surface relief about 15 feet. A shallow auger test hole in the trough beside one of the ridges (SW$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$, sec. 25, T. 110 N., R. 65 W.) showed the following sequence of sediments:

Feet	Description of Material
0- 4	Alluvium, black, silty
4- 9	Alluvium, gray, stratified, grading to a yellow pebbly clay
9-17	Clay, yellow, sandy (till?)
17-19	Till, yellow-brown, pebbly

This log suggests that erosion has modified the original surface by lowering the ridge and filling the depression. Thus, before the adjacent depression was partly filled with alluvium the height of the individual ridge may have been as much as 24 feet. Other test holes in two of the ridges and inspection of one outcrop indicate that some of the ridges may be composed mostly of till, while others may contain mostly stratified drift with a thin covering of till present or absent.

With the evidence available, it seems probable that the flutings in Beadle County were formed in a manner similar to that of the drumlins near Velva, North Dakota, and thus parallel, at least locally, the direction of ice movement.

Landforms Associated with Stratified Drift

Stratified drift can be subdivided into two classes (Flint, 1957, p. 136) depending on the place of origin and conditions of deposition. Those deposits carried by glacial meltwater beyond the margin of the ice are termed outwash deposits and those which were deposited in immediate contact with the ice are called ice-contact deposits. Further subdivision can be made within each major category of stratified drift based on surface form and lithology.

Ice-Contact Stratified Drift

Ice-contact stratified drift in Beadle County is present in kame terraces, kames, eskers, and undifferentiated ice-contact drift.

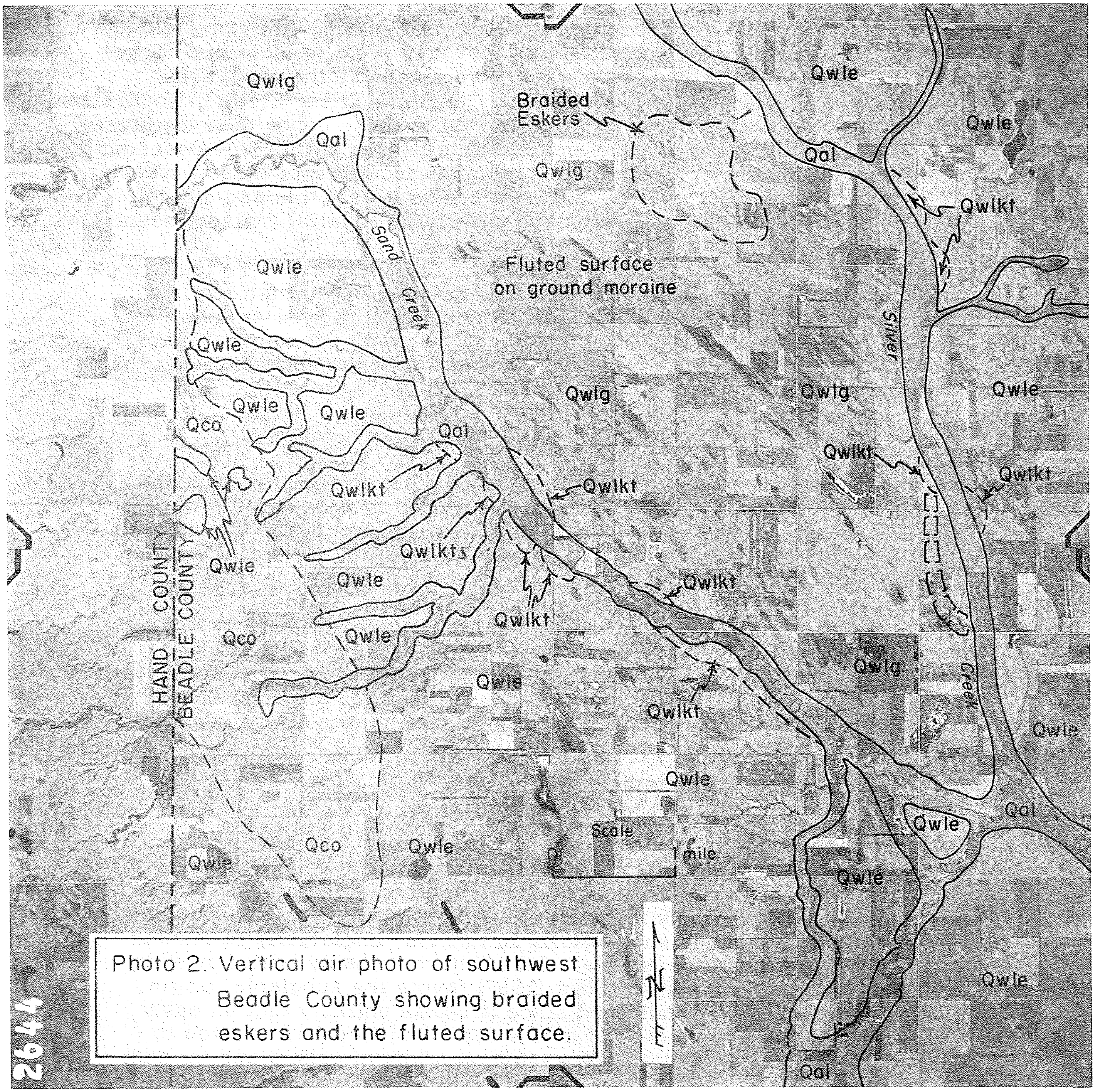

Photo 2. Vertical air photo of southwest Beadle County showing braided eskers and the fluted surface.

Kame terrace

A kame terrace is a body of ice-contact stratified drift that was deposited between ice and a confining hill or valley wall. The important factor distinguishing a kame terrace is that it is not a remnant of a former valley fill, but that it was never much more extensive than at present.

Kame terraces are present along Sand Creek and Silver Creek in southwestern Beadle County (pl. 1). The material in these deposits is mainly silt with minor amounts of sand and clay interbedded with a heterogeneous mixture of sand, gravel, and cobbles. The surface form of these terraces is not conspicuous because the deposits are relatively thin and did not completely mask the topography of the underlying material. Also, recent erosion has somewhat modified the terraces.

Another kame terrace is present in secs. 23, 26, and 27, T. 112 N., R. 60 W. along Shue Creek. The material comprising this terrace is a boulder-cobble gravel about 3 to 5 feet thick. The internal structure of part of this terrace was observed and clearly showed the material draped over the lip of the valley wall and dipping at about the same angle as the underlying till which comprises the valley wall.

Kames

Kames are hills formed either singly or in groups, and are composed of ice-contact stratified drift. Kames are formed from deposition in openings within a glacier or as alluvial fan-like structures at the ice margin.

In Beadle County five definite kames were mapped. Two of these are in the northwest part of the county; one at the junction of secs. 11, 12, 13, and 14, T. 113 N., R. 65 W. and the other in secs. 8 and 17, T. 112 N., R. 65 W. (pl. 1). Both of the kames are low-rounded hills 10 to 20 feet high and are nearly ovate in plan view.

A series of 3 kames is present 3 miles northeast of Huron in secs. 15 and 22, T. 111 N., R. 61 W. (pl. 1). These features are cone shaped, 15 to 20 feet high, and are roughly ovate in plan view. These kames are composed of poorly sorted coarse sand and fine gravel.

Eskers

An esker as defined by Flint (1957, p. 152) is, "...a long narrow, ice-contact ridge commonly sinuous and composed chiefly of stratified drift." The form of an esker may be compound, braided or reticulated and some eskers may connect downstream with fans or deltas.

Eskers may be formed subglacially in tunnels, englacially in tunnels or in superglacial stream valleys. Eskers have probably been formed by all three processes; however, Flint (1957) favors the subglacial origin. Near stagnation is also indicated since it seems unlikely that an esker would be preserved in an area of active ice. The reader is referred to Flint (1957) for more detailed discussion on origin of eskers and for additional references.

The only definite eskers in Beadle County are a series of braided eskers in secs. 10, 11, 14 and 15, T. 110 N., R. 65 W. These features are easily distinguished on air photos although they are less conspicuous on the ground (photo 2). The series of eskers is situated in a group 1 mile in length and half a mile wide, and is oriented northwest-southeast. The maximum height of any individual ridge is 15 feet. A test hole located in the NW corner sec. 14, T. 110 N., R. 65 W., showed gravel to a depth of 15 feet, suggesting that the maximum height is also the maximum thickness of the esker deposit.

Undifferentiated ice-contact deposits

Undifferentiated ice-contact deposits are found randomly throughout the county as small isolated hills, ridges or mounds that probably were formed as ice-contact features but which cannot be positively identified as kames or eskers. These deposits are small in extent and are not conspicuous landforms. They usually contain poorly sorted sand and gravel intercalated with blocks of till.

The best example of undifferentiated ice-contact deposits is in T. 113 N., R. 65 W., where several small deposits are shown on the geologic map (pl. 1).

Outwash

Landforms representing outwash deposits in Beadle County are valley fill, outwash plains, and terraces.

Valley-fill outwash

Valley-fill deposits are confined within the valley walls; the term excludes Recent sediments and ice-contact drift. These deposits exhibit a flat to slightly undulating surface.

Much of the material comprising the valley-fill outwash was undoubtedly deposited as valley-train deposits (outwash deposited in a pre-existing valley), but may also include other types of stratified drift of uncertain origin. Valley-fill outwash is found in most of the present stream valleys in Beadle County with the exception of the James River, which is a special case and will be discussed under landforms associated with glacial Lake Dakota.

In the valleys east of the James River the valley-fill outwash generally does not exceed 10 feet in thickness and is covered with Recent alluvium. The valleys west of the James River contain up to 40 feet of valley-fill deposits and may be covered with Recent alluvium. The valley-fill deposits generally are coarse sand to fine gravel, although locally, finer or coarser material may predominate.

At several locations, test holes drilled in the valley floors have penetrated stratified drift to a greater depth than was previously mentioned. Where this occurs (see west part of cross sections A-B and G-H, pl. 3) evidence indicates that the valley-fill deposits directly overlie older stratified deposits which were exposed during valley downcutting and thus do not represent valley fill associated with the existing valley.

Outwash plains

Outwash plains are underlain by sediments deposited outward from an ice sheet by meltwater streams. In Beadle County, outwash plains are formed in topographic lows partly confined by end moraines or in topographically low areas within end-moraine complex.

The nearly continuous outwash plain west of the James River extends southward from Broadland to within one-quarter mile of the Sanborn County line (pl. 1). Local relief of this plain is generally less than 10 feet, except where dissected by drainages or where an end-moraine knob protrudes through the sediments. Although local relief is small, the outwash plain is slightly undulating throughout much of its extent. The undulations probably represent the topography of the underlying till surface.

That part of the outwash plain from Huron northward generally has sand and fine gravel at the surface, whereas south of Huron, silt commonly is the surface material. Locally throughout the area, silt, sand, gravel, or small patches of till may be at the surface. The maximum thickness of the outwash is 30 feet, and the average thickness is 10 to 15 feet. The small outwash-plain deposits mapped east of the James River are mostly sand and fine gravel. Paralleling the east side of the James River from Huron southward in a band 1 to 4 miles wide are scattered exposures of sand and fine gravel up to 5 feet thick. The erratic distribution and small areal extent of these deposits made mapping them impractical; however, their presence suggests that a more extensive outwash plain may have once existed in this area.

Outwash terraces

Outwash terraces are remnants of former depositional sites for glacial outwash material. Subsequent downcutting of streams has left these nearly level surfaces above the present valley floor.

Outwash terrace deposits are present in northeastern Beadle County along Shue Creek and its tributaries (pl. 1). The largest terrace is in sec. 17, T. 113 N., R. 59 W., and covers nearly one square mile. Most of the terraces, however, cover less than 40 acres. The outwash terraces are nearly flat and are underlain by as much as 20 feet of fine sand to coarse gravel.

Landforms Associated with Glacial Lake Dakota

Glacial Lake Plain

The glacial lake plain associated with Lake Dakota is a nearly flat surface underlain by glaciolacustrine sediments carried to the lake by glacial meltwater. The meltwater collected in a regional basin, which was dammed partially by ice and partially by glacial drift.

The plain of glacial Lake Dakota (Todd, 1885, p. 393) is present in north-central Beadle County covering an area of approximately 70 square miles (pl. 1). The lake plain is nearly level, except where cut by recent drainages, where knobs of till protrude through the lake sediment, and in the Lake Byron channel. Most of this lake plain in Beadle County is underlain with sediments consisting of fine to medium sand. Locally, well-sorted gravels are present and toward the extreme southern end of the lake plain, silt and fine sand are the major deposits. The maximum known thickness of these deposits in Beadle County is 15 feet and the average thickness is about 5 feet.

Flint (1955) recognized those glaciolacustrine deposits north of Lake Byron as forming part of an early southeast embayment of Lake Dakota. The glaciolacustrine deposits south of Lake Byron (pl. 1) are included with the southeast embayment deposits in this report.

James River Trench

The drainage of glacial Lake Dakota released a large volume of meltwater quite rapidly. The erosive energy of this meltwater was responsible for forming the James River trench (Flint, 1955), which is a steep walled, flat-bottomed trench 75 to 100 feet deep, one-half to three quarters mile wide, and now has been partially refilled with as much as 25 feet of alluvium. Flint (1955) attributes the lack of extensive terraces along the James trench to rapid and continuous downcutting.

Cut-Off Channel

A cut-off channel of the James River is situated at the north Beadle County line (pl. 1). This cut-off channel is at approximately the same elevation as the present James River floodplain and has a boulder-gravel floor on its upstream end. The cut-off channel was abandoned when downcutting reached the boulder-gravel and the meltwater was unable to carry away this coarse material. Downcutting and refilling of the James River trench continued in its present position.

James River Terrace

Another feature associated with the drainage of Lake Dakota is a terrace 3 miles long, half a mile wide, and 35 feet above the present floodplain. The terrace is about 2 miles northeast of Huron and parallels the west edge of the James River trench (pl. 1). The floor of this terrace is a boulder-gravel about 3 feet thick. It appears that this terrace was cut to its present level by the Lake Dakota drainage waters and was then abandoned and the trench downcutting continued in its present position.

Meltwater Channels

Meltwater channels are valleys or trenches cut by the meltwater from a glacier. A meltwater channel forms outward from the margin of a glacier or along the ice front; in the latter case the channel is an ice-marginal meltwater channel partially outlining the former edge of the glacier.

The generally arcuate pattern of the present drainages is in close alignment with end moraines and the present streams are underfit. These two features strongly indicate that the streams originated as meltwater channels.

Occasionally one or both ends of a meltwater channel ends abruptly in glacial drift and has little or no relationship to the present drainage system. This form of channel was obviously short lived and ceased to carry meltwater after a minor change in the position of the ice margin. This type of feature is characterized at present by a trench which contains no active stream but usually contains a large slough or series of smaller ones.

In Beadle County several of the short-lived meltwater channels are present; the most conspicuous one being in the west-central part of the county (pl. 1). The headwater of this channel is in the northeast corner of T. 112 N., R. 64 W. From here it trends southward for a distance of 6 miles, ultimately terminating at Cain Creek. The channel is about one-quarter mile wide and 10 to 20 feet deep, and has a relatively flat floor. Part of the channel floor is composed of laminated silt; elsewhere the floor is till, sand and gravel, or alluvium. Examples of other small meltwater channels are 3 miles northeast of Huron and 6 miles west of Virgil (pl. 1).

Partially Buried Drainages

Former drainages which are partly buried by glacial drift have been recognized in Beadle County. One of these channels is the Lake Byron channel which is the east-west trending bedrock low in northern Beadle County (pl. 2). Its persistence throughout much of Pleistocene time is recorded in the erosional and depositional cycles indicated from drill-hole information. The surface expression of this channel is an east-west trending trench more than 50 feet deep in north-central Beadle County which now contains Lake Byron. The maximum width of the trench is about 2 miles in a north to south line across Lake Byron. West of the James River the trench abruptly loses its surface expression, while to the east the trench gradually loses its surface expression.

Lake Cavour also overlies a former bedrock channel and probably represents a partially buried drainage.

What may be another partially buried drainage is present southeast of the east end of the Lake Byron channel (pl. 1). This former channel is represented by a series of discontinuous depressions up to 25 feet deep which now contain small lakes or sloughs. The southernmost depression ends abruptly against glacial drift in the same manner as the meltwater channel previously described. No evidence of bedrock control was found associated with this partially buried drainage and it therefore may be a partially buried glacial meltwater channel.

GEOLOGY OF SURFICIAL DEPOSITS

The surficial deposits of Beadle County include all the unconsolidated material overlying the bedrock. The thickness of the surficial deposits range from zero, where bedrock is at the surface, to more than 450 feet in the Lake Byron channel. A generalized section of the surficial deposits is shown in table 2 and their areal distribution is shown on plate 1.

Quaternary System: Recent Series

Recent sediments in Beadle County are those which have been deposited since the area was deglaciated approximately 11,000 years ago. The older Recent deposits probably started accumulating immediately after the area was deglaciated and continuous deposition has continued to some degree up to the present time. The Recent deposits in Beadle County are colluvium, eolian (windblown) sand, and alluvium.

Colluvium

Colluvium, as defined by the Glossary of Geology and Related Sciences (Howell, 1957), is "A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff and brought there chiefly by gravity." For the purpose of this paper the definition is expanded to include deposits brought to the foot of a slope by running water and wind as well as gravity.

In Beadle County two types of colluvium are found. The first type of colluvium is found in the southwest corner of the county paralleling the Coteau du Missouri as a discontinuous colluvial apron as much as $1\frac{1}{2}$ miles wide (pl. 1). The colluvium is composed almost entirely of reworked till, is dark colored and contains gravel, sand, silt and clay, and is poorly stratified to unstratified. This deposit attains a thickness exceeding 5 feet.

The second type of colluvium is found in the James River trench. This deposit consists of sandy silt and resembles the fine outwash plain deposits on the adjacent uplands. The exact origin of these deposits is unknown, but they may owe their origin to slope wash and wind. These deposits could also be remnants of material deposited by meltwaters from glacial Lake Dakota in late Wisconsin time.

Eolian Sand

Eolian sand is composed of sand particles which have been transported and deposited by the wind. In Beadle County eolian sand is present as a thin, nearly continuous mantle on glacial till in a 10-square mile area southwest of Hitchcock and in other smaller areas throughout the county (pl. 1). The maximum thickness is about 5 feet, and the average is about 3 feet thick. In most cases the sand contains clay, silt and pebbles probably derived from the underlying till and mixed with the sand through cultivation.

Table 2.--Generalized geologic section of the surficial deposits of Beadle County, South Dakota.

Age			Deposit	Thickness (feet)	Description
Recent			Alluvium	0- 25	Silt and clay, gray to black, stratified; may contain minor amounts of sand and gravel; fossiliferous.
Pleistocene and Recent			Eolian sand	0- 5	Sand, fine to medium, silty; slightly frosted; usually dark colored.
Pleistocene and Recent			Colluvium	0- 5+	Silt and clay containing pebbles; reworked till along Coteau du Missouri. Silt, clayey, locally sandy, yellow; in James River trench.
Pleistocene	Wisconsin	Late	Lacustrine deposits	0- 15	Silt, yellow, laminated, and fine, well-sorted gravel.
Pleistocene	Wisconsin	Late	Surface outwash	0- 30	Gravel, sand, silt and some clay, stratified, moderately well-sorted; average thickness about 10 feet.
Pleistocene	Wisconsin	Late	Till	0-150 (?)	Boulder clay, yellow where oxidized, olive-gray to blue-black where unoxidized; locally contains sand and gravel lenses; average thickness about 50 feet.
Pleistocene	Wisconsin	Early	Till and buried outwash	0-220	Boulder clay, olive-gray and sand and gravel, upper few feet oxidized in several test holes; crops out in Lake Byron channel and James River trench.
Pleistocene	Wisconsin	Early	Lacustrine sand	0- 90	Sand, fine to coarse, horizontally and cross bedded; contains much lignite and organic debris.
?			?	?	? ?
Pleistocene	Pre-Wisconsin		Lacustrine silt	0-400	Silt, dark-gray, contains thin beds of fine sand and clay; composed chiefly of detrital Pierre Shale and Niobrara Marl; clay content increases downward.
Pleistocene	Pre-Wisconsin		Buried outwash and till	0- 13	Clay, dark-gray, shale pebbles, and gravel.

An outwash valley west of Hitchcock now partially covered with alluvium was the likely source of sand for the sandy area southwest of Hitchcock. Most of the eolian sand is situated east of the valley, indicating that the predominant wind direction was from the west. A northward extension of this same valley in Spink County (sec. 36, T. 114 N., R. 64 W.) has sand thick enough to form dune topography. The undulating topography of the eolian-sand area in Beadle County is a reflection of the underlying end-moraine ridge paralleling the east side of this valley.

Alluvium

Alluvium is found in stream valleys and beds of lakes and sloughs (pl. 1). It consists of dark-brown to black clay and may contain a high percentage of silt; sand and gravel, however, are minor constituents.

In the James River floodplain, alluvium attains a maximum thickness of 25 feet. The smaller tributary streams locally contain alluvium up to 10 feet thick but the alluvium averages about $2\frac{1}{2}$ feet thick.

Several areas near Lake Byron contain as much as 10 feet of alluvium. These areas are now sloughs or under cultivation and probably represent lacustrine sediments deposited when Lake Byron was at a higher stage late in the Pleistocene Epoch or early Recent time.

Gastropod and pelecypod shells were observed in many exposures of alluvium. Two of the most conspicuous occurrences were in NW$\frac{1}{4}$SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 20, T. 113 N., R. 60 W. in a dugout and in NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 14, T. 113 N., R. 62 W. in a cut in the James Valley floodplain opened during construction of a dam on the James River.

Quaternary System: Pleistocene Series

During Pleistocene time four major glacial invasions occurred on the North American continent. These are oldest to youngest: Nebraskan, Kansan, Illinoian and Wisconsin. Deposits of Kansan and Nebraskan age have long been recognized in western Iowa (Kay and Apfel, 1929) and eastern Nebraska (Lugn, 1935) and more recently in South Dakota (Steece, Tipton and Agnew, 1960). Because of their presence to the south it is inferred that the corresponding ice sheets may have once glaciated Beadle County. The third major invasion, the Illinoian, is inferred to have covered Beadle County by Warren (1952) and Flint (1955) who suggest that the diversion of part of the Missouri River occurred during the Illinoian Glaciation. White (1964), however, dates the Missouri River as early Wisconsin in age. Studies in the southeastern part of the State indicate the presence of a glacier in that area during Illinoian time (steece, 1959a, b; Tipton, 1959a, b; Steece, Tipton and Agnew, 1960; Tipton, 1960; Steece, 1965; and Christensen and Stephens, 1967).

More knowledge of the deposits from the Wisconsin Glaciation exists than for deposits of any of the other glaciations. It has long been recognized that the deposits of the Wisconsin Glaciation could be subdivided. However, a standard subdivision which fits one region has generally been found to be unusable for other areas. This fact has become increasingly evident with the advent of radiocarbon dating.

There are relatively few radiocarbon dates in South Dakota at present; certainly there are too few dates to allow acceptance of any present time-stratigraphic classification. The South Dakota Geological Survey currently is mapping drift borders and associated deposits and numbering each major Wisconsin ice advance in the order which it occurred. As further detailed stratigraphic and geomorphic information and additional radiocarbon dates become available, the glacial deposits in South Dakota may eventually be placed in an acceptable time-stratigraphic classification.

Nomenclature and Age Determination

Flint (1955) mapped the glacial deposits of eastern South Dakota using Leighton's (1933) classification. The basis for using Leighton's subdivision evolved from the recognition of four glacial units which were judged to have substage[1] significance and:

> "Because the number of subdivisions is the same as those recognized as standard farther east, and because they are of the same order of magnitude, namely, of the order of substages, the four Wisconsin drift sheets in South Dakota are believed to be the approximate correlatives of the four standard substages of the Wisconsin stage." (Flint, 1955, p. 77)

The four substages in South Dakota which Flint recognized are, oldest to youngest, Iowan, Tazewell, Cary and Mankato Substages. The Valders Substage has been used for a fifth glacial substage outside of South Dakota.

Although Flint recognized four Wisconsin substages in South Dakota, the only significant stratigraphic break demonstrated within the Wisconsin Stage was the Tazewell-Cary interval. The Tazewell and older drift is nearly devoid of undrained depressions and has a well-integrated drainage pattern, whereas the Cary and younger drift are poorly drained and have many closed depressions. Stratigraphic evidence suggesting a significant Tazewell-Cary break is the presence of dark humified soil zones accompanied by weathering profiles developed in loess and overlain by loess, leached eolian sand, and peat. The stratigraphic and morphologic evidence for the Iowan-Tazewell and Cary-Mankato break suggests a much shorter time interval than the Tazewell-Cary break.

Deposits in South Dakota identified by Flint as Mankato in age were traced into South Dakota by him from the type area of occurrence of the Mankato drift near Mankato, Minnesota. Wright and Rubin (1956, p. 625)

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[1] The Code of Stratigraphic Nomenclature, Article 40, suggests the use of glaciation and interglaciation as fundamental units of geologic-climate classification. Stade and interstade are subdivisions of glaciation. In the following discussion the term substage is synonymous with stade and is used as employed in the literature of the time the cited articles were written.

pointed out that Lake Agassiz radiocarbon dates indicate a pre-Valders age for the Des Moines lobe and thus for the drift at Mankato, Minnesota. They therefore correlated the drift at the town of Mankato with the Cary (pre-Two Creeks) rather than with the Valders (post-Two Creeks).

Radiocarbon dates in South Dakota (fig. 3) from the "Mankato" and "Cary" drift sheets are about the same age. In addition, no significant stratigraphic breaks have been found separating these two drifts in South Dakota. Thus, it appears that the Mankato and Cary (of Flint) in South Dakota are really "Cary" as originally used by Flint.

The use of the term Cary as an age designation in South Dakota is questionable, however, because the Cary drift in Illinois (at the type locality) is older than the known Cary drift of both the Des Moines and James lobes and may represent an older drift. Thus, in order to avoid confusion over the use and meaning of the term Cary, the South Dakota Geological Survey has informally divided the Wisconsin Stage into early and late Wisconsin Substages (Lemke and others, 1965). Table 3 shows how this classification compares with other classifications for the Wisconsin Stage and it is the basis of classification of Wisconsin deposits used in this paper.

In the classification for the Wisconsin Stage in South Dakota (Lemke and others, 1965) the major Wisconsin ice advances were assigned a number in order of deposition. Number one advance represents Iowan and/or Tazewell (Flint, 1955) deposits undifferentiated. In the new classification these undifferentiated deposits are called early Wisconsin. Advances two, three and four (Cary-Mankato of Flint) represent late Wisconsin advances. According to Lemke and others (1965) all the surficial deposits in Beadle County would probably be the result of number two late Wisconsin advance. However, recent studies in Campbell County (Hedges, in preparation) show that advance number three is more extensive in that area than indicated by Lemke and others, and probably covered all of Beadle County during its maximum extent. Thus, this paper treats all the glacial deposits at the surface in Beadle County as being the result of late Wisconsin major advance number three.

A generalized section of the Quaternary deposits is shown in table 2, and plate 1 shows their distribution where they are present at the surface.

Pre-Wisconsin Deposits

None of the Pleistocene deposits in Beadle County can with certainty be called pre-Wisconsin in age; however, stratigraphic relations suggest that a thin basal till and outwash unit and an overlying lacustrine silt unit in the Lake Byron channel may be of pre-Wisconsin age. The pre-Wisconsin deposits are confined to a limited area in north-central Beadle County very closely approximating the trace of the longitudinal cross section in the Lake Byron channel (pl. 4).

The basal till and outwash lie on bedrock and consist of gravelly till and some gravel with a maximum known thickness of 13 feet in test hole 113-62-27aaaa. Samples from this test hole were poor so description of the basal till is given from test hole 112-62-2abbb.

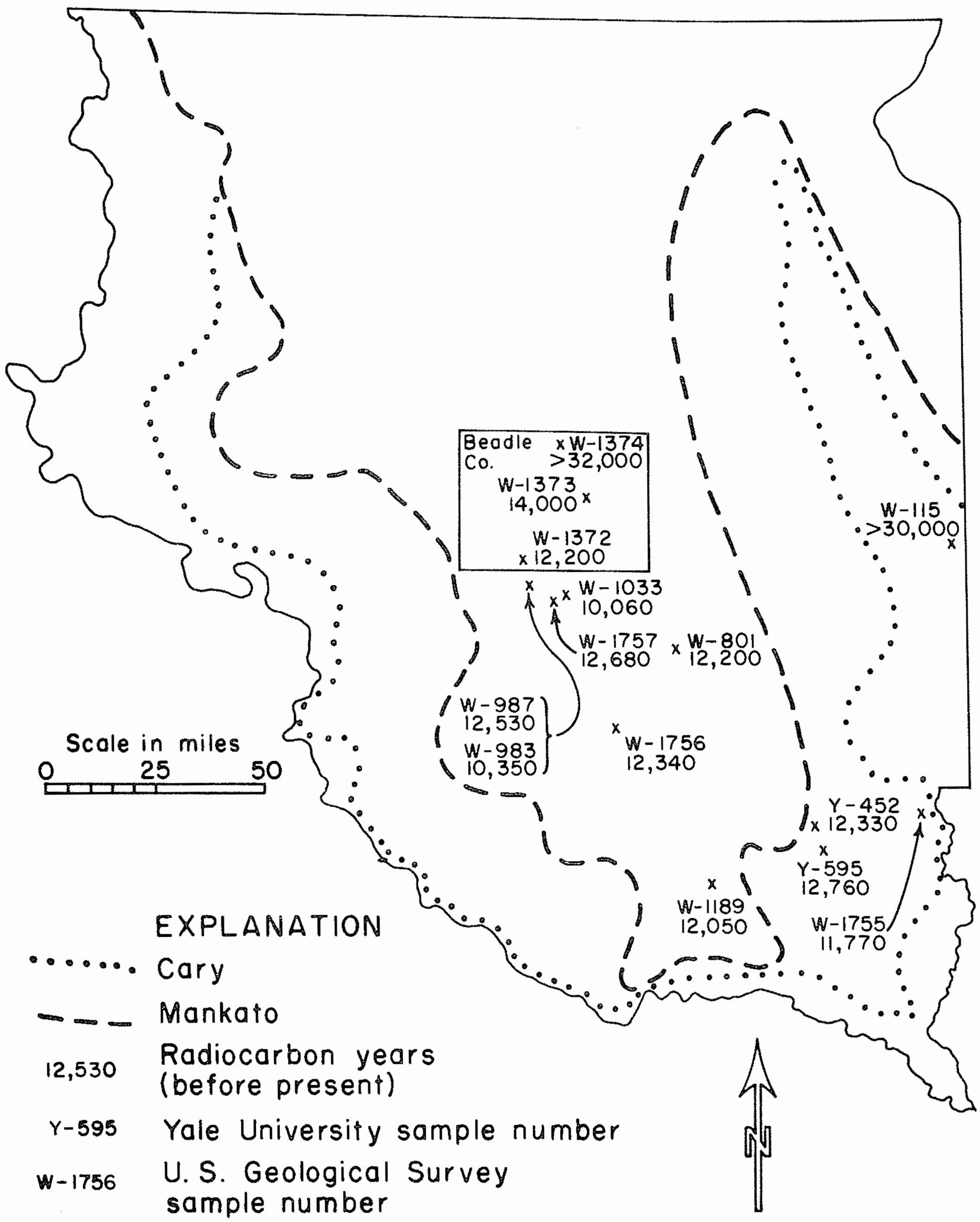


Figure 3. Map of eastern South Dakota showing Cary and Mankato drift borders of Flint (1955) in relation to radiocarbon dates.

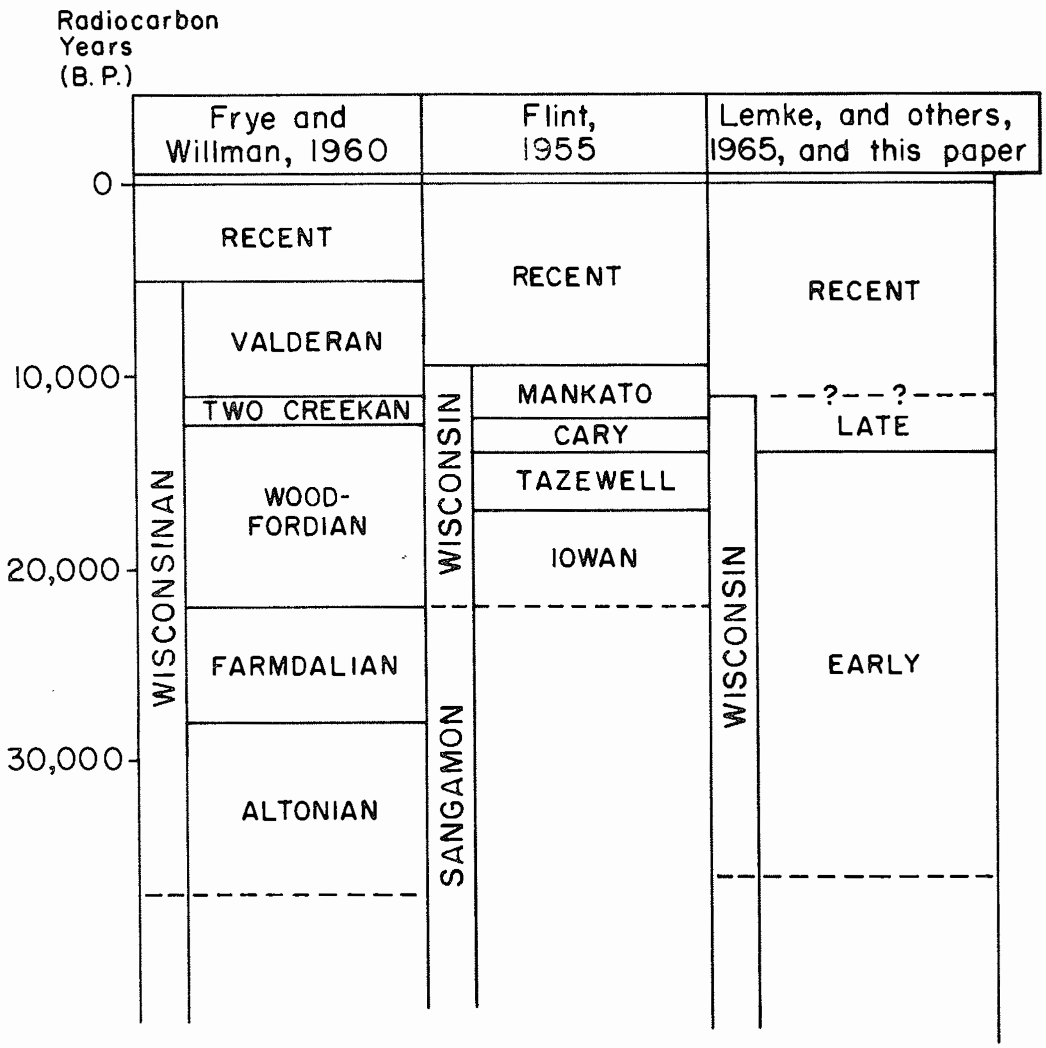


Table 3. Chart showing various Wisconsin classification and the classification used in this report.

Description	Feet
Clay, black, very sandy, very gravelly; abundant black shale pebbles; rocks at 115 and 116 feet	113-116

Although this basal till and outwash may be more prevalent than now recognized in test holes, it cannot be differentiated lithologically from younger tills, so at present its distribution is inferred only where it underlies the pre-Wisconsin lacustrine silt unit.

The lacustrine silt unit consists of as much as 400 feet of clayey to sandy silt and is confined to the Lake Byron channel area. The lower part of the unit is clayey and is composed predominantly of detrital bedrock material with some quartz grains present. The upper part of the silt unit has fine sand interbedded with a sandy silt. Upwards in the unit the quartz content increases and the bedrock detritus decreases. Fragmental lignite is disseminated throughout the section, but is more abundant near the upper part. Thin gravel lenses are present but are not common. Laminations are visible in rotary-drill cuttings and in cored intervals from test hole 113-62-27bbbb.

The southernmost occurrence of the lacustrine silt unit is in test hole 112-62-13bbbb and the easternmost extent of these sediments is in test hole 113-60-20daaa. Their extent to the northwest into Spink County has not been determined.

The longitudinal section of the Lake Byron channel (pl. 4) shows the stratigraphic relationship of the pre-Wisconsin deposits (unit 3) and the younger deposits (units 1 and 2). The lacustrine silt unit occupies the deeper portions of the bedrock channel and directly overlies bedrock or a thin basal till and outwash. In test hole 113-62-27bbbb the lacustrine silt unit was encountered at a depth of 60 feet and was not completely penetrated at a depth of 450 feet, giving a minimum total thickness of 390 feet. This same test hole provides the lowest bedrock elevation in Beadle County which is less than 845 feet above sea level. The lowest bedrock elevation in the bedrock channel thus is yet to be determined.

The age of the basal till and outwash and the overlying lacustrine silt unit is judged to be pre-Wisconsin in age from the following evidence:

(1) The presence of the basal till and outwash underlying the lacustrine silt places the deposits within the Pleistocene Epoch.

(2) The pre-Wisconsin deposits underlie early Wisconsin glacial deposits. In test hole 113-61-34adad the lacustrine silts underlie two buried oxidized zones (see pl. 4). The upper oxidized zone marks the early-late Wisconsin boundary and the lower oxidized zone may mark the pre-Wisconsin-early Wisconsin boundary.

(3) A significant time lapse is indicated by the unconformity between pre-Wisconsin and early Wisconsin deposits as suggested by as much as 200 feet of downcutting before deposition of the early Wisconsin drift (see pl. 4).

(4) A peaty material from the upper part of the overlying early Wisconsin lacustrine sand (unit 3, pl. 4) gave a radiocarbon date of greater than 32,000 years before present (W-1374) (Levin and others, 1965) which makes these deposits at least as old as the early Wisconsin.

The limited stratigraphic evidence now favors a pre-Wisconsin age for the basal till and outwash and the lacustrine silt unit, although an early Wisconsin age cannot be precluded. No other pre-Wisconsin deposits have been discovered in the central James Basin region nor have similar deposits been described elsewhere in South Dakota outside of Beadle County, so these sediments cannot be correlated with any particular pre-Wisconsin stage.

In Stutsman County, North Dakota, Winters (1963, p. 35) described deposits from the James Valley which are lithologically similar to the lacustrine silt in Beadle County. In North Dakota these deposits occupy a deep bedrock channel which may be a northward extension of the same drainage present in northern Beadle County. Winters postulates that the thick lacustrine sequence may have accumulated in a deep bedrock drainage system which was dammed by ice to the north. The thick lacustrine sequence in Beadle County probably had a similar origin.

Early Wisconsin Deposits

As much as 220 feet of early Wisconsin till and outwash underlie the late Wisconsin drift and is present throughout much of Beadle County. The thickest deposits of early Wisconsin drift are found in the bedrock channels. The early Wisconsin drift may be absent locally or where the bedrock is at or near the surface of the ground. Plates 3 and 4 show the stratigraphic relationships of the early Wisconsin deposits and indicate their general continuity.

The exposed early Wisconsin till is buff colored, sandy, and is very similar in appearance to the late Wisconsin till exposed over the western two-thirds of Beadle County with the exception that it is slightly more compact. Its appearance and physical characteristics, however, are markedly different from the late Wisconsin till exposed in the eastern portion of the county as can be seen from the following description of the Lake Byron stratigraphic section.

LAKE BYRON SECTION

Silage pit cut, south bank of small tributary, north edge of Lake Byron channel, NW$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 15, T. 113 N., R. 60 W.

Late Wisconsin: drift C

3. Till, weathered to a dark blue-gray, blocky, calcareous; contains abundant shale fragments; finely jointed, joint faces stained reddish-brown or black; abundant finely disseminated selenite crystals---------------------- 3 to 5 feet

Boulder Pavement:

2. Boulders, upper surface planed flat and indistinctly striated; composed mostly of soft metamorphic rocks or coarse-grained igneous rocks up to 18 inches in diameter; the flat side of the boulders coincide with the top of the underlying till-------------------------- 1 foot

Early Wisconsin:

1. Till, weathered light-yellowish brown, pebbly and silty; massive and more compact than overlying till; no soil or leached zone present at upper surface; upper one foot contains boulders of boulder pavement-------- 3 feet

Total 6 to 8 feet

In test-hole cuttings the unweathered early Wisconsin till cannot be readily distinguished from older or younger tills. Subsurface correlation is made because the till underlies a buried oxidized zone or is correlated by inferred stratigraphic position.

The early Wisconsin outwash consists mostly of coarse sand and gravel. The outwash is composed of three groups of rocks: (1) igneous and metamorphic, (2) sedimentary (mostly carbonates), and (3) local sedimentary rock types such as the Pierre Shale and the Niobrara Marl. Rocks of the first two groups are present in about equal proportions and predominate over the local rock types. The percentage of local rock types and quartz sand is usually greater in the finer portions of the outwash. The maximum thickness of early Wisconsin outwash is 220 feet in test hole 113-60-20daaa (pl. 4).

A lacustrine (?) sand unit is present in north-central Beadle County. The distribution of this unit is essentially the same as the pre-Wisconsin lacustrine silt unit (see pl. 4 and cross section A-B, pl. 3). In the deep parts of the Lake Byron channel the sand unit directly overlies the lacustrine silt unit, whereas to the north the lacustrine sand overlies till which has an oxidized zone in its upper surface (test hole 113-63-1aaa, cross section A-B, pl. 3) and underlies late Wisconsin till. The lacustrine sand consists primarily of fine to coarse laminated sand and contains abundant lignite throughout; some thin gravel units may also be present. The average thickness of the lacustrine sand unit is about 40 feet. The Huron Colony section just north of the Lake Byron Channel is thought to contain part of this sand unit.

HURON COLONY SECTION

East bank of the James River trench, east end of dam, SE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 13, T. 113 N., R. 62 W.

Late Wisconsin:

3.	Silt, yellow, laminated, calcareous; upper 1 to 1$\frac{1}{2}$ feet recent soil (Lake Dakota silts)-----------	3 to 6 feet
2.	Till, oxidized light-yellowish brown, sandy----------	3 to 7 feet

Early Wisconsin:

1.	Lacustrine sand and gravel unit	
	a. Sand, fine, well-sorted, horizontally bedded thin beds composed of about 90 percent organic debris alternating with beds of clean fine sand; one dark organic bed 5 inches thick---------------------	4 feet
	b. Gravel, fine to medium, clean; cross bedded; sharp even contact with overlying sand; base of gravel covered--------------	2 feet
	Total	12 to 19 feet

A sample of the organic debris from unit 1 of the above section was collected and sent to the U. S. Geological Survey radioisotope laboratory in Washington for radiocarbon dating. The results gave an age of greater than 32,000 years before present (sample W-1374) (Levin and others, 1965).

The stratigraphic relationship of the lacustrine sand and gravel unit is uncertain at present. It cannot positively be correlated with the early Wisconsin buried outwash throughout the county nor can that part of the lacustrine sand unit which overlies till (cross section A-B, pl. 3) be positively correlated with the rest of the unit which directly overlies the pre-Wisconsin lacustrine silt as shown in cross section C-D (pl. 3) and in plate 4. However, the lacustrine sand unit occupies a stratigraphic position below the late Wisconsin drift similar to the early Wisconsin outwash, and is older than late Wisconsin as indicated by the radiocarbon date and the presence of an oxidized horizon in its upper surface (test hole 112-62-3bbab, cross section C-D, pl. 3). Therefore, the lacustrine sand unit is tentatively correlated with the early Wisconsin drift.

The early Wisconsin outwash is buried beneath an average of 35 feet of late Wisconsin drift, except for possible areas of small extent in the Lake Byron channel where it may be exposed. Plate 1 (Howells and Stephens, 1967) shows the thickness and distribution of saturated sand and gravel. The sand and gravel included on this figure does not show the less permeable outwash deposits and it may locally include outwash of more than one age; however, it is a good approximation of the thickness and distribution of the buried early Wisconsin outwash. A close examination of the above-mentioned plate with plate 2 of this report illustrates the close relationship of the buried outwash deposits to the bedrock channels.

The buff, sandy till underlying the dark, clayey till in northeastern Beadle County, the till or tills (excluding the basal till underlying the pre-Wisconsin lacustrine silt) in the subsurface, and most of the buried outwash deposits throughout the county are early Wisconsin in age. Test holes shown on plates 3 and 4 (and other test holes not illustrated) show oxidized zones at the top or within the early Wisconsin drift. The buried outwash in Beadle County is traceable in the subsurface to Sanborn County where similar stratigraphic sections are shown and which Steece and Howells (1965) have called early Wisconsin. The buried early Wisconsin drift is correlated with the Iowan and Tazewell drift (undifferentiated) of Flint (1955).

Late Wisconsin Deposits

The evidence for dating all the surficial drift in Beadle County as part of number three late Wisconsin drift has already been presented. However, it has long been known that significant halts in ice recession or slight readvances have occurred within the major drift boundaries. This is shown in the recognition and mapping of the various named end moraines in South Dakota and adjacent states. The use of named end moraines has been abandoned in this paper, however, because of discrepancies introduced when tracing the end moraines in the Sanborn, Jerauld and Beadle County area. Flint's (1955, p. 119) subdivision of glacial advances has also been abandoned for the same reason.

Within the late Wisconsin substage in Beadle County the ice apparently halted four times during the process of deglaciation. Each of these halts is marked by an end moraine, or its position is inferred from other evidence. The distribution of drift which resulted from each of these halts is shown on figure 4. This same figure also shows the position of the outer margin of the ice associated with each drift. The various drifts are referred to simply as drift A, B, C, or D oldest to youngest and figure 5 shows how this designation of drift and drift borders correlates with designations used by Todd (1904a and b) and Flint (1955).

During the course of mapping the surficial deposits of Beadle County it soon became apparent that two distinct lithologic types of tills existed. One till weathers dark gray, is jointed, and the joint faces are stained reddish-brown to blue-black (Late Wisconsin: drift C, p.32). Secondary gypsum is often concentrated in the joints as well as being disseminated throughout the till. This till was determined to be present approximately northeast of the drift D (outer) line (fig. 4). The surface till west of this line generally is yellow, non-compact, sandy, lacking in joints and apparently contains fewer shale fragments. Three samples of the dark till and five samples of the yellow till were collected and analyzed in the

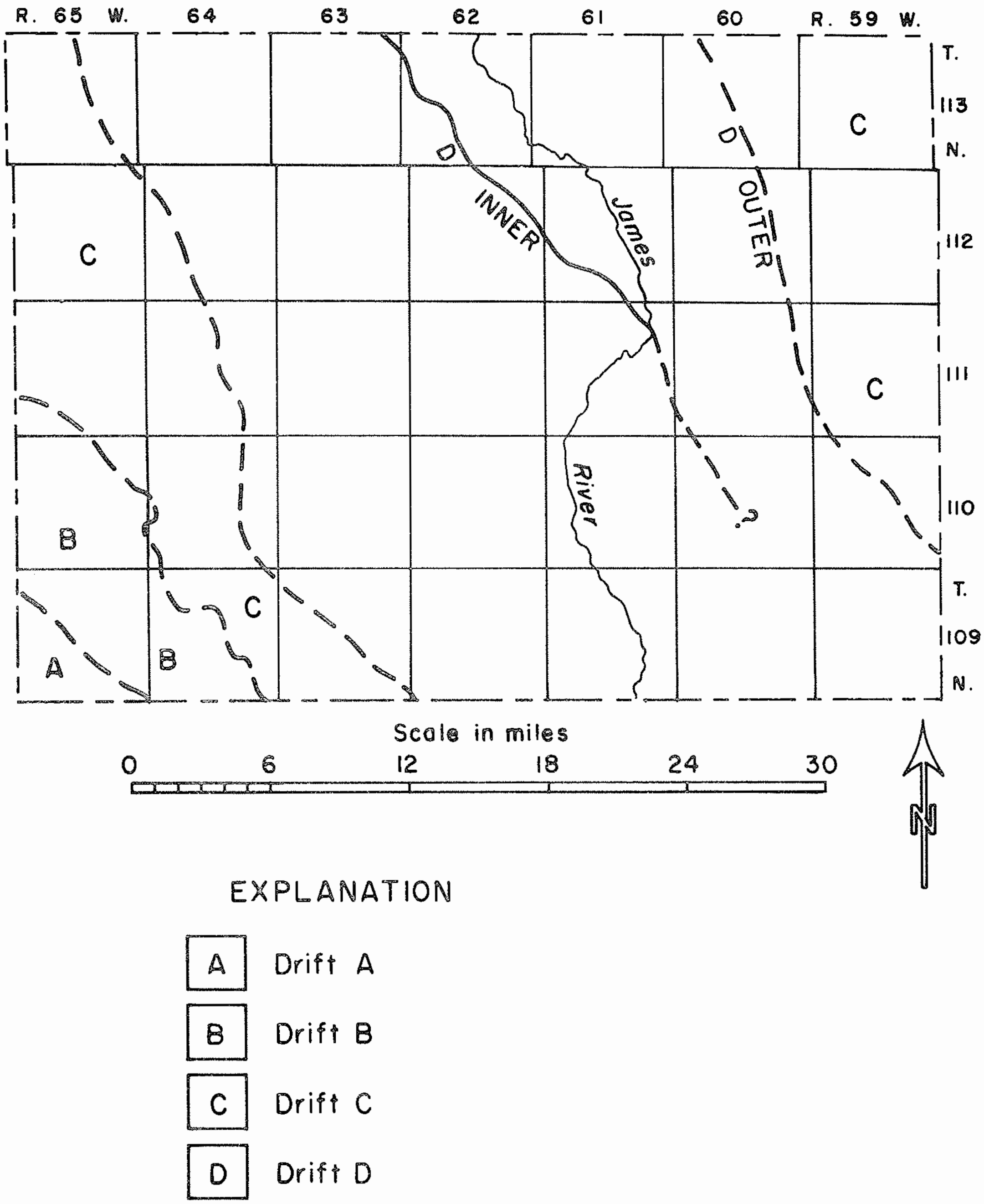


Figure 4. Map showing distribution of drifts A, B, C and D during late Wisconsin time in Beadle County.

<table>
<tr><th colspan="2">Todd (1904)</th><th>Flint (1955)</th><th>This Report</th></tr>
<tr><td>Antelope Moraine</td><td>3
2
1</td><td>B3</td><td>D</td></tr>
<tr><td rowspan="2">Gary Moraine</td><td>2</td><td>B2
B1</td><td>C</td></tr>
<tr><td>1</td><td rowspan="2">A3
A2</td><td rowspan="2">B</td></tr>
<tr><td colspan="2" rowspan="2">Altamont Moraine</td></tr>
<tr><td>A1</td><td>A</td></tr>
</table>

Figure 5. Diagram comparing various designations of ice margins in Beadle County used by Todd (1904), Flint (1955), and this report.

laboratory to determine the gross pebble composition and grain size. The results of these tests are shown in Hedges (1966). The dark till was found to contain nearly 50 percent local rock types (Pierre Shale and Niobrara Marl) and contains between 42 and 51 percent clay whereas the yellow tills have a maximum of 31 percent local rock types and a clay content ranging from 21 to 32.5 percent. These figures support the field observation that the dark till is shale rich as compared with the yellow till.

The surface distribution of the dark till in Beadle County corresponds closely with the distribution of the Beadle series soils (Watkins and others, 1924, map in pocket). Watkins concluded that the soils of this series were derived from a different parent material than the soils in the rest of Beadle County. Locally, patches of the buff till may be found at the surface northeast of the drift D (outer) limit. This is not the general rule, however, as field checking of road cuts and soil sample tests showed the dark till to be at the surface on the flat uplands between drainages as well as being exposed on the slopes adjacent to the drainages.

One stratigraphic section exposed the two late Wisconsin tills.

PEARL CREEK COLONY SECTION

Silage pit cut, east bank of Middle Pearl Creek, SW¼NE¼NE¼ sec. 21, T. 110 N., R. 59 W.

Late Wisconsin:

5. Outwash-alluvium: fine to medium silty sand, yellow-brown, massive; contains pebbles; resembles loess in weathered section---------------- 4 feet
4. Till, light-yellow brown, sandy and silty, (drift D)-- 3 feet
3. Boulder pavement, weakly developed; no striations on boulders, boulders up to 12 inches in diameter---------------------------------- 1 foot
2. Till, medium olive-gray, clayey, finely jointed, compact and tough; contains many shale fragments (drift C)---------------------- 3 feet

Cretaceous:

1. Clay, dark-gray, thin bentonite stringers (½-1 inch) and clay ironstone concretions; (undifferentiated Pierre Shale)----------------------- 1.5 feet

Total 12.5 feet

Todd (1909, p. 37) described a section which showed three tills superposed. In this section an upper yellow till (thought to be drift D) overlies a dark "gumbo-like" till (inferred to be drift C) which in turn overlies a boulder pavement on top of a buff till (probably early Wisconsin). This section is located about 1 mile west of the Lake Byron section and is within the drift D border. The section described by Todd is what a composite of the Lake Byron and Pearl Creek Colony sections would show. Unfortunately, the writer was unable to locate the section described by Todd.

The only late Wisconsin drift boundary which is determined by lithology is the one between drift D and C in eastern Beadle County. Although these drift units and drifts A and B are present in western Beadle County (fig. 4), they are not separable lithologically and are similar to drift D. Thus, the lithology of the late Wisconsin drift varies vertically and laterally. This phenomenon will be considered in more detail in the next section of this report which discusses the synthesis of Pleistocene geology.

Stratified drift is subdivided into many lithologic and landform units as already indicated in a previous section of this paper. When considered as a stratigraphic unit, stratified drift is actually just a part of a drift sheet. The detailed descriptions of the various stratified drift units are undertaken in the section of this paper describing glacial landforms and their associated deposits. Likewise, the late Wisconsin glaciolacustrine stratigraphic units are also discussed in this same section. Stratigraphically, the bulk of the late Wisconsin stratified drift and lacustrine deposits overlie the late Wisconsin till. As indicated on the geologic cross section (pl. 3) very little of the buried glaciofluvial and glaciolacustrine deposits are considered to belong to the late Wisconsin Substage.

In north-central and northeastern Beadle County, remnants of an extensive boulder pavement can be seen cropping out along most of the more deeply incised drainageways. In most cases the exposed boulders are no longer in place, but litter the slope below a certain nearly horizontal plane along the valley walls. Many of the boulders show direct evidence of contact with the ice in the form of planation and striations. One particularly well-developed boulder pavement with the boulders in place was found along Shue Creek in SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 26, T. 113 N., R. 60 W. Flint (1955, p. 58) gives a good description of this boulder pavement. Tentative conclusions of this writer are that the above-mentioned boulder pavement and remnants of others seen along valley walls in north-central and northeastern Beadle County are the contact of the early and late Wisconsin drift. The Pearl Creek Colony section (p. 37) also listed a boulder pavement which separates two late Wisconsin tills; however, this pavement is poorly developed and has not been observed as being widespread.

Striations on the Shue Creek boulder pavement uniformly range from S. 16 degrees E. to S. 21 degrees E. on undisturbed boulders. The very limited data indicates that the earlier late Wisconsin ice was probably expanding southeasterly at the location of the boulder pavement. This conclusion is in general harmony with the proposed direction of flow of ice in the James Basin during late Wisconsin times as deduced from the distribution of end moraines.

More detailed work is needed in eastern Beadle County and the surrounding area to provide additional insight into the stratigraphic relationship and significance of the two till lithologies, their ages, drift boundaries and the associated boulder pavements.

Synthesis of Late Wisconsin Glacial History

Drift A

From the very limited data now available it seems likely that the late Wisconsin ice advanced into South Dakota as much as 14,000 years ago. This date is supported indirectly by radiocarbon dates from the Des Moines lobe in northwestern Iowa which has produced many dates averaging 14,000 years from the basal late Wisconsin drift (Ruhe and Scholtes, 1959, p. 592). In Beadle County, pelecypod shells from lacustrine sediments stratigraphically lower than late Wisconsin till have been dated 14,000± 500 years before present (W-1373, Levin and others, 1965) which suggests a near maximum age for the late Wisconsin in South Dakota. Other dates in South Dakota from late Wisconsin deposits (Steece and Howells, 1965) give dates ranging between 12,050 and 12,760 radiocarbon years.

The deposits of the first late Wisconsin glacial advance in Beadle County (ice advance two of Lemke and others, 1965) were completely buried by advance three which probably also covered all of Beadle County. However, strongly developed end moraines in the extreme southwest portion of the county indicate that in this area the ice margin did not extend far beyond the county. Advance three built pronounced end moraines along much of its border outside of Beadle County. As the ice retreated to some unknown position, end moraine or ground moraine was deposited on the Coteau du Missouri slope in Beadle County. This is the drift referred to in this paper as drift A. Morphologic separation of the drift on the coteau slope is complicated by several factors:

(1) Much of the coteau slope may be only thinly veneered with drift as evidenced by several Pierre Shale outcrops (pl. 1) and several drill holes which show the Pierre Shale to be near the surface.
(2) The coteau slope is highly dissected by small drainages and thus many of the original features are destroyed.
(3) An apron of colluvium covers much of the lower slope of the coteau and possibly masks original constructional features. Following the retreat of the ice from the coteau slope, colluvium probably started collecting and may have been collecting while ice was still present in or near Beadle County.

Drift B

The ice that deposited drift B covered all of Beadle County except for 10 to 15 square miles in the southwest corner (fig. 6). During this time the ice was expanding laterally in the James lobe until it abutted the

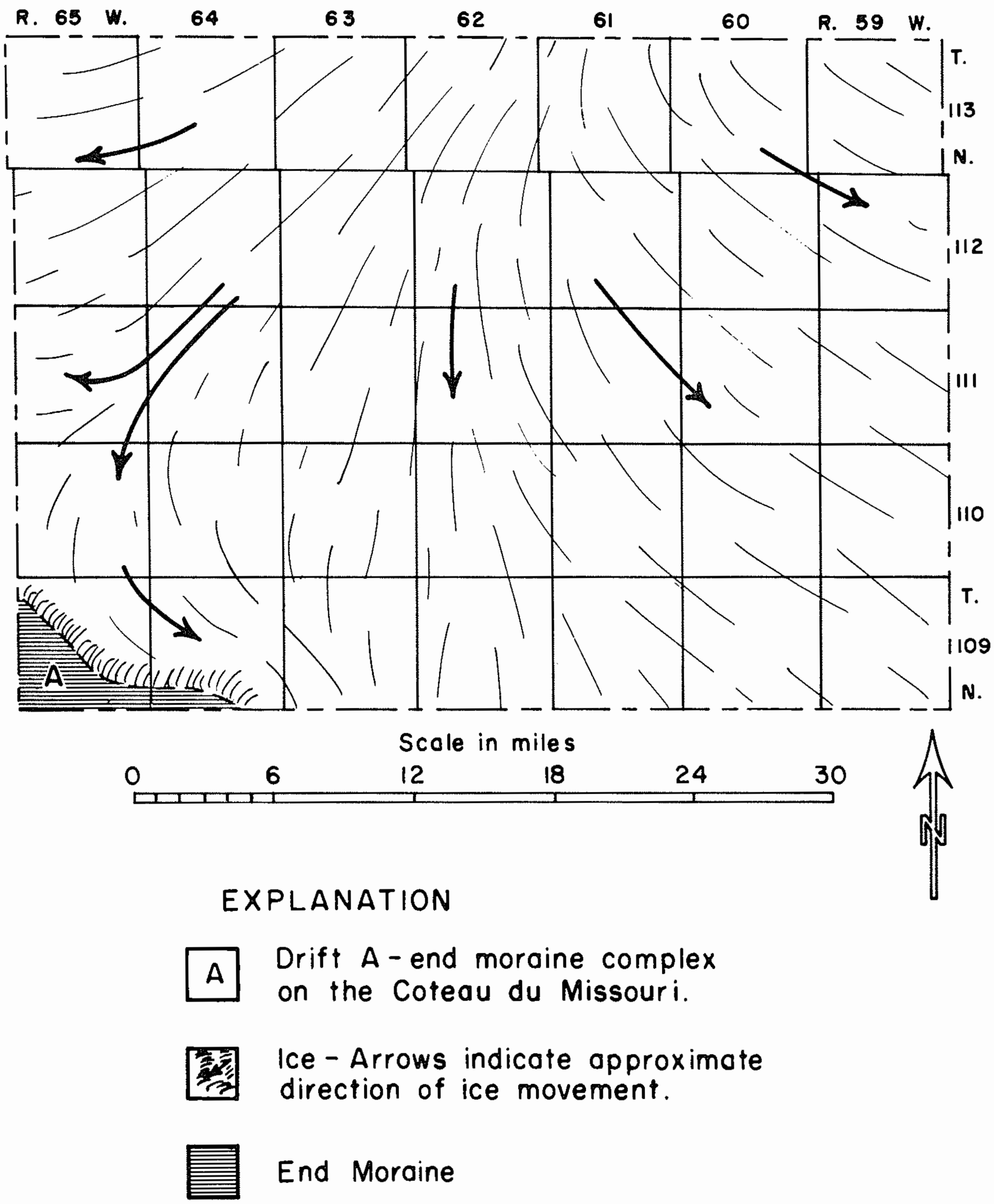


Figure 6. Map showing distribution of drift A and the ice during drift B phase of late Wisconsin time in Beadle County.

Coteau du Missouri escarpment. Being unable to override the coteau, a tongue of the ice moved locally in a southeasterly direction parallel to the coteau and deposited end moraine and ground moraine (fig. 7). The position of the outer margin of the ice is represented by a discontinuous series of end-moraine knobs in Beadle County which correlate with a strongly developed end moraine in Jerauld County. The emplacement of Firesteel Creek as an ice-marginal channel probably occurred during the ice maximum. The flutings on the ground-moraine surface represent deposition by active ice, and braided eskers and kame terraces on Sand Creek represent deposition by stagnant or near stagnant ice.

Drift C

The ice that deposited drift C covered all but 70 square miles in southwestern Beadle County (fig. 7). The boundary of this ice in Beadle County is not well defined. Its presence is inferred mainly from evidence just south of the Beadle County line where a well-developed end moraine was built between the outer margin of drift B and drift D, both of which are easily traced into Beadle County. Topography transitional between end-moraine complex and hummocky ridge make up most of the deposits of this drift. The series of hummocky upland end moraines (?) may represent a recessional feature of the ice that deposited drift C. In northeast Beadle County, drift C is represented by ground moraine and very poorly developed end-moraine complex which was deposited by the retreating ice (fig. 8).

Drift D

The western margin of ice that deposited drift D in Beadle County is fairly well defined by a series of discontinuous ridges along its outer margin (pl. 1) which are traceable into Sanborn County; there a well-developed end moraine is present. Further delineations of recessional positions of the ice along the western edge were not possible although minor fluctuations apparently did occur along the eastern margin of the ice.

On the east side of the lobe, the ice occupied a position approximated by the drift D (outer) line (fig. 8). As already indicated, this contact is based mainly on a lithologic break rather than on landform. Since the ice blocked westward-flowing drainages from the Coteau des Prairies, lacustrine sediments should have been deposited in or adjacent to these drainages. Lack of any lacustrine deposition indicates a short time of occupancy at the maximum position of ice that deposited drift D.

The ice of drift D retreated from a position in eastern Beadle County marked by the border of drift D (outer) to a position marked approximately by the border of drift D (inner, fig. 8). The position of the ice border shown by drift D (inner) is well marked by the end moraine along much of its course. It was during this final stand of ice that Lake Dakota in Beadle County was at its maximum extent as indicated by figure 8. Although the ice at position D (inner) probably marked the maximum extent of Lake Dakota in Beadle County, most of the Lake Dakota sediments were probably deposited just prior to the time of deposition of drift D (inner)

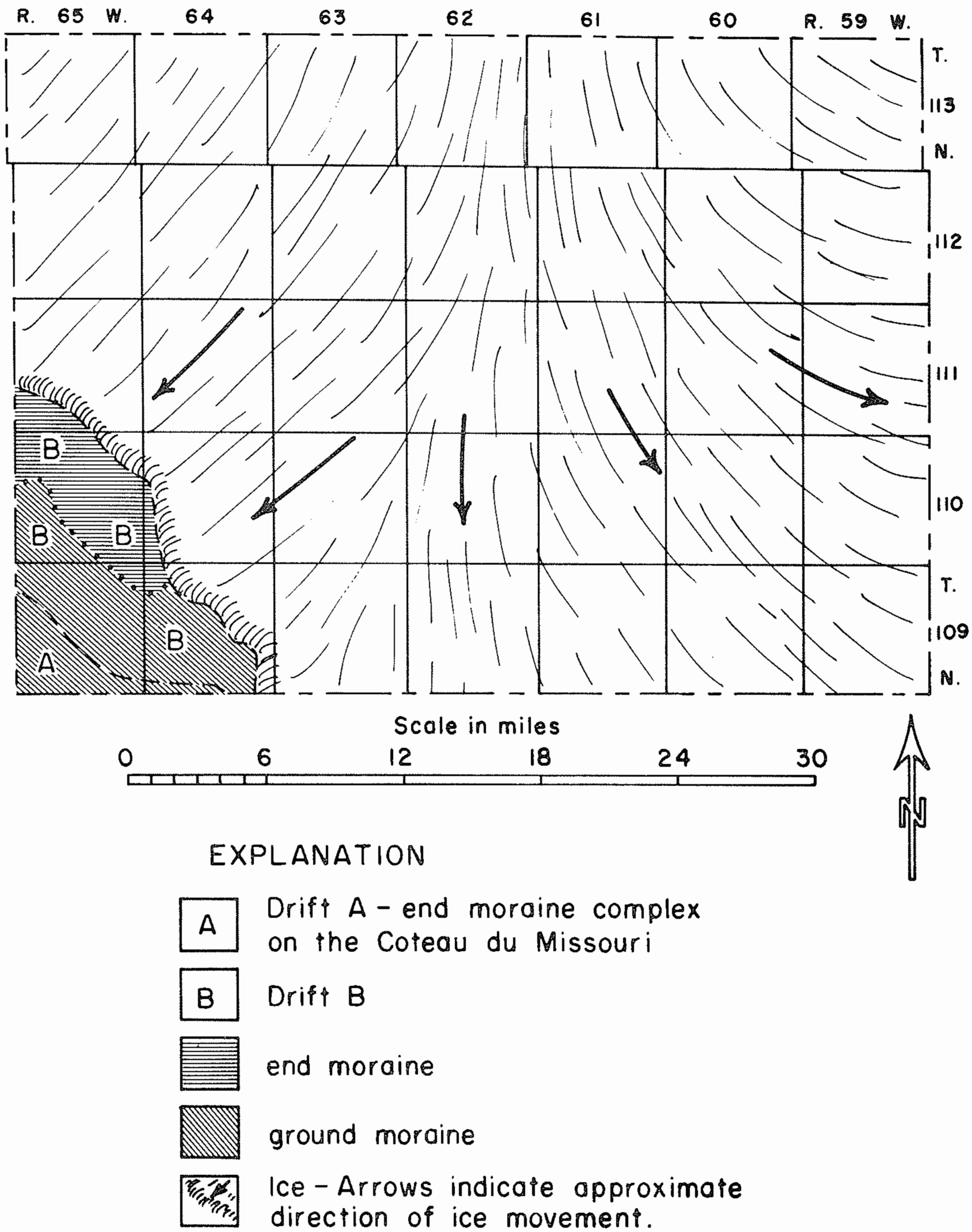
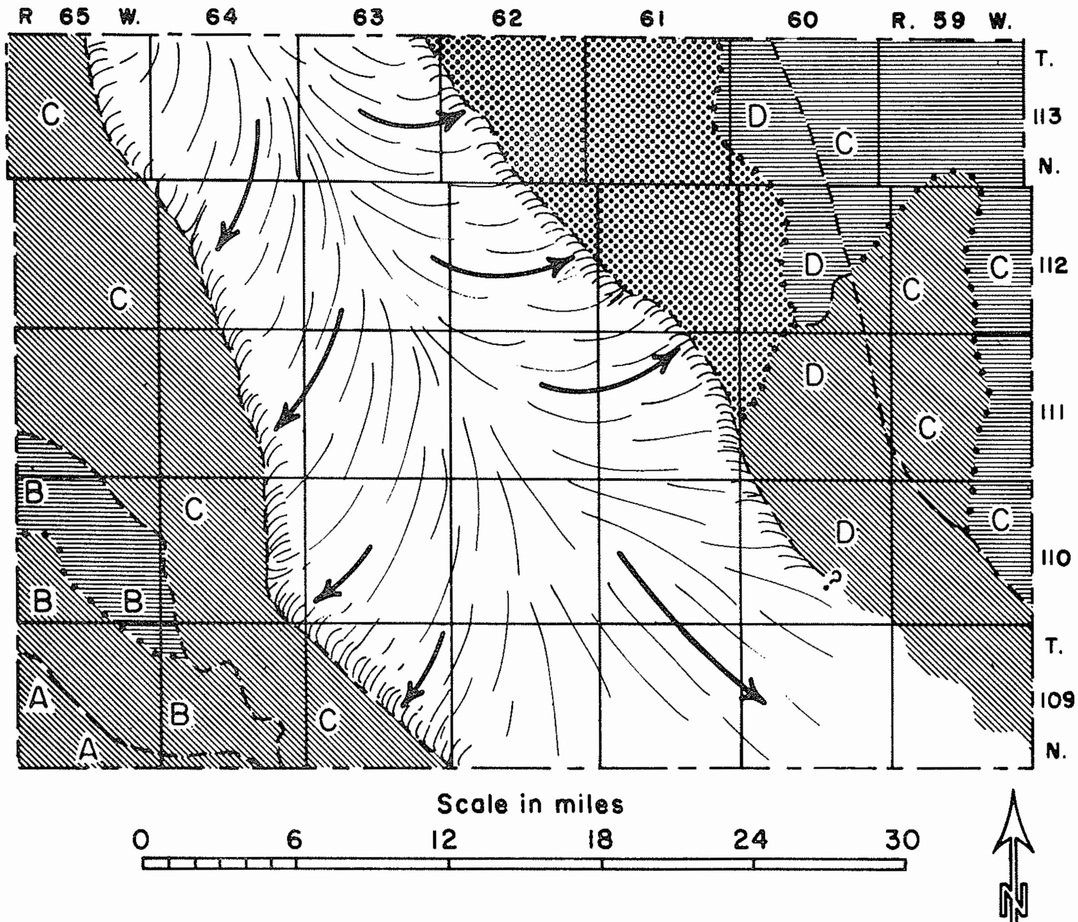


Figure 7. Map showing distribution of drifts A and B and the ice during drift C phase of late Wisconsin time in Beadle County.



EXPLANATION

A	Drift A - end moraine complex on the Coteau du Missouri
B	Drift B
C	Drift C
D	Drift D

end moraine

ground moraine

Ice - Arrows indicate approximate direction of ice movement

Maximum extent of Lake Dakota in Beadle County partly underlain by Drift D ground moraine and partly underlain by Lake Dakota sediments.

Figure 8. Map showing distribution of drifts A, B, C and D (outer) and the ice of drift D (inner) phase during late Wisconsin time in Beadle County.

when the ice margin was approximately along the course of the present James River in the northern half of the county. The evidence for this line of reasoning is the lack of abundant lacustrine deposits west of the present James River.

Most of the surficial glacial deposits between drift D (outer) and drift D (inner) were deposited from the ice that deposited drift D, but most of the linear features which have been interpreted as end-moraine complex are transverse to the trend of the ice margin. This anomaly can be explained only by the assumption that the thin drift D deposits did not completely mask the pre-existing topography.

During the retreat of the ice that deposited drift D, much of the Woonsocket Outwash was deposited in Sanborn County. Further recession of the ice from drift D (inner) in Beadle County opened up shallow basins north and south of Huron. These basins initially received a thin mantle of outwash gravel. Later, as the ice margin receded still further and the volume of meltwater diminished, the sediments carried into these basins became finer until fine sand or silt was deposited.

Sometime after the ice receded from a position marked by drift D (inner) the James Basin in Beadle County was free of ice and southward drainage was offered for the escape of Lake Dakota water. The meltwater flowing down the site of the present-day James River continued downcutting to a depth of about 75 feet. Basal deposits in the James River trench may consist of sediments deposited from the meltwater as its volume gradually decreased. Later, 10 to 25 feet of silty alluvium was deposited in the James River trench.

GEOLOGY OF BEDROCK DEPOSITS

In a recent publication of the South Dakota Geological Survey, Agnew and Tychsen (1965) outline the development of stratigraphic nomenclature for South Dakota and give bibliographic references. The following discussion of the bedrock geology uses the terminology adopted for South Dakota by the State Geological Survey as shown in that publication. The State has been divided into four areas listing those stratigraphic units acceptable in each area: (1) Western Basin, (2) Black Hills, (3) Siouxia Arch, and (4) Iowa "Basin." Beadle County lies in the Siouxia Arch area and the following terminology is that adopted for this area.

Table 4 is a generalized columnar section of the bedrock formations present in Beadle County. Plate 5 is an electric log profile showing the bedrock stratigraphy in Beadle County and adjacent areas as interpreted from electric logs.

Tertiary System

The geologic events that occurred in Beadle County from the Upper Cretaceous to the Pleistocene are largely unknown as no Tertiary deposits have been found in Beadle County. Therefore, inferences must be made from data outside Beadle County.

Table 4.--Geologic section of the bedrock formations in Beadle County, South Dakota.

System and series		Strati-graphic unit	Thick-ness (feet)	Description
Cretaceous	Upper Cretaceous	Pierre Shale	0-600	Clay shale and silty shale, containing bentonite and iron carbonate concretions; marly and chalky zones present; contain Baculites; crops out locally; subcrops locally beneath glacial drift.
		Niobrara Marl	0-110	Marl, light- to medium-gray and tan speckled chalk; abundant Foraminifera; subcrops locally beneath glacial drift.
		Codell Sand-stone Member	0- 52	Sandstone, fine to medium grained, dark colored; generally present in eastern two-thirds of Beadle County; generally absent in western one-third of the county.
		Carlile Shale	160-270	Clay shale, dark-gray to black; contains gypsum and pyrite; subcrops locally beneath glacial drift.
		Greenhorn Limestone	20-110	Fragmental limestone, gray and speckled marl; contains Foraminifera and Inoceramus.
		Graneros Shale	80-280	Shale, gray, and siltstone with sandstone stringers; may contain glauconite.
	Upper and Lower Cretaceous	Dakota Group	0-550	Predominantly sandstone interbedded with shale; contains pyrite and some tan limestone.
Pre-cam-brian		Sioux Quartzite	0- 59	Orthoquartzite, pink, cemented; locally present.
		Granite	?	Granite, red to pink, and gray biotitic granite.

Todd (1896, p. 32), Todd and Hall (1904, p. 22), and Darton (1905, p. 137) all refer to locations in eastern South Dakota where Tertiary deposits are present. Steece (1967) shows Tertiary deposits in Jerauld County. Green (1965, p. 103-107) described a vertebrate fauna from the Tertiary in Jerauld County and dated it as Late Miocene, or equivalent to the Valentine Formation of the Ogallala Group. Green also dated similar deposits at Ree Heights 20 miles west of Beadle County as Late Miocene (?) and at the Bijou Hills 50 miles southwest of Beadle County, as Late Miocene.

These few isolated outcrops strongly suggest that active deposition was occurring near Beadle County, at least as late as the beginning of Pliocene time. Therefore, much of the wholesale stripping of bedrock in the James Basin may have occurred during Pliocene and/or early Pleistocene time.

Cretaceous System

Pierre Shale

The Pierre Shale is at the surface over a large portion of western South Dakota and it would be exposed over much of eastern South Dakota had it not been buried beneath glacial drift. The Pierre Shale has been divided and subdivided by many investigators. Crandall (1958) gave a good summary of the most important contributions during the period 1937-1958. He divided the Pierre Shale into eight members, which are (youngest to oldest): Elk Butte, Mobridge, Virgin Creek, Verendrye, DeGrey, Crow Creek, Gregory and Sharon Springs. Only the Mobridge Member has been positively identified in Beadle County.

In Beadle County the Pierre Shale consists of light- to dark-gray shale with marly zones and "chalky" beds. Thin limestone beds, concretions, and bentonite stringers may also be present in the section. The Pierre Shale is the major bedrock unit underlying the glacial drift (pl. 2) and in the southwest corner of the county attains a thickness exceeding 600 feet.

The Pierre Shale crops out in two general areas in the county (see pl. 1). One outcrop area is in the southwest part of the county where the abrupt escarpment of the Coteau du Missouri rises above the James Basin. In this area several isolated patches of Pierre Shale have been mapped. Much of the face of the coteau is probably Pierre Shale with a thin veneer of glacial debris strewn over its surface. This same general relationship is true in Jerauld County along the southward extension of the Coteau du Missouri (Steece, 1967).

One exposure of Pierre Shale in southwestern Beadle County (NE$\frac{1}{4}$NE$\frac{1}{4}$ NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 19, T. 109 N., R. 65 W.) yielded several moderately weathered fossils from a 3-foot deep silage pit. Several specimens were collected and given to Dr. R. E. Stevenson who sent the fossils to W. A. Cobban for identification. Cobban (personal communication to Dr. Stevenson) identified the specimens as <u>Baculites Clinolobatus</u> and stated that they are diagnostic of the upper Pierre Shale. This particular outcrop is at an elevation of about 1,600 feet.

Another nearby outcrop of Pierre Shale ($SW\frac{1}{4}NE\frac{1}{4}SW\frac{1}{4}NW\frac{1}{4}$ sec. 18, T. 109 N., R. 65 W.) consists of gray to brownish-gray marl overlain by massive white to orange weathered limestone. The elevation of this outcrop is approximately 1,650 feet. According to Searight (1937, p. 45) the "southern exposures" of the Mobridge are essentially chalk in the basal beds. Beadle County is about 120 miles southeast of Mobridge, South Dakota, the type area of the Mobridge Member, and thus probably qualifies for Searight's "southern exposures." Furthermore, the chalky, marly beds are not recognized in the underlying Virgin Creek or the overlying Elk Butte members elsewhere in South Dakota. Thus, the only conclusion that can be made from the evidence presented is that both of the previously described outcrops are part of the Mobridge Member of the Pierre Shale.

The second outcrop area of Pierre Shale is in eastern Beadle County along the valley walls of Shue and Pearl Creeks. Several exposures of Pierre Shale are noted on plate 1. In addition, several dugouts in the valley floors contained unreworked (?) shale in the excavated debris.

The shale cropping out in eastern Beadle County is dark-gray to black, fissile, and contains ironstone concretions and several bentonite stringers up to 1 inch thick. No megafossils were observed in any of these shale exposures; however, tubular iron-stained accretionary structures with a hollow center were observed weathering out from a dugout debris pile.

The electric logs of the subsurface formations (pl. 5) indicate three stratigraphic units in the Pierre Shale which are generally traceable in the subsurface on electric logs. These units may correlate with all or parts of the Sharon Springs, Gregory and Mobridge Members as indicated on that plate.

Niobrara Marl

The Niobrara Marl is predominantly a light- to dark-gray speckled marl with some "chalk" and shaly beds. The marl contains shells of Foraminifera which give it the characteristic white-speckled appearance. The maximum thickness of the Niobrara Marl in Beadle County is 110 feet.

Bolin (1952) has divided the Niobrara into two members, the Smoky Hill (upper) and Fort Hays (lower), on the basis of Foraminifera. No attempt has been made during the present study to differentiate the Niobrara Marl in Beadle County.

The Niobrara Marl underlies the glacial drift in a band several miles wide near the southern border of the county and narrows to a strip about 1 to 2 miles wide in the deeper bedrock valleys in northern Beadle County (pl. 2).

Carlile Shale

The Carlile Shale is a light-gray to black shale containing sandy and silty zones and has a maximum thickness of 270 feet. At the base of the Niobrara Marl or separated from it by a shale interval, the Codell Sandstone Member may be present. In eastern Beadle County, two sand units may be present, while in the central part of the county only one sand unit is present. In the western one-third of the county the sand unit is present only locally (see pl. 5). The maximum known aggregate thickness of the Codell Sandstone Member in Beadle County is 52 feet. In Sanborn County about 24 miles south of Beadle County, the Codell Sandstone Member attains a thickness of 120 feet (Steece and Howells, 1965). Steece attributes this thickness to proximity of the Sioux Ridge, a probable source area.

The Carlile Shale underlies the glacial drift in a narrow band in the bottom of a buried bedrock valley in northern Beadle County (pl. 2).

Greenhorn Limestone

The Greenhorn Limestone consists of gray marl with a white-speckled appearance and fragmental limestone in which the fossil Inoceramus is dominant. The formation ranges from 20 to 110 feet in thickness and probably averages about 40 feet thick as determined from electric-logging data. The actual range in thickness may be less than indicated since the marly beds may show the same resistivity and self-potential on electric logs as do the overlying Carlile Shale and underlying Graneros Shale.

Calcium carbonate prisms from the fragmental limestone and the characteristic "kicks" on electric logs generally make this an easily recognizable unit and thus it is a good stratigraphic marker bed.

Graneros Shale

The Graneros Shale is a marine sequence of gray shale to sandy shale or siltstone containing much pyrite and occasionally some glauconite. Thin sand stringers also are present throughout the section, becoming thicker and more abundant near the base. The Graneros Shale ranges from 180 to 280 feet thick and averages about 200 feet.

Dakota Group

Dakota Group is the name used to designate the Cretaceous sediments underlying the Graneros Shale and overlying older sedimentary rocks in eastern South Dakota. This is the oldest known rock unit in Beadle County, excepting the Precambrian rocks.

Most of the information for the Dakota Group comes from information supplied by well drillers and from electric-log interpretations. On electric logs the top of the Dakota Group is picked when the predominantly shaly sequence of the Graneros Shale ends and the sandy sequence of the Dakota Group starts (pl. 5). Most of the wells completed in the Dakota Group penetrate only the upper portion, so very little data exists for the lower part of this unit. A sample description of the Huron State Fairground Well (Rothrock, 1936) reports alternating beds of gray shale, gray and tan limestone, sandy shale, and loose to fairly well-cemented sandstone. Pyrite and lignite are also quite abundant.

One well (number 19, table 5) in the northeast part of the county reported no Dakota sand overlying the Precambrian surface, while a well drilled in the southwest part of the county penetrated over 550 feet of sediment below the Graneros Shale; however, it is possible that the lower part of this sequence may contain rocks older than Cretaceous. The average thickness of the Dakota Group in Beadle County is about 300 feet.

A structure contour map on the Dakota Group (fig. 9) shows a relatively level surface. Further comparison of an isopach map of the Dakota Group (fig. 10) with the Precambrian surface map (fig. 11) shows the Dakota Group thin or absent on Precambrian "highs" and corresponding thickening in the Precambrian "lows." Thus, it seems apparent that deposition of the Dakota Group filled in the Precambrian lows and left a nearly level surface on which the younger Cretaceous sediments were deposited.

Precambrian System

The Precambrian rocks in Beadle County are the Sioux Quartzite, and various types of granitic rocks. Where present, the Sioux Quartzite overlies older granitic rocks.

Sioux Quartzite

The Sioux Quartzite underlies a large area in Minnesota, Iowa and South Dakota, forming a prominent buried ridge. The Sioux Quartzite crops out near Mitchell, South Dakota, 33 miles south of the Beadle County line, but is buried beneath more than 900 feet of sediment in Beadle County. Apparently the Sioux Quartzite is present only in small isolated patches in Beadle County as most wells penetrate granite directly underlying the Cretaceous sediments.

The Sioux Quartzite is a hard, massive, pink, siliceous orthoquartzite which is horizontally bedded, cross bedded and jointed. It is interbedded with pink to red sericitic claystone known as catlinite or pipestone. The Sioux has been estimated to be as much as 3,000 feet thick (Baldwin, 1949) and in the Palensky #1B Wagner oil test in Charles Mix County, 3,800 feet of Sioux was penetrated (Bolin and Petsch, 1954). The maximum measured thickness is 500 feet (Theil, 1944) in Minnesota.

The Sioux Quartzite has been reported in three wells in Beadle County (table 5). There have also been several questionable reports of this formation. Where reported, it lies about 900-1,100 feet below the surface. The maximum thickness reported in Beadle County is 59 feet (Darton, 1909).

A potassium-argon age determination on a sample (KA-50) of the pipestone or catlinite near Pipestone, Minnesota, gave a minimum age of 1.2 billion years (Goldich and others, 1959). They felt this was probably minimum and gave a maximum age of 1.6-1.7 billion years.

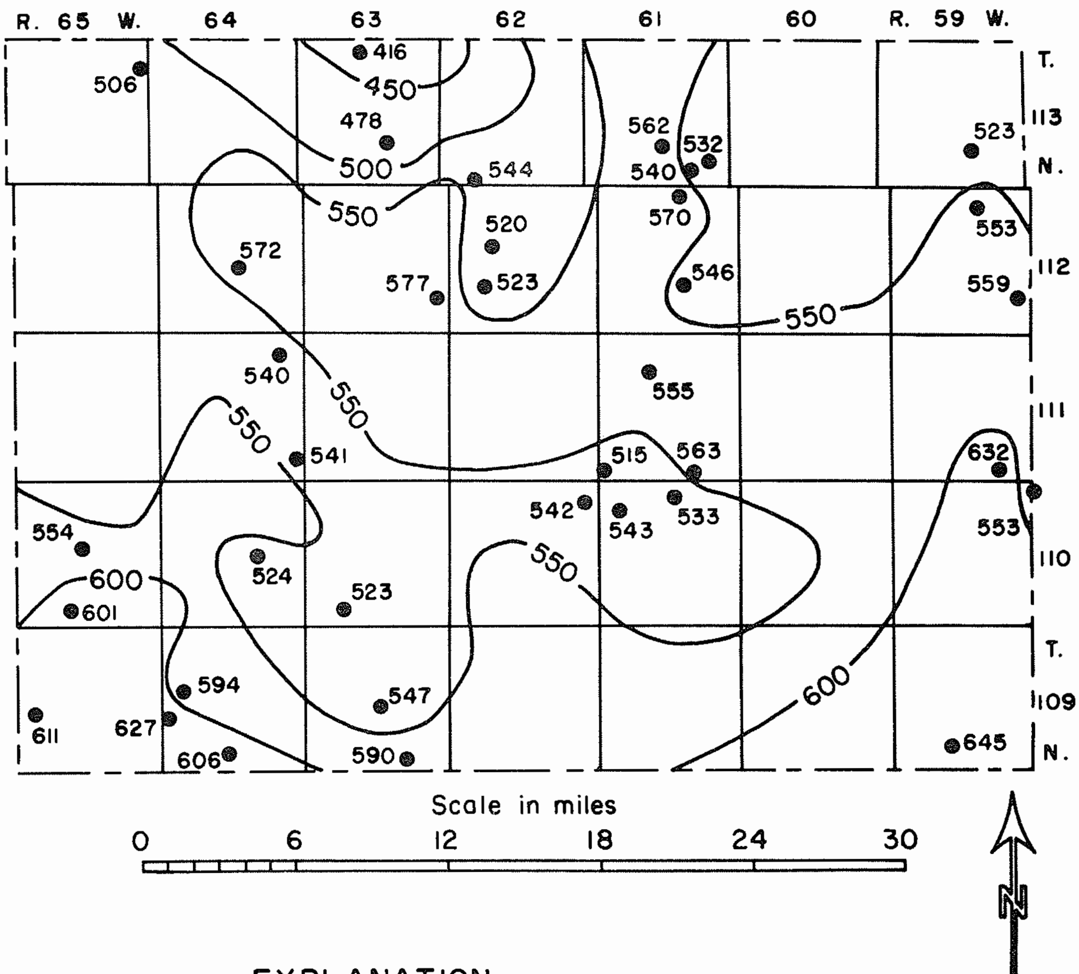
Older Rocks

Deep wells in Beadle County have penetrated red to pink granite, red granite gneiss and gray biotitic granite (table 5) underlying the isolated knobs of Sioux Quartzite.

Table 5.--List of wells showing control data for the Precambrian surface.

Name	Location	Land surface elevation	Elevation* on top Precambrian	Source of Information	Remarks
1.	109-62-1da	1300	125	Driller's report	Granite (?)
2. Iroquois City Well	110-59-1a or 110-58-6b	1380	335	Driller's report	Granite
3. South Dakota State Fish, Game, & Parks	110-58-1a or 110-62	1290	114		Gray biotite granite - Samples SDGS
4.	110-62-1dd	1280	190		Pink granite - Samples SDGS
5.	110-64-22a	1390	-29**	"E" log SDGS files	No Precambrian
6.	110-65-19a	1425	220	Driller's report	Granite
7.	111-59-1c	1400	477	Driller's report	Quartzite
8.	111-62-25	1295	170	Driller's report	Granite
9.	111-62-33c	1305	100	Driller's report	Granite
10. Wolsey #1 Kuschow	111-64-2dc	1325	134	Oil test	Red granite gneiss
11. Wolsey City Well	111-64-24	1350	422	Rothrock, 1941, p. 3	Pink quartzite overlying granite gneiss
12. Wolsey Swimming Pool	111-64-24	1350	130**	Driller's report	No Precambrian
13.	111-65-2a	1400	272	Driller's report	Granite
14.	113-58-4b	1560	570	Driller's report	Granite
15.	113-59-9	1475	489	Driller's report	Granite (?)
16.	113-59-12a	1500	500	Driller's report	Granite
17. Kleinsasser, farm	113-60-4	1360	420	Driller's report	Red granite
18. Glidden, farm	113-63-5 or 8	1330	247	Darton, 1909	Quartzite 1083-1142; granite 1142-1150
19.	114-59-34	1440	500	Driller's report	Granite - driller reported no sandstone above Precambrian
20.	114-62-12c	1290	250	Driller's report	Granite - driller reported "granite pebbles" above granite

* Referred to sea level
** The Precambrian had not yet been penetrated at this elevation.

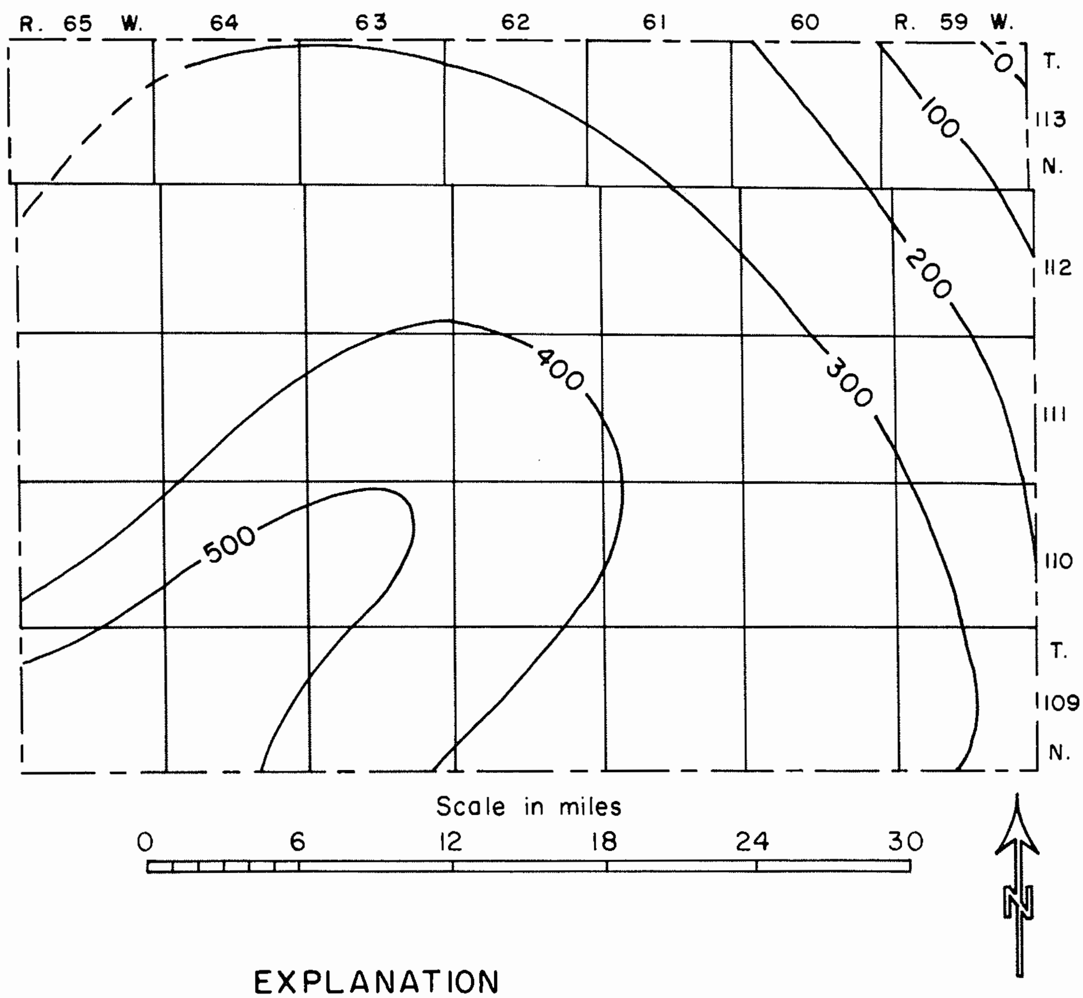


EXPLANATION

500 — Contour on top of Dakota Group; number is Elevation above Sea Level; contour interval = 50 feet.

572 • Control point showing elevation above sea level of the top of the Dakota Group; tops taken from electric logs and drillers logs.

Figure 9. Structure Contour map on top of the Dakota Group in Beadle County.

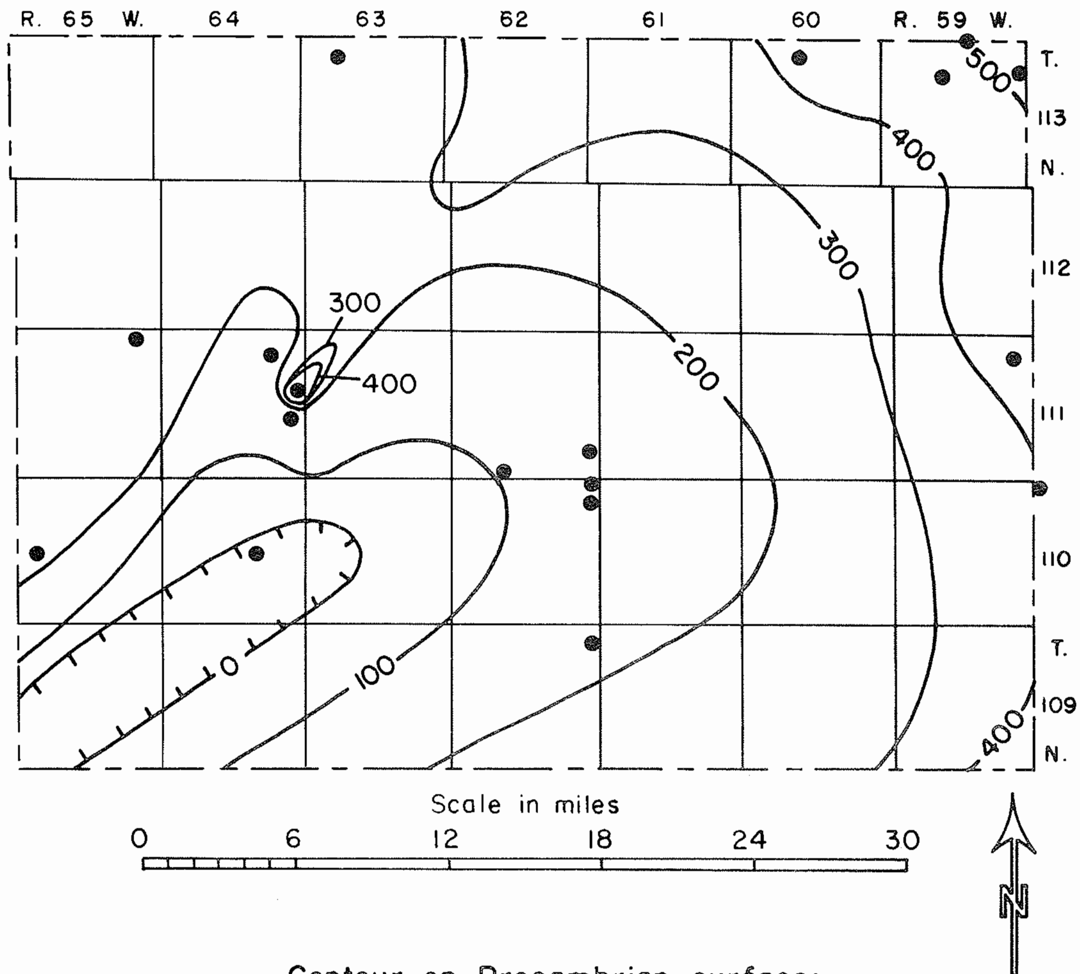


EXPLANATION

500 Contour lines of equal thickness of the Dakota Group; contour interval = 100 feet.

(This figure was constructed from data points acquired by superposition of the Dakota Group structure contour map over the Precambrian surface map and using the intersection of contours for data points.)

Figure 10. Generalized isopach map of the Dakota Group in Beadle County.



—200— Contour on Precambrian surface; number is elevation above sea level; contour interval = 100 feet.

● Data point; contour lines in southeastern Beadle County extrapolated from Steece and Howells, 1965, fig. 11.

Figure 11. Generalized contours on the Precambrian surface in Beadle County.

The generalized topography of the eroded granitic terrain is shown in figure 11. The dominant feature of the Precambrian surface in Beadle County is a Precambrian low trending northeast across the county and gradually fading out toward the northeast corner. The lowest elevation at which the Precambrian was penetrated is 100 feet above sea level. However, a deep farm well in sec. 22, T. 110 N., R. 64 W. penetrated to a depth of 29 feet below sea level and did not reach the Precambrian surface (well 5, table 5).

The age of the granitic rocks can only be ascertained by indirect methods. Goldich and others (1959, p. 660) gave a maximum age of 1.6-1.7 billion years for the overlying Sioux Quartzite. Since the Sioux Quartzite overlies the granite, the granite must be older than 1.6-1.7 billion years. A rhyolite porphyry core from Sanborn County has been dated 1.64 ± 0.09 billion years (Goldich and others, 1966) (W. R. Muehlburger, University of Texas, written communication, 1963). In northeast South Dakota the Milbank granite has been dated at 1.97 billion years (KA-57B, Goldich and others, 1961) and a granite from Marshall County has been dated at 2.27 ± 0.11 billion years (Goldich and others, 1966). A granite gneiss from the Black Hills, South Dakota, was recently dated at 2.5 billion years by Zartman, Norton and Stern (1964), who stated that this date correlates with Superior rocks in eastern South Dakota, Minnesota and the Bighorn Mountains. These authors felt that much more of the Precambrian basement between the Black Hills and eastern South Dakota would also contain rocks dating about 2.5 billion years.

Bedrock Topography and Drainage History

The pre-Wisconsin bedrock topography in Beadle County was generally quite rugged. The detailed map of the bedrock surface (pl. 2) shows a maximum relief on the bedrock surface of nearly 900 feet with the highest elevation of 1,700 feet in the southwest corner of the county on the Coteau du Missouri and the lowest elevation of less than 800 feet (not shown on pl. 2 because of scale) in the Lake Byron channel. Although the bedrock surface illustrated on the map must reflect modification during late Pleistocene time, the general trends shown were present earlier in the Pleistocene.

The main bedrock drainage trends north-south through the central part of the county at an elevation of 1,120 feet and throughout its course has completely cut through the Pierre Shale into the Niobrara Marl. Near T. 113 N. the channel joins the Lake Byron channel, a northwest trending drainage of this same (?) major drainage system, and inexplicably drops to an elevation less than 900 feet, where the channel is cut into the Carlile Shale.

The bedrock surface outside the channel slopes gently toward the axis of the James Basin at an elevation between 1,300 and 1,400 feet. This surface is occasionally cut by tributaries approaching the main bedrock drainage leaving interfluves connected with the uplands. The bedrock is more highly dissected where tributaries join the main bedrock valley. At many of these points the interfluves have been cut off and a series of isolated knobs and ridges remain (pl. 2).

The drainage history of the bedrock valleys in the James Basin was first briefly treated by Todd (1885). He visualized a large drainage area in the James Basin which was the result of a confluence of the five major east-west flowing rivers in western South Dakota (Grand, Moreau, Cheyenne, Bad and White Rivers). These rivers, by Todd's views, joined and drained to the north, eventually reaching Hudson Bay.

Using topographic evidence supplemented with scanty drill-hole information Flint (1955, pl. 7) inferred that the Bad and White Rivers joined in Sanborn County and flowed southeastward to Clay County in extreme southeastern South Dakota where they joined the Ancient Niobrara River. The controlling factor of this drainage was the Ancient Redfield divide which Flint supposed was part of the continental divide separating the drainage of the Arctic Ocean and the Gulf of Mexico.

Recent detailed work in Sanborn County (Steece and Howells, 1965, pl. 6) has failed to produce evidence of a major bedrock drainage entering southwest Sanborn County nor does it indicate a southeastward drainage from the northeastern part of the county as Flint describes. In fact, the information shows the bedrock drainage to be from south to north and indicates that a divide is approached near the southern border of Sanborn County.

Assuming that the bedrock drainage pattern as shown in plate 2 is pre-Missouri River diversion, the Redfield divide was probably not part of the continental divide, and the Ancient Bad River probably flowed toward the north. Since the present bedrock drainage is toward the north, the bedrock drainage divide must be south of Sanborn County. A possible location of the divide would be in the Sioux Ridge region where the Sioux Quartzite is near the land surface.

The gradient of the main bedrock valley in Sanborn County is toward the north where it enters southern Beadle County at an elevation of 1,120 feet. This elevation is maintained northward through Beadle County to the Lake Byron channel where the bedrock surface drops to nearly 850 feet. Northward in the State the data is limited but there is presently no evidence of a major bedrock valley in South Dakota which would correspond to the 850-foot elevation found near the Beadle County line. Perhaps detailed investigations in counties to the north will reveal such a valley.

STRUCTURAL GEOLOGY

The structural influences in Beadle County cannot be adequately discussed without first placing Beadle County within the framework of the regional structural patterns.

The Sioux Ridge is a massive ridge trending southeastward from a point northwest of Pierre through Sioux Falls into Minnesota. Baldwin (1949) indicated that these beds have been gently warped and tilted and the average dip of the beds is about 3 to 4 degrees from the axis of the ridge. The Sioux Quartzite surface is deeply dissected, leaving isolated knobs of quartzite buried beneath younger sediments.

The Precambrian granitic basement rocks underlie the Sioux Quartzite and slope gently to the northwest into the Williston Basin syncline in South Dakota, North Dakota and Canada.

Beadle County is situated just off the north flank of the Sioux Ridge and thus is in the transitional zone between the gently sloping granitic basement and the north flank of the Sioux Ridge.

The dominant structural control in Beadle County is the northeast trending Precambrian low extending into Beadle County from the southwest (Steece, 1961) and the Precambrian highs which are isolated knobs of Sioux Quartzite. Structural contour maps drawn on the subsurface Cretaceous sediments generally reflect control by these features. Thus, bedrock formations are high over Precambrian highs, and are lower over Precambrian lows. Most of the structural features of the sedimentary rocks in Beadle County are therefore probably the result of differential compaction of the Cretaceous sediments.

MINERAL RESOURCES

Sand and Gravel

No extensive surficial deposits of sand and gravel are known to exist in Beadle County. Most of the present gravel pits have been developed in small valley outwash deposits or small isolated ice-contact stratified drift deposits and have been nearly depleted. The largest known deposits of surficial gravel are present in northeastern Beadle County and occur as terraces along Shue Creek (pl. 1). Smaller terraces along the creeks in northeastern Beadle County may provide additional material, although the extent of these terraces is difficult to delineate without extensive detailed test drilling.

The outwash valley west of Hitchcock, the upper reaches of Cain Creek in northwestern Beadle County and the deeper and wider parts of Sand and Silver Creeks in southwestern Beadle County contain up to 30 feet of outwash sand and gravel. However, the quality of the material, high water table, and locally thick alluvial cover make much of this area undesirable for exploitation.

The outwash plain deposits northwest of Huron contain some basal sand and gravel deposits buried by as much as 20 feet of finer outwash material. Locally, gravel may be present at the surface but it is thin and of small areal extent. The volume of sand and gravel is not known because of its uneven thickness and erratic distribution. Where present, the coarse sand and gravel rarely exceeds 10 feet in thickness.

The outwash plain deposits south of Huron and west of the James River are generally too fine for aggregate although abundant, clean, fine- to medium-grained sand is present.

The scattered exposures of outwash plain deposits along Pearl Creek consist of sand and gravel known to be at least 5 feet thick at some localities but are thin and small in extent.

The Lake Dakota deposits north of Shue Creek and south of Lake Byron are mostly sand with some gravel and are as much as 14 feet thick, but the average thickness is much less.

By far the greatest sand and gravel reserves are buried outwash. North of Huron and in a strip about 1 to 5 miles wide paralleling the James River much of the buried outwash underlies less than 25 feet of till (see cross sections, pl. 3). If stripping operations would prove economical, this area would offer huge reserves of sand and gravel.

Oil and Gas

One test has been made for oil in Beadle County (Wolsey #1 Kuschow) near Wolsey in which no oil or gas was found. In addition, many of the deep water wells have penetrated the entire sedimentary sequence and to date no oil or gas of commercial value has been found in any of these wells.

Magnetometer Survey

A magnetometer survey of Beadle County was published by Tullis (1942) and was slightly modified by Petsch (in preparation). Petsch incorporated all previous magnetometer data available into a single statewide map and report. The following section on Principles of Magnetometer Surveying was written by Petsch and printed in Steece and Howells (1965, p. 50-51) and the section on Magnetic Anomalies and Geologic Interpretation are from Tullis (1942) and Petsch (in preparation) with modifications.

Principles of Magnetometer Surveying

Theoretically, the earth itself is a natural magnet. The forces set up between the north and south magnetic poles are made of four components; declination, inclination, horizontal intensity, and vertical intensity. The vertical component is the most satisfactory to measure because of ease and accuracy; its magnitude is a resultant of all forces that influence the magnetic field emanating from the earth. These forces are caused by paramagnetic, diamagnetic, and nonmagnetic substances in the Precambrian basement rocks, in overlying rocks, and at the ground surface.

In addition to changes in the earth's magnetic field caused by rock types and geologic structures, there is a gradual increase in the magnetic intensity toward the north magnetic pole. In South Dakota the vertical intensity increases about 8.7 gammas per mile north latitude, and 3.6 gammas per mile east longitude (Jordan and Rothrock, 1940). The application of this regional correction to a survey tends to result in a constant magnetic surface. Therefore, an anomaly on this surface should reflect a geologic feature.

The vertical intensity of the terrestrial magnetic field is illustrated by contour lines (isograms) which connect points of equal value. Variations of intensity are recognized as positive and negative forces commonly known as magnetic highs and lows, or anomalies. The composite effect of the earth as a great magnet and the local variations in intensity that are caused by geologic features, determine the size and shape of anomalies. Magnetic anomalies are generally important when prospecting for oil and mineral deposits.

Magnetic surveys are made to discover general trends, which may then be investigated with more exact geologic and geophysical surveys.

Possible causes of magnetic anomalies are: (1) differences in lithologic composition of the Precambrian basement rocks; (2) concentration of magnetic minerals in the overlying sedimentary rocks and the "granite wash," or conglomerate overlying the basement rocks; (3) deep-seated magnetic iron-bearing bodies; (4) changes in thickness "red-bed" sections; (5) structure of the sedimentary formations; and (6) differences in depth and relief of the Precambrian surface.

It is advantageous to make magnetic surveys over areas where the geology is unknown. The solution of a magnetic problem is aided when comparison can be made with a problem that has been correctly interpreted in another area.

Magnetic Anomalies in Beadle County

The arbitrary vertical magnetic intensity base selected for South Dakota is 500 gammas (Jordan and Rothrock, 1940, p. 10), as the true readings of 55,000 to 58,000 gammas are unwieldy in calculations.

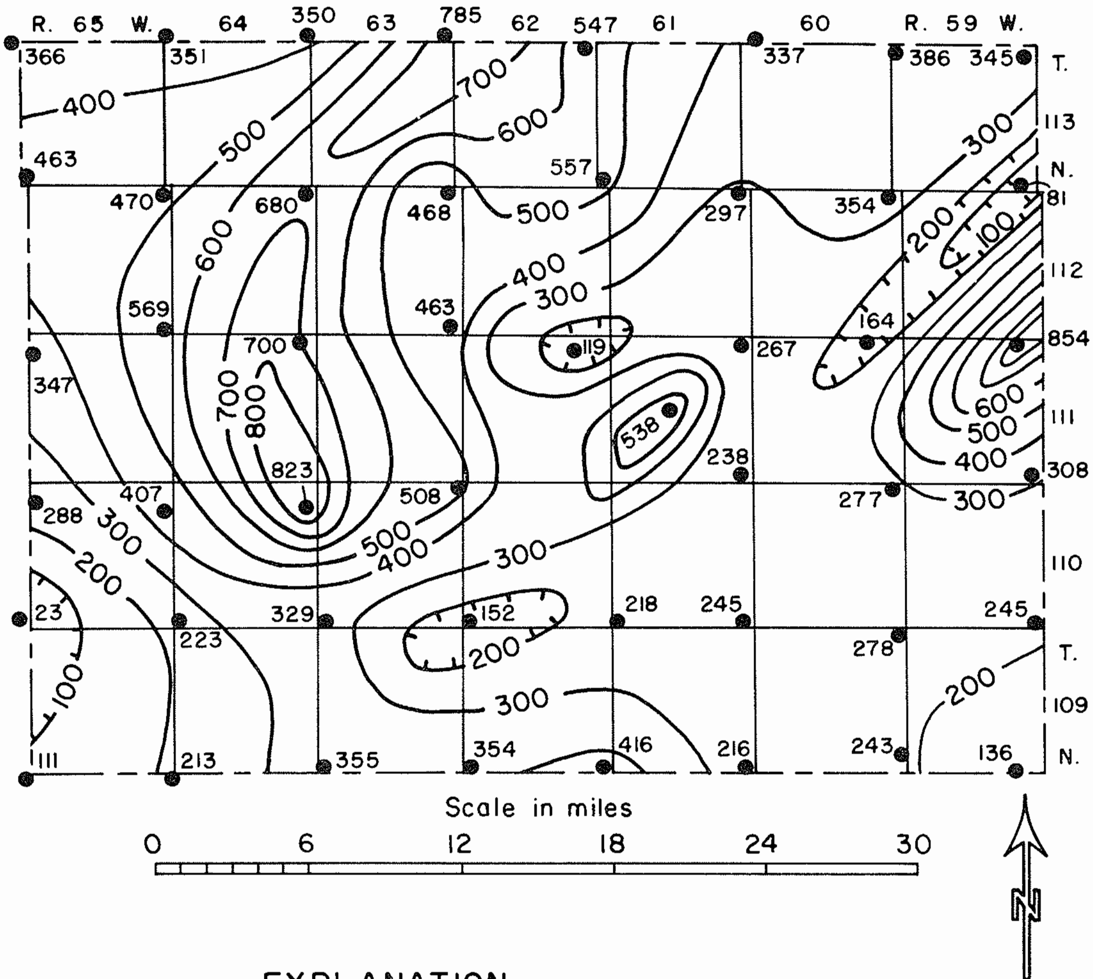
The lowest reading shown (fig. 12) is in Hand County 6 miles north of the southwest corner of Beadle County; it has an intensity of 23 gammas. The maximum reading is 854 gammas 12 miles south of the northeast corner of the county with a similar reading of 823 gammas in the southwest central part of the county. Other highs are 785 gammas on the Beadle-Spink County line northwest of Huron and 538 gammas 3 miles northeast of Huron.

Geologic Interpretation

About the northern three-fourths of Beadle County is in the Canadian Shield structural province as determined from the trends of magnetic highs (Petsch, in preparation). The southern quarter of the county is located in the Sioux Ridge structural province. These conclusions await verification pending more detailed Precambrian studies.

The map showing contours on the Precambrian surface (fig. 11) and the map showing magnetic anomalies (fig. 12) exhibit the same general trend of low and high areas. Both show a generally broad low region extending through Beadle County from the southwest to northeast with adjacent higher areas to the northwest and southeast. The greater detail of the magnetic map shows minor highs and lows within the general trends. The resemblance of the two maps illustrates the general relationship between magnetic intensity and the Precambrian topography.

It is interesting to note that the three greatest magnetic intensities occur over or near Precambrian topographic highs which also correspond to the only areas where the Sioux Quartzite has been reported in wells.



EXPLANATION

● Control point

~200~ Contours show vertical magnetic intensity in gammas; hashured contours indicate magnetic "lows"; interval = 100 gammas.

Modified from E. L. Tullis (1942).

Figure 12. Map of Beadle County showing magnetic anomalies.

GLOSSARY OF GEOLOGIC AND HYDROLOGIC TERMS

Andesite.--A volcanic rock composed essentially of andesine and one or more dark-colored minerals such as pyroxene, hornblende, or biotite.

Bedrock.--Any solid rock underlying the looser materials of the earth's surface.

Bentonite.--A clay formed by the decomposition of volcanic ash and largely composed of the clay minerals montmorillonite and beidellite.

Calcite.--A mineral composed of calcium carbonate; similar to aragonite; a very common mineral; the principal constituent of limestone.

Chalk.--A very soft, white to light-gray porous, friable limestone composed of the shells of floating microorganisms and some bottom dwelling forms in a mass of microscopic calcite crystals.

Clay ironstone.--A clayey carbonate of iron; heavy, compact and fine grained; occurs in nodules or concretions.

Colluvium.--Loose or incoherent deposits, usually at the foot of a slope, brought there chiefly by gravity.

Diamagnetic.--Pertaining to materials which are repelled by a magnetic field.

Drift.--All rock material transported by glacial ice; all material predominantly of glacial origin deposited in the sea or in bodies of glacial meltwater, whether rafted in icebergs or transported in the water itself; includes till, stratified drift, and scattered rocks.

Dune sand.--Windblown sand that has drifted to form low hills or dunes.

Electric log.--The log of a well or bore hole obtained by lowering electrodes in the hole and measuring various electrical properties of the geological formations.

Elevation.--Generally refers to the height in feet above mean sea level.

Eolian.--A term applied to the erosive action of the wind, and to deposits which are due to the transporting action of the wind.

Erosion.--The group of processes whereby earthy material or rock material is loosened and moved from place to place; includes weathering, corrasion, and transportation.

Floodplain.--That part of a river valley adjacent to the river channel, which is built of sediments during the present regimen of the stream and which is covered with water when the river overflows its banks at flood stage.

Foraminifera.--Animals, usually microscopic, a subclass of the Sarcodina, phylum Protozoa, that have exoskeletons called tests, which usually are composed of calcium carbonate.

Fossil.--The remains or traces of animals or plants that have been preserved by natural causes in the earth's crust, exclusive of organisms buried since the beginning of historic time.

Gamma.--In geophysics, the name given the common unit of magnetic intensity equal to 10^{-5} oersted.

Glacial drift.--See drift.

Glacial lake.--A natural lake fed by glacial meltwater.

Glaciation.--A glaciation was a climatic episode during which extensive glaciers developed, attained a maximum extent, and receded.

Glaciofluvial.--Pertaining to streams flowing from glaciers or to the deposits made by such streams.

Granite.--An igneous, coarsely crystalline rock consisting essentially of alkalic feldspar, quartz; usually contains small amounts of muscovite, biotite, hornblende, or rarely, pyroxene.

Igneous.--Pertaining to rocks formed by solidification from a molten or partially molten state; plutonic, volcanic.

Intercalated.--One body of material interbedded or interlaminated with another.

Interglaciation.--An episode during which the climate was incompatible with the wide extent of glaciers that characterized a glaciation; time period between glaciations.

Interstade.--A climatic episode within a glaciation during which a secondary recession of a stillstand of glaciers took place.

Lacustrine.--Of, or pertaining to, or formed or growing in, or inhabiting lakes.

Limestone.--A bedded sedimentary deposit consisting chiefly of calcium carbonate.

Lithology.--Physical character of a rock, generally as determined megascopically or with the aid of a low power magnifier.

Loess.--A homogeneous, nonstratified, unconsolidated deposit consisting predominantly of silt with small amounts of very fine sand and/or clay; eolian in origin.

Magnetic anomaly.--Any departure from the normal magnetic field of the earth as a whole. May be high or low, subcircular, ridge or valley-like, or linear or dike-like.

Magnetometer.--An instrument used for measuring magnetic intensity; in ground magnetic prospecting usually an instrument for measuring the vertical intensity.

Marl.--A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells. Also calcareous deposits of lakes which contain 30 to 90 percent of calcium carbonate.

Orthoquartzite.--A clastic sedimentary rock composed of silica-cemented quartz sand.

Oxidation.--Process of combining with oxygen; an increase in positive valence or decrease in negative valence.

Oxidized zone.--That portion of a deposit which has been subjected to the action of surface waters carrying oxygen, carbon dioxide, etc.

Paramagnetic.--Pertaining to materials that are attracted by a magnetic field.

Physiography.--The study of the surface of the earth--its physical form and the processes and forces that mold and change that surface.

Pipestone (Catlinite).--Indurated sericitic claystones and siltstones; deposits in southeastern South Dakota, southwestern Minnesota, and northwestern Iowa are interbedded with Sioux Quartzite. Used by the Dakota Indians for making pipes, tools, and ornaments.

Porphyry.--Rock that contains conspicuous, large crystals in a fine-grained groundmass or matrix.

Quartz.--A mineral, silicon dioxide (silica), having hexagonal crystals and a Mohs hardness of 7; most abundant mineral in earth's crust.

Quartzite.--1. A granulose metamorphic rock consisting essentially of quartz. 2. Sandstone cemented by silica which has grown in optical continuity around each fragment.

Radiocarbon dating.--Determination of the age of a material by measuring the proportion of the isotope C^{14} (radiocarbon) to the total carbon content. The method is suitable for the determination of ages of as much as 45,000 years.

Rhyolite.--A rock which is the extrusive equivalent of a granite; composed mainly of quartz and alkalic feldspar.

Rock-stratigraphic unit.--A subdivision of the rocks in the earth's crust distinguished and delimited on the basis of lithologic characteristics.

Sandstone.--A cemented or otherwise compacted detrital sedimentary rock composed predominantly of sand-size quartz grains.

Sericite.--A fine-grained variety of mica; occurs in small scales, especially in schists.

Shale.--A laminated sedimentary rock, in which the constituent particles are predominantly of the clay grade.

Siltstone.--A very fine-grained consolidated fragmental sedimentary rock composed predominantly of particles of silt grade.

Stade.--A climatic episode within a glaciation during which a secondary advance of glaciers took place.

Stratification.--Layering of rock produced by deposition of sediments in beds or layers (strata), laminae, and other essentially tabular units.

Stratigraphy.--That branch of geology which treats of the formation, composition, sequence and correlation of the stratified rocks.

Surficial.--Characteristics of, pertaining to, formed on, situated at, or occurring on the earth's surface; especially alluvial or glacial deposits lying on the bedrock.

System.--The fundamental unit of worldwide time-stratigraphic classification of Phanerozoic rocks; contains strata deposited during the corresponding geologic periods.

Terrace.--A relatively flat, horizontal or gently inclined surface, usually long and narrow, that is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side; when typically developed is step like in character.

Texture.--Geometric aspects of the component particles of a rock, including size, shape, and arrangement.

Topography.--The physical features of the land surface, especially the relief and contour.

Valley.--An elongate depression in the earth's surface, usually with an outlet, ordinarily occupied by a stream or river.

Weathering.--The group of processes whereby rocks on exposure to the weather change in character, decay, and finally crumble into soil.

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