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GEOLOGY AND WATER RESOURCES OF CHARLES MIX AND DOUGLAS COUNTIES, SOUTH DAKOTA

PART I: GEOLOGY

by

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Prepared in cooperation with the
United States Geological Survey,
Fort Randall Conservancy Sub-District,
and Charles Mix and Douglas Counties

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ABSTRACT

Charles Mix and Douglas Counties include an area of approximately 1,540 square miles in southeastern South Dakota in the Coteau du Missouri, a division of the Great Plains physiographic province. Outstanding physiographic features in the area are the 700-foot deep Missouri River trench and the broad linear low areas marking the former courses of ancient streams.

Precambrian Sioux Quartzite underlies all of the two-County area and is as much as 3,787 feet thick. Overlying the Sioux Quartzite are Cretaceous shales, sandstones, limestones, and marls as much as 1,700 feet thick. These formations from oldest to youngest are: Fall River Formation and Skull Creek Shale, Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Marl, and the Pierre Shale. Tertiary rocks consist of about 150 feet of silt, clay, and sandstone. The Tertiary rocks are Miocene-Pliocene in age and are mapped as Ogallala undifferentiated and the Fort Randall Formation.

Glacial and non-glacial surficial deposits as much as 400 feet thick mantle the bedrock. The surficial deposits are thickest over bedrock channels and are thinner where the bedrock elevation increases. The major bedrock channels were cut by the White River after it was diverted from its channel north of the study area. The Wagner Formation (new name), a non-glacial western derived fluvial deposit, was deposited by the diverted White River.

During the maximum advance of the Illinoian glacier, the White River and other east flowing streams were diverted along the course of the present Missouri River for a sufficient length of time to become permanently entrenched below the level of the former drainages.

The Yarmouth and Sangamon Interglacials were primarily periods of weathering and erosion as was much of Early Wisconsin time.

Late Wisconsin ice advanced to the Missouri River and stagnated on the higher elevations while remaining active in the lowlands. A small discontinuous recessional end moraine was built in extreme northeastern Douglas County and probably marks the position of the last active ice in the area.

Large reserves of ground water and surface water are available for development. Large sand and gravel reserves are also present but accessibility presently limits the development of this natural resource. Present data indicate no significant metallic or fossil fuel resources in Charles Mix and Douglas Counties.

INTRODUCTION

Purpose

This report is the sixth in a series of investigations to determine the geology and water resources of parts of South Dakota. This study was made possible by the joint efforts of the South Dakota Geological Survey, United States Geological Survey, Fort Randall Conservancy Sub-District, and Charles Mix and Douglas Counties. Unlike earlier investigations which studied one county only, this investigation was conducted for Charles Mix and Douglas Counties. The goals of this investigation are to evaluate the mineral and water resources of the two Counties and provide the basic geologic and hydrologic framework for further exploration and development of the Counties' natural resources.

The results of the Charles Mix and Douglas Counties investigation are published in three parts. Part I (this report) contains the geology, with special emphasis on deposits of Pleistocene age; Part II contains an evaluation of the water resources; and Part III is a compilation of all basic data resulting from the investigation.

Location

Charles Mix and Douglas Counties include an area of 1,540 square miles in southeastern South Dakota (fig. 1). Charles Mix County is the larger, containing 1,097 square miles and Douglas County 443 square miles. Douglas and Charles Mix Counties have common borders along their southwest and northeast borders respectively. The southwestern border of Charles Mix County is the Missouri River and Lake Francis Case. To the north Charles Mix is bordered by Brule County and Aurora County, the latter also common to Douglas County. To the east of Charles Mix County is Bon Homme County and Hutchinson County, the latter also common to Douglas County. The northeastern corner of Douglas County is bordered by Davison County (fig. 2).

Previous Investigations

Probably the earliest geologic descriptions of Charles Mix and Douglas Counties are found in the writings of Lewis and Clark (Thwaites, 1959). About 60 years later, Meek and Hayden (1861) briefly described the stratigraphy and landforms of parts of the two-County area while making a survey of the Nebraska Territory.

Many reconnaissance studies dealing with water resources, bedrock, and general geology have included parts or all of the two Counties (Chamberlin, 1883; Todd, 1885, 1894, 1896, 1900; Darton, 1896, 1905, 1909; and Rothrock, 1943). Flint (1955) made a reconnaissance study of the Pleistocene deposits of eastern South Dakota which included Charles Mix and Douglas Counties.

As part of a program to study the bedrock geology along the Missouri River a series of 15-minute geologic quadrangles were published by the South Dakota Geological Survey. Five of these include parts of Charles Mix County (Stevenson and Carlson, 1950, 1951; Baker, 1951; Baker and Carlson, 1951; and Carlson, 1950). A sixth quadrangle (Walker, 1963) describes geology and water resources of the Wagner quadrangle.

The Delmont outwash received a detailed study by

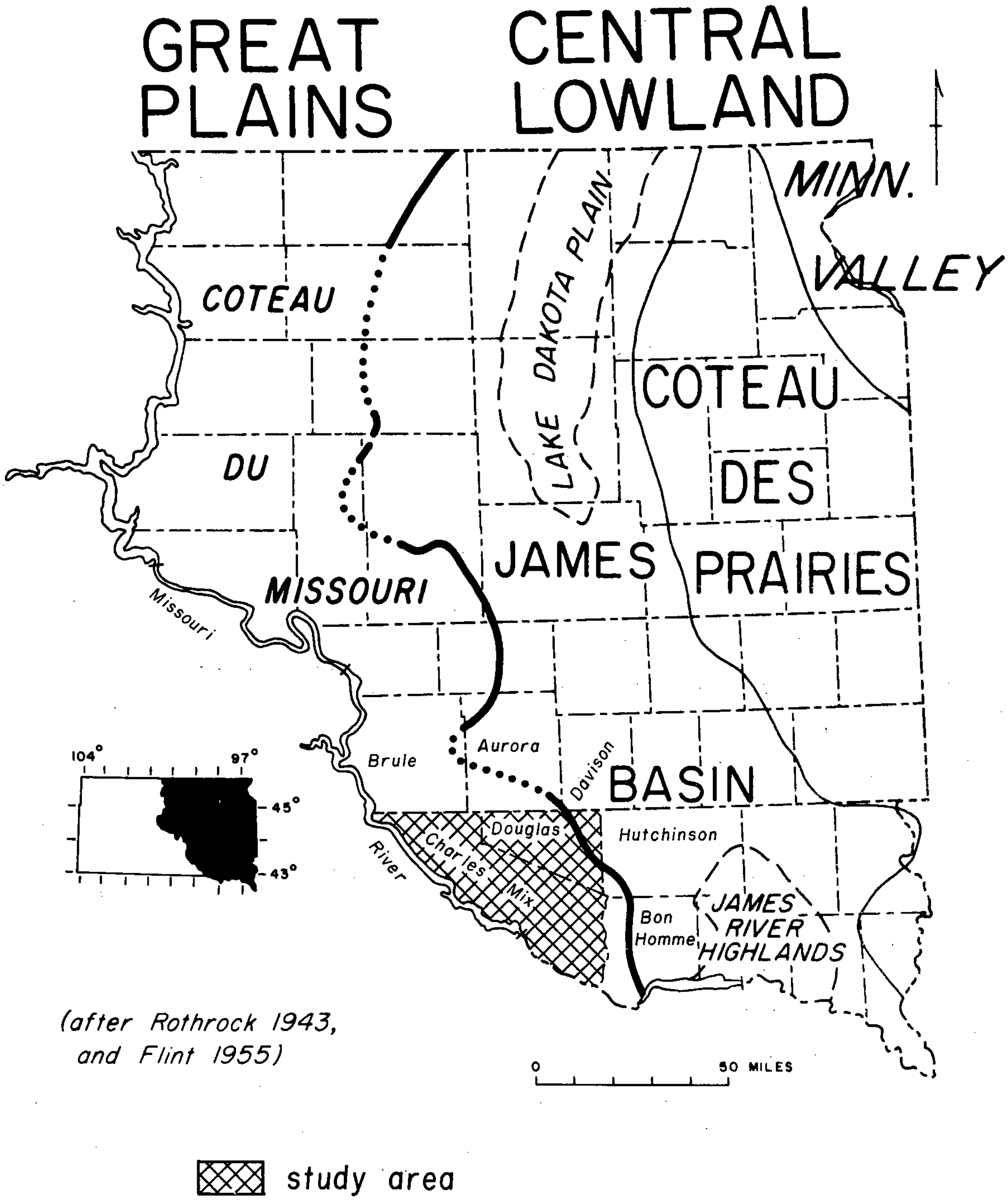

Figure 1. Map of eastern South Dakota showing the physiographic divisions and location of Charles Mix and Douglas Counties.

Stoley (1956) and a shallow ground-water resources investigation was conducted in the Wagner area including parts of Charles Mix and Douglas Counties (Walker, 1961). In addition, a ground-water supply study was conducted for the municipality of Lake Andes (Shurr, 1966).

A new formation, the Fort Randall Formation, was identified in extreme northwestern Charles Mix County (Skinner and Taylor, 1967).

Method of Procedure

Much of the information contained in this report was obtained during the summer field seasons of 1967, 1968, and 1969. The geologic data were plotted on aerial photographs having a scale of approximately 1:70,000 (about 1 inch = .9 miles) and were then transferred to a base map of the same scale. The base map was a standard South Dakota Department of Highways map (scale 1:63,000) reduced to the proper size.

Mapping of the geology was accomplished by inspection of natural and man-made exposures of rock material, information from hand auger holes, and data from many hundreds of test holes and wells. The published geologic maps mentioned in the previous section of this report were valuable aids, especially in mapping the bedrock formations. The published soils map for Douglas County (Watkins and Williams, 1928) and unpublished soils data for Charles Mix County were useful in determining geologic boundaries. Subsurface information was obtained from sample cuttings and electric logs of rotary test holes and power auger holes drilled by the South Dakota Geological Survey and United States Geological Survey. Much subsurface data were also available from records compiled by the Division of Resource Management (Department of Natural Resource Development), United States Bureau of Reclamation, and United States Corps of Engineers as well as data from files of local well drillers and from a well inventory which was conducted in the two Counties (see Parts II and III of this report).

Acknowledgements

The investigation and preparation of this report were performed under the supervision of Duncan J. McGregor, State Geologist. Special thanks go to Cleo M. Christensen and Jack Kume for their advice and assistance during several field conferences and later for their help in the preparation of this report. All members of the staff of the South Dakota Geological Survey are thanked for their assistance during the project.

The writer wishes to thank the Department of Transportation for their cooperation in providing information pertaining to gravel resources. Thanks are also due the local well drillers who provided subsurface information.

This study was requested by the County Commissioners of both Counties and the cooperation of the Commissioners and residents is acknowledged.

Monies for this investigation were furnished by the South Dakota Geological Survey, United States Geological Survey, Fort Randall Conservancy Sub-District, and Charles Mix and Douglas Counties.

Geography

Soils

At present no detailed soils maps are completed for Charles Mix or Douglas Counties. Although an old edition soils map (Watkins and Williams, 1928) is available for Douglas County, the terminology is now outdated. Therefore, a detailed discussion of the soils classification for the two Counties is not presented. On the basis of the topography and geology, it is possible to determine the general type of soil that may be present at specific localities.

Table 1 shows the various major types of soils that exist within the two Counties. The first group of soils mentioned are basically loams, silt loams, and clay loams developed on clay rich glacial till. Differences in topography and local variations in texture of parent material will cause these soils to be excessively drained, well drained, or poorly drained and the soils series will vary accordingly.

Group 2 soils are upland soils developed in thick loess which consists primarily of windblown silt.

The soils of group 3 are intermediate between groups 1 and 2 and are developed under similar conditions except due to the thin loess cover over till, more clay is likely to be present. Thus, soils of this group are primarily silty clay loams.

Soils of group 4 developed from outwash material are generally moderately well drained to excessively drained. A sandy loam soil will develop on outwash material consisting of sand and gravel. A silty or silty clay loam soil will develop on fine-grained outwash material such as silty fine sand or clayey silt.

Soils of group 5 are usually poorly drained to well drained. They develop over clay-rich and silt-rich alluvium along streams. A sub-division of this soil type is the poorly drained alluvial soils found in large and small undrained depressions. These are extremely clay-rich soils.

Group 6 soils are restricted to bedrock outcrop

Table 1. Soil Types in Charles Mix and Douglas Counties

Group	Parent Material	Soil Type	Topography
1	Glacial till	Loams, silty loam clay loam	Highly variable
2	Loess	Silty loam	Flat to moderately sloping
3	Loess over till	Silty clay loam	Flat to moderately sloping
4	Outwash (coarse)	Sandy loam	Flat to rolling
	Outwash (fine)	Silty loam, silty clay loam	Flat to slightly rolling
5	Alluvium	Clay loam, silty clay loam, silt loam, clay	Flat to sloping
6	Bedrock	Silty clay loam clay loam	Generally very rugged

areas in Charles Mix County. These soils are generally poorly drained to moderately drained, silty clay or clay-loam soils.

The general distribution of the soil types can be determined from the geologic map (pl. 1).

Physiography

All of Charles Mix and Douglas Counties, except for a few square miles in northeastern Douglas County, lie within the Coteau du Missouri section of the Great Plains physiographic province (fig. 1). This highland occurs unbroken north-south throughout North Dakota and South Dakota varying from 75 miles to less than 25 miles wide. Along much of its course in North Dakota and South Dakota the transition between the Coteau du Missouri and the James Basin to the east is a prominent escarpment. In northeastern Douglas County the transition is so gradual that one would hardly notice passing from one division to the other. The surface of the James Basin generally is 200 to 300 feet lower in elevation than the surface of the Coteau and does not usually portray the rugged and highly dissected appearance that is evident throughout much of the Coteau du Missouri.

Present within the Coteau du Missouri in Charles Mix and Douglas Counties are a variety of topographic features. Most conspicuous of these features is the steep-walled Missouri River trench which in northwestern Charles Mix County is over 700 feet deep. Adjoining the Missouri River, and eastward for several miles, is a highly dissected ridge. In northern and southeastern Charles Mix and central Douglas Counties are hummocky uplands. Between the dissected ridges along the Missouri River and the hummocky uplands the topography is less rugged and low-lying. These less rugged areas in general mark the courses of ancient stream valleys now partially filled with glacial debris.

STRATIGRAPHY

Stratigraphic Relations

The stratigraphic nomenclature used in this report conforms to that accepted by the South Dakota Geological Survey (Agnew and Tychsen, 1965) and to the Code of Stratigraphic Nomenclature (American Commission of Stratigraphic Nomenclature, 1961). Any deviations from the above guidelines will be pointed out during discussion in the text.

The following stratigraphic section lists all of the deposits that are recognized in Charles Mix and Douglas Counties. They are listed in order of their occurrence from the youngest deposit at the top to oldest at the bottom.

Quaternary System
- **Recent Series**
  - **Alluvium**
  - **Colluvium**
- **Recent and Pleistocene Series**
  - **Loess**
  - **Terrace Deposit**
- **Pleistocene Series**
  - **Wisconsin Glaciation**

Late Wisconsin
Early Wisconsin
Sangamon Interglaciation
Illinoian Glaciation
Yarmouth Interglaciation
Kansas Glaciation
Aftonian-Early Kansan
Miocene-Pliocene Series
Ogallala undifferentiated
Fort Randall Formation
Cretaceous System
Upper Cretaceous Series
Pierre Shale
Niobrara Marl
Carlile Shale
Greenhorn Limestone
Graneros Shale
Upper and Lower Cretaceous Series
Dakota Formation
Precambrian System
Sioux Quartzite and older rocks

Pre-Pleistocene Deposits

Precambrian Rocks

The Sioux Quartzite underlies a large area in Minnesota, Iowa, and South Dakota, forming a prominent ridge (Schoon, 1971, fig. 13, p. 14). The Sioux Quartzite crops out near Mitchell, South Dakota, about 15 miles north of Douglas County, but in south-central Douglas County and southeast Charles Mix County it is buried beneath more than 800 feet of sediment. The sparse deep drilling records indicate that all of Charles Mix and Douglas Counties are underlain with Sioux Quartzite except for a couple of questionable reports of granite in northeastern Douglas County (Steece, 1961) which may be older than the Sioux Quartzite.

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. In the Palensky-Weaver No. 3 oil test in southeastern Charles Mix County SE¼ SE¼ NW¼ SW¼ sec. 15, T. 95 N., R. 64 W.), Sioux Quartzite was still being encountered when drilling ceased at 3,787 feet. The Douglas Development Company oil test in south-central Douglas County drilled 7 feet of Sioux Quartzite, the last few inches being cored.

A potassium-argon age determination on a sample of pipestone from a location near Pipestone, Minnesota, produced a minimum age of 1.2 billion years (Goldich and others, 1961). They suggested a maximum age of about 1.7 billion years for the Sioux Quartzite.

Cretaceous Rocks

The bedrock of Charles Mix and Douglas Counties is primarily of Cretaceous age although Schoon (1971, fig. 9, following p. 10) suggests the possibility of older rocks being present in northwestern Charles Mix County.

The Cretaceous rocks consist mostly of shales, marls, limestones, and sandstones. In ascending order they are the Fall River Formation, Skull Creek Shale, Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Marl, and the Pierre Shale.

Fall River Formation and Skull Creek Shale

The Clark No. 1 Douglas Development Company oil test in south-central Douglas County penetrated a sequence of shale and sandstone deposits about 100 feet thick which are tentatively correlated with the lower Cretaceous Skull Creek Shale and the Fall River Sandstone. About one-half of the thickness is attributable to each unit. The Fall River Formation consists of white, fine- to coarse-grained sandstone, and the Skull Creek Shale is a dark-gray shale.

Subsurface data needed to verify the presence and extent of these rocks are lacking. However, the tentative identification of these rocks at this aforementioned location suggests that they could occur at least sporadically in the western two-thirds of the study area.

Dakota Formation

The Dakota was first described by Meek and Hayden (1861) from an exposure in Dakota County, Nebraska, and was designated by them as Formation No. 1 of the Cretaceous. The term "Dakota" has since been overly used, misused, and abused in the literature. The term Dakota Formation used in this report conforms to those sediments as originally described by Meek and Hayden and recently verified by Schoon (1971).

The Dakota Formation is composed of alternating beds of varicolored siltstone, sandstone, and shale. The maximum known thickness of the Dakota Formation in the two Counties is about 450 feet in the Douglas Development Company oil test in Douglas County. A thickness of 528 feet was reported in the Palensky-Weaver No. 3 oil test in south-central Charles Mix County but this may include some older deposits. To the northeast and southeast towards the Sioux Ridge the Dakota Formation thins rapidly (Schoon, 1971, fig. 1) to about one-half its maximum thickness.

A structure contour map (fig. 3) drawn on top of the Dakota Formation shows a nearly uniform rise in elevation of its upper surface from 700 feet in the extreme southeastern part of Charles Mix County to nearly 900 feet in elevation across the northern boundaries of the two Counties. This structural control no doubt reflects influence of the Sioux Ridge.

Graneros Shale

Gilbert first described the Graneros from an exposure near Graneros Creek, Pueblo County, Colorado, in 1896. The name was suggested by R. C. Hill (Agnew and Tychsen, 1965). The Graneros is a widespread formation in South Dakota and it is present in the subsurface throughout Charles Mix and Douglas Counties overlying the Dakota Formation.

The Graneros Shale is a marine sequence of medium to dark gray, noncalcareous, silty shale. In Charles Mix and Douglas Counties it varies in thickness from about 50 feet in southern Charles Mix County to about 90 feet thick in northern Charles Mix and Douglas Counties.

Greenhorn Limestone

The Greenhorn Limestone was first described and named by Gilbert from an exposure near Greenhorn Station, 14 miles south of Pueblo, Colorado (Agnew and Tychsen, 1965).

The Greenhorn Limestone consists of gray marl with a white-speckled appearance and fragmental limestone in which the fossil *Inoceramus labiatus* is most common. There are no exposures of the Greenhorn in Charles Mix and Douglas Counties. Well records indicate the Greenhorn varies in thickness from 25 to 60 feet but probably averages about 35 feet thick.

The calcium carbonate prisms from the fragmental limestone make this formation easily recognizable in well cuttings. The characteristic "kick" of this formation on electric logs and radioactivity logs makes this an easily recognizable unit and thus it is a good stratigraphic marker bed in the Upper Cretaceous sediments of South Dakota.

The surface of the Greenhorn Limestone has a nearly uniform slope from an elevation under 800 feet in the southeastern part of Charles Mix County to an elevation of about 1,000 feet around Platte in north-central Charles Mix County (fig. 4). This structural control is probably due to the influence of the Sioux Ridge.

Carlile Shale

The Carlile Shale was first described and named by G. K. Gilbert in 1896 from an exposure near Carlile Spring and Carlile Station, 21 miles west of Pueblo, Colorado (Agnew and Tychsen, 1965).

The Carlile consists of a medium gray to black, noncalcareous, fissile shale with silty zones.

The Codell Sandstone Member of the Carlile Shale is widespread in the two Counties. This sandstone unit is as much as 55 feet thick and averages about 30 feet thick. The Codell may occur at the top of the Carlile in contact with the Niobrara Marl, or it may be separated from the Niobrara by as much as 20 feet of Carlile Shale. The Codell Sandstone Member of the Carlile Shale is fine to medium grained, and may be unconsolidated or cemented. The color may be gray, brown, green, reddish-brown, or black.

Maximum known thickness of the Carlile Shale including the Codell Sandstone Member is 250 feet in the two-County area. The Carlile Shale directly underlies the glacial drift in the eastern parts of Charles Mix and Douglas Counties (fig. 5).

Niobrara Marl

Meek and Hayden (1861) first described the Niobrara Marl from an exposure along the Missouri River near the mouth of the Niobrara River, Knox County, Nebraska. However, according to Agnew and Tychsen (1965), no type location has ever been designated for this formation.

In Charles Mix and Douglas Counties the Niobrara Marl is predominantly a light- to dark-gray speckled marl with some "chalk" and limestone as well as thin shaly beds. The Niobrara has an average thickness of about 150 feet in Charles Mix and Douglas Counties. The Niobrara Marl is exposed in Charles Mix County along the Missouri River bluffs below Fort Randall Dam (see pl. 1). Where exposed, the marl weathers white to orange-yellow.

The matrix of the Niobrara has a high microfossil content. Common planktonic forms are *Globigerina, Planomalina*, and *Heterohelix*. Common macrofossils in the Niobrara are *Ostrea congesta* and *Inoceramus gigantica*. On the basis of foraminifera Bolin (1952) has divided the Niobrara into an upper Smoky Hill Member and lower Fort Hays Member. For this study there has been no attempt to differentiate and map the Members of the Niobrara Marl.

The Niobrara Marl underlies the glacial drift throughout much of the two-County area (fig. 5). Because the top of the formation has been eroded throughout much of the study area, control data for a structure contour map on top of the formation are limited. A map showing the reconstructed surface of the Niobrara is shown in figure 6. This figure shows a generally southeasterly sloping surface with a high

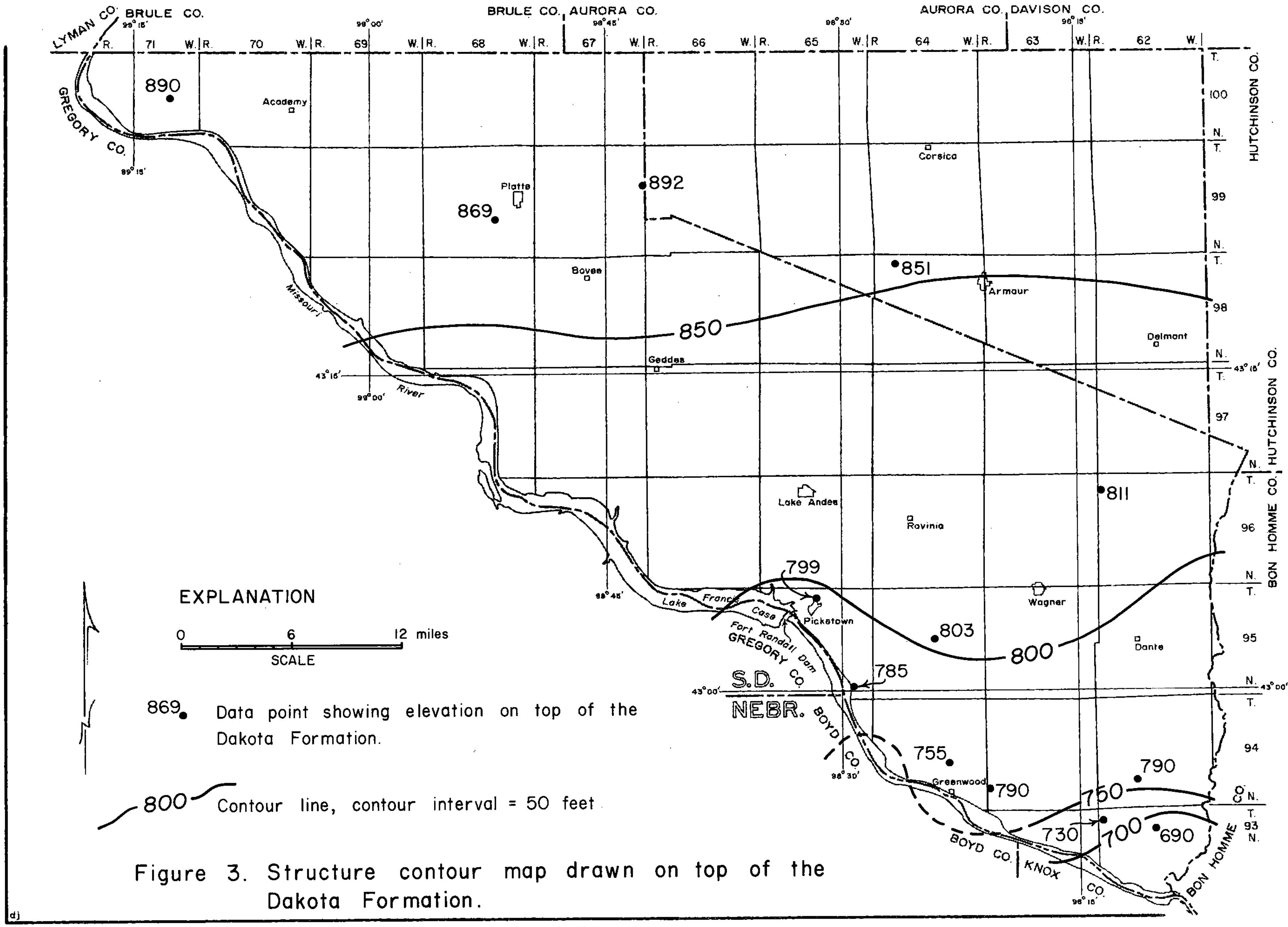

Figure 3. Structure contour map drawn on top of the Dakota Formation.

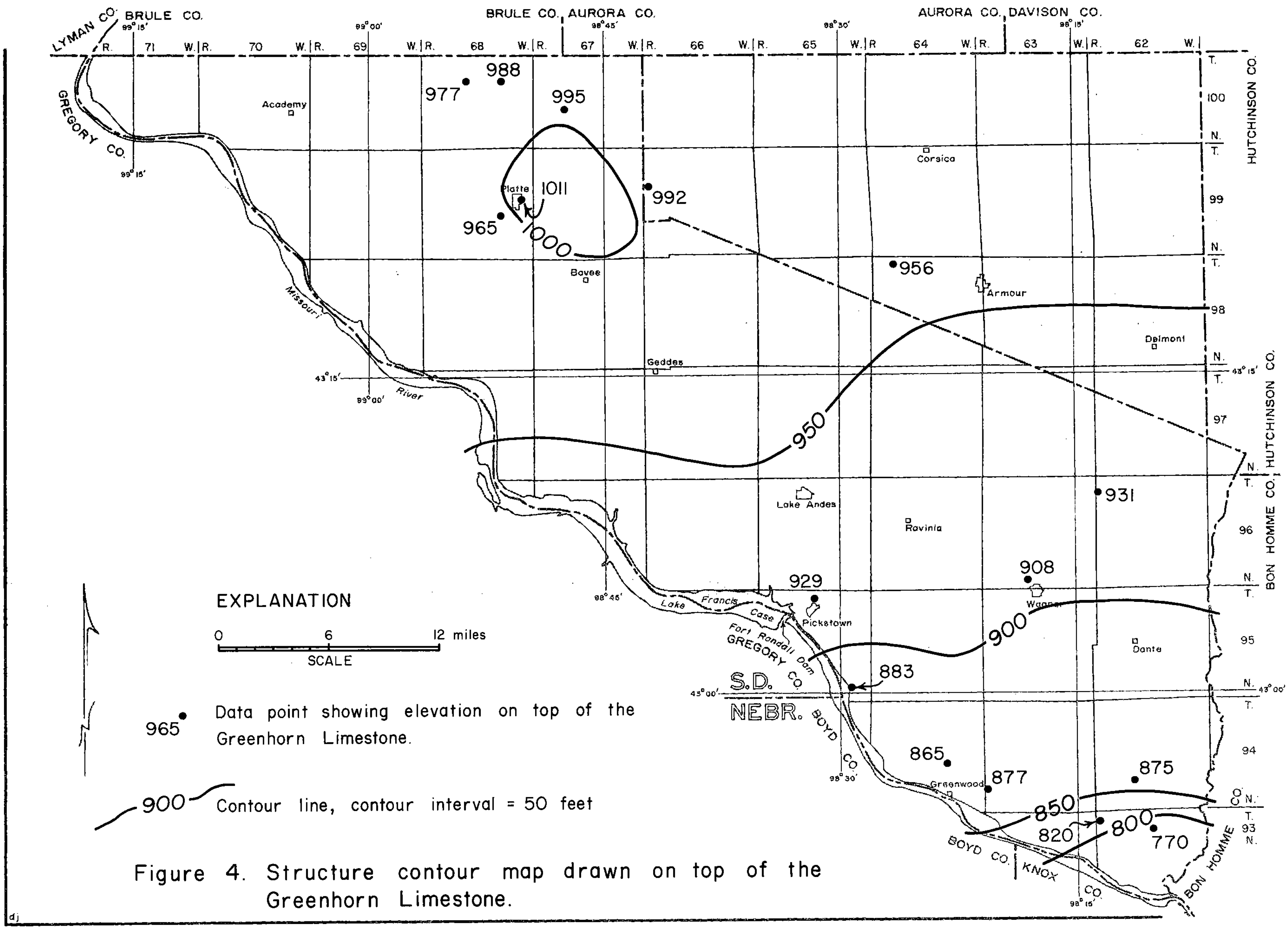

Figure 4. Structure contour map drawn on top of the Greenhorn Limestone.

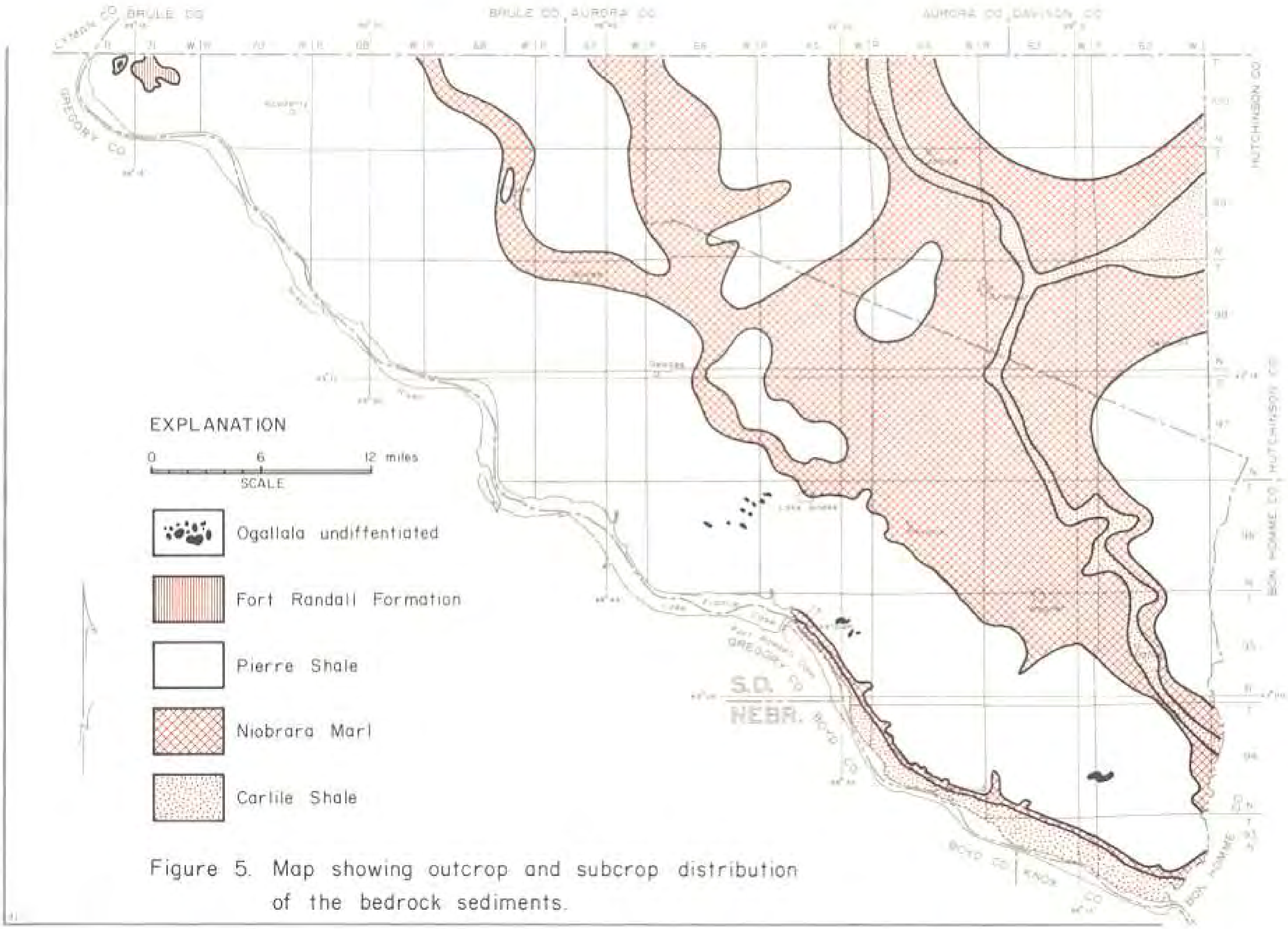

Figure 5. Map showing outcrop and subcrop distribution of the bedrock sediments.

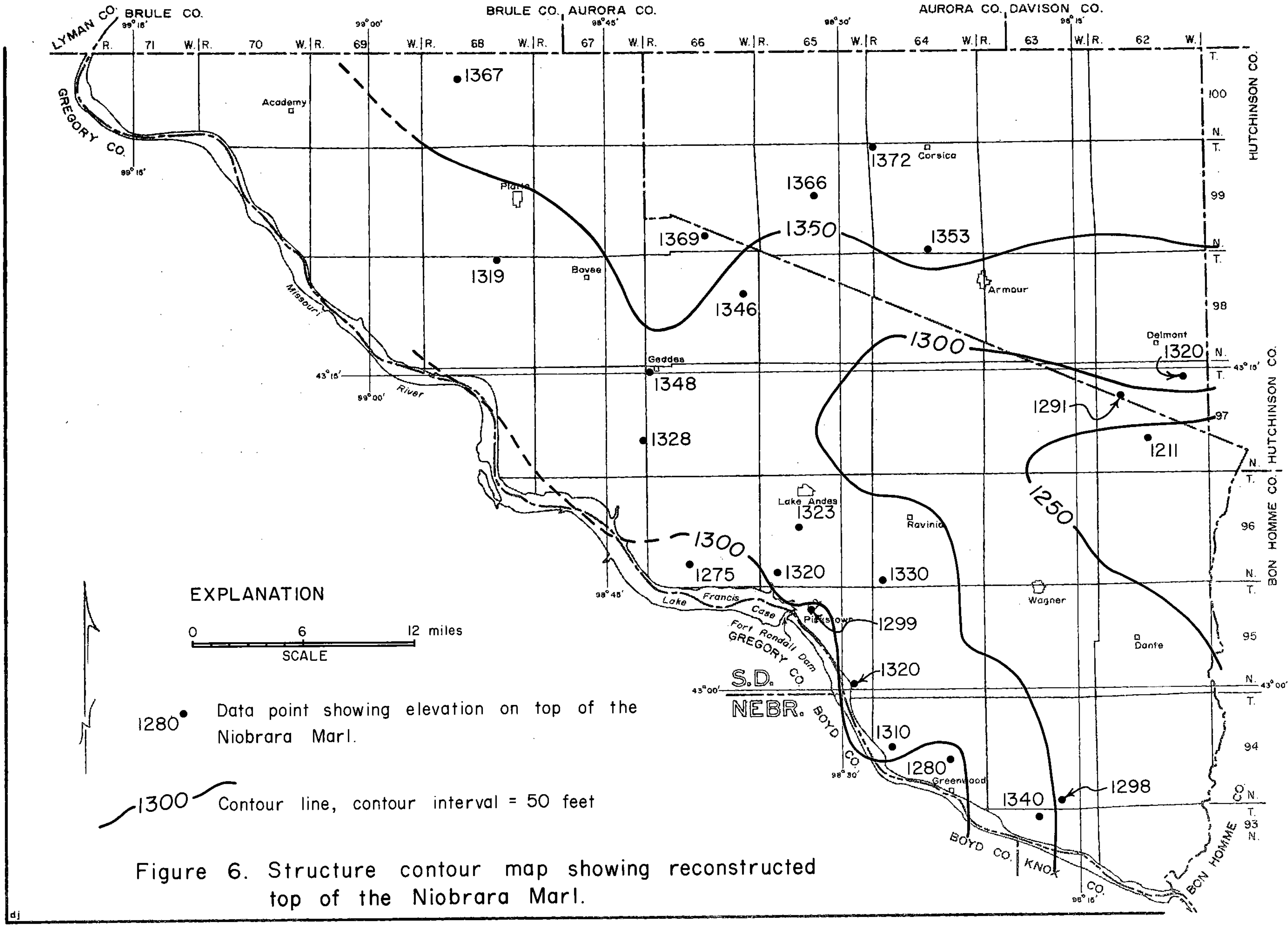

Figure 6. Structure contour map showing reconstructed top of the Niobrara Marl.

elevation near 1,400 feet in the north, and a low elevation of just over 1,200 feet in the southeastern part of the area.

Pierre Shale

The Pierre Shale was first named the Ft. Pierre Formation by Meek and Hayden (1861) and the name was shortened to Pierre by Darton as early as 1896. Development of nomenclature for subdividing the Pierre in central South Dakota has resulted in the following classification now accepted by the South Dakota Geological Survey:

Elk Butte Member	(upper member)
Mobridge Member	
Virgin Creek Member	
Verendrye Member	
DeGrey Member	
Crow Creek Member	
Gregory Member	
Sharon Springs Member	(lower member)

The above classification was first used by Crandell (1950). Later, Crandell (1958) used this same classification in his report on the Pierre Shale around the city of Pierre, South Dakota. In the latter report Crandell also provided a current history of nomenclature for members of the Pierre Shale.

In Charles Mix County the Pierre Shale crops out extensively along the Missouri River and some of its tributaries. In Douglas County the Pierre Shale crops out in only one small area in a road cut in a gully near Choteau Creek 7 miles east and 1 mile north of Corsica (pl. 1). A composite section of the Pierre Shale taken along the Missouri River reveals nearly the complete sequence of rocks except possibly for the upper part of the Elk Butte Member which may be partially eroded. The total thickness of the Pierre Shale in Charles Mix County exceeds 600 feet. The Pierre Shale is also the first Cretaceous bedrock beneath the glacial drift throughout much of the two-County area (fig. 5).

The Pierre Shale is a light-gray to black clay shale. Depending on which members are present, the shale may contain ferruginous and limestone concretions, bentonite beds, marl zones, and at its base a black organic clay shale. The weathered shale is generally medium to dark gray although locally varicolored beds are present.

In this report the various members of the Pierre Shale have not been differentiated. Much of the exposed Pierre Shale in Charles Mix County has been mapped in detail and published in several geologic quadrangle maps. The locations and names of these quadrangles are shown in figure 7.

Miocene-Pliocene Rocks

Fort Randall Formation

The Fort Randall Formation was named by Skinner and Taylor (1967) from outcrops on South Bijou Hill in the extreme northwestern corner of Charles Mix County (pl. 1). This hill and possibly some of the uplands immediately adjacent are the only known occurrences of this formation in Charles Mix and Douglas Counties.

The Fort Randall Formation represents cyclic deposition of gray to pink siltstones and clays and contains a secondary barite crystal zone. The known thickness of the Fort Randall Formation varies from 60 to 120 feet. There is an unconformity between the Fort Randall and the underlying Cretaceous Pierre Shale. An unconformity also is present between the overlying Ogallala and the Fort Randall Formation and it represents a time span partially equivalent to that between the Lower Snake Creek beds and the Lower Valentine Formation of Nebraska (Skinner and Taylor, 1967).

Ogallala Undifferentiated

In 1861 Meek and Hayden (p. 433, 435) included the present Ogallala or "Tertiary grit" in the upper part of the Loup River beds. Darton (1899) later gave the name Ogallala to these deposits.

Ogallala deposits were not found in Douglas County during this study but they were recognized at several widespread locations in Charles Mix County. The Ogallala overlies the Fort Randall Formation on South Bijou Hill in extreme northwestern Charles Mix County and is nearly 50 feet thick, by far the greatest thickness in the two-County area. At this location the Ogallala is predominantly a loose, well-sorted, channel-type sand deposit with beds of greenish-brown clay and hard orthoquartzite layers 1 to 5 feet thick. The orthoquartzite forms resistant ledges where it is present.

The Ogallala crops out in several locations 2 to 5 miles southwest of the city of Lake Andes and at several locations 2 to 3 miles southeast of Pickstown. In both of these areas the Ogallala consists of less than 10 feet of resistant greenish orthoquartzite capping the uplands. At some locations glacial till may overlie the Ogallala. The Ogallala also crops out in southeastern Charles Mix County 10 miles south and 3 miles east of Wagner (pl. 1). At this location several feet of orthoquartzite are exposed and overlain with glacial drift. The thickness of the Ogallala at this location is unknown.

In the literature there has been some confusion

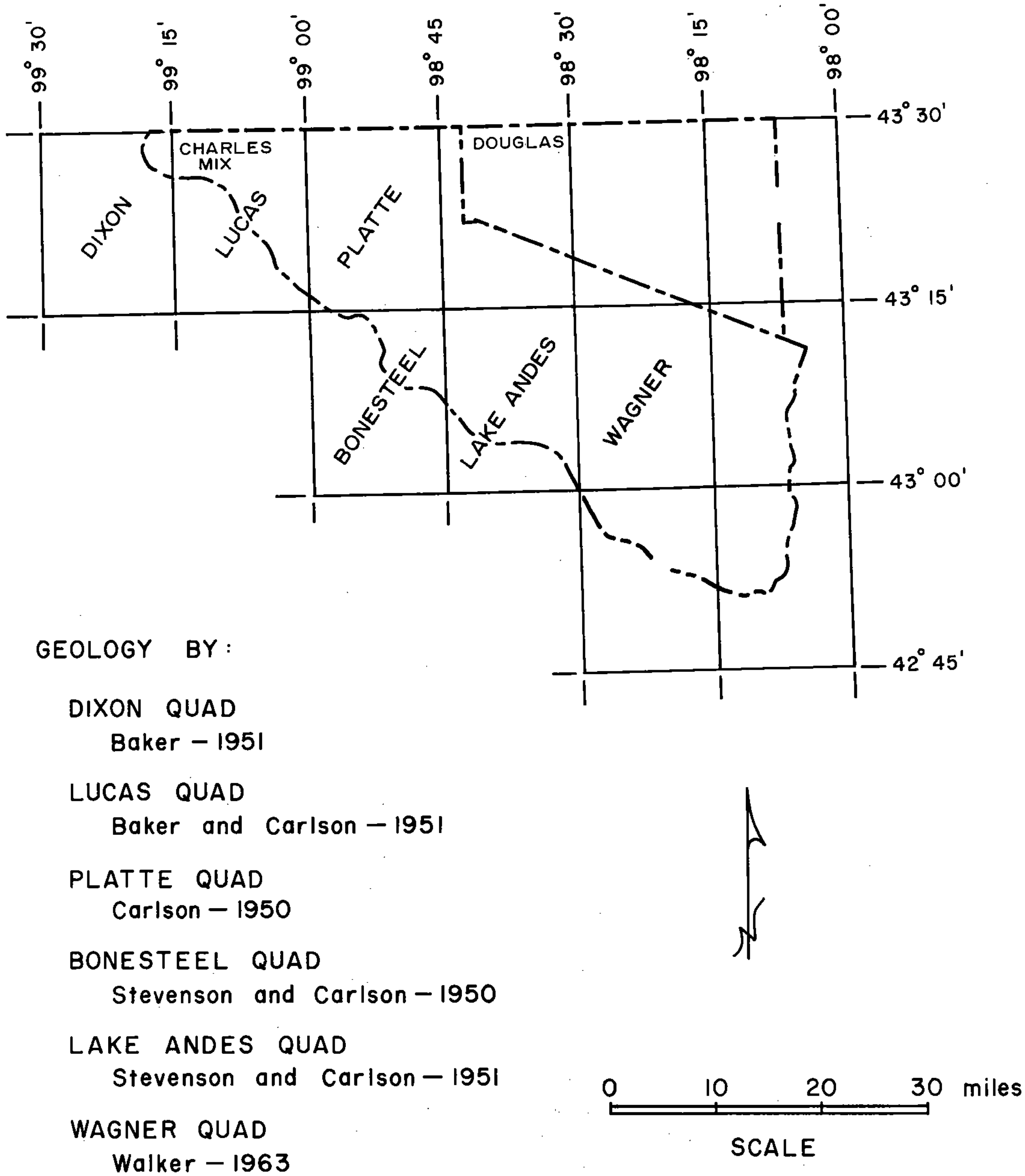

Figure 7. Location of mapped geologic quadrangles in Charles Mix and Douglas Counties.

about classifiying the greenish orthoquartzite layers. Skinner and Taylor (1967, p. 7) offer a summation of their conclusions in the following quotation:

"It is our contention that the 'Bijou Quartzite' or facies, is not a formation but a post-depositional cementation of certain sand beds that may, and does, occur throughout several lithic units or formations of the Tertiary and is not confined to any of them."

Pleistocene Deposits

Pleistocene deposits in Charles Mix and Douglas Counties consist of non-glacial sand and gravel deposits of western origin, loess, and glacial drift. The maximum thickness of glacial drift in the two Counties has not been determined but several test holes indicate more than 400 feet of glacial and non-glacial Pleistocene deposits.

Dating the Pleistocene deposits is especially difficult because materials commonly used for absolute dating are lacking and the fossil material so far collected has not proved to be diagnostic. Therefore, the age determinations are based mainly on topography, physical characteristics, and stratigraphic relationships.

In Charles Mix and Douglas Counties there are no known deposits of Nebraskan age. The Nebraskan glacier probably did not reach as far west as Charles Mix and Douglas Counties and any non-glacial deposits of Nebraskan age probably were reworked or completely removed through erosional processes.

Aftonian-Early Kansan Non-Glacial Deposits

At scattered locations throughout Charles Mix and Douglas Counties there are high-level western derived non-glacial fluvial deposits. These sand and gravel deposits directly overlie bedrock and occur above 1,475 feet elevation. For location and elevation relationsips, see figure 8.

The western derived sand and gravel consists of clear quartz with varying amounts of pink feldspar. Shale fragments are completely lacking but traces of iron and manganese concretions, coal, and clay lumps are occasionally present. These deposits are easily distinguished from glacial outwash sand and gravel by lack of shale fragments as shown by the quartz to shale ratios in table 2. Stratification is usually well developed and is of the lenticular cut and fill type. According to samples analyzed by the U.S. Corps of Engineers and the Department of Transportation, Materials Testing Laboratory, the deposit near Pickstown contains medium to coarse sand with as much as 30 percent (by weight) granules (Walker, 1963, app. N.).

Stratigraphically the high-level deposits overlie bedrock of Cretaceous or Tertiary age and they are overlain by Late Wisconsin glacial deposits. Thus, the age of these deposits must be inferred from other methods. Mammalian bone and tooth fragments from the Casper sand pit exposure just east of Pickstown and the pit on the Charles Mix-Douglas County line (fig. 8) were identified by C. B. Schultz and W. D. Frankforter (Flint, 1955, p. 48-51). They expressed the opinion that the meager fossil assemblage suggested an Aftonian age or an age no younger than early Kansan. The present writer agrees with this age designation for the two localities previously discussed and for all the high-level non-glacial sand and gravel deposits in Charles Mix and Douglas Counties.

The high-level gravels at Pickstown were correlated with and mapped as the Herrick gravels on the Lake Andes quadrangle (Stevenson and Carlson, 1951). Walker (1963) correlated these deposits with the Red Cloud formation of Aftonian or early Kansan age.

Kansan Glacial Deposits

Kansan Till

A till inferred to be of Kansan age is present in Charles Mix and Douglas Counties. This till occurs only in the subsurface at several limited locations (pls. 2 and 3). The known thickness of the till varies from 18 feet in test hole 96-63-14bbbb to 113 feet in test hole 96-6-117aaaa (pl. 3). Recognition of this till is inferred by its stratigraphic relationship because lithologic correlation of various tills from drill hole cuttings is not feasible in this area. Thus, the only till that can be tentatively identified as Kansan is that till underlying the late Kansan Wagner Formation. The Kansan till may be more extensive than indicated by the cross sections but probably would still be restricted to only the deeper parts of the bedrock channels.

This till has been assigned a Kansan age because it is stratigraphically lower than the Wagner Formation which is tentatively dated as late Kansan. Other indirect evidence precludes the possibility of Nebraskan age glacial deposits in Charles Mix County, so the till most probably is Kansan. Flint (1955, p. 34) recognized three tills exposed during construction of the Fort Randall Dam. The lower most of these tills may be equivalent to the Kansan till described herein and which Flint correlated with Illinoian. The reasons for this discrepancy in correlation will be discussed in the next section of this report under Wagner Formation.

Kansan Outwash(?)

Kansan outwash, like Kansan till, is present only at limited locations and always in the deeper parts of the bedrock channels. Like Kansan till, the presence of Kansan outwash can only be inferred by

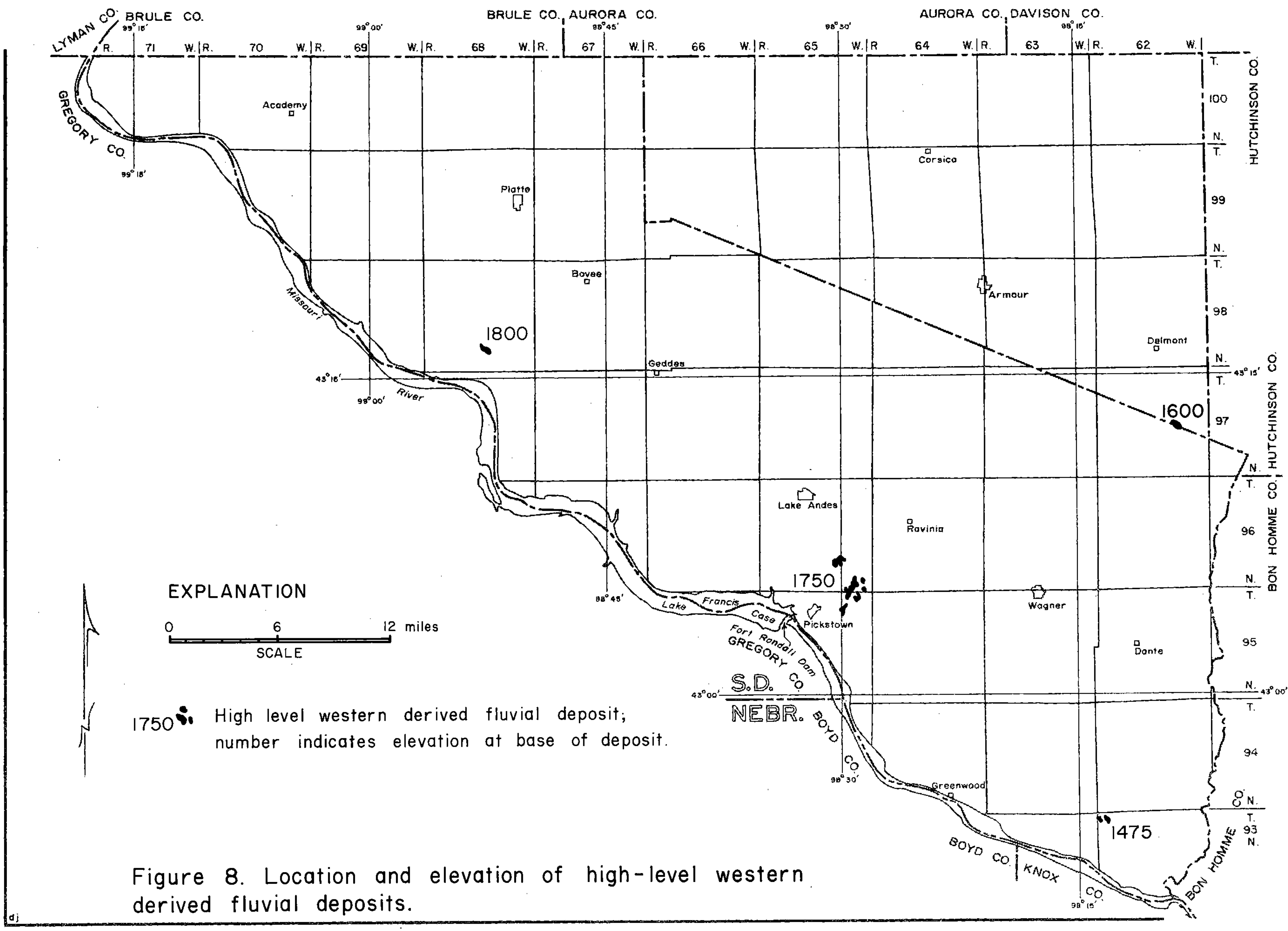

Figure 8. Location and elevation of high-level western derived fluvial deposits.

Table 2. Quartz/Shale Ratios of Samples from Glacial Outwash, Aftonian-Kansan Sand and Gravel and Kansan-Yarmouthian Sand and Gravel Deposits (after Walker, 1963, p. 71).

Sample Type and Location	Number of Quartz Grains	Number of Shale Fragments	Sand/Shale Ratios
97-63-36 Glacial Outwash	Average of 5 samples (after Stoley, 1956)		3.9
Well Kansan-Yarmouthian	580	6	96.6
95-65-36ccd Aftonian-Kansan	700	0	∞

stratigraphic relationship. Thus Kansan outwash can be postulated only where outwash is present underlying the late Kansan Wagner Formation.

The main occurrence of Kansan outwash is illustrated in cross section (pl. 3) where as much as 135 feet of fine, gray sand is present. At some locations the fine, gray sand contains thin gravelly outwash beds. The presence of the outwash gravel interbedded with the fine sand suggests that the deposit is primarily a glacial outwash deposit or outwash-alluvium complex rather than a western derived non-glacial deposit.

Wagner Formation

Test drilling in Charles Mix and Douglas Counties has contributed a substantial amount of knowledge about a Pleistocene stratigraphic unit which has not previously been recognized as a formal stratigraphic unit. This report recognizes the rock unit as a formation and proposes the new name Wagner Formation for this rock unit. The new name, Wagner Formation, has been reserved by the Geologic Names Committee for designating the new formation (George V. Cohee, Chairman, Geologic Names Committee, written communications, November 6, 1972).

General Occurrence

The Wagner Formation is a non-glacial, fluvial deposit of western origin which is present in the subsurface throughout many of the buried channels in Charles Mix and Douglas Counties.

Walker (1963) first described the Wagner Formation as a blanket-like deposit averaging 50 feet in thickness covering an area of about 225 square miles. Additional test drilling since Walker's report has revealed that the formation is not continuous over a broad area as supposed by Walker but is probably a series of disconnected remnants. The channel boundaries (fig. 9) outline the inferred maximum former extent of the deposit.

With the completion of the study in Charles Mix and Douglas Counties, it seems almost a certainty that the Wagner Formation was deposited by the White River during a time that it was flowing through the study area. This concept is strongly supported by comparing Flint's map showing elements of the inferred prediversion drainage system of eastern South Dakota (Flint, 1955, pl. 7) with a newly revised map of the area emphasizing Charles Mix and Douglas Counties (fig. 10). In general, Flint's interpretation (fig. 10) shows east-west trending divides and drainages south of the White River. The revised interpretation shows northward projecting drainages breaching the inferred divide area and trending toward the White River.

Flint described a low-level western derived sand and gravel in the eastern wall of the Missouri River trench opposite the mouth of the White River (Flint, 1955, p. 48 and 51). This exposure occupies the floor of the abandoned prolongation of the White River. The western derived sediments in this exposure are very similar lithologically to the Wagner Formation. Furthermore, the base of the abandoned valley floor at the mouth of the White River is about 1,475 feet which is higher than the valley floors in the study area. The above relationships plus the absence of any other major drainages entering the study area leave only one conclusion. That is, the White River once flowed southeast through Brule County, and possibly through Aurora and Davison Counties, and then into Charles Mix and Douglas Counties.

Designation of Type Section

Because no exposures of the Wagner Formation are present in Charles Mix and Douglas Counties, the type section is a test hole drilled by the South Dakota Geological Survey located in NW¼ SW¼ SW¼ NW¼ sec. 14, T. 96 N., R. 64 W. about 6 miles northwest

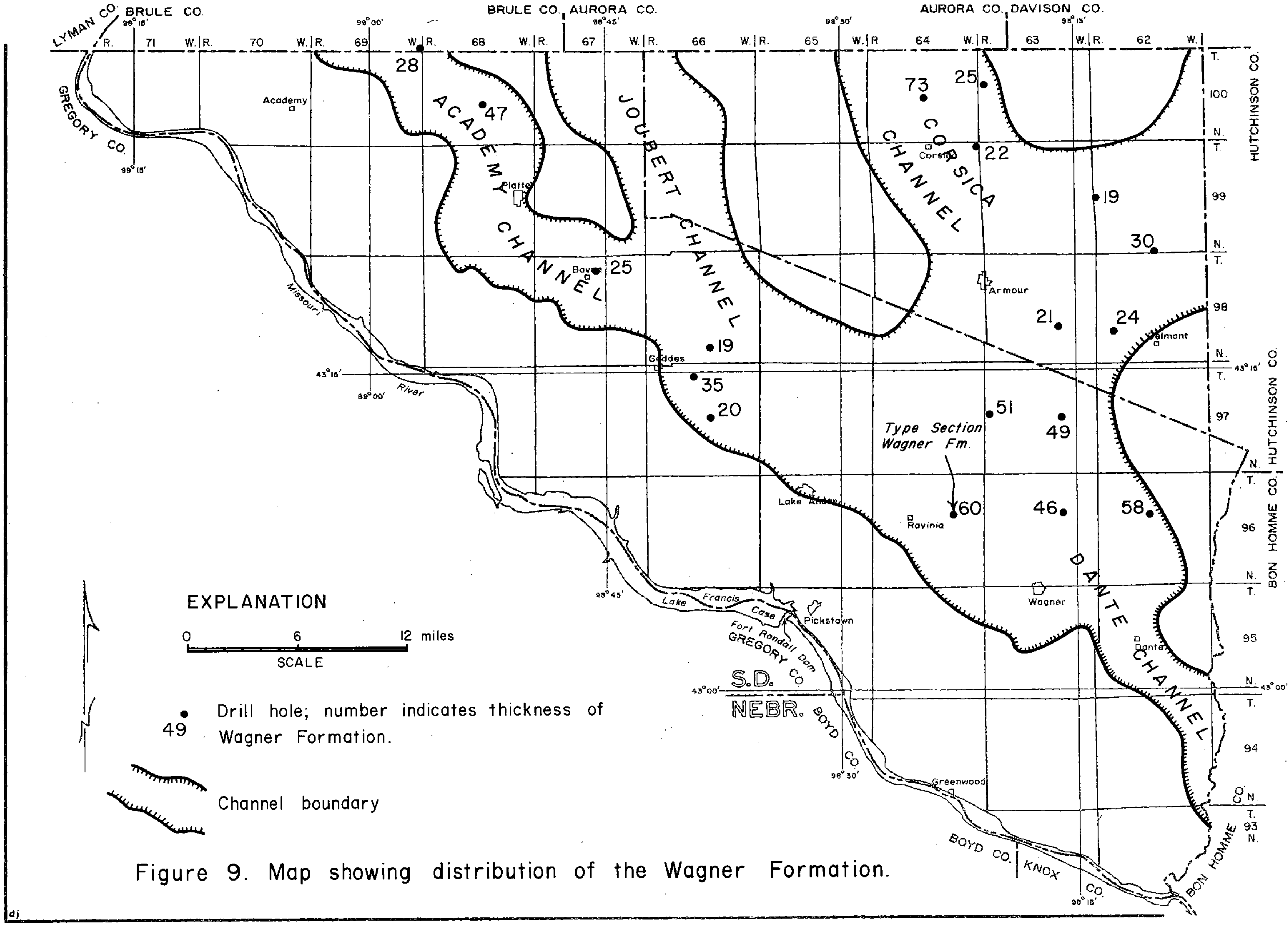

Figure 9. Map showing distribution of the Wagner Formation.

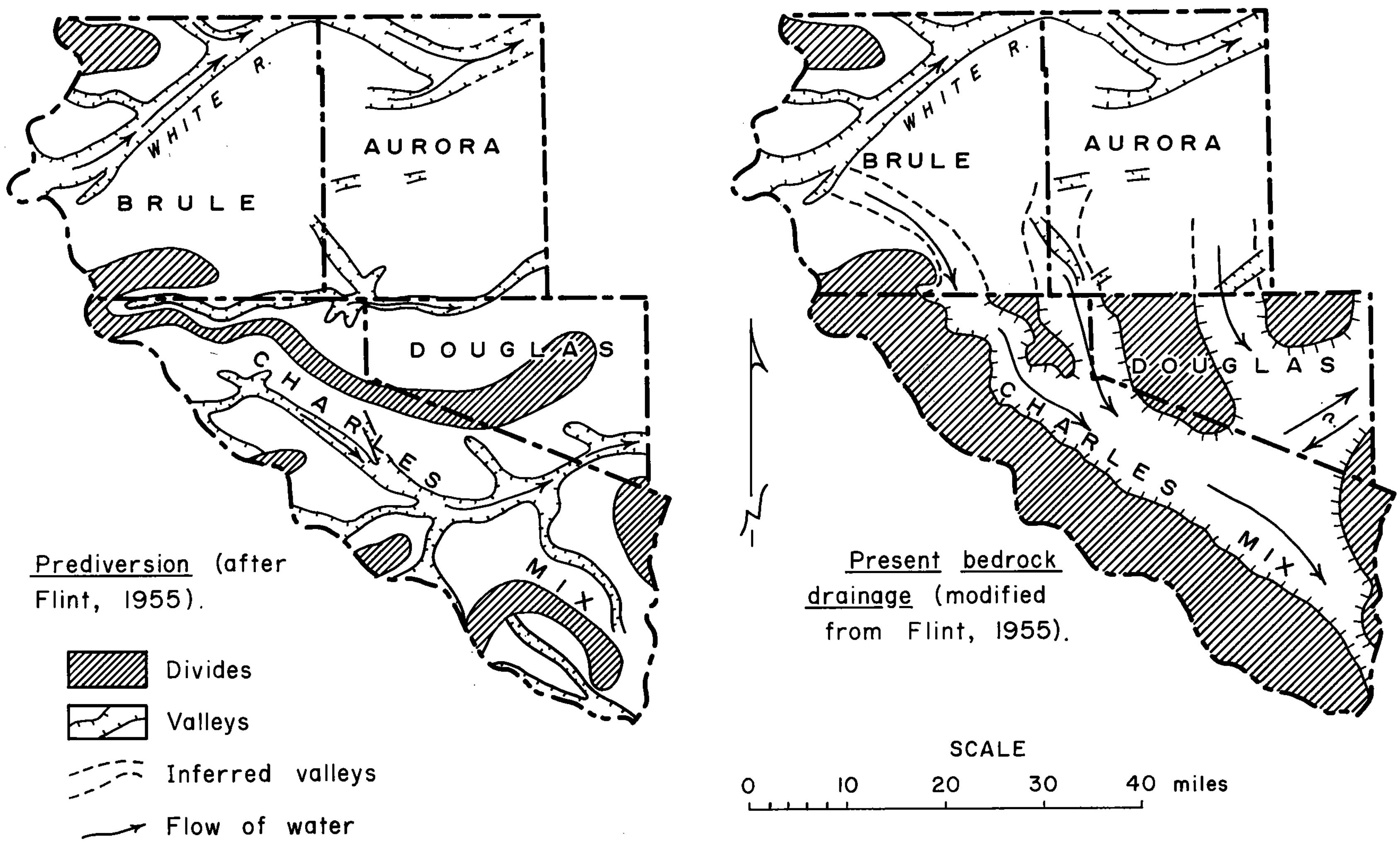

Figure 10. Map showing inferred prediversion drainage and present bedrock drainage.

of the city of Wagner, Charles Mix County, South Dakota (fig. 9). This test hole was chosen as the type section because it contained one of the thicker sequences of the rock unit, there was good sample recovery from the test hole, and an electric log of this test hole is available. The formation description is based on rotary drill cuttings collected at 10-foot intervals. The upper and lower contacts are based on drilling characteristics and the electric log. Drill hole samples as well as the electric log are on file at the South Dakota Geological Survey, Akeley Science Center, Vermillion, South Dakota.

Description

At its type section the Wagner Formation consists of 60 feet of unconsolidated gravelly sand. The sand- and gravel-sized particles consist of pink feldspar, quartz, white and brown quartzites, chalcedony, and other volcanic rock fragments. The abundance of pink feldspar gives the sand a pinkish cast and the formation is often referred to locally by well drillers as "rainbow sand." This particular suite of rock fragments is characteristic of fluvial deposits derived from the Black Hills or Rocky Mountain area of Colorado. These lithologic characteristics plus the absence of local shale and marl fragments as well as granitic rocks from the Canadian Shield make this formation easily distinguishable from glacial outwash if reworking and mixing have not occurred. No fossil material was observed in the drill hole cuttings. A lithologic log and electric log at the type section are shown in figure 11. These logs are typical of the formation throughout its known extent.

Stratigraphic Relationship

The Wagner Formation underlies glacial deposits 130 to 300 feet thick. Much of the bulk of the drift overlying the Wagner Formation is Late Wisconsin in age although by inference the glacial deposit directly overlying the formation is of probable Illinoian age (pls. 2, 3, and 4). Northwest of Lake Andes the Wagner Formation lies on the eroded bedrock surface which is either Niobrara Marl or Pierre Shale of Cretaceous age. To the east and northeast the Wagner Formation overlies Cretaceous bedrock or glacial till and outwash alluvium of probable Kansan age.

Thickness and Distribution

The Wagner Formation varies from 19 to 73 feet in thickness (fig. 9). Considering the fact that the channels containing the Wagner Formation carried diversion water at least once during the Kansan glaciation, and meltwaters twice more during the Illinoian and Late Wisconsin glaciations, the assumption is that the formation was probably considerably thicker than present data would indicate.

The continuity of the formation in the subsurface is conjectural. Data from some areas seem to indicate a fairly continuous blanket-like deposit, whereas in other areas only isolated remnants are present. The Dante Channel (fig. 9) is presently filled mostly with outwash and some till, primarily of Late Wisconsin age. If the Wagner Formation originally occupied this channel, it was removed by the large torrents of meltwater and later replaced by outwash and till from the advancing ice. Very little drill hole data are available from the Joubert Channel so the presence or absence of the Wagner Formation in this area cannot presently be confirmed.

Evaluation of the present known distribution of the Wagner Formation should consider the following facts:

1. The formation is somewhat discontinuous due to subsequent erosion;

2. Much of the drilling information is from sources other than the South Dakota Geological Survey and the formation may not have been recognized or properly identified if it was recognized;

3. Where the Wagner Formation is overlain with considerable thicknesses of outwash the samples could be so badly mixed that the formation was not recognized;

4. The Wagner Formation may have been reworked and incorporated into the outwash at the time the outwash was being deposited; and

5. Many test holes and wells did not penetrate to a sufficient depth to reach the deposit.

Age and Correlation

The low-level western derived fluvial deposit in Charles Mix and Douglas Counties herein named the Wagner Formation was first described by Walker (1963). On the basis of knowledge then available, he assigned the date of deposition as probably Illinoian or possibly late Yarmouthian and the deposit was correlated with the Crete Formation of Nebraska. This interpretation was based mainly on the work of Flint who arrived at a similar conclusion for the low-level western derived deposits near the mouth of the White River (Flint, 1955, p. 48 and 51).

The present writer favors a Kansan age for the Wagner Formation and thus by correlation also the low-level deposit at the mouth of the White River. The basis for this conclusion is offered in the following discussion.

Evidence of Early Wisconsin glaciation

(Iowa-Tazewell) in South Dakota, other than in the extreme eastern part of the State, has never been satisfactorily demonstrated. In Bon Homme County, Christensen (1974) found no evidence of Early Wisconsin glaciation. The present study in Charles Mix and Douglas Counties likewise found no evidence of Early Wisconsin glaciation. In Bon Homme, Charles Mix, and Douglas Counties, three tills were tentatively identified: one Late Wisconsin till and two pre-Wisconsin tills, presumably Illinoian and Kansan respectively. In Charles Mix and Douglas Counties, the oldest till underlies the Wagner Formation which in turn is overlain by two more tills. These two upper tills then would be Illinoian and Late Wisconsin respectively, thus bracketing the Wagner Formation by Illinoian till and Kansan till. A history of the geomorphic evolution of the area suggests that the Wagner Formation was deposited as a result of diversion of the White River by the ice that deposited the lowermost till and hence is late Kansan in age rather than Yarmouth.

Several unanswered questions raise uncertainties in age designation. A brief discussion of these questions follows.

1. Are there really three tills in the area? Conclusive evidence exists for identification of a Late Wisconsin till and one pre-Wisconsin till. The presence of a third till (Kansan or other) is based mainly on inconclusive stratigraphic evidence. The age of the known pre-Wisconsin till itself is in doubt. Although assumed to be Illinoian, it could also belong to another glaciation.

2. Resolution of the extent of Early Wisconsin glaciation in South Dakota, if any occurred, would help tremendously in resolving the geomorphic and stratigraphic history not only of this area but the whole State.

3. What is the age of the high-level western derived sand and gravel fluvial deposits? The very few fossil remains found in these gravels to date are at best poorly diagnostic.

When one or more of the above questions can be reliably solved, much of the Pleistocene history of this area and eastern South Dakota will be clarified.

Illinoian Deposits

Till

Glacial till of probable Illinoian age crops out at several locations in the southeastern and south-central part of Charles Mix County (fig. 12). The exposures are not marked on the geologic map (pl. 1) because in all cases the outcrops do not expose more than a few feet of till. These exposures were visited during early summer of the first field season soon after unusually heavy spring rains. The large runoff caused headward erosion in gullies and flushed clean the gully floor, thus exposing the older till. Later inspection of most of these outcrops revealed that the Illinoian till was poorly exposed or not exposed at all.

The exposed but unoxidized Illinoian till is dark gray or greenish-gray, hard, blocky, and calcareous. The distinguishing feature of the Illinoian till is the boxwork joint system. The joints are oxidized 2 to 5 inches on either side of the joint. The joints are generally filled with gypsum or calcium carbonate as much as one-half inch thick. At some localities the Illinoian till exhibits concentric oxidized rings up to 3 inches in diameter with a central iron-carbonate core about one-fourth inch in diameter. These features are probably formed by rootlets decaying with the resulting opening providing a pathway for downward percolation of water.

The writer found no exposures of Illinoian till which showed a mature Sangamon type soil in Charles Mix or Douglas County. However, commonly associated with the Illinoian till is a loess deposit which has weathering characteristics related to the underlying Illinoian till. The following stratigraphic sections (p. 21) provide descriptions and show the relationships of the Late Wisconsin till, Early Wisconsin loess, and Illinoian till.

The exposures of Illinoian till show only the lower unweathered or partially weathered till. The upper soil profile and completely oxidized parent material have been removed through erosional processes leaving only the truncated surface of till exposing an oxidized joint pattern. Since the till lacks evidence of soil formation, the overlying loess could not have been deposited without a considerable lapse of time during which a mature soil was formed and later truncated.

Walker (1963, p. 78) found two exposures containing Illinoian till in the Wagner quadrangle. These were located in 95-65-12dcdd and 95-65-36dbda. At the first location a well-developed soil horizon was developed in the lower of two tills. This soil horizon was identified as a Sangamon soil type and was the primary basis for correlating the till. Walker reported the Illinoian till as very hard, having a well-developed joint system, and breaking into large chunks several feet in diameter. The writer attempted to locate these outcrops in order to make comparisons with other till exposures, but was unsuccessful.

In the subsurface the Illinoian till, if present, cannot be positively identified due to lack of stratigraphic evidence such as oxidized zones or interglacial deposits. The cross section (pl. 5) shows one oxidized zone(?) and two possible interglacial

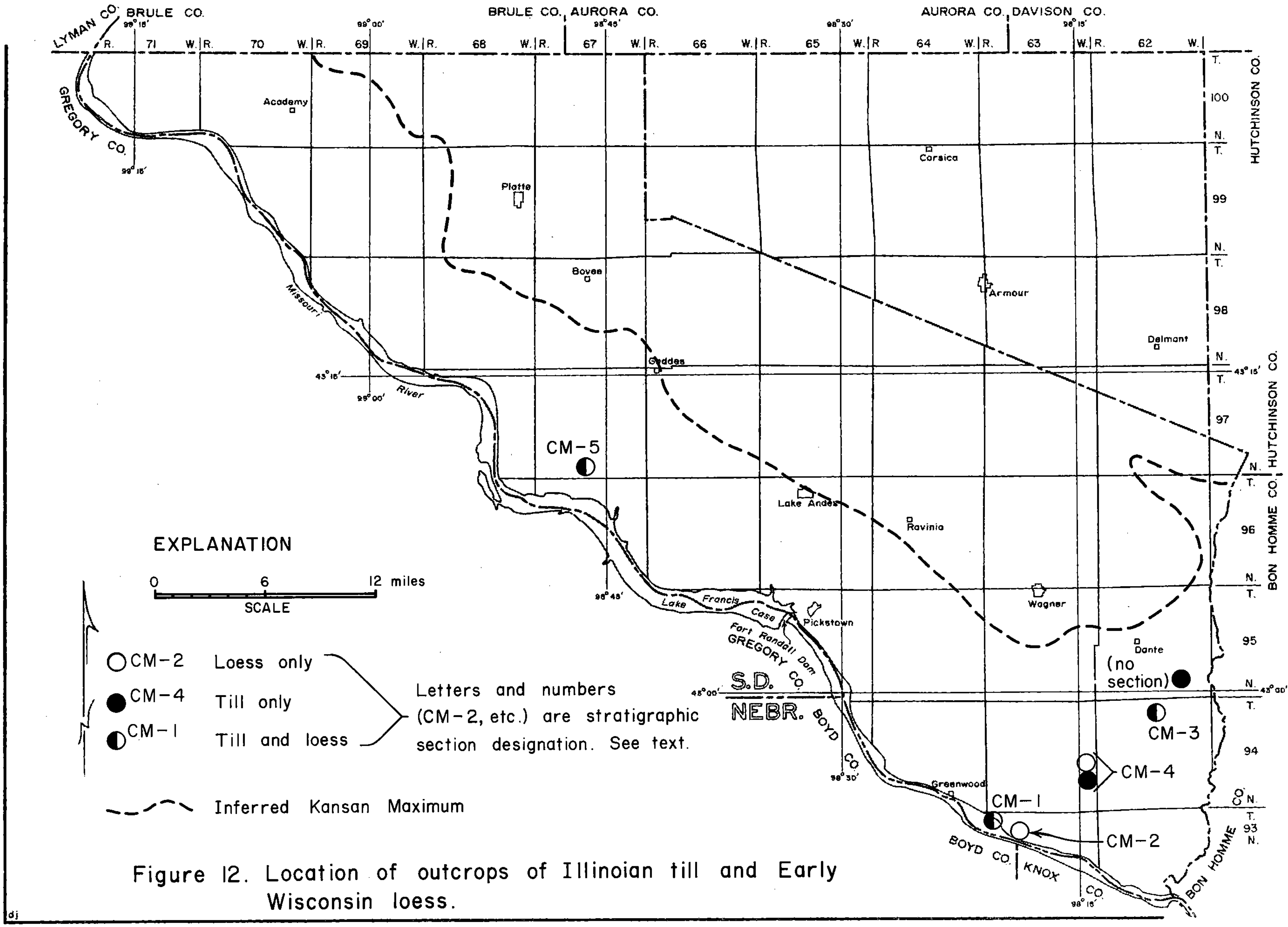

Figure 12. Location of outcrops of Illinoian till and Early Wisconsin loess.

STRATIGRAPHIC SECTION CM-1

Location at head of small gully at contact of uplands and Missouri River breaks. Location 93-62-7dbcc.

Unit	*Thickness (feet)*
4. Partly stratified, reworked till, soil and loess (Recent colluvium)	*5*
3. Till, oxidized (Late Wisconsin)	*5*
2. Loess, upper 3 feet partly oxidized, lower 1 foot unoxidized; oxidized joints up to 5 inches wide. Iron carbonate replaced root tubules (Early Wisconsin)	*4*
1. Till, partly oxidized, oxidized joints, joint fillings ¼ inch wide; joints extend upward into the loess and tubules downward into the till (Illinoian)	*3*
Total	*17*

STRATIGRAPHIC SECTION CM-2

Small northwest trending gully crossing farm lane about one-half distance to house from county road. Location 93-62-9ab.

Unit	*Thickness (feet)*
5. Clay, black to brown; tests of gastropoda (Recent alluvium)	*5*
4. Silt, brown to gray, loess; (Late Wisconsin)	*2*
3. Till (Late Wisconsin)	*3*
2. Silt, yellow, iron carbonate replaced root tubules with iron-stained concentric rings, loess; (Early Wisconsin)	*3*
1. Shale, black, slightly calcareous; Pierre Shale; (Cretaceous)	*2*
Total	*15*

STRATIGRAPHIC SECTION CM-3

Located in gully above pond. Location 94-62-3cc.

Unit	*Thickness (feet)*
4. Till, and ice-contact outwash interfingered; (Late Wisconsin)	*10*
3. Sand, very fine, silty, iron carbonate replaced root tubules jointed, partially oxidized; loess (Early Wisconsin)	*4*
2. Till upper 5 feet partially oxidized, jointed; joints extend upward into the loess and the tubules downward into the till (Illinoian)	*10*
1. Pierre Shale (Cretaceous)	*5*
Total	*29*

STRATIGRAPHIC SECTION CM-4

In gully at base of ridge. Composite section taken along creek bottom. Location 94-63-25bd.

Unit	*Thickness (feet)*
3. Silt, yellow, loess (Recent)	*5*
2. Till, upper 3 feet partially oxidized, jointed, iron carbonate replaced root tubules. Lower 2 feet light gray and fresh dark grayish-green with joints and tubules as above. Looks like till with much Ogallala in matrix (Illinoian)	*5*
1. Mobridge member Pierre Shale in bottom of gully	*1*
Total	*11*

STRATIGRAPHIC SECTION CM-5

In ravine at head of lake behind Dowd Dam. Location 97-67-27cdc.

Unit	*Thickness (feet)*
3. Clay, gray to black, silty, contains gastropoda tests (Recent alluvium)	*5*
2. Silt, oxidized joints, loess (Early Wisconsin)	*3*
1. Till, jointed; joints extend upward into the loess (Illinoian)	*2*
Total	*10*

deposits(?) which may separate Late Wisconsin drift from Illinoian drift. Test holes with electric logs located primarily in Douglas County often showed an abrupt change to a more resistant till at a depth of about 120 to 200 feet. This physical characteristic could also mark a break between two tills.

The basic reasons for assigning an Illinoian age to the till discussed in this section are:

1. The Illinoian outcrops are outside the inferred Kansan maximum (fig. 12) and are pre-Late Wisconsin;

2. The possible Illinoian in the subsurface overlies the low-level western derived fluvial deposit which is late Kansan to Yarmouthian in age; and

3. The Early Wisconsin (Iowan) glacier probably did not reach this far west in South Dakota so the tills could not be Early Wisconsin.

Outwash

Illinoian outwash cannot be differentiated lithologically from outwash of other glacial advances. Therefore, relative stratigraphic position must be used to distinguish outwash of Illinoian age. On this basis only relatively small amounts of the outwash in the subsurface can be assigned an Illinoian age.

The cross sections (pls. 2 and 5) show the presence of Illinoian till but very little outwash. The cross section (pl. 4) shows considerable buried outwash in the Wagner-Choteau Creek area, but lacks stratigraphic evidence for assigning ages to the outwash. Walker (1963) reasoned that much of the first outwash above the low-level western derived fluvial deposit was probably Illinoian age. The present writer agrees to the possibility of this age designation.

Sangamon Interglacial

In Charles Mix and Douglas Counties there are no deposits which can be assigned to the Sangamon Interglacial. This period of time in Charles Mix and Douglas Counties was a relatively long time characterized by soil formation and erosion. The relative stability of the landscape during the Sangamon will be discussed later under Geomorphic Development.

Early Wisconsin Deposits

Loess

The only known Early Wisconsin deposit in Charles Mix and Douglas Counties is loess. This loess is known from several exposures in southeastern Charles Mix County and one outcrop in south-central Charles Mix County (fig. 12). A few loess-like deposits beneath till have been described in drill hole cuttings as far north as Douglas County. If these deposits do correlate with the loess in the exposed sections, then the loess mantle was probably widespread throughout the two Counties during Early Wisconsin. Since adequate exposures exist to verify the presence and describe the loess deposit, the discussion will be confined to outcrop locations.

The exposed loess is light yellow and may grade downward to a light to medium gray. Mottling may occur and concentric rust-colored rings associated with rootlets may be present. Where underlain by till, oxidized joint patterns from the underlying till may extend upward into the loess. The loess is generally composed of silt with minor amounts of clay, or it may be silty, very-fine to fine sand. The loess is calcareous and attains a maximum thickness of 4 feet in exposures. The upper part of the loess has in all instances been removed so its original thickness is unknown. The stratigraphic relationship of the loess to other Pleistocene deposits can be seen in stratigraphic sections CM-1, CM-2, CM-3, and CM-5 in the previous section under Illinoian till.

The age of the loess has been determined to be Early Wisconsin because it is a weathered deposit underlying Late Wisconsin till and overlies Illinoian till which has undergone considerable weathering and erosion before deposition of the loess.

Late Wisconsin Deposits

The surficial glacial drift in Charles Mix and Douglas Counties lie north of Wisconsin ice advance number 2 of Lemke and others (1965, p. 17). Thus, according to Lemke and others (1965) the surficial drift in the study area would be correlated with the outer Late Wisconsin ice advance. Radiocarbon dates from material within the drift area support this conclusion (Lemke and others, 1965). For a comparison of this classification and correlation with some other well established classifications, see table 1 (Lemke and others, 1965, p. 20).

Till

Till of Late Wisconsin age is present over much of the surface of Charles Mix and Douglas Counties (pl. 1) and is the parent material for most of the soil. Nearly all till in roadcuts and natural surface exposures is of Late Wisconsin age.

The weathered till is light yellow-brown to brown and grades downward to a light to dark olive-gray. The upper weathered or oxidized zone varies from a few feet thick to as much as 50 feet thick but averages about 25 feet in thickness.

Late Wisconsin till consists of clay, silt, sand, and gravel with minor amounts of pebbles, cobbles, and boulders. Its general texture is a silty or sandy clay. Joints in the till are closely spaced and poorly developed and only occasionally the joints have a filling of selenite up to one-fourth inch thick. The thickness of the Late Wisconsin till cannot be accurately determined due to the difficulty of distinguishing it from older tills in the subsurface. From the cross sections (pls. 2-6) the average thickness of Late Wisconsin till is estimated to be about 125 feet with a maximum thickness of about 250 feet.

Outwash

Late Wisconsin outwash deposits are found at numerous localities in Charles Mix and Douglas Counties (pl. 1). In general, the outwash deposits occur as valley-fill, terrace deposits, collapsed outwash plain deposits, and small undifferentiated outwash bodies. Within each of these divisions texture of the outwash material and geomorphic expression may vary to considerable degrees.

The valley-fill deposits occur mainly in the valleys of Choteau Creek and Platte Creek and are more sporadic in occurrence in the smaller creeks and streams. These deposits are nearly flat lying and may be covered with alluvium as much as 15 feet thick. Although some test holes penetrated more than 25 feet of sand and gravel in some valley floors, the maximum thickness of the valley outwash is estimated to be 25 feet. The greater thicknesses penetrated are thought to be due to buried outwash directly underlying the valley outwash (pls. 2-6).

The Delmont valley-fill outwash covers about 13 square miles 3 to 6 miles west of Delmont at the confluence of Choteau Creek and its tributaries (pl. 1) and has been studied in some detail by Stoley (1956). Most of the outwash is located in Douglas County, but about 2 square miles are present in Charles Mix County. Stoley (1956) conducted pebble analyses, microscopic analyses, porosity tests, and size analyses on sediments from the Delmont outwash. On the basis of these analyses, Stoley concluded that the composition and texture of this outwash was highly variable. The maximum thickness of the outwash is 50 feet and averages about 25 feet. In general, the finer portions of the outwash are near the margins and near its southern border. The border of the outwash as mapped by Stoley has been only slightly modified during the present study.

Outwash terrace deposits occur primarily along Choteau Creek, Platte Creek, and Andes Creek. These outwash terrace deposits are generally flat to sloping and occupy an intermediate level between the valley floor and the top of the valley wall. Terrace deposits average an estimated 15 feet in thickness and overlie till or valley outwash sediments. Texture of the outwash terrace deposits range from fine sand to coarse sand and gravel. Some ice-contact terraces occur and these are generally gravelly with cobbles and boulders.

A broad undulating collapsed outwash plain occurs along the northern border of Douglas County starting at a point 5 miles north of Corsica westward to about 3 miles into Charles Mix County (pl. 1). Texture varies from a sandy silt to coarse sand and gravel and has a maximum thickness of 35 feet. The textural units are mappable as shown on plate 1.

Isolated patches of outwash occur as undifferentiated outwash deposits throughout the two Counties (pl. 1). The seemingly random location and form of these deposits plus variable thickness and texture make these isolated deposits difficult to locate and map.

Terrace Deposits

Terraces along the Missouri River (pl. 1) are underlain primarily with coarse-grained outwash deposits as much as 90 feet in thickness; however, till, loess, alluvium, or colluvium may be locally present.

Generally the outwash is finer grained near the surface and grades downward to a coarse gravel or cobbly boulder gravel. The outwash is highly oxidized and may contain layers several feet thick which are cemented with iron carbonate. The fine portion of the outwash increases in thickness away from the Missouri River and also contains more till, loess, alluvium, or colluvium. Origin of these terraces is explained later in this report under the section Geomorphic Development. The following stratigraphic sections (p. 24) were taken from terraces along the Missouri River.

Loess

Late Wisconsin loess is found at the surface in southeastern Charles Mix County adjacent to and within a maximum distance of about 5 miles from the Missouri River (pl. 1). Maximum thickness of the loess is about 10 feet with most of it ranging from 3 to 6 feet in thickness. The terraces along the Missouri River also have a discontinuous silty fine sand at the surface which may be in part loess but for purposes of this report are not considered to be mappable units.

The loess is composed of silt or sandy silt and is completely oxidized to a light yellow-brown. It is massive, calcareous, and has a weak soil development. None of the Late Wisconsin loess was observed to have the iron stained rootlets and joint pattern similar to the Early Wisconsin loess overlying Illinoian till.

STRATIGRAPHIC SECTION CM-6

A small terrace just north of the mouth of Snake Creek. Location 99-70-16ab.

Unit	*Thickness (feet)*
5. Silt, buff-colored, weak soil locally present 2 to 3 feet from top. (Loess)	*0 to 7*
4. Silt, sandy and clayey, mostly horizontally bedded (colluvium-alluvium)	*0 to 10*
3. Till and gravel intermixed	*10 to 35*
2. Gravel, mostly cobbles and boulders, well cemented with iron carbonate cement; boulders as much as 10 feet in diameter	*5*
1. Pierre Shale, black, non-calcareous, upper 4 feet alternating thin shale (1 to 3 inches) and bentonite (1 to 6 inches) beds	*10*

STRATIGRAPHIC SECTION CM-7

Mouth of Cedar Creek (section below described by Baker, 1949, from unpublished field notes). Location 98-69-36da.

Unit	*Thickness (feet)*
5. Loess, gray	*6*
4. Gravel and sand, glacial outwash contains boulders up to 2 feet in diameter but most of material is sand and gravel size	*80*
3. Conglomerate, outwash gravel cemented by calcium carbonate which has been deposited by ground water; springs at base of conglomerate	*10*
2. Pierre Shale (Sharon Springs member)	*8*
1. Alluvium of flood plain	----

This particular area was visited by the author during 1969. Water from the reservoir covered the bottom three units and part of the fourth unit. About 15 feet from the top a 2-foot thick till unit was present. The till graded laterally to sandy clay, then to sand.

STRATIGRAPHIC SECTION CM-8

Composite section taken on North Wheeler terrace at head of gully draining toward reservoir. Location 96-68-2aa.

Unit	*Thickness (feet)*
3. Soil, modern; mostly loess and landslide material	*5*
2. Sand, reddish-brown, some clay, pebbly throughout but gradationally fewer pebbles from bottom to top; pebbles near base appear to be bedded; snail tests absent or rare near base, common to abundant 18 inches or more above base; contact with unit below somewhat gradational	*3 to 10*
1. Sand and gravel, oxidized, dry; mostly coarse sand, pebbly, and cobbly gravel down to water level	*50*

STRATIGRAPHIC SECTION CM-9

Section taken at south edge of terrace at picnic site. Location 96-68-1ad.

Unit	*Thickness (feet)*
4. Sand, black, very fine, silty; grades downward to grayish-brown, very fine silty sand with occasional pebbles; non-stratified; contains snail tests and few small mammal bones	*6*
3. Soil, black, silty, sandy, quite loose; developed in loess; abundant snail tests and mammal bones	*1*
2. Clay, reddish-brown, sandy, porous; contains pebbles and occasional rock	*2*
1. Sand, reddish-brown, mostly medium, but some coarse sand present, bedded; poorly sorted to well sorted	*4*

Total thickness of unit 1 below water level is unknown.

Recent Deposits

Recent deposits in Charles Mix and Douglas Counties consist mainly of alluvium which is widespread throughout the two Counties, and colluvium which is found in mappable quantities in the southeastern part of Charles Mix County.

Colluvium

Colluvium refers to any deposit moved downslope chiefly by gravity and includes material of normal mass-wasting processes plus that material carried by running water. The colluvium just south and southeast of Greenwood along the Missouri River (pl. 1) is composed of a dark-gray to black clay about 20 feet thick. This material is composed predominantly of reworked shale. Four miles northeast of Greenwood (pl. 1) there occurs another small area of colluvium which is primarily a clayey silt. This deposit does not exceed 10 feet in thickness and is probably derived from loess and till.

Alluvium

Recent alluvium is present along all the major streams and most of the minor tributaries in Charles Mix and Douglas Counties. Alluvium is generally dark gray to black, humic, poorly stratified, and consists predominantly of clay or silty clay with minor amounts of sand and gravel. Various gastropoda tests are often associated with alluvium although there was no attempt to identify them during this study.

Alluvium along the Missouri River is as much as 50 feet thick. The upper 10 to 20 feet are generally gray to black silty clay or silt which overlies fine sand that grades downward into medium to coarse sand.

Along Choteau, Platte, and Andes Creeks the alluvium is as much as 15 feet thick and is a dark-gray to black silty clay locally containing sand and gravel. The other smaller mapped areas contain alluvium of variable texture and usually do not exceed 10 feet in thickness.

GEOMORPHIC DEVELOPMENT

Geomorphic development of Charles Mix and Douglas Counties was based primarily on a series of drainage adjustments. These adjustments drastically affected a drainage system established as long ago as late Pliocene or early Pleistocene time. Glaciers occupying the area during the Pleistocene Epoch, blocked existing drainages with drift and ice, and forced the water to find new outlets. Following the retreat of the ice some of the streams returned to their former valleys while the remainder were permanently blocked. The permanently abandoned channels are visible today as broad shallow depressions. All of the newly established waterways remained active until blockage again occurred by still later ice advances.

In order to set the stage for a discussion on the geomorphic development of Charles Mix and Douglas Counties, an overall understanding of the major physiographic divisions of the State and the major drainage elements is essential.

Figure 13 shows the present major physiographic divisions of South Dakota and the locations of early Pleistocene drainages in the western two-thirds of the State. The dominant features of this map are the eastward flowing streams crossing the position of the present day Missouri River and emptying into the broad, relatively flat, James Basin. This Basin is situated between two bedrock high areas, the Coteau des Prairies on the east, and the Coteau du Missouri on the west. East flowing streams carved broad valleys through the Coteau du Missouri and are represented at present by broad sags. These low areas are shown on figure 13 by dotted lines that indicate an indistinct topography boundary. The escarpment forming much of the boundary of the present Coteau du Missouri is underlain by thick deposits of glacial drift which accumulated on, and against, the bedrock escarpment during various glaciations. This in effect moved the Coteau escarpment eastward from the original bedrock escarpment. On figure 13 the inferred position of the original bedrock escarpment is shown for Charles Mix and Douglas Counties. This factor is significant because the position of the first glacier in the area was controlled by the dominant features of the then existing topography rather than the later modified location of these topographic features.

Pre-Pleistocene Land Surface and Drainage

Only very general assumptions can be made about the pre-Pleistocene land surface of Charles Mix and Douglas Counties.

Elevation of stream beds crossing these Counties at the close of the Pliocene had a minimum elevation of about 1,650 feet which is at least 300 feet higher than stream elevations just prior to the Kansan glaciation. The minimum elevation of 1,650 feet is inferred from the presence of early Pleistocene stream-deposited gravels of western origin with a minimum base elevation of 1,650 feet in the two Counties.

Inferred location of drainages during early Pleistocene time is speculative. All pre-glacial western-derived gravels are now found only on the bedrock high areas in the two Counties, while at the time of their deposition those same locations were stream beds occupying the lower elevations. Thus,

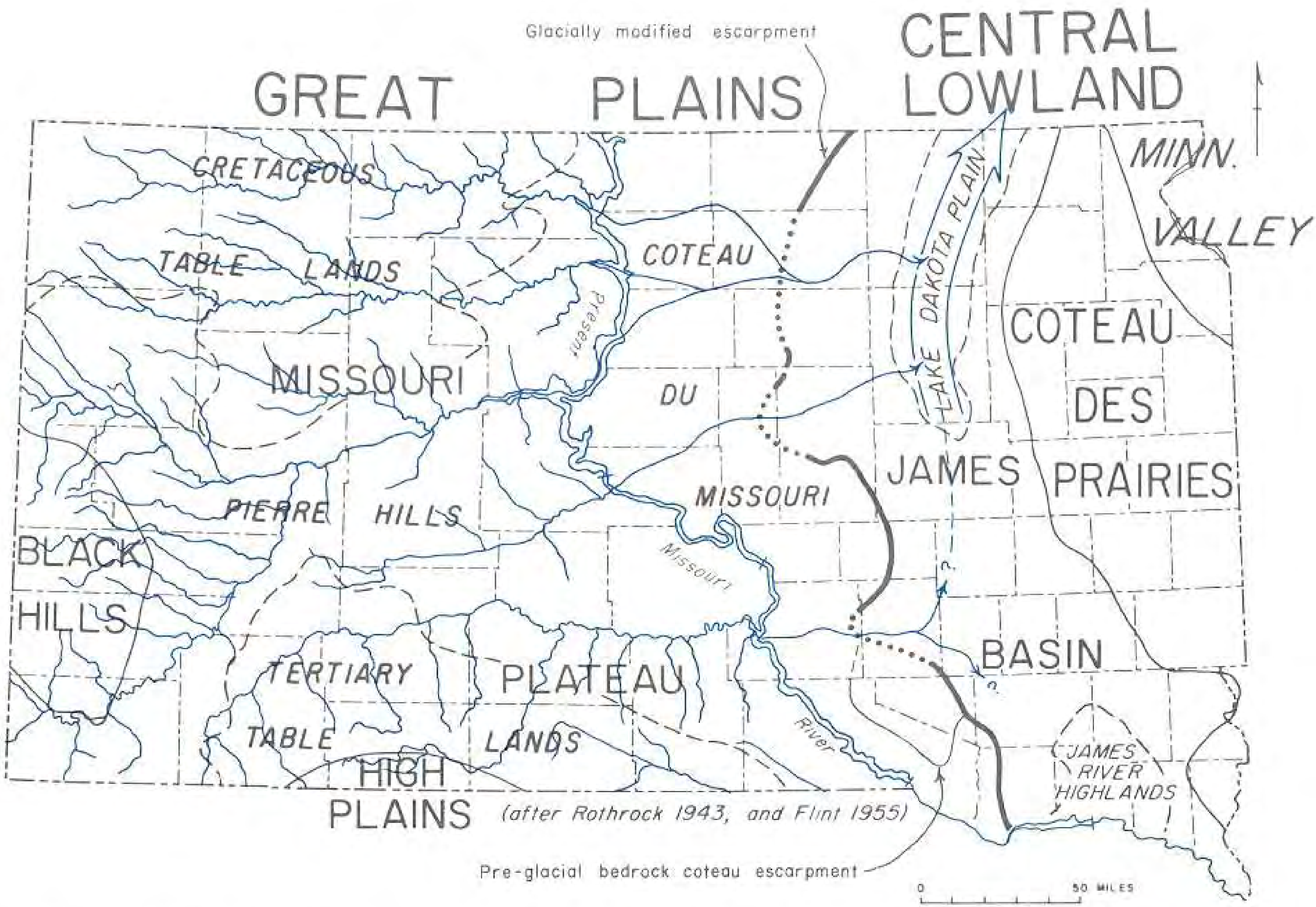

Figure 13. Map of South Dakota showing major physiographic divisions and inferred pre-Kansan drainage.

sometime after deposition of the gravels and before the Kansan Glaciation had occurred, there was a general inversion of topography throughout much of the two-County area.

Pre-Kansan Land Surface and Drainage

A generalized reconstruction of the land surface in Charles Mix and Douglas Counties just prior to the Kansan Glaciation is shown in figure 14. No Nebraskan glacial deposits are known in Charles Mix and Douglas Counties, and the Nebraskan glacier is thought not to have covered this part of South Dakota even though Nebraskan till is recognized in eastern Nebraska (Reed and Dreezen, 1965).

There probably were no major streams in the two-County area at this time since the whole region formed an interfluve area between the converging White and Ponca-Niobrara River systems. The drainage net consisted of small streams and gullies which were probably similar to that illustrated in figure 14 with much of the two-County area eventually draining into the ancestral White River drainage system.

In Charles Mix and Douglas Counties the minimum elevation of the James Basin has been determined in the following manner. The entire area was an interfluve from which most of the surface drainage was tributary to the ancestral White River and thus the drainages must have been graded to the White River. The base of the ancestral White River where it crosses the present Missouri River is about 1,475 feet elevation (Flint, 1955, fig. 11, p. 51). The minimum gradient of the ancestral White River in Charles Mix and Douglas Counties is about 4 feet per mile. This minimum figure is supported by gradients determined for the ancestral White River west of the Missouri River (Kahil, 1970). Thus, tributary streams graded to the ancestral White River in northwestern Charles Mix County would have to have a minimum base elevation of about 1,550 feet. Tributary streams in northeastern Douglas County, about 55 miles to the east, would have had a minimum base elevation of 1,300 feet.

On the basis of the previous discussion, the inferred surface bedrock distribution at the beginning of Kansan time would be significantly different from that at the close of the Kansan Glaciation which is essentially represented by the bedrock map (pl. 7). The upper surface of the Niobrara Marl has a maximum elevation of 1,372 feet (fig. 6). Therefore, if the minimum surface elevation was 1,300 feet, the only place the Niobrara would have been exposed would be in narrow strips along the tributaries flowing northeast to the White River. The Carlile Shale would not have been exposed at all just prior to Kansan Glaciation.

Kansan Glaciation

As Kansan ice spread southwestward in South Dakota, all streams flowing to the north and east were blocked and the ponded water from streams and meltwater were diverted progressively westward. The ponded water eventually cut diversion channels across low divides seeking its ultimate outlet to the Gulf of Mexico.

The first Kansan ice in the study area covered northeastern Douglas County similar to that shown in figure 15. At this position the Kansan ice blocked the northward and eastward flowing streams emerging from Douglas County and diverted the water southward along the margin of the glacier towards the southeastern part of Charles Mix County. Throughout Douglas and Charles Mix Counties the diverted water and meltwater cut a deep narrow channel along the general course of the present Choteau Creek. The water emptied into the ancient Ponca drainage system in southwestern Bon Homme County and thence a short distance to the ancient Niobrara-Missouri drainage system (Christensen, 1974). During this initial diverson and downcutting stage the Carlile Shale was probably exposed. It seems likely that the White River was also diverted during this initial phase although probably not long enough for the newly formed diversion channel to be cut down to grade. The encroaching ice advanced farther into Charles Mix and Douglas Counties (fig. 16) and diverted the water still farther westward in northern Douglas County. Just prior to, and during this second stage, outwash and till were deposited in the newly cut diversion channel of stage one. The second stage of Kansan ice was probably also so short-lived that the new diversion channel did not reach the grade of the White River.

The third stage of Kansan ice diverted the White River and meltwater still farther westward so that it now entered the area in northwestern Charles Mix County (fig. 17). The ice pushed far enough westward during its final thrust that the diverted water ran along and slightly encroached upon the bedrock escarpment of the Coteau du Missouri. The duration of ice even at its maximum must have been relatively short-lived because the last formed diversion channel did not have enough time to establish a channel to grade with the White River. If the last diversion channel had been eroded to grade with the White River it would never have returned to its original channel once the ice retreated.

In the previous paragraphs it has been stated that the Kansan diversion channels probably did not carry water a sufficient length of time for the channels to entrench themselves at grade with the White River. Reasoning for this conclusion is that the major stream was dammed up by encroaching ice and the upstream

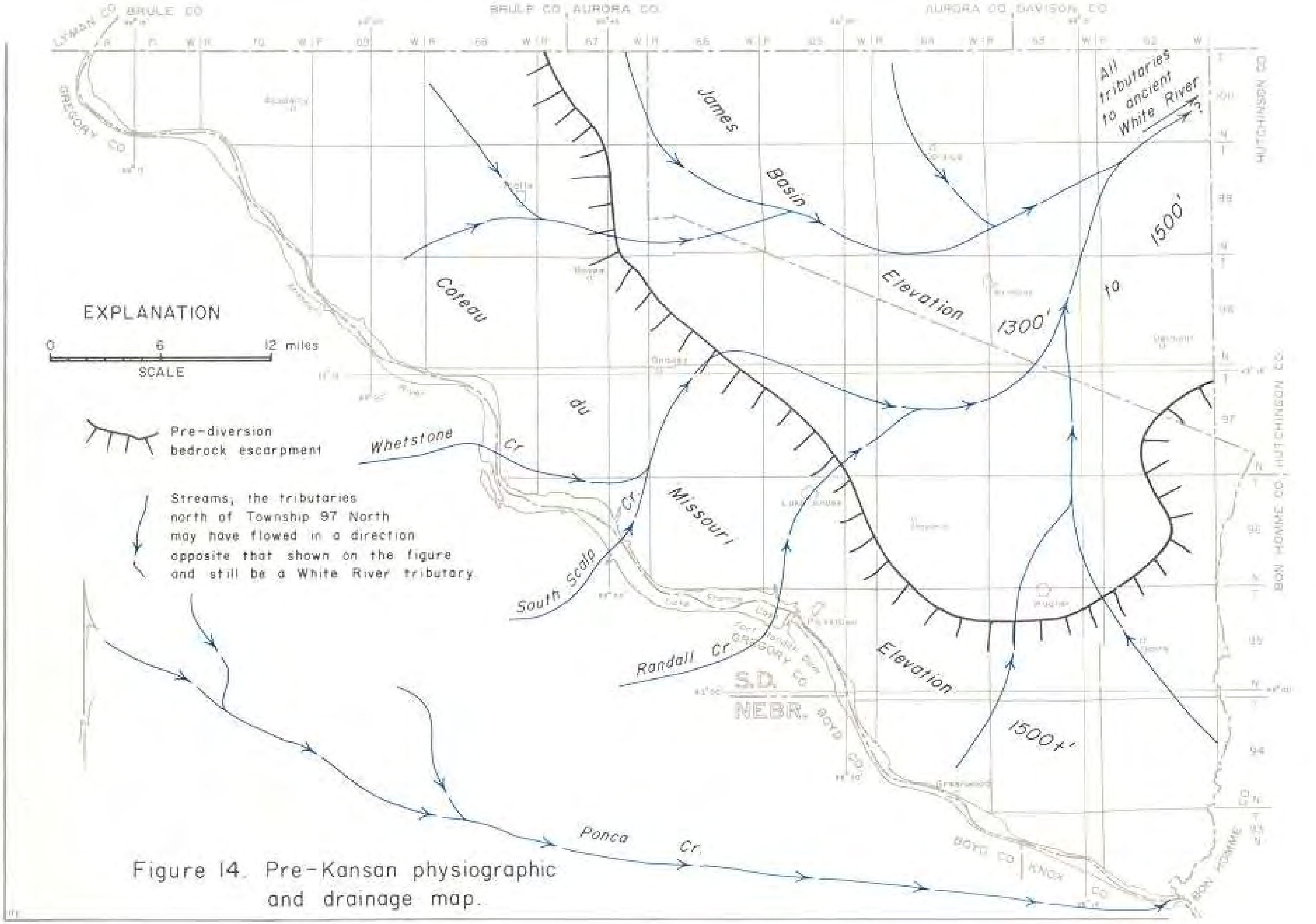

Figure 14. Pre-Kansan physiographic and drainage map.

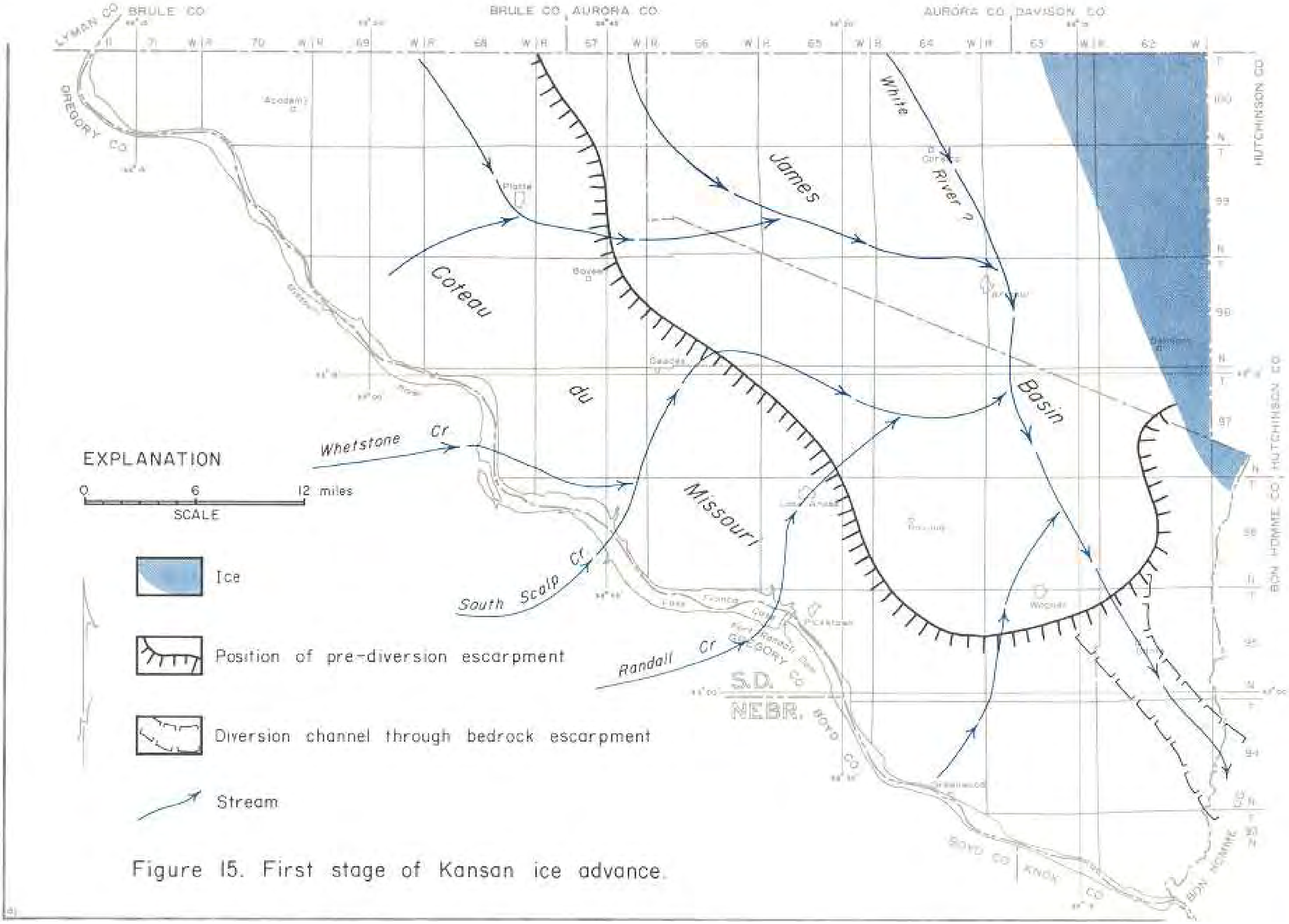

Figure 15. First stage of Kansan ice advance.

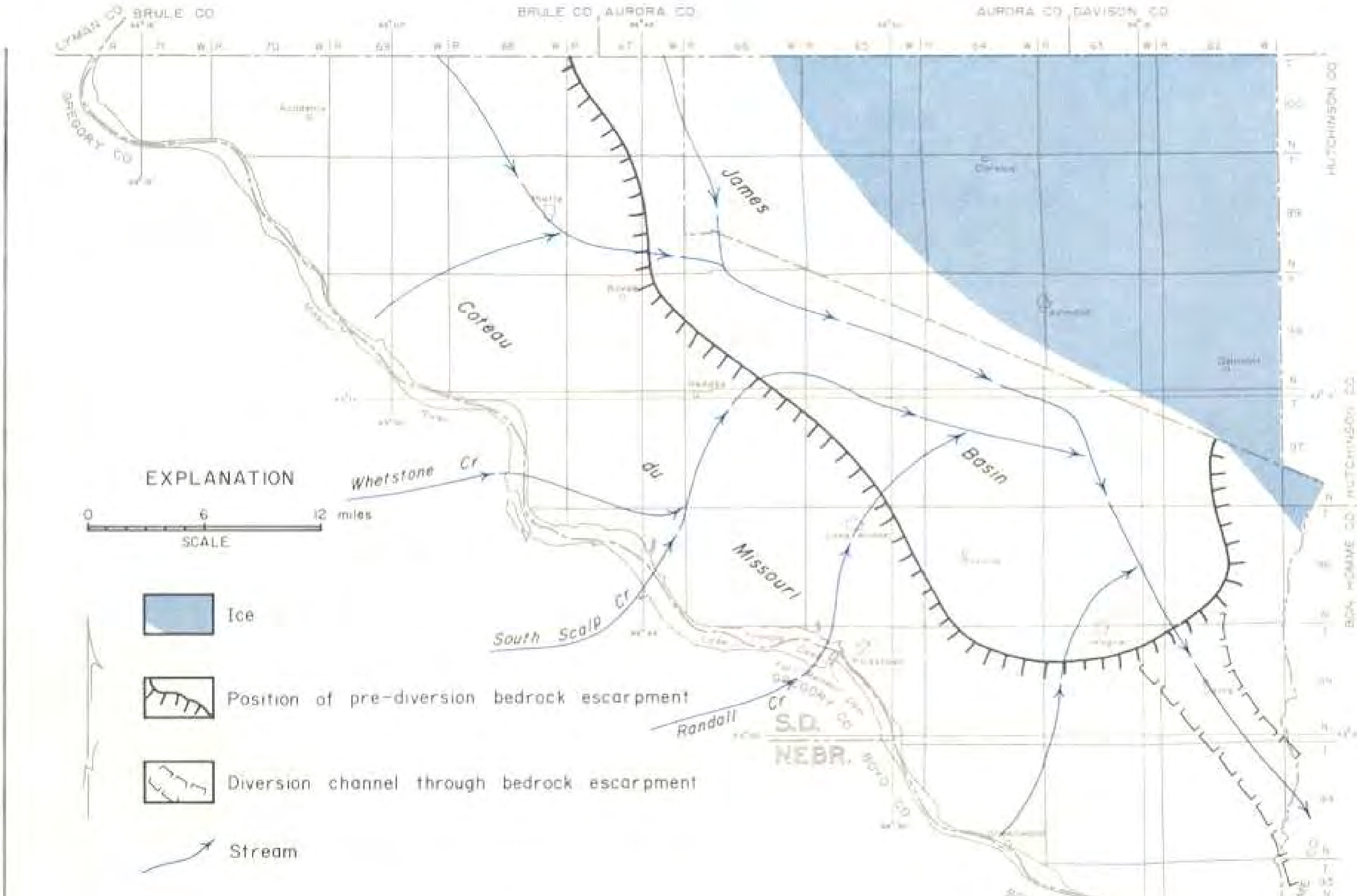

Figure 16. Second stage of Kansan ice advance.

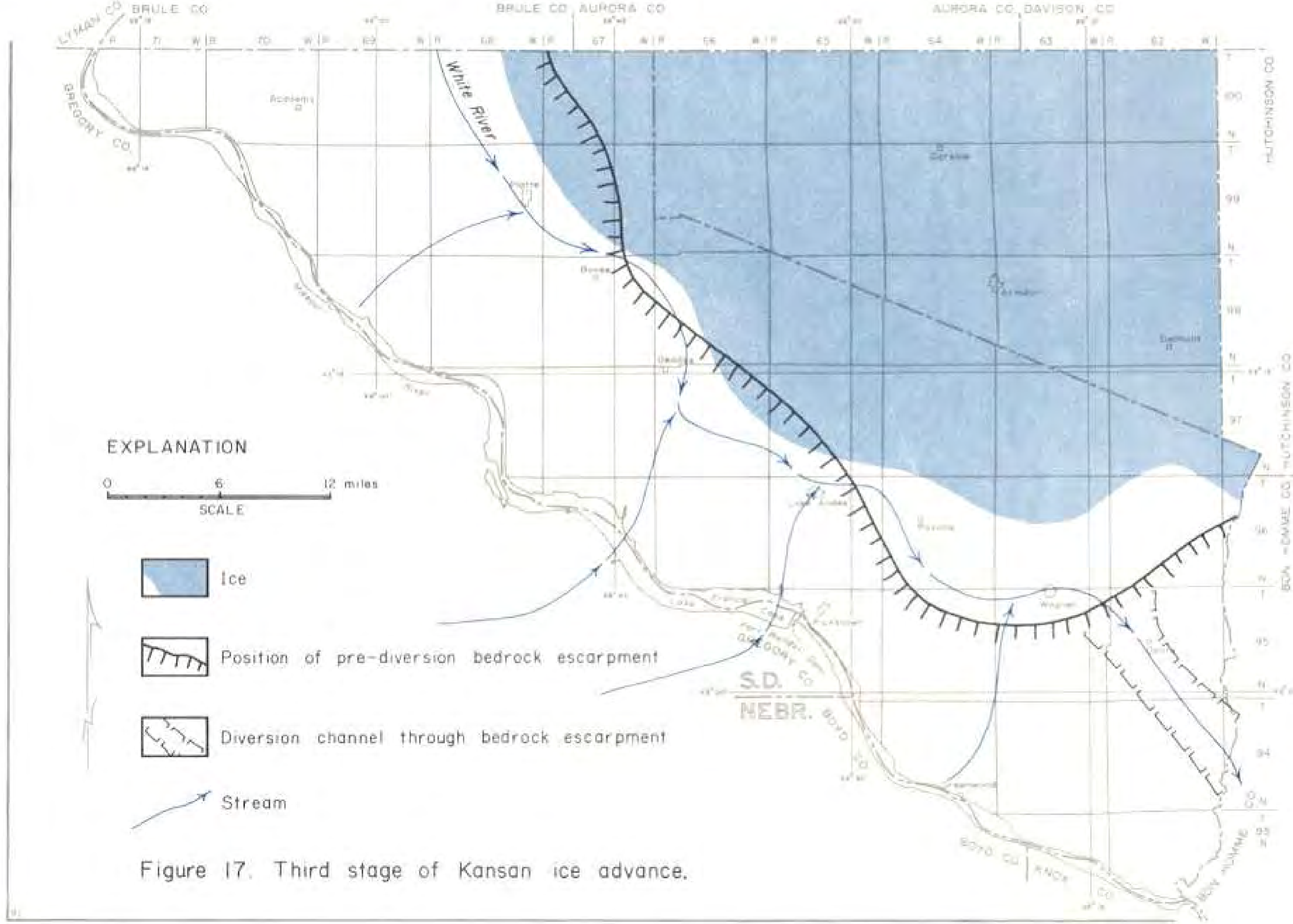

Figure 17. Third stage of Kansan ice advance.

portion aggraded due to decreased velocity. The ponded water eventually started entrenching a new channel once the divide areas were breached. Downcutting was the dominant factor until sufficient time elapsed to allow the new channel to approach grade with the White River. Only after downcutting approached grade would any appreciable aggradation occur in the diversion channel.

When the ice margin had retreated several miles east of the westernmost diversion channel, meltwater and western water continued downcutting in the diversion channel thus stripping the valley of any Kansan glacial deposits that may have existed. As the channel approached grade with the White River, the western derived sediments started eroding from the choked White River valley and were redeposited in the diversion channel. Eventually this channel became choked off, the ice margin receded farther to the east, and the White River started flowing down the next diversion channel to the east repeating the entire process again and again until finally Charles Mix and Douglas Counties were ice free, and the White River had returned to its former channel.

Once the White River had returned to its original channel, the surface drainage in Charles Mix and Douglas Counties may have again become tributary to the White River, thus flowing generally northeast, or it may have flowed southeast through the newly cut diversion channel and emptied into the Ponca-Niobrara drainage system. Present data do not indicate which concept is valid.

The maximum thickness that the Wagner Formation attained is unknown. Present thicknesses range from 20 to 90 feet suggesting a minimum original thickness of 90 feet. Considering the fact that two continental glaciers later overrode the area it is reasonable to assume that the original thickness may have exceeded 90 feet.

At the end of the Kansan Glaciation the bedrock surface northeast of and including the Academy Channel was sculptured to nearly its present form (pl. 7). The deposits at the surface of Charles Mix and Douglas Counties at the close of the Kansan Glaciation are shown in figure 18.

Yarmouth Interglacial

The land surface of Charles Mix and Douglas Counties was fairly stable during much of the Yarmouth Interglacial. Downcutting of drainages was minimal because the immediate post Kansan landscape was not appreciably altered prior to the beginning of the Illinoian glaciation. Weathering and soil formation were dominant and perhaps enough erosion took place to remove much of the Kansan drift. Much of the remaining Yarmouth soil and Kansan drift was eroded when downcutting accelerated with the advent of the Illinoian Glaciation. Thus, the Illinoian ice encroached Charles Mix and Douglas Counties on a landscape not significantly changed from the post Kansan landscape as shown in figure 18.

Illinoian Glaciation

The Illinoian ice that advanced into the two-County area had a profound and lasting effect on the geomorphology and drainage patterns. The pattern of invasion and diversion was probably very similar to that explained (section under Kansan Glaciation) and illustrated (figs. 15, 16, and 17) for the Kansan Glaciation. However, the Illinoian ice apparently was active enough to encroach on the bedrock highlands along the southwestern margin of Charles Mix County. After the Illinoian ice approached a position similar to the Kansan maximum (fig. 17), it crossed over the position of the Academy Channel and encroached the bedrock highlands, thereby effectively blocking all existing northeasterly drainage (fig. 19) from as far north as the White River. Perhaps meltwater and diversion water from more northern points were already ponded and seeking an escape route to the already established Ponca-Niobrara system at the southwestern corner of Bon Homme County. Regardless of the ultimate source of all the water, the ponded water in Charles Mix County flowed south and west up the gradient of former northeasterly-flowing tributaries (fig. 19). Eventually Illinoian ice occupied a position very closely approximating the present Missouri River. The ice formed an effective blockade sufficiently long for meltwater and stream water to erode a trench deep enough that the diverted waters of all east-flowing streams in central South Dakota were permanently captured to form the present Missouri River. After the ice receded nearly all of the two Counties had a complete cover of Illinoian till.

Sangamon Interglacial

The warmer Sangamon Interglacial was a period of weathering and erosion and probably relatively little incision by streams. There are no known deposits of the Sangamon Interglacial in the two Counties although in extreme eastern South Dakota substantial thicknesses of loess accumulated. Walker (1963) reported two occurrences of well-developed soils of Sangamon age in the Wagner quadrangle but the present author was unable to locate these outcrops. In an earlier section of this report eroded remnants of a highly weathered till were described which presumably represented Illinoian till with Sangamon weathering. A long period of weathering and erosion is further substantiated by the presence in eastern South Dakota of a well-developed Sangamon soil (Steece and Tipton, 1965).

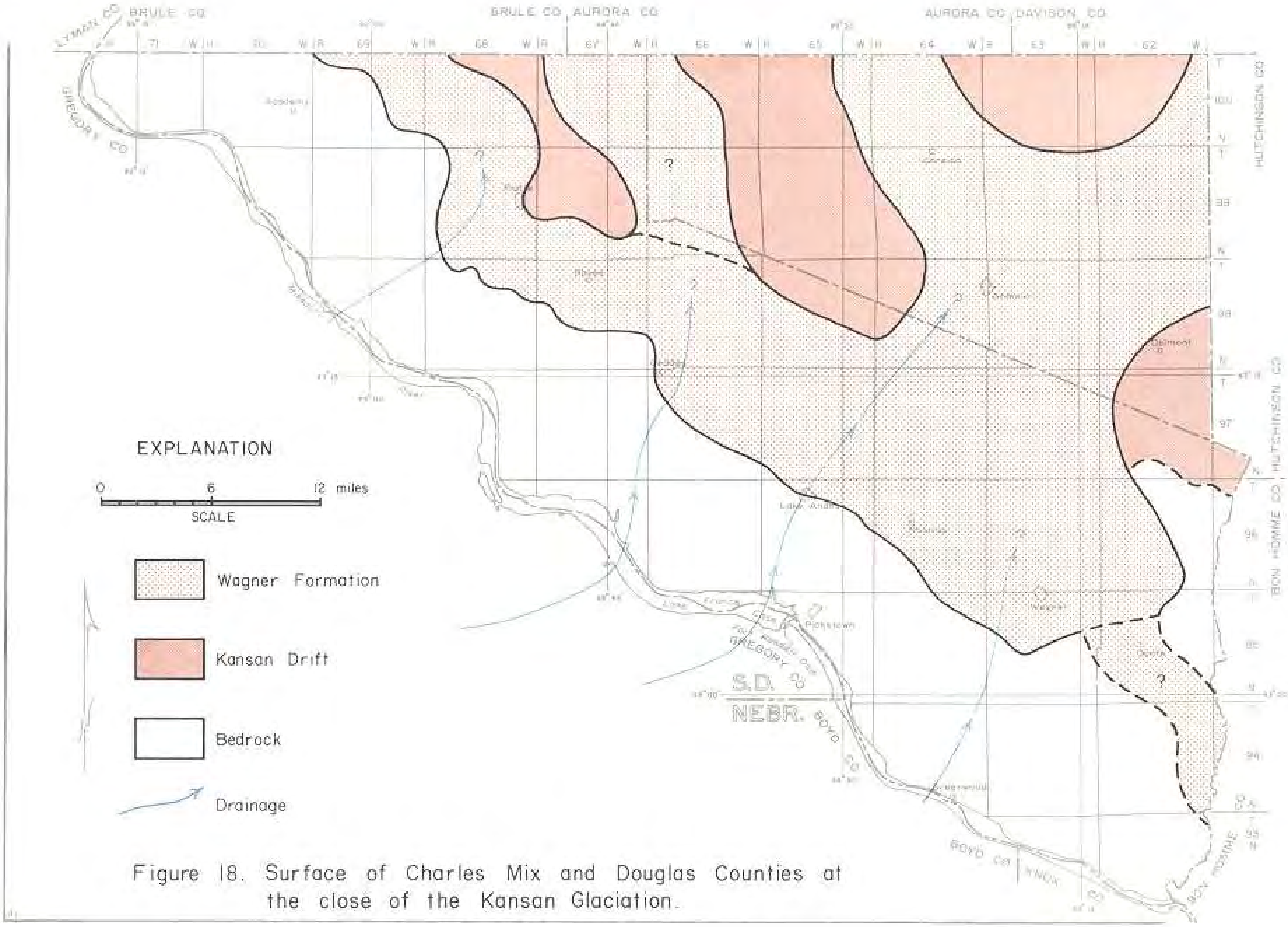

Figure 18. Surface of Charles Mix and Douglas Counties at the close of the Kansan Glaciation.

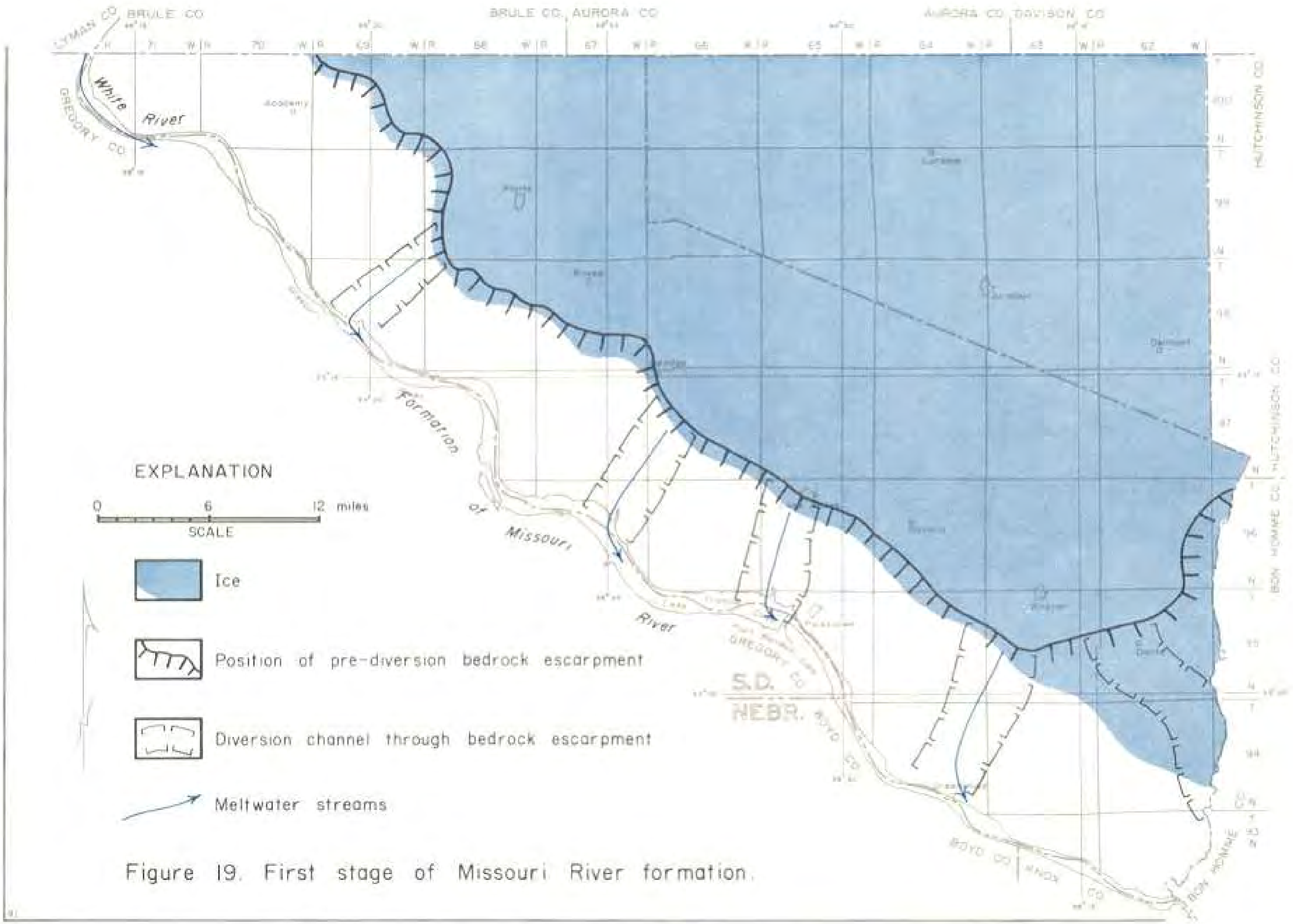

Figure 19. First stage of Missouri River formation.

Early Wisconsin Glaciation

The Early Wisconsin glaciers did not reach westward to Charles Mix and Douglas Counties. During this time the study area was still undergoing weathering and erosion. By this time or during it, much of the Illinoian till on the uplands was eroded away. At some point during the Early Wisconsin, loess accumulated on the truncated soils which had formed on Illinoian till. Christensen (1974) also reports loess accumulation in Bon Homme County during the Early Wisconsin.

Weathering and erosion were nearly continuous processes from the end of the Illinoian Glaciation up to the Late Wisconsin Glaciation. During this time much of the Illinoian glacial drift was removed but no significant drainage alterations occurred.

Late Wisconsin Glaciation

Ice of Late Wisconsin age covered all of Charles Mix and Douglas Counties except for a small area in northwestern Charles Mix County including the Bijou Hills and possibly some other very restricted high areas along the Missouri River.

The Late Wisconsin ice entered the mapped area from the north and northeast generally following a low broad topographic depression carved out by the White River and diversion channels associated with previous glacial advances. As the ice encroached the study area, its direction of flow was strongly influenced by the local topographic features. The ice generally followed the paths of least resistance which were the paths of former drainages. Eventually, small tongues of active ice reached the Missouri River trench through the abandoned Illinoian diversion channels presently occupied by Platt, Pease, Garden, and Choteau Creeks. At the same time or shortly after, ice overrode the adjacent highlands and eventually reached the Missouri River.

The major thrust of active ice which overrode the highlands and reached the Missouri River was short-lived; the ice was relatively thin and it carried a relatively small amount of debris. The basis for reaching this conclusion is the lack of glacial drift on the highlands and in the Missouri trench next to the highlands. The general direction of ice movement as it entered and moved through the two Counties to the Missouri River is shown on figure 20.

The advancing ice deposited outwash in existing channels, cut new channels and deposited outwash in them, and then overrode the area depositing till on top of the outwash. In the cross sections (pls. 2-6) most of the buried outwash first encountered below till is thought to be proglacial outwash associated with the Late Wisconsin ice advance.

Glacially Modified, Stream-Eroded Topography

During the Late Wisconsin maximum (fig. 20) the ice overrode highly dissected bedrock high areas along much of the Missouri River and deposited a blanket of till (Qwltd on pl. 1). The till has a maximum thickness of 150 feet although most of the area has a thin covering 50 feet or less in thickness. The drainage is nearly everywhere integrated although slopes are gentler, local relief is less variable, and drainage density is less than in the eroded Pierre Shale bedrock topography adjacent to it (pl. 1). Stagnant ice probably remained in this area for a short period of time.

Stagnation Drift

The term "stagnation drift" is used here to denote till and various glacio-fluvial deposits which were deposited under conditions of large scale glacial stagnation. As pointed out by the writer in an earlier paper (Hedges, 1972), the term stagnation drift was preferred for use in South Dakota because similar terms such as dead-ice moraine, hummocky stagnation moraine, and others have been used in other areas to denote till and associated deposits which were deposited under similar conditions. However, these other terms have all been used in areas where apparently there were relatively large amounts of englacial or superglacial material in the stagnant ice. It was apparent that in South Dakota there were areas which contained drift which had been associated with stagnant ice but which apparently lacked the abundance of englacial and superglacial drift during its deposition. For more thorough discussion of this topic the reader is referred to Hedges (1972, p. 22).

Soon after the initial thrust of glacial activity during which the Late Wisconsin ice reached its maximum position (fig. 20), the thin ice for a while experienced compressive flow and marginal thrusting along and onto the higher areas in the two Counties. This build up of ice and drift further restricted the flow of ice until active ice was present only in the lower areas where unrestricted flow to the Missouri River trench was available. This stage of the Late Wisconsin glaciation is represented in figure 21. At this point about 50 percent of the higher areas were covered with stagnant ice while the active ice was confined mostly to the lowlands and had basically unrestricted flow.

Eventually the James ice lobe was no longer able to sustain active ice flow except in the extreme northeastern corner of Douglas County. By this time the area was almost completely covered with stagnant ice or was ice free (fig. 22). The areas of non-drift covered thin stagnant ice in the lowlands melted quite rapidly allowing the meltwater to cut channels into

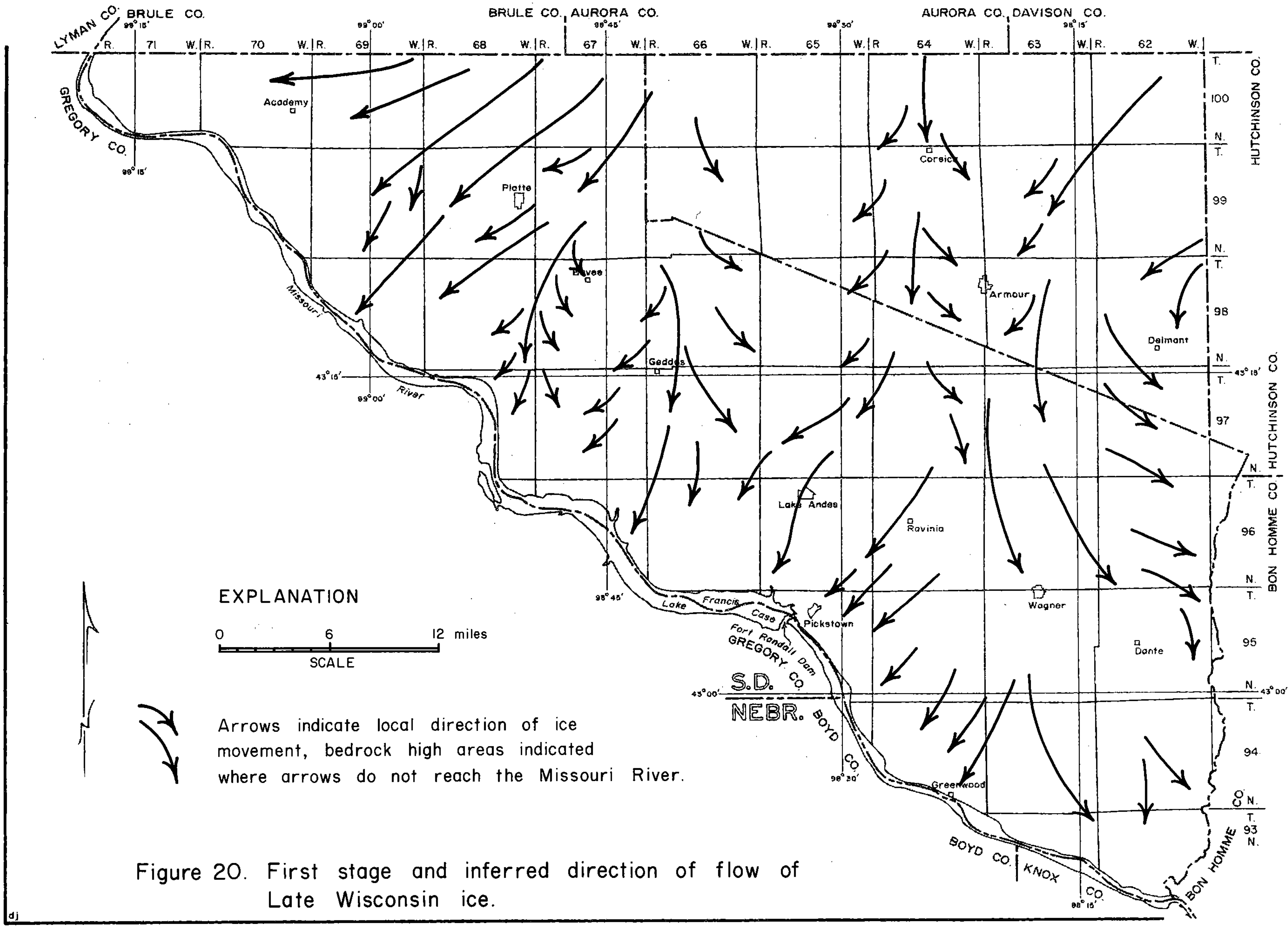

Figure 20. First stage and inferred direction of flow of Late Wisconsin ice.

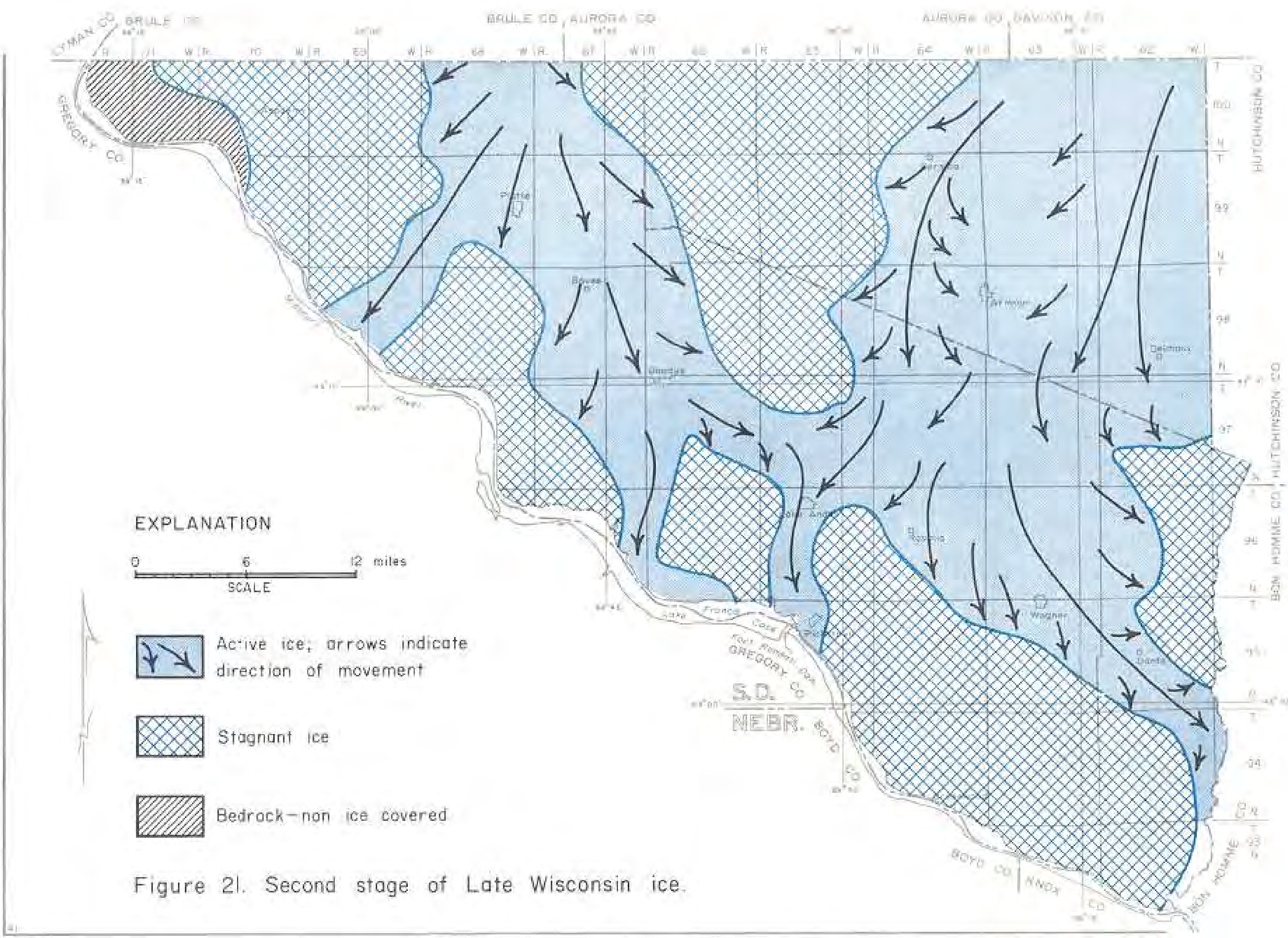

Figure 21. Second stage of Late Wisconsin ice.

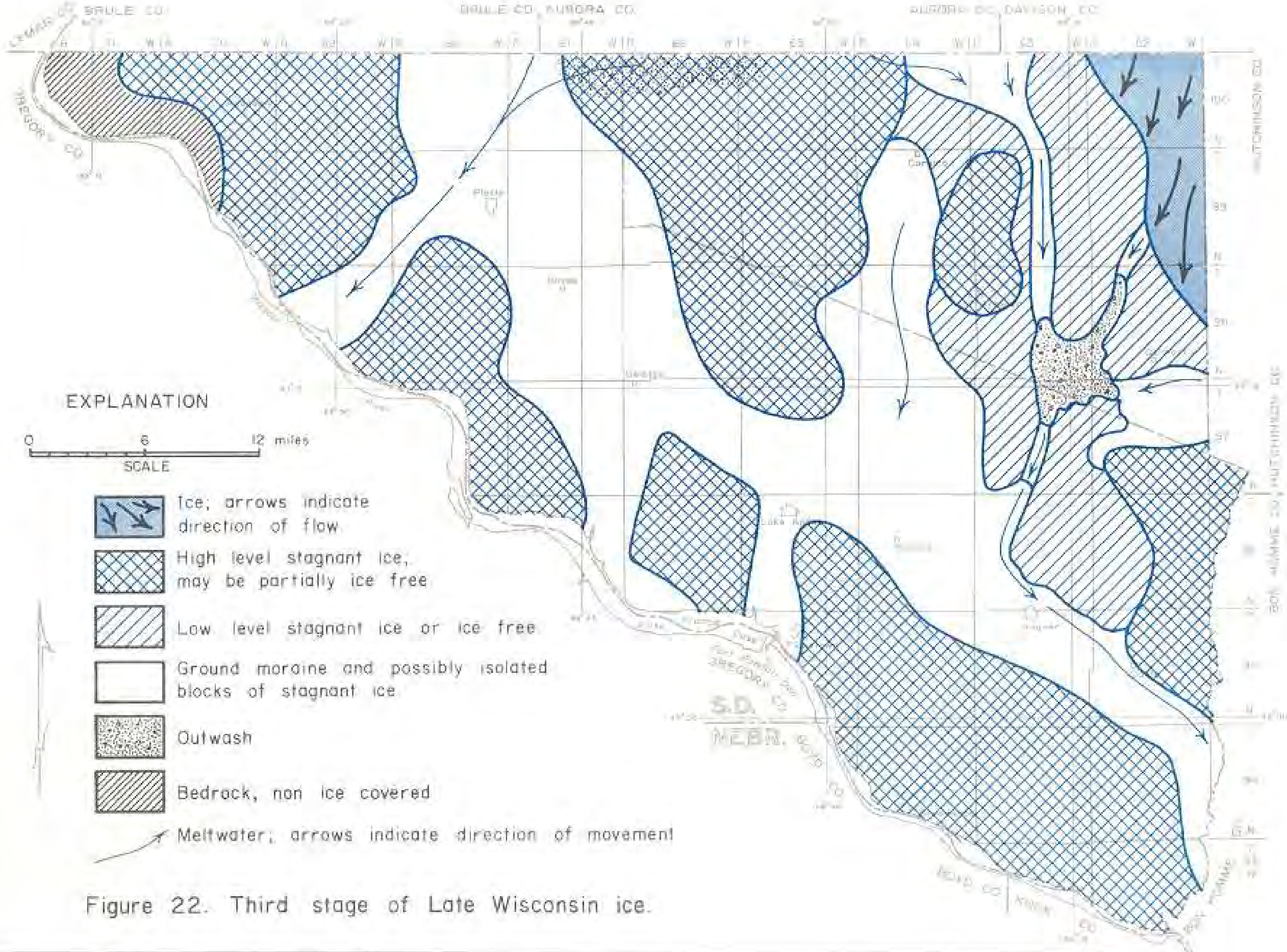

Figure 22. Third stage of Late Wisconsin ice.

the underlying drift. The till deposited in these areas consisted mostly of lodgement till and basal ablation till which is the ground moraine on plate 1.

Active ice was still present in a few square miles in extreme northeastern Douglas County (fig. 23). The rest of the two-County area was either covered with stagnant ice or was ice free.

The two principal drainages at this time were Choteau Creek and Platte Creek (fig. 23). The broad flat extensive surficial Delmont outwash was deposited at this time under essentially ice free conditions although the headwaters probably originated in stagnant ice.

Platte Creek was ice free southwest of Carroll Lake but its headwaters originated to the northeast in a large superglacial outwash plain in northwestern Douglas County. Additional meltwater and sediments were contributed from stagnant ice in the northern reaches of Platte Creek in Aurora County.

Most of the meltwater and outwash sediments in Choteau Creek, Platte Creek, the Delmont outwash, and the collapsed outwash in northwestern Douglas County originated from outside the study area. Nearly conclusive proof supporting this conclusion is based on the relationship and history of Lake Andes to the overall drainage.

A study of topographic maps shows that Lake Andes would drain to the southwest through Garden Creek or to the east through Choteau Creek if the present lake elevation was 15 feet higher. There is presently no indication of a drainage channel at either of these locations. If water did indeed overflow these areas, it was for a very short period of time. Thus, since the basin containing Lake Andes was not completely filled by internal drainage, the large volumes of meltwater required for deposition of the outwash must have originated outside the Counties. Lending support to the previous conclusion is the presence of former wave cutting at a maximum height of about 15 feet and lack of significant lake sediments above the present shorelines.

The previous discussion about the near absence of meltwater runoff from ice within the two Counties is the main reason that ice-contact features normally associated with stagnant ice are rare in the study area.

The stagnation drift in Charles Mix and Douglas Counties can be divided into three types based mainly on topographic expression.

Low Relief Stagnation Drift

Low relief stagnation drift ($Qwlts_1$, pl. 1) is found throughout Charles Mix and Douglas Counties. This drift consists of hummocky till with numerous depressions and has mostly non-integrated drainage. Maximum local relief is about 35 feet and the thickness of underlying till is variable ranging from 50 to 250 feet. Small ice-contact hills and ridges are present but are not common in low relief stagnation drift. Drift of this description covers much of the uplands of Douglas County and occupies intermediate elevations throughout Charles Mix County.

High Relief Stagnation Drift

The city of Armour in Douglas County is situated on the south edge of high relief stagnation drift ($Qwlts_2$, pl. 1). The other occurrence of this type drift is in Charles Mix County northwest of Platte. High relief stagnation drift is characterized by knob and kettle topography or high relief hummocky topography with local relief as much as 60 feet. Drainage is non-integrated and large steep-walled depressions are common. Although not abundant, ice-contact features are more likely to occur in the high relief stagnation drift than in the low relief stagnation drift. Till underlying this drift generally is 100 to 200 feet thick.

Ice Disintegration Ridges

In eastern Charles Mix County and adjacent Bon Homme County there is an extensive area of stagnation drift ($Qwlts_3$, pl. 1; Avon Moraine, Christensen, 1974) characterized by circular to oblong disintegration ridges. Features such as these have been referred to as "prairie mounds" by Gravenor (1955) or "doughnuts" by Gravenor and Kupsch (1959, p. 52). The stagnation drift in this area varies from low relief to high relief.

These ridges are as much as 15 feet high although they generally range from 5 to 10 feet. An individual ridge is normally several hundred feet across. Many ridges were inspected in road cut exposures and by hand auger, and in all cases the ridges were found to be composed of till. On aerial photographs these features are easily distinguished but they are difficult to discern on the ground without the aid of the aerial photos.

Ground Moraine

Ground moraine covers about 20 percent of the mapped area and has been subdivided into two types on the basis of topography ($Qwltg_1$ and $Qwltg_2$, pl. 1). Ground moraine now occurs in those low areas where active ice flow was last to cease and where superglacial drift cover was minimal.

Flat Ground Moraine

Flat ground moraine occurs in extreme

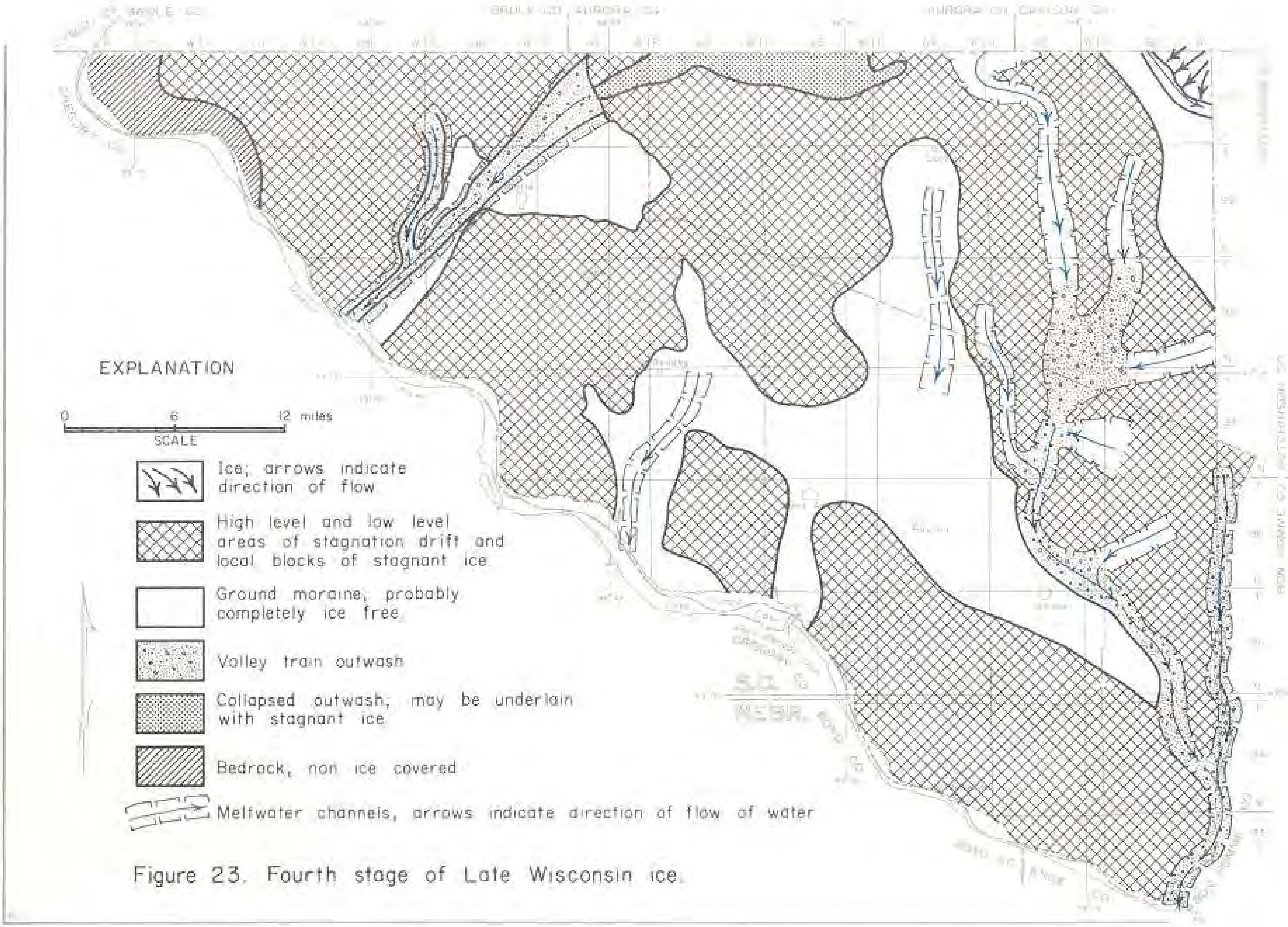

Figure 23. Fourth stage of Late Wisconsin ice.

northeastern Douglas County and in a large area around Platte in Charles Mix County ($Qwltg_1$ pl. 1). As the descriptive name implies the topography of these areas is nearly flat. Local relief rarely exceeds 10 feet and sloughs are less numerous than in the undulating ground moraine or stagnation drift. The drift underlying these areas is usually less than 75 feet in thickness.

Undulating Ground Moraine

Undulating ground moraine covers about 15 percent of the study area ($Qwltg_2$). This ground moraine is found primarily over the low areas marking the former course of major diversion channels. It consists primarily of partly dissected slopes transitional from the lowest elevations in the County to the intermediate elevations containing the stagnation drift. Local relief on this ground moraine is about 15 feet.

End Moraine

Linear ridges in drift which are associated with active ice margins are found only in extreme northeastern Douglas County (Qwlte, pl. 1). The active ice margin apparently was stationary at this location for a short period of time during deglaciation forming an end moraine that is composed of a series of discontinuous ridges 10 to 15 feet high on the ground moraine. A small tributary to Twelve Mile Creek in Davison County flows southeast along the distal portion of this moraine before it turns northeast and leaves Douglas County. This stream probably originated as a meltwater channel around the front of the ice while it was building the small moraine.

The lack of end moraine at the terminus of a large glacier like the James Lobe requires some explanation. This phenomenon can be explained by examining the flow patterns of the ice indicated in figures 20 through 23 while taking into consideration the regimen of this ice sheet.

Recent studies in wide-spread locations throughout eastern South Dakota, especially near the outer margins of the Late Wisconsin, indicate that the regimen of the glacier was such that the marginal active ice was relatively thin and was able to maintain flow on the higher elevations only for a brief period (Christensen, 1974; Hedges, 1972). Consequently, active ice was found only in the lowlands where movement occurred in many small sublobes. These sublobes found unrestricted flow to the Missouri River trench where end moraine equivalents were built in the form of boulder gravel or cobble gravel several tens of feet thick. Stratigraphic sections 6, 7, and 8 (p. 24, this report) illustrate these end moraine equivalents. Eventually the ice thinned enough so that active flow was no longer possible outside the James Basin leaving Charles Mix and Douglas Counties essentially devoid of end moraine development.

Recent Development

Geomorphic development of the land surface since the close of the Pleistocene Epoch has resulted in only minor changes in the landscape.

Most of the present drainage pattern was established at or shortly after the close of the Pleistocene although headward erosion in gullies is still locally quite rapid, especially along the Missouri River highlands. Likewise, slumping, landslides, and creep are also significant factors along the Missouri River highlands. Elsewhere in the two Counties these processes operate at a more modest pace.

Except during floods the dominant stream action is lateral erosion resulting in gradual migration of stream channels. Since the construction of the Ft. Randall Dam on the Missouri River, the lateral movement of the Missouri River channel below the Dam has been greatly reduced.

The establishment of Lake Francis Case upstream from the Dam has initiated relatively large scale valley wall erosion where wave action undercuts the nearly vertical valley walls thus increasing the landslide potential. This material plus sediment carried into the Lake from tributaries is responsible for siltation of the Lake. Siltation is potentially a problem of major concern.

Alluvium is slowly being deposited in present stream valleys, lakes, and sloughs. Most of the soils have been formed during the Recent age.

ECONOMIC GEOLOGY

Mineral Resources Investigations

Water

Water is probably the single most important mineral commodity to the people of Charles Mix and Douglas Counties. Fortunately the study area has an abundant supply of water available, either in surface water from Lake Francis Case and the Missouri River, or as ground water from several different aquifers.

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

The companion parts of this report discuss the water resources in detail and tabulate the basic data used in compiling the reports. These reports will be available at the South Dakota Geological Survey in Vermillion, South Dakota. Following is the listing for all three of these reports:

Hedges, L. S., 1975, Geology and water resources of Charles Mix and Douglas Counties, Part I, Geology: South Dakota Geol. Survey, Bull. 22

Kume, Jack, in preparation, Geology and water resources of Charles Mix and Douglas Counties, Part II, Water Resources: South Dakota Geol. Survey, Bull. 22

Hedges, L. S., and Kume, Jack, in preparation, Geology and water resources of Charles Mix and Douglas Counties, Part III, Basic Data: South Dakota Geol. Survey, Bull. 22

A generalized preliminary report showing aquifer locations is also available. It is referenced below:

Kume, Jack, 1972, Major aquifers in Charles Mix and Douglas Counties, South Dakota: South Dakota Geol. Survey, Information Pamphlet No. 2

Sand and Gravel

Relatively large amounts of sand and gravel are present in Charles Mix and Douglas Counties. The major problems related to the development of this resource are its uneven distribution and quality restrictions for certain specifications. Detailed information about sand and gravel resources can be found in the following publication which is available only from the County Auditor's office in Charles Mix and Douglas Counties:

Hedges, L. S., 1972, Sand and gravel resources in Charles Mix and Douglas Counties, South Dakota: South Dakota Geol. Survey, Circ. 42

Other Mineral Commodities

Several tests for oil and gas have been made in the study area although no commercial quantities of either have been discovered. For information about these tests the reader is referred to Schoon (1970).

Chalky zones within the Niobrara Marl may have commercial value. Detailed specification testing for each specific potential use would be required before any development of this resource. Chalk is used for building stone, lime, in the manufacture of paint whiting, putty, oil cloth, gun powder, rubber, leather, and roofing cement.

Locally, abundant rock from the glacial drift could be used for rip-rap.

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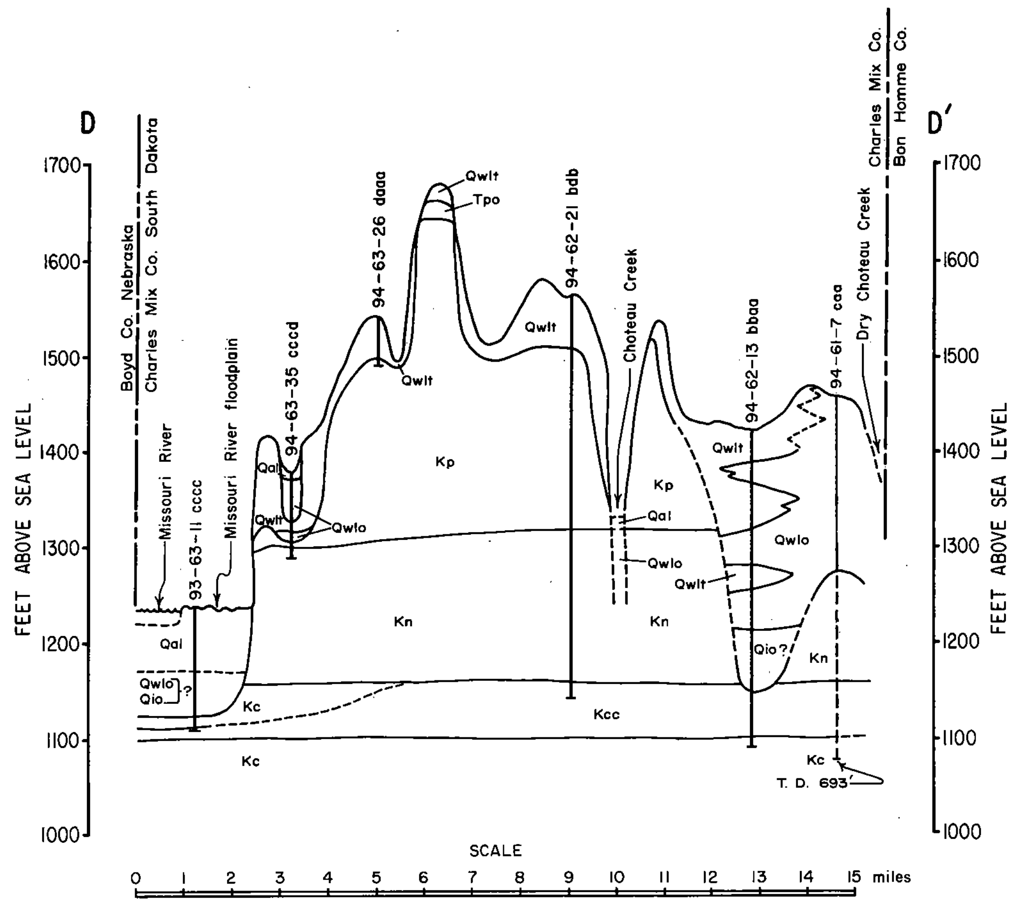
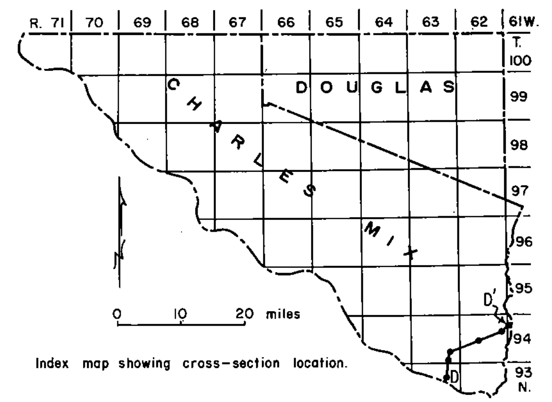
Plate 6. Stratigraphic section D-D'.



QUATERNARY	RECENT		Qal–alluvium
	PLEISTOCENE	LATE WISC.	Qwloc–collapsed outwash
			Qwlou–undifferentiated outwash
			Qwlt–till (may include older deposits where undifferentiated.)
			Qwlo–outwash (buried) (may include older deposits where undifferentiated.)
		ILLINOIAN	Qia–alluvium
			Qit–till
			Qio–outwash
		KANSAN	Qkw–fluvial deposit, Wagner Formation
			Qkt–till
			Qko–outwash
TERTIARY	MIOCENE-PLIO.		Tpo–Ogallala undifferentiated
			Tpf–Fort Randall Formation
CRETACEOUS	UPPER CRET.		Kp–Pierre Shale
			Kn–Niobrara Marl
			Kc–Carlile Shale
			Kcc–Codell sandstone member; Carlile Shale

Logs of test holes available in Hedges, 1975.



Index map showing cross-section location.

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