STATE OF SOUTH DAKOTA
Ralph Herseth, Governor

STATE GEOLOGICAL SURVEY
Allen F. Agnew, State Geologist

MISCELLANEOUS INVESTIGATIONS
No. 1

SOME SURFACE GLACIAL DEPOSITS IN HAND COUNTY, SOUTH DAKOTA*

by

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FOREWORD

The following report by Dr. Everett M. White of South Dakota State College is published herewith by the State Geological Survey because it represents a contribution to our knowledge of the glacial geology of South Dakota.

It is a pleasure to acknowledge the interest in South Dakota geology shown by Dr. White, and to recognize it by this publication. Dr. White is an agronomist who possesses a considerable background in geology.

The reader will note that some terms are used in this report with a soils connotation, rather than a geologic one.

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ABSTRACT

Two and possibly three glacial drifts of Wisconsin Age are exposed in Hand County, South Dakota. Each glacier added some surficial sediments and probably altered some of the earlier Pleistocene or pre-Pleistocene topography. The Pierre Formation, which underlies the glacial deposits, is exposed in the southern part of the county. Drift in the Ree Hills also may locally overlie Tertiary strata.

A sporadic poorly developed weathered zone is present on the older drift surface beneath a discontinuous loess mantle. Several areas of collapsed drift occur in the older drift. The collapsed drift may possibly have been deposited by a glacier younger than the one whose meltwater deposited a high gravelly terrace, dissected remnants of which are present along Elm Creek in the southwestern part of the county. All of the chronological relationships of Elm Creek features and those of other streams in the county have not been completely worked out.

Several areas of glacial outwash, ranging from gravels to clays, occur on the younger drift surface. Most of these sediments probably were deposited from meltwater contained temporarily by land areas that protruded above the margin of the glacier.

INTRODUCTION

This report contains geologic information collected as a by-product during the field work in 1954-57 for a soil survey of Hand County, South Dakota (White and others, in preparation), and is presented herein so that it will be available for the use of the geologic profession. Because the morphology of soils is influenced by the topography, the kind of geologic material, and the length of time that weathering processes have acted, as well as by the biotic and climatic factors of soil formation, a soil surveyor must try to use the geologic information in order to map the soils. Field examinations made during soil mapping frequently are more detailed than is possible in many investigations of surficial geology.

Hand County, in east-central South Dakota (fig. 1), is drained to the Missouri River by tributaries of the James River, except for the southwestern part of the county, which is drained by Elm Creek. The northwestern and southern parts of this area of 1440 square miles are generally included in the Missouri Coteau Physiographic Province, which is poorly defined in this area. Topographic features in the county were formed partly in the Pleistocene Epoch or later, and are due partly to earlier erosional processes which acted on the Tertiary and Cretaceous strata. Tertiary strata are reported in the Ree Hills, but locations of the exposures are not given. The few other bedrock exposures are of Pierre shale. The glacial drifts were assigned to the Cary and Mankato Subages of the Pleistocene Wisconsin Age by Flint (1955) before the Mankato type locality was found to be Cary in age (Wright and Rubin, 1956). The Cary and Mankato names are thus used provisionally in this report for the two drifts in Hand County. The older Cary glacier moved over the entire county, while the younger Mankato glacier did not cover the area south of the Ree Hills and Wessington Hills (fig. 2).

ACKNOWLEDGEMENTS

The writer expresses his appreciation to Dr. Fred C. Westin, South Dakota State College, under whose direction the State soil survey program is carried out, for his encouragement in the preparation of this report, and to Dr. Allen F. Agnew and the State Geological Survey for reviewing the report, for preparing the final figures and maps, and for publishing the report. The writer wishes to relieve the State Geological Survey of any responsibility for the geologic interpretations presented therein.

EXPOSED SEDIMENTARY ROCKS

The surficial glacial till is underlain by Cretaceous and possibly by some Tertiary formations. Tertiary rocks have been cited as the bedrock beneath the Ree Hills by Rothrock (1943, p. 35), and Flint (1955, p. 12, 24) refers these beds to the Ogallala Group. A number of Pierre shale exposures occur in the southern part of Hand County.

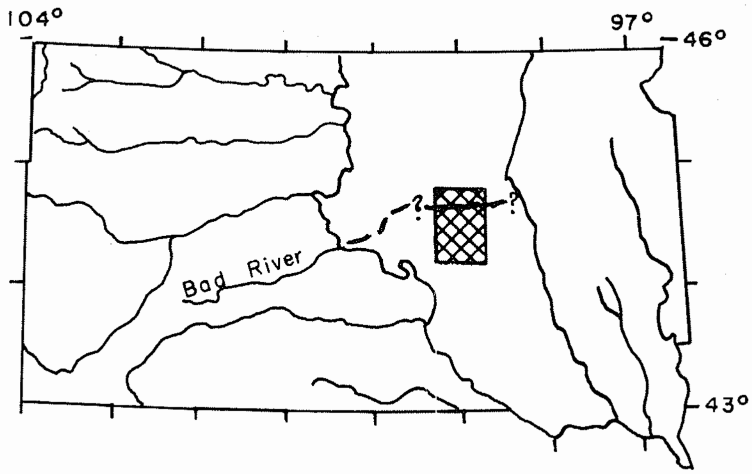


Figure I. Index map of South Dakota, showing Hand County and the ancestral Bad River (Flint, 1955).

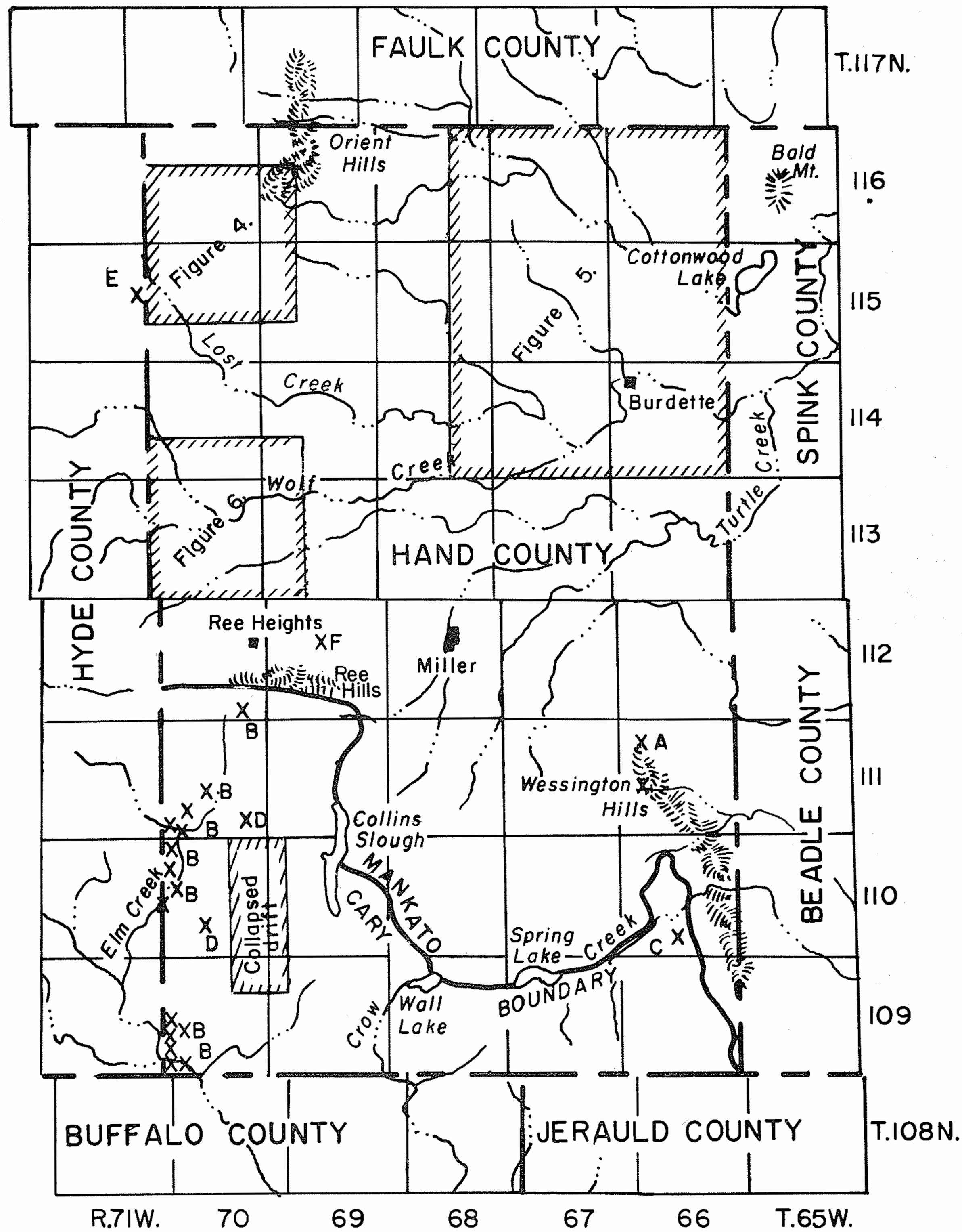


Figure 2. Map showing Mankato-Cary (of Flint, 1955) drift border revised, significant topographic features, and areas covered by subsequent figures.

An easily accessible exposure of Pierre shale is in a road ditch at the NW corner NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 8, T. 111 N., R. 66 W. (fig. 2, A). These two exposures contain a bedded, siltier deposit, which may not be a part of the Pierre Formation, resting on the finer textured, more compact Pierre shale. Another exposure is about 2$\frac{1}{2}$ miles to the south in a cut formed by a driveway into an abandoned building site. It is 0.1-mile west and 0.35-mile south of the NE corner of sec. 20, T. 111 N., R. 66 W. Additional exposures are probably present along incised gullies in the Ree Hills and Wessington Hills.

Numerous areas of Pierre exposures occur along the Elm Creek valley in the southwestern part of the county. Most of the outcrops are located in the following areas (fig. 2, B): Sec. 35, T. 112 N., R. 70 W.; eastern part of Secs. 21, 29, 31, and 32, T. 111 N., R. 70 W.; Secs. 6, 7, 18, and NW$\frac{1}{4}$ sec. 19, T. 110 N., R. 70 W.; SW$\frac{1}{4}$ sec. 18, Sec. 19, W$\frac{1}{2}$ sec. 20, NW$\frac{1}{4}$ and lower slopes elsewhere in Sec. 30, lower slopes in Secs. 31 and 32, T. 109 N., R. 70 W. The upper few feet of the shale in most of these areas has been disturbed by glaciers which mixed a few pebbles and boulders with the crushed and tilted blocks of shale.

Most of the shale is composed of clay particles, although some strata seem more silty than others. No bentonitic beds were found. All of the shale is calcareous, but the carbonates may be secondary because of weathering of the upper materials. Whether the olive or yellowish color of some of the shale is a fresh or weathered feature could not be determined, as no thick exposures of unaltered shale were found in the county.

PLEISTOCENE DEPOSITS

Cary Substage

General Description

Topographically, the Cary drift area in Hand County (fig. 2) is mainly a rolling plain of drift superimposed on an earlier irregular surface (Flint, 1955, p. 104). Post-glacial erosion has been minor except along the main streams, and these streams may be partly pre-Cary in age. Many shallow depressions occur in the irregular drift surface. Some larger depressions appear to be aligned and probably are located in partially drift-filled pre-Cary stream valleys. A thin, discontinuous loess mantle has obliterated many of the minor irregularities in the drift surface.

Till

The Cary drift is composed primarily of materials transported into the area either by the Cary ice or by earlier glaciers and, secondarily, of Pierre shale and crushed concretions from the shale, which could have been derived locally. These shale fragments and some of the clay in the drift, which presumably was present originally in the shale, impart to the drift a dark-olive color that is distinct from the color of the average Mankato till in the county. A few areas--for example, part of the upland east of Crow Creek (T. 109 N., R. 68 W.)--contain some till without the olive cast. There is some local variation in the composition and grain size of the till, although it is no more variable than most glacial tills. Most of the Cary till is slightly plastic and not as friable as the Mankato till. At some localities, a thin alluvium of interbedded sands, silts, and clays occurs at the contact of the till and the overlying loess.

Loess on the Cary Drift

The thin discontinuous loess mantle overlies a faint weathered zone in the upper part of the Cary drift, but is recognizable in only a few exposures. A thin leached humic soil zone was found beneath about 30 inches of loess that is carbonate-free in the upper part, at the NW corner of the NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 33, T. 110 N., R. 66 W. in a graded road ditch (fig. 2, C). The leached zone was exposed along the edge of the ditch for about 10-15 feet. Although the 4- to 6-inch humic silt is structureless, there is a thin layer of bedded calcareous silt between it and the till substratum. The weathered zone in most cuts, if leached, shows an accumulation of secondary carbonates from the weathering of the overlying loess. The zone is usually darker than the till and has prismatic structure.

Some depressions in areas of thicker loess have a light-colored silty layer that is underlain by a thin humic fossiliferous zone above the till, and overlain by recent dark-colored alluvium. The silt is thought to be loess. Most depressions contain dark-colored fill that has accumulated gradually without any apparent interruptions. It is questionable whether or not the humic zone beneath the silty layer in some depressions is analogous to the weak-weathered zone at the contact of the till and the loess.

The calcareous loess is a silt loam, although it may contain some gravel and pebbles. The coarser material could have been eroded from a higher position during loess deposition, or it could have been incorporated into the loess by rodents burrowing into the underlying drift. No eolian sands are associated with the loess except at the southeastern edge of Collins Slough (T. 110 N., R. 69 W.). At this site, along the terminal area of the Mankato drift, some post-Cary or probably Mankato coarse silt or very fine sand mantles the silty loess.

Most of the loess has been altered by weathering. The carbonates have been leached from the upper foot or two of the loess and at least partly re-deposited as secondary disseminated or soft concretionary carbonates in the lower part of the loess or in the drift below. Because no unoxidized sections of loess were found in the area, it is not known whether the buff color of the loess is due to weathering and oxidation, or is inherent in the sediment.

Collapsed Cary Drift

Within the Cary drift area are knolls of horizontally laminated silty clay loam with some laminae of silt loam and silty clay. These knolls are interspersed with other knolls that appear to have glacial till cores. Areas with laminated sediment have a distinct topography--a more or less continuous moat-like network of drainageways and depressions that surround and separate the knolls. The gently sloping or nearly level summits, a few acres in size, usually are flanked by continuous moderately steep slopes that are composed of non-sorted till or drift. Differences in elevation between the summits of the knolls and the lower parts of the drainage network range from 10 to 30 feet and do not seem to be related either to the size of the knoll or to the texture of the alluvium. In general the topographic features and the sediment are similar to those described by Flint (1957, p. 152) as "collapsed masses". Two representative areas are in the SW$\frac{1}{4}$ sec. 2, T. 110 N., R. 70 W. and in the SW$\frac{1}{4}$ sec. 36, T. 110 N., R. 69 W.

Equipment was unavailable to examine these deposits deeper than about 10 feet. In the upper 10 feet the horizontally laminated sediment is devoid of gravel, although a few very thin strata of fine sand were found at some localities. The surface of some of the knolls appears to be loess-covered, but in most areas the loess is not discernible.

No areas of gravel are associated with the laminated drift. The source of the finer material is unknown, but it may have been derived from detrital sediment in the upper part of the glacier. Two areas of gravel (SW$\frac{1}{4}$ sec. 28, T. 110 N., R. 70 W. and NE$\frac{1}{4}$ sec. 35, T. 111 N., R. 70 W.), along small tributaries of Elm Creek (fig. 2, D), may have been deposited by meltwaters from the collapsed drift area after the water was concentrated into larger streams.

It is postulated that the horizontally laminated drift was deposited in pools by slow-flowing water in and on the temporarily stagnated thin marginal ice of the Cary glacier. In Hand County, these deposits are oriented in a gently curved, discontinuous area that could have been the margin of the glacier.

Some depressions within the largest, most continuous area (fig. 2) of collapsed drift seem to have long axes that trend northwest-southeast, the direction of the collapsed drift pattern. If ground and terminal moraines are deposited in the manner proposed by Goldthwaite (1951), then an orientation of depressions in positions formerly occupied by ice-core moraines might be expected (fig. 3). Circular or irregular depressions without a directional orientation were not included in this diagram.

The average orientation of these depressions is about N. 20 degrees W. (fig. 3), the postulated trend of the front of the receding glacier at the time the collapsed drift was deposited. The writer could find no studies of the orientation of depressions in uniform till areas, so this interpretation is speculative. Ice-core moraines might form in the margin of a stagnant glacier for a short period while the sloping ice margin was intact, so the orientation of the depressions is alone not adequate evidence that the glacier was active. The topographic contours are nearly parallel to the NNW-SSE direction, so that gullies in the pre-Cary landscape probably developed at right angles to this direction. Presumably the depressions are not related to the pre-Cary surface. Any alteration of the original form of the depression during post-Cary time could result in an inherent error in the measurement of the direction of orientation. Because there are no areas of eolian sand, deflation can probably be eliminated as a factor.

Outwash in the Cary Drift Area

Elm Creek channel and terraces.--The incised Elm Creek valley (fig. 2) extends into the Ree Hills and ends abruptly, without much decrease in the depth of the valley floor in relation to the adjacent upland. A high gravel terrace occurs discontinuously at the edges and as remnants in the center of the valley. If the terrace were continuous, then a large volume of sediment has been removed since Cary time by a stream with a very small drainage area at its head. Post-glacial erosion in the upland is negligible because there are many shallow depressions without well-developed drainage outlets. Glacial meltwaters may have been concentrated in the Elm Creek valley and destroyed the terrace.

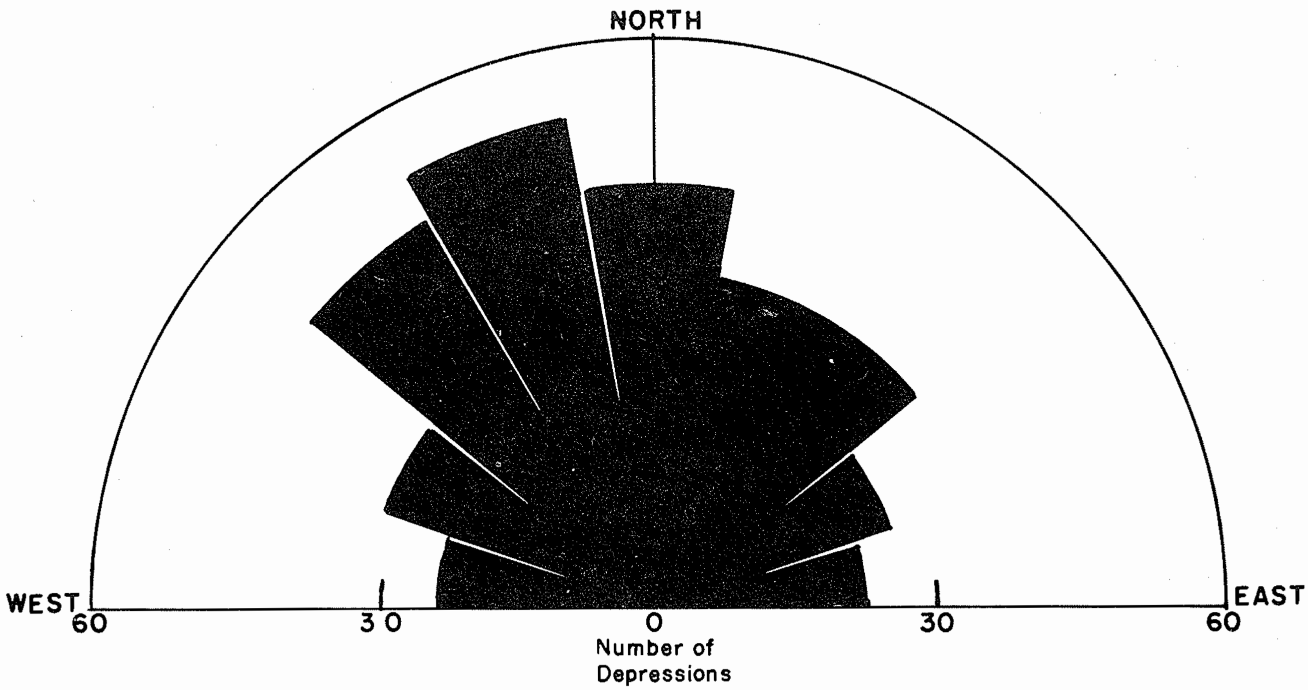


Figure 3. Orientation of depressions in collapsed area

An area of collapsed drift is located at the edge of the Elm Creek channel. Meltwater from this collapsed drift area and from the glacier to the north of the Ree Hills could have collected in this stream. Because the fine sediment in the collapsed drift area was deposited by relatively slowly flowing water, this meltwater going into Elm Creek could not transport much material. Erosion then could occur as the water was concentrated into a fast-flowing stream.

Sediment in the Elm Creek valley floor is moderately fine except at the edge of the high gravel terrace remnants. The creek has an indistinct channel in the valley for the first 5 or 6 miles and then gradually deepens to about 10 feet. Some small streams flowing into the valley from the upland have deposited fans and forced the creek to flow along the opposite bank.

A number of nearly level upland areas adjacent to Elm Creek appear to be till-mantled terraces. A high gravelly area (NW$\frac{1}{4}$ sec. 28, T. 111 N., R. 70 W.) may be part of an early terrace system. An exposure of fossiliferous, water-deposited sediments that may be related to this system is present near the top of a hill in the SE corner NE$\frac{1}{4}$ sec. 21, T. 111 N., R. 70 W. The importance of this exposure cannot be evaluated until the fossils are studied by a geologist.

Sand Creek-Crow Creek channel and terraces.--Sand Creek flows eastward and Crow Creek flows westward and then southward along a continuous valley in southern Hand County (fig. 2). The divide between the two creeks is difficult to determine because the valley apparently was created earlier by a larger stream. Whether the original stream flowed eastward or westward is indeterminate, as the present plain east of the Wessington Hills is considerably lower in elevation than the floor of the stream valley. Part of the continuous valley forms the boundary of the Mankato glacial drift area (White, 1957).

No detailed topographic map of the valley is available, so an interpretation of the two apparent glacial terraces is difficult, although the height of the higher terrace above the lower one appears to decrease westward from Spring Lake along Crow Creek. At Spring Lake, the high terrace gravels contain small, rounded till balls that, in part, are armored (Leney and Leney, 1957). Other gravel pits along the valley do not contain till balls.

The high terrace at Spring Lake may have been deposited while the glacial ice occupied the northern side of the valley. The gravels could not have been transported very far from the glacier margin, or the till balls would have been destroyed by abrasion. If the higher terrace is older, the difference in the gradient of the two terraces can be explained. The lower terrace probably is Mankato in age, whereas the higher terrace could be either earlier Mankato or Cary in age.

Spring Lake and Wall Lake were probably formed by large blocks of ice left in the channel as the Mankato glacier receded. According to local residents, both of these lakes were dry in the 1930's; Spring Lake had a mud bottom, but the south-central part of Wall Lake has a cobble and stone floor. Wall Lake apparently has not been filled with post-glacial sediment to the same extent as Spring Lake. The absence of the lower terrace gravels along part of the channel apparently cannot be attributed to post-glacial erosion, or the Wall Lake bottom should be covered with post-glacial alluvium. A small tongue of Mankato glacial ice may have extended down the valley and left stagnant blocks of ice, and the terrace gravels were deposited later in areas devoid of this ice.

A number of silty fans have been deposited in the valley by small streams flowing out of the uplands. These fans probably have blocked the small creek channel so that small ponds were formed and collected clay sediments. However, areas of clay occur in positions below the lower terrace gravels and thus cannot be explained in this manner. The writer thinks it likely that most of this clay was deposited early in the post-glacial period, when the small streams from the upland were adjusting to the new channel in the valley, and to the post-glacial climate.

Mankato Substage

General Description

The Mankato glacier moved over the Cary drift in the northern and eastern part of the county. It covered the rolling and steep Orient Hills, the nearly flat ancestral Bad River valley (fig. 1), and the gentle slope from the south in the south-central part of Hand County (fig. 2). The larger topographic features of the Mankato landscape, like that of the Cary landscape, are pre-glacial. Flint (1955, plate 1) shows generalized terminal moraines, ground moraines, terraces, and outwash deposits of the Mankato drift plain. Small depressions are most numerous in the west-central part of the ground moraine area.

Till

The average Mankato till is slightly less olive colored than the Cary till; the color difference is probably due to a slight variation in the content of Pierre shale in the two drifts. However, there are occasional blocks of Pierre shale in the Mankato drift. Mankato till in the eastern and central parts of the county is slightly coarser textured and more friable than is its counterpart in the area north of the Ree Hills. This difference in the till may have been caused by the accumulation of shale in the till as the glacier advanced farther from non-shale bedrock exposures. Much of the till has very weak horizontal bedding at a depth of three to five feet, which is observable only when the material is very dry. No evidence was found that the bedding was caused by stratification and sorting of the till. The drift is uniform in the central and west-central parts of the county, but very heterogeneous in the morainal areas of the northern part of the county.

Loess on the Mankato Drift

Most of the Mankato drift surface is devoid of loess. Only one conspicuous area of loess was found in the Orient Hills (fig. 4). About three miles to the south, in nearly level areas between morainal ridges, additional silts were found, but the possibility that they are aqueous sediments could not be excluded. The loess does not appear as well sorted as the loess on the Cary drift farther south in the county. Several level sites were examined fruitlessly for loess in Hyde County, just a few miles west of the area of Mankato loess. A sag in the landscape north of the loess area might have been filled with a large volume of stagnant glacial ice or glacial meltwater that contained fine debris. Winds could then

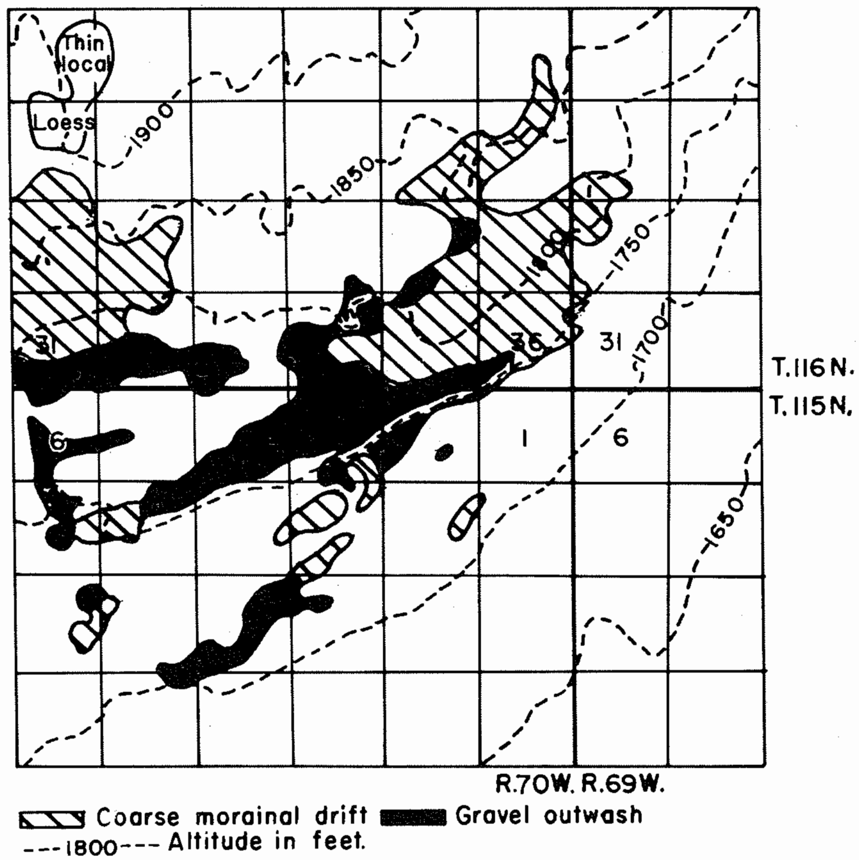


Figure 4. Orient Hills Area.

have transported and redeposited the sediment from this sag. Because the Mankato glacier over-rode some areas in southern Hand County at an elevation greater than 1900 feet, there is only a very slight possibility that the loess area referred to above, with about the same elevation, could be an island of Cary drift not covered by the Mankato glacier.

Outwash in the Mankato Drift Area

Four general areas of meltwater deposits are the Burdette, Orient Hills, Wolf Creek, and the Ree Hills and Wessington Hills footslope areas (fig. 2). Other minor areas of gravelly and silty drift occur throughout the Mankato drift. Most of the gravelly glacial terraces occur in or adjacent to the Burdette area, with the exception of the lower terrace along the Sand Creek-Crow Creek channel, as has already been discussed.

Burdette area.--Part of this area (fig. 5) has a sorted loam deposit, several feet thick, overlying the glacial till. The sediment appears to be a medium-textured outwash that is sandy at some places and silty at others. A few gravels and small pebbles occur locally in the outwash.

Gravelly terraces and bottomlands in sags in the landscape to the northwest of the medium-textured outwash are not completely related to present-day streams. The terrace slope increases to the west and southwest, and decreases to the east and northeast. Bald Mountain, a prominence in Spink County (fig. 2), stands about 150 feet above the adjacent drift plain. Between Bald Mountain and the slope to the west, an unobstructed active sublobe of the Mankato glacier might have flowed southward and persisted for a time during the general recession of the glacier. Low discontinuous recessional or terminal moraines outline the former positions of the margin of this sublobe (fig. 5).

Meltwater flowing to the west from this lobe and from the margin of the glacier to the northwest, was concentrated along the edge of the glacier by the surface slope to the west. The sediment load of this meltwater was deposited along the channels where it flowed. Coarser materials (gravelly outwash) were left in the sags, and the medium-textured sediments (loamy outwash) were deposited as the water spread across the landscape to the south of the sublobe.

The smaller isolated areas of medium-textured outwash shown in Figure 5 may have been deposited at different stages of the Mankato recession. They also may represent depressions in which thicker deposits accumulated. The exact boundaries of the outwash are not known, as the differentiation of a thin mantle of medium-textured outwash from the underlying medium-textured till, following the formation of a soil, is impossible. Some depressions and gentle rises are present in the outwash so that the topography is not distinctly different from an area of nearly level ground moraine.

Orient Hills area.--This area is located in and along the side slope of a remnant topographic high north of the ancient Bad River valley. The segment of Lost Creek in central Hand County (fig. 2) follows approximately the channel of the ancient Bad River (Flint, 1955, pl. 7). Glaciers advanced up this old valley, which was called the Ree Valley by Todd (1896), until they acquired sufficient thickness to cover this high area. During the recession, the Orient Hills rose above the lateral margin of the glacier. Meltwaters flowing from this ice margin were contained between the glacier and the Orient Hills. The outwash deposits discussed below probably were deposited by this meltwater.

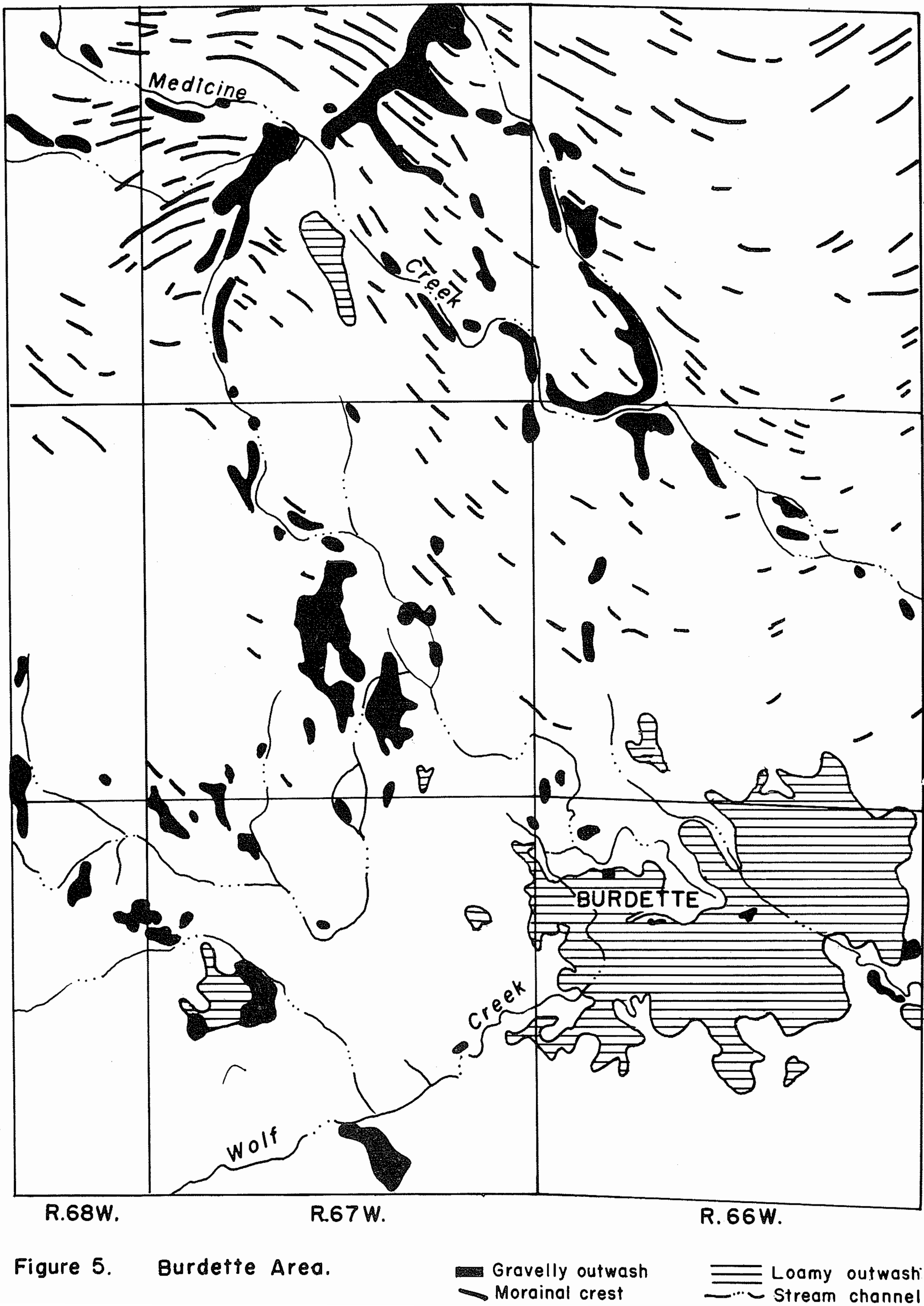


Figure 5. Burdette Area.

The pattern formed by the coarse morainic drift and outwash areas tends to follow the present topographic contours of the area (fig. 4). Morainic drift areas are composed of ice-contact materials and coarse collapsed drift, while the outwash is mainly stratified gravels. In a gravel pit in Hyde County about half a mile west of the Hand County line, (SE$\frac{1}{4}$ sec. 13, T. 115 N., R. 71 W.) small lenses and blocks of till were incorporated in the stratified gravels (fig. 2, E). An area of outwash, mainly in Sec. 16, T. 115 N., R. 70 W., is composed of silty and sandy strata or pockets in a gravel matrix.

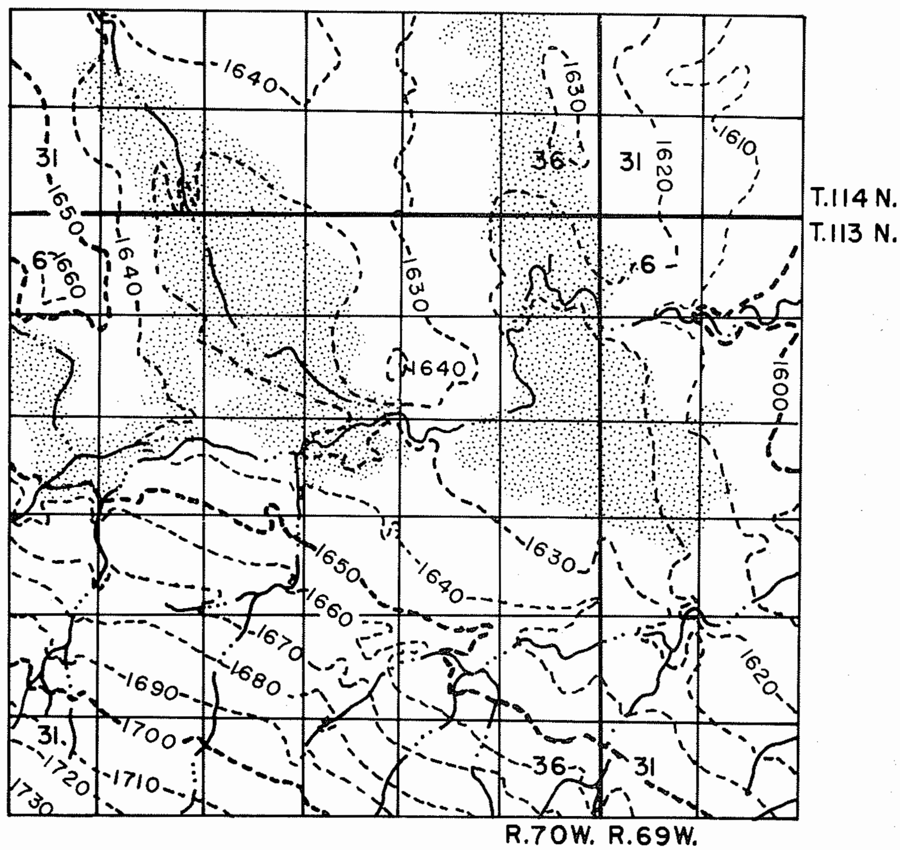
The juxtaposition of the coarse morainic drift on the upslope side of the gravelly outwash could be interpreted as evidence that the outwash was derived from the morainic areas. Some knolls in the morainic drift are capped by horizontally bedded gravels, however, so the relationships between the two areas may be coincidental.

Elongate areas of outwash in the lower part of Figure 4 are surrounded by, or adjacent to lower-lying ground moraine. This outwash may have been deposited in troughs between ice-core moraines (Goldthwaite, 1951), which later melted to expose the adjacent areas of till. Possibly these outwash deposits were formed in ice-controlled streams, in which case they could be called eskers. Meltwater from this area could have flowed westward and then southward around the margin of the glacier. Medium-textured outwash may have been deposited in Hyde County to the west.

Wolf Creek area.--This nearly level area is located in the ancient Ree Valley between the Ree and Orient Hills (fig. 2). Because the general surface slope is to the east, streams flowing to the east could have been obstructed by the Mankato glacier as it receded from the west. A shallow glacial meltwater lake probably formed in the lower portion of this area. Part of this area of alluvium (fig. 6) has been called a glacial lake deposit (Flint, 1955, p. 122 and plate 1). If the alluvium had been deposited recently, the rate of accumulation of the fine sediment from intermittent streams flowing into such a shallow lake could be slow enough for weak soil zones to form. Buried soils are not numerous, so the sediment must have accumulated rapidly. Sediment could have accumulated rapidly either if the area were a collecting basin for glacial meltwater, or if small streams to the west were cutting channels through unstable moraines before Wolf Creek had cut into the ground moraine to drain the basin.

Silty clay and clay occur in the eastern patch of alluvium, in the central part of the middle patch, and in Sec. 7, T. 113 N., R. 70 W. In Sec. 8, T. 113 N., R. 70 W., there are stratified silts, sands and gravels that probably were deposited at the front of the glacier. Some silty topographic rises occur in the clay alluvium in the northern part of the middle basin. A thin discontinuous silty clay or clay alluvium mantles the till in the northern part of the eastern patch.

The boundary between the alluvium and the ground moraine is not easy to locate because some depressions occur in both landscapes. At some places (NE$\frac{1}{4}$ sec. 2, T. 113 N., R. 70 W.) adjacent to the basin there is a poorly sorted moderately fine-textured mantle a few feet thick, which contains some gravel and pebbles. Locally this mantle is separated from the till substratum by a thin discontinuous pebble band. Although this surficial material could be a mixture of ice-rafted till and lacustrine sediment, there does not appear to be enough evidence to permit its differentiation from ablation moraine.



Alluvium

Generalized Altitudes in feet.(after U. S. Geological Survey topographic maps of Ree Heights and Highmore quadrangles.)

Figure 6. Wolf Creek Area.

The eastern patch of alluvium is part of a shallow trough that extends northward almost to Lost Creek. Lost Creek probably flowed down this trough when the glacier still blocked the area to the east. In addition, this trough may have been part of a pre-Mankato stream because there is a continuous winding dark-colored area on the 1939 air photo index sheet, from northwest of Ree Heights through the eastern patch of alluvium to Lost Creek.

Lost Creek heads in the outwash deposits of the Orient Hills area. Another creek which flows into the middle patch of alluvium also heads a few miles south of Lost Creek. Both streams probably transported some sediment from the Orient Hills area. However, because the Orient Hills outwash deposits are 50-150 feet higher than the Wolf Creek basin, the glacier probably was not present in both areas at the same time.

Wolf Creek is incised 15-20 feet into the till substratum in the eastern and middle patch of alluvium; therefore the dissection of the basin must be post-glacial in origin. A few small areas within the basins are flooded periodically by runoff from the adjacent nearly level slopes and from small streams that flow across the middle and west basins.

Ree Hills and Wessington Hills footslopes.--There is some question as to whether these slopes should be called alluvium-mantled pediments or coalesced alluvial fans. Probably the latter is more accurate, as the slope was shaped by glacial erosion instead of by stream erosion. The steep slopes at the foot of the hills gradually become nearly level where the fans merge with the ground moraine.

The texture of the fans is variable and ranges from till-like material at the base of the hills, to clays in the nearly level areas. In general the texture becomes finer as the distance from the hills increases, although there are some exceptions. Gravel areas, which are elongate down the fans, occur particularly in the area north of the Ree Hills and are most abundant in the northeastern part of Sec. 15, T. 112 N., R. 69 W. (fig. 2, F). Some of these gravels may have been deposited by small streams as channel-fill or natural levees. However, some of the thicker more highly sorted gravels are found on gentle slopes of only two or three percent and do not appear to be related to small drainageways. An alternate explanation is that stagnant glacial ice was protected against the Ree Hills and melted after the recession of the glacier. Gravels in the ice, or possibly deposited on the ice by streams flowing on the edge of the glacier, could have been sorted into these oriented deposits as the ice melted.

Part of the fan area north of the Ree Hills has been called a glacial lake bed (Flint, 1955, plate 1). Most of the sediment probably was deposited after the Mankato glacier has receded some distance from the area, although soils formed at the surface of some of the fans have about the same development as soils in the ground moraine. Soils that occur several feet beneath the surface at some places probably could have been formed only during post-glacial time. A great volume of sediment may have been eroded very rapidly from the steep, unstable slope created by the glacial erosion of the Ree Hills and Wessington Hills, and deposited as fan alluvium during late Mankato time. Some alluvium is still being deposited on part of the fans.

GEOLOGIC HISTORY

The two surficial drifts have been correlated with the Cary and the Mankato substages (Flint, 1955). This correlation was based on the Mankato type locality in Minnesota, which later was shown to be Cary in age (Wright and Rubin, 1956). Therefore, Flint's "Mankato" drift in Hand County is probably Cary (A. F. Agnew, oral communication, April, 1958), and his "Cary" is thus probably a pre-Cary drift, although there are no radiocarbon dates from Hand County as yet, nor have the drifts been traced here from Mankato, Minnesota. The difference in development of soil profile between the two drifts is very slight, so that the older drift probably is not significantly older than the younger. Nevertheless, because the Mankato-Cary terminology is published, those names will be used in the following discussion although they possibly are used incorrectly.

The age of the loess on the Cary drift is somewhat doubtful. A source for the loess has not been located, and no sorting pattern was detected, although in such a small area it is improbable that a textural difference could be found. The very weak weathered zone on the drift surface could have formed in a short period following the recession of the glacier, and the loess could thus have been deposited at the beginning of the interglacial substage. Vegetation probably was sparse at the margin of the glacier (Martin, 1958). Colonies of plants may have become established in more favorable or random sites, in order to form the weak soil and later to stabilize loess blown from adjacent barren areas. Because neither a well-formed pebble band nor eolian sands occur at the till-loess contact, this explanation of a local origin may be erroneous.

The Elm Creek valley and the Sand Creek-Crow Creek channel have been described in other sections. Low gravelly outwash terraces occur along the latter but not along the former. Because part of the Sand Creek-Crow Creek channel was at the margin of the Mankato glacier, the lower terrace is probably Mankato in age. Low gravel terraces are not present in the Elm Creek channel, and a high topographic divide with a sag about a mile long separates the channel from the broad, lower plain north of the Ree Hills. If Elm Creek had carried meltwater from the receding Mankato glacier, this sag should have been dissected and low terrace gravels should have been deposited. These differences between the Elm Creek valley and the Sand Creek-Crow Creek channel could be attributed to post-glacial erosion, as the stream gradient is about 10 feet per mile for Elm Creek (much greater than for Crow Creek). Sand Creek has a very steep gradient in the Wessington Hills, and a deep gully has been cut, gradually becoming less entrenched upstream away from the hills. Wolf Creek, formed in Mankato drift, is entirely a post-Mankato stream; it has about the same gradient as Elm Creek. Wolf Creek is incised some 20-40 feet in Hand County, but the depth of the valley decreases upstream. Elm Creek ends abruptly without much of a decrease in the channel depth.

Todd (1896, p. 27) discussed "Two interesting peculiarities" in the Ree Hills. One was Elm Creek,

> "--the elaborate drainage system found at the east end of the hills. From a gap about a mile and a half southwest of Ree Heights and 150 feet above that station the channel begins,

> and, with widening natural to such features, runs nearly directly southward for eight or nine miles. It receives from the west and southwest three or four tributaries and from the east about as many more, but smaller. About five miles from Ree Heights, where it receives two large tributaries from the southwest, its bottom is about 90 feet above the station. Its sides are 60 to 70 feet in height, abrupt, and very stony. Occasional mounds of gravel are found in the channel."

This rather detailed description of Elm Creek may indicate that Todd was not sure of the significance of this channel. The lack of symmetry in the tributaries from the east and west could be due to the greater elevation of the area south of Highmore in Hyde County, in comparison to the elevation of the area south of the Ree Hills, or it could be that there is a difference in landscape age on the two sides of the stream.

As was stated earlier, meltwater from the area of collapsed drift to the east may have removed most of the high terrace gravels. Evidence that the channel of Elm Creek may have been lower than the gravel terrace at the time meltwater flowed from the collapsed drift, occurs in a small tributary stream from the east. A gravel pit (west side, NW$\frac{1}{4}$ sec. 36, T. 111 N., R. 70 W.) near the upper end of the stream contains poorly sorted gravels and a discontinuous silty mantle. This silt appeared to be loess. About a quarter of a mile west, down the stream at a lower elevation, there is another small gravel pit with bedded gravels that seem more sorted than those in the upper pit. A sloping area between the two pits is more or less continuous and underlain by gravels. The lower gravel pit appears to be beneath the surface of the high gravelly terrace along Elm Creek. A detailed study and reconstruction of the terrace surface would be necessary before this observation could be confirmed. If the high terrace was deposited at the front of a glacier receding parallel with the area of collapsed drift, then the terrace may be a complex of kame terraces with a very irregular surface. Lower terrace surfaces also could have been created if a continuous high terrace had been dissected in the post-Cary period.

Areas of collapsed drift occur near the margin of the Cary glacier in other parts of South Dakota. The elevation of at least part of these areas probably could have been attained at one time by the glacier. Areas of collapsed drift, similar to those in Hand County, are described as extensive to the east (Flint, 1955; Steece, 1958a,b; Tipton, 1958a,b,c,d).

In this eastern area the glacier was at the edge of a topographic high where surface drainage away from the terminus of the ice would be slow. Because the surface in southwestern Hand County slopes away from the area covered by the glacier that deposited the collapsed drift, the meltwater should have drained more rapidly from the margin of the glacier there than it did in the eastern area. If the time of deposition of the collapsed drift were simultaneous in all of these areas, then the area of collapsed drift in Hand County may be a terminal feature of the glacier. The drift farther southwest then would have to be pre-Cary in age.

The trough south of Lost Creek, through the east Wolf Creek basin and the dark area on the air photo index north of Elm Creek, may not be related to an ancestral channel of Elm Creek. The elevation at the trough south of Lost Creek is about 1620 feet above sea level, at Ree Heights it is 1730 feet, and according to Todd (1896) it is 1880 feet at the head of Elm Creek and 1820 feet about 5 miles down Elm Creek to the south. If an ancestral Elm Creek flowed from the area north of Ree Heights, then the channel must have been much deeper than it is now. According to a local rancher, wood that is no longer available for examination was found at a depth of about 30 or 40 feet in a well in the Elm Creek bottom (N. side, sec. 17, T. 110 N., R. 70 W.). Since hills composed of Pierre shale stand some 100 to 200 feet above the Elm Creek bottom a mile or so to the northwest, and additional outcrops of shale occur about 75 feet above the bottom on the eastern bank of the stream about 2 miles to the southwest of the well, it is probable that at least part of the channel is pre-Cary in age (Flint, 1955, pl. 7). The wood had to be deposited in a channel that was cut into the shale, although not necessarily a channel that is related to the present Elm Creek. A study would have to be made of the substratum before any definite conclusions could be made about an ancestral Elm Creek that extended north of the Ree Hills. A pre-Mankato stream also may have flowed northward from the Ree Hills to the Wolf Creek basin area.

SUMMARY

Hand County, South Dakota, has at least two surficial glacial drifts of Wisconsin age. Several areas of glacial meltwater deposits were formed when the younger glacier blocked the drainage eastward to the James River basin. Collapsed drift in the older drift area may be a terminal feature of that stagnated glacier or possibly of a third glacier intermediate in age to the two discussed. A number of terrace and stream channel problems need to be solved before the goelogy of the older drift area can be more fully understood.

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