STRATIGRAPHY, ORIGIN, AND CLIMATIC IMPLICATIONS OF LATE QUATERNARY UPLAND SILT IN NORTH DAKOTA

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ABSTRACT

The Oahe Formation is a surface layer of silt on gently sloping surfaces throughout much of North Dakota and adjacent areas. It is as much as 6 m thick. The formation is subdivided, from bottom to top, into (1) the Mallard Island Member, (2) the Aggie Brown Member, (3) the Pick City Member, and (4) the Riverdale Member, which are differentiated in the field by color differences. Most of the Oahe Formation is wind-blown silt. Two paleosols have been recognized: the Thompson Paleosol in the lower part of the Riverdale Member and the Leonard Paleosol in the Aggie Brown Member. The Mallard Island Member is thought to be Late Wisconsinan in age. The Aggie Brown is Wisconsinan or Holocene. The Pick City and Riverdale Members are Holocene. The Mallard Island Member was derived in part from floodplains of melt-water streams. The dark layers in the remainder of the formation formed during moist times when hillslopes were stable, and the light layers formed during dry times when hillslopes were unstable.

INTRODUCTION

The Oahe Formation is a layer of silt found on gently sloping surfaces throughout much of North Dakota and adjacent areas (fig. 1). It is late Quaternary in age and consists largely of wind-blown sediment. It was first informally described by Bluemle (1971, p. 25) and Clayton and Moran (1971). It is here named for the Oahe Reservoir in south-central North Dakota. The type section of the Oahe Formation and its four members is the Riverdale Section in the vertical shore bluffs of Lake Sakakawea near the center of sec 22, T147N, R84W, 4 km north of Riverdale, in McLean County, North Dakota (figs. 2 and 3).

DESCRIPTION OF THE OAHE FORMATION

The Oahe Formation consists largely of unlithified silt. Along the Missouri River it is typically silt loam, using U.S. Department of Agriculture grain-size terminology (Soil Survey staff, 1951). At the Riverdale Section the Oahe Formation averages 75 percent silt (4 μm to 64 μm), 15 percent clay (less than 4 μm), and 10 percent sand (64 μm to 2 μm) (fig. 4 and table 1). In the southwestern part of North Dakota it is typically loam, sandy loam, or silty clay loam. In the eastern and northern part of the state it is almost entirely loam. In some places the Oahe Formation contains scattered pebbles, cobbles, and rarely even boulders. Most of the cobbles and boulders are artifacts such as hearth stones. Artifacts consisting of pebble-size chips of Knife River Flint are common in the Oahe Formation along the bluffs of the Missouri River. Terrestrial fossils, such as bison bones, also occur in the Oahe Formation. The silt is unbedded or contains diffuse beds at least 0.1 m thick that are slightly different in grain size or color. In dry vertical bluffs, the silt commonly has vertical columnar jointing. The columns are at least 0.1 m across. The clay-mineral composition of the less-than-4-μm fraction and the carbonate content of the less-than-74-μm fraction in the Riverdale Section are shown in figure 4. This data will be discussed in greater detail below.

The Oahe Formation is generally restricted to upland areas that have slopes of less than about 5° (0.1 rad). It is thickest on the top of the high bluffs southeastward from the Missouri River floodplain, where it is as much as 6 m thick (fig. 1). It is commonly absent on steeper slopes, at the base of steep slopes, and on lowland sites such as floodplains and the bottoms of closed depressions. Where it occurs, the Oahe Formation is always the

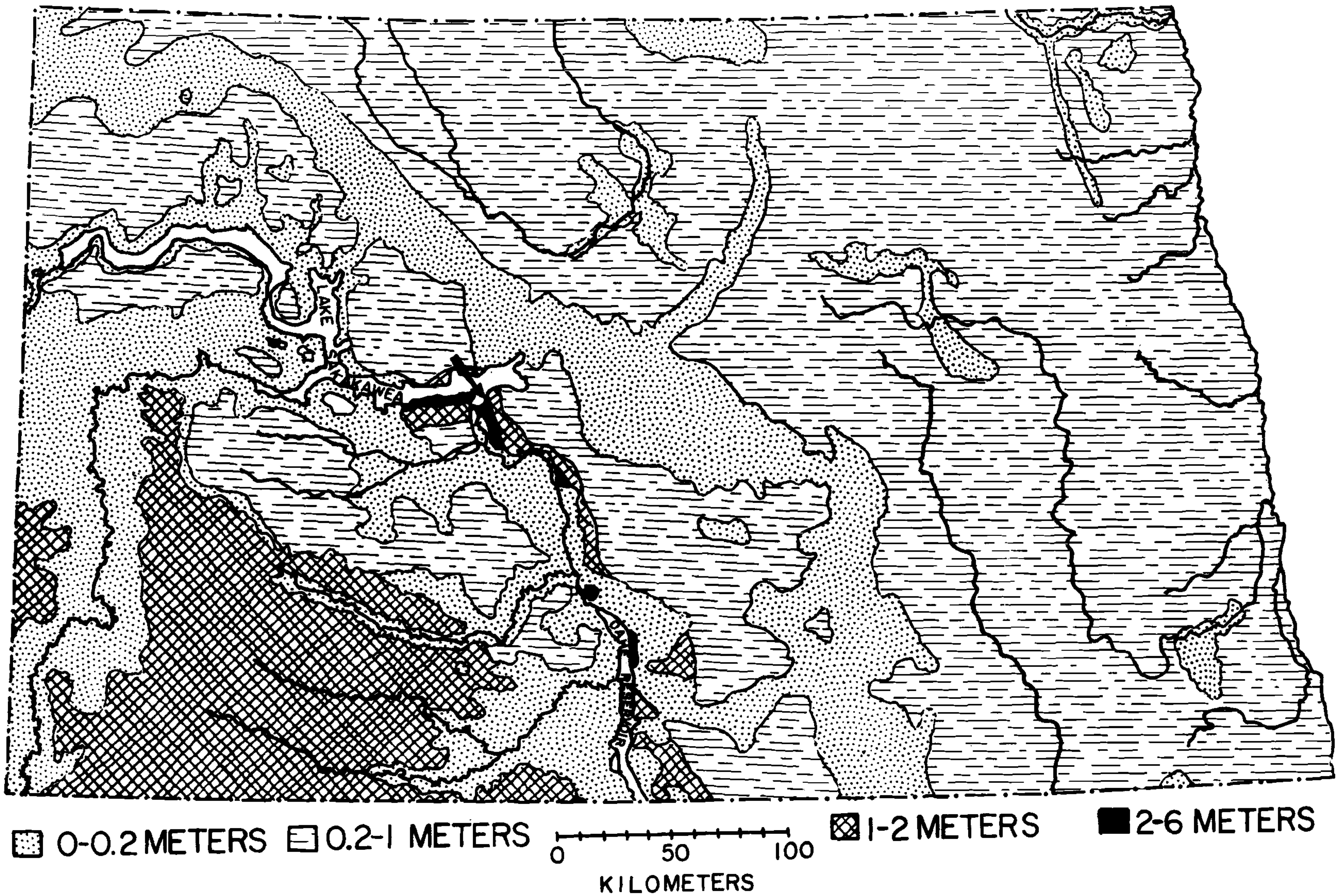

Figure 1. Map of North Dakota showing the approximate thickness of wind-blown silt of the Oahe Formation. Compiled from a variety of sources. The silt is thinnest where other Holocene sediment (such as stream sediment and wind-blown sand) has been deposited or where slopes are steep. It is 0.2 to 1 m thick on flat to rolling late Wisconsinan surfaces. It is 1 to 2 m thick downwind from the Missouri River floodplain and on flat to rolling early Wisconsinan or older surfaces. It is 2 to 6 m thick immediately downwind from the Missouri River floodplain. The arrow in the east end of Lake Sakakawea indicates the location of the Riverdale Section.

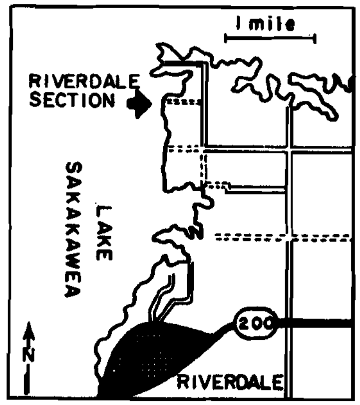

Figure 2. Access to the Riverdale Section.

surface lithostratigraphic unit. It may lie on top of any of the other near-surface formations in the state (Bickley, 1972).

In the bluffs along the Missouri River and throughout much of the rest of the state the Oahe Formation can be subdivided, on the basis of color, into four members (figs. 3 and 4). These members are easily recognizable at about nine-tenths of the several hundred exposures of the Oahe we have looked at.

MALLARD ISLAND MEMBER

The lowest member of the Oahe Formation is the Mallard Island Member, here named for Mallard Island in Lake Sakakawea, 3 km northeast of the Riverdale Section. The Mallard Island Member is commonly very pale brown (10YR 7/3, dry). It is redder than the Pick City Member, though the two members are almost the same color in some outcrops at the east end of Lake Sakakawea; they can everywhere be differentiated by the presence of the intervening Aggie Brown Member. The Mallard Island Member is 0.1 to 1.0 m thick southwest of the Missouri River. It is 1 to 2 m thick on the uplands east of the Missouri River in the southern part of the state. The Mallard Island Member is commonly underlain by a thin layer of lag pebbles eroded from the underlying Quaternary or Paleocene formations.

The Mallard Island Member is about 15 percent sand, 73 percent silt, and 12 percent clay (mean of nine samples) in the Riverdale Section. It contains 14 percent total carbonate (mean of nine samples) and has a calcite-to-dolomite ratio of 0.52. The mean clay-mineral composition of eight samples is 10 percent kaolinite and chlorite (0.7 nm d-spacing, glycolated), 9 percent illite (1.0 nm d-spacing, glycolated), and 81 percent smectite (1.7 nm d-spacing, glycolated). The Mallard Island Member is the sandiest, most dolomitic, and, except for the Aggie Brown Member, most smectitic of all the members in the Oahe Formation (fig. 4).

In the Riverdale Section, the upper 0.3 m of the Mallard Island Member contains more than twice as much clay as the rest of the member. In this same position the smectite has been completely altered to a nonexpanding clay with 1.4 nm d-spacing, probably vermiculite (fig. 4).

AGGIE BROWN MEMBER

The Aggie Brown Member is here named for Aggie Brown Coulee, which flows into Lake Sakakawea 2 km south of the Riverdale Section. The member has two submembers.

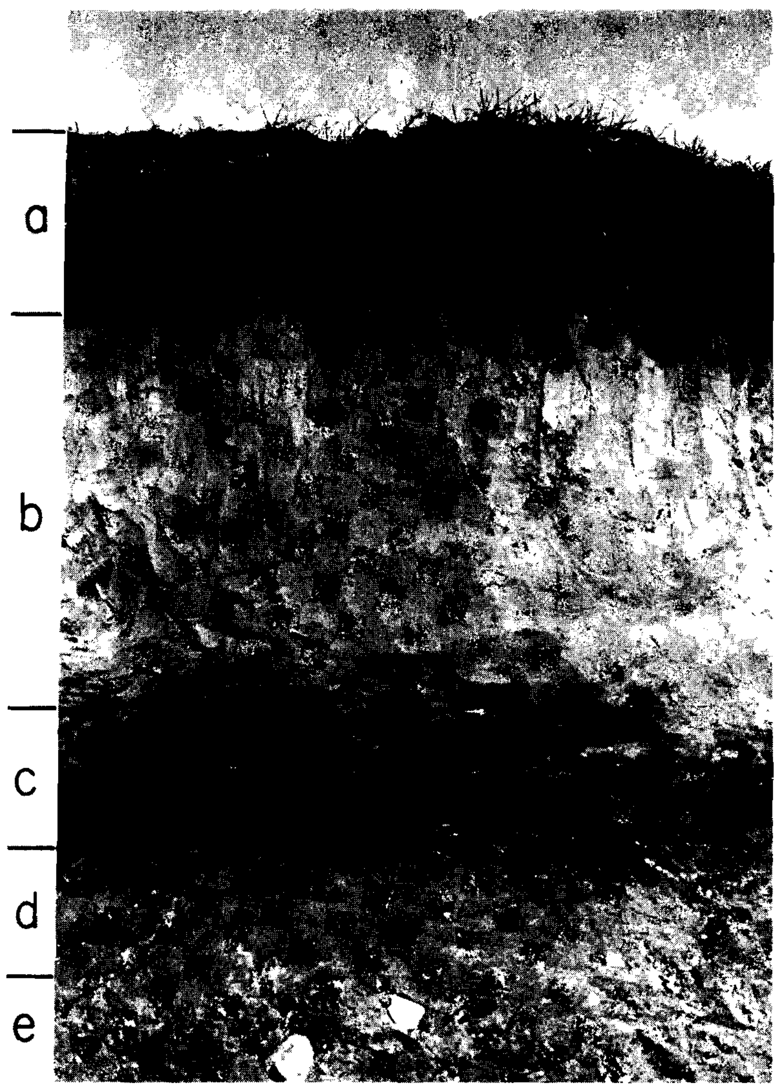

Figure 3. Top: photograph of the Oahe Formation at the Riverdale Section (a: upper Riverdale Member, b: middle Riverdale Member, c: lower Riverdale Member, d: Pick City Member, e: Aggie Brown Member, f: Mallard Island Member, g: glacial sediment). Bottom: photograph of the Oahe Formation at the Artifact Ditch Section, at the northeast edge of the town of Riverdale (a: Riverdale Member, b: Pick City Member, c: Aggie Brown Member (filled animal burrows are conspicuous), d: Mallard Island Member, e: glacial sediment).

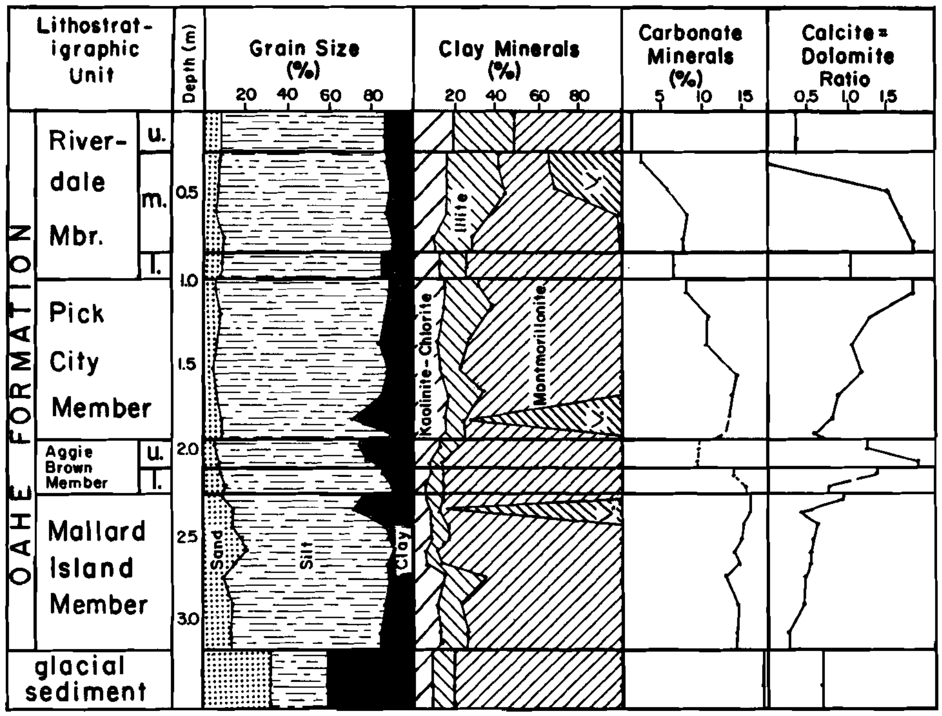

Figure 4. The Oahe Formation at the Riverdale Section, showing grain-size distribution, clay mineralogy, the carbonate content of the less-than-74 μm fraction, and the calcite:dolomite ratio in the carbonate fraction. "v" indicates vermiculite.

The lower submember is commonly light brown (7.5YR 6/4, dry) and is conspicuously redder than any other part of the Oahe Formation. The upper submember is dark gray or very dark gray (10YR 4/1, 3/1, 3/0, dry); it is darker than any other part of the Oahe Formation. The Aggie Brown Member is typically 0.1 to 0.5 m thick. Small fragments of charcoal and red baked zones, presumably caused by forest fires, were observed at the top of the Aggie Brown Member in several places along several kilometers of pipeline trench near Dickinson, in southwestern North Dakota.

Although the Aggie Brown Member is the most readily recognizable member within the Oahe Formation, it is the most variable in composition. It consists of about 9 percent sand, 72 percent silt, and 19 percent clay (mean of four samples). It contains 12 percent total carbonate and has a calcite-to-dolomite ratio of 1.09. The mean clay-mineral composition of six samples is 9 percent kaolinite and chlorite, 7 percent illite, and 84 percent smectite.

In the Riverdale Section, the upper submember contains nearly twice as much clay as the lower submember and the rest of the formation. The upper submember also contains less carbonate and relatively more calcite than the underlying and overlying sediment (fig. 4).

PICK CITY MEMBER

The Pick City Member is here named for the village of Pick City, 8 km southwest of the Riverdale Section. It is commonly light gray (2.5Y 7/3, dry). It is distinguished in the field from the Mallard Island by being less sandy and by the presence of the intervening Aggie Brown Member (fig. 4). It is distinguished from the lower submember of the Aggie Brown Member by being less red and from the upper submember of the Aggie Brown by

Table 1. *Description of the Riverdale Section (sec 22, T147N, R84W).*

Depth (m)	
0-0.30	Silt loam, grayish brown (10YR 5/2, dry), unbedded (upper Riverdale Member).
0.30-0.95	Silt loam, light grayish brown (10YR 6/2, dry), unbedded (middle Riverdale Member).
0.95-1.10	Silt loam, grayish brown (10YR 5/2, dry), unbedded (lower Riverdale Member).
1.10-1.80	Silt loam, light gray (2.5Y 7/3, dry), unbedded (Pick City Member).
1.80-1.95	Silt loam, dark gray (10YR 4/1, dry), unbedded (upper Aggie Brown Member).
1.95-2.15	Silt loam, light brown (7.5YR 6/4, dry), unbedded (lower Aggie Brown Member).
2.15-3.10	Silt loam, noticeably sandier than overlying units, very pale brown (10YR 7/3, dry), unbedded (Mallard Island Member).
3.10-29.0	Clay loam with scattered stones, unbedded; some sandy or gravelly layers; (largely glacial sediment); base of section at lake level.

being lighter colored. It is distinguished from the overlying Riverdale Member by being lighter colored. The Pick City Member is about 1 m thick along the Missouri River valley.

The Pick City Member has 7 percent sand, 77 percent silt, and 14 percent clay (mean of 17 samples from the Riverdale Section). It contains 11 percent total carbonate (mean of 19 samples) and has a calcite-to-dolomite ratio of 0.79. The mean clay-mineral composition of 12 samples is 13 percent kaolinite and chlorite, 13 percent illite, and 74 percent smectite.

In the Riverdale Section, the lower 0.2 m of the Pick City Member contains about twice as much clay as the rest of the member. In this same zone, a nonexpanding clay mineral with a 1.4 nm d-spacing, probably vermiculite, makes up about 75 percent of the clay-mineral assemblage. No smectite is present (fig. 4). Both the Pick City Member and the Riverdale Member contain slightly more illite, kaolinite, and chlorite and slightly less smectite than the two lower members.

RIVERDALE MEMBER

The Riverdale Member is here named for the town of Riverdale, 4 km south of the Riverdale Section. It is the uppermost member of the Oahe Formation. It is about 1 m thick near the Missouri River. In many places, it has three submembers of roughly equal thickness that are differentiated from each other by their color. The lower and upper submembers are commonly grayish brown (10YR 5/2, dry). The middle submember is commonly light brownish gray (10YR 6/2, dry). The upper and lower submembers are darker than all other parts of the Oahe except the upper submember of the Aggie Brown Member. The upper few centimeters of the upper submember of the Riverdale Member is lighter in color than the rest of the upper submember in many areas.

The Riverdale Member is very similar in composition to the Pick City Member. The Riverdale Member has 8 percent sand, 80 percent silt, and 12 percent clay (mean of nine samples from the Riverdale Section). It contains 7 percent total carbonate (mean of five samples) and has a calcite-to-dolomite ratio of 1.45. The mean clay-mineral composition of two samples is 11 percent kaolinite and chlorite, 11 percent illite, and 78 percent smectite. The upper part of the member is generally partly leached. The amount of kaolinite, chlorite, and illite is increased, and the amount of smectite is decreased in this zone. In some places part of the smectite is replaced by a nonexpanding clay mineral with a 1.4 nm d-spacing, probably vermiculite (fig. 4).

ORIGIN

The Oahe Formation is interpreted to be largely wind-blown sediment for several reasons. The predominance of silt is typical of eolian suspended-load sediment. The formation is draped over the highest hilltops, as if it were deposited by the wind. The Mallard Island Member tends to decrease in thickness southeastward, downwind from probable source areas; the prevailing wind is from the northwest today, and the orientation of fossil dunes and sand-blast grooves indicates that it was from the northwest during most of late Quaternary time.

The Oahe Formation is not lacustrine offshore sediment because it has very diffuse bedding, has terrestrial fossils, and much of it occurs in areas, such as major drainage divides, that are unlikely to have been covered by lakes in Holocene time.

Most of the Oahe Formation is not fluvial overbank sediment because it occurs in many areas, such as major drainage divides, that could never have been flooded in Holocene time. However, wind-blown silt on low river terraces is easily confused with overbank sediment; overbank sediment may also have a high silt content, diffuse bedding, and terrestrial fossils. Overbank sediment that is not included in the formation can generally be distinguished from the Oahe Formation in valley bottoms by the presence of sand with ripple crossbedding, by the presence of clay beds, and by the absence of the sequence of members and submembers described above. However, surface overbank sediment that has the physical characteristics of the Oahe Formation must be considered to be part of the Oahe Formation, because origin must have no part in the definition of lithostratigraphic units.

The Oahe Formation may contain some slopewash sediment near the base of hillslopes, where the wind-blown sediment has been reworked. Where sediment containing significant amounts of clay, sand, or gravel has been washed into the silt, the character of the slopewash sediment may be so changed that it is no longer considered to be part of the Oahe Formation.

PALEOSOLS

A. F. Bahr (State Soil Correlator, U.S. Soil Conservation Service, Bismarck, North Dakota) has described the entire type section of the Oahe Formation (letter dated 21 September 1970; sample number 570 NDAK-28-1).

The upper submember of the Aggie Brown Member is considered to be an A1 horizon by Bahr. It has been named the Leonard Paleosol by Bickley (1972). It is considerably blacker than the modern soil, suggesting a more moist environment of formation. Filled insect or worm burrows are conspicuous in much of the Leonard Paleosol but are inconspicuous in the modern soil, also suggesting a different environment. The lower submember of the Aggie Brown Member may be a B soil horizon, but not enough quantitative data is available to prove or disprove this. A white zone of lime enrichment is commonly present beneath the Aggie Brown Member.

The lower part of the Riverdale Member is considered to be an A1 horizon by Bahr. It has been named the Thompson Paleosol by Bickley (1972). It differs little from the A1 horizon of the surface soil (the Mandan Series, a pachic haplustall), suggesting that it formed in an environment much like the modern one.

CORRELATION

Not enough information is available to accurately correlate the Oahe Formation and its members with stratigraphic units in areas outside of North Dakota. The Oahe Formation may be at least in part equivalent to the Sanborn Group of Kansas and Nebraska (Frye and Leonard, 1952, p. 106; Hibbard, 1958, p. 55). Subdivisions of the Sanborn include the Peoria Formation (Frye and Leonard, 1952, p. 128), which may be in part equivalent to the Mallard Island Member, and the Bignell Formation (Frye and Leonard, 1952, p. 138), which may be equivalent to the Pick City Member and Riverdale Member. The Brady Paleosol (Frye and Leonard, 1952, p. 132; Ruhe, 1968, p. 61-62) at the top of the Peoria Formation, may be equivalent to the Leonard Paleosol; the Brady Paleosol has also been identified in South Dakota (Flint, 1955, p. 99). These correlations are, at best, tentative.

HILLSLOPE STABILITY

Some of the silt in the Mallard Island Member came from the floodplains of large rivers, because the Mallard Island tends to become thinner downwind from the Missouri River floodplain. Throughout most of North Dakota, however, there is little apparent relation between thickness and rivers (fig. 1). Instead the silt was apparently derived in large part from steep hillslopes. The most recent period of numerous dust storms was during the period from about A.D. 1930 to 1940 (the Dirty Thirties) when a few tens of millimeters of light-colored silt was deposited at the top of the Riverdale Member in many areas.

The conditions during the Dirty Thirties may be taken as representative of conditions during earlier periods when wind-blown silt was being deposited. Hamilton (1967) has shown that the Dirty Thirties was a period of instability on steep hillslopes in the Little Missouri Badlands of western North Dakota; a layer of sediment 1 or 2 m thick was washed from hillslopes into valley bottoms throughout most of the area. The age of this layer of sediment has been determined with considerable precision using artifacts (miscellaneous junk such as car hood ornaments and bottles), annual growth rings of partly buried trees, old photos (including air photos taken at the end of the 1930s), and historic records (Hamilton, 1967). Both before and after the 1930s little sediment was deposited in valley bottoms, gullies were cut, steep hillslopes were stable, and soils were formed on hillslopes. The mean annual temperature during the Dirty Thirties was 2°C or 3°C warmer than usual, and the annual precipitation was about 100 mm less than usual (Bavendick, 1952). By analogy, it is probable that dryer periods in the northern Great Plains during the late Quaternary were periods when steep hillslopes were unstable, when valley bottoms were alluviating, when a large amount of sediment was available to the wind, when dust storms were numerous, and when silt was actively being deposited on gentle slopes. In contrast, during more moist periods, steep hillslopes were stable, rivers were downcutting, little sediment was available to the wind, there were few dust storms, and soils were formed (fig. 5). This is in agreement with the generalizations of Schumm (1965), who showed that more hillslope erosion occurs during dryer periods in humid and subhumid areas.

Therefore, it is likely that the Aggie Brown Member and the upper and lower part of the Riverdale Member were formed during moist times when steep hillslopes were stable, and the Pick City Member and the middle part of the Riverdale Member were deposited on gentle hillslopes during dry times when steep hillslopes were unstable. This is supported by the fact that the middle part of the Riverdale Member and all older units have been removed from steep slopes, but the upper part of the Riverdale Member is developed on steep slopes (fig. 6).

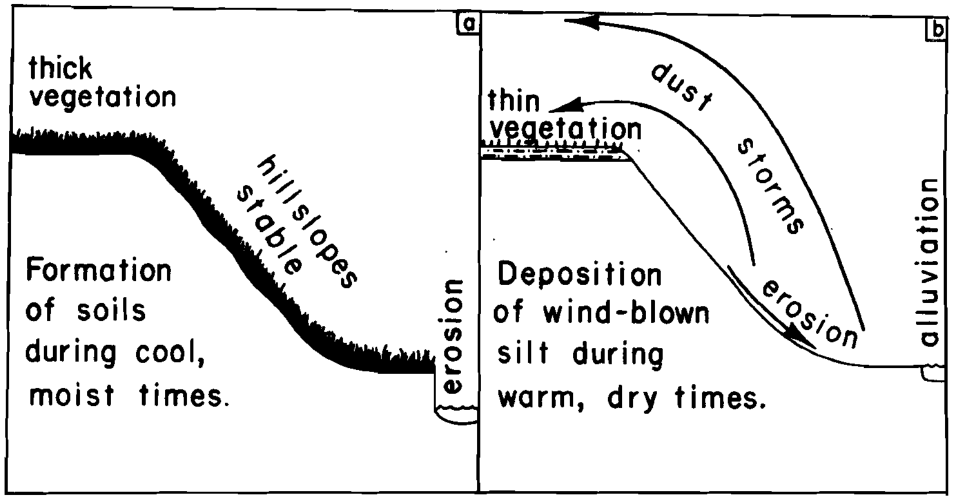

Figure 5. Depositional conditions controlled by hillslopes stability and climate.

The clay mineralogy at the Riverdale Section (fig. 4) gives additional evidence of unstable slopes during deposition of the Pick City Member. Vermiculite, presumably of pedogenic origin, occurs in two places at the base of soils: in the upper part of the Riverdale Member at the base of the modern soil and in the upper part of the Mallard Island Member at the base of the Leonard Paleosol. Vermiculite also occurs near the base of the Pick City Member, where there is no other field or laboratory evidence for a paleosol. The most likely source for the vermiculite is erosion of the lower part of the Leonard Paleosol on adjacent steeper slopes.

CHRONOLOGY

Most of the Oahe Formation has not been precisely dated. None of the organic material in the dark layers in the Oahe Formation has been radiocarbon dated because of the presence of modern rootlets. The best material for radiocarbon dating in the Oahe Formation may be charcoal from hearths in archeological sites, but no analyses have yet been made.

The bottom of the Mallard Island Member rests on sediment of the Napoleon Glaciation in Emmons County in southern North Dakota (Bickley, 1972). The time of the Napoleon Glaciation is unknown, but a variety of inconclusive evidence suggests that it was Early Wisconsinan (Clayton, 1966).

The top of the Mallard Island Member probably coincides with the end of the Late Wisconsinan glaciation in central and eastern North Dakota. Throughout northern and eastern North Dakota, where the surface glacial sediment is known to be about 13 000 years old (Salomon and others, 1973), and on the Missouri River 10-m terrace, which has been correlated with the latest Wisconsinan glaciation, the Mallard Island Member is missing (fig. 6). In these areas the lowest unit in the Oahe Formation is the Aggie Brown Member. The Mallard Island Member occurs only in areas that were not glaciated in Late Wisconsinan time.

It is therefore likely that much of the silt in the part of the Mallard Island Member deposited near the Missouri River floodplain was derived from silt deposited on the floodplain by glacial melt water, rather than from unstable hillslopes. This is supported by the carbonate mineralogy of the Oahe Formation (fig. 4). As described above, dolomite is the dominant carbonate mineral in the Mallard Island Member, but calcite is more abundant in the rest of the formation (fig. 4). The glacial sediment in the region contains considerably

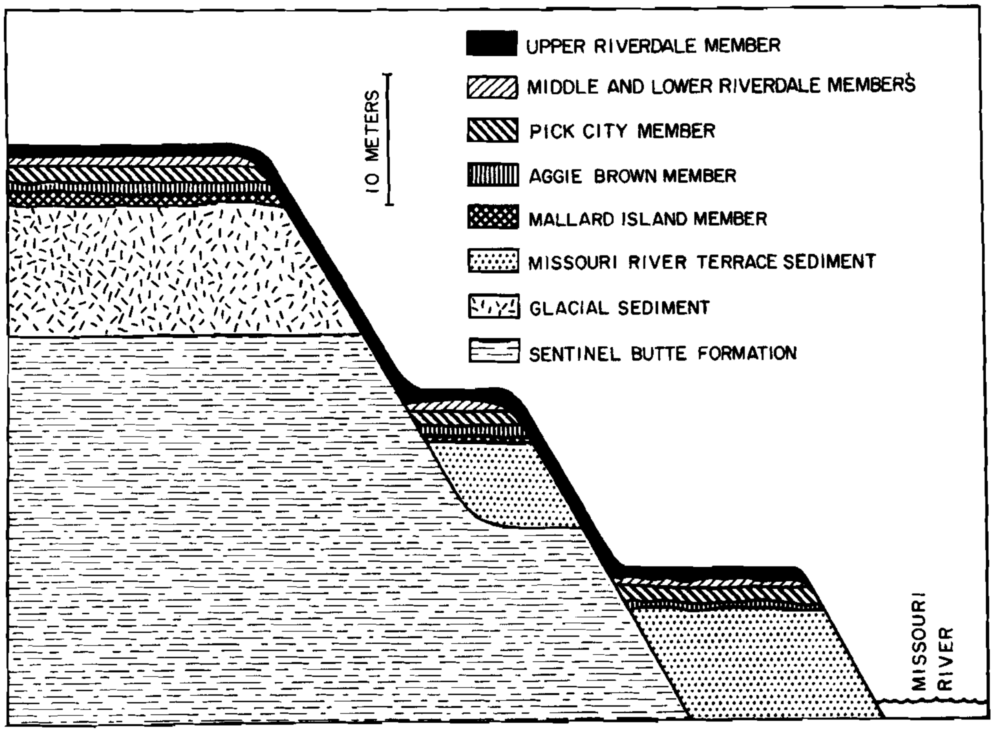

Figure 6. Cross section showing the typical relationships between the members of the Oahe Formation and the topographic surfaces in the Riverdale area.

more dolomite than calcite in the fraction smaller than 74 μm ; silt blown from outwash would be expected to contain more dolomite than calcite. The Paleocene Sentinel Butte Formation and Tongue River Formation, which are the surface units of most of western North Dakota, including the area drained by the middle reaches of the Missouri River, contain more calcite than dolomite (Royse, 1967, p. 159-161); silt blown from the Missouri River floodplain after the cessation of melt-water flow would be expected to be derived to a greater extent from local tributaries and to therefore contain more calcite than dolomite. Therefore, it is likely that the Mallard Island Member was deposited while the Missouri River still carried glacial melt water, before about 13 000 B.P., and the upper three members were deposited after the cessation of melt-water flow, after 13 000 B.P.

The chronology of contained artifacts may eventually be used to refine the chronology of the Oahe Formation. Artifacts, such as chips of Knife River Flint, hearth stones, and bones of butchered bison are common down to the top of the Aggie Brown Member in the Riverdale area. Artifacts of Knife River Flint are known to have become common in this area during early Holocene time (Clayton, Bickley, and Stone, 1970).

The history of postglacial climatic changes in the northern Great Plains can be used to more closely estimate the age of the subdivisions of the Oahe Formation (fig. 7-F). The climatic changes in the northern Great Plains during latest Wisconsinan and Holocene time are known with some precision (fig. 7-A, 7-B) from paleoecologic interpretations of pollen and macrofossils in postglacial pond deposits in Minnesota, South Dakota, and North Dakota (Wright, 1970; McAndrews, 1966; McAndrews and others, 1967; Watts and Bright, 1968; Cvancara and others, 1971) and from climatic syntheses in adjacent parts of North America (Wendland and Bryson, 1974; Birkeland, Crandell, and Richmond, 1971; and Denton and Karlen, 1973). Late Wisconsinan time (until about 10 000 B.P., radiocarbon years) was probably more moist and several degrees cooler than at present; a spruce-aspen woodland existed throughout much of North Dakota at that time. Early Holocene time

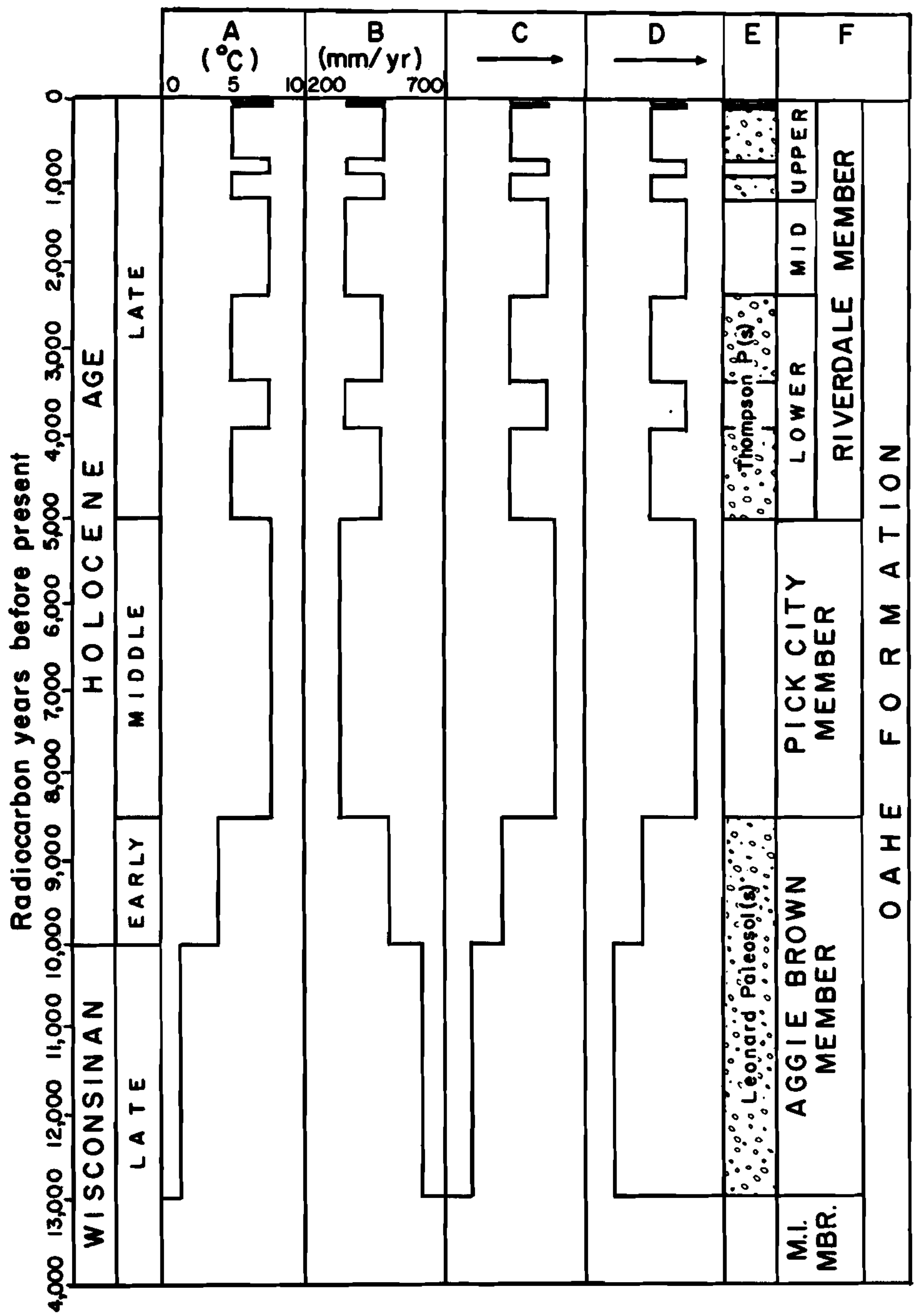

Figure 7. Postglacial (A) mean annual temperature, (B) precipitation, (C) slopewash erosion on steep slopes, (D)eeolian deposition on gentle slopes, (E) periods of conspicuous soil formation, and (F) suggested correlations with the subdivisions of the Oahe Formation. Values are extremely approximate. Many small fluctuations have been omitted.

(about 10 000 B.P. to 8 500 B.P.) was probably fairly cool and humid, not too different from today; prairie probably covered much of North Dakota at that time. Middle Holocene time (about 8 500 B.P. to 5 000 B.P.) was drier and a few degrees warmer than today; much of the area was probably covered by semiarid grassland. Late Holocene time (after about 5 000 B.P.) probably fluctuated between periods that were fairly cool and humid like today and periods that were a few degrees warmer and perhaps 100 mm/year drier, like the 1930s.

As suggested in the previous section, these climatic changes should have resulted in changes in hillslope stability (fig. 7-C). Hamilton (1967), Walker (1966), and Bickley and Clayton (1972) have shown that sedimentation in small valleys and ponds in Iowa and North Dakota has been controlled by climate, which controlled hillslope erosion. After vegetation became established in latest Wisconsinan time, there were probably periods (fig. 7-D, 7-E) when the climate was cool and moist, vegetation stabilized hillslopes, little hillslope erosion took place on steep slopes, little eolian silt was deposited on gentle slopes, soil formation took place, and the dark subdivisions of the Oahe formed. These alternated with periods when the climate was warm and dry, little vegetation stabilized the hillslopes, considerable hillslope erosion took place on steep slopes, considerable eolian silt was deposited on gentle slopes, little soil formation took place, and the light-colored subdivisions of the Oahe formed.

So it seems reasonable to suggest that the Aggie Brown Member was formed during latest Wisconsinan and early Holocene time, the Pick City Member formed during middle Holocene time, and the three subdivisions of the Riverdale Member formed during three major subdivisions of late Holocene time.

In many areas the uppermost few tens of millimeters was deposited during the dry dust-bowl years of the Dirty Thirties. This layer is lighter colored than most of the rest of the Riverdale Member, and in some places it overlies modern artifacts such as glass and wire. (Along many former fence rows in North Dakota, the blowdirt deposited during the Dirty Thirties is 1 or 2 m thick, but it is generally too sandy to be considered part of the Oahe Formation.)

SOIL GENESIS

The above discussion suggests alternate interpretations on the origin of some soils of the northern Great Plains.

Where the Oahe Formation is thickest, the parent material is commonly interpreted by pedologists to be wind-blown sediment (Omodt and others, 1968, p. 11). But where it is thinner, other interpretations are generally given. The Morton Series (a typic argustoll that is widespread in the northern Great Plains) has about 1 m of wind-blown sediment of the Oahe Formation, generally overlying the Tongue River or Sentinel Butte Formations (Paleocene); the wind-blown sediment has been generally interpreted to be "residuum" (Larson and others, 1968, p. 85 and 100). The Manning Series (a typic haplustoll) has 0.3 to 1 m of wind-blown sediment overlying sand and gravel of Pleistocene pediments (generally with fossil tundra ice-wedge polygons); the wind-blown sediment has been interpreted to be "alluvium" (Larson and others, 1968, p. 99). The Barnes Series (a udic haplustoll that is widespread in the northeastern Great Plains) has about 0.4 m of wind-blown sediment overlying glacial sediment; the wind-blown sediment has been interpreted to be glacial sediment that has been altered by weathering in place (Seago and others, 1970, p. 11 and 75; Omodt and others, 1968, p. 23; Redmond and Omodt, 1967). The Renshaw Series (a udic haplustoll) has about 0.5 m of wind-blown sediment overlying Pleistocene fluvial or shoreline sediment; the wind-blown sediment has been interpreted to be "outwash" (Seago and others, 1970, p. 35; Omodt and others, 1968, p. 32).

It is commonly assumed that the modern soils of the northern plains were formed in sediment of Late Wisconsinan age and that the vegetation and climate of all postglacial time was like that of today (Omodt and others, 1968, p. 11-12, 14; Larson and others, 1968, p.

86; Seago and others, 1970, p. 75-76). However, as indicated above, most of these soils, or at least their upper part, were formed in wind-blown sediment of Holocene or even late Holocene age. Where the Oahe Formation is thick (such as along the bluffs of the Missouri River) the surface soil is developed entirely in sediment of late Holocene age in response to climatic conditions for the most part similar to those of today. But, as indicated in the sections above on paleosols and hillslope stability, both the climate and vegetation have changed markedly during Late Wisconsinan and Holocene time. Where the Oahe Formation is thin, all of its members and submembers are compressed together (and so are separately indistinguishable) within the A and B horizons of the surface soil, as in the Barnes Series. For this reason, the characteristics of soils like the Barnes Series should be interpreted as resulting from soil-forming processes controlled by all of the different climates and types of vegetation that existed in the area during the time that the soils were forming, including the cool, moist period when spruce forest was widespread in Late Wisconsinan time. That is, many surface soils in the northern Great Plains must be considered, at least in part, to be composite paleosols.

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REFERENCES

Bavendick, F. J., 1952, Climate and weather in North Dakota: Bismarck, North Dakota State Water Conservation Commisssion.

Bickley, W. B., Jr., 1972, Stratigraphy and history of the Sakakawea Sequence, south-central North Dakota: unpublished Ph. D. dissertation, University of North Dakota.

Bickley, W. B., Jr., and Clayton, Lee, 1972, Sedimentation in small sloughs in the mid-continent area during late Quaternary time: North Dakota Academy of Science Proceedings, v. 25, p. 36-42.

Birkeland, P. W., Crandell, D. R., and Richmond, G. M., 1971, Status of correlation of Quaternary stratigraphic units in the western conterminous United States: Quaternary Research, v. 1, p. 208-227.

Bluemle, J. P., 1971, Geology of McLean County, North Dakota: North Dakota Geological Survey Bulletin 60-I.

Clayton, Lee, 1966, Notes on Pleistocene stratigraphy of North Dakota: North Dakota Geological Survey Report of Investigation 44.

Clayton, Lee, Bickley, W. B., Jr., and Stone, W. J., 1970, Knife River Flint: Plains Anthropologist, v. 15-50, p. 282-290.

Clayton, Lee, and Moran, S. R., 1971, Late Quaternary loess in central North Dakota: Geological Society of America Abstracts with Programs, v. 3, p. 256.

Cvancara, A. M., and others, 1971, Paleolimnology of late Quaternary deposits: Seibold Site, North Dakota: Science, v. 171, p. 172-174.

Denton, G. H., and Karlen, Wibjorn, 1973, Holocene climatic variations–their pattern and possible cause: Quaternary Research, v. 3, p. 155-205.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: United States Geological Survey Professional Paper 262.

Frye, J. C., and Leonard, A. B., 1952, Pleistocene geology of Kansas: Kansas Geological Survey Bulletin 99.

Hamilton, T. M., 1967, Late-Recent alluvium in western North Dakota, *In* Glacial geology of the Missouri Coteau and adjacent areas (Lee Clayton and T. F. Freers, eds.): North Dakota Geological Survey Miscellaneous Series 30, p. 151-158.

Hibbard, C. W., 1958, New stratigraphic names for early Pleistocene deposits in southwestern Kansas: American Journal of Science, v. 256, p. 54-59.

Larson, K. E., and others, 1968, Soil survey of Stark County, North Dakota: Washington, D.C., United States Soil Conservation Service.

McAndrews, J. H., 1966, Postglacial history of prairie, savanna, and forest in northwestern Minnesota: Torry Botanical Club Memoir, v. 22-2.

McAndrews, J. H., Stewart, R. E., Jr., and Bright, R. C., 1967, Paleoecology of a prairie pothole: a preliminary report, *In* Glacial geology of the Missouri Coteau and adjacent areas (Lee Clayton and T. F. Freers, eds.): North Dakota Geological Survey Miscellaneous Series 30, p. 101-113.

Omodt, H. W., and others, 1968, The major soils of North Dakota: North Dakota State University Agricultural Experiment Station Bulletin 472.

Redmond, C. E., and Omodt, H. W., 1967, Some till-derived chernozem soils in eastern North Dakota: I. morphology, genesis, and classification: Soil Science Society of America Proceedings, v. 31, p. 89-99.

Royse, C. F., Jr., 1967, A stratigraphic and sedimentologic analysis of the Tongue River and Sentinel Butte Formations (Paleocene), western North Dakota: unpublished Ph. D. dissertation, University of North Dakota.

Ruhe, R. V., 1968, Identification of paleosols in loess deposits in the United States, *In* Loess and related eolian deposits of the world (C. B. Schultz and J. C. Frye, eds.): Lincoln, University of Nebraska Press, p. 49-65.

Salomon, N. L., and others, 1973, Late Quaternary glacial history of the Upper Midwest: Geological Society of America Abstracts with Programs, v. 5, p. 347.

Schumm, S. A., 1965, Quaternary paleohydrology, *In* The Quaternary of the United States (H. E. Wright and D. G. Frey, eds.): Princeton, NJ, Princeton University Press, p. 783-794.

Seago, J. B., and others, 1970, Soil survey of Wells County, North Dakota: Washington, D.C., United States Soil Conservation Service.

Soil Survey Staff, 1951, Soil survey manual: United States Department of Agriculture Handbook 18.

Walker, P. H., 1966, Postglacial environments in relation to landscape and soils on the Cary Drift, Iowa: Iowa State University Agriculture and Home Economics Experiment Station Research Bulletin 549.

Watts, W. A., and Bright, R. C., 1968, Pollen, seed, and mollusk analysis of a sediment core from Pickerel Lake, northeastern South Dakota: Geological Society of America Bulletin, v. 79, p. 855-876.

Wendland, W. M., and Bryson, R. A., 1974, Dating climatic episodes of the Holocene: Quaternary Research, v. 4, p. 9-24.

Wright, H. E., Jr., 1970, Vegetational history of the central Plains, *In* Pleistocene and Recent environments of the central Great Plains (Wakefield Dort, Jr., and J. K. Jones, Jr., eds.): Lawrence, University of Kansas Press, p. 157-172.