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Description and Genesis of selected Glacial Deposits, Walsh County, North Dakota

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DESCRIPTION AND GENESIS

OF SELECTED GLACIAL DEPOSITS,

WALSH COUNTY, NORTH DAKOTA

by Harlan K. Friestad

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ABSTRACT

Glacial deposits and features in central Walsh County, North Dakota were investigated during the summer of 1965 to determine both their origin and their relationship to the history of glacial Lake Agassiz. The deposits included till and lake sediments exposed in cuts along the Park River, while the features included two end moraines and an esker.

The field study consisted of mapping the deposits, studying their morphology and composition, constructing cross-sections, and collecting selected samples. Laboratory studies of these samples included particle size analyses, feldspar staining, magnetic separation, and mineralogical analyses by X-ray diffraction.

The glacial feature located on the Grand Forks-Walsh County border is a steep-sided, branching, sinuous ridge. It is 4½ miles long, averages 250 feet in width and it varies in height from 15 feet in the northwest to 75 feet in the east. It is concluded to be a combination esker and an interblock or "crevasse" filling on the basis of: (1) the sinuous and reticulate form, (2) the composition, which is chiefly gravel and stratified drift, and (3) the size and shape of the feature. The stream that deposited the esker apparently flowed to the southwest and was diverted to the northwest when its path was probably blocked by sediment or blocks of ice. Evidence for this is: (1) a gradual decrease in height from east to northwest, (2) a gradual decrease in particle size in the same direction, and (3) the truncation of one ridge by another.

The end moraines located immediately north of the esker are only slightly younger than the esker, and represent brief stands of the

glacier prior to the formation of the Edinburg moraine, which lies about 4 miles to the northeast. The southernmost moraine is a small branching, northwestwardly trending ridge which is 6½ miles long and averages 15 feet in height, and 250 feet in width. The northernmost moraine, parallel to the one south of it, is a broad, low, ridge, 6½ miles long, averaging 800 feet in width and 25 feet in height. Both moraines have abundant boulders scattered on their surface and are quite variable in composition; they are composed largely of till and fine to medium sands.

Sediments at the Park River site, on the western margin of the Edinburg moraine, indicate that this area was once covered by a proglacial lake. Distorted till and lake sediments indicate subsequent modification by solifluction and frost action. Homme Reservoir sediments one mile east of the Edinburg moraine, reveal evidence of deposition in close association with ice. Furthermore, it is concluded that the processes of glacial, fluviatile, and lacustrine deposition were all occurring at essentially the same time at this site, adding to the complexity of the geologic history.

Additional investigations should support the conclusion that these features were deposited approximately 11,740 years ago, the age of the Upper Herman beach.

DESCRIPTION AND GENESIS OF SELECTED GLACIAL DEPOSITS, WALSH COUNTY, NORTH DAKOTA

INTRODUCTION

General

The purpose of this study is to interpret some of the late Pleistocene history of northeastern North Dakota through the study of glacial deposits and features in Walsh County. Among deposits studied were an esker, two end moraines, and two river cuts exposing till and lake sediments. A field study of these deposits was begun in the summer of 1965 to evaluate their origin, significance, and relationship to other deposits in the area.

The investigation consisted of mapping these deposits, studying their morphology and composition, constructing cross-sections, and undertaking a laboratory analysis of selected samples. The laboratory study included mineralogical composition by X-ray diffraction, magnetic separation, staining tests, and particle size analyses.

Previous work

The glacial history of this area has been studied by many researchers. The first work was that of Upham (1896) who published a monograph on glacial Lake Agassiz which is the best known work and is still a standard reference today.

Leverett (1932) also did a great deal of work on the glacial geology of the area, working mainly in Minnesota. Elson (1954) carried out extensive research in Manitoba, Canada, and contributed greatly to the understanding of this area. He concluded that the glacial Lake Agassiz II sediments were deposited in a lake formed by the Valders ice sheet. Laird (1964) more recently summarized the literature concerning the origin and present knowledge of this area. Schulte (1965), as a National Science Foundation Undergraduate Research Participant, investigated the Edinburg moraine and its related features in the summer of 1964 and concluded that the Valders ice never advanced into North Dakota. Kume(North Dakota Geological Survey) has recently mapped northern Grand Forks County and recently presented a paper at the 1966 annual meeting of the North Dakota Acadamy of Science on the esker which is described in detail in this report.

Acknowledgments

This research was carried out under a National Science Foundation Undergraduate Research Participation grant to the University of North Dakota, Director, Dr. Wilson M. Laird, Supervisor, Dr. John R. Reid. I especially want to thank Dr. Reid for his supervision of my field studies, his help in the interpretation of the glacial history, and his helpful suggestions throughout the course of this research. I also want to thank Dr. Karner for his guidance in the operation of the x-ray equipment and aid in the interpretation of the data. Bruce Switzer, as pilot, made an aerial flight over the study area allowing Dr. Reid and myself to take aerial photographs of the features. LaVerne Rude made helpful suggestions on procedures of particle size analysis by the proposed North Dakota Geological Survey Standard Procedure A-65. My brother, David, assisted me during the summer with the measurement of sections. To all these persons, as well as the landowners in Walsh County who allowed me to study on their property,

I express my sincere appreciation.

METHODS OF INVESTIGATION

Field study

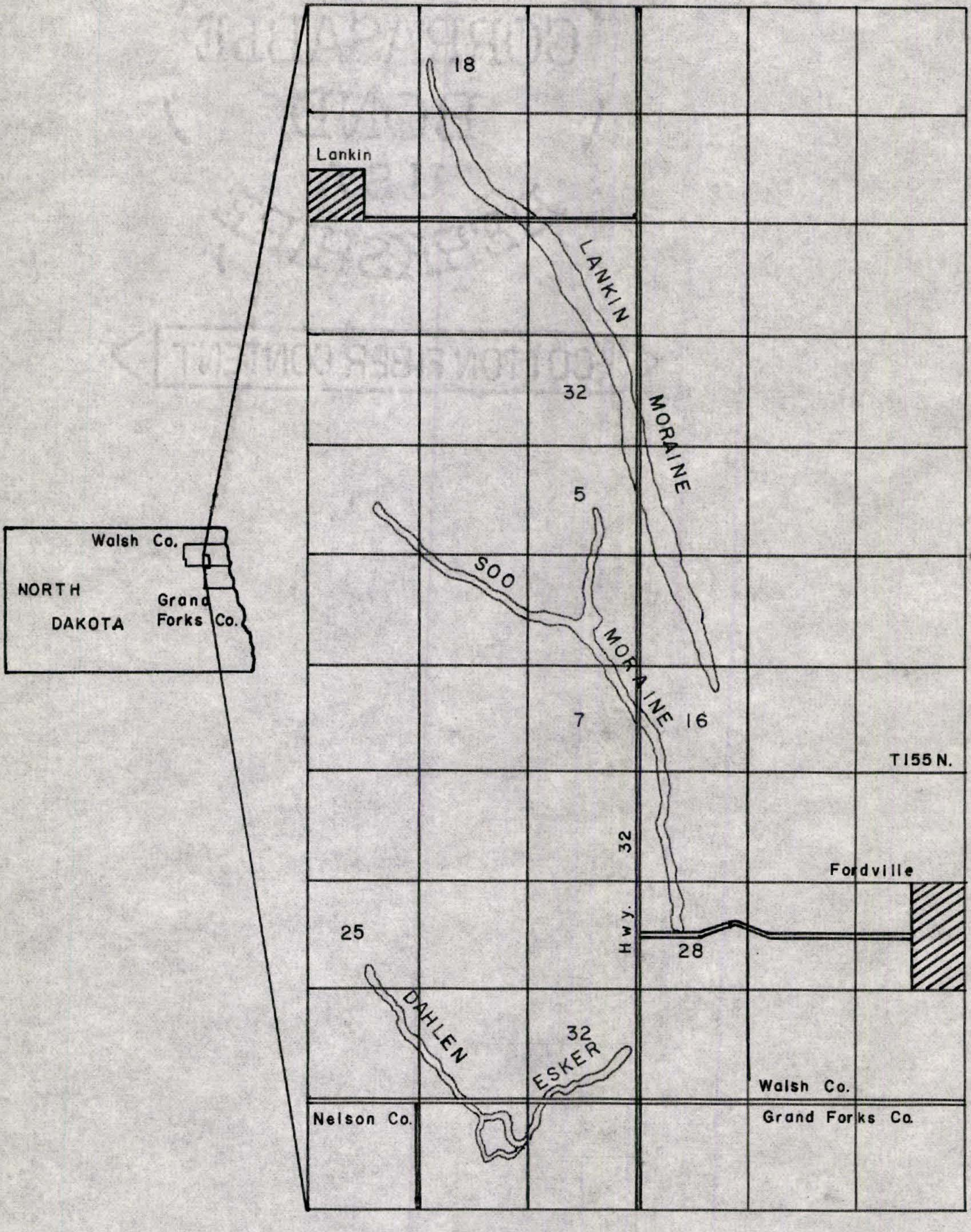
Aerial photographs (United States Department of Agriculture, Commodity Stabilization Service, 1952), and general highway maps of Walsh County (North Dakota Highway Department, 1963) were used to locate and construct general maps of the extent of the esker and two end moraines. Each feature was traced completely by physically walking them out, and the height and width were measured every ¼ mile by hand leveling and pacing. Exposures on the river cuts were measured by pacing and taping, and cross-sections of these were later drawn. The location of the features and exposures are shown in figure 1.

Auger samples were taken on the moraines and esker every ½ mile. Boulder counts were taken along the moraines only a concentration of boulders occurred. Samples from the Homme Reservoir and Park River cuts were taken from each distinct unit. Several additional samples were taken of the two tills at the Park River site for X-ray analysis.

Laboratory analysis

Particle size of selected samples was determined using the proposed North Dakota Geological Survey Standard Procedure A-65, developed by Dr. Lee Clayton, Department of Geology, University of North Dakota, which is yet unpublished. The samples were separated into gravel, sand, silt, and clay fractions. Nineteen of the selected samples were then analyzed for their mineralogical composition by

Fig. 1-Location map of features studied.



X-ray diffraction. Standard preparation techniques developed by Dr. Frank R. Karner, Department of Geology, University of North Dakota were used. A paper by the writer, entitled "Quantitative Analysis of X-ray Data of Four Glacial Units in Walsh County, North Dakota", gives the procedures, standards, and results of this study, and is on file in the Department of Geology, University of North Dakota.

The medium sand fraction of samples that were X-rayed, was subsequently separated according to their magnetic susceptibility, into five mineral fractions by the Frantz Isodynamic Magnetic Separator. Each fraction was weighed and its percentage computed. After these samples had been separated into the magnetic fractions, the light, nonmagnetic fraction was used for feldspar staining tests. A grain count of each prepared slide was made to determine the percentage of K-feldspar, Na-Ca feldspar, quartz, and other minerals.

HISTORY OF FEATURES IN RELATION TO LAKE AGASSIZ

Shortly before or perhaps at an early phase of the formation of Lake AgassizI, the esker in Walsh and Grand Forks County was deposited. As the ice retreated and the lake began to develop, the Upper Herman beach was formed. This was followed shortly by the deposition of the two small end moraines described in this paper, and then the Edinburg moraine. After the deposition of the Edinburg moraine, the Lower Herman and Tintah beaches were formed; these beaches are now found superimposed on the Edinburg moraine (Upham, 1896, and Schulte, 1965).

Radiocarbon dating of the Upper Herman beach gives an age of 11,740 years B.P. (Shay, 1965). Thus, it is concluded that the esker and two end moraines were deposited about 11,740 years ago.

The sediments at the Park River site, on the western margin of the Edinburg moraine, were deposited during and after the Edinburg stand of the ice. The Homme Reservoir sediments, two miles east of the moraine were deposited contemporaneous with the upper deposits at the Park River site.

DAHLEN ESKER

Description

A glacial deposit interpreted to be an esker is located in south-central Walsh County and northeastern Grand Forks County. Its eastern margin is in the SE¼, Sec. 32, T.154N., R.56W., just east of N.D. Highway 32. It extends southwestward into Grand Forks County for about ½ mile, where it branches into two ridges that join ½ mile to the northwest. The ridge continues northwestward with its terminus in the SE¼, Sec. 25, T.154N., R.56W., 4½ miles from its origin (Fig. 2).

Fig. 2- Northwest branch of Dahlen esker showing irregular surface and relief of about 50 feet.

The characteristic cross-section of the esker is roughly triangular, with the base ranging from 200 to 400 feet wide, and height varying from 15 feet at the northwest end to about 75 feet at the east end. The sides appear relatively steep, with the slope angle varying from 10° to 15°.

No topographic coverage was available on this area, but Kume (oral communication, North Dakota Geological Survey) states that there is a rise of about 300 feet in 7 miles in a northwesterly direction, which is due to the Pembina escarpment. The esker is excellently preserved, and road cuts and gravel pits expose its interior in only a few places. Boulders are abundant at the surface in the northwest end, but become rare at the eastern end.

Eskers are generally described as long, narrow, sinuous ridges composed chiefly of waterworked, stratified drift. They normally range in height from 5 to 150 feet, in width from 10 feet to as much as 600 feet, and in length from less than 300 feet to many miles.

Formation of eskers is apparently controlled by subglacial topography, usually running from higher to lower ground. They most commonly occur in regions of low relief such as valleys, and trend parallel to the direction of flow of the glacier from which they originated.

The composition of eskers differs little from the local till and they usually both contain a large percentage of local material. Sand and gravel are the chief constituents, though both silt and boulders are present in places. Sediments are commonly cross-bedded, indicating deposition by streams. The general direction of foreset beds, the orientation of the pebbles, and the decrease in grain size indicates the direction in which the depositing stream flowed (Pettijohn, 1957, p. 165).

Eskers are formed in several ways, but one mode of origin seems to be favored above all the others; the most common is in tunnels at the base of the glacier (Fling, 1957, p. 157). Water derived chiefly from surface melting works its way downward through crevasses and other openings in the ice forming subglacial streams. These streams, flowing under considerable hydrostatic pressure, enlarge the openings to form tunnels at the base of the glacier, depositing sediment at the same time.

Eskers apparently are not constructed throughout their length all at once; the upglacier end is usually deposited last (Charlesworth, 1957, p. 421).

Interpretation

The Dahlen esker is believed to have formed by glacial streams penecontemporaneous with the deposition of the Edinburg moraine. The original stream that deposited the northeast upstream branch apparently flowed to the southwest, deriving water from superglacial streams that flowed toward the ice margin. The southern branch of this original course is presently represented by a low relief, light-colored ridge shown in figure 3. This early stream was probably structurally controlled, as evidenced by the angular ridge broken by several gaps. It does not exhibit the sinuous form that is characteristic of eskers; thus, the northeast branch is interpreted to be a "crevasse" or interblock filling.

The stream course then made a right angle bend to the northwest as a result of more rapid thinning of the ice in that direction, which perhaps was due to a rise in slope of the Pembina escarpment (Fig. 4 -a).

Fig. 3.- Aerial view of Dahlen esker looking northeast with Fordville in background. Original stream path followed light, low-relief area in lower right of photograph and was diverted northward.

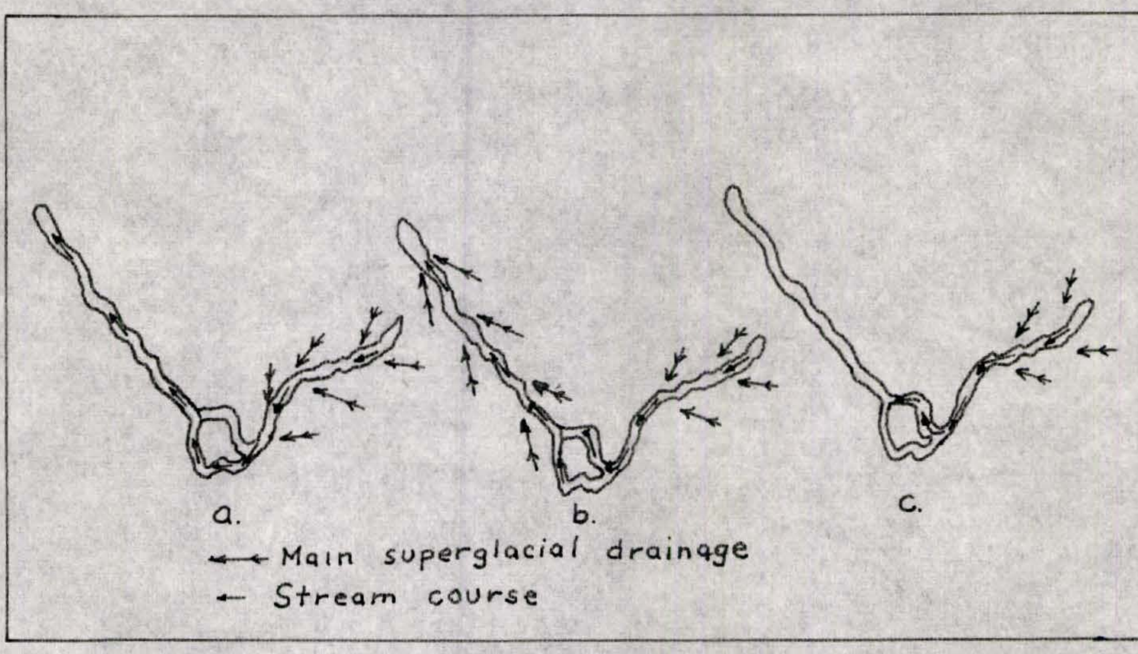


Fig. 4- Order of development of esker.

The northwest branch is interpreted to represent a true esker deposited in a subglacial tunnel at the base of the glacier because of the fact that it is a very sinuous ridge.

The stream flowed in this course for a short time, but soon it apparently became blocked by excessive sediment or blocks of ice which caused it to be diverted northwestward about ½ mile from the southernmost part of the channel, where it joined the original stream at a right angle (Fig. 3, left center of photo). The greater height of the diverted branch is evidence that it flowed there for a longer time than along the original path.

Evidence for the direction of stream flow from east to west are: (1) a gradual change in height from 75 feet in the eastern end to 15 feet in the northwest, (2) a decrease in particle size from east to west, (3) cross-bedding observations in gravel pits on the northwest branch (Kume, 1966), and (4) the truncation pattern of the ridges.

According to Kume (1966), the land rises to the northwest, necessitating hydrostatic pressure for the formation of the esker. However, no topographic coverage was available on the area, so it is not known if the present slope is the same as the slope that existed during the formation of the esker. This could be determined by comparing the gradient of the beaches in the area to the gradient of the land adjacent to the esker. Thus, there may or may not have been hydrostatic pressure during the formation of the Dahlen esker.

SOO AND LANKIN MORAINES

Description

Two glacial features interpreted to be end moraines are located just north of the Dahlen esker in south-central Walsh County. The southernmost one, informally called the Soo moraine is branched in the form of a Y. The northwestern branch originates in the SE¼, Sec.1, T.155N., R.56W. (Fig. 5), and the northeastern branch in the SW¼, Sec. 18, T.156N., R.56W. The branches join in the SE¼, Sec. 8, T.155N., R.56W., (Fig.6) and the moraine extends to the NW¼, Sec. 28, T.154N., R.55W., just north of the Fordville road.

Its total length, including both branches, is about 6½ miles; its height ranges from less than 3 feet in the south end to 30 feet in the northwest branch, with an average of about 15 feet; its width averages 300 feet. The surface is slightly undulatory and is covered with boulders up to 4 feet in diameter, except on the last mile of the southern branch.

The larger end moraine, one mile northeast of the Soo moraine and roughly paralle to it, is here informally called the Lankin moraine. It is a very low, broad moraine and is hardly discernible from the air. Its northern end begins in the SW¼, Sec. 18, T.155N., R.56W. and extends southeastward into the NE¼, Sec. 16, T.154N., R.55W., 6½ miles from its origin. Its height varies from 10 feet in the north end to 40 feet in the middle, and its width ranges from 100 feet in the north to 1000 feet in the middle.

The surface is very uneven and rolling with surface boulders randomly scattered throughout its extent. It has a characteristic asymmetrical shape with the steeper side to the east. Both moraines

Fig. 5.- Northwest branch of Soo moraine exhibiting low relief.

Fig. 6.- Branching of Soo moraine along highway 32, looking east. From light building in upper left to intersection on right is ½ mile.

are similar in composition, consisting largely of clay till with boulders and fine to medium sands.

End moraines are ridge-like accumulations of drift built along any part of the margin of a glacier. The surface is normally very irregular with a knob and kettle appearance due both to melting of ice blocks after deposition and variations in distribution of material originally deposited. The size of the moraine is largely controlled by the duration of glacial stand, the rate of ablation, amount of meltwater, and amount of drift in the glacier.

Most end moraines consist of till with some stratified drift. Those with a large amount of clay till are likely to be broad and flat with a smooth undulatory surface; those built largely of stratified drift have sharply irregular surfaces, marked by knobs, hummocks, and closed depressions (Flint, 1957, p. 134).

Interpretation

The Soo and Lankin moraines are interpreted to have formed a short time after the Dahlen esker was deposited, some time after Lake Agassiz I began to develop. The branching of the Soo moraine was probably due to the retreat of the glacier faster in the north than in the south, due to the topographic rise of the Pembina escarpment to the northwest.

The ice front then retreated less than a mile northward from the Soo moraine and deposited the Lankin moraine, standing in this position longer that at the previous stand. Solifluction and sediment creep off the glacier and the moraine crest caused the west side of the moraine to be very low and broad. Boulder pavements on the surface of both moraines (Fig. 7) were probably deposited by ablation and solifluction off the glacier, followed by the removal of the finegrained sediment by wave and sheet wash erosion.

Fig. 7.- Boulder concentration on surface of Lankin moraine, looking northwest.

PARK RIVER SITE

Description

The Park River site is located along the Park River where it crosses N.D. Highway 32, five miles west and one mile north of the city of Park River, in the SW¼, Sec. 15, T.157N., R.56W. Two other associated cuts are located 1/10 and 1/4 miles south of the main site. These exposures are all on the western margin of the Edinburg moraine and reveal glacial and postglacial history of this area (Fig. 8). Figure 9 is an aerial photograph of the Park River site, showing its relation to the Edinburg moraine.

The exposure here shows two tills separated by a thin boulder pavement. Overlying the upper till are stratified lake sediments and outwash deposits which, in turn, underlie eolian sands and silts (Fig. 10).

Fig 8 - Cross section of Park River site

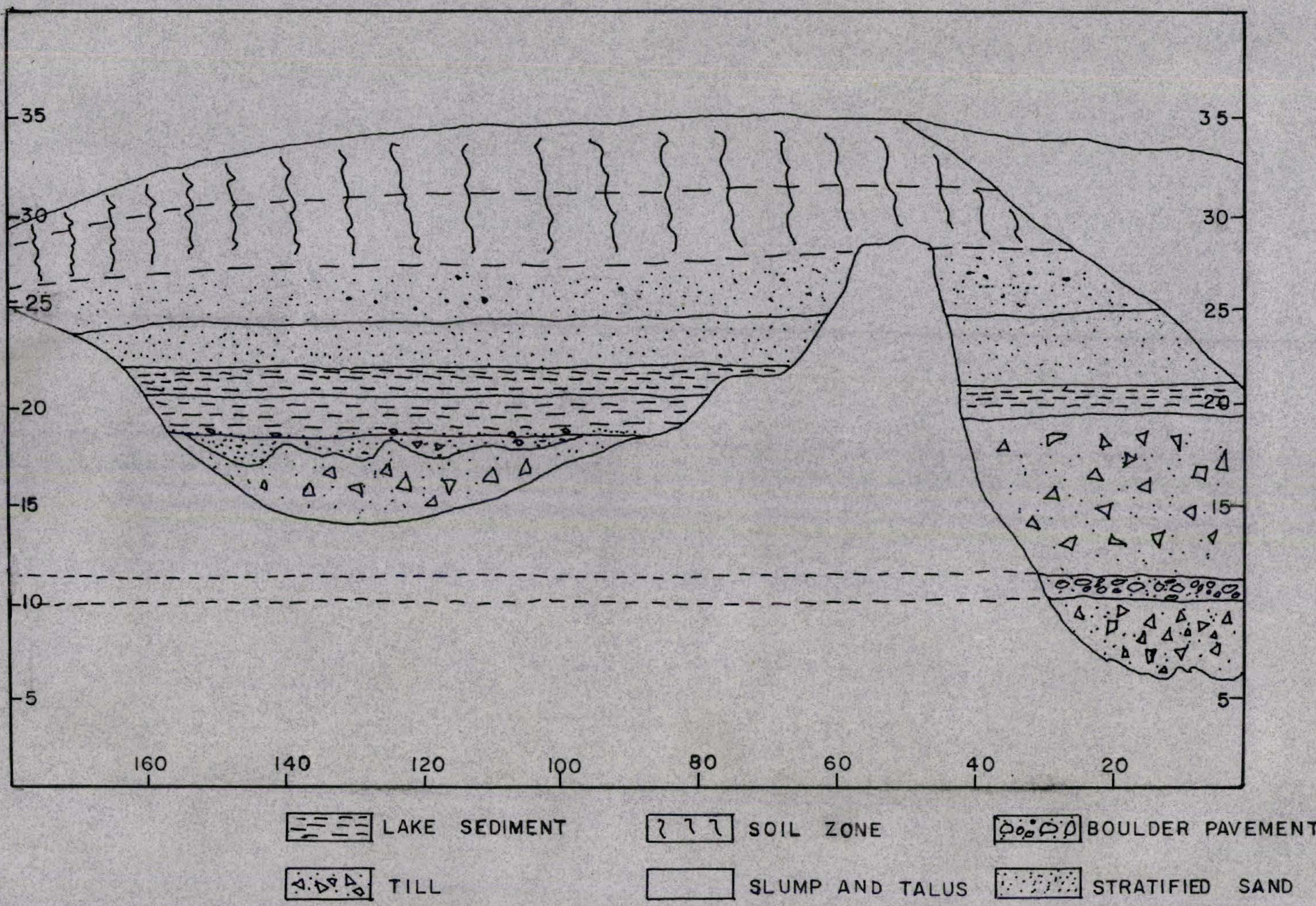


Fig. 9.- Aerial view of Park River site looking northeast. The main site is directly west of the building in the center of the photograph. The Edinburg moraine is the light, spotted area trending north-south.

Fig. 1 [illegible] verlain by outwash and eolian deposits. Spade in center is 1½ feet in length.

The lower till is a light gray, compact, highly fractured, pebbly clay till containing few large boulders. Occurring at the upper boundary in a few places are lenticular masses of shaly sand truncated by the boulder pavement. The height above normal level water level of the lower till at the Park River site is about 12 feet and it decreases to about 4 feet at a site 300 feet west of Highway 32. Figure 11 shows the two tills and intervening boulder pavement 500 feet south of the main site. The boulder pavement consists largely coarse gravel with a few large boulders (Fig. 12). Springs are found in several places seeping through the boulder pavement.

The upper till is a buff, loosely compacted till that is commonly iron-stained in fractures. It contains more boulders than the lower till and varies in thickness from 10 feet at the main site, to 7 feet at the site west of Highway 32. Schulte (1965) made till fabric and pebble counts of both tills and found them to be essentially identical. X-ray analysis of the two tills also shows them to be quite similar mineralogically (see p.27).

A very thin zone of pebble and gravel concentrate separates the upper till from the overlying lake sediment. This lake sediment consists of two units each 10 inches thick, which are dark gray, organic-rich, and made of clayey silts with some fine and medium sand. X-ray analysis shows that they are composed of approximately 80% clay minerals with minor amounts of quartz and cristobalite. The lake sediments at the main site are undisturbed, but in the cut ¼-mile south they have been partially eroded.

Outwash sands and gravels, 5 to 6 feet thick, consisting mainly of quartz, rest upon the lake sediment. These, in turn, are overlain

Fig. 11.- Exposure along Park River showing two till and two boulder pavements.

Fig. 12.- Close-up view of boulder pavement.

by eolian silts and sands in which the soil has developed. At the site ¼-milesouth of the main site, shale sands, 1 to 3 feet thick, are found superimposed on an erosional surface of the outwash sands and lake sediment.

Interpretation

The till and lake sediments at the Park River site are part of the Edinburg moraine and are thus interpreted to have been deposited during the early stages of Lake Agassiz I. The lower till was probably deposited as a lodgement till at the base of the glacier. This was followed by a slight glacial retreat of perhaps a mile at which time streams flowing west off the glacier deposited the boulder pavement.

The upper till was deposited during a readvance from the east. The upper surface of this till was subsequently modified by solifluction after the ice had retreated. This is revealed by the asymmetrical folds and sand deposits in the upper part of the till (Fig. 13). The wave length of the folds averages about 6 feet and the amplitude averages 1½ feet. The thin zone of pebbles and gravel above the folded till probable represent reworked, near-shore sediments from a small lake that began to develop at this time. This lake was a marginal, proglacial, ice-dammed lake, that existed for only a short time. After the lake drained from this level, the sediments were exposed to erosion.

Streams from the northeast (concluded from cross-bedding observations) deposited quartz sands upon the lake sediments. The climate at this time was probably periglacial as evidenced by frost wedging and involution in the outwash sediments (Fig. 14).

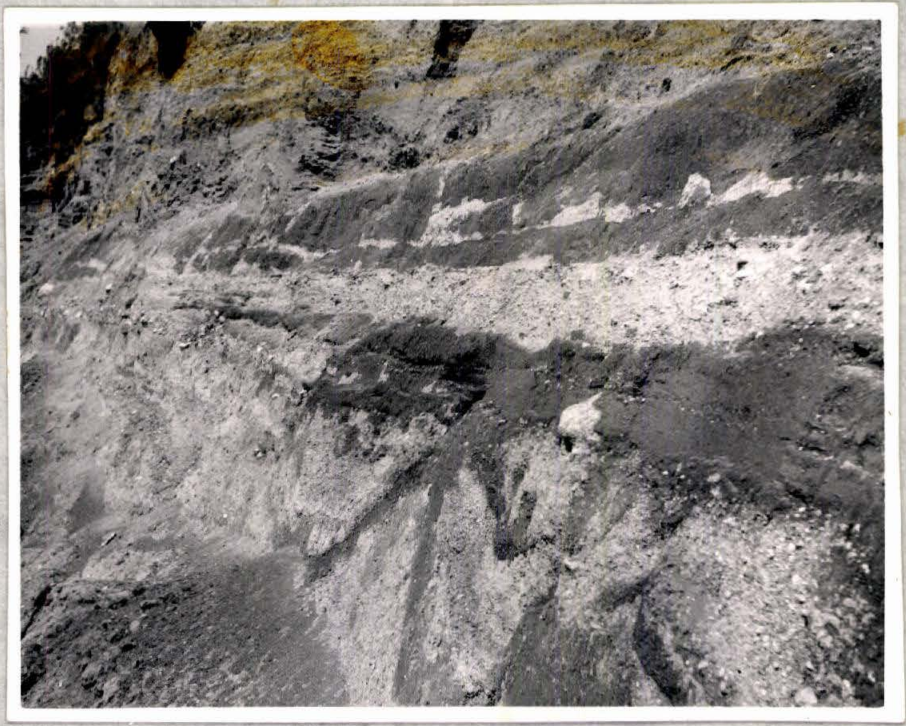


Fig. 13.- Folding in upper till caused by solifluction. Wave length of folds averages 6 feet.

Fig. 14.- Ten-inch layer of lake sediment overlain by folded and involuted outwash sediments.

Stream flow then changed from the northwest, bringing in coarse shale sands, presumably derived from the Cretaceous Pierre Shale. After these streams were either diverted or dried up, eolian silts and fine sands were deposited, and are probably still being deposited today. These are the sediments upon which the soil is developed.

HOMME RESERVOIR SITE

Description

The Homme Reservoir site is on the northeast bank of the Homme Reservoir in the NE$\frac{1}{4}$, Sec. 24, T.157N., R.56W., two miles east of the Edinburg moraine or 2 miles west and $\frac{1}{2}$ mile north of the city of Park River (Plate 1).

At the base of the 600 foot exposure is an organic-rich lake sediment consisting mainly of silt and fine sand. It is finely cross-bedded, mixed with some light sediments at the base, but grades into a homogeneous, dark gray lake sediment. It upper surface varies from 4 feet above normal water level at the east end, to 25 feet in the central part of the cut.

The lake sediment is overlain by three types of sediments along the cut. A U-shaped body of coarse, stratified, quartz sand overlies the lake sediment in the central part of the cut. A sharp, erosional contact separates the two sediments (Fig. 15). Small scale faulting and tilting has occurred in these sediments.

Uncomformable overlying the quartz sand and extending over the lake sediment is a very coarse, poorly bedded shale sand Fig. 16). West of the shale deposit is a very compact, buff clay till containing very few boulders and abbutting against the shale sand and resting on the lake sediment. This till is blobby and crudely bedded and is also

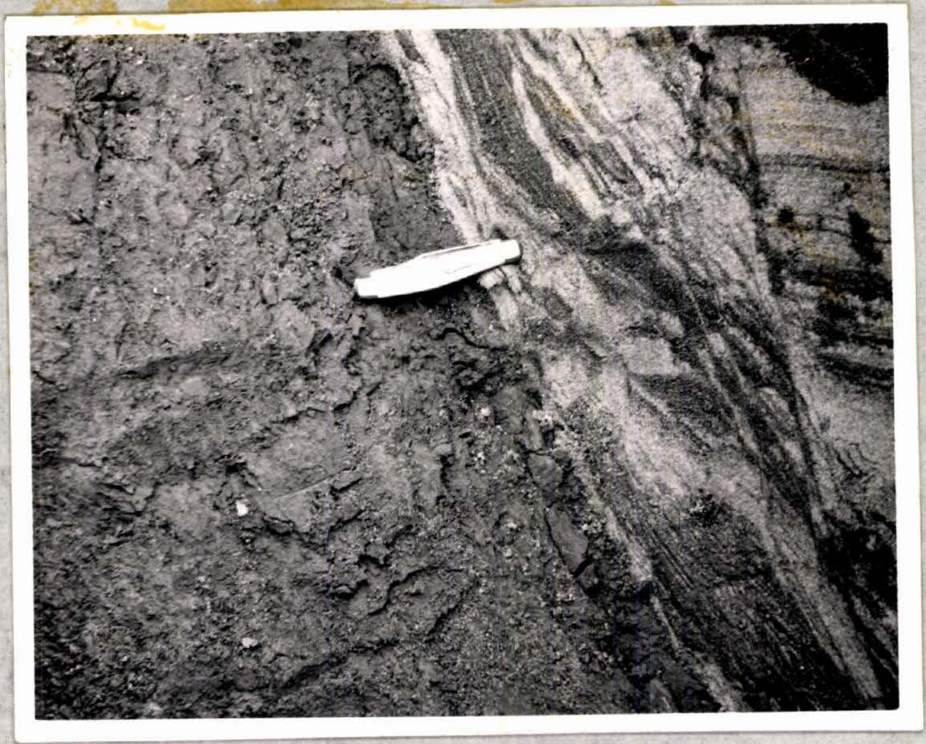


Fig. 15.- Sharp contact of organic-rich lake sediment and stratified quartz sands at Homme Reservoir site.

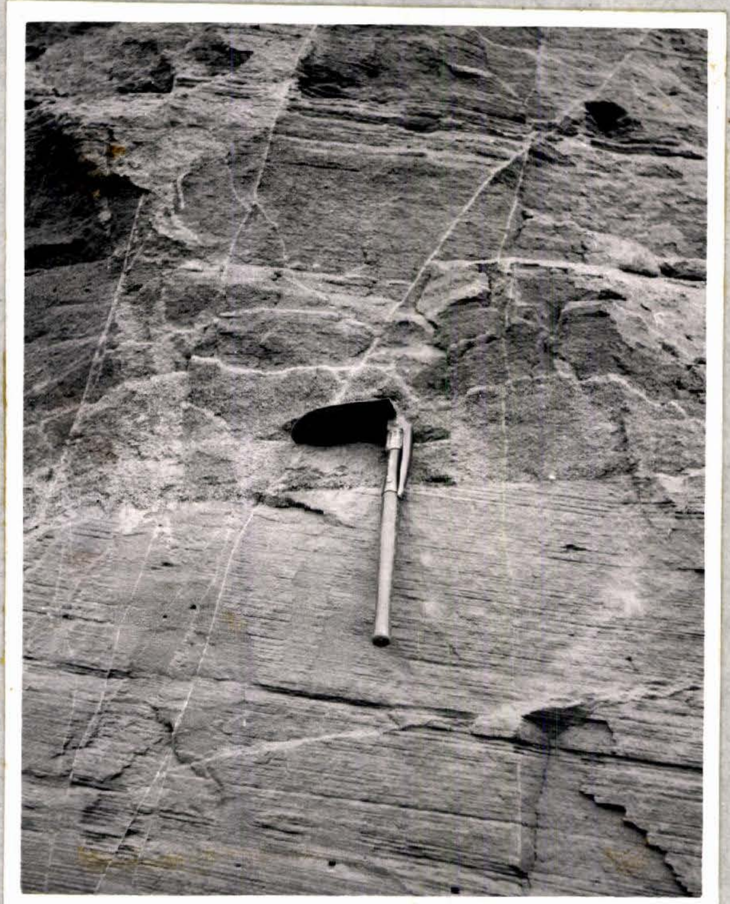


Fig. 16.- Tilted stratified quartz sand overlain by coarse shale sands.

found in large blocks east of the quartz sand where it is surrounded by shale sand, and also at the eastern end of the site.

At the east and west margins of the exposure are small deposits of cross-bedded, coarse-grained, well-sorted quartz sands mixed with shaly sands (Fig. 17). A very thin boulder pavement consisting entirely of cobbles and boulders overlies the shale sand and part of the till. On top of all these sediments, there are silts in which a very thin soil zone, 2 to 8 inches thick, is developed.

Interpretation

The sediments exposed at the Homme Reservoir site are interpreted to have been deposited during and shortly after the deposition of the Edinburg moraine. Sediments at this site are closely related to the upper sediments found at the Park River sites. The upper and lower tills exposed at the Park River site, however, are not found at the Homme Reservoir. A till similar to the lower till presumably underlies the highly organic lake sediment at this site. This lake sediment is unlike any other lake sediments found in this area, and its age and origin is uncertain.

The lake sediment was probably deposited in a proglacial lake after the ice front had retreated from the Edinburg moraine. Streams from the northeast, flowing into this lake, eroded the lake sediment and deposited quartz sands. These sands are probably identical to those at the Park River site and are interpreted to have been derived from the same source and at the same time.

The streams from the northeast were replaced by streams from the northwest which began depositing shale sands, presumably derived from Pierre Shale, which crops out a few miles to the northwest.

Fig. 17.- Cross-bedding in quartz sands at western margin of Homme Reservoir exposure indicating stream deposition from the northeast.

Penecontemporaneous with the deposition of shale sands was the deposition of the till, which apparently flowed off an ice block or glacier into the lake. This till mixed with the underlying lake sediments and shoved them over the quartz sands as shown in Plate 1. The till flowed into the shale sands without appreciably disturbing their stratification. But, microfaulting and tilting of the beds did occur. Large blocks of till either flowed over the shale sands or around them, and are found east of the body of quartz sand where masses are completely surrounded by shale sand. Evidence for this interpretation is the tilted orientation of the till blocks, disruption of the shale sands around the blocks, and the shoving of the lake sediments over the quartz sands.

Fig. 17.- Cross-bedding in quartz sands at western margin of Homme Reservoir exposure indicating stream deposition from the northeast.

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Cross-bedded quartz sands, deposited by southwesterly flowing streams, overlie both till and lake sediments in the east and west margins of the site.

The boulder pavement, overlying the shale sand and part of the till, was probably formed by a narrow, rapidly flowing stream flowing into the area of the Homme Reservoir site. Silts and fine sands of eolian origin overlie the sequence of sediments in which the thin soil zone is developed.

In summary, it is concluded that the processes of glacial, fluviatile, and lacustrine deposition were all occurring at essentially the same time at this site, adding to the complexity of the geologic history.

COMPOSITION AND TEXTURE

X-ray analysis

Procedure. The purpose of the X-ray analysis was to determine, by quantitative methods, the composition of some of the glacial units studied in Walsh County. The units analyzed were (1) upper and lower till and lake sediment of the Park River site, (2) flow till of the Homme Reservoir site, and (3) till from the Lankin moraine.

The samples were ground to 400-mesh size and from this powder a randomly-oriented mount was prepared by the end loading method of Dr. Frank R. Karner, (Dept. of Geology, U.N.D.). An initial X-ray trace was run of this mount, which was used to determine the bulk composition. Oriented slides of 1-2 micron clay were prepared from water suspensions of each sample, dried, and X-rayed to determine the clay mineral composition.

Percentages of each mineral were determined by comparing the height of the major peaks on the X-ray trace of each sample to the height of the major peaks in pure, standard samples, which had previously been run. Table 1 shows the average mineralogical composition of each glacial unit X-rayed. The data for each sample are shown in Appendix I.

Interpretation. All four tills are very similar in composition, with the greatest variation occurring in the content of clay minerals and quartz, which are the major constituents. The lake sediment can be easily differentiated from the tills by its characteristically high clay content, approximately 80%, and low quartz content, approximately 10%. The lake sediment has no carbonates or feldspars, whereas the tills consistently have small amounts of both mineral groups.

The high clay content of the lake sediment indicates that reworking and leaching were important in converting the source rocks into clay minerals. The source of both the till and lake sediment were probably similar; they were largely derived from the Pierre Shale, which is high in illite content, and the soils in the area, which are high in both montmorillonite and illite.

In glacial tills, any of the clay minerals may be found, depending on the character of the source material, since there is likely to be very little alteration of the clay minerals. The Pleistocene till of North America has been extensively studied, and illite is the dominant clay mineral, with kaolinite, montmorillonite, and chlorite of minor importance (Grim, 1953, p. 360). The results obtained in this study, however, indicate that montmorillonite and illite are of about equal in abundance with kaolinite a minor constituent.

From the X-ray analysis, it is evident that tills of similar age cannot be diffenentiated from one another by X-ray diffraction. However, it is believed that different environments of deposition (glacial,

TABLE 1.-AVERAGE MINERALOGICAL COMPOSITION OF SELECTED GLACIAL UNITS BY X-RAY DIFFRACTION.

Constituent	Lake Sediment (P.R.)	Upper Till	Lower Till	Homme Dam Till	Soo Moraine Till
Clay Minerals					
Montmorillonite	53	40	48	52	49
Illite	39	51	44	43	45
Kaolinite	8	9	8	5	6
Total Sediment Composition					
Total clay	79	35	34	28	35
Quartz	12	27	32	28	29
Cristobalite	13	8	7	7	11
K-Feldspar	-	2	2	1	1
Plagioclase	-	3	3	2	5
Calcite	-	7	7	5	5
Dolomite	-	7	7	4	5
Gypsum	-	-	-	5	-

lacustrine, and eolian) may be identified by X-ray diffraction and further work needs to be done on this aspect of glacial studies.

Magnetic mineral separation

The medium sand fraction of twenty-five samples was separated into five mineral fractions using the Frantz Isodynamic Magnetic Separator. The procedures of H.H. Hess (Princeton University) were followed. The theory behind this method is that the common heavy minerals in sediments can be subdivided into groups according to their magnetic susceptibility, by varying the current induced in the magnet.

After the samples were separated into the five groups, each fraction was weighed on a Mettler scale exact to five decimal places, and its percentage computed. Shale particles were observed to concentrate in the fourth fraction, so their approximate weight percentage in the medium sand fraction was found. Results of this study are shown in table 2. They show that the medium sand fraction of all samples analyzed contains about 75% quartz and feldspar, 25% shale, and minor amounts, up to 3%, of accessory minerals such as magnetite, garnet, hornblende, biotite, and augite.

Feldspar staining tests

After the selected samples had been separated into the various fractions by magnetic methods, the light, nonmagnetic fraction was subjected to feldspar staining tests. The procedure by Hayes and Lugman (1959, p. 227-232) was followed and a brief summary of it is given here.

Grains from the light fraction are mounted on slides over a thin

TABLE 2.-WEIGHT PERCENTAGE OF FIVE FRACTIONS BY MAGNETIC SEPARATION

	Common Minerals	MAGNETITE Pyrrhotite	GARNET Ilmenite Olivine Chromite	BIOTITE HORNBLENDE Epidote Tourmaline Chlorite	SHALE	QUARTZ FELDSPAR Zircon Rutile Fluorite
	Sample					
Park River	1.	0.22	0.79	1.70	18.47	78.82
Park River	2.	0.28	0.90	1.51	19.03	77.52
Park River	3.	0.27	0.78	2.15	26.88	69.92
Park River	4.	0.24	0.90	1.54	17.88	79.44
Park River	5.	0.17	0.39	0.84	26.67	11.93
Park River	6.	0.31	0.62	2.55	11.24	85.28
Park River	7.	0.28	0.98	1.50	20.14	77.10
Park River	8.	0.21	0.66	2.17	26.66	70.30
	Average	0.25%	0.74%	1.87%	22.65%	74.40%
Homme Dam	9.	0.29	0.66	2.83	36.92	59.30
Homme Dam	10.	0.21	0.81	2.09	15.25	81.64
Homme Dam	11.	0.21	0.59	2.13	11.41	85.66
Homme Dam	12.	0.14	0.64	1.13	15.46	82.63
Homme Dam	13.	0.27	0.58	2.10	32.30	64.75
	Average	0.22%	0.61%	1.86%	18.61	78.67
Soo and Lankin Moraines	14.	0.70	2.18	5.46	8.97	82.69
Soo and Lankin Moraines	15.	0.31	0.87	3.16	21.12	74.54
Soo and Lankin Moraines	16.	0.18	0.64	2.64	25.71	70.83
Soo and Lankin Moraines	17.	0.24	1.05	4.37	18.59	75.75
Soo and Lankin Moraines	18.	0.39	0.65	2.17	18.41	78.38
Soo and Lankin Moraines	19.	0.28	0.51	1.64	23.98	73.59
Soo and Lankin Moraines	20.	0.30	0.58	2.25	35.70	61.17
Soo and Lankin Moraines	21.	0.21	2.47	4.74	39.53	55.27
Soo and Lankin Moraines	22.	0.28	0.75	2.15	13.95	82.87
Soo and Lankin Moraines	23.	0.26	0.51	3.00	31.34	64.89
Soo and Lankin Moraines	24.	0.14	0.45	1.97	42.00	55.44
Soo and Lankin Moraines	25.	0.16	0.62	1.06	25.30	72.86
	Average	0.24%	0.91%	2.60	27.45%	69.11%
	Total average	0.23%	0.82%	2.35%	23.32%	73.33%

film of Lakeside-70 and exposed to hydrofluoric acid fumes for 10 to 15 minutes. The slide is then covered with sodium cobaltinitrite and after two minutes is washed and allowed to dry. A grain count using a binocular microscope is made; K-feldspars have a yellow stain, Na-Ca feldspars have a white powdery coating, and quartz appears colorless and transparent. Percentages can then be computed. Results of these tests are shown in table 3.

When compared to X-ray data, the results of the feldspar staining tests show a definite pattern as expected. The ratio of quartz to total feldspar by X-ray is about 9:1, whereas by staining tests it is about 2:1. This can be explained on the basis of the particle size used; in X-ray, sand, silt, and clay ground to 400-mesh size was analyzed, whereas in staining tests, only medium sand was analyzed.

Quartz is a stable mineral found in abundance in all size fractions of a given source rock, whereas feldspars occur mainly in sand and larger size fractions. This is due to the weathering susceptibility of the feldspars, changing to clay minerals in the smaller size fractions.

Boulder composition

A boulder count was made on the Lankin and Soo moraines every ¼ mile to confirm the suspicion that they had a similar boulder composition; this was expected since they were deposited from the same glacier only a short time apart. At each locality, an average of 150 boulders over 6 inches in diameter was identified, and the percentage of each type was computed. Results, shown in table 4, indicate that the boulders from both moraines are quite similar in composition.

TABLE 3.-COMPOSITION OF MEDIUM SAND FRACTION BY FELDSPAR STAINING

	Sample	Quartz	Plagioclase	K-Feldspar
Park River	1.	76.2	23.4	2.4
	2.	67.1	30.0	2.9
	3.	66.7	32.0	0.6
	4.	74.5	22.4	3.1
	5.	68.4	29.1	2.5
	6.	70.8	29.2	0.0
	7.	61.2	36.8	2.0
	8.	67.3	26.1	6.6
	Average	68.8%	28.9%	2.4%
Homme Dam	9.	67.4	31.3	1.4
	10.	68.1	27.7	4.2
	11.	72.7	24.4	2.9
	12.	71.4	24.6	4.1
	13.	58.5	41.5	0.0
	Average	64.2%	33.4%	2.5%
Soo and Lankin Moraines	14.	53.0	44.8	2.2
	15.	62.3	37.7	1.1
	16.	67.4	30.8	1.9
	17.	59.5	36.9	3.5
	18.	68.8	30.6	0.6
	19.	60.1	37.8	2.2
	20.	63.8	35.3	0.9
	21.	67.6	23.5	9.0
	22.	60.5	39.1	0.4
	23.	61.7	36.3	1.9
	24.	77.6	19.0	3.4
	25.	67.6	31.3	1.4
	Average	66.4%	31.2%	2.5%

TABLE 4. COMPOSITION OF BOULDERS IN INDIVIDUAL BOULDER COUNTS

	Sample Number	Granitic	Basic	Metamorphic	Carbonate
Soo moraine	1.	82.7	11.3	2.5	3.5
	2.	92.3	3.6	0.5	3.6
	3.	81.0	0.0	0.0	13.9
	4.	94.0	3.0	0.0	3.0
	5.	91.3	2.7	0.0	6.0
	6.	85.6	5.2	0.0	9.2
	7.	85.7	2.2	1.4	10.7
	8.	92.8	3.6	0.0	3.6
	9.	95.8	2.1	0.0	2.1
	10.	83.3	11.4	0.0	5.3
	Average	88.5%	4.5%	0.4%	6.1%
Lankin moraine	1.	93.3	1.8	0.0	4.9
	2.	93.3	2.8	0.0	3.9
	3.	93.8	3.1	0.0	3.1
	4.	95.7	0.5	0.0	3.8
	5.	95.0	2.7	0.0	2.3
	6.	94.6	1.6	0.5	3.3
	7.	98.0	1.3	0.0	0.7
	8.	82.5	2.3	1.0	14.2
	9.	92.4	4.2	0.0	3.4
	10.	87.6	3.2	0.8	8.4
	Average	92.6%	2.4%	0.2%	4.8%

Sediment size analysis

Selected samples from each glacial deposit were analyzed for particle size using the proposed North Dakota Geological Survey Standard Procedure A-65. Each sample was divided into gravel, sand, silt, and clay and percentages of each computed. Percentages of all samples analyzed are shown in Appendix II. Using this information, a triangular diagram was constructed with sand and gravel, silt, and clay as the three corners (Fig. 18). This figure indicates that the till is composed of about 15-20% clay, 30-40% silt, and 40-55% sand and gravel. Lake sediment has a high content of silt and clay with little sand or gravel. Most of the other samples were high in sand and gravel content.

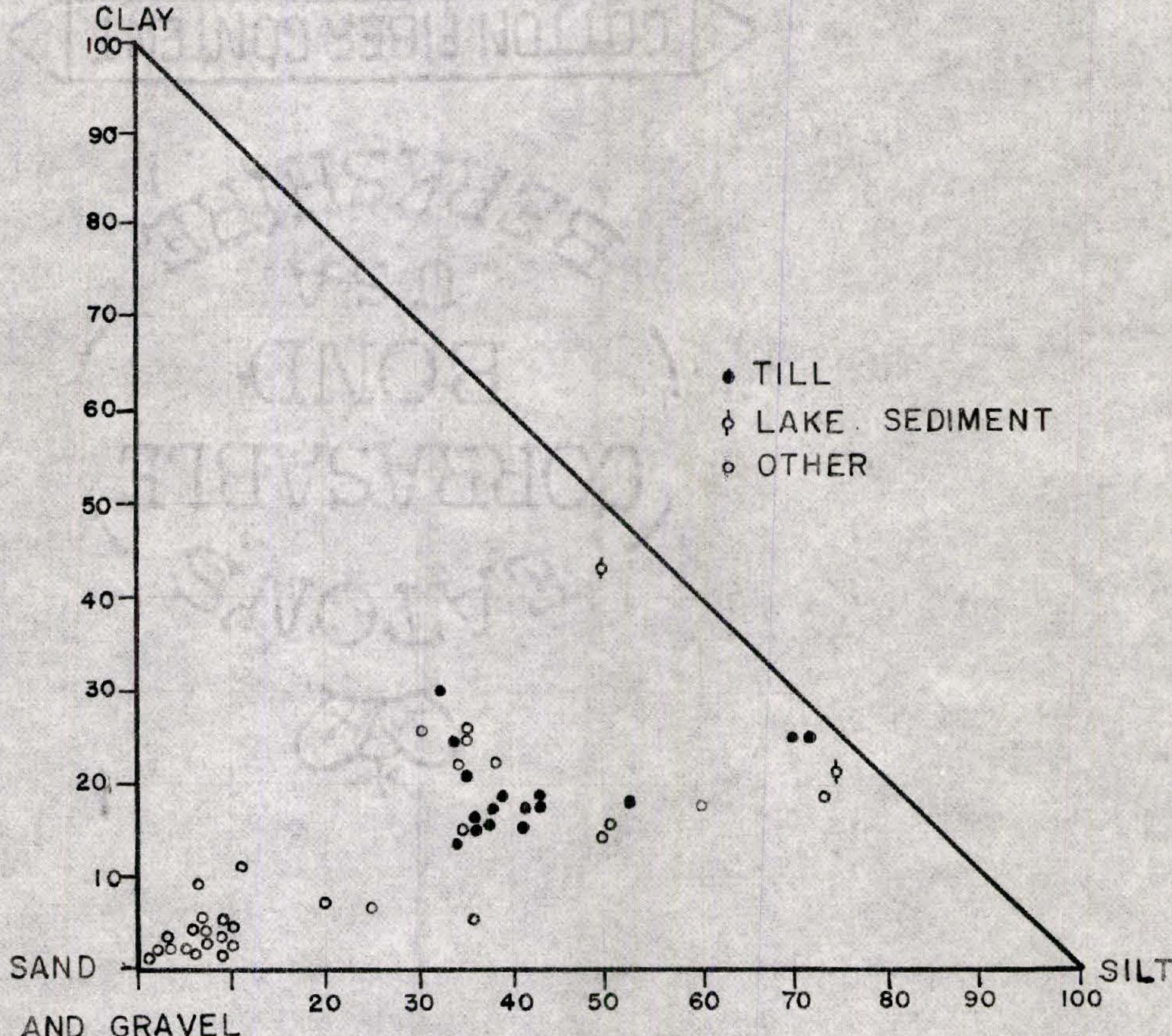


Fig. 18.- Triangular diagram of selected samples.

SUMMARY AND CONCLUSIONS

As a result of the detailed investigation of glacial deposits in Walsh County during the summer of 1965, and the subsequent analysis of selected samples in the laboratory, several conclusions can be made:

1. The Dahlen esker is interpreted to have been deposited in a subglacial tunnel by a southwestward flowing stream. The northeastern segment, which was structurally controlled, is an interblock or "crevasse" filling, whereas, the northwestern part is a sinuous ridge deposited as a true esker.

2. The Soo and Lankin moraines represent brief stands of the glacier prior to the formation of the Edinburg moraine.

3. Because these features were formed shortly before and after the Upper Herman beach, they are concluded to have been deposited about 11,740 years B.P.

4. Sediments at the Park River and Homme Reservoir sites indicate that this area was covered at various times by proglacial lakes.

5. The processes of glacial, fluviatile, and lacustrine deposition were occurring simultaneously at the Homme Reservoir site.

6. The dark, organic-rich lake sediment exposed at the Homme Reservoir site is unlike any other lake sediment in this area. Further study on its age relation to the Park River sediments and its high organic content needs to be carried out.

In conclusion, this study has given me a valuable insight into some of the problems that exist and methods and techniques that can be used when undertaking a research problem. Much of what I have learned during the course of this research will serve as the foundation for my future work in the field of geology.

REFERENCES

Charlesworth, J.K., 1957, The Quaternary Era: Edward Arnold Publishers Ltd., London, p. 400-430.

Flint, R.F., 1957, Glacial and Pleistocene Geology: John Wiley and Sons, Inc., New York, p. 490-494.

Grim, R.E., 1953, Clay Mineralogy: McGraw Hill Book Company, Inc., New York, p. 353-360.

Hayes, J.R. and Lugman, M.A., 1959, Feldspar Staining Methods: Jour. Sed. Petrology, v. 29, p. 227-232.

Hess, H.H., 1959, Notes on operation of Frantz Isodynamic Separator, Princeton University.

Laird, W.M., 1964, The Problem of Lake Agassiz: North Dakota Academy of Science, vol. XVIII, p. 114-134.

Pettijohn, F.J., 1953, Sedimentary Rocks: Harper & Brothers, New York, p. 172-178.

Schulte, Frank, 1965, The Edinburg Moraine of Northeastern North Dakota, unpublished senior thesis, 32p.

Shay, C.T., 1965, Postglacial vegetation development in northwestern Minnesota, and its implications for prehistoric man, University of Minnesota, unpublished M.S. thesis.

Von Engeln, O.D., 1942, Geomorphology: The Macmillan Company, New York, p. 400-430.

Upham, W., 1896, The Glacial Lake Agassiz: Monograph 25, United States Geological Survey.

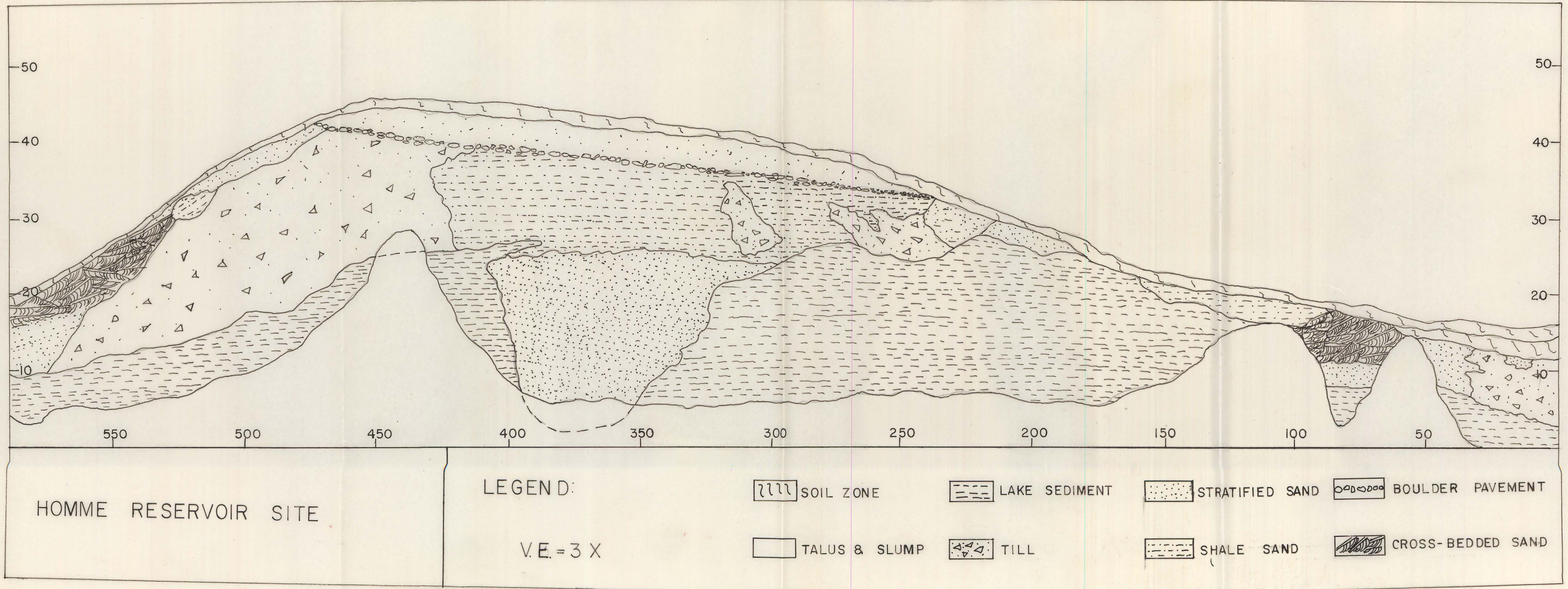
Appendix I.-Mineralogical composition of selected samples by X-ray diffraction.

Sample	Upper till (Park River)								Lower till				Lake sed.	Till of Soo Mor.				Homme Dam till		
	1	3	5	6	8	9	27	51	2	4	7	26	52	16	18	24	29	13	33	35
Constituent																				
Clay Minerals																				
Montmorillonite	52	20	56	41	52	55	18	25	40	52	42	56	53	55	74	33	35	58	58	41
Illite	42	72	33	47	41	35	75	66	53	39	50	35	39	40	22	58	60	37	36	55
Kaolinite	6	8	11	12	7	10	7	9	7	9	8	9	8	5	4	9	5	5	6	4
Whole rock comp.																				
Total clay	34	29	28	36	32	28	41	35	41	34	28	34	79	36	38	29	36	29	28	26
Quartz	30	25	29	24	30	29	23	25	33	36	32	28	12	31	37	32	18	30	34	26
Cristobalite	7	7	8	6	8	8	9	7	8	6	7	8	13	6	8	8	21	8	6	8
K-Feldspar	1	1	2	-	2	1	1	6	2	2	2	-	--	2	1	1	-	1	1	1
Plagioclase	4	3	6	4	-	-	3	4	-	3	4	4	--	5	5	4	5	2	2	2
Calcite	6	6	9	7	6	7	6	6	6	7	8	6	--	5	-	5	4	4	7	5
Dolomite	6	6	6	8	6	8	7	7	7	6	7	6	--	6	-	4	5	3	6	4
Gypsum	-	-	-	-	-	-	-	-	-	-	-	-	--	--	-	-	-	4	-	7

APPENDIX 2.-PARTICLE SIZE OF SELECTED SEDIMENT SAMPLES

Sample	Gravel	Sand	Silt	Clay
1.	5.7	34.7	41.9	17.8
2.	10.6	30.8	40.9	17.9
3.	4.6	35.2	42.5	17.6
4.	10.2	32.4	32.9	24.4
5.	9.4	34.4	37.6	18.5
6.	8.4	33.1	42.3	15.9
7.	11.2	36.7	36.8	15.2
8.	9.9	34.4	38.0	17.6
9.	6.1	40.4	36.4	17.3
10.	0.0	93.5	4.4	1.8
11.	0.2	93.3	4.7	1.7
12.	0.2	88.5	9.3	5.0
13.	7.3	30.6	32.4	29.9
14.	---	--	--	--
15.	44.0	42.5	10.1	3.6
16.	5.8	34.0	37.7	21.8
17.	60.5	30.2	4.6	4.7
18.	3.3	41.2	34.8	20.8
19.	13.1	30.0	30.7	26.1
20.	9.5	68.0	11.7	11.0
21.	74.4	16.8	9.1	1.7
22.	7.4	37.0	34.4	21.2
23.	9.2	29.4	35.3	26.1
24.	8.0	45.7	33.2	13.2
25.	0.7	57.0	37.8	4.7
26.	8.0	21.6	52.8	17.8
27.	15.2	31.7	36.5	16.8
28.	00.0	35.9	50.2	13.8
29.	9.2	42.0	34.2	14.7
30.	0.4	3.5	75.6	20.6
31.	1.3	5.0	50.0	43.7
32.	00.0	67.8	25.0	7.2
33.	0.2	5.2	70.3	24.6
34.	00.0	94.5	2.5	3.0
35.	0.5	1.4	73.2	25.2
36.	8.6	24.4	51.3	16.0
37.	66.3	23.6	7.7	1.8
38.	11.4	30.6	34.0	24.0
39.	4.9	16.4	60.2	18.5
40.	5.1	79.0	6.7	9.5
41.	46.5	44.0	5.3	4.2
42.	49.5	43.0	4.0	3.5
43.	65.0	28.2	4.2	2.6
44.	1.2	72.7	13.1	14.0
45.	30.9	56.5	6.3	6.3
46.	70.0	18.0	7.5	4.5
47.	1.9	94.5	1.6	2.0
48.	23.8	64.0	8.4	3.8
49.	69.5	27.0	2.1	1.4
50.	00.0	6.4	74.7	18.8

PLATE I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HOMME RESERVOIR SITE
V.E. = 3 X
LEGEND:
SOIL ZONE
LAKE SEDIMENT
STRATIFIED SAND
BOULDER PAVEMENT
TALUS & SLUMP
TILL
SHALE SAND
CROSS-BEDDED SAND