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Deflation basin stratigraphy: southwestern North Dakota

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DEFLATION BASIN STRATIGRAPHY: SOUTHWESTERN NORTH DAKOTA

by

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This dissertation submitted by Robert E. Seidel in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

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This dissertation meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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Dean of the Graduate School

Permission

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Signature Robert Seidel

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ABSTRACT

The goal of this study was the determination of a similar depositional sequence for sediments from a number of shallow basins in southwestern North Dakota and the comparison of this sequence with other work either in the area or in similar geographic environments.

Samples were obtained by augering, coring, and trenching selected basins. They were analyzed by means of: core description; detailed texture analyses on selected cores by sieve, pipette, and SediGraph techniques; and mineralogy by x-ray diffraction. Computer analyses were used to characterize grain-size distributions and to correlate texture and mineralogy by cross-association.

The results of the study verified a similar depositional sequence in the basin sediments. The sediments exhibited two dominant colors, olive and brown. The reduced olive colors were lower in the basin sediments and were associated with silt and clay-size material. Overlying these sediments was the zone of brown, oxidized sediments, which in basin margin or near-shore locations was composed of sand-size particles. In central basin locations the near-surface sediments were oxidized silt and clay particles. The sand layer, therefore, occurred as a wedge on the upwind sides of the basins. This sequence with minor variations was repeated from basin to basin.

The mineralogy of the sediments was simple, with quartz the most commonly occurring non-clay, and montmorillonite the most common clay mineral. The mineralogic association of the clay minerals suggests their presence is largely sedimentologic and not pedologic.

The analyses provided three major conclusions. First, the sediments in the basins have a related geologic history as verified by the depositional sequence. This sequence fits the post-glacial climatic sequence worked out for this area as well as Texas and New Mexico. Briefly, that sequence consisted of a period of moist climatic conditions, followed by a period of extremely dry climatic conditions. This dry period was followed by a return to more moist climatic conditions, which have continued to the present. Second, the quartz/feldspar ratios and oxidized zones at the bedrock contact indicate the basins are significantly older than the sediments in them, which are primarily Holocene in age. Third, the bedrock contact determination so critical to the study can be made on the basis of the quartz/feldspar ratios, oxidized zones, physical character of the bedrock and the presence of in situ lignite.

INTRODUCTION

Statement of Problem

Lacustrine sediments have often been used to interpret changes in erosional and depositional environments within lakes, as well as within the areas around them. This study investigated the depositional environments of a number of basins in southwestern North Dakota to see if they share a common geologic history.

The analyses focused on a variety of physical and mineralogical properties of sediments from the basins. The purpose was to establish that lacustrine conditions are present or have previously been present in the basins. It was hoped that a common depositional sequence could be established; this would indicate some regional controls rather than localized effects within single basins. It was expected, however, that certain localized differences would exist.

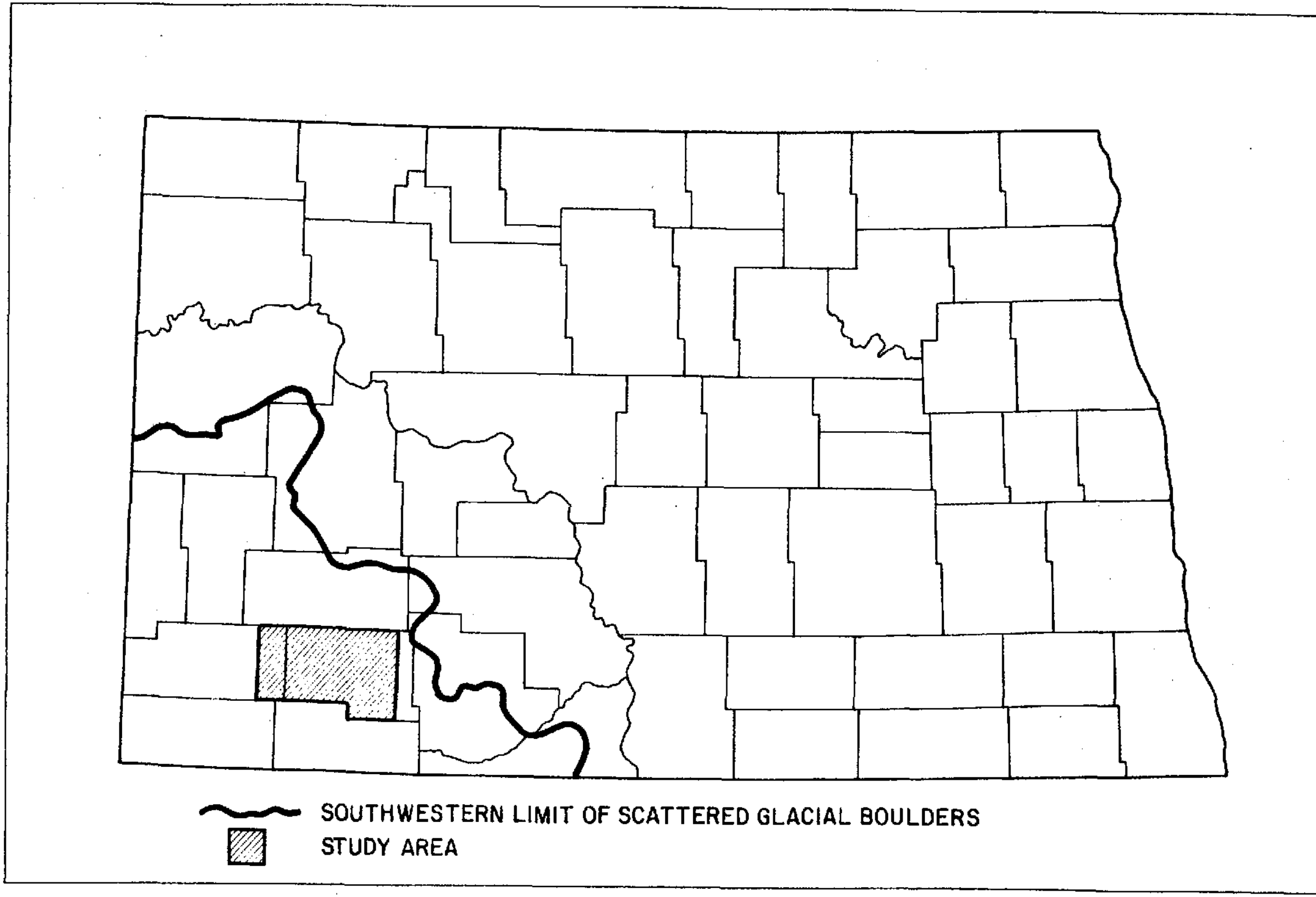
The regional control of greatest interest is climate. If some depositional sequence could be established, it would be compared with other geologic and climatologic studies from North Dakota and adjoining states. Comparison with studies from similar environments but farther away also would be attempted. The importance of these basins is that they have never been studied, and the specific geologic and geographic environment in which they exist has been studied very little.

Location

These basins are located beyond the glacial margin in southwestern North Dakota (Figure 1). Although they are difficult to recognize from the ground, they are clearly visible on air photos. The largest of these basins is 4.5 km long, but most are 1 km or less in length. Few are characterized by standing water at the present time, but many are just wet enough to make them difficult, if not impossible, to cultivate. Therefore, these basins are often used as pasture for livestock, which aids in identification of them on aerial photographs. Many of them are wet enough to be shown as swampy areas on topographic and county highway maps.

The basins are scattered across the unglaciated portion of southwestern North Dakota, with the highest concentration in eastern Slope County (Clayton, 1980), although Grant and Hettinger Counties also contain large numbers. An area including eastern Slope County and the western two-thirds of Hettinger County was chosen for study because it is a fairly broad geographic area containing a large number of basins. Also, this region has basins which are variable in size, some recently drained, and many which are easily accessible.

Fig. 1. Map delineating the study area in southwestern North Dakota.


SOUTHWESTERN LIMIT OF SCATTERED GLACIAL BOULDERS
STUDY AREA

Origin and Climatic Implications

Although the shapes of the basins are variable, most have some elongation in a NW-SE direction, paralleling past and present-day prevailing wind direction, as indicated by NW-SE sandblast-scour marks on the surfaces of Paleocene chert beds which crop out in the area. This evidence suggests a deflation origin for these basins (Clayton and others, 1980). The age of the basins, however, is open to question. The exact time of their formation is not known, but a maximum age of early Wisconsinan or just prior to it is suggested as they occur on an upland stability surface which most probably formed during this time (Clayton, 1969; Moran and others, 1976, p. 147; Clayton and others, 1980).

The location of the basins close to, but beyond, a glacial margin should have placed them in an environment affected by a steep climatic gradient. Sediments in them should have recorded fluctuations of the ice sheet throughout the Wisconsinan glaciation. As the climate in the area fluctuated between moist and dry conditions, the water levels in the basins should also have fluctuated. These fluctuations should be reflected in the types and particle sizes of the material accumulating in the basins. Studying these sediments should therefore yield information about their geologic and climatic history and an associated history for the surrounding area.

Purpose

The primary purposes of this study are:

1. To gain a better understanding of the origin and age of the basins.
2. To interpret the geologic and climatic history of the sediments in these basins.
3. To evaluate the effects of a nearby glacial environment on the depositional/erosional history of the sediments and the surrounding area.
4. To correlate the geologic and climatologic events in the area with events recorded for other areas.

Attainment of these goals was sought by:

1. Obtaining cores from a number of basins in the area.
2. Preparing detailed descriptions of the cores and identifying different strata and structures present.
3. Sampling of these strata to provide information on particle size and mineralogy.
4. Correlating this information from core to core within a basin and from basin to basin.
5. Analyzing any floral or faunal remains.
6. Radiocarbon dating of suitable material.

Previous Work

Studies of lacustrine environments deal with a wide variety of research problems such as those found in Haworth and Lund (1984). The major contribution of such work has been in deducing fluctuations of past climates. With few exceptions, lakes or lacustrine environments which have been studied for this purpose can be divided into two primary types, those which lie within glacial boundaries, and pluvial lakes.

Lakes in Glaciated Regions

Lakes in glaciated regions have been most studied. This is because they are numerous, they are usually accessible, and, as they originated at the time of deglaciation, their maximum ages can be fairly well established. Many early studies on lakes of this type were done in Europe (Charlesworth, 1957) and some later (Woillard, 1978). Recently, however, more research has been done in the United States, where both large and small lakes have been investigated.

Examples of studies on small glacial lakes are numerous and cover a broad spectrum of topics and geographic locations. For north-central United States they include: Willman and others (1971), and Jacobs (1970) in Illinois; Swain (1978), Van Zant and others (1980), Winkler and others (1986), Maher (1982) in Wisconsin; Waddington (1969), Wright and others (1963, 1965), Jelgersma (1962), Winter (1962), Fries

(1962), Fries and others (1961), Brugam (1980), Dean and others (1984), Baker (1965), all in Minnesota; Van Zant (1979), Van Zant and Hallberg (1976), Baker (1979), and Dodd and others (1968), all in Iowa; and Ossian (1970), Watts and Bright (1968), and Haworth (1972) in South Dakota.

Large lakes in glaciated regions have also been studied by researchers interested in paleoclimates. For example, the Great Lakes have been studied by Hough (1958), Reid (1961), and Farrand (1969). In North Dakota glacial Lake Agassiz has been studied most. These studies include: Upham (1895), Johnston (1946), Clayton and others (1965), Brophy (1967), and Arndt (1977). Two volumes on Lake Agassiz have provided summaries of work to the present day. The first was a compilation of work through the mid-1960's (Mayer-Oakes, 1967), and the second was an attempt to summarize all major aspects of Lake Agassiz: its stratigraphy, history, hydrology, biology, and post-glacial legacy (Teller and Clayton, 1983).

Sherrod's (1963) discovery of fossil fishes in glacial lake sediments in central North Dakota caused increased interest in late Quaternary lake basins, resulting in studies by Cvancara and others (1971), Bickley and others (1971), and Bickley and Clayton (1972). These studies were on lakes less than 13,000 years old and which are no longer in existence. Studies such as Callender (1968), Stoermer and others (1971), and Van Alstine (1980) have been done on Devils Lake of east-central North Dakota, a remnant of Lake Minnewaukan. Devils

Lake, which still exists, is also less than 13,000 years old.

Pluvial Lakes

Pluvial lakes, in contrast to lakes in glaciated regions, exist or existed in areas now characterized by arid to semi-arid climates, often far removed from the margins of former glaciers. Such lakes are interpreted to have formed from increased effective precipitation related to glacial maxima in other parts of the world (Morrison, 1968a, 1968b). The sediments in these basins have provided valuable data on former climates in these areas.

The most famous of lakes of this type is Lake Bonneville, the ancestor of Great Salt Lake in Utah. Gilbert (1890) began the study of Lake Bonneville, and the work has continued until today (Davis, 1984). Morrison (1965a, 1965b, 1966) has shown that the history of the lake is very complex and extends back more than 70,000 years.

Lake Lahontan (Russell, 1885; Jones, 1925), on the California-Nevada border and the precursor of present-day Pyramid and Walker Lakes, is another pluvial lake which has been studied extensively. Benson (1978) has worked out a detailed climatic history of Lake Lahontan for the last 40,000 years, but a generalized climate has been extended back to 70,000 years (Morrison, 1964). Studies on Walker and Pyramid Lakes are continuing at the present time (Robinson, 1984).

Searles Lake is another pluvial lake from which sediments extending beyond 70,000 years have been studied (Stuiver, 1964; Peng and others, 1978). In west Texas, Frye and Leonard (1968) reported on Lake Lomax, which apparently has existed since Kansan time. A summary of these lakes and others can be found in Smith and Street-Perrott (1983).

Outside of the United States, the most widely studied pluvial lakes have been in Africa. In the United States, pluvial episodes have been correlated with glacial maxima, but the correlation in Africa is much more complicated (Butzer, 1963). Most of the African studies have been done in the Sahara (Budel, 1963; Rognon, 1976). However, other areas of Africa have also been studied: the rift zone (Richardson and Richardson, 1972); South Africa (Butzer and others, 1973); and East Africa (Hillaire-Marcel and others, 1986). Bowler (1970) has worked on pluvial lakes in Australia.

Lakes which are neither glacial nor pluvial provide another possible source of paleoclimatic data, although the research in this area is limited. Kershaw (1974) studied lake sediments in volcanic craters in Australia and described a pollen sequence extending back 60,000 to 70,000 years. Similar sediments have been studied in Japan (Horie, 1968).

In the United States, lakes that are neither glacial nor pluvial have received little attention. Watts' (1975) study of Lake Annie in Florida, describing a sediment sequence extending back 37,000 years, was one of few attempts to investigate lakes of this type until this North Dakota study was started. The lake basins under study in southwestern North Dakota provide another example of this type of lake. As stated previously, these basins are beyond the glacial margin, but close to it, and their stratigraphy has never been investigated. Because they are beyond the glacial limit, they have the potential of being older than the glacial lake basins in the rest of the state, which are all younger than about 13,000 years old (Moran and others, 1973). Recently Holliday (1984) has described sediments from some ephemeral lakes in the southern High Plains which seem to share a similar environment with those in North Dakota, but are at a much greater distance from the former ice margin.

GEOLOGIC AND GEOGRAPHIC SETTING

The study area is within the Unglaciated Missouri Plateau Section of the Great Plains Province (Fenneman, 1946). In North Dakota, the boundary of this section is approximated by the limit of scattered glacial boulders (Figure 1). The rocks exposed in the unglaciated portion of North Dakota range from the Pierre Shale (Upper Cretaceous), which has a limited outcrop in the extreme southwestern corner of the state, to strata of the White River Group (Oligocene), exposed on the tops of buttes and ridges. Also, undivided sediments, ranging from Upper Tertiary to Quaternary, can be found scattered throughout this area (Clayton and others, 1980). The dips of the relatively flat-lying, near-surface strata in the area shift from a north to northeast orientation in the western part of the area to a northwest direction in the east and southeastern part of the area. These dips reflect the effect of the Williston Basin, a large intracratonic basin centered in McKenzie County (Carlson, 1982, 1983).

Paleocene rocks, which comprise the bedrock throughout most of the region, and specifically within the study area, share, for the most part, a similar history and lithology. They are composed largely of sand, silt, and clay-size particles in varying ratios, depending on the depositional environments of their formation. The sediments forming the Ludlow and Cannonball Formations were deposited at the beginning of the Tertiary; the Ludlow sediments are dominantly nonmarine, but contain material from the coextensive and laterally correlative marine Cannonball Formation (Moore, 1976). The Cannonball Formation is the notable marine exception in the Paleocene rocks (Cvancara, 1976).

Younger Paleocene sediments, which comprise the Slope, Bullion Creek, and Sentinel Butte Formations, all were deposited under similar conditions. These sediments were formed in association with several eastward-flowing rivers, and include overbank, flood basin, point bar, and deltaic deposits (Jacob, 1976; Clayton and others, 1977). Swampy conditions in this setting account for the occurrence of lignite in the Paleocene section. Jacob (1976) concluded that the younger overlying Golden Valley Formation (Paleocene and Eocene) formed in much the same way. An angular unconformity separates the Golden Valley Formation from the overlying White River Group. The White River Group is Oligocene in age and consists of sand, silt, clay, conglomerate, and volcanic ash from distant sources (Jacob, 1976).

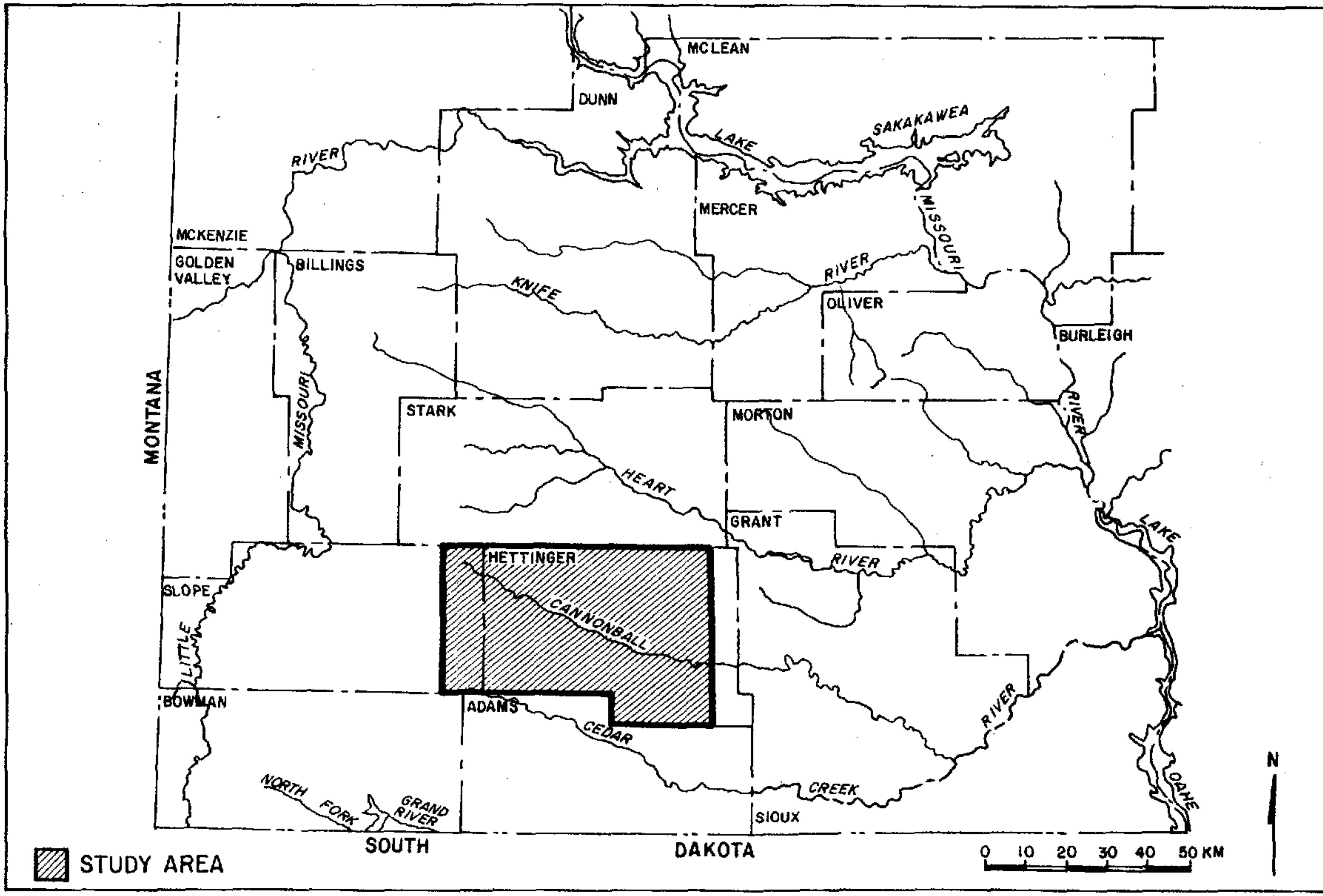
The study area is underlain, for the most part, by the Sentinel Butte Formation, with minor outcrops of the Bullion Creek Formation to the south and east. On buttes and ridge tops, some rocks of the White River group and undivided sediments of Tertiary and Quaternary age can be found (Clayton and others, 1980).

The topography of the region is characterized by gently rolling uplands interrupted by buttes and ridges capped by more resistant rocks. Bullion, Black, Sentinel, Flat Top, White, and Rainy Buttes are capped by resistant sandstones and limestones of the White River Group, whereas lower buttes throughout the region are often capped by clinker or "scoria" (Carlson, 1979, 1983). The "scoria" is the result of the burning of lignite underground, baking the overlying sediments (Sigsby, 1966).

Another major topographic interruption is badland topography, located predominantly along the western edge of the region in association with the Little Missouri River. These badlands originated when the drainage of the preglacial Little Missouri, which flowed to the northeast, was captured by the ice-marginal, southeast-flowing Missouri River (Lemke and others, 1965). The capture provided a lower base level for the Little Missouri River and resulted in the formation of the badlands (Carlson, 1983). The major drainage in the unglaciated portion of North Dakota is provided by the Little Missouri River, which flows northward before turning sharply east in southern McKenzie County (Figure 2).

The other prominent drainage streams are the Heart, Cannonball, and Knife rivers and Cedar Creek. These streams flow to the southeast, shifting to the northeast in their eastern reaches. Although these streams are incised from

Fig. 2. Major drainage lines of southwestern North Dakota.


MCLEAN
DUNN
LAKE
SAKAKAWEA
RIVER
MERCER
MISSOURI
MCKENZIE
GOLDEN
VALLEY
BILLINGS
KNIFE
RIVER
OLIVER
BURLEIGH
MONTANA
MISSOURI
STARK
MORTON
RIVER
HEART
GRANT
LAKE
HETTINGER
RIVER
SLOPE
CANNONBALL
LITTLE
BOWMAN
ADAMS
CEDAR
RIVER
NORTH
FORK
GRAND
RIVER
CREEK
SIOUX
OAHE
SOUTH
DAKOTA
N
0 10 20 30 40 50 KM
STUDY AREA

600 to 900 m, the drainage between them is not well integrated, leaving broad, fairly undissected upland surfaces. It is on these upland surfaces that the deflation basins are located.

METHODOLOGY

Field Methods

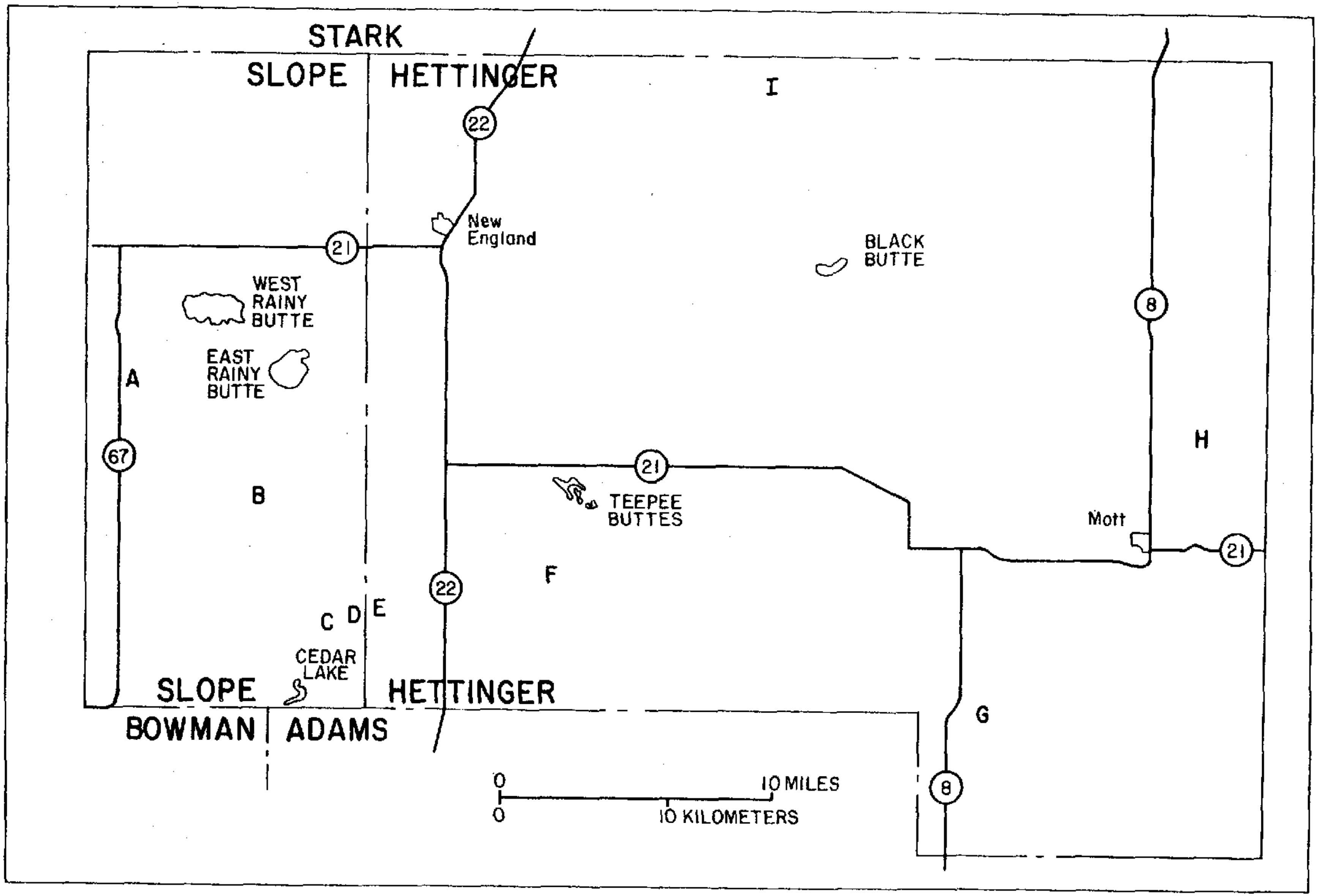
Basin and Core Location Selection

Deflation basins, although widely scattered throughout southwestern North Dakota, are more abundant in certain areas. Eastern Slope and western Hettinger Counties contain concentrations of such basins, possibly the largest concentration in area and number in North Dakota (Clayton, 1980). This part of North Dakota was therefore the focus of the study (Figure 3).

The selection of individual basins for investigation was made using a variety of resources and criteria. Air photos, topographic maps, and county highway maps were studied and field reconnaissance done to select the most suitable locations. Preferred basins were well delineated, not modified by recent ditching, as undisturbed by farming as possible, and readily accessible. Large basins were preferred because of their potential for having the thickest sediment accumulations.

Many basins in the area are farmed intensively, reflecting the fact that they are usually dry. Therefore, basins were sought that were still wet or that have had water standing in them recently. For example, basin I, one of the largest in the region, was drained in the 1950's, as it was previously too wet for farming. Basin G, another large basin,

Fig. 3. Location of the basins sampled in the study area. Basin locations marked with letters A-I.


STARK
SLOPE
HETTINGER
I
22
New England
21
BLACK BUTTE
WEST RAINY BUTTE
EAST RAINY BUTTE
A
8
67
H
B
TEEPEE BUTTES
Mott
F
C
D
E
CEDAR LAKE
SLOPE
HETTINGER
G
BOWMAN
ADAMS
0
10 MILES
0
10 KILOMETERS

had standing water in it, and, according to people living in the area, "always" has had. Basin F is typically under water a few weeks every spring.

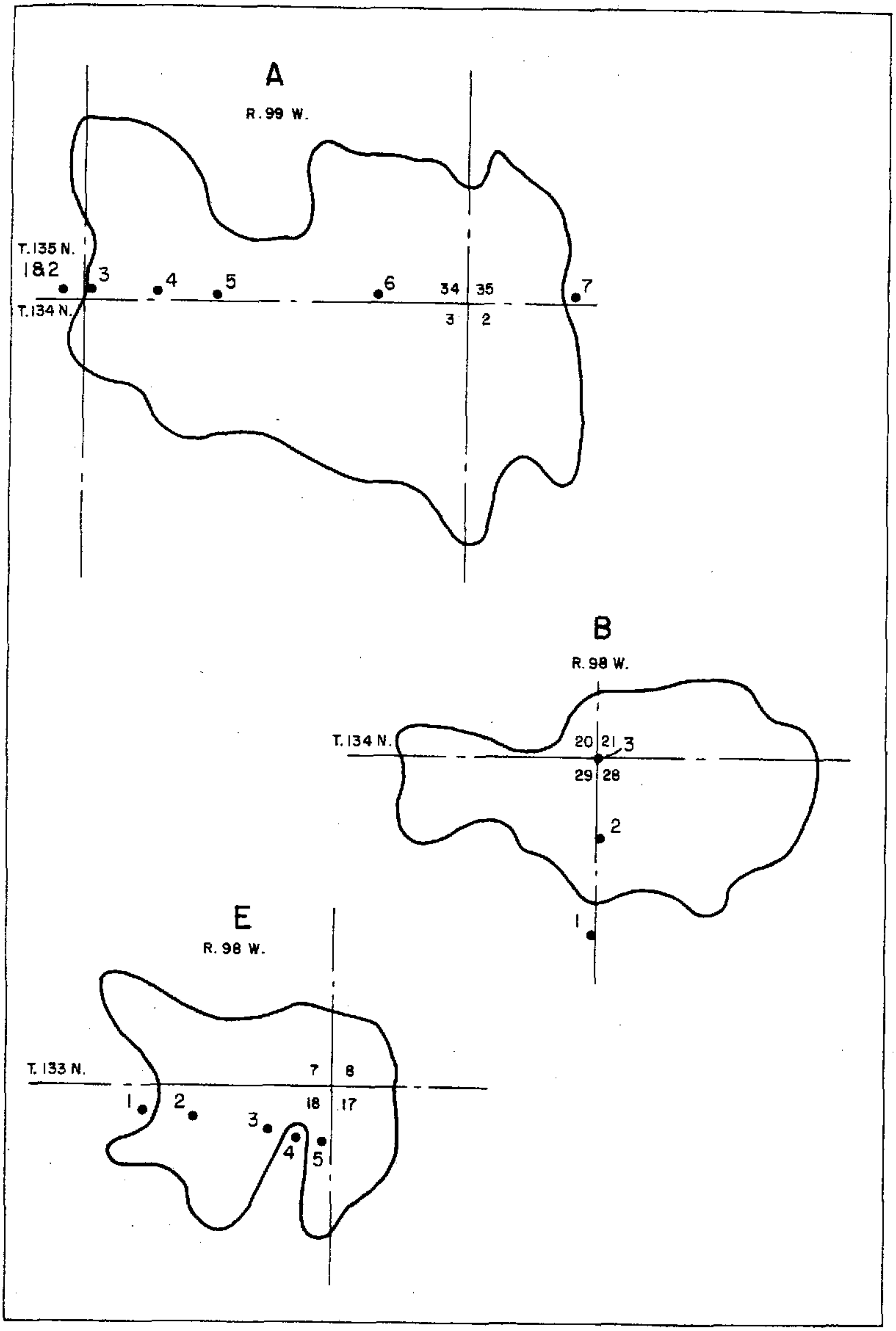
The basins chosen were cored marginal to standing water, if possible, or in postulated near-shore or shoreline positions, and in the central part of the basin or inferred position of former deepest water. The central basin location was expected to provide the most continuous record of sedimentation. The near-shore or shoreline cores were expected to reflect the variable influxes of coarser particles with changing water levels. The marginal positions were expected to record more sub-aerial, most likely eolian, sedimentation. Figures 4, 5, and 6 show the location of various cores and trenches relative to the basins from which they were extracted. If only one core was extracted from a basin, as in the case of basins H and G, the central or deepest water location was chosen.

Correlation of cores within a basin was intended to provide cross sections of the basin and the environments of deposition of basin sediments. The data were also expected to enable correlations to be made from basin to basin and to delineate the boundary between the underlying bedrock and the basin sediments.

Coring

Field work for this study started in May of 1979

Fig. 4. Locations of cores extracted from basins A, B, and E. Basin locations shown on Fig. 3.



A
R. 99 W.
T. 135 N.
T. 134 N.
1&2
3
4
5
6
7
34
35
3
2
B
R. 98 W.
T. 134 N.
20
21
3
29
28
2
1
E
R. 98 W.
T. 133 N.
7
8
18
17
1
2
3
4
5

Fig. 5. Location of cores extracted from basins F, G, and H. Basin locations shown on Fig. 3.

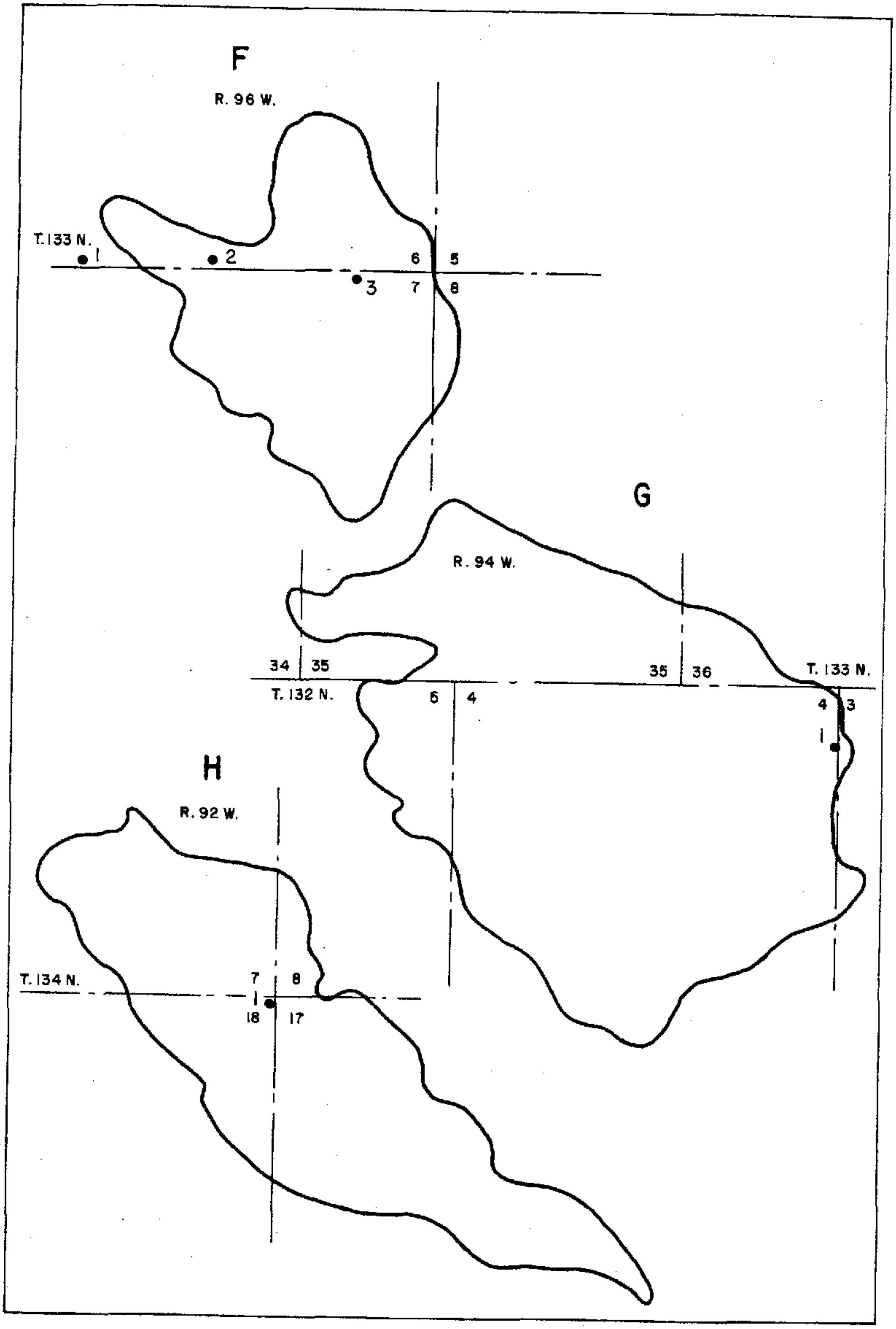
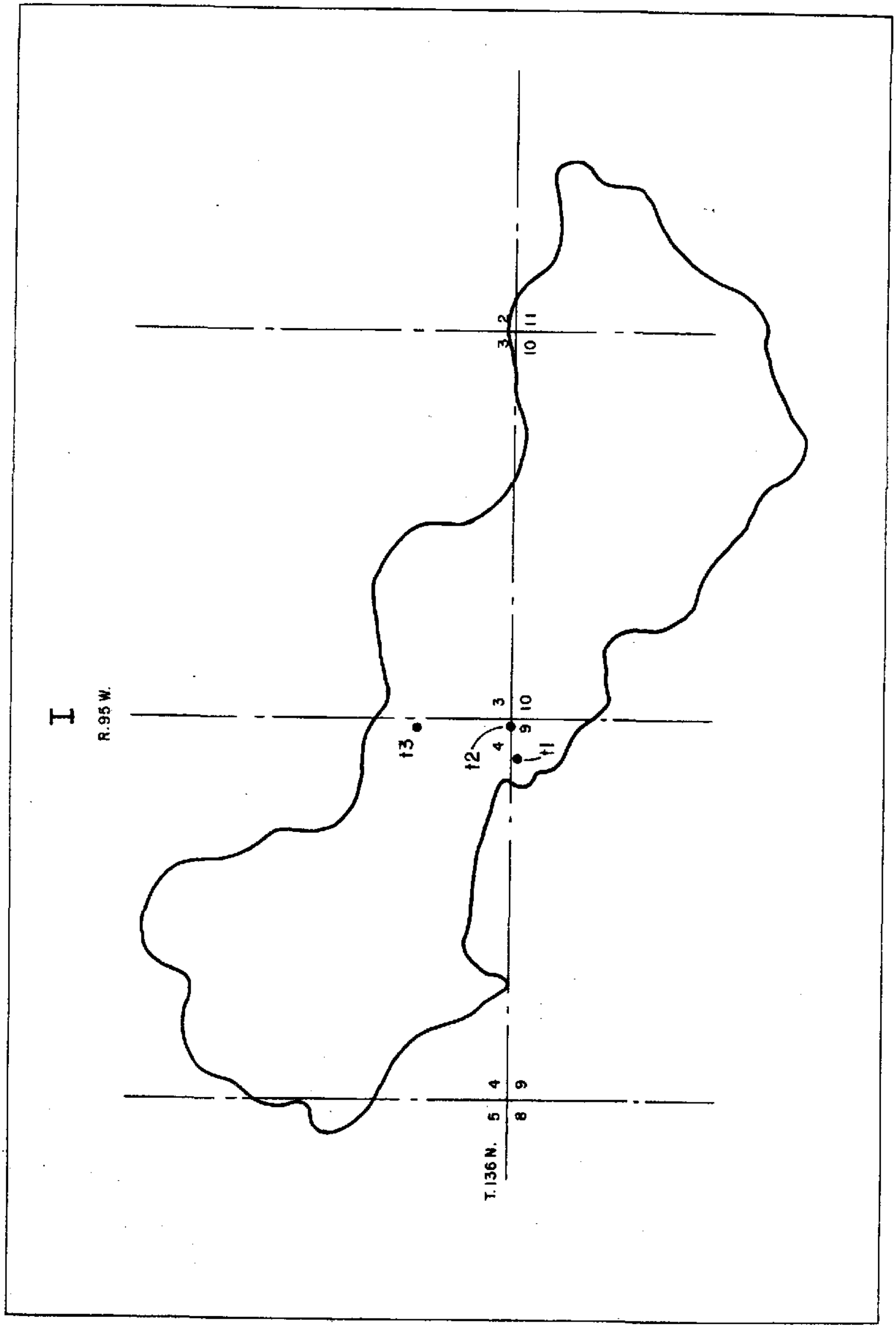

F
R. 96 W.
T. 133 N.
1
2
3
6
5
7
8
G
R. 94 W.
34
35
35
36
T. 133 N.
T. 132 N.
5
4
4
3
1
H
R. 92 W.
T. 134 N.
7
8
18
17

Fig. 6. Location of trenches sampled from basin I. Basin location shown in Fig. 3.


I
R. 95 W.
T. 136 N.
t1
t2
t3
3 2
10 11
3 10
4 9
5 8

when several holes were drilled in basins A, C, D, and E (Figure 3). Field observations and analysis of the sediments indicated that there was potential for a lacustrine study in the area.

In August of 1979 additional cores were recovered from basins A and B, with a Giddings probe. In order to preserve the cores, they were wrapped in plastic as they were extruded from the core barrel. At the University of North Dakota, the cores were stored in a cold room, where they were frozen for later detailed laboratory description and analysis. Cores 4.5 cm and 2 cm in diameter can be taken with a Giddings probe. In order to obtain the largest possible sample, a large diameter core barrel was used until limiting resistance was encountered; a small diameter core barrel was then substituted. Some core was compacted, or was not retained in the core barrel, as when sands were sampled. The loss was minor, however, and nearly continuous cores were recovered from all the holes. Such loss amounted to between 2 percent and 3 percent of the total core material.

In May of 1980, additional cores were taken from basin A, with a Mobile Drill Rig. In addition to gaining a larger data base, the express purpose for this drilling was to extract core which would help delineate the boundary between the sediments and the underlying bedrock of the depression in which they had accumulated. This drill rig was used, as it had the capability of coring to greater depth through relatively indurated sediments.

During September of 1982, a backhoe was used to open trenches in basin I, one of the largest in the area. This trenching had a twofold purpose. First, material sampled from this basin would increase the geographic area of the data base and expand the scope of the study. Second, these trenches would increase the chances of finding materials suitable for radiometric dating.

Additional cores were taken with the Giddings probe in September of 1983 from basins H and F, and finally, in the fall of 1984, basin G was investigated. This basin had standing water in it, and would therefore be more likely to have had water during drier times in the past, and certainly during more moist climatic intervals. It was hoped that this basin would contain a more continuous stratigraphic sequence than some of the basins sampled.

In the fall of 1985 additional coring was done in basin E. The sediments in this basin were re-sampled, for during the first drilling in 1979 a gastropod shell was recovered from this basin. As faunal evidence was rarely recovered in this study, it was hoped that concentrated coring in this basin might uncover some useful faunal remains.

Laboratory Methods

The laboratory methods employed in this study are a combination of standard and new techniques. For example, some of the detailed size analyses were done using standard sieve and pipette techniques, while most of the silt and clay analyses were completed using a new piece of equipment called a SediGraph. This piece of equipment has a number of advantages, to be discussed later, which made its use highly practical.

The detailed size analyses were needed, for, as will be documented, the sediments were for the most part very fine-grained. The fine-grained nature of the material made it difficult with the naked eye or with a microscope to accurately document the magnitude of changes in particle size with depth in the cores, or the expected gradation of particle size across the basins. Detailed analyses allowed this to be done.

The mineralogical analyses were done using a standard x-ray diffractometer. The only departure in technique was employed in the sample preparation. The samples included sand, silt, and clay, using a technique which lends itself to studies in which large number of samples must be run. This technique will be discussed in detail later.

Statistical and computer methods were employed in the analyses, as a large number of correlations had to be made. The computer greatly reduced the time needed to make these correlations. As the establishment of a depositional sequence was important, it was necessary, when texture or mineralogy from different cores was being compared, to know that the patterns were non-random. The technique of cross-association aided in this, and it was also used because the sampling interval was not the same in every core.

Size Analysis

Sampling Interval

The choice of sampling interval in the cores for size analysis was complicated by a variety of factors. The majority of the cores taken were of a small diameter, 2 cm or 4.5 cm. The sediments in the cores ranged from nearly 80 percent sand to nearly 100 percent silt and clay. If a 10-cm sampling interval were chosen and samples taken large enough to provide usable data, the entire core would have had to be destroyed. This would leave no material for other analyses or for later reexamination. If the sampling interval were increased to 20 cm to provide larger samples, smaller but significant layers might be overlooked.

It was decided, therefore, to take samples from each layer identified during the core description process. The core descriptions are summarized in Appendix I. This commonly provided samples large enough to be useful, while keeping a portion of the core intact. Some of the layers identified were thin but distinct. In these cases, small samples were taken to give an indication of particle size distribution, although the sample size was generally insufficient to be statistically valid. All samples, regardless of size, were prepared for analyses in exactly the same manner to maintain consistency.

Sieve and Pipette Technique

Size analysis of the sediments was performed using two techniques. Cores taken early in the study were analyzed with standard sieve and pipette techniques outlined in Folk (1974). The samples were disaggregated and wet-sieved at the 4ø interval. The sand and larger fraction was dried and sieved at ¼ø intervals, whereas the silt and clay fraction was pipetted with aliquots taken at whole ø intervals.

During the course of the study, however, the Department of Geology and Geological Engineering acquired a SediGraph 5000E Particle Size Analyzer, and it was decided to utilize the SediGraph for the following reasons. Although sample preparation is essentially the same for both the SediGraph and the sieve and pipette techniques, analysis time is much shorter with the SediGraph. Also, the SediGraph eliminates the possibility of human error in taking and weighing aliquots. In addition, whole and partial intervals in the silt-to-clay fraction are available from the output of the instrument. At the time the instrument was made available, a large share of the size analyses remained to be completed.

SediGraph Technique

The SediGraph measures sedimentation rates of particles dispersed in a liquid by means of a finely collimated beam of x-rays which determines the concentration of particles remaining at decreasing sedimentation depths as a function of time. The liquid containing the sediments is pumped into a sample chamber through which the x-rays are passed. "The logarithm of the difference in transmitted x-ray intensity is electronically generated, sealed, and presented linearly as 'Cumulative Mass Percent' on the Y axis of an X-Y recorder" (Micromeritics Instruction Manual I-1).

The SediGraph reduces by several hours the time required for analyses. Silt and clay analysis that would take from 12 to 17 hours using standard pipetting techniques can be reduced to less than one hour in some cases. The speed of analysis is the result of the fact that as the sediment is settling, the sample chamber is also moving relative to the x-ray beam. The rate at which the sample chamber moves is dependent on a number of factors: particle density, liquid density and viscosity, and the starting (largest) diameter of the particles to be analyzed.

This rate is defined by:

$$\text{Rate} = \frac{211.80\ (\rho - \rho o)}{(50/Dm)^2\ \eta}$$

where ρ is the density of the material, o is the density of the liquid in which the material is suspended, η is the viscosity of the liquid, and Dm is the size of the largest particle to be analyzed.

For this study, water was chosen as the suspension liquid as it was the major component in the disaggregation and wet-sieving process. Therefore the density and viscosity values of water had to be determined, as they were needed for the rate calculations. As these values change with the temperature of the water, a correction table in the instruction manual was used to determine the values. Also, the sediments were composed of a variety of minerals with varying densities. As quartz was a major component of the sediments, its density, 2.65 g/cm^3, was chosen as the average density. Although the SediGraph can accommodate particles up to 3ø-4ø in diameter (very fine sand), the sediments were wet-sieved at the 4ø interval so that the results would be comparable with the size analyses from sieving and pipetting, which were also wet-sieved at the 4ø interval.

The major difficulty in the use of the SediGraph is sample concentration. Although there is no particular concentration needed, the dispersed sample ideally should reduce the beam intensity from 40 percent to 50 percent. Reduction in beam intensity of more or less than these values results in inaccuracies in the data. A sediment concentration of approximately five volume percent will provide a usable sample, and such a solution is easily prepared when known amounts of dispersant and particles are used. When wet-sieving natural sediments, it is often difficult to stay within the tolerances of the instrument.

The first attempts at sample preparation for analysis on the SediGraph produced solutions much too dilute to reduce the beam intensity by the proper amount. To gain better control over the amount of dispersant in the SediGraph samples, a wet splitter was used to provide a small but representative split of the sample. After disaggregation the whole sample was wet-split and the smaller split wet-sieved, providing the SediGraph solution. The smaller amount of sediment allowed for better control over the amount of water needed to complete the wet-sieving process. The control was so effective that some of the resulting solutions had to be diluted before they could be run properly. However, a few of the wet-sieved portions were still so dilute that they needed to be concentrated through evaporation.

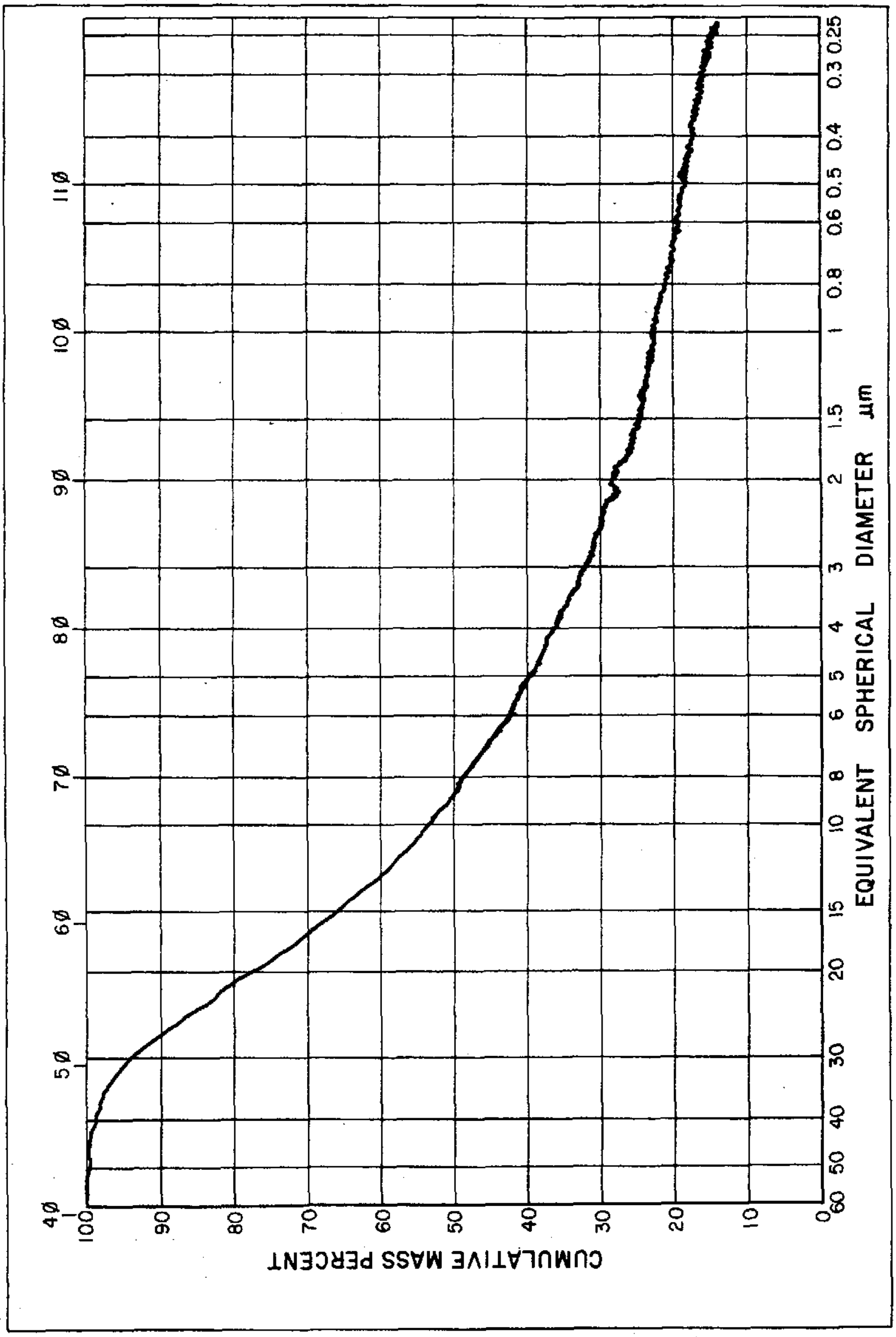
The larger splits were needed to provide usable data on the sand and larger fraction of the sample, sieved using the standard technique. The sand/silt/clay percentages determined from the smaller splits but representative of the total sample, were used in the calculations which are necessary to complete the sand and larger portion of the analysis.

Figure 7 illustrates a sample of the output from the SediGraph, and Appendix II contains the basic size data from selected cores derived from all the various size analysis methods outlined.

Mineralogy

X-ray diffraction is a standard technique used to determine the mineralogy of rocks and sediments. Typically, x-ray diffraction analyses of samples containing both clay

Fig. 7. Sample output from the SediGraph 5000E Particle Size Analyzer.


CUMULATIVE MASS PERCENT
EQUIVALENT SPHERICAL DIAMETER µm
4Ø
5Ø
6Ø
7Ø
8Ø
9Ø
10Ø
11Ø

and non-clay minerals are performed in two stages. The clay minerals are studied using oriented samples of mechanically separated particles, as discussed in Carrol (1970) and Gibbs (1965). The non-clay minerals are studied using randomly oriented powders, as summarized by Klug and Alexander (1974). Karner and Wosick (1975) described a method whereby the bulk mineralogy of both clay and non-clay materials can be determined by the single diffraction analysis of one sample. Using this method, sample preparation time is greatly reduced.

This method consists of preparing a glycolated pellet from a sample, using the following basic procedure. After air drying, the sample is ground with a mortar and pestle to reduce it to particles which will pass a 177-micron screen; 3-4 grams are then ground in a Spex 8000 mixing mill for five minutes. The pellet is prepared using 1 gm of sample, 0.8 ml ethylene glycol, and 2 gm of cellulose powder (Avicel) and a simple die technique, modified from that described by Baird (1961). The sample and ethylene glycol are mixed and molded into a rough disc on a sheet of plastic film (Saran wrap) and placed into the die where the cellulose powder is added. The die is then placed onto the stage of a hydraulic press where a pressure of 1.38×10^8 N/m^2 (10 tons/inch^2, 4 tonnes/cm^2) is applied for 20 seconds. A smooth-surfaced, cellulose-backed glycolated pellet 24 mm in diameter and 4 mm thick is thus formed for x-ray analysis.

There were two basic reasons for using this method in this study. The determination of the bulk mineralogy of a large number of samples was planned, and according to Karner and Wosick (1975), this method works best when running a large number of samples for routine analysis, augmented by more specific mineralogic studies.

The second reason this method was so useful for this study is related to the particle sizes of the material being studied. To be prepared for the mixing mill, the particles must be reduced to approximatey the size of fine sand, or particles which will pass a 177-micron screen. The particle sizes of the sediments being studied were predominantly fine sands and smaller. Use of the mortar and pestle was then disaggregation and not crushing, which reduced sample preparation time as well.

The bulk mineralogy of the sediments in the basins was determined by x-ray diffraction. The minerals were identified from the resulting x-ray traces. Quartz percentages were calculated using a novaculite standard. The counts for the standard, which represents 100 percent quartz, were compared with the counts of quartz for the various samples and the percentages calculated. For example, if the sample produced 500 counts and the standard 1,000, then the sample contained 50 percent quartz.

The best procedure for the determination of such percentages is to make standards from the samples themselves, so that the composition of the standard and the mineral under study are the same, or as similar as possible. But the fine-grained character of the material and the small sample sizes precluded the use of such a technique in this study. The composition of quartz is not as variable as the feldspars or clays, however, and use of a foreign standard is not as serious.

The comparisons and correlations of the other minerals are based on the peak-height intensities measured on the x-ray traces. Peak-height intensities give usable data for determining trends or patterns in the amounts of various minerals. Peak-height intensities of quartz were also measured. It makes little difference whether absolute intensities or calculated mineral percentages are used, the relative gains or losses are internally consistent (Dr. Don H. Halvorson, 1976, written communication).

Statistical Methods

Data Sequences

Sequences of data, or data sets characterized by the position of data along a single line, are commonly used in geology for collection and presentation of data. Examples of data of this type cover a wide range of possibilities, including changes in lithology with depth in drill holes. As most of the data in this study were collected from core samples, the use of statistical analytical techniques which work best with sequences of data is necessary.

There are two basic types of data sequences. The first type is characterized by carefully measured variables and scales along which the data are located. That is, the measured variables are located at equal intervals along the line. The second type of sequence is characterized by nominal or ordinate data, or data which are not amenable to direct measurement, for example, changes in state with depth, where data describe lithology, i.e., limestone, sandstone, or shale, rather than measured quantities. In such a sequence, the bed thicknesses may vary, and data, therefore, are not positioned equally along the line. Their position in the sequence, however, is of great importance and must be analyzed carefully. These two basic types of data require different analytical techniques.

A number of statistical techniques can be applied to sequences of data. Some of them, such as runs tests and regression analyses, are used when analyzing a single sequence. The logical outgrowth of the analysis of one sequence is the comparison or correlation of two or more of them. Correlation of data within one basin and from basin to basin is a major part of this study, and any statistical method which will assist in this correlation is of interest. According to Davis (1973, p. 175), there are two methods which are closest in operation to the actual mental processes involved in correlation: cross-correlation for measured data and cross-association for nominal data. These analyses can be done manually, but they are tedious and time-consuming, especially if there are many possible correlations to be made, as in this study. There are, however, computer programs available which will perform these analyses (Davis, 1973). It should be emphasized that these techniques are not intended to replace the visual correlation of data, but to help in the interpretation, especially where variability of data is slight and visual correlation is difficult.

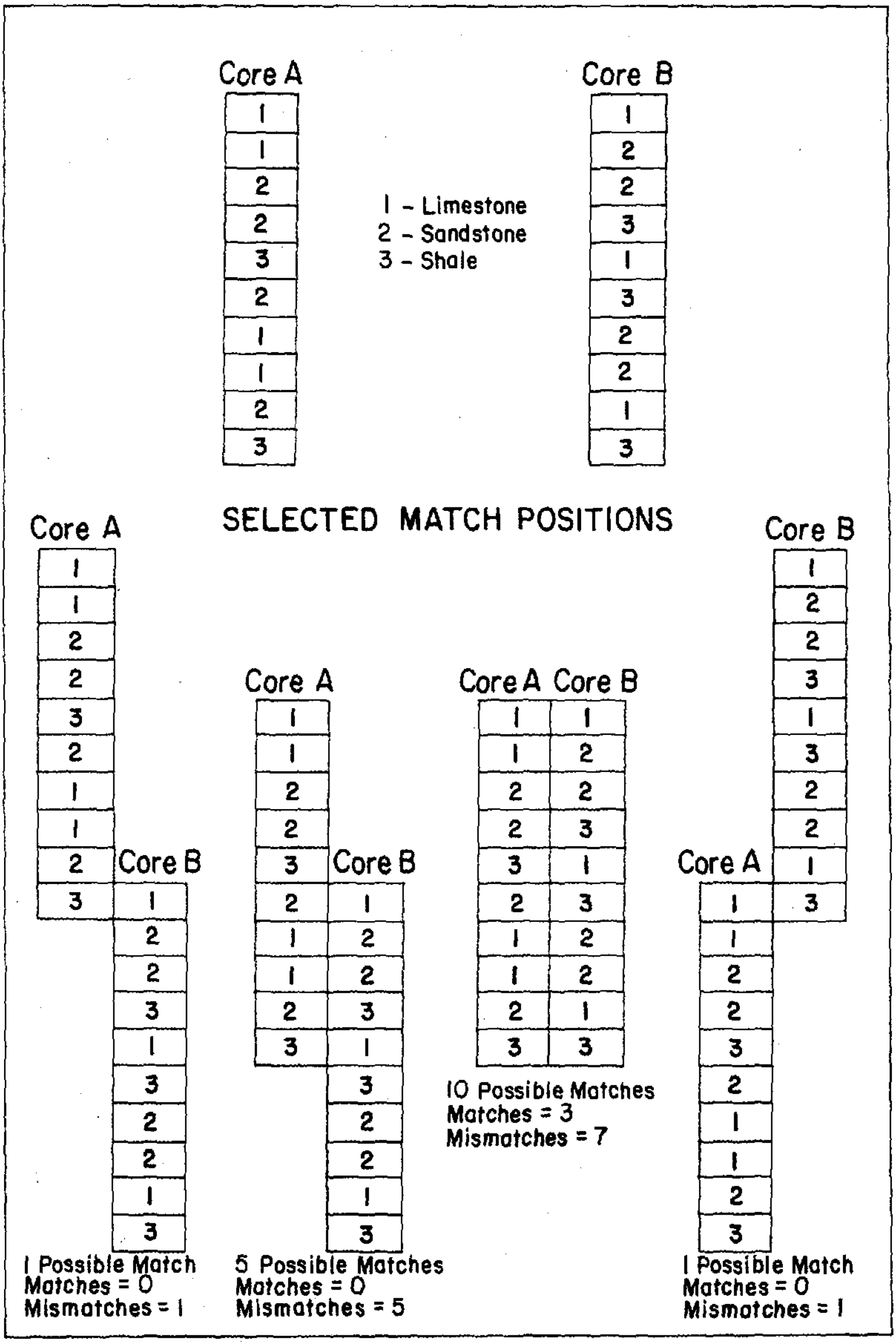
Cross-Association Technique

Although cross-association and cross-correlation differ in terms of the types of data used, the same basic operations are performed in both analyses. First, two sequences of data are chosen for comparison. At the top of Figure 8, data from two hypothetical cores are shown. In this hypothetical example the technique to be used is cross-association, as changes in lithology are being correlated. In this example, 1 = limestone, 2 = sandstone, and 3 = shale; they are entered into the computer as columns of numbers.

The diagrams in Figure 8 would seem to indicate that the individual beds of limestone, sandstone, and shale are all the same thickness, which in reality would be highly unlikely. These individual units are shown as equal in thickness for purposes of demonstrating the technique, as cross-association is concerned with position in the sequence, not thickness.

These two strings of data are placed adjacent to each other, with the bottom unit of one core in contact with the

Fig. 8. A hypothetical example of cross-association, a technique used to test for randomness of pattern in data sequences being compared.


Core A
Core B
1 - Limestone
2 - Sandstone
3 - Shale
SELECTED MATCH POSITIONS
I Possible Match
Matches = 0
Mismatches = 1
5 Possible Matches
Matches = 0
Mismatches = 5
10 Possible Matches
Matches = 3
Mismatches = 7
I Possible Match
Matches = 0
Mismatches = 1

top unit of the other, as in the lower left of Figure 8. The sequences are then moved past each other, one data unit at a time, each movement constituting one match position, until the units on the opposite ends come into contact, assuring that all possible matches have been made. For each match position, the number of matches and mismatches are counted, and the number of probable matches and mismatches from totally random series are used in a X^2 significance test. The formula for the X^2 test is:

$$X^2 = \frac{(O-E)^2}{E} + \frac{(O'-E')^2}{E'}$$

where

O = observed number of matches,

O' = observed number of mismatches,

E = expected number of matches,

E' = expected number of mismatches.

If any match position is to be significant, the result of the X^2 test must exceed a critical value which would indicate that the match is more than just a random association of variables (Table 1). It is possible that the critical value may be exceeded in more than one match position. In this case, the match position where the critical value is exceeded by the greatest amount will indicate the best statistical correlation between the two sequences of data, and potentially, the best correlation of the two cores in terms of the variables in question. This information, along with the geologic

TABLE 1: Critical Values of χ^2 for ν Degrees of Freedom and Selected Levels of Significance

Significance level, α (%)

Number of degrees of freedom, ν	20	10	5	2.5	1
1	1.64	2.71	3.84	5.02	6.63
2	3.22	4.61	5.99	7.38	9.21
3	4.64	6.25	7.81	9.35	11.34
4	5.99	7.78	9.49	11.14	13.28
5	7.29	9.24	11.07	12.83	15.09
6	8.56	10.64	12.59	14.45	16.81
7	9.80	12.02	14.07	16.01	18.48
8	11.03	13.36	15.51	17.53	20.09
9	12.24	14.68	16.92	19.02	21.67
10	13.44	15.99	18.31	20.48	23.21
11	14.63	17.28	19.68	21.92	24.72
12	15.81	18.55	21.03	23.34	26.22
13	16.98	19.81	22.36	24.74	27.69
14	18.15	21.06	23.68	26.12	29.14
15	19.31	22.31	25.00	27.49	30.58

Source: Statistics and Data Analysis in Geology: Davis (1973, p. 118) interpretations and visual correlation, should provide the best possible match.

RESULTS

General

The results of a variety of analyses of the physical and mineralogic properties of the sediments provided correlatable and coherent sets of data. For example, color analysis revealed that the sediments in the basins exhibited two basic patterns of comparison. The first is a color change related to depth, which was found in all the cores and trenches investigated. The second basic pattern which could be discerned is related to the position of the core or trench in or around the basins. As a position changed, so did the color and depth association, but in an entirely coherent manner. The range of dominant colors was not great, but where mottled sediments were found in the cores, the colors of the mottles were quite variable.

The texture of the sediment provided some insights into these color patterns, as it also was found to vary consistently with depth and relative basin location. As expected, the variation in texture suggested a more complex geologic history than did color, but one which was consistent with the information the color patterns provided. There was a consistent variation in grain sizes with depth, allowing for understandable change due to core location changes, and the gradation in grain sizes across various basins provided a coherent geologic framework.

The mineralogical analysis revealed a fairly simple mineral assemblage, but variations in amounts of specific minerals provided a number of consistent correlations within basins and from basin to basin. The variations also provided results which indicated that the mineralogy was related more to sedimentologic processes than pedologic processes. Resistant to non-resistant mineral ratios did provide some evidence that weathering has affected the sediments, but the greatest effect seemed to be where these ratios were related to the bedrock below the sediments.

Color

One of the most obvious of all the physical properties of soil and surface deposits is color, because it normally is the first characteristic seen or noticed when working with any earth materials. It is, however, one of the most difficult to work with, for as Hunt (1972, p. 246) stated, the causes of color differences are imperfectly understood, and our knowledge of what produces these colors has lagged behind our ability to measure and describe them. For these reasons, color, as a physical property and an indicator of environmental change, must be used with care. In this study it will be used, along with other types of physical evidence, to gain a better understanding of the geologic and climatic history of the basins.

In a general sense, the color of soils or surficial materials is determined by the amount and state of iron and the amount of organic matter contained in them (FitzPatrick, 1980, p. 91). Any attempts to determine the amount of iron and organic matter from color would be impractical, if not impossible, for as both Ritter (1978, p. 101) and FitzPatrick (1980), p. 91) pointed out, a very small amount of pigment can cause intense coloration. Some of the other substances which can have a significant effect on coloring are the elements manganese and sulfur and the mineral calcite.

As a part of this study, any color and any color changes seen during the core description phase were carefully noted. The result was at first a very complex picture of colors and shades of color, which seemed to preclude any real commonality from core to core. Upon closer examination, however, common patterns began to emerge. These can be divided into two main categories. First there are basic patterns which can be seen in nearly every core, depending primarily on the depths from which the core was recovered. The second major category is variations in the patterns which are associated with the position of the core relative to the basin from which it came, that is, was the core taken from marginal, shoreline or near-shore, or deeper-water location?

Range of Colors

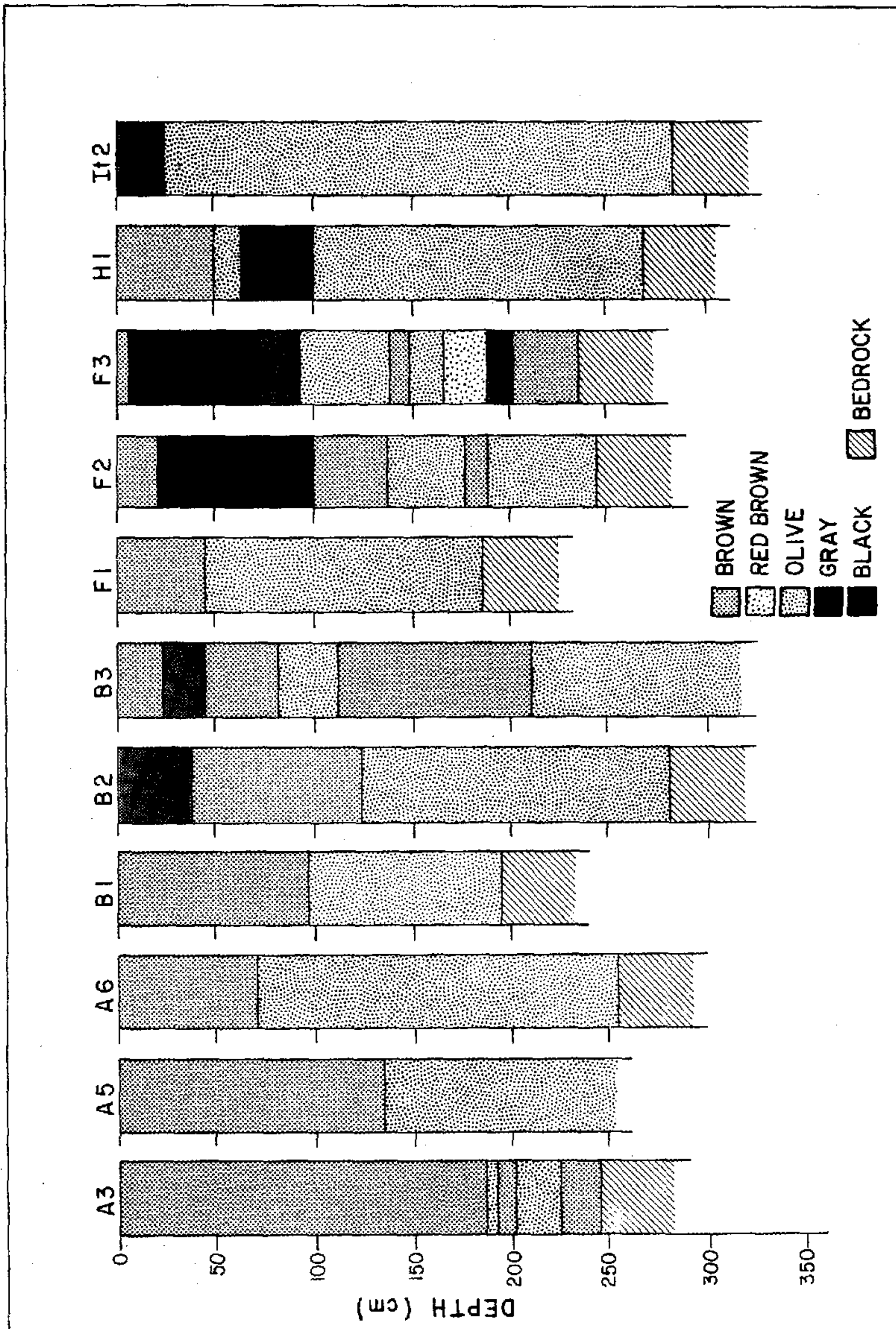
A common feature of the first category, basic color patterns dependent on depth, is that a few hues accounted for most of the color. These hues, identified using the Standard Munsell Soil Color Chart (1973), varied between 7.5YR to 10YR, and 2.5Y to 5Y, when looking at dominant colors. Some oxidized patches and zones exhibited redder hues, ranging between 10R and 2.5YR to 5YR. This range of hues is not unusual; most modern soil and surficial materials have a limited range of hues within 10R, 5YR to 10YR and 5Y (Hunt, 1972, p. 247). It should be noted that the color identifications were made when the materials were moist.

Dominant Colors Related to Depth

One color pattern related to all the cores emerged during field work and core extrusion. During this phase of the study, change in the dominant colors with depth was observed. Later, detailed laboratory descriptions verified these observations, although the dominant colors were sometimes difficult to ascertain due to the presence of zones of intense mottling in some of the cores. Mottled and oxidized zones in the cores will be discussed later in this section. As can be seen in Figure 9, in almost every core there is a change from brown material closer to the surface to olive-color sediments at depth.

It should be emphasized, however, that the picture was not quite this straightforward, as there were various shades of brown and olive present which are not shown on the

Fig. 9. Dominant colors exhibited in selected cores. Core locations can be found in Figs. 4, 5, and 6.



A3
A5
A6
B1
B2
B3
F1
F2
F3
H1
It2
DEPTH (cm)
0
50
100
150
200
250
300
350
BROWN
RED BROWN
OLIVE
GRAY
BLACK
BEDROCK

figure. The reason they are not included is that, in most cases, the variations were very slight and therefore probably not a reflection of major changes in the climatic or geologic history of these basins. It is possible also that some of these variations may be artificial. For example, as previously stated, the cores were sometimes mottled to varying degrees, and selection of a dominant color was often difficult. The interference of the mottles may have caused slight variations in chroma or value selection. Also, slightly lighter colors may have been selected due to partial drying of the sediments during core description, although every effort was made to minimize this.

One of the important variations in the olive-color sediments was related to the gray colors at the bottoms of cores A3, B2, F2, and F3 (Figure 9). If olive-gray were included as a separate color, there would have been "gray" materials shown at or near the bottoms of cores A6, B1, F1, and It2 as well. The "gray" color in these materials is most likely due to the presence of the typically fine-grained incoherent bedrock at these depths; for in many of the cores lignite stringers were found in the bedrock near the sediment-bedrock interface, and this lignite can influence the coloring. Also, the bedrock could retain some organic matter residues from vegetation growing on it prior to the filling of these basins; thin organic-matter layers were seen in some cores at these intervals. Material from these layers could have added to the gray colors found near the bottoms of the cores.

Cores A5, B3, and H1 (Figure 9) did not appear to bottom in gray material. The most plausible reasons for cores A5 and B3 not having this zone is that they were not deep enough to penetrate bedrock. Core H1 bottomed in a thick, strong brown-color oxidized zone. At the sediment-bedrock interface thin oxidized zones were commonly found, but at this location the oxidized zone was thicker than in other cores and the soil probe was not able to penetrate it.

The nearer-surface brown sediments also contain some gray materials. The black zones in cores F2 and F3 and gray layers in cores B2, B3, and It2 seemed, at first, out of place. If, however, gray-brown were to have been added to the figure as a separate color, cores A3, A6, A5, and H1 would also have had "grays" present at or near the surface. These near-surface black, gray-brown, and associated dark brown colors are the result of the presence of organic matter in the sediment.

To summarize the dominant colors in the cores, there is a pattern, though not complete in every case, that at or near the surface, black, gray, and dark brown sediment predominates. Below sediment of these colors is a zone of lighter brown sediment, followed, at depth, by a zone of olive sediment. At the bottom of most of the cores there is a zone of gray material which is most likely related to the presence of organic material in or on poorly consolidated bedrock.

The presence of dark materials near the surface and at the bottoms of cores has been explained, but the presence of the dominant colors, brown and olive, needs further explanation. The most widely accepted explanation for the occurrence of these colors in sediments is related to the processes of oxidation and reduction. Iron is the element commonly involved with these processes, as it is one of the few elements found in a reduced state in primary materials (FitzPatrick, 1980, p. 68).

Oxidation takes place when iron from primary minerals is released into aerated rock and soil materials, resulting in a change from ferrous to ferric iron (Buol and others, 1980, p. 80). Krauskopf (1979, p. 88) stated that the colors resulting from this process are reds if the minerals formed are simple oxides and yellow to brown-color if hydrates are formed, although the conditions under which hydration and dehydration take place are imperfectly known. On the other hand, if iron is released into an anaerobic invironment, the iron will remain in a ferrous state (FitzPatrick, 1980, p. 68). If this ferrous iron remains in the system, it can react to form sulfides and related compounds (Buol and others, 1980, p. 81). Although many of the precise pigmenting compounds have not been identified, a range of colors from grayish-blue to olive-gray to olive has been commonly found in horizons that are permanently or temporarily saturated with water (FitzPatrick, 1980, p. 93).

The basic relationship of the dominant colors indicates that there has been a major change in the environmental history of these basins. The olive shades at depth indicate a period when the sediments accumulated in a reducing environment. This could be associated with a relatively moist climatic period, when high water tables resulted in standing water in these basins.

This major period of relatively moist conditions was then followed by a drier period during which the accumulating sediments were exposed to the air more frequently and oxidation occurred as they accumulated. During this time the sediments may have been moist for long periods of the year. Paler brown colors and oxidation can be associated with such conditions (FitzPatrick, 1980, p. 93). Many of the cores have a lighter brown below with dark brown, black, and gray colors close to the surface; this indicates a trend toward more moist conditions in recent times, resulting in more vegetation growth and consequently more organic matter accumulation in near-surface materials.

Color and Relative Core Location

Changes in dominant color patterns of the second category, patterns related to core location relative to the basins from which they were taken, give supporting evidence for this proposed environmental change. The exact pattern is not repeated from one basin to another, as basin morphology is not identical. Changes in basin morphology would affect water table conditions and preclude exactly comparable marginal, near-shore or shoreline, and central-basin locations. However, when trends in color patterns are studied, the evidence for the basin change in environmental conditions can be seen.

For example, a definite pattern emerges when cores A3, A5, and A6 are compared (Figure 4). Core A3 is a probable shoreline position, whereas core A6 is presumed to have been a deeper-water location. At the different core locations from shallow water to deeper water, the ratio of brown to olive-color materials is different as well. Deeper water locations have a smaller percentage of brown, oxidized material.

This color pattern is consistent with the idea proposed earlier of a relatively moist climate followed by a period of drier climate. The shallowest water location should dry out first, with a larger percentage of the sediments exposed to oxidizing conditions. In a deeper-water location, where standing water and saturated conditions should have lasted longer, a shorter period of oxidation should have occurred. This would cause exactly the pattern seen in this basin.

Basin B (Figure 4) from which cores B1, B2, and B3 were taken, shows much the same picture; core B1 is marginal, core B3 is near-shore, and core B2 is a presumed deeper-water location. A comparison of cores B3 and B2 shows the same thin zone of oxidation that can be seen in the deeper-water locations. A complicating factor in core B3 is the yellowish-brown zone from 114 to 216 cm in depth. This zone represents one of the most highly mottled zones in all the cores, making the choice of a dominant color difficult. There were olives, grays, olive-grays, yellow-browns, and even some small amounts of dark reddish-brown colors in this zone. Yellowish-brown was one of the most common colors, so it was used as the dominant color.

Cores F1, F2, and F3 (Figure 5), in Basin F, were taken from marginal, near-shore, and more central-basin locations. The sediments are not as thick in this basin as in others. This complication, along with the presence of a wider range of colors, obscures the previously seen pattern of thin oxidized zones from sediments having been deposited in deeper water.

Core H1 from Basin H (Figure 5) and material from trench It2 (Figure 6), both central-basin locations, exhibit dominant color patterns consistent with their basin location. Core H1 has a thin oxidized zone overlying a much thicker olive-tone zone of reduction. Slightly different conditions exist in the sediments taken from It2. In this trench a layer of organic, gray material overlies a thick zone of olive-tone reduced sediments. This particular profile is consistent, however, with the fact that this basin was so wet throughout the year that it was drained approximately 30 years ago by the area farmers so that it could be more readily cultivated.

Marginal basin locations, such as for core B1 and core F1, show a slightly different profile, but one which is consistent with basin morphology and the suggested environmental change. Due to their marginal and consequently drier location, the depth to bedrock is not as great as in central-basin locations. The sediments in these marginal locations have been more susceptible to erosional processes throughout their history and therefore do not have as much sediment accumulated as do those nearer the basin centers.

The dryness of the location is also manifested in the colors seen in the core materials. For example, the near-surface materials lack the dark-gray and black colors commonly found in cores farther into the basins. This is likely the result of sparse vegetation growth there. Also, the sediments exhibit a thick zone of brown colors associated with oxidation overlying a thin zone of reduced material. This relatively larger amount of oxidized material indicates a longer period of oxidation. The reduced zone, which is at the interface between the sediments and the bedrock, could be the result of two factors: higher water tables associated with past more moist climates, or perched water tables caused by relatively impervious underlying bedrock. Gleying conditions can be restricted to part of a profile if the downward flow of percolating water is impeded (Birkeland, 1974, p. 118).

Color Mottling

In the preceding paragraphs, oxidation and reduction are discussed as if they are mutually exclusive in the places where they occur. A more common situation than either oxidation or reduction is a fluctuation from oxidizing to reducing conditions (Buol and others, 1980, p. 81). The situation most often responsible for this is a change in water content due to fluctuating water tables. Quite commonly, under these fluctuating moisture conditions, part of the affected materials will be oxidized and part reduced, with the characteristic colors being mixed. These intermixed colors are described as mottled (Birkeland, 1974, p. 118). FitzPatrick (1980, p. 91) stated that "mottling" is used for color patterns which are dominantly gray, olive, or blue, and contain lesser areas of yellow, brown, or red. Olive, with lesser areas of yellow, is the primary mottling association seen in the cores of this study, but olive with lesser areas of brown and red can also be found.

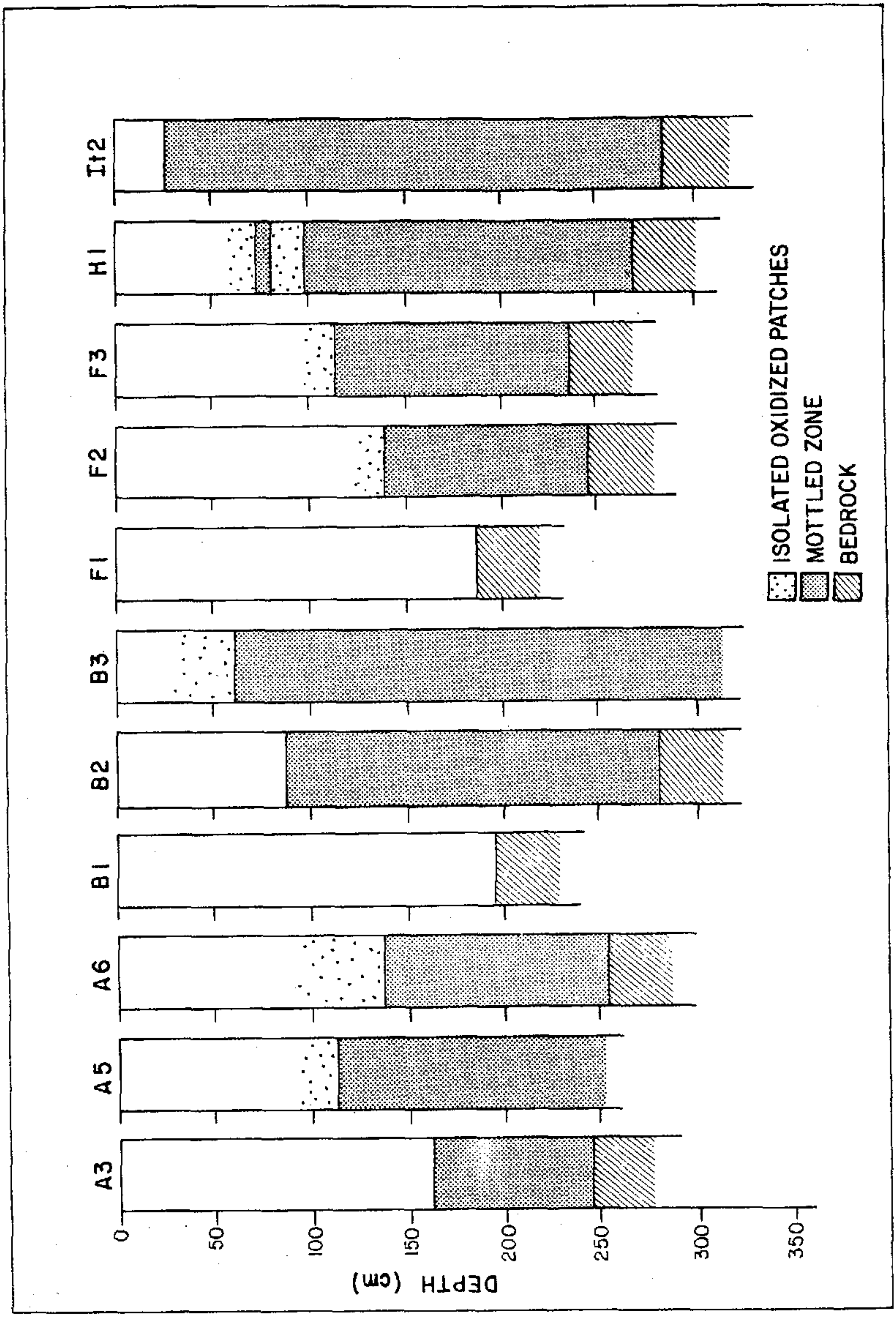
Oxidizing and reducing conditions always have some effect on the rate of weathering of iron-bearing minerals. Iron in the ferric state is apparently able to be maintained for relatively long periods of time, even under anaerobic conditions. But, when ferrous iron enters an aerobic atmosphere, it is quickly oxidized to the ferric state (FitzPatrick, 1980, p. 68). Although this relationship is not fully understood, there seem to be a number of factors which contribute to it.

Evidence indicates that the oxidation process takes place relatively rapidly; dissolution experiments on iron-bearing minerals show that oxides can form in the matter of a few days. It is further suggested that this iron oxide forms a rind on the mineral which controls further dissolution by requiring diffusion of silica, cations, and oxygen through this surface barrier (Siever and Woodford, 1979). This process serves to slow the rate of weathering.

Another important factor is the ferric iron ion itself. It does not move appreciably in solution in soil profiles. Additionally, the low solubility product of one of the more common ions, ferric hydroxide, makes it necessary for highly acidic conditions to be present before soluble ferric ions become important in the solution phase (Marshall, 1977, p. 77). In the basins under study, the sediments exist in an alkaline environment which would serve to further slow the reduction of ferric iron.

Figure 10 shows mottled zones derived from cores which, when looked at in detail, present a very complex picture. Changes in color of mottles can be seen within one core, or a core may exhibit just one basic mottling color varying in intensity. Differences in mottling cannot be

Fig. 10. Zones of mottling and their positions in selected cores.


It2
H1
F3
F2
F1
B3
B2
B1
A6
A5
A3
ISOLATED OXIDIZED PATCHES
MOTTLED ZONE
BEDROCK
0
50
100
150
200
250
300
350
DEPTH (cm)

expected to be exactly the same from basin to basin, as each location could likely be subject to dissimilar sets of water table controls. Therefore, attempting detailed correlations of mottling from basin to basin is risky.

Although detailed correlation of mottling might not be feasible, there are some broader relationships which can be seen. One such relationship is that which exists between dominant color and mottling. When one compares Figure 9 with Figure 10, one can see that the dominantly olive zones and the mottled zones occupy the same relative position in each core. This relationship suggests that even during more moist conditions, water table fluctuations were common. This could be related to the shallowness of the basins, as this would make them more susceptible to minor climatic changes.

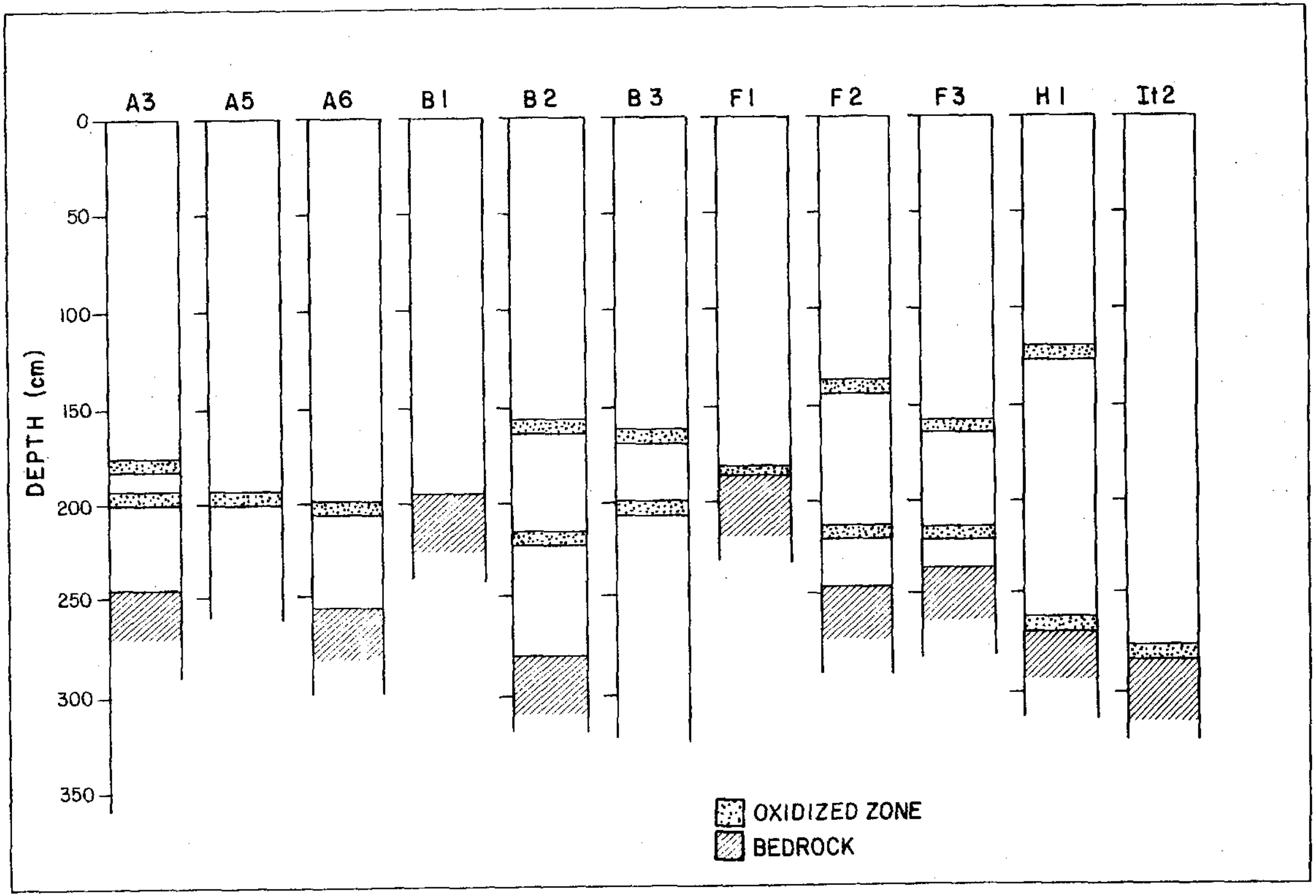
The major divergence from this association is in those cores which are marginal to the basins, such as cores B1 and F1. In these locations the sediment accumulating on the bedrock lacks mottling. The marginal location of these cores places them at higher elevations where water table fluctuations were not as likely to have been a factor as in deeper-water locations. This is consistent with previously presented color information, as these cores exhibit little olive-colored material; therefore they likely represent a drier environment.

Oxidized Zones

A further suggestion of fluctuating moisture conditions is the presence within the mottled horizons of more intensely oxidized zones. The position of these zones is depicted in Figure 11. For the most part, these zones are thin, a few centimetres thick, and in many cases they are an intensification of the mottling. There are, however, zones which exhibit a color different from the mottling, suggesting more intensified oxidizing conditions. One such zone is the upper zone in core B3, which has a reddish tone (Munsell 2.5YR-2.5Y4) quite different from the mottling. As the cores are small in diameter, it is possible that these zones are just larger mottles, the edges of which are not visible. However, in some zones, as the one above, the core separates very easily as if there had been a brief hiatus in basin wetting and sedimentation.

As can be seen from Figure 11, some of the oxidized zones are at roughly correlatable intervals, and there is some indication from cores A3, B2, and B3 that there may have been two or three periods of more intense oxidation. Commonly, the oxidized zones occur where the mottling intensifies in the cores. This intensification of mottling may be an indication of gradual drying conditions, culminating in oxidized zones. This is especially true of cores A5, A6, and B3.

Fig. 11. Positions of oxidized zones in selected cores. Oxidized zones not drawn to scale.


A3
A5
A6
B1
B2
B3
F1
F2
F3
H1
It2
DEPTH (cm)
0
50
100
150
200
250
300
350
OXIDIZED ZONE
BEDROCK

Some of the oxidized zones in those cores which exhibited redder hues and strong brown colors are associated with bedrock surfaces. In some cases these zones, as with cores A6, F2, F3, H1, and trench It2, have helped to identify the interface between the basin sediments and bedrock. These oxidized zones might be indicators of dry conditions on the bedrock sometime prior to deposition of the basin sediments.

Textural Analysis

Grain parameters have been widely used to aid in the interpretation of depositional environments, as factors such as grain size, grain-size distribution, fabric, and others are controlled by hydrodynamic conditions present at the time of deposition (Reineck and Singh, 1980, p. 132).

Based upon field work and laboratory core description, detailed grain size and texture analysis was done on selected cores. Each of the layers identified during the core description process was sampled. Each sample was sieved, pipetted, or analyzed by use of the SediGraph, as previously described in the methodology section.

Grain-Size Distribution

Once the grain-size distribution of a sample is known, a variety of statistical parameters can be calculated. The parameters used in this study are those as defined by Folk (1974): mean, mode, sorting, skewness, and kurtosis. These parameters, as well as the histograms, frequency and cumulative curves used in this study, were generated by the Folk program (Tank, 1984) which uses the weight of the particles in specified phi intervals. The modes of the samples were derived from the frequency curves.

Some authors, such as Folk and Ward (1957), Friedman (1967), and Doeglas (1968), have attempted to relate statistical parameters to depositional environments, but as Reineck and Singh (1980), reveal, they have met with only limited success. There are several reasons for this. First, the grain size and texture of sediments are influenced by the grain size and texture of the source material. If the source material is initially well sorted, sediment derived from it will likely be well sorted, too. Secondly, in environments where fine materials are intermixed with coarser materials, it is impossible, based on granulometric analysis alone, to determine if the fine materials were a part of the original sediments or added later. Third, weathering might add fine materials or cause aggregation of smaller grains, which would alter the resulting grain-size distribution. Analyses dealing only with statistical parameters based on grain-size distribution would not be able to solve these problems. Some of these problems are intensified when one attempts to analyze ancient environments as opposed to sediments from modern environments (Selley, 1978, pp. 6-7).

However, to the extent that grain-size distributions are controlled by hydrodynamic conditions at the site of deposition, information based upon them can be very useful if used in combination with other parameters such as geologic setting, sediment structures, et cetera.

Data generated by grain-size analyses can be presented in a variety of ways. One of the more common is in graphic form such as histograms, frequency curves, or cumulative curves. Graphs of these types provide visual comparisons of data sets, as well as specific information such as median, mode, and values for mean grain size calculation. Folk (1974) suggested that the ideal way to evaluate sets of samples is by comparing the curves visually, as this allows the total character of the samples to be seen. It is, however, difficult to derive from the curves precise information on such factors as degrees of sorting or specific differences in values, especially when large numbers of comparisons need to be made. The basic solution to the problem is to utilize a variety of statistical parameters which describe quantitatively certain features of the curves. These types of data are more easily tabulated and compared, and provide a more precise basis for discussion.

Mean

Observations made during the field work and core description phases of the study indicated that the particle sizes of the sediments were for the most part very fine grained. The sediments in those cores with relatively high percentages of sand and a few pebbles were also of a fine sand size, on the average. Detailed analyses have verified these observations. For example, the mean grain size for all the samples is 6.54ϕ (Table 2). This places the average particle size of these sediments clearly in the middle of the silt range. The means of individual samples range from 2.86ϕ from core A1, located on a basin margin, to 9.28ϕ, from a trench sample, It2, recovered from the center of one of the largest basins studied.

Mode

Further analysis reveals that the average mode, the most frequently occurring particle size, is 4.56ϕ, also within the silt range (Table 3). The overall range of particle size is fairly large, from clay particles to one fragment which measured -5.0ϕ. It should be noted that clasts of pebble size number only in the tens of particles. A few are very large, and their weight causes a shift in the mode to a slightly larger size. If the few particles larger than -1.0ϕ are removed from the calculations, the mode of all the samples moves closer to the sample mean, with a value of 5.22ϕ. When the mode of any specific sample falls within the range of sand-size particles, it rarely falls outside the 2-3ϕ range. The range of modes for specific samples varies from 2.0ϕ to the previously mentioned -5.0ϕ.

TABLE 2: Mean Grain-Size Values With Depth For Selected Cores

Core A1		Core A3		Core A5		Core A7		Core B2		Core F3		Core It2	
Interval (cm)	Mean (ø)	Interval (cm)	Mean (ø)	Interval (cm)	Mean (ø)	Interval (cm)	Mean (ø)	Interval (cm)	Mean (ø)	Interval (cm)	Mean (ø)	Interval (cm)	Mean (ø)
0-51	3.45	0-114	3.38	0-51	4.05	0-51	6.35	0-25	7.89	4-25	8.65	28-142	9.28
51-107	2.86	114-165	4.22	51-81	4.24	51-97	5.18	25-51	8.03	25-51	7.99	142-183	4.96
		165-191	3.64	81-89	3.40			51-76	7.95	51-76	8.33	183-285	7.06
		191-198	8.26	89-132	4.43			76-102	6.63	76-102	8.22	285-287	8.18
		198-203	6.18	132-165	7.75			102-114	5.82	102-117	6.59	287-318	7.98
		203-224	8.26	165-198	7.29			114-135	7.89	117-127	5.56	318-323	3.85
		224-249	6.52	198-206	6.34			135-155	7.01	127-142	5.25	323-335	9.18
		249-267	6.85	206-265	7.62			155-183	8.85	142-154	5.21		
		267-279	7.08					183-216	7.93	154-168	4.56		
								216-229	5.94	168-193	6.44		
								229-249	8.08	193-218	7.96		
								249-279	6.38	218-244	8.75		
								279-305	5.54	244-279	7.96		
Core Mean	3.16	Core Mean	6.04	Core Mean	5.64	Core Mean	5.77	Core Mean	7.23	Core Mean	7.04	Core Mean	7.21

The mean for all samples = 6.54.

TABLE 3: Modal Grain-Size Values With Depth For Selected Cores

Core A1		Core A3		Core A5		Core A7		Core B2		Core F3		Core It2	
Interval (cm)	Mode (ø)	Interval (cm)	Mode (ø)	Interval (cm)	Mode (ø)	Interval (cm)	Mode (ø)	Interval (cm)	Mode (ø)	Interval (cm)	Mode (ø)	Interval (cm)	Mode (ø)
0-51	2.50	0-114	2.00	0-51	3.00	0-51	3.00	0-25	9.00	4-25	10.00	28-142	9.00
51-107	2.50	114-165	2.00	51-81	2.00	51-97	3.00	25-51	2.50	25-51	9.75	142-183	-2.50
		165-191	2.00	81-89	2.00			51-76	9.75	51-76	10.00	183-285	6.00
		191-198	7.00	89-132	2.00			76-102	3.50	76-102	9.25	285-287	-3.50
		198-203	3.00	132-165	5.50			102-114	3.00	102-117	2.50	287-318	7.50
		203-224	10.00	165-198	5.75			114-135	6.00	117-127	2.50	318-323	-5.00
		224-249	2.00	198-206	4.75			135-155	4.00	127-142	2.50	323-335	8.75
		249-267	2.00	206-254	6.00			155-183	6.00	142-154	2.50		
		267-279	4.75					183-216	6.75	154-168	2.50		
								216-229	-3.50	168-193	8.00		
								229-249	6.00	193-218	8.75		
								249-279	6.00	218-244	8.75		
								279-305	3.50	244-279	10.00		
Core Mean	2.50	Core Mean	3.86	Core Mean	3.88	Core Mean	3.00	Core Mean	4.81	Core Mean	6.69	Core Mean	2.89

The mean for all samples = 4.56.

The mode calculations illustrate one of the problems that can occur when performing grain-size analyses; that is, the presence of a few large atypical particles can influence calculated distributions. Such particles, however, cannot be ignored. In some specific samples, the weight of the pebbles results in their being the modal size, where pebbles clearly are not the most frequently occurring particle size. Fortunately, in this study, this situation was not common.

Sorting

Another problem that can be encountered in grain-size analysis is the effect large amounts of fine-grained materials have on sorting values. Fine-grained materials from a variety of depositional environments can be, and characteristically are, poorly sorted (Reineck and Singh, 1980, p. 137; and Friedman and Sanders, 1978, p. 27).

Folk (1974) presented a numerical and descriptive classification for sorting. Sediments which are very well sorted have a value of under 0.35ϕ, whereas values of over 4.0ϕ are indicative of sediments which are extremely poorly sorted. Sediments which generally are best sorted are those with a mean size in the fine-sand range, or 2-3ϕ (Griffiths, 1967). Particles of this size are considerably larger than the mean size of all but one sample from this study found in core A1.

The best sorting attained by natural sediments is about 0.20-0.25ϕ, whereas some glacial till and mud flows have values in the range of 5.0ϕ to 8.0ϕ or even 10.0ϕ. The division between moderate and poor sorting values is 1.0ϕ (Folk, 1974).

Because fine-grained materials are predominant in this study, the calculated sorting values are high. The mean sorting value for all samples is 3.36ϕ which places it nearly in the middle of the very poorly sorted range (Table 4). The lowest sorting value for any specific sample is 1.94ϕ, which is still poorly sorted.

Although the samples in this study are statistically poorly sorted, they are, in terms of geologic application, well sorted. For example, calculations show that only about 6 percent by weight of all the samples analyzed are larger than 2.0ϕ (coarser than fine sand). Trench It2 exposed two layers which contain most of the large particles found. If only the particles from this trench larger than -2.0ϕ are removed from the calculations, the percentage of material larger than 2.0ϕ drops to 2.42 percent, another indication that, although large particles in this study are rare, they can have a noticeable impact on the grain-size distribution of the samples in which they are found.

The pebble-size particles are composed primarily of three types of material: aggregates, concretions, and mudstone fragments. One layer from the trench, containing the largest number of pebbles, is characterized by calcite cementation of particles which has produced aggregates. A

TABLE 4: Sorting Values With Depth For Selected Cores

Core A1		Core A3		Core A5		Core A7		Core B2		Core F3		Core It2	
Interval (cm)	Sorting (ø)	Interval (cm)	Sorting (ø)	Interval (cm)	Sorting (ø)	Interval (cm)	Sorting (ø)	Interval (cm)	Sorting (ø)	Interval (cm)	Sorting (ø)	Interval (cm)	Sorting (ø)
0-51	2.56	0-114	2.20	0-51	2.93	0-51	3.61	0-25	3.90	4-25	3.62	28-142	2.80
51-107	1.96	114-165	3.08	51-81	3.12	51-97	2.80	25-51	4.08	25-51	3.16	142-183	6.25
		165-191	1.94	81-89	2.55			51-76	3.78	51-76	3.79	183-285	2.83
		191-198	3.36	89-132	3.34			76-102	4.06	76-102	3.09	285-287	4.09
		198-203	3.77	132-165	3.42			102-114	4.64	102-117	3.93	287-318	2.56
		203-224	3.15	165-198	3.21			114-135	3.89	117-127	4.02	318-323	5.82
		224-249	3.75	198-206	2.68			135-155	3.67	127-142	3.87	323-335	2.41
		249-267	4.22	206-254	2.89			155-183	3.39	142-154	3.66		
		267-279	2.91					183-216	3.37	154-168	2.99		
								216-229	4.60	168-193	2.81		
								229-249	2.89	193-218	2.60		
								249-279	3.00	218-244	2.77		
								279-305	3.10	244-279	1.59		
Core Mean	3.54	Core Mean	3.15	Core Mean	3.02	Core Mean	3.21	Core Mean	3.72	Core Mean	3.29	Core Mean	3.82

The mean for all samples is 3.36.

more widespread type of pebble is also found in the trench samples and three or four cores, namely ironstone concretions or fragments of ironstone concretions. A third kind of pebble is fragments of bedrock in place.

Skewness

Two other statistical measures which are not as commonly used as mean or mode, or as often discussed as sorting, but which are useful in describing and evaluating curves, are skewness, which measures the degree of asymmetry of curves, and kurtosis, which measures their peakedness. Folk (1974) discussed the classes and ranges of values for skewness, with +1.00 and -1.00 representing absolute mathematical limits. Those curves with a positive skewness have excess fine material and a tail to the right; those with a negative skewness have an excess of coarse material and a tail to the left. Curves with a value of 0.00 are perfectly symmetric, while values approaching ±1.00 represent extreme asymmetry. Few curves have values beyond ±0.80.

The skewness values for samples in this study range from +0.86 to -0.35. The mean value for all the samples is 0.26, fine skewed (Table 5). This is a further indication of the overall fine-grained character of the samples. It should be noted that because the material is, for the most part, fine-grained, some of the curves may be describing variation from "coarse" to "fine" for a sample which contains

TABLE 5: Skewness Values With Depth For Selected Cores

Core A1		Core A3		Core A5		Core A7		Core B2		Core F3		Core It2	
Interval (cm)	Skewness	Interval (cm)	Skewness	Interval (cm)	Skewness	Interval (cm)	Skewness	Interval (cm)	Skewness	Interval (cm)	Skewness	Interval (cm)	Skewness
0-51	0.72	0-114	0.68	0-51	0.67	0-51	0.27	0-25	-0.18	4-25	-0.19	28-142	0.06
51-107	0.67	114-165	0.78	51-81	0.68	51-97	0.37	25-51	-0.18	25-51	-0.35	142-183	-0.12
		165-191	0.59	81-89	0.63			51-76	-0.35	51-76	-0.21	183-285	0.14
		191-198	0.10	89-132	0.71			76-102	0.43	76-102	-0.22	285-287	-0.28
		198-203	0.15	132-165	0.43			102-114	0.54	102-117	0.24	287-318	0.27
		203-224	-0.12	165-198	0.46			114-135	0.06	117-127	0.83	318-323	0.45
		224-249	0.001	198-206	0.29			135-155	0.46	127-142	0.86	323-335	0.18
		249-267	-0.06	206-254	0.34			155-183	-0.05	142-154	0.83		
		267-279	0.005					183-216	0.25	154-168	0.80		
								216-229	0.02	168-193	-0.08		
								229-249	0.42	193-218	0.05		
								249-279	0.48	218-244	0.09		
								279-305	0.80	244-279	-0.25		
Core Mean	0.70	Core Mean	0.24	Core Mean	0.53	Core Mean	0.32	Core Mean	0.21	Core Mean	0.18	Core Mean	0.10

The mean for all samples is 0.26.

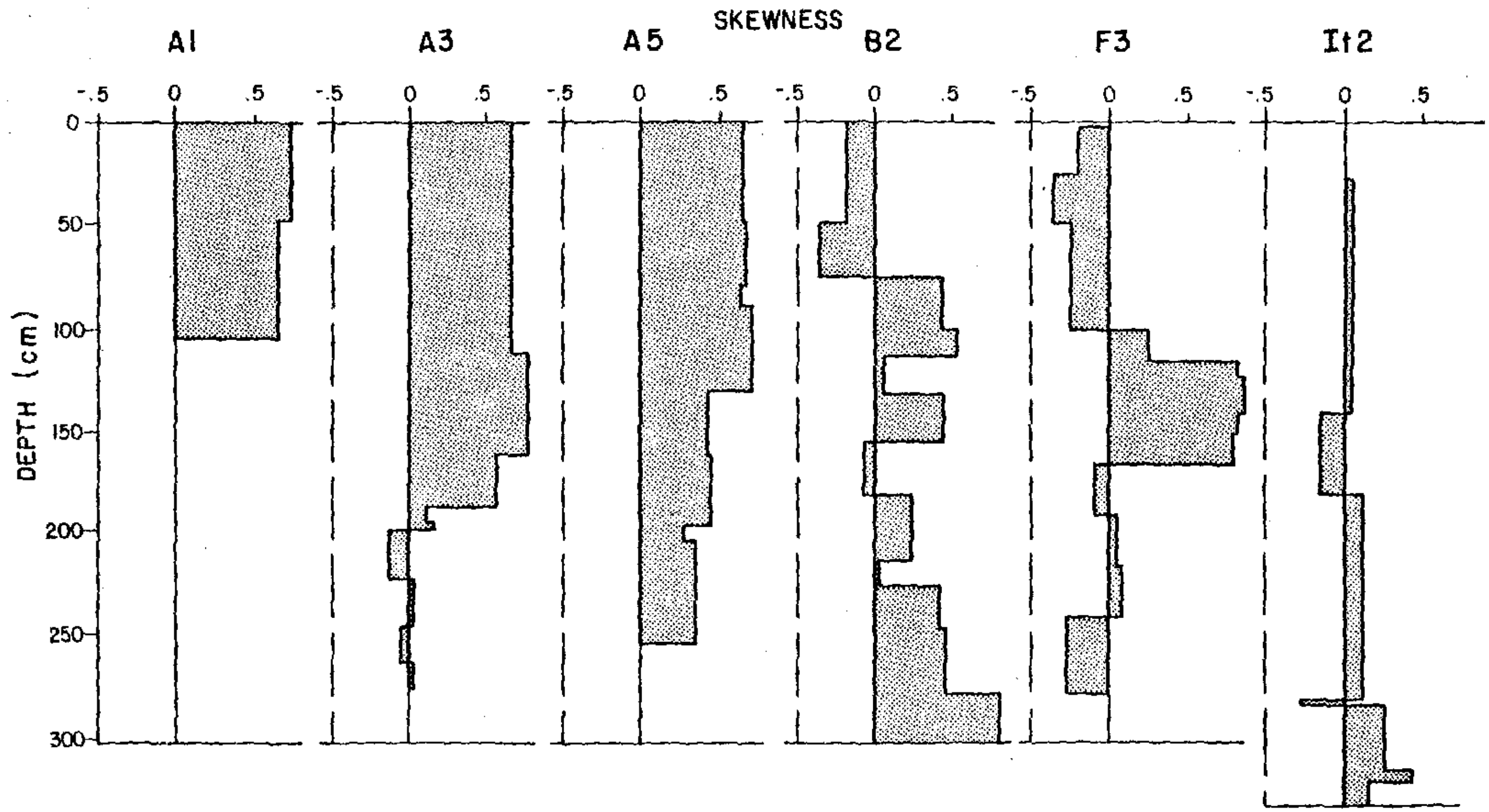
only fine-grained material. In other words, the terms "coarse" and "fine," as used statistically, are relative terms only. Such analysis, therefore, may give variation to the data which is not really significant, geologically.

The numerical skewness values and the verbal limits associated with them, although directly comparable, are not really amenable to visual comparison. To help with this problem, and to avoid attaching too much significance to values from individual samples, a graphic presentation of the skewness data was prepared (Figure 12). In this figure, patterns seen in cores A3 and A5 are quite similar, with a tendency toward a more symmetric, normal distribution with depth. Patterns for B2 and F3 also seem to correspond, with similar variations in positive and negative values. The significance of these patterns and others will be discussed later in this section.

Kurtosis

A normal curve is considered to have a peakedness value of 1.00, representing the ratio between sorting of the tails and central portion of the curve. Those curves described as being leptokurtic, or more peaked, have values >1.00 and are better sorted in the central portion of the curve. Platykurtic, or flatter curves, have values <1.00 and are better sorted in the tails of the curve. The absolute mathematical limits for kurtosis are 0.41 and infinity,

Fig. 12. A graphic presentation of skewness, or the degree of asymmetry of the frequency curves derived from grain-size distributions, for selected cores.


SKEWNESS
A1
A3
A5
B2
F3
It2
-.5
0
.5
DEPTH (cm)
0
50
100
150
200
250
300

but few samples have a value < 0.60 and > 5.0 (Folk, 1974).

The kurtosis values for this study range from 0.26 to 3.14, with a mean value of 0.98, approximating a normal curve (Table 6). A graphic presentation of the kurtosis data is presented in Figure 13. The patterns again show similarities between cores A3 and A5, as well as B2 and F3. The implications of these comparisons will also be presented in the following discussion.

Grain Size Parameter Correlations

Even though the sediments in this study are fine grained and poorly sorted, there are textural variations, many necessarily subtle due to the dominance of fine-grained material, which indicate that these sediments share some common depositional history. For example, there is a significant difference in particle sizes between samples from cores outside the basins and samples from within the basins. Samples from outside the basins have a larger mean grain size than do those from within basins. Samples from core A1, from the western margin of Basin A, have a mean grain size of 3.16ϕ, whereas the mean grain sizes from cores A3 and A4, from within the basin, are 6.04ϕ and 5.64ϕ (Table 2).

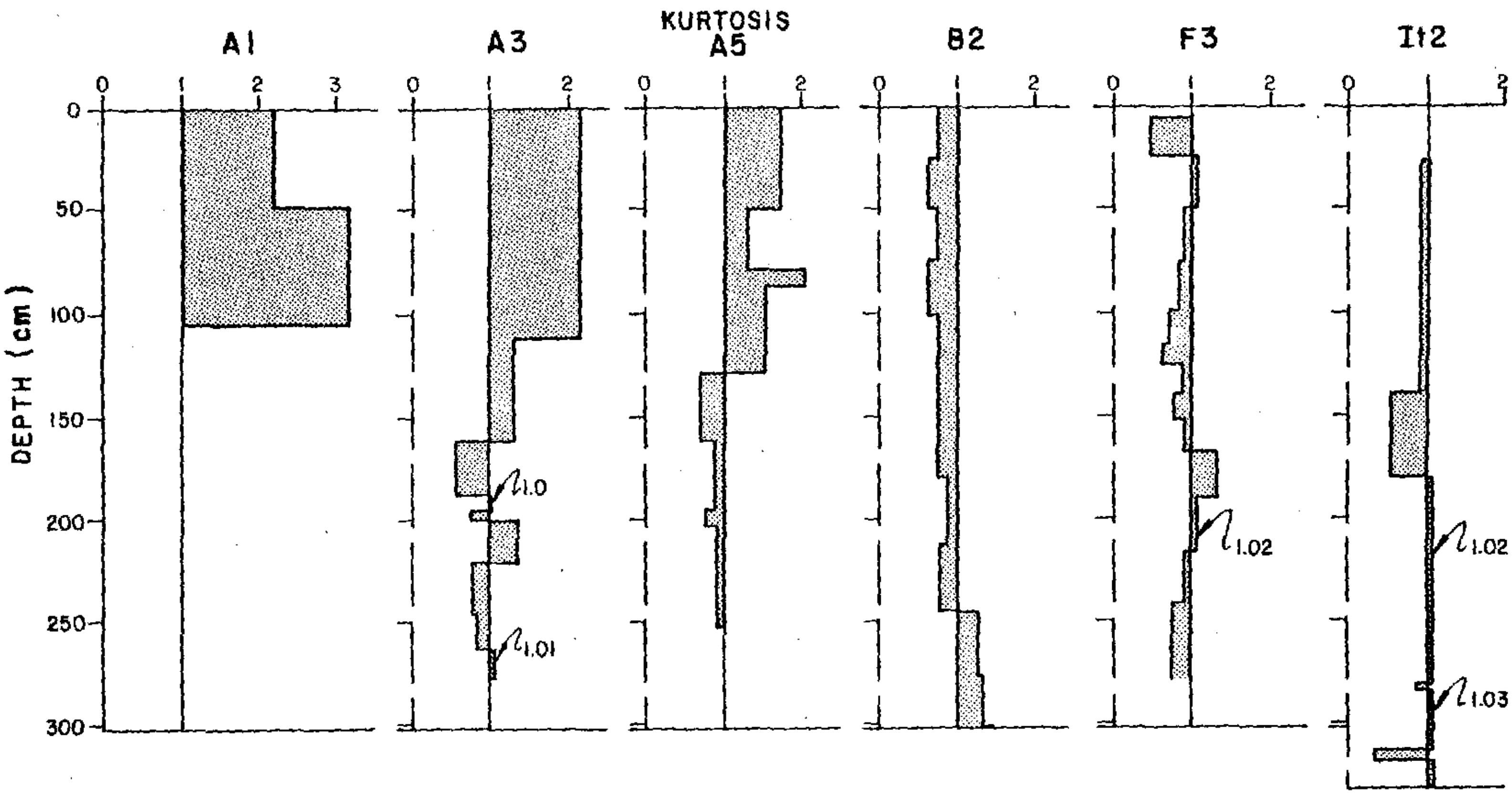
The dominance of sand and a larger mean particle size in cores from similar marginal locations is obvious. Samples from core F1, marginal to Basin F, contain 71.5 percent sand and larger particles on the average, with a

TABLE 6: Kurtosis Values With Depth For Selected Cores

Core A1 Interval (cm)	Core A1 Kurtosis	Core A3 Interval (cm)	Core A3 Kurtosis	Core A5 Interval (cm)	Core A5 Kurtosis	Core A7 Interval (cm)	Core A7 Kurtosis	Core B2 Interval (cm)	Core B2 Kurtosis	Core F3 Interval (cm)	Core F3 Kurtosis	Core It2 Interval (cm)	Core It2 Kurtosis
0-51	2.16	0-114	2.18	0-51	1.66	0-51	0.81	0-25	0.78	4-25	0.43	28-142	0.91
51-107	3.14	114-165	1.23	51-81	1.28	51-97	0.61	25-51	0.63	25-51	1.23	142-183	0.52
		165-191	0.56	81-89	2.04			51-76	0.73	51-76	0.90	183-285	1.02
		191-198	1.00	89-132	1.51			76-102	0.60	76-102	0.83	285-287	0.83
		198-203	0.70	132-165	0.64			102-114	0.71	102-117	0.63	287-318	1.03
		203-224	1.39	165-198	0.82			114-135	0.70	117-127	0.60	318-323	0.26
		224-249	0.72	198-206	0.74			135-155	0.68	127-142	0.92	323-335	1.11
		249-267	0.74	206-254	0.91			155-183	0.69	142-154	0.73		
		267-279	1.01					183-216	0.81	154-168	0.93		
								216-229	0.75	168-193	1.31		
								229-249	0.76	193-218	1.02		
								249-279	1.22	218-244	0.89		
								279-305	1.29	244-279	0.76		
Core Mean	2.65	Core Mean	1.06	Core Mean	1.20	Core Mean	0.71	Core Mean	0.80	Core Mean	0.86	Core Mean	0.81

The mean for all samples is 0.98.

Fig. 13. A graphic presentation of kurtosis, or the peakedness of the frequency curves derived from grain-size distributions, for selected cores.


KURTOSIS
A1
A3
A5
B2
F3
It2
DEPTH (cm)
0
50
100
150
200
250
300
0
1
2
3
1.0
1.01
1.02
1.03

range from 53.6 percent to 80.4 percent sand from individual layer samples. It is likely that a relatively large mean grain size would be shown if detailed analyses had been done on these samples. Core F3 from the central part of this same basin contains an average of 30.9 percent sand with a range of individual samples from 1.56 percent to 70.4 percent. The detailed texture analyses for this core reveal a mean grain size of 7.04ϕ (Table 2).

Comparison of mean grain sizes of central-basin-location cores from other basins shows that the sediments in these locations are also very fine grained, with a value of 7.23ϕ for Basin B and 7.21ϕ for Basin I. The latter mean is from the largest of the basins studied, the one which was drained for farming. It also contains some of the largest concentrations of carbonate-cemented pebble-size aggregates, as in the carbonate layer described previously. Despite this, the mean size is still very fine grained, nearly clay size.

Core H1, from the center of Basin H, also contains large amounts of fine-grained sediment. A complete analysis of the sand and larger size material was not done due to the small percentages of these particles in the samples, but sand/silt/clay ratio calculations show that 90 percent and more of all the sediments in this core is silt- and clay-size particles. The clay percentages of individual samples range from 35.8 percent to 89.9 percent. Clearly, a detailed analysis would yield a very-fine mean grain size for this core, one which would be comparable to the fine-grained sediment in other central-basin locations.

Although detailed grain-size analysis was not done on core A6 from Basin A, it was described in detail. The samples from this core are composed primarily of clay-size particles with some admixture of sand and silt near the surface. The major components are silt and clay, consistent with the other central-basin locations.

Comparisons of two other statistical measures also indicate some variations which suggest that the sediments in the study basins share a similar history. Variations in the skewness and kurtosis patterns seen in Figures 12 and 13 present some comparisons which were alluded to previously in this section. For example, the skewness patterns of samples taken near the surface from cores A3 and A5 are both positive and to almost the same degree, 0.65 (Figure 12). With depth, there is a tendency toward more symmetric curves. Both of these cores are from relatively near-shore locations and should thus reflect similar depositional conditions. Core A1 is marginal to the basin and reflects a pattern somewhat similar to A3 and A5 throughout the length of the core. But the loose sand at the surface prevented a deeper core from being collected, as the drill anchors would not hold. A Shelby tube core, A2, extracted with the Mobile Drill Rig from this same location, showed that the sand in core A1 continues relatively unchanged to bedrock. The similarity of pattern for core A1 and the upper portions of cores A3 and A5 suggests a similar depositional history or environment.

The skewness patterns from cores B2 and F3 also exhibit some noticeable similarities, with shifts from positive to negative skewness occurring at corresponding depth in the cores (Figure 12). These patterns suggest a similar history for cores extracted from the centers of basins located some 24 km apart. The graph of another central-basin location, It2, appears to be quite different, although some similarities to the graphs of cores B2 and F3 are apparent. The major reason for this difference is the sampling interval. The samples were from a trench, and only the major units were sampled. Therefore, any minor changes which might have been present were not specifically sampled but were included in a larger sample. The important comparison is the mean skewness value of 0.10 for these trench samples; this value compares well with the 0.18 for core F3 and the 0.21 for core B2 (Table 5).

Values approaching symmetry, or 0.00, appear to be the norm for central-basin locations, as opposed to a value of 0.70 from core A1, a marginal core. Cores A3 and A5, located between the basin edge and basin center, have mean skewness values of 0.24 and 0.53, which are intermediate to the skewness values from marginal and central-basin locations and reflect their intermediate geographic location.

The kurtosis graphs exhibit location and depth correlations which are quite similar to those seen in the skewness patterns. Cores A3 and A5 exhibit similar patterns; this again indicates similar near-shore environments of deposition (Figure 13). Near the surface, the values indicate more peaked curves with a change to less peaked curves at depth. This change occurs at similar depths in the cores. On the average the curves at depth more nearly approximate the peakedness of the normal curve.

Cores B2 and F3, as well as the trench samples from It2, all central-basin locations, exhibit similar patterns. The major feature is that these cores more nearly approximate the peakedness of the normal curve throughout their length. Core A1, the marginal core, simply exhibits a greater peakedness than the other cores.

The mean kurtosis values for these cores illustrate the same basic gradation within the basin, as did the skewness values. Core A1, the marginal core, has a value of +2.65, whereas the central-basin locations of samples from B2, F3, and It2 have values of 0.80, 0.86, and 0.81, respectively (Table 6). Cores A3 and A5, with values of 1.06 and 1.20, are again intermediate in value and location.

It seems, then, that although the sediments are, in large part, fine grained, there are size variations from core to core, and from basin to basin, which indicate that the sediments share some similar and correlatable depositional history.

Sand/Silt/Clay

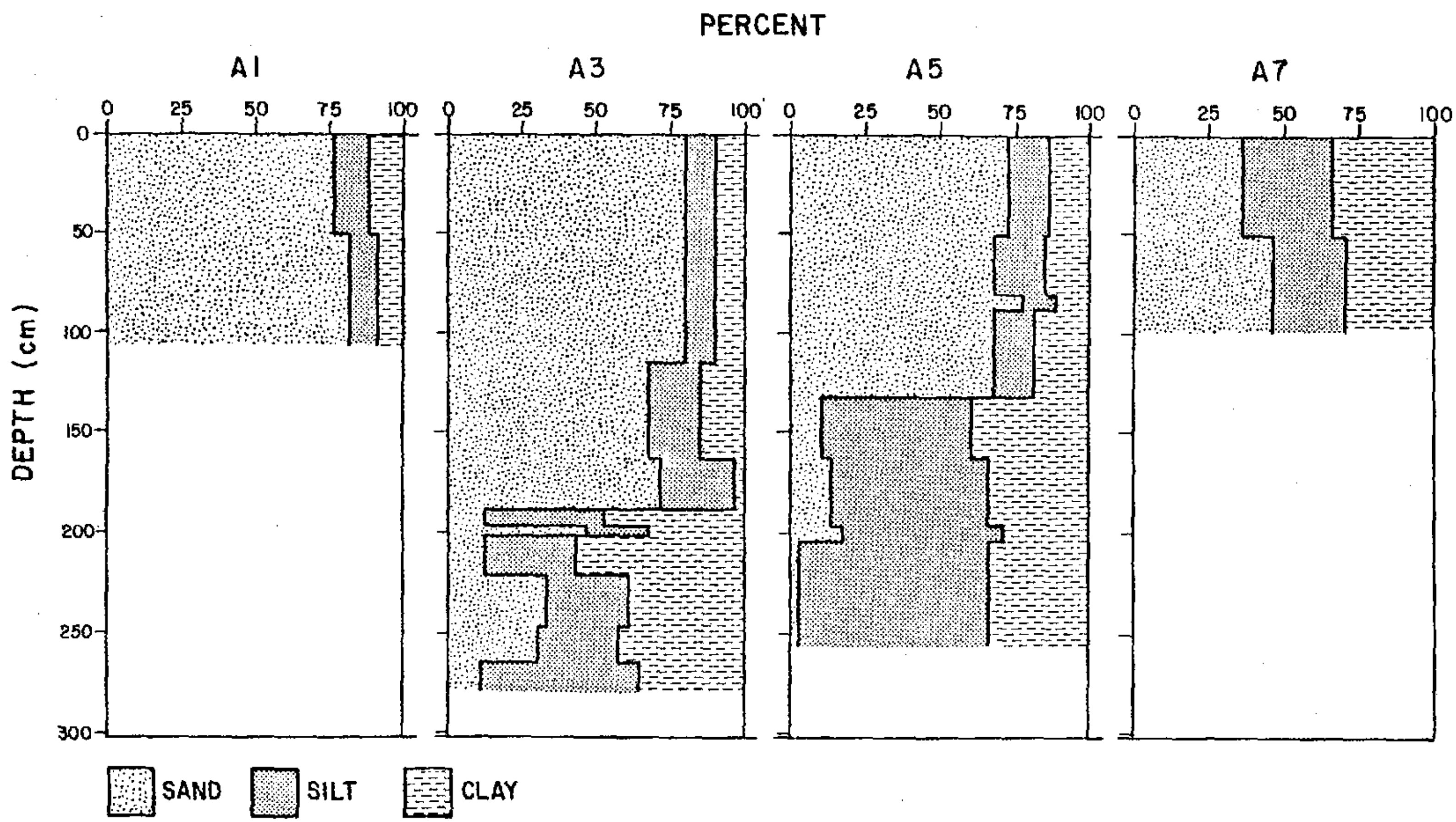
The grain size analysis just discussed has shown that the sediments deposited in the basins are typically fine grained. Despite this, there are important variations in the amounts of sand, silt, and clay from sample to sample, and these relationships are an important part of this study. They provide a more visual and geologically useful examination of the sediments. Appendix III contains the basic sand, silt, and clay percentages from selected cores. The data were used to construct Figures 14 and 15, which graphically portray the variations at depth. In this study the symbol S/S/C will be used when the terms sand, silt, and clay percentage or ratio are used in the text.

Intra-basinal Transect Comparisons

Figure 14 illustrates the S/S/C of four cores from basin A. As can be seen in Figure 14, these cores were from an E-W transect of the basin, with cores A1 and A7 from the margins, and A3 and A5 from within the basin. Taken together, they provide correlatable profiles of the sediments in this basin.

Core A3 was retrieved from a probable shoreline

Fig. 14. Variation with depth of percentages of sand-, silt-, and clay-size sediments of samples from four basin A cores. See Fig. 4 for their relative locations.


PERCENT
A1
A3
A5
A7
0
25
50
75
100
DEPTH (cm)
0
50
100
150
200
250
300
SAND
SILT
CLAY

location, and exhibits the same S/S/C near the surface as core A1, a short distance away. This S/S/C continues to 191 cm deep, where the sand percentage drops to about 25 percent through the rest of the core, with a marked increase in the silt and clay percentages in some layers. The change with depth in the S/S/C is even more pronounced in core A5, although at a higher level in the core. Core A5 was from a former deeper-water site in the basin. Core A7, from the eastern margin of the basin, exhibits a slightly different profile from that of core A1; the sand content is lower, with a resulting increase in both silt and clay.

The sequence shown by cores A3 and A5 (Figure 14) indicates a major shift in the depositional environment within this basin at some time in the past. At 191 cm deep in core A3 and 127 cm in core A5, there is more sand, which suggests that this basin was much drier during this period, and sand particles could be moved by the wind farther into the basin. There are several reasons for the depth variation in these cores, located fairly close to each other. One is that core A3 represents a shoreline or near-shore location where sand could be mixed into the sediments in larger amounts over a longer time than in the deeper-water location of core A5. It is also possible that slope wash has contributed to the increased sand content in core A3. Another factor which may be involved is that core A5 was taken from a slightly lower topographic location. A slight readjustment of the profiles to accommodate this difference brings about a closer match. Still another possibility is that sedimentation, continuing at a faster rate in the shoreline position, could produce a thicker layer.

The S/S/C in the upper 114 cm of core A3 is nearly identical to core A1, whereas the upper 51 cm of core A5 shows a slight decrease in sand and a corresponding increase in silt and clay. These relationships presumably reflect the effect of distance from the source and the sorting effect of wind and water over a short distance.

The S/S/C of cores A3 and A5 also contain one or two other features which merit attention. Core A3 exhibits more abundant, and certainly sharper, fluctuations than A5. It should be expected, however, that a shoreline location would experience more fluctuations in the depositional environment with rising and lowering water levels than a deeper water location. In core A5 the fluctuations are fewer and less distinct.

Although both are marginal, cores A1 and A7 exhibit variations in S/S/C. Core A1 contains a very high percentage of sand, about 78 percent, whereas core A7 is composed of more nearly equal percentages of sand, silt, and clay, especially near the surface. Possibly, as sand was transported by wind from west to east across the basin, it tended to become trapped, especially when the basin contained standing water, or at least was moist. Finer sediment such as silt and clay, once airborne, would be transported across the basin. Also, during drier periods, transportation of silt and clay from within the basin could contribute to a concentration of these particles along the eastern margin of the basin.

Core A6, as described in Appendix I, helps to substantiate this idea. This core is from the deepest part of basin A and should represent the site of deepest water. It is composed of clay or silty clay throughout most of its length. The upper 31 to 38 cm is silty clay, and the zone from 38 to 97 cm is a silt with clay and some sand. The rest of the core is clay with a small but variable silt fraction. The location of this core east of A3 and A5 indicates that there is a change from large amounts of sand in the cores from west to east across the basin to a higher percentage of silt and clay toward the east. This basin is in Slope County just south of West Rainy Butte. A transect across basin F south of Teepee Buttes in Hettinger County, approximately 32 km from basin A, was chosen for comparison. The cores from this basin were all extracted with the soil probe: Core F1, from the western margin: F2, from a shoreline or near-shore location; and F3, from a deeper-water or central-basin location. These compare with cores A1, A3, and A6 from basin A. Although only one of the cores from this basin was studied in detail, the core descriptions

(Appendix I) reveal that the same basic sedimentation history is present.

Core F1, extracted from the western margin, has basically the same texture as core A1. Near the surface, it has silty sand, with the silt fraction decreasing with depth. Core F2, extracted, as was core A3, from a shoreline or nearshore location, exhibits the same basic texture as core A3: sand is a common component through the length of the core, with varying amounts of silt and clay. Although core F1 was not taken as close to the shoreline as was core A3, it is close enough to be influenced by it. Movement of sand by wind and slope wash to this location could explain the relatively high sand percentage.

The configuration of basin F also has an effect on the sediments of core F2. Because it is a steeper-sided basin than the other basins studied, the steeper slopes would provide more slope wash, especially during periods of lower water levels. The one basic difference between cores A3 and F2 is the presence of more clay in F2. This can be explained by the basin configuration as well, for there would be deeper water closer to shore in a steep-sided basin.

Core F3 represents the deepest-water or central location for this basin. As would be expected, this core has a much higher percentage of clay throughout its length, much as core A6 does. At depth and near the surface core F3 is predominantly silt and clay. From 102 to 168 cm deep, there is a noticeable layer of sand. This layer also corresponds with the particle size increase in core A6 from 38 to 97 cm deep.

Basin B (Figure 4) also produced a fairly complete transect. Core B1, from a marginal location, contains primarily sand with a slight upward increase in silt content. This relationship is consistent with marginal cores A1, A2, and F1, discussed previously.

Core B2 contains a sequence of textures which is similar to those already discussed for cores A6 and F3, both central-basin or deeper-water locations. Its intermediate position between cores B1 and B3 might suggest a shoreline or near-shore location, but close by, small trees and shrubs are growing, an indication that this location is rarely, if ever, cultivated. Its position probably represents the wettest location in the basin because it is at the lowest elevation. Throughout the core, silt and clay dominate, with the layer of sand appearing here between 76 and 114 cm deep, a consistent pattern with cores A6 and F3.

Core B3 contains a relatively large amount of sand throughout its length, but its location fairly close to the northwestern basin margin could provide a nearby source of sand. Core F2, from Basin F, presents a very similar profile and suggests a near-shore location for core F2 as well.

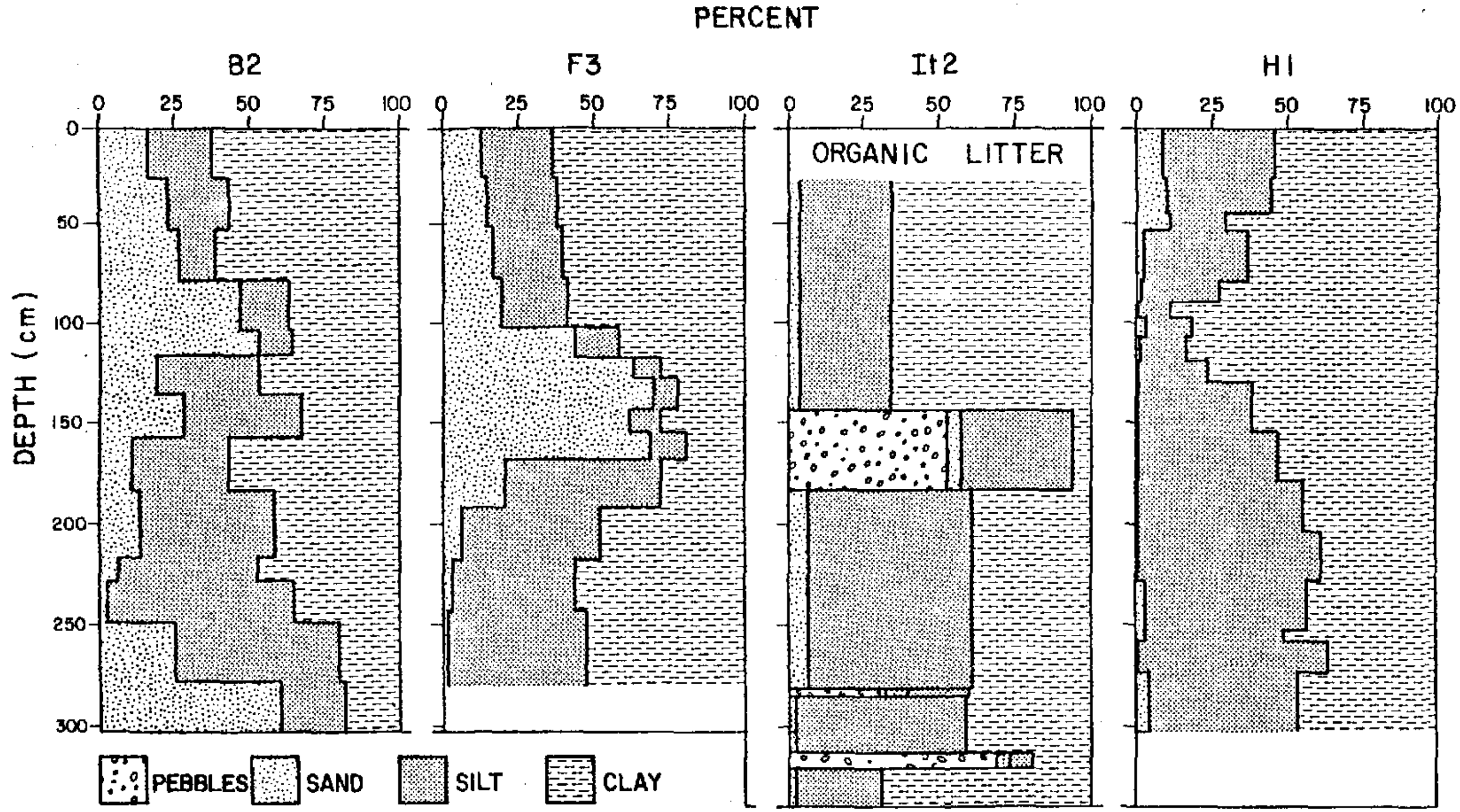
The transects across basins A, B, and F, although different in some respects, provide data which suggest that the sediments in and around the basins have shared a similar history. The profiles indicate the possibility of a moist climatic period followed by a drier period. There is also evidence in these basins which indicates that from basin to basin, similar locations contain similar depositional environments.

Central-Basin or Deepest-Water Core Comparisons

Figure 15 presents the S/S/C of sediments extracted from the same depositional environment at or near the centers or the deepest portions of their basins. The samples from three of the sites were extracted using the soil probe, whereas the samples from the fourth, It2, were from a trench. The graph for It2 appears to present a much simpler picture than the other three. The reason for this is that only layers which were most obvious during field inspection were sampled, and minor layers may have been combined. They do, however, present a sequence of deposition which is similar to the sequences found in the other three sites. Cores B2 and F3 have been referred to briefly before, whereas data from It2 and core H1 are presented for the first time. The S/S/C are the result of detailed analyses of these samples.

There are a number of points of comparison which can be made on the S/S/C of these cores. For example, the upper portions of these graphs, from the surface down to 76 cm in

Fig. 15. Variations with depth of percentages of pebble-, sand-, silt-, and clay-size sediments of samples from four central or deepest-water locations from basins B, F, I, and H. See Figs. 4, 5, and 6 for their relative location.



PERCENT
B2
F3
It2
H1
0
25
50
75
100
DEPTH (cm)
0
50
100
150
200
250
300
ORGANIC LITTER
PEBBLES
SAND
SILT
CLAY

B2, 102 cm in F3, 143 cm in It2, and 76 cm in H1, all exhibit S/S/C which are relatively stable with depth. Although there are minor shifts, the silt contents of each of them is about 25 percent, and the amounts of sand and clay are quite similar. The sand and clay amounts are most similar when comparing B2 with F3, or It2 with H1.

The next major point of comparison is a layer in each of the cores which marks a major shift in particle size. In cores B2 and F3, this change is related primarily to an increase in the sand percentage to approximately 50 percent in B2 and 65 percent in F3. In core B2 this layer is from 76 to 114 cm deep. In core F3 this same layer is found from 102 to 168 cm below the surface. The samples from It2 also increase in particle size through this layer, but they vary from those of cores B2 and F3 in that over 50 percent of this layer has particles larger than sand size. The reason for this greater particle size is cementation of grains by calcium carbonate. For this reason, the actual percentages of individual sand, silt, and clay-size particles were not determined. In the trench It2, the layer is from 142 to 183 cm deep, and in core H1, the comparable layer is 76 to 127 cm deep.

Along with an increase in sand-size and larger particles in these intervals there is a decrease in silt-size particles evident in all the cores. In the trench the individual particle sizes are masked by cementation, and this silt decrease is not easily documented. One core exhibits a major shift in particle size which is different from the others. In the interval between 76 to 127 cm deep from core H1 a decrease in silt-size particles is seen, but the corresponding increase in sand and larger particles is absent.

There are a number of possible explanations for these shifts in particle size as well as the anomalous change in core H1. Some of these explanations are most likely related to a change in climate. The graphs for B2 and F3 reflect a trend toward slightly drier conditions as the sand content increases gradually upward. As the environment becomes drier, sand is more easily entrained by the wind and consequently moved farther into these central-basin locations. The presence of large amounts of carbonate-cemented aggregates in It2 also reflects a drier climate regime. This drying trend culminates in the abrupt change at 114 cm in B2, 167 cm in F3, and correspondingly at 183 cm in It2. During this drier period, erosion as well as deposition is likely. A widespread period of erosion and transportation of material could help to explain this abrupt change in particle size.

Other possibilities which help explain the size changes are related to geographic aspects of the basins. The samples from basins H and I, for example, contain very little sand. The most obvious answer is that these basins might not have had as much sand present on their margins, and even though the environment was drying, not much sand was available to be moved. Another possibility with these two basins is related to their size. Both are large basins. The samples were taken from central basin locations, which, in these basins, were a long distance from the northwestern margins, the most likely source of sand. At such distances silt- and clay-size particles should and do dominate. Erosion could help explain the decrease in silt in core H1 during this time interval as well. With no large sources of sand or with the source, the northwestern margin of the basin, farther away, removal of silt during this erosive phase might have reduced the amounts of silt relative to the clay, as silt-size particles would possibly be more easily eroded (Bagnold, 1941).

Statistical Correlation and Levels of Significance

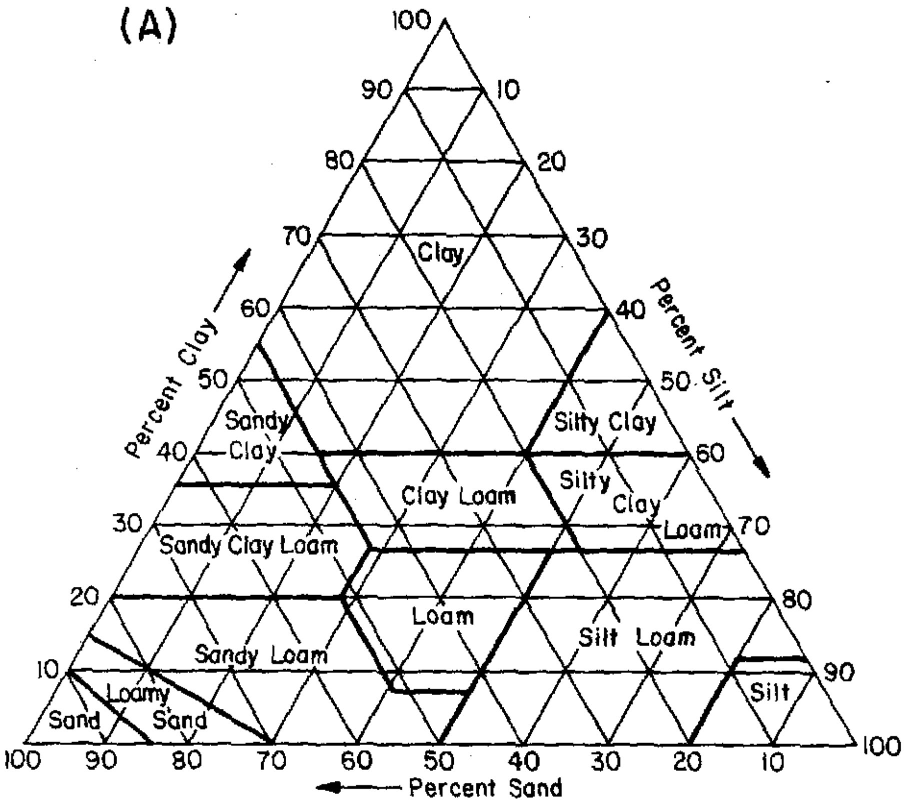
As seen in the previous paragraphs, visual correlation of S/S/C provided valuable information for interpreting changing depositional environments in the basins. Sediment profiles like those in cores H1 and F3 can be interpreted as resulting from the same sequence of environmental changes although they appear to be quite different.

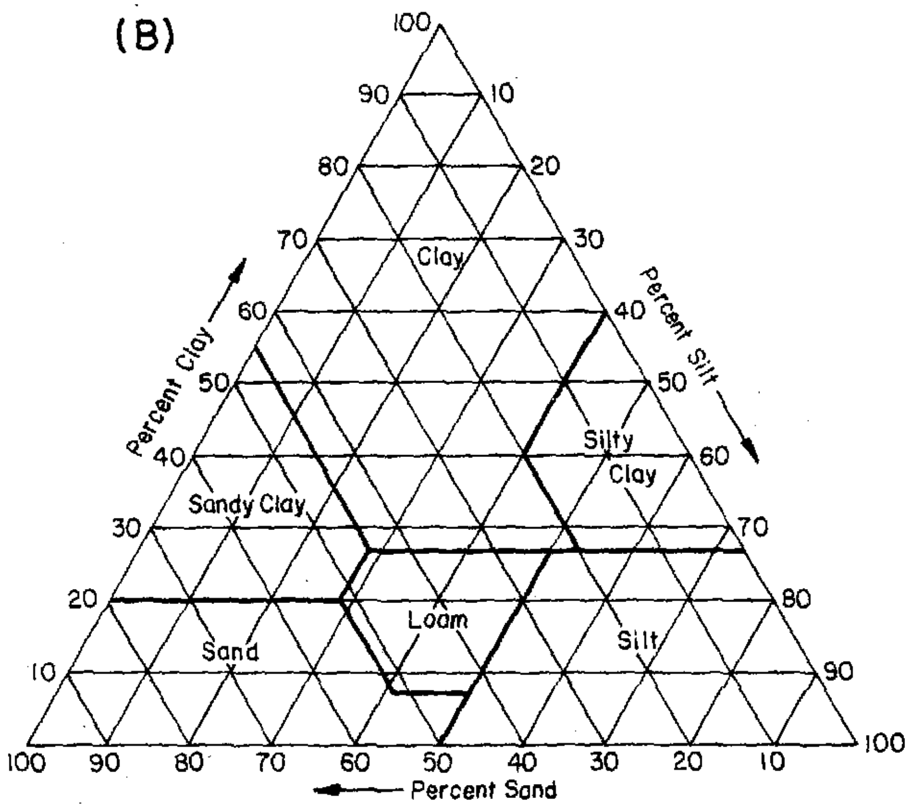
The possibility exists, however, that a comparison is being made between two random sequences of data and the fit is coincidental. To deal with this problem, statistical techniques have been devised which test the probability that correlation of two sets of data is non-random; that is, the observations contain evidence of a trend or pattern. The cross-association technique, outlined in the methodology section, is appropriate for this. In order to make such comparisons of the textures of the layers identified in these cores, specific texture groups needed to be determined.

The texture groups identified in the core descriptions could be used. These groups, although subjectively accurate, may contain some personal interpretation bias and might not provide the consistency necessary to establish specific limits for textural classes, especially in sediments which contain such large percentages of similar fine-grained material. To remove this bias and provide more internal consistency, the textural groups were determined by plotting measured amounts of sand, silt, and clay on a textural triangle. The triangle used (Figure 16) was modified from the standard, as defined by the United States Department of Agriculture (Soil Survey Staff, 1951). The number of texture classes was reduced from 12 to 6, a more appropriate number for use with the cross-association technique.

To determine critical levels of significance (Appendix IV), the cross-association technique, as discussed in the methodology section, utilizes a X^2 test. For this study, unless otherwise stated, a significance level of 5 percent with one degree of freedom was used. These limits have a critical

Fig. 16. (A) The textural triangle as used by the Soil Survey Staff of the United States Department of Agriculture. (B) The modification of the Soil Survey Staff textural trinagle used in this study.


(A)
Percent Clay
Percent Silt
Percent Sand
Clay
Sandy Clay
Silty Clay
Clay Loam
Silty Clay Loam
Sandy Clay Loam
Loam
Silt Loam
Sandy Loam
Loamy Sand
Sand
Silt


(B)
Percent Clay
Percent Silt
Percent Sand
Clay
Silty Clay
Sandy Clay
Loam
Sand
Silt

X^2 value of 3.84. This means that any value which is higher than 3.84 is significant and provides a correlation which is non-random. For example, when cores A3 and A5, two intra-basinal cores, from a shoreline and a slightly deeper-water location, are compared, a X^2 value of 6.18 ($p<0.05$) is derived. This value is significant and provides a correlation which is non-random. This is an expected correlation, as the cores are from environmentally adjacent locations in the same basin. It should be noted that the entire lengths of both cores are involved in the comparison.

Another possible match ought to be a slightly deeper-water core and a deepest-water core, as they share a somewhat similar environmental situation. Comparing cores A5 and H1 produces a X^2 value of 6.22 ($p<0.05$), which provides a significant match. There are two important facts involved in this comparison. First, this match involves the entire length of core A5 but only the 51-224 cm of core H1. The difference is the loss of the near-surface portion of H1, which is composed of sediments postulated to have formed during a return to more moist conditions in the basin. This may not be seen in core A5, a shallower water core, if the rising water levels fell short of this higher topographic location. Secondly, this match involves cores from basins which are 63 km apart. A match this good from basins this far apart suggests that the depositional histories of these basins are related.

A similar deeper-water, deepest-water locational comparison of cores A5 and F3 produces a X^2 value of 2.83 ($p<0.10$). This comparison matches the upper 206 cm of core A5 with the segment of core F3 from 76-292 cm. As with the match of cores A5 and H1, this includes basically the deeper zone of moist conditions and the overlying sand layer, and not the sediments resulting from a return to moist conditions seen in the deepest-water locations. This is the same association seen in the match of A5 and H1, but with the slightly lower significance level. The difference in basin configuration could account for this.

As might be expected, the poorest matches are found when comparing shoreline positions with deepest-water locations, as these locations involve the two most dissimilar environments. Significant matches are found, but they involve only limited core segments.

The comparisons or correlations which are most likely to produce the best matches are those associated with central-basin or deepest-water locations. They are the most likely to produce conditions which from basin to basin will be stable through time; they will not be as susceptible to minor climatic variation. There should be fewer and less marked fluctuations in these sediments, in contrast to the shallower water locations which are more likely to be influenced by climatic fluctuations.

The most significant correlation was from a comparison of core B2 with core F3, two central-basin locations. A X^2 value of 12.43 ($p<0.01$) was derived when the top 249 cm of core B2 were matched with the segment from 76-279 cm of core F3, which is nearly that core's entire length.

A comparison of cores B2 and H1 also exhibits a high level of significance, 6.76 ($p<0.01$) when comparing the upper 330 cm of core B2 with the 51-305 cm segment from core H1. Central basin cores F3 and H1 provide the poorest correlation in this series, but one which is still significant, with a value of 3.05 ($p<0.10$). Some facet of basin configuration could account for this. Core F3, although the deepest-water location, is much closer to the northwestern basin margin, and consequently contains a higher percentage of sand. This percentage is especially high in the level where the previously discussed major particle size shift occurs.

Although these statistical correlations do not by themselves constitute conclusive proof, they do help verify the proposed environmental changes which have been outlined.

Mineralogy

Bulk Mineralogy

The analyses of the sediments reveal a fairly simple mineral assemblage. The components are: quartz, feldspar, calcite, mica, montmorillonite, kaolinite, and chlorite. The dominant material in the non-clay fraction is quartz;

montmorillonite is the most common clay mineral. Another important component, present in all the samples to some degree, but not evident on the x-ray traces, is lignite. The bedrock in the area is the Sentinel Butte Formation, which contains significant amounts of lignite. This is reflected in subsequently reworked sediments.

Peak-height intensities, tabulated in Appendix V, are used for determining trends or patterns in the amounts of various minerals, and for comparison and correlation of these trends and patterns. As previously stated in the methodology section, it makes little difference whether absolute intensities or calculated mineral percentages are used for this purpose. To illustrate this point, Figure 17 contains graphs which compare the variations in quartz percentage and peak-height intensities of quartz for core A4. As can be seen, the magnitude of the changes is not exact, but the relative changes and overall pattern are fairly consistent.

<u>Quartz</u>

As already stated, the dominant mineral in all the samples is quartz. This is not unexpected, as quartz is resistant to weathering and stable in a wide variety of environments. Figure 18 illustrates quartz percentages with depth in three cores and a trench. The amounts vary from approximately 10 percent to 35 percent, with an average of 20 percent to 25 percent. There are a number of comparisons

Fig. 17. A comparison of calculated quartz percentages and peak-height intensities derived from x-ray diffractograms, for a selected core. See Fig. 4 for location.

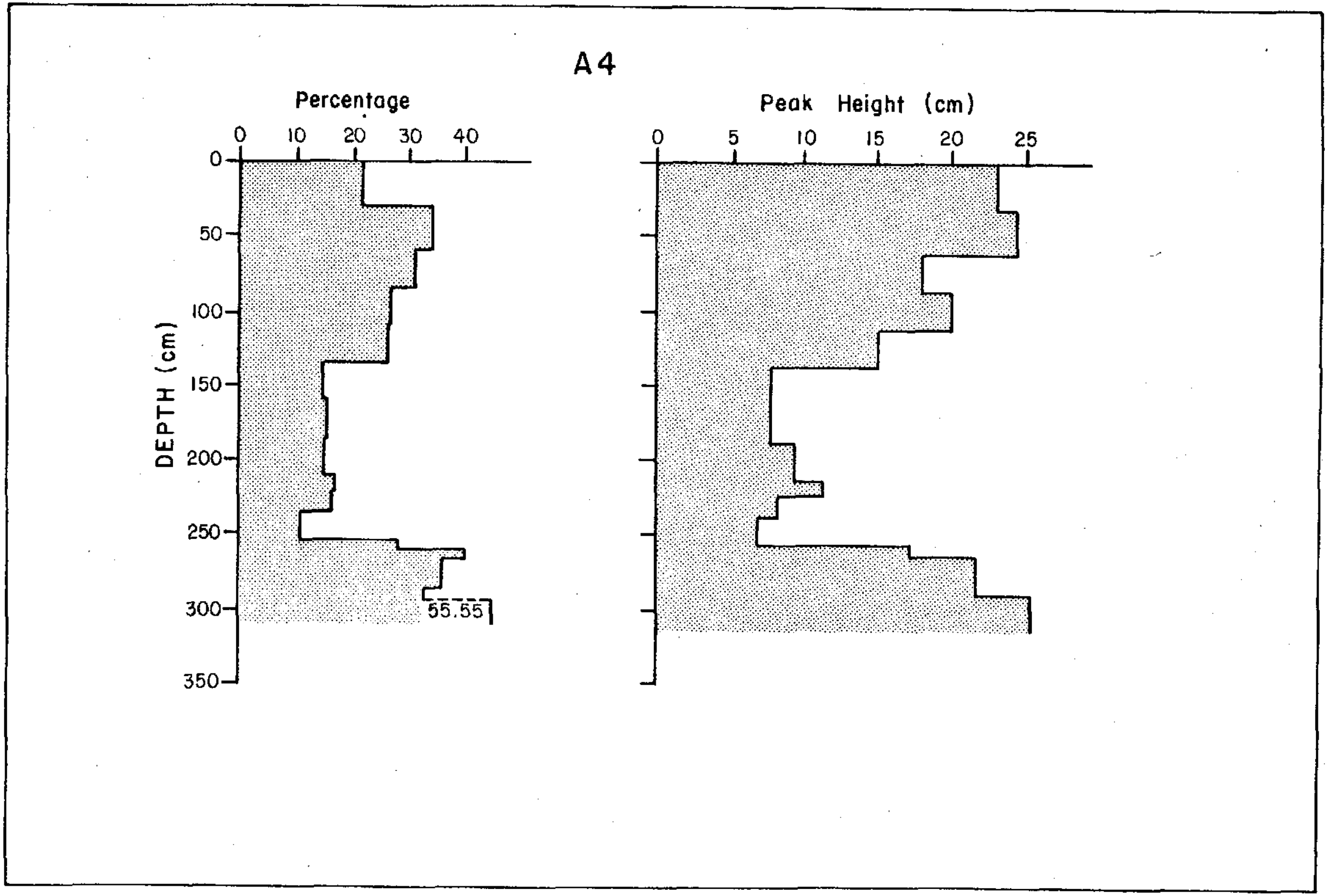
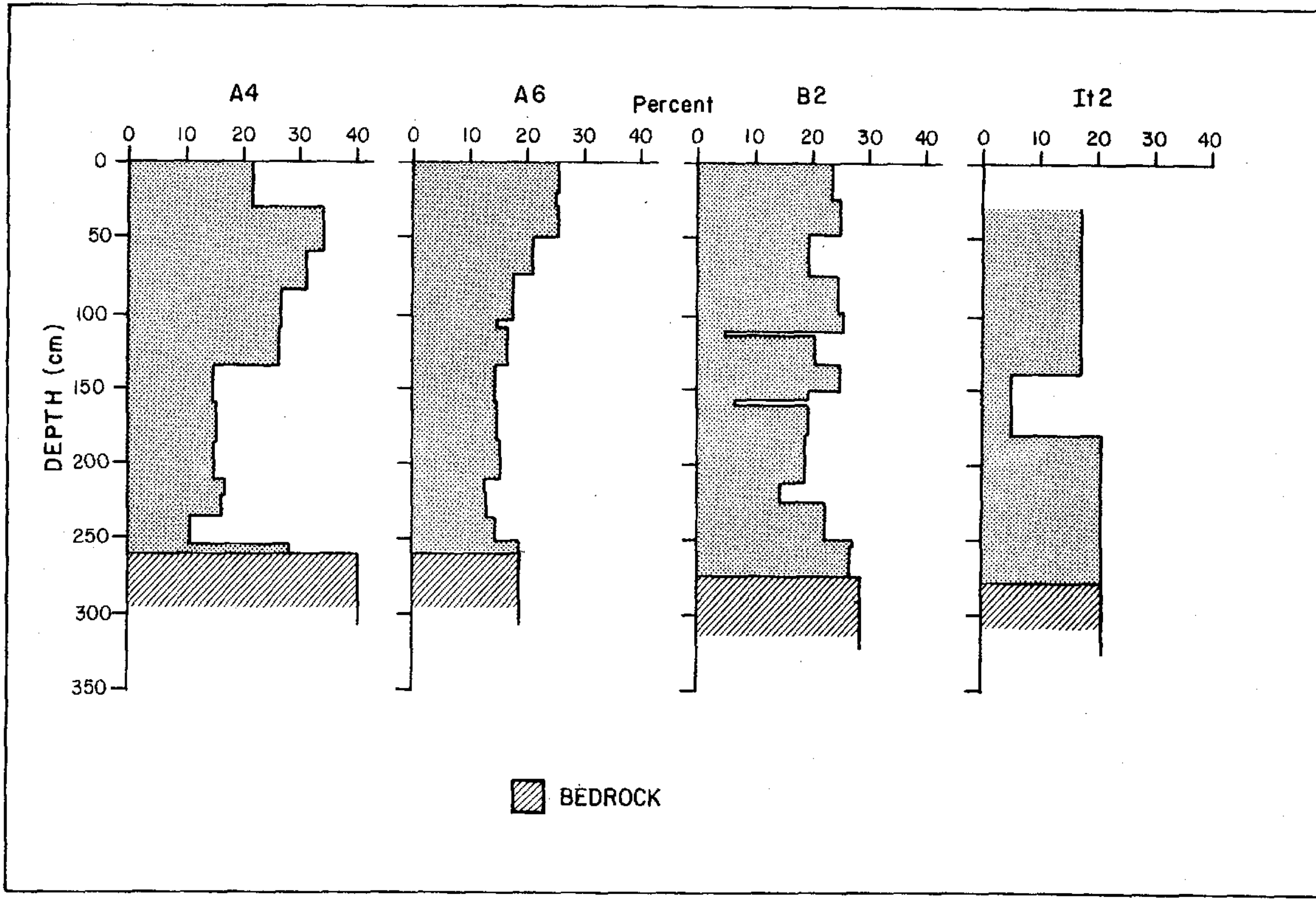

A4
Percentage
0 10 20 30 40
Peak Height (cm)
0 5 10 15 20 25
DEPTH (cm)
0 50 100 150 200 250 300 350
55.55

Fig. 18. Variations with depth of quartz percentages from four selected cores. See Figs. 4 and 6 for their relative locations.


A4
A6
Percent
B2
It2
0
10
20
30
40
DEPTH (cm)
0
50
100
150
200
250
300
350
BEDROCK

which can be made. For example, cores A4 and A6 (Figure 4) exhibit very different profiles. Core A4 is from a location between cores A3 and A5, both of which are at the shoreline and near-shore locations discussed previously. For such cores the textures vary widely due to a highly changing depositional environment. As expected, a wide variation can be seen as well in the quartz percentages from core A4. Core A6, on the other hand, as previously discussed (p. 96), is characterized by a more stable texture throughout its length due to its central-basin location. The percentage of quartz in that core is not as variable, additional evidence of a more stable environment.

In spite of the difference in variations between cores A4 and A6, one pattern is clear. There is a decrease in the percentage of quartz with depth in the sediments when the near-surface variation is ignored. In core A4 there is a fairly gradual decrease in quartz content to about 130 cm, below which the precentage drops markedly. If this profile is compared with the texture graphs of cores A3 and A5 (Figure 14), it can be seen that the drop in quartz content corresponds with the decrease in sand at approximately this depth. The higher percentage of quartz near the surface is related to the presence of larger amounts of sand-size particles in the sediments.

Core A6, from the center of the basin, should have had deeper water for longer periods, and clay, therefore, should be more prevalent throughout the core. As was discussed in the texture section, this is the case, with an increase in sand-size particles near the surface. This increased sand content is reflected in the higher percentages of quartz near the surface.

Core B2 is another central-basin core. The quartz percentage profile is slightly more variable than the profile for core A6, but not as variable as the profile for core A4. The two major divergences at 114 cm and 160 cm can be partially explained by the presence of a large ironstone pebble comprising a large part of the sample at 114 cm, plus an oxidized zone at 150 cm, in which the quartz percentage is less, due possibly to the more extensive weathering which produced the zone.

The quartz profile from core B2 does not show as clearly the same decrease in quartz with depth as seen in cores A4 and A6. There are two major quartz increases which tend to mask the decrease. One is from 76 to 114 cm deep, and the other a few centimetres thick, centered around 145 cm. If the quartz and texture profiles are compared (Figures 18 and 15), it can be seen that those quartz increases coincide with increases in sand-size material. The layer of relatively high quartz from 76-114 cm deep coincides exactly with the sand layer discussed previously (p. 102). Again, the quartz increases appear to be related to increases in sand content. The thin layers of less quartz at 114 cm and

160 cm do not appear on the texture graph, as not enough sample was available for analysis.

The graph for the trench, It2, Figure 18, exhibits a much simpler profile, for, as outlined in the texture section, the samples were taken only from the obvious layers; smaller layers were ignored or combined. It does, however, show similar quartz percentages and reflects the stability of the central basin location, with one major exception, the layer from 142-183 cm. This is the layer which contains large amounts of secondary calcite and corresponds to the influxes of sand seen in other central-basin locations. Any increase in sand in this layer is masked by the calcite cement. The calcite peak for this layer is six times larger than any other calcite peak in all x-ray traces from the samples. The other two layers marking decreases in quartz percentages are both layers with large pebbles of ironstone.

The increases in quartz content at approximately 270 cm in core A4, and to a lesser extent in core B2, are a reflection of bedrock at this depth. Weathering for a longer period should have increased the relative quartz percentage in the bedrock at the expense of less resistant materials.

Statistical Analysis of Quartz Profiles

In spite of the variability in the quartz content profiles, patterns do exist. The non-randomness of the patterns can be substantiated using the cross-association technique previously discussed. To prepare the data for the computer, the measured peak-height intensities were tabulated for quartz for each of the cores. The largest peak height in a profile was given a value of 100 percent. Classes were established into which the other peak heights were placed relative to the largest peak. Peak heights ranging from 0-25 percent of the largest peak were indicated by the symbol 1, 25-50 percent by the symbol 2, 50-75 percent by the symbol 3, and 75-100 percent by the symbol 4. Thus the relative quartz content for each profile was reduced to a column of numbers that could be applied to the cross-association program.

The results of the computations give good X^2 correlations. For example, when comparing the quartz peak intensity profiles from cores A4 and A6, a X^2 value of 7.5 ($p<0.01$) is generated. This comparison involves the surface down to 297 cm for core A4 and from 31-310 cm for core A6. One reason which might account for the very significant correlation is that both cores are from the same basin, even though from slightly different environments of deposition.

The comparison of quartz profiles for cores A4 and B2 yields a X^2 of 2.16 ($p>0.10$). This is a reasonable correlation for nearly all of core A4 and from the surface down to 260 cm in core B2, despite the fact that the cores are from different basins and slightly different environments. Core A4 is from a near-shore site, and core B2 is central basin.

When cores A6 and B2, both central-basin locations, are compared, a X^2 value of 2.12 (p>0.10) is generated. Although both of these cores are from central-basin or deepest-water locations, basin configuration becomes a factor. Core B2 is nearer to the former shore than core A6, and, as was shown in the texture section, greater influxes of sand are present. These influxes of sand affect the quartz variability and result in a less significant correlation.

Quartz percentages were calculated and peak-height intensities measured for the sample from trench It2. Cross-association was not run, however, as not enough intervals were identified in the trench to make the technique usable. X-ray diffraction was run, however, on one other core, core F3, a central-basin or deepest-water location from basin F. Cross-association of the quartz peak-height intensities from this core and cores A4, A6, and B2 again provide some fairly significant X^2 values. In all the comparisons, essentially the entire length of each core was involved.

The comparison of cores A4 and F3, a near-shore and central-basin comparison, yielded a X^2 value of 3.15 (p<0.10). Cores A6 and Fe, both central-basin locations, generated a X^2 value of 2.92 (p<0.10). The correlation of cores B2 and F3 provided a X^2 value of 2.51 (p>0.10). As was stated in the texture section, cores B2 and F3 contained higher influxes of sand than some of the other central-basin cores, and this fact might be responsible for the relatively lower correlation value.

Quartz-Feldspar Ratios

The ratio of resistant to non-resistant materials has been used by various researchers to aid in interpretation of past climatic events (Ruhe, 1956; Brophy, 1959; Birkeland, 1974; Mahaney and Halvorson, 1986). Determination of rates of weathering was an important part of these studies, for basically, materials exposed to weathering over a longer time have higher ratios of resistant to non-resistant minerals (Birkeland, 1974, p. 158). In those studies, however, the ratios were applied primarily to soil profiles and relatively steady-state soil-forming conditions. In an environment where alternating wet and dry conditions or alternating depositional and erosional conditions exist, however, the significance of such ratios is doubtful.

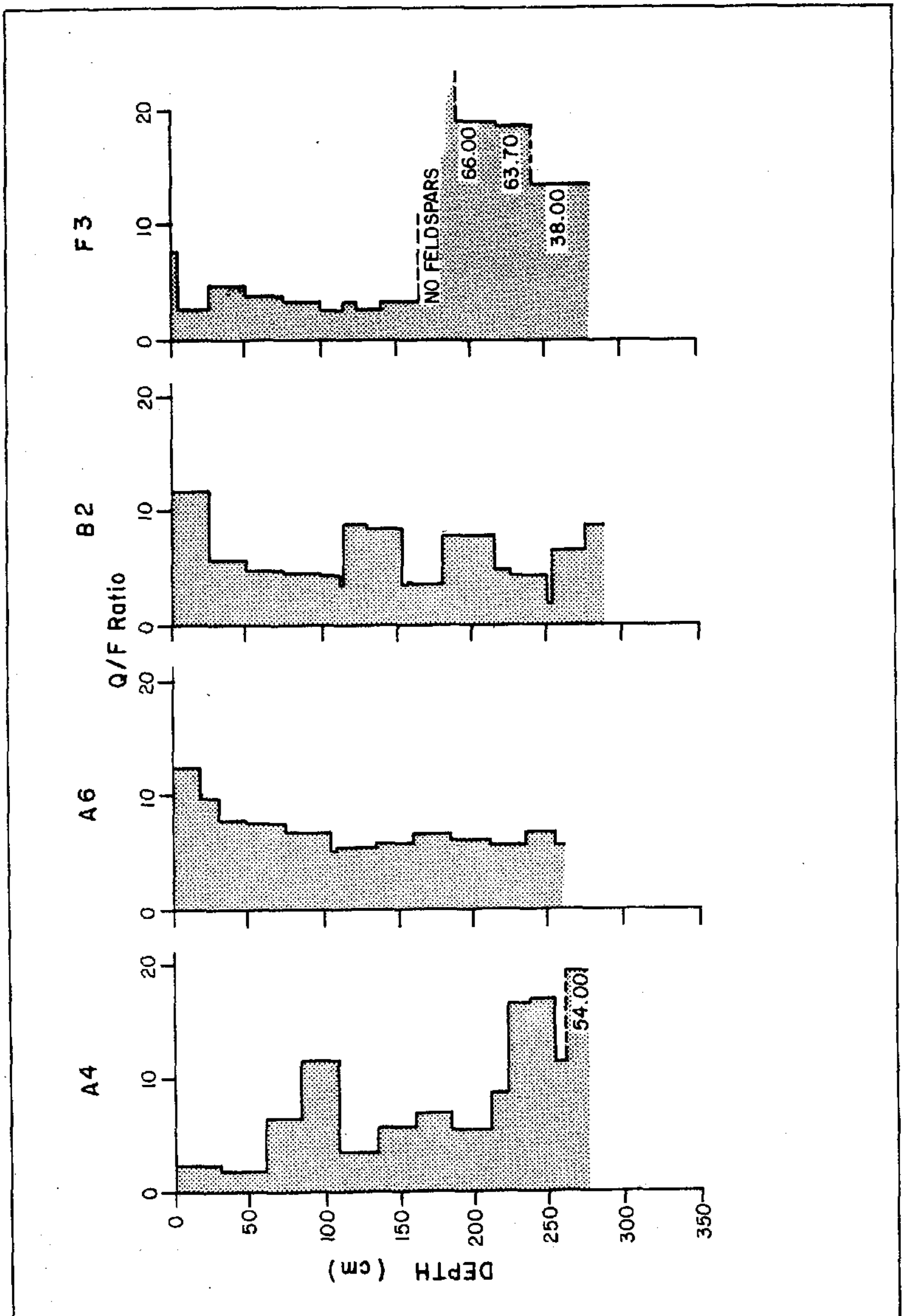
Wherever such studies were attempted, a consistent parent material was assumed. The ratio of resistant to non-resistant minerals is one way to test this assumption; more resistant minerals should be more abundant nearer the surface, whereas non-resistant minerals should increase with depth. Ratios of these minerals can be used to indicate trends, and the changes with depth should be gradual. Any sharp inflections or reversals of ratios indicate a lack of uniformity of parent material (Birkeland, 1974, p. 145).

For this study quartz and feldspar were selected, primarily because they are commonly used by researchers, but also because they were the only suitable minerals in the samples. The ratios were derived using total counts calculated from the peak heights on the diffractograms. Total counts for all feldspars were used in the calculations. In this study the symbol "Q/F" will be used when referring to quartz/feldspar ratios. The results of the study reveal numerous fluctuations in the ratios for the four cores depicted on Figure 19.

As previously noted, cores A6, B2, and F3 are all central-basin cores from different basins. Core A3 is a near-shore core. The configuration of the Q/F profiles indicates a lack of uniformity of parent material. It is these reversals and inflections, however, which help to substantiate some of the previous observations made concerning these sediments. As has been outlined previously, the sediments in the basins, although sharing a common history, are the product of changing environments which have produced a variety of parent materials. Other than the oxidized zones previously discussed in the section on color, (p. 66), no evidence exists for paleosols. The only recognized zone of soil is associated with the present surface, and that soil is not well developed there.

The basic soil type common to the basins is the Dimmick silty clay (Thompson, 1978). This soil is fine-textured and very poorly drained, with a surficial A-horizon approximately 50 cm thick overlying a C-horizon. It is

Fig. 19. Variations with depth of quartz/feldspar ratios from four selected cores. See Figs. 4 and 5 for their relative locations.


F 3
B 2
A 6
A 4
Q/F Ratio
DEPTH (cm)
0
10
20
0
50
100
150
200
250
300
350
NO FELDSPARS
66.00
63.70
38.00
54.00

commonly mapped in association with the Heil soil which is present along the basin margins. That soil contains many of the Dimmick characteristics, but the slightly better drainage allows for a modest B-horizon development and a diminished A-horizon (Thompson, 1978).

Despite the lack of paleosols and the variety of parent materials, when these profiles are placed individually into the sequence of events that has been postulated, some corroborating information can be found. Core A6, for example, has been described as demonstrating a fairly stable environment through time. Silt and clay make up the major portion of the materials, with a slight increase in sand correlated with the major particle size shift discussed previously. It can be seen from the Q/F profile (Figure 19) that throughout the length of the core the environment does seem to have been stable, with the sediments that have been added containing fairly consistent amounts of quartz and feldspar. The increase in Q/F values toward the surface is possibly related to present weathering conditions, with feldspar being weathered more rapidly than quartz. There is a similar pattern in core B2 as well, and a thin layer at the surface in core F3 also shows a higher Q/F value likely related to present-day weathering.

Cores B2 and F3, Figure 19, as already described, have more noticeable changes in texture related to major changes in the environment of deposition. At a depth of

114 cm in core B2, and 168 cm in core F3, there is a major change in the sand content (Figure 15). This increase has been attributed to a change to much drier conditions. A period of erosion has been postulated at this level, followed by the deposition of sand, which is, in turn, followed by increased amounts of silt and clay toward the surface, reflecting a return to more moist conditions.

If the sediments at this level were exposed to the surface for some time, weathering could preferentially have removed the feldspars, leaving concentrations of quartz. This is very evident in core F3, as the layer from 168 to 193 cm contains essentially no feldspar, at least on the scale at which the x-ray traces were run. There is no doubt that the relative amounts of feldspar are diminished at this level. In core B2, the same condition is repeated from 117-155 cm, but the Q/F value is lower. This lower value is likely due to the fact that the period of drying was not as extreme here as in the other basin, due possibly to basin configuration. The sediments, especially the deeper silt and clay, are not as thick in core F3 as in B2, an indication that moist conditions were not as prevalent in basin F.

Core A4, Figure 19, exhibits a variable profile, which is probably the result of its near-shore location; fluctuations in depositional environment are more likely in such a location, which would lead to greater fluctuations in the Q/F profile. Core A5, Figure 14, is the core nearest to

A4 on which detailed texture analyses were done, and it shows a major influx of sand beginning at 132 cm deep. In core A4 there is a major shift in the Q/F profile at 112 cm, which is probably correlative to the initial increase in sand in core A5.

In some of the cores there is a noticeable increase in the Q/F ratio at depth. For example, in core A4 at approximately 270 cm, there is a sizeable increase in the Q/F value. This is the inferred bedrock contact. In core A6 there is a slight increase at the 250 cm level, which is the bedrock contact for that core. In core B2 the increase is not as obvious, but there is an increasing value with depth, and the bedrock contact, although not as easy to identify in this core, is presumably in the 270-280 cm range. Core F3 provides the most difficult bedrock contact to identify, but it appears to be in the 250-260 cm range. It seems likely, therefore, that the presence of bedrock is reflected in the Q/F ratio.

Clay Minerals

The topography in the study area has previously been described as a gently rolling upland surface with some closed depressions, which are the focus of the study. It has been assumed that in topography such as this, the differences in soils are a function of topographic position and *in situ* pedogenesis, and that the various parts of the landscape are approximately the same age (Birkeland, 1974, p. 189). Recent work is casting doubt on this model, for it fails to consider the movement of material into the basins from the surrounding hills.

As has been previously discussed, the sediments in the basins exhibit a depositional gradation from the margins to the centers of the basins. The distribution of grain sizes across the basins, with clays more common in the center and deepest-water locations, and the gradation of S/S/C ratios across the basins, substantiate this. These data agree with a study in Iowa on closed depressions and associated hill-slopes, where increases in clay and organic matter toward the centers of the depressions were documented, along with a decrease in gravel content (Walker, 1966). The major lateral differences in soil-particle sizes are therefore sedimentologic, not pedologic.

Another variation associated with topography of the type under study is in the kinds of clay minerals in the depressions. In environments where leaching conditions are slight, retention of montmorillonite as the main clay mineral is common. In environments where leaching conditions are high, the formation of kaolinite is favored (Birkeland, 1974, p. 190 and 238). As stated earlier, the mineralogy of the sediments in the study area is fairly simple. The clays are montmorillonite, kaolinite, mica-illite, and chlorite in very minor amounts. The 7Å kaolinite/chlorite peak is used primarily in this study, as the combined amounts of these clays provide peaks which are large enough to be useful. Although generally too small, the 14Å chlorite peak data are discussed later to help illustrate a particular feature of the clays.

Figures 20 and 21 show depth profiles of the peak heights of montmorillonite and 7Å kaolinite/chlorite from selected cores. In the central basin cores, A6, B2, and F3, there are obvious variations in the amount of clay present, but these variations are not of the same magnitude as those seen in core A4. These lesser variations are due to the fact that clay is present in fairly large amounts throughout the cores from these locations.

In core A4 there is wider variation in peak heights with depth. As previously documented for near-shore locations such as this, there is also a wider variation in texture, with sharp increases in the amount of clay-size sediments in the 150-200 cm depth range. Therefore, increases in various clay minerals at this depth would be expected. Another factor in the rather sharp increases in clay minerals at depth in core A4 is the presence of high percentages of sand in the surface layers. The increased permeability of the sand would allow percolating water to translocate clay-size particles more easily. This could therefore increase the percentages of clay minerals with depth.

Another feature in core A4 is the depth at which

Fig. 20. Variations with depth of montmorillonite from four selected cores. See Figs. 4 and 5 for their relative locations.

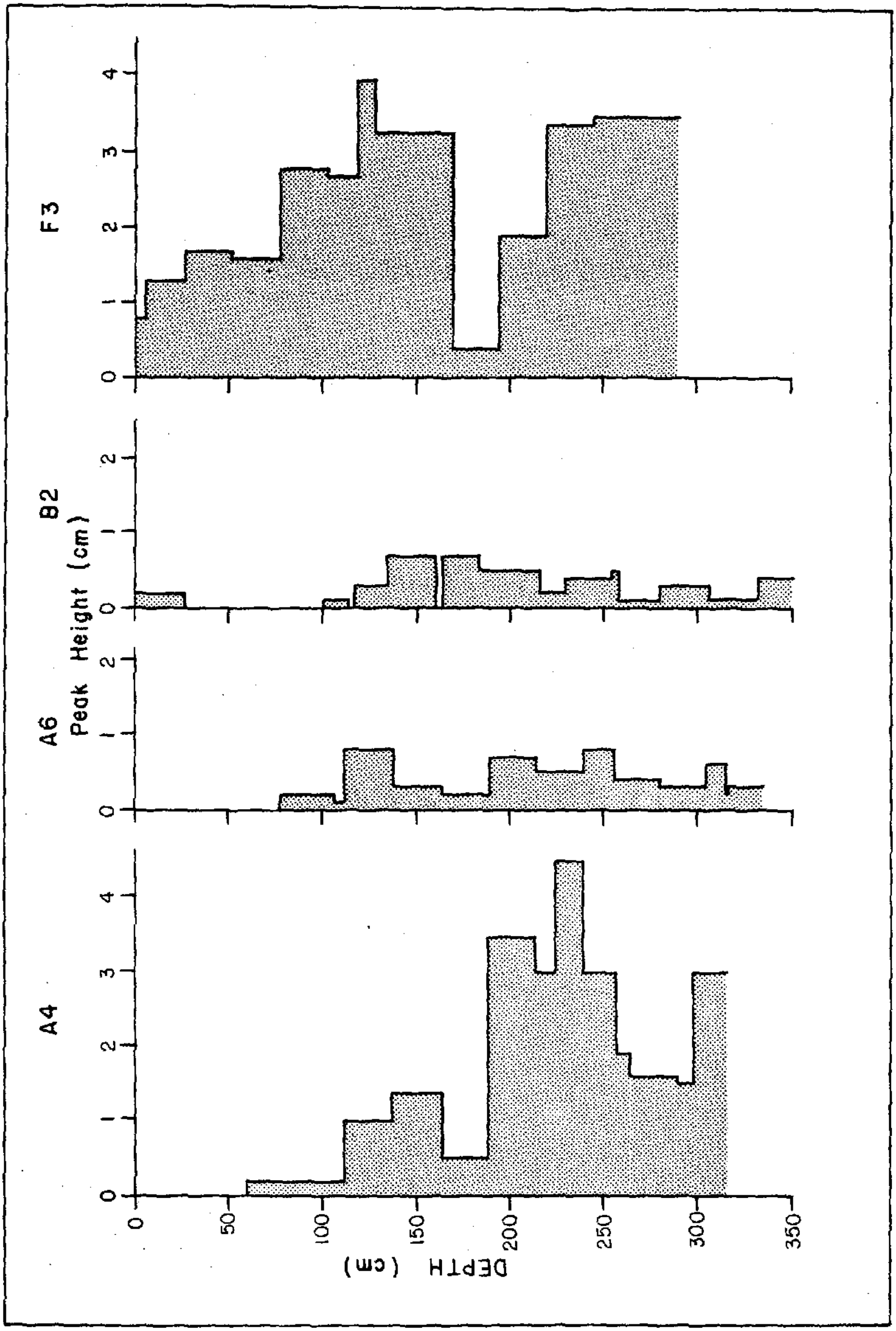
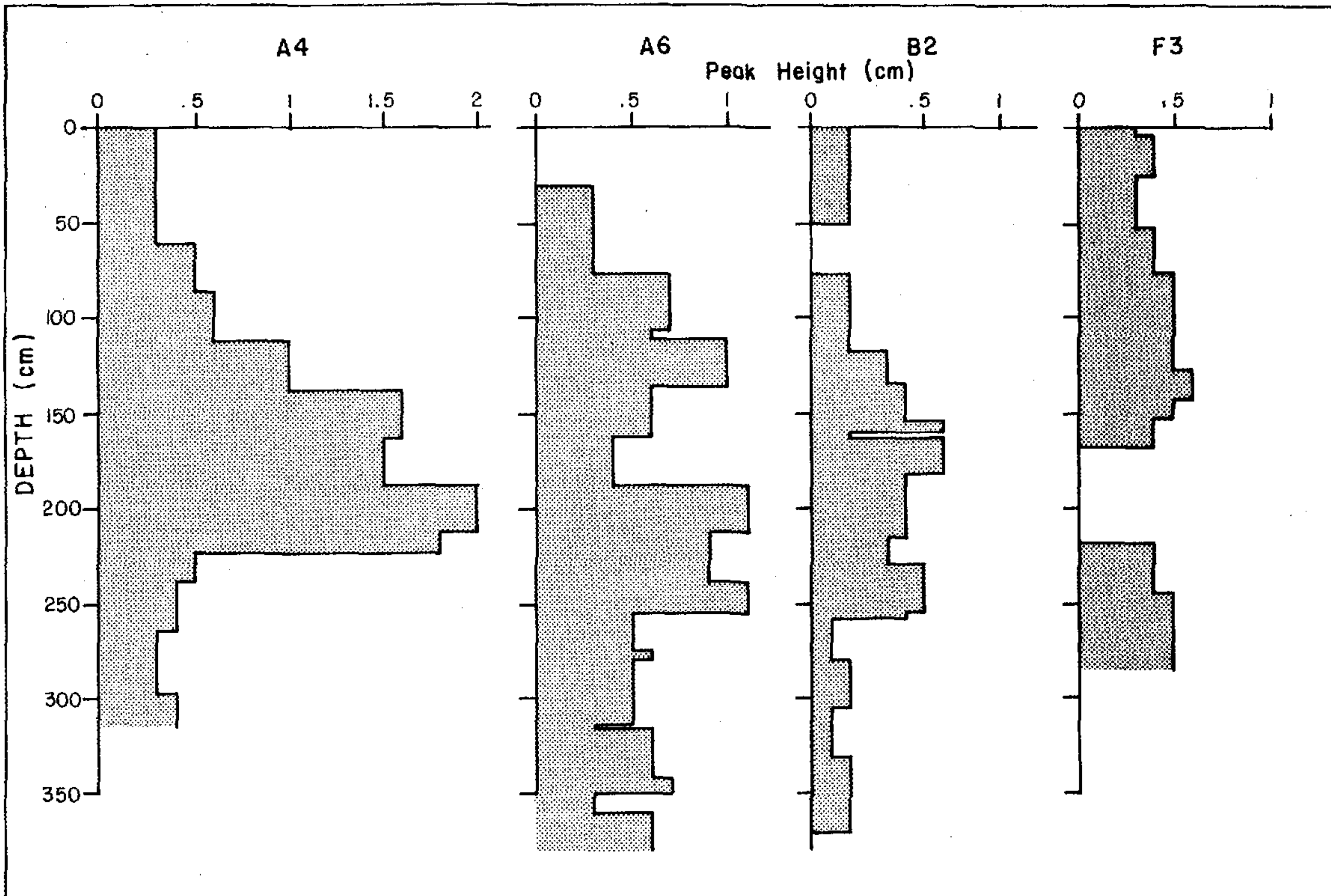

F3
B2
A6
A4
Peak Height (cm)
DEPTH (cm)
0
1
2
3
4
0
50
100
150
200
250
300
350

Fig. 21. Variations with depth of 7Å kaolinite/chlorite from four selected cores. See Figs. 4 and 5 for their relative locations.


A4
A6
B2
F3
Peak Height (cm)
DEPTH (cm)
0
.5
1
1.5
2
0
50
100
150
200
250
300
350

the major increases in the two different clay minerals occur. The major increase in kaolinite is between 100 and 150 cm, whereas the major increase in montmorillonite is near the 200 cm depth.

The near-shore location has a higher percentage of sand in the upper 150 cm of core, and it is higher topographically, which means that leaching conditions should be more favorable here compared to the central-basin location, core A6. As suggested earlier, where better leaching conditions are present, the formation of kaolinite is favored. At this location kaolinite may be forming from montmorillonite higher in the column. With a decrease in the leaching at depth, montmorillonite is more abundant. In the central-basin locations, leaching is minimal due to poor drainage conditions, and montmorillonite is retained as the major mineral there.

There is one other possible leaching association that can be seen when comparing the montmorillonite profiles and the 7Å kaolinite/chlorite profiles from the central-basin locations of A6 and B2. Montmorillonite is lacking near the surface in both these cores, whereas small amounts of kaolinite/chlorite are present. In fact, the appearance of kaolinite/chlorite is again higher in the column than montmorillonite, as in core A4. This is likely related to leaching conditions at present.

The peak-height intensities on the depth profiles indicate that the amounts of montmorillonite and kaolinite in the cores are similar. However, the shape of the peaks on the diffractograms suggests that montmorillonite is far more abundant; the montmorillonite peaks, in addition to being higher in general, are much broader, an indication of greater abundance (Frank Karner, oral communication, 1986).

Statistical Analysis of Clay Mineral Profiles

Because montmorillonite is the clay mineral most likely to be retained in the low leaching conditions of the basins, as well as being the most abundant, it ought to be the clay mineral which will provide the best correlation of cores within basins and between basins. In fact, when the peak-height intensities of montmorillonite are correlated, very high levels of significance are commonly derived. These high levels of significance suggest that the montmorillonite in the basin sediments shares a common geologic and climatic history.

In comparing the montmorillonite from cores A4 and A6, near-shore and central-basin locations, a X^2 value of 4.80 ($p<0.05$) is derived. This comparison includes the entire lengths of both cores. A comparison of the montmorillonite from cores A4 and B2, near-shore and central locations from different basins, gives a X^2 value of 8.58 ($p<0.01$). This comparison includes all of core A4, and the segment from 25-280 cm of core B2, which is nearly its entire length. The best correlation is the comparison of montmorillonite from cores A6 and B2, both central-basin locations, which generated a X^2 of 8.99 ($p<0.01$). This correlation included all of core B2 and the segment from 20 cm down for core A6. This is not unexpected, for, as can be seen in Figure 20, the profiles do not exhibit large variations, as they are from similar environments.

The major problem in the cross-association of the montmorillonite peak heights is core F3. When correlations of core F3 with other cores are attempted, only short core segments give significant values. As can be seen on Figure 20, the montmorillonite profile for core F3 is quite different from those of the other central basin cores. The peaks are higher, and there is a major decrease in intensity from 170-190 cm. This is the same level at which the quartz-feldspar ratio was high for which a major period of leaching has been inferred on p. 126.

Another consideration, however, is that the samples from core F3 were collected and the x-ray diffractograms run at a later date than the rest of the samples. It was discovered that there was a calibration problem with the instrument at that time. The traces were not at all similar to the previous traces, and the samples had to be rerun. The second set of results from the samples was much better, but some calibration inconsistencies could have affected the peak-height intensities and resulting correlation values. Internally, within the core, the relative values are comparable, but direct correlation with other cores may not be possible or should be done with these limitations clearly in mind.

Cross-association of the other clays does not provide as good an overall correlation as do the montmorillonite profiles. The mica/illite peak provides only correlation of short segments of core, as does the 14Å chlorite peak, traces of which are found in only three cores. The only 14Å chlorite peak comparison which is useful is for cores A6 and B2, two central-basin locations for which a X^2 value of 3.77 ($p<0.10$) is derived.

The 7Å kaolinite/chlorite peak, being a combined peak, provides a more distinguishable and variable peak on the diffractograms. There are, again, segments of various cores which show good correlation, but correlation over major parts of any cores is found only in the same cores, A6 and B2. All of core B2 and the segment from 20 cm down in core A6 gives a X^2 of 3.45 ($p<0.10$).

There is one factor which seems to add support to the idea that the sedimentologic, rather than pedologic, forces are dominant in the clay mineral association. When comparing the cross-association for montmorillonite, 7Å kaolinite/chlorite and 14Å chlorite for cores A6 and B2, both central-basin locations, the same segments of these cores are correlated, with significant X^2 values. This fact suggests that rather than some clays forming at the expense of others, all of them were added at the same time and they coexist in a state of relative equilibrium, with the possible slight weathering exceptions suggested previously.

Amorphous Silica

During identification of the minerals, a peak on some diffractograms proved difficult to identify; it was not large, on the order of 1-2 cm in height, but it was characteristically broad. The peak centered approximately on 22°, suggesting a silica mineral, but its shape made specific identification impossible. A study of the Pierre Formation shale (Schultz, 1964) includes a note on the presence of a similarly-shaped peak at this same location on diffractograms. The term "disordered cristobalite" was used to identify the peak because of the distortions in crystal lattice which apparently produced the characteristic broad peaks. This distortion was interpreted to have been caused by small amounts of alumina, water, and alkalis in the cristobalite lattice.

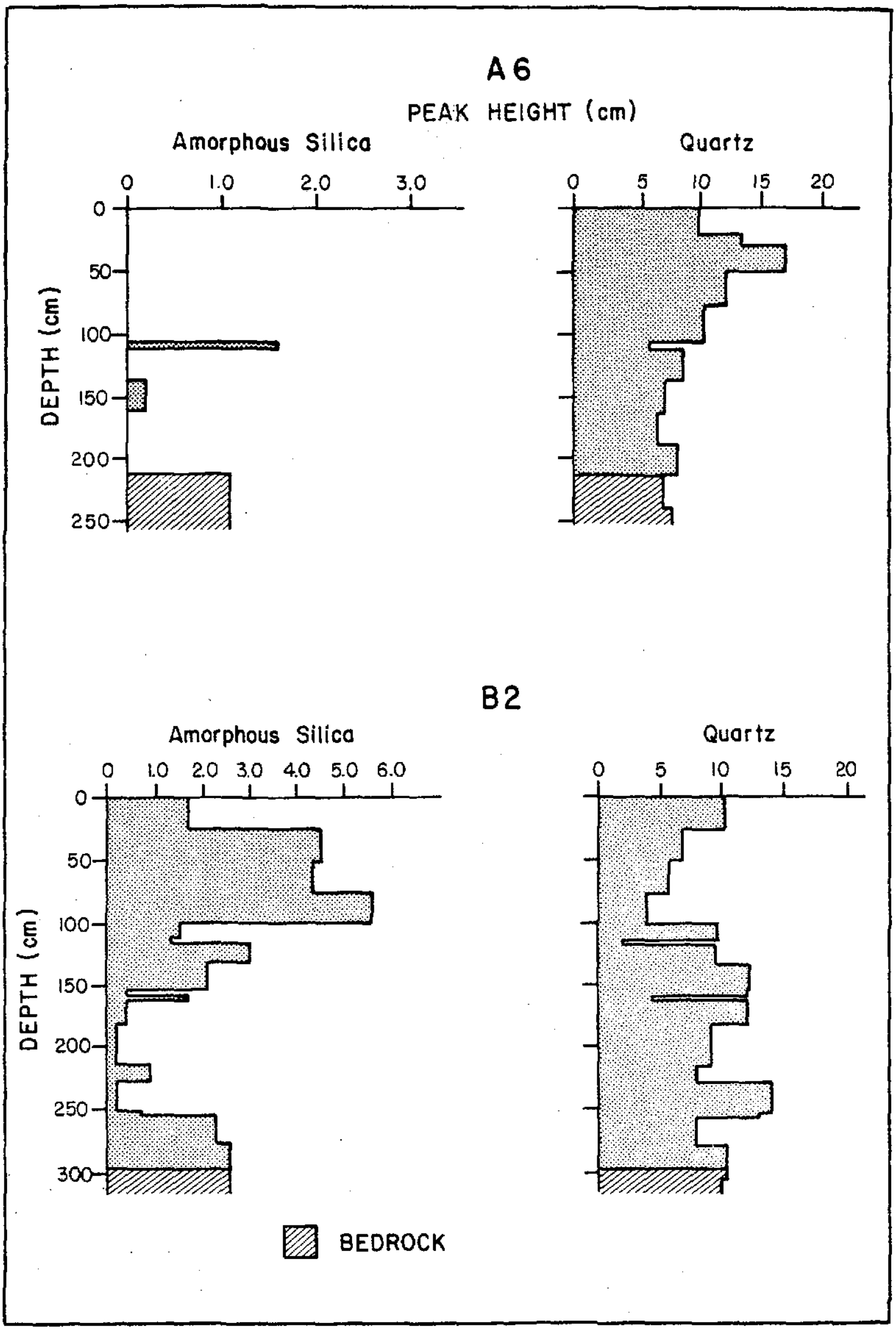
Another possibility is that the peaks were caused by the presence of biogenic opal in the sediments. Phytoliths of a variety of types, composed of amorphous silica, form broad peaks at a similar location on diffractograms (Wilding and Drees, 1974). These remnants of former vegetative growth maintain surficial characteristics formed by the plants in which they grew, allowing them to be identified. A scanning electron microscope was employed to identify the possible phytoliths, but none were found.

The most plausible explanation is that the peaks are caused by amorphous silica derived from the dissolution of crystalline quartz. The condition most favorable for dissolution of quartz is the presence of groundwater with a pH of 8 or higher (Ritter, 1986, p. 70). The sediments in the basins are presently alkaline, and probably have been alkaline over at least the past 6,000 years. Quartz presumably is being dissolved.

To test this idea, the peak-height intensities of quartz have been compared with peak-height intensities of the proposed amorphous silica. The profiles from two cores, core A6 and B2, are shown in Figure 22. Not all of the diagrams are drawn to the same horizontal scale; the amorphous silica peak heights are exaggerated to highlight the comparison.

The profiles present a fairly complex relationship. This is not surprising, for the data presented thus far in this study have shown that the sediments have a fairly complex history. There are layers which show a gain in both components, while other layers show a loss in both. There are several layers in each core which show an inverse relationship between quartz and amorphous silica. Without detailed laboratory analyses, which go beyond the scope of this study, the percentage of loss and gain of quartz/amorphous

Fig. 22. Comparisons of peak heights of amorphous silica and quartz from (A) core A6 and (B) core B2. See Fig. 4 for locations.


A6
PEAK HEIGHT (cm)
Amorphous Silica
Quartz
0
1.0
2.0
3.0
0
5
10
15
20
DEPTH (cm)
0
50
100
150
200
250
B2
Amorphous Silica
Quartz
0
1.0
2.0
3.0
4.0
5.0
6.0
0
5
10
15
20
DEPTH (cm)
0
50
100
150
200
250
300
BEDROCK

silica and the exact locations of this loss and gain are impossible to document.

The inverse relationships that do exist, however, help support the idea of loss of quartz and resulting gain of amorphous silica. Of relevance is the fact that some of the more evident of these inverse relationships coincide with some major textural changes previously documented. For example in core A6 the layer at 100 cm is where a change occurs from clay below to a sand/silt/clay mixture above (Appendix I).

Core B2 contains two such small layers, one at 114 cm and another at a depth of 160 cm. Comparing this profile with the texture profile of core B2 (Figure 15), it can be seen that these layers coincide exactly with major texture changes. These changes suggest shifts from wetter to drier climatic conditions. Such a shift could set up a situation in which increased alkalinity during the drying phase could elevate the pH of the water percolating downward, causing dissolution of the quartz.

Another possibility for dissolution exists at the 76-100 cm level in core B2. There is an obvious inverse relationship at this level which could be related, in this case, to a shift from drier to wetter conditions. The texture change at the 76 cm level suggests this shift. During the period of drying the sediments in the sand layer could have become more alkaline. With a return to slightly wetter conditions, dissolution of the salts could have provided groundwater with a pH high enough to dissolve quartz, setting up a loss/gain condition in the layer from 76 - 100 cm deep.

The data presented here do not constitute proof of such a relationship. However, enough information is provided to suggest that a relationship exists between the two materials, and that a suitable environment has existed in the basins in the past to cause the suggested events to happen. This information also provides data which support previously presented data and ideas.

DISCUSSION

Limitations

This project has produced data which compare favorably with geologic and climatic studies from areas adjacent to and at some distance from the study area in southwestern North Dakota. During the course of the work, however, limitations developed which were difficult to deal with and which influenced the outcome of the research.

At the inception of the study it was hypothesized that the sediments in the basins might provide a continuous record of sedimentation for perhaps the last 100,000 years. Such a record would provide data which could be used to evaluate the effects of a nearby glacial environment on the depositional and erosional history of the sediments and the surrounding area. One of the major limitations has been the character of the basins themselves. All the augering, coring, trenching, and follow-up analyses indicate that the basins are shallow. This fact alone might preclude the accumulation of sediments over a long period.

Secondarily, the shallowness increases the likelihood that the basins will be ephemeral in character, in the long term or even in the short term. Changes in climate, in combination with basin topography, are likely to produce an environment which is highly variable and unlikely to provide a long-term continuous data base.

The shallowness of the basins is also a clue to their origin. It has been suggested that the basins are deflation in origin (Clayton and others, 1980). In the Great Plains of the United States it is possible that deflation has been responsible for more basins than any other cause (Thornbury, 1969, p. 291). Basins which have been suggested to be the result of deflation range in size from hollows in Arizona, which are up to 10 m wide, 17 m long and 1 m deep (Cooke and Warren, 1973, p. 251), to the P'and Kiang depressions of Mongolia, which are 100 m deep and 10 km in diameter (Mabbutt, 1977, p. 150). The largest depression thought to have been formed solely by deflation is the Qattara Depression in northwestern Egypt, which covers an area of 18,000 km^2 and reaches a depth of 132 m below sea level (Glennie, 1970, p. 26).

Small troughs and deflation hollows are easily related to wind erosion as they typically are elongated relative to wind direction (Ritter, 1986, p. 314; Cooke and Warren, 1973, p. 252). In some areas of the world, flat-floored depressions called pans are believed to be the work of wind. They range in size from a few hundred square metres to 300 km^2 and are 7-10 m deep (Cooke and Warren, 1973, p. 253; Buckle, 1978, p. 158), but their deflation origin is more difficult to prove, as many have no clear, preferred orientation (Ritter, 1986, p. 314). It is fairly widely agreed as well that many of the very large basins, such as the Qattara Depression, are likely the result of a combination of factors, with tectonic activity and groundwater solution helping to enlarge the depressions (Mabbutt, 1977, p. 150; Glennie, 1970, p. 28; Cooke and Warren, 1973, p. 254).

The importance of the water table in deflation basins is another area of agreement; the depth to which a basin can be deflated is primarily controlled by the water table (Buckle, 1978, p. 158; Glennie, 1970, p. 26). In fact, the term deflation base is defined as "the level deeper than which significant removal of sand cannot go (sic) under existing conditions, usually set by the water table" (Cooper, 1967, p. 24). This situation, then, has a great deal to do with the fact that most deflation basins are relatively shallow compared to their area, especially when these basins have standing water or very moist conditions for part of the year.

The results of this study would support a deflation origin for the southwestern North Dakota basins. The abundance of fine to very fine sand and silt around the margins of the basins suggests that wind is the dominant process there at the present time. The existence of a layer of fine to very fine sand, with even finer-grained material above and below, was documented in several cores. As sand can be carried farther into the basins during a drier phase, this sand layer is further support that eolian activity has played a significant role in the addition of sediment into and removal of sediment from the basins. Higher water tables in the past, and flooded or moist conditions today, have caused greater cohesion of particles and prevented the basins from being eroded deeply.

This information, when combined with the elongation of many of the basins parallel to past and present prevailing winds, the lack of integrated drainage over much of the area, and the relatively small size of the basins, argues for their deflation origin.

It was hoped that this study would provide more precise information on the age of the basins. It was suggested earlier that the basins were formed in early Wisconsinan time or just prior to it. This study has not substantially changed this interpretation, as no sediments could be found in the basins which approach this age. Evidence has been found, however, which indicates that the basins are considerably older than the sediments presently in them. The presence of highly oxidized zones and very large Q/F ratios on some bedrock contacts shows that the bedrock has been exposed to weathering for a long period or periods. It is possible that the basins, because they are shallow, may have had sediment removed numerous times, and the resulting oxidation and weathering seen at the bedrock contact is the result of more than a single weathering episode.

With such Q/F values and highly oxidized zones at the bedrock contact, an age of 40,000 B.P., early Wisconsinan, for the basins is certainly possible. It is also possible that they may have formed during the Dunn or Verone advances of the ice (Clayton and others, 1980). Evidence exists in southwestern North Dakota for these advances, but they are beyond the range of radiocarbon dating. At these times the ice terminus was not far from the study area. The Napoleon advance, also early Wisconsinan, was fairly close, too. Basin H is located approximately 25 km from the limit of scattered glacial boulders shown on Figure 1. This limit marks the approximate advance of the ice sheet associated with the Dunn glaciation.

Erosion of the study basins during one or more of these periods of ice advance is certainly a possibility, as the basin elongation parallels the margins of the ice. During these glaciations the ice sheets and the katabatic winds associated with them would have formed a barrier along which the prevailing winds would have been deflected. This wind activity would have been further enhanced by storm-wind activity, which also would have been deflected along the front of the ice.

The Greenland ice cap presently is a major north-south barrier to westerly atmospheric circulation. Commonly in colder regions the strongest winds are super-gradient. The flow set up by pressure gradients is reinforced by the effects of terrain. Air flowing around topographic barriers is funneled or channeled by them, and a katabatic wind component often becomes part of the system (Wilson, 1967, 1969). Also, the orientation of inland dunes in Sweden is interpreted to have been the result of deflection of wind along the front of the Scandinavian ice sheet. The high pressure built up above the ice sheet caused normally prevailing westerly winds to change direction (Seppälä, 1972).

It is possible that the basins may have been filled and exhumed many times. During the last major advance of the ice into North Dakota, about 20,000 B.P. (Clayton and Moran, 1982), conditions for the deflection of prevailing and storm winds would have been repeated. These winds could have caused preferential erosion in the sites of the previously eroded basins, exhuming them. Following this exhumation and a change to more moist conditions in late Wisconsinan time, deposition began filling the basins with the sediments which are presently found there.

Another major limitation which developed during the course of the study was the lack of a usable radiocarbon chronology. There are a number of reasons for this problem. One of the major reasons is the presence of lignite in the bedrock from which the basin sediments were derived. This dead-carbon contamination would result in dates that are too old. For example, one radiometric date was run on a muck sample from the shoreline of basin A. The sample was retrieved from a depth of 2 metres from the same site as core A3. An age of 32,370±775 B.P. (Beta-1135) was reported. This date is too old, because it would account for an average sedimentation rate of only 0.007 cm/year. There is one positive outcome of the radiocarbon date. That is, it gives a maximum age for the sediments there. In spite of concentrated efforts to find suitable material for dating, such as pieces of wood, none was found.

To deal with this contamination problem, the possibility of using pollen as a dating mechanism was investigated, and samples bounding the location of the muck sample were analyzed. The samples were found to be barren, or nearly so, of any Quaternary pollen, for the environment in the basins was apparently not good for pollen preservation (Richard Baker, written communication, 1981). Oxidizing and desiccating environments have provided major hiatuses in Quaternary pollen records (Adam, 1984), and both of these environments have been present in the basins under study. Some samples, however, contained abundant Paleocene spores. They were preserved; slightly degraded pollen becomes more resistant than fresh pollen (Richard Baker, written communication, 1981). It appears that as the bedrock in the area was being reworked and deposited in the basin, the pollen was carried along with it. Clearly, these Paleocene spores would also contaminate the samples and reflect older than actual dates.

The only bit of faunal evidence found in all the drilling, coring, and trenching was one gastropod retrieved from an auger sample from basin E early in the project. In spite of extensive coring in this same basin at a later time, no additional remains were found. Apparently, the environment in the basins has been and continues to be fairly inhospitable.

Evidence indicates that the basins contained "permanent" bodies of water in their early phases; since then, however, they have been strictly ephemeral. The combination of basin topography and fluctuations in climate produces an environment which is highly variable and not conducive to forming uninterrupted sedimentation. A logical conclusion might be that no data can be found which would be useful. This is not true, for these basins provided a variety of data which indicate that the sediments in the basins had some interconnecting geologic and climatic history.

Summary

Color

The initial evidence which appeared in the cores indicating that the basins had some interconnecting geologic and climatic history was the color of the sediments. Overlying the bedrock, in those cores from within basins, there is a zone, variable in thickness, which is basically olive-green in color. This color indicates that in the past there was a moist period capable of maintaining a reducing environment. It is possible that this zone is also affected by present-day water tables or at least by the fact that these basins are wet at various times. However, when the augering, coring, and trenching were being done, moisture was present in the sediments of this zone, but the water table was encountered only in the bedrock below the sediments in one trench. The different thicknesses at this zone show that the influence of this reducing environment varies from core to core, but within these variances there is a pattern.

The deeper-water locations have thicker reducing sections, an indication of standing water or very high water tables for longer periods. In those cores nearer shore or at the shoreline, the reduced zone becomes progressively thinner, the result of shallower water being unable to maintain a reducing environment for as long a time; the basins dried out. Cores marginal to the basins lack this reduced zone, or at best have only a thin layer developed, related to a seasonally perched water table over the relatively impermeable bedrock contact.

As the basins began drying there was a period of water-table fluctuation which is evidenced by mottling in the cores. The mottling, some very intense, is located basically in the same zone or slightly above the reduced portion of the sediments. Once oxidation occurs, fluctuating water tables would not be sufficient to cause reversal to a reduced state, for reduction of iron is possible only under conditions of prolonged anaerobism (FitzPatrick, 1980, p. 68). Although correlation of mottling zones is not possible, the mottling is in itself evidence that fluctuating water levels occurred even during fairly moist periods, a further evidence of the ephemeral nature of the lakes.

Overlying this zone of reduced and mottled sediments is a zone of basically brown-colored sediments. This suggests that following the moist period, there was a period of drier conditions during which oxidation was taking place as the sediments accumulated. The fact that some basins flood every spring or that the largest basin was drained within the last thirty years would suggest that even during this drier period there have been occasions when the basins have had water in them. Even though sediments are moist for long periods of the year, brown colors and oxidation are common (FitzPatrick, 1980, p. 93). Obviously these periods are too short-lived to produce a reducing environment. In the basin that was drained, basin I, the oxidized zone is very thin: the reduced zone is continuous nearly to the surface, suggesting that the sediments in this basin have been subjected to a reducing environment for nearly their entire existence. Additionally, in some cores, especially those in more moist central-basin locations, there is some organic matter accumulation within the oxidized zone, causing gray to black sediments near the surface.

Briefly then, the color of the sediments suggests a moist climatic period followed by a drier one, with a return to slightly more moist conditions, as evidenced by increased organic matter accumulation near the surface in some cores.

Texture

If a major change in the environment took place, as suggested by the color, there should be some concomitant evidence in the grain-size and texture distribution of the sediments. The data presented in the texture-analyses section provide this evidence.

It was documented that in every core and trench, basically similar changes in particle size with depth could be found, with the variations explainable by the relative locations of the cores. Also, there was documented gradation in particle size across the basins from sand to silt, or in extreme cases, clay, and then to relatively coarser sizes on the other side of the basin. This gradation characterizes a change in depositional environment from eolian on the margins to quiet water in the centers of basins.

There was also a depth variation of grain size in the cores. In the margin cores, the particles were basically sand throughout. In near-shore, or shoreline locations, layers of sand-size particles were found to overlie layers of silt and clay particles. In central-basin locations, this same sand over silt and clay association is seen, but the silt and clay layer becomes thicker relative to the sand layer. In some of the cores there was an exact correlation of the color and particle size, but generally the silt and clay layer was associated with the zone of reduction, and the sand layer with the oxidized zone.

In addition to grain size, S/S/C ratios were analyzed for selected cores. These analyses not only corroborate the color and grain size association, but add details which give an even deeper insight into the history of the sediments.

In the graphs of S/S/C (Figures 14 and 15) the change from silt and clay layers below to layers with increased sand content above is clear. The level at which the major increase in sand takes place exhibits an abrupt texture boundary. In many of the cores, this boundary also truncates the olive-green of the reducing zone. This major and abrupt truncation suggests a major change in the depositional environments related to climate. In some cores a gradual drying trend can be seen below this level, most likely related to the fluctuating water levels and mottling described previously. In some cores there are very minor oxidized zones, suggesting that during these fluctuations there were short hiatuses during which the basin sediments were exposed. Cores like A3, a shoreline core, exhibit a much more varied texture related to shorter drying episodes, due to their position in shallower water. The major truncation of texture and color suggests an extreme period of drying and possibly erosion of basin sediments during this time. As the result of drier conditions, sand was moved much more readily and transported to the central locations in the basins.

In central-basin locations, like B2 and F3, there appears to have been a return to slightly more moist conditions, as the silt and clay content of the sediments near the surface increases. This change is documented in the core descriptions of other central-basin cores as well. In marginal or near-shore locations, the return to more moist conditions is not documented, as higher water levels may not have reached these topographically higher locations.

Mineralogy

The mineralogical analyses of the basin sediments presented a fairly simple assemblage, with quartz the most commonly occurring mineral. This is not surprising, as it is a stable mineral in many environments and very resistant to abrasion while being transported. Although it is quite common, it can vary widely in amount from sample to sample. One of the major factors involved in the amounts is the presence of greater or lesser percentages of sand. In those basin sediments where sand is more prevalent, the percentage of quartz also shows a general increase; whereas in those portions where silt- and clay-size particles are dominant, there is a relative decrease in quartz percentages. In a general sense, the percentage of quartz decreases with depth in the basins, for the particle size in the sediments decreases with depth, related to a possible climatic change. Also the percentage of quartz shows greater variation in those cores which are shoreline or near-shore, whereas the central-basin locations have fewer changes, the result of a more stable depositional environment.

Quartz is also a valuable component in the calculation of resistant to non-resistant mineral ratios. They are used to help interpret past climatic events, and they also test for uniformity of parent materials. If the sediments are the result of changing environments, a variety of parent materials would most likely be present. The Q/F profiles exhibited numerous inflections and reversals, a strong indication of a non-uniform parent material.

Despite this, the Q/F ratios added important details to the history of the sediments. At levels in some cores, where it is postulated that the basin sediments were exposed and subjected to weathering, increased Q/F values corroborate this. Increased Q/F ratios near the present surface may indicate current weathering conditions. In addition, increased Q/F values have been useful in helping to identify the basin sediment and poorly consolidated bedrock contact. In some cores this increase is very noticeable, while in others, it is more subtle. These values correlate with the increased quartz percentages at these levels, which most likely are the result of ancient weathering of the bedrock surface.

The Q/F profiles of the cores also help confirm the changing depositional micro-environments with core location. In shoreline cores, where changes in environment should take place more often and to a greater magnitude, the Q/F ratios are noticeably more variable. In central-basin locations, where the environment is more stable and quartz and feldspar are being added in more equal increments, the ratios are much more stable with depth.

If quartz content is at least a partial indicator of the presence or absence of sand-size material, then those core segments with little or no quartz should indicate the presence of finer-grained material, possibly clay minerals. The clay mineral content of the sediments corroborates this, for both montmorillonite and kaolinite/chlorite content increase with depth in most cores. In central-basin locations, where fine-grained material is more prevalent throughout the sediments, the clay mineral content is more evenly distributed. In shoreline or near-shore locations the variation is more pronounced.

It appears that quartz and the clay minerals have a basic inverse relationship. This relationship correlates well with the proposed environmental changes, in that at depth in the sediments the evidence favors a more moist climatic environment. Such an environment increases the potential for the accumulation of finer-grained material. In the overlying sediments, which characterize a drier climatic condition, quartz percentages increase as the particle sizes increase.

Montmorillonite is the most commonly occurring clay mineral. The reason for this is that in the basins, leaching conditions are relatively poor and in environments such as this, montmorillonite is the favored clay mineral. In some core locations where leaching is more favored, as along the margins, where the cores are from topographically higher sites and the sand content is relatively high, there is some evidence to indicate that montmorillonite may be weathering to kaolinite. There is some slight indication that this may be happening as well in the very near-surface layers of some central basin cores. In those layers, there is an increase in Q/F values in all cores. These factors, along with montmorillonite weathering to kaolinite, help to substantiate the conclusion suggested by texture and color, that there has been a return to more moist conditions in recent times.

Cross-Association Analyses

It is possible that the patterns seen in the texture and mineralogy analyses provide only random associations and that there is no real connection from one core or basin to another. The cross-association technique was applied to test for randomness of pattern. The results provided correlations with high levels of significance, especially where cores from the same basin, or from similar locations in separate basins, were compared. These high levels of significance suggest that the patterns seen in the texture and mineral profiles are the result of similar environmental conditions existing in different basins at the same time. The sediments have resulted from similar deposition at different locations.

The cross-association of the clay minerals also suggests that their presence in the basins is the result of sedimentologic and not pedologic processes, i.e., exactly the same segments of the cores had correlations with high levels of significance for montmorillonite, 7Å kaolinite/chlorite, and 14Å chlorite. This association confirms that rather than one clay mineral forming from the weathering of another, the clays were deposited concurrently, and any changes that have taken place since their deposition would necessarily be slight, as was suggested previously.

One other mineralogic factor associated with quartz was investigated. The possibility exists that the alkalinity of the basins has provided an environment where amorphous silica may have formed from the dissolution of quartz. There are a number of marked inverse relationships between the amounts of quartz and the amounts of a broad peak on the diffractograms identified in this study as amorphous silica. These periods of dissolution occur at levels in the sediments which place them in ideal environments for this process to take place, and which fit appropriately the model of environmental changes proposed.

Climates

The sequence of geologic and climatic events which has taken place in the basins has been deduced. A moist period capable of producing a reducing environment, and depositing a layer of fine-grained silt and clay, was present when sediments began filling the basins; these basins had formed at a significantly earlier time, based on the degree of weathering of the bedrock. Following this, a slight drying trend began which provided fluctuating water tables and caused previously deposited sediments to become mottled. Any sediments added during this time also became mottled. In some locations slightly oxidized zones developed when those basin sediments were exposed to surface weathering.

At some point a major period of drying took place, which caused the sediments in some basins to be eroded and weathered. During this period, deposition of sand-size particles in the basins increased significantly. Major textural changes occurred in most cores. In one trench, the textural changes were masked by the deposition of calcite, which most likely formed as the environment in this large basin became increasingly dry.

In many shoreline or near-shore environments, this drier condition has been maintained due to their topographically higher position. In central-basin locations, the evidence gathered from color, texture, and mineralogy suggests that there has been a return to more moist conditions in recent time. This is likely due to a shift toward a cooler and wetter climate. The question becomes, how does this geologic and climatic history compare with the work that other researchers have done?

It is postulated that the first event, the filling of the basins in southwestern North Dakota, was one of more moist conditions during which basins experienced higher water tables, standing water, and reducing conditions. This agrees with interpretations of a wet and cool climate in North Dakota following deglaciation (Aronow, 1963; Callender, 1968).

The sequence of events for the basins is being placed into this relative time framework for two reasons. First, the data, as will be seen, fit the sequence of events compiled by other researchers for this time interval. Second, the dated muck sample from this study was taken from sediments deposited during this first moist interval. This means that the sediments from which the dated sample was taken can be no older than 32,370±775 B.P. Because the sample was contaminated by lignite the sediments are probably considerably younger; their age might approximate the period following deglaciation.

By about 9600 B.P. the active ice front was north of what is now the Canadian border (Clayton and Moran, 1982). The Devils Lake region, for example, was much wetter and cooler, as evidenced by Lake Minnewaukan, which covered an area three times as large as Devils Lake, which occupies the Minnewaukan basin today. This period of cool, wet, and moist conditions lasted until about 6800 B.P. At this time Devils Lake was entering a major dry period, during which Callender (1968) stated the lake dried entirely. This major dry period lasted from about 6800 B.P. to 3500 B.P., correlating with a warm, dry period recognized nearly around the world -- the postglacial thermal maximum or the Hypsithermal (Deevey and Flint, 1957).

This change from moist to dry conditions has been well documented in this study: color, textural, and mineralogical evidence all suggest such a change. The presence of oxidized zones, zones of increased Q/F values, and major increases in particle size all indicate a major period of drying.

Recent work in environments similar to those in this study has produced similar evidence. In some ephemeral lake basins in northwestern Texas and eastern New Mexico, a sand wedge within lake clays is interpreted to have accreted throughout the Holocene (Holliday, 1984). This wedge is on the upwind side of the basins, indicating that eolian activity moved the sediments into the basins at the time when clays were not being deposited as rapidly.

Such a wedge in lake sediments also occurs in the basins studied. From west to east across the basins the wedge thins, and in those basins where the deepest water and central basin coincide, there is only a minor increase in the sand content of the sediments (Figure 23).

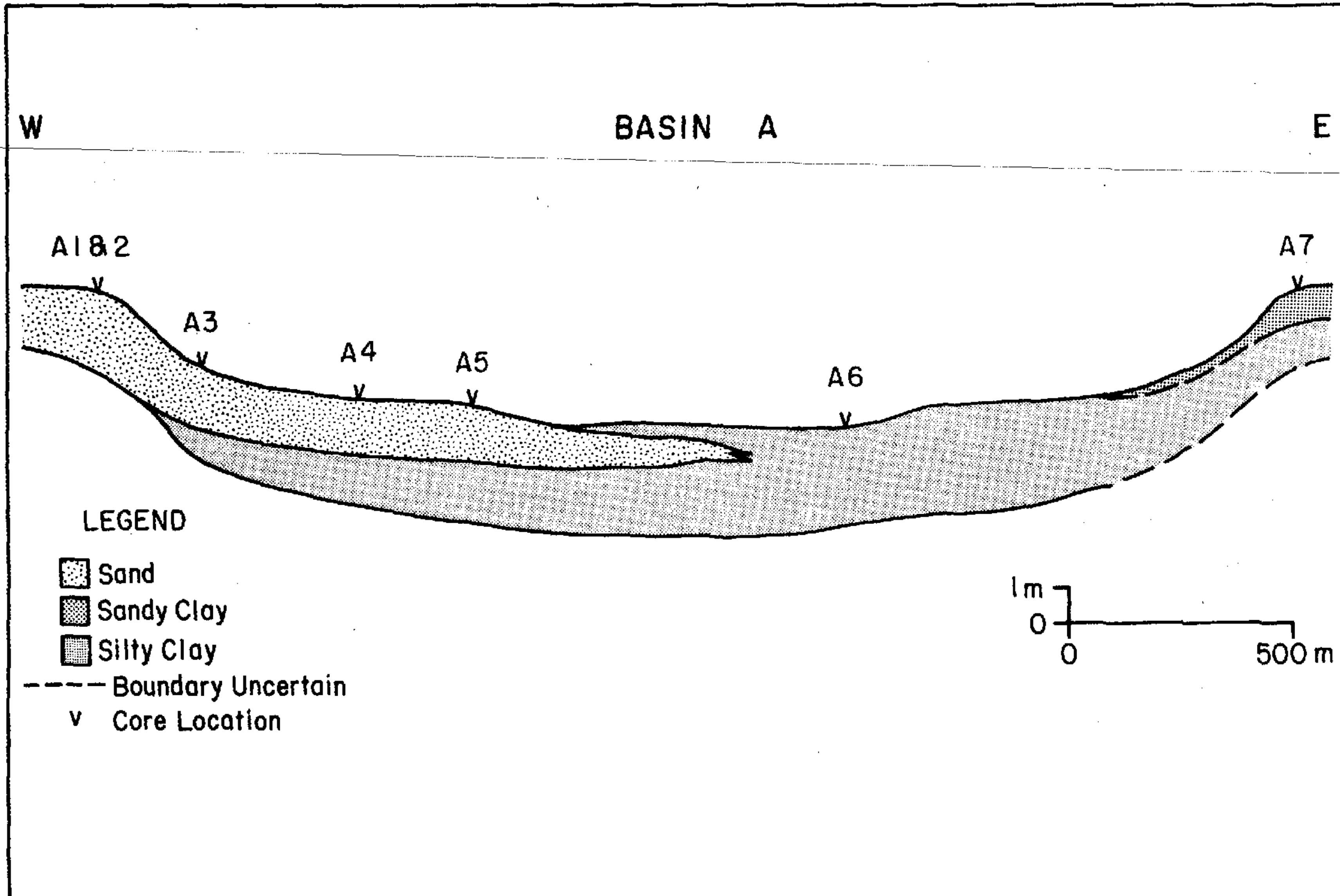
Also, in some of the Texas and New Mexico basins, there is evidence that silt, deflated from the basin floors, has accumulated on the downwind margins (Holliday, 1984). This same relationship exists for some of the basins in this study.

The wedge of sand in the Texas and New Mexico basins was deposited about 5000 B.P. which places it in the time framework of the dry period in North Dakota. Eolian deposits in other environments extend the range of the dry period in the southwest from 6500 B.P. to 4500 B.P. (Holliday, 1984). The sand wedge is thicker in the southwestern United States, due most likely to more arid conditions farther from the ice front, allowing greater erosion and transport of eolian material.

Both above and below the wedge, there is finer-grained material, from a relatively moister environment. The evidence in North Dakota reflects the same situation (Aronow, 1963; Callender, 1968; Clayton and others, 1976).

In this study, in the deepest-water/central-basin locations, which would be most affected by more moist conditions, there is a noticeable increase in the percentage of

Fig. 23. Characteristic cross-section of basin sediments as illustrated by an east-west transect across basin A.


W
BASIN A
E
A1&2
A3
A4
A5
A6
A7
LEGEND
Sand
Sandy Clay
Silty Clay
Boundary Uncertain
v Core Location
1m
0
0
500 m

silt and clay above the sand wedge as well as below it. Evidence for more moisture is also indicated in near-surface layers where weathering of feldspars and increases in quartz percentages occur. These changes may be related to present-day climatic conditions.

Nonetheless, all of the above work fits fairly well into the general climatic model which has been developed for the midwestern United States. This model, derived largely from studies of past vegetation, is one of gradual increases in warmth and dryness from about 8500 years ago to maxima around 7000 years ago, and gradual decreases in these factors to more or less present conditions about 4000 years ago (Dean and others, 1984).

Within this general climatic model, however, evidence is growing that there may have been significant shorter-term fluctuations. Callender (1968) suggested a number of high lake levels for Devils Lake. Moran and others (1976) cite evidence from slough sediments and loess deposits along the Missouri River that the Holocene was characterized by alternating warm, dry periods and cool, moist periods. Clayton and others (1976) present much the same concept, emphasizing many such fluctuations in late Holocene time. Bryson and others (1970) argued that Holocene climate, rather than being typified by gradual change, was punctuated by numerous rapid transitions from dry to moist periods. This study has shown many fluctuations in texture and mineralogy, many of which have likely been accentuated by the ephemeral nature of the basins.

One particular portion of the Holocene has been generating a great deal of recent work. Evidence is growing that during the period from approximately 8000 years ago to 4000 years ago, two major drying periods were experienced (Benedict, 1979; Dean and others, 1984; Holliday, 1982, 1983). Although the lack of reliable dating methods makes correlation with other work impossible, there is some evidence in the sediments from this study that suggests two periods of drying. In some cores two oxidized zones within the basin sediments can be seen. Two major fluctuations in quartz and quartz/feldspar ratios have been identified in some cores, as well as two major pulses of texture change. In many cases these fluctuations of different factors, such as oxidized zones and texture, can be correlated from core to core.

Conclusions

The results of this study have provided the basis for a number of conclusions:

1) The basins at one time had standing water in them; the association of textures and dominant colors attest to that. The degree of mottling in most of the cores, however, gives evidence that these basins have experienced repeated water-table fluctuations, even possibly during the

most moist period. The fact that most basins flood and dry periodically even now, and are at least wet enough to prevent their cultivation, further confirms that these are ephemeral in character.

2) One of the reasons for this ephemeral nature is that the basins are so shallow, on the order of 3-5 m deep. Their depth is very likely related to their origin, as it was postulated that they are deflation basins. Their elongation is parallel to prevailing winds, past and present, and during maximum glaciation in North Dakota their elongation would have paralleled prevailing winds and storm winds along the ice front. The sediments around the basins are basically composed of the fine to very fine sands and silts, typical of eolian activity. The sediments in the basins show evidence for past eolian activity as a major part of the depositional and erosional history of the basins. The results of this study support a deflational origin for these basins.

3) This study confirms that the sediments from the various basins have a related geologic history. The mineralogy and textures of the basin sediments provided a number of good points of correlation. The sediments within basins showed coherent transects of minerals and textures across basins. When correlations were made of cores from basin to basin, the same high levels of significance were obtained, especially when comparing cores from similar environments. It is important to note that the correlations involved the

entire length, or nearly so, of all the cores that were compared. This means that the entire history of the sediments in the basins was involved, and not just isolated and possibly random segments.

4) One of the major goals of this study was to investigate the role that past climates may have played in the history of the basin sediments. As the basin sediments do confirm a related geologic history, one possible regional control is climate. When the geologic evidence from this study is placed into the Holocene climatic sequence which has been worked out for this area, the fit is very good. There is even some evidence in the basins for a two-stage Hypsithermal, which is being investigated by a number of people at the present time. Lacking reliable dates, and using one radiocarbon date which gives a maximum age for the sediments, it appears that the sediments in the basins are basically Holocene in age.

5) This age for the sediments and other geologic evidence obtained during the course of the study show that the age of the basins is significantly older than the sediments presently in them. Very high Q/F ratios, one seemingly asymptotic, and oxidized zones associated with the bedrock surface indicate that the basins were exposed to an extensive period or periods of weathering. An age of early Wisconsinan or before seems entirely reasonable.

6) The presence of large Q/F values and oxidized zones associated with the bedrock surface were extremely useful in solving a major problem which developed in this study. As the basin sediments were derived from the bedrock on which they were being placed, this contact was difficult to determine. The bedrock differs from the overlying sediments in that it tends to have:

a) Higher quartz/feldspar values

b) Well developed oxidized zones

c) Increased percentages of quartz

d) Thin organic matter horizons

e) A higher degree of induration

f) Stringers of lignite _in situ_.

All these factors aided in the identification of bedrock; in some cores and trenches, bedrock was identified exactly, whereas in others, where the contact was more subtle, estimates had to be made. Using all the above information, these estimates could be made with confidence.

7) One of the best pieces of evidence for identifying bedrock, the presence of lignite stringers, proved to be the source of another major problem; that is, organic contamination of samples. Contamination of the sediments, in these basins and the area, by Tertiary pollen and lignite, will continue to be a major problem in dating unless some method or uncontaminated material can be found which will produce reliable dates.

APPENDICES

APPENDIX I

CORE DESCRIPTIONS

TABLE 7

CORE DESCRIPTIONS*

Interval (cm)	Texture	Color	Remarks
		CORE A1	
0-25	Sand	10/YR/3/3 Dark brown	
25-51	Silty sand	10/YR/3/3 Dark brown	clay particle 3mm
51-76	Silty sand	10/YR/4/3 Brown	silt lessening
76-102	Silty sand	10/YR/4/3 Brown	
102-107	Silty sand	10/YR/4/3 Brown	
		CORE A2	
0-25	Silty sand	10/YR/3/3 Dark brown	
25-51	Silty sand	10/YR/4/3 Brown	
51-61	Silty sand	10/YR/4/3 Brown	silt lessening
61-86	Silty sand	10/YR/4/3-4 Brown to Dark yellowish brown	few coarser particles some lignite chips
86-112	Silty sand	2.5Y/5/4 Light olive brown	lignite chips silt lessening
112-137	Silty sand	2.5Y/5/4-6/4 Light olive brown to Light yellowish brown	lignite chips present
137-163	Silty sand	2.5Y/5/4-6/4 Light olive brown to Light yellowish brown	small bright orange oxidation flecks
163-188	Silty sand	2.5Y/5/4-6/4 Light olive brown to Light yellowish brown	some oxidation increase
188-213	Silty sand	5Y/5/4 Olive	silt content less
213-226	Silty sand	5Y/5/4 Olive	

* Cores are described from top to bottom.

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE A2 (cont.)			
226-239	Silty sand	5Y/6/3 Pale olive	
239-252	Silty sand	5Y/6/3 Pale olive	bottom 1.5 cm peat to lignite layer
252-254	Silty clay	5Y/7/4 Pale yellow	few sand grains
254-269	Silty clay	5Y/3/2-4 Dark olive gray to Dark olive	fragments of more indurated material lignite flakes and chunks
269-290	Silty clay	5Y/3/2 Dark olive gray	parallel partings of core
CORE A3			
0-15	Silty sand	10YR/3/2 Very dark grayish brown	sand grains somewhat aggregated
15-36	Silty sand	10YR/3/2 Very dark grayish brown	
36-61	Silty sand	10YR/Dark brown	silt fraction reduced
61-81	Sand	10YR/4/3 Dark brown to Brown	
81-107	Sand	10YR/3/3 Dark brown	
107-117	Sand	10YR/3/3 Dark brown	grains aggregating
117-142	Sand	7.5YR/3/2 Dark brown	silt/clay fraction increase
142-168	Silty sand	10YR/3/3 Dark brown to Dark yellowish brown, 10YR/4/4-6, in lower portion of interval	165 cm oxidized through core core cohesive
168-198	Silty sand to clay with depth	10YR/4/4 Dark brown to 10YR/5/6 Yellowish brown 5Y/4/3 Olive in clay portion of interval, mottled	abrupt change in particle size at 188 cm clay layer begins

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE A3 (cont.)	
198-224	Clay	5Y/5/3 Olive upper 5 cm 10YR/5/6-8 Yellowish brown, mottled	upper 5 cm sandy clay
224-249	Silty sand with clay pebbles	10YR/3/2 Very dark grayish brown, mottled	some cobble-size clay agglomerates
249-279	Silty clay	10YR/3/1 Very dark gray mottled 5Y/6/2 Light olive gray	
		CORE A4	
0-31	Silty sand	10YR/3/2 Very dark grayish brown to 10YR/2/2 Very dark brown	
31-63	Silty sand	10YR/3/2 Very dark grayish brown	blebs of gypsum
63-86	Sandy/silty clay	2.5Y/3/2 Very dark grayish brown to 2.5Y/4/4 Olive brown	core more cohesive due to increase in fine material
86-112	Sandy clay	2.5Y/3/2 Very dark grayish brown to 2.5Y/4/2 Dark grayish brown	two quartzite pebbles found at 104 cm some medium to coarse sand
112-139	Sandy clay	2.5Y/3/2 Very dark grayish brown to 2.5Y/4/2 Dark grayish brown	
139-163	Clay	5Y/4/2 Olive gray mottled with 10YR/5/8 Yellowish brown to 10YR/6/8 Brownish yellow	142 cm calcareous blebs and oxidized zone
163-188	Clay	5Y/5/2 Olive gray with oxidation mottles as in above section, 139-163	oxidation increases slightly

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE A4 (cont.)	
188-213	Clay	5Y/5/2 Olive gray with oxidation mottles	oxidation increases slightly
213-226	Clay	5Y/5/2 Olive gray with oxidation mottles	oxidation increasing lignite present
226-239	Clay	7.5YR/4/0 Dark gray	concentration of lignite
239-264	Clay	7.5Yr/4/0 Dark gray to 10YR/4/2 Dark grayish brown with 10YR/6/8 mottles to 257 cm 10YR/3/2 Very dark grayish brown to Black below 257 cm	lignite dominant from 257-264 cm with lignite stringers appearing
264-315	Silty clay	10YR/2/2 Very dark brown to 10YR/4/2 Dark grayish brown to 298 cm Lighter gray below 10YR/5/2	core very dry and blocky more indurated
		CORE A5	
0-25	Silty sand	10YR/3/3-4 Dark brown to Dark yellowish brown	
25-51	Silty sand	10YR/3/3 Dark brown	
51-76	Silty sand	10YR/2/2 Very dark brown	silt increase
76-89	Sand	10YR/2/2 Very dark brown to 10YR/3/6 Dark yellowing brown in lower portion of interval	
89-114	Sand	10YR/2/2 Very dark brown to 10YR/3/3 Dark brown in lower portion of interval	some coarse sand particles
114-122	Clayey sand	10YR/3/3 Dark brown	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE A5 (cont.)			
122-140	Silty clay	2.5Y/4/2 Dark grayish brown with oxidation mottling	silt decreasing in lower part of interval
140-165	Silty clay	5Y/4/2 Olive gray with oxidation mottling	clay increasing cohesiveness of core
165-191	Silty clay	5Y/4/2 Olive gray to 5Y/4/3 Olive with oxidation mottling	silt fraction decreases
191-198	Silty clay	5Y/4/2 Olive gray with oxidation mottling	silt increase and some very fine sand present
198-224	Silty clay	5Y/4/2 Olive gray grading downward to 5Y/5/2 Olive gray	some very fine sand upper 5 cm oxidation increase
224-254	Silty clay	5Y/4/3 Olive with yellowish mottles	silt fraction decreasing
CORE A6			
0-28	Silty clay	10YR/3/2 Very dark grayish brown	pebbles at 18 cm
28-56	Clayey silt	10YR/5/2 Grayish brown to 10YR/6/2 Light grayish brown, with a few scattered oxidized particles	some sand with a few coarse sand particles present
56-81	Clayey silt	10YR/4/2 Dark grayish brown with 5Y/4/3 Olive in bottom half of interval scattered oxidized particles	a few gypsum particles present
81-107	Clayey silt	5Y/4/3 Olive scattered oxidized particles	grades to silty clay in lower portion of interval a few gypsum particles present

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE A6 (cont.)	
107-127	Clay	5Y/4/2 Olive gray to 5Y/4/4 Olive scattered oxidized particles	slight oxidized zone at 112 cm
127-163	Clay	5Y/4/4 Olive mottled with 5Y/5/6	
163-188	Clay	5Y/4/4 Olive mottled with 5Y/5/6	clusters of gypsum particles
188-213	Clay	5Y/4/4 Olive to 5Y/5/4 Olive 2.5Y/5/6 Light olive brown layer at 208 cm	gypsum particles, one cluster 1 cm across
213-239	Clay	5Y/3/2 Dark olive gray to 5Y/5/4 Olive to 2.5Y/6/6 Olive yellow, mottled some 7.5YR/5/6 Strong brown along partings	
239-254	Clay	5Y/4/2 Olive gray to 5Y/5/6 Olive	small gypsum layer
254-280	Silty clay	5Y/4/3 Olive to 5Y/5/4 Olive	2 cm thick organic matter layer at 254 cm
280-305	Silty clay	5Y/4/3 Olive lighter zone 2.5Y/6/6 Olive yellow at 295 cm	lamination of thin lignite stringers
		CORE A7	
0-25	Clayey sand	10YR/3/3 Dark brown	rock fragment at 13 cm, 2 cm in diameter
25-48	Clayey sand	10YR/3/3 Dark brown to 2.5Y/4/2 Dark grayish brown in lower part of interval	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE A7 (cont.)	
48-76	Clayey sand	2.5Y/4/2 Dark grayish brown	
76-97	Clayey sand	2.5Y/4/2 Dark grayish brown	granules at bottom of core
		CORE B1	
0-28	Silty sand	10YR/4/3 Dark brown to Brown	
28-53	Silty sand	10YR/4/3 Dark brown to Brown	silt fraction diminished
53-76	Silty sand	10YR/4/3 Dark brown to Brown	
76-99	Silty sand	10YR/4/3 Dark brown to Brown grading to 10YR/5/3 Brown in lower portion of interval	
99-140	Silty sand	2.5Y/4/4 Olive brown	silt fraction much less
140-185	Sand	5Y/4/3 Olive	some medium-size sand grains
185-213	Sand	2.5Y/4/4 Olive brown	some medium-size sand grains
213-236	Clay	5Y/5/2 Olive gray mottled with 5Y/7/3 Pale yellow	vertical sand fillings
236-254	Clay	5Y/5/2 Olive gray mottled with 5Y/7/3 Pale yellow	silt increasing in bottom of interval
254-297	Silty clay	5Y/4/2 Olive gray mottled with 5Y/8/2 Pale yellow	
		CORE B2	
0-25	Silty clay	5YR/3/1 Very dark gray	organic matter content high related to present vegetation
25-51	Silty clay	5Y/3/1 Very dark gray	
51-76	Silty clay	2.5Y/3/2 Very dark grayish brown	some sand-size material present

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE B2 (cont.)	
76-86	Silty sand	2.5Y/4/2 Dark grayish brown	some clay present
86-102	Sand	2.5Y/5/2 Grayish brown mottled with 2.5Y/5/6 Light olive brown	slight silt fraction
102-112	Clayey sand	2.5Y/5/2 Grayish brown mottled with 2.5Y/5/6 Light olive brown	
112-122	Silty clay	2.5Y/5/2 Grayish brown mottled with 2.5Y/5/6 Light olive brown	sand filling vertical cracks pebbles of ironstone at 114 cm
122-154	Silty clay	5Y/3/2 Dark olive gray to 5Y/6/3 Pale olive mottled with 10YR/6/8 Brownish yellow	sand increase in lower portion of interval
154-178	Silty clay	5Y/4/3 Olive mottled with 5Y/7/3 Pale yellow	oxidized patch or zone at 162 cm few sandy patches
178-203	Clay	5Y/5/3 Olive mottled with 5Y/6/8 Olive yellow 5Y/7/2 Light gray one basic color difficult to pick	slight silt fraction few sandy stringers associated with light gray color
203-229	Silty clay	5Y/5/3 Olive mottled with 5Y/6/8 Olive yellow 10YR/5/8 Yellowish brown oxidized zone	oxidized zone at 221 cm
229-249	Silty clay	5Y/5/3 Olive and Lighter olive	
249-279	Sandy silt	5Y/5/4 Olive top 4 cm 5Y/3/2 Dark olive gray	slight clay content some organic matter in top 3-4 cm increase in moisture

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE B2 (cont.)			
279-305	Sandy silt	5Y/4/4 - 5Y/5/4 Olive	thin layers of lignite blocky structure
305-330	Silty sand	5Y/4/3 Olive to 5Y/6/6 Olive yellow	lignite chips and horizontal layers
CORE B3			
0-25	Sandy clay	5YR/2.5/2 Dark reddish brown	
25-50	Sandy clay	10YR/3/1 Very dark gray to 10YR/3/2 Very dark grayish brown	oxidized patches
50-91	Clayey sand	2.5Y/3/2 Very dark grayish brown to 10YR/4/6 Dark yellowish brown lower portion of interval 5Y/5/4 Olive	clay fraction diminished
91-117	Clayey sand	5Y/4/3 Olive mottled with 10YR/5/6 Yellowish brown and shades in between	clay fraction further diminished
117-127	Clayey sand	5Y/4/3 olive mottled with 10YR/5/6 to 10YR/6/6 Yellowish brown and other shades	
127-147	Clayey sand	colors highly variable 10YR/5/1 Gray, 10YR/5/6 Yellowish brown, 5Y/5/1 Gray, 5Y/5/2 Olive gray, and others	
147-170	Clayey sand	colors highly variable 10YR/5/6 basic. 10YR/5/1 Gray, 5Y/5/1 Gray, 5Y/5/3 Olive gray some slight 2.5YR/2.5/4 Dark reddish brown	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE B3 (cont.)			
170-193	Clayey sand	colors now in larger patches 10YR/5/6 Yellowish brown, 5Y/5/1 Gray, 5Y/5/3 Olive gray, 2.5YR/2.5/4 Dark reddish brown but not abundant	
193-218	Sandy clay	colors varied, 10YR/5/6 Yellowish brown, 5Y/5/1 Gray, 5Y/5/3 Olive, 10YR/5/6 Yellowish brown through the core at 208 cm	
218-236	Clayey sand	5Y/5/3 Olive basic color	
236-262	Clayey sand	5Y/5/3 Olive	organic matter in upper 5 cm moisture content increase
262-287	Clayey sand	5Y/4/3 Olive 10YR/5/6 Yellowish brown in horizontal streaks	lignite chips
287-320	Clayey sand	5Y/5/3 to 5Y/5/4 Olive	clay increase moisture content still elevated lignite chips and possibly very thin stringers < 1mm
CORE F1			
0-25	Silty sand	7.5YR/3/2 Dark brown	ant head at 5 cm
25-36	Silty sand	7.5YR/3/2 Dark brown	few ant fragments
36-51	Silty sand	10YR/4/3 Dark brown to 10YR/4/4 Dark yellowish brown	
51-76	Silty sand	2.5Y/4/4 Olive brown to 2.5Y/5/4 Light olive brown	silt content down

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE F1 (cont.)	
76-102	Silty sand	5Y/4/3 to 5Y/5/3 Olive some 2.5Y/4/4 Olive brown	
102-127	Sand	5Y/5/2 Olive gray to 5Y/5/3 Olive	silt nearly gone
127-152	Sand	5Y/5/2 Olive gray to 5Y/5/3 Olive	
152-178	Sand	5Y/5/2 Olive gray to 5Y/5/3 Olive	
178-191	Sand	5Y/5/3 Olive bottom 5 cm 10YR/5/8 Yellowish brown and 5YR/3/3 Dark reddish brown oxidized zone	vertical calcareous fillings 0.5 cm thick large lignite fragments in oxidized zone
191-203	Silty sand	10YR/4/6 Dark yellowish brown mottled with 5YR/3/3 Dark reddish brown	lignite fragments
		CORE F2	
0-10	Silty sand	10YR/3/2 Very dark grayish brown	
10-25	Clayey silt	2.5Y/3/2 Very dark grayish brown	some sand present
25-51	Clayey silt	10YR/2/1 Black	sand present two pebbles at 38 cm
51-76	Silty Clay	10YR/2/1 Black	sand present core fairly moist
76-102	Silty clay	10YR/2/1 Black	core still fairly moist
102-114	Silty clay	2.5Y/3/2 Very dark grayish brown	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE F2 (cont.)			
114-145	Silty clay	10YR/3/2 Very dark grayish brown to 10YR/3/3 Dark brown in lower portion of interval	sand increase in lower portion of interval also, calcareous filling in vertical cracks
145-165	Silty sand	2.5Y/6/8 to 5Y/6/8 Olive yellow 10YR/5/8 Yellowish brown 2.5YR/2.5/4 Dark reddish brown stringers, core highly mottled	abrupt particle size change at 145 cm
165-170	Sand	2.5Y/5/6 Light olive brown to 2.5Y/6/6 Olive yellow	slight silt content
170-185	Silty sand	2.5Y/5/6 Light olive brown mottled with 10YR/6/8 Brownish yellow	
185-196	Silty sand	2.5Y/5/2 Grayish brown, tinge of olive	
196-208	Silty sand	2.5Y/5/4 to 2.5Y/5/6 Light olive brown	some medium sand grains some clay
208-221	Silty sand	color variable 2.5Y/5/4 to 2.5Y/5/6 Light olive brown, 2.5Y/6/8 Olive yellow, 7.5YR/5/6 Strong brown	some clay
221-246	Silty sand	wide variety of colors 2.5Y/5/2 Grayish brown, 2.5Y/5/4-2.5Y/5/6 Light olive brown, 2.5Y/6/6 Olive yellow salt and pepper appearance to core	clay causing core to be more cohesive

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE F2 (cont.)			
246-284	Silty sand	2.5Y/5/2 Grayish brown to 2.5Y/5/4 Light olive brown still salt and pepper appearance	core fairly cohesive
284-294	Silty sand	2.5Y/6/2 Light brownish gray	bottom 5 cm of core well consolidated
CORE F3			
0-25	Silty clay	10YR/2/2 Very dark brown upper 5 cm, remainder of core 2.5Y/2/0 Black	pebble at 13 cm
25-51	Silty clay	5Y/2.5/1 Black	
51-76	Silty clay	5Y/2.5/2 Black	some coarser sand-size particles
76-102	Silty clay	5Y/2.5/2 Black to 5Y/3/2 Dark olive gray at the bottom of the interval	slight clay increase two small pebbles at about 93 cm
102-117	Sandy silt	5Y/4/3 Olive grading to 2.5Y/4/4 in bottom of interval	
117-127	Sandy silt	2.5Y/5/6 Light olive brown	calcareous filling in vertical fracture
127-142	Silty sand	2.5Y/6/6-2.5Y/6/8 Olive yellow slightly mottled	
142-155	Silty sand	10YR/5/8 Yellowish brown, 10YR/6/6 Brownish yellow. Mottled	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE F3 (cont.)	
155-168	Silty sand	2.5Y/5/2 Grayish brown with 2.5Y/6/8 Pale yellow mottling	167-168 cm oxidized zone 2.5YR/2.5/4 Dark reddish brown
168-193	Silty sand	2.5YR/2.5/2 Very dusky red	calcareous layer at 168-170 cm some lignite fragments
193-218	Silty clay	colors variable: 10YR/5/2 Grayish brown, 5YR/6/2 Pinkish gray, flecks of 2.5YR/2.5/2 Very dusky red	
218-244	Silty clay to clay at bottom of interval	2.5Y/5/2 Grayish brown top 5 cm 7.5YR/6/8 Reddish yellow	finely disseminated lignite patches
244-285	Silty clay	2.5Y/5/2 Grayish brown to 2.5Y/6/2 Light grayish brown colors patchy	stringers of lignite
		CORE H1	
0-25	Sandy silt	10YR/3/2 Very dark grayish brown to 10YR/3/3 Dark brown	
25-51	Silty clay	2.5Y/3/2 Very dark grayish brown	ironstone pebble at 38 cm
51-76	Silty clay	5Y/3/2 Dark olive gray grading to 5Y/4/2 Olive gray in bottom half of interval	
76-86	Clay	5Y/6/2 Light olive gray mottled with 5YR/5/8 Yellowish red	
86-94	Clay	5Y/3/1 Very dark gray	
94-102	Silty clay	5Y/4/1 Dark gray	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
CORE HI (cont.)			
102-127	Clay	5Y/5/2 Olive gray at 117 cm in oxidation zone 5YR/5/8 Yellowish red, 2 cm thick, core mottled also	
127-152	Silty clay	5Y/4/3 - 5Y/5/3 Olive mottled with oxidized material	
152-178	Silty clay	5Y/5/2 Olive gray to 5Y/5/3 Olive mottled with oxidation patches, brightest color is 5YR/5/8 Yellowish red	157-162 cm gypsum crystals silt fraction lessened
178-203	Silty clay	5Y/5/2 Olive gray to 5Y/5/3 Olive, oxidation mottling, 7.5YR/6/6 Reddish yellow	
203-229	Silty clay	5Y/5/2 Olive gray to 5Y/5/3 Olive, oxidation 7.5YR/5/8 Strong brown	lignite particles disseminated through core
229-254	Silty clay	5Y/5/2 Olive gray to 5Y/5/3 Olive, mottling not as apparent	some gypsum crystals disseminated lignite
254-279	Silty clay	5Y/5/3 Olive to 5Y/6/3 Pale olive bottom 5 cm oxidized zone 10YR/6/6 Brownish yellow	well indurated toward bottom of interval calcareous layer at 258-259 cm organic matter layer at 259-261 cm
279-305	Clayey silt	2.5Y/6/6 Olive yellow with 7.5YR/5/8 Strong brown	

TABLE 7 (cont.)

Interval (cm)	Texture	Color	Remarks
		CORE It2	
0-28	Clayey silt	5Y/3/1 Very dark gray	
28-142	Silty clay	5Y/4/2 Olive gray slightly mottled	a few sand-size particles sediments have massive appearance in trench wall
142-183	Clayey silt within larger granules	5Y/5/3 Olive to 5Y/6/3 Pale olive patches of 5Y/6/8 Olive yellow	appears to be pebbly-granular texture from secondary cement highly calcareous
183-285	Silty clay	2.5Y/4/4 Olive brown, 5Y/4/3 Olive in spots oxidation mottling	
285-287	Silty clay matrix	10YR/5/8 Yellowish brown	ironstone concretions present, some 2-3 cm in size
287-318	Silty clay	5Y/5/4 Olive	particles of lignite present
318-323	Clay	10YR/6/8 Brownish yellow	irregular chunks well indurated
323-348	Clay	5Y/4/2 Olive gray to 5Y/5/3 Olive	chunky and well indurated

APPENDIX II

GRAIN-SIZE DISTRIBUTION BY WEIGHT

FOR SELECTED CORES

TABLE 8

Grain-Size Distribution for Selected Cores

CORE A1

Ø	Intervals (cm) 0-51	51-107
-4.0		
-3.5		
-3.0		
-2.5		0.28*
-2.0	0.13*	0.13
-1.5	0.00	0.00
-1.0	0.01	0.01
-0.5	0.07	0.08
0.0	0.08	0.06
0.5	0.14	0.13
1.0	0.15	0.13
1.5	2.47	1.91
2.0	20.01	21.10
2.5	26.10	26.64
3.0	18.39	15.70
3.5	6.41	4.86
4.0	3.42	2.41
4.5	3.96	2.06
5.0	3.97	2.06
5.5	0.53	0.25
6.0	0.53	0.26
6.5	0.79	0.77
7.0	0.80	0.78
7.5	1.05	0.77
8.0	1.06	0.78
8.5	1.59	1.02
9.0	1.59	1.03
9.5	0.53	0.78
10.0	0.53	0.78
10.5	1.01	0.48
11.0	1.02	0.49
11.5	1.07	0.68
12.0	1.08	0.69
12.5	1.07	0.68
13.0	1.08	0.69
13.5	1.07	0.46
14.0	1.08	0.46

CORE A7

Ø	Intervals (cm) 0-51	51-97
-4.0		
-3.5		
-3.0		
-2.5		
-2.0		0.22*
-1.5	0.54*	0.26
-1.0	0.37	0.23
-0.5	0.39	0.21
0.0	0.28	0.30
0.5	1.10	0.26
1.0	0.17	0.26
1.5	0.47	0.84
2.0	2.56	4.76
2.5	3.82	7.28
3.0	6.82	12.11
3.5	5.43	7.79
4.0	5.87	5.33
4.5	4.56	5.06
5.0	4.56	5.07
5.5	2.85	0.56
6.0	2.86	0.56
6.5	2.28	1.12
7.0	2.28	1.13
7.5	2.85	3.37
8.0	2.85	3.38
8.5	3.99	9.00
9.0	3.99	9.01
9.5	2.85	2.81
10.0	2.85	2.82
10.5	1.93	0.30
11.0	1.93	0.31
11.5	1.89	0.46
12.0	1.90	0.46
12.5	1.68	0.46
13.0	1.69	0.46
13.5	1.89	0.46
14.0	1.90	0.46

*weight in grams

TABLE 8 (cont.)

CORE A3

Intervals (cm)

Ø	0-114	114-165	165-191	191-198	198-203
-4.0					
-3.5					
-3.0					
-2.5					
-2.0					
-1.5		0.06*		0.08*	0.01*
-1.0	0.03*	0.03	0.06*	0.00	0.00
-0.5	0.01	0.09	0.04	0.04	0.00
0.0	0.09	0.09	0.04	0.04	0.00
0.5	0.21	0.15	0.06	0.04	0.02
1.0	0.18	0.14	0.05	0.02	0.02
1.5	2.98	2.41	1.40	0.09	0.05
2.0	22.03	15.58	19.87	0.32	0.84
2.5	21.84	15.35	18.45	2.28	4.34
3.0	18.98	14.63	13.30	1.58	3.77
3.5	7.74	6.65	7.06	1.75	5.13
4.0	3.60	4.91	3.65	1.12	2.85
4.5	1.04	1.92	0.27	0.55	1.17
5.0	1.05	1.92	0.28	0.54	0.27
5.5	1.30	3.57	2.17	0.54	0.28
6.0	1.31	3.57	2.18	3.79	0.83
6.5	1.04	1.36	10.16	3.80	0.83
7.0	1.05	1.37	10.16	4.33	1.93
7.5	1.57	1.37	0.27	4.34	1.94
8.0	1.58	1.37	0.27	4.33	1.66
8.5	2.08	1.37	0.27	3.20	1.10
9.0	2.09	1.37	0.28	3.20	1.10
9.5	1.30	1.64	0.27	3.30	1.11
10.0	1.31	1.65	0.27	2.71	1.93
10.5	0.55	0.97	0.08	2.71	1.94
11.0	0.56	0.97	0.09	2.23	0.81
11.5	0.25	0.96	0.08	2.24	0.82
12.0	0.26	0.97	0.09	2.27	0.96
12.5	0.50	1.21	0.08	2.27	0.97
13.0	0.51	1.21	0.09	2.27	0.85
13.5	0.25	0.96	0.01	2.27	0.86
14.0	0.26	0.97	0.01	2.43	0.96
				2.44	0.97

*weight in grams

TABLE 8 (cont.)

CORE A3 (cont.)

Intervals (cm)

ø	203-224	224-249	249-267	267-279
-4.0				
-3.5				
-3.0				
-2.5				
-2.0				
-1.5				
-1.0	0.03*	0.02*	0.58*	0.01*
-0.5	0.00	0.01	0.06	0.01
0.0	0.02	0.04	0.16	0.11
0.5	0.03	0.07	1.19	0.15
1.0	0.03	0.08	2.16	0.15
1.5	0.39	0.93	2.80	0.19
2.0	2.98	6.29	3.36	0.19
2.5	1.93	5.52	2.43	0.24
3.0	1.43	4.99	3.07	0.25
3.5	0.77	2.16	1.80	0.16
4.0	0.40	1.22	1.35	0.11
4.5	1.08	3.84	2.14	2.92
5.0	1.08	3.84	2.14	2.92
5.5	1.62	1.10	2.14	0.73
6.0	1.62	1.10	2.14	0.73
6.5	3.23	1.65	2.14	0.36
7.0	3.24	1.65	2.14	0.37
7.5	4.86	3.29	2.67	1.82
8.0	4.86	3.30	2.68	1.83
8.5	5.39	3.84	2.67	1.46
9.0	5.40	3.85	2.68	1.46
9.5	6.47	3.29	3.21	0.73
10.0	6.48	3.30	3.21	0.73
10.5	1.85	1.35	2.06	0.33
11.0	1.86	1.36	2.06	0.34
11.5	1.90	1.57	1.99	0.37
12.0	1.90	1.57	1.99	0.38
12.5	1.90	1.57	1.99	0.37
13.0	1.90	1.57	1.99	0.38
13.5	1.90	1.57	1.99	0.37
14.0	1.90	1.58	1.99	0.38

*weight in grams

TABLE 8 (cont.)

CORE A5

Intervals (cm)

Ø	0-51	51-81	81-89	89-132	132-165	165-198	198-206	206-254
-4.0								
-3.5								
-3.0	0.85*							
-2.5	0.00							
-2.0	0.00		0.17*					
-1.5	0.13	0.04*	0.27			0.12*	0.05*	
-1.0	0.04	0.03	0.07	0.08*		0.11	0.03	0.01*
-0.5	0.09	0.11	0.33	0.34	0.02*	0.23	0.10	0.01
0.0	0.30	0.30	0.68	0.85	0.04	0.18	0.10	0.04
0.5	0.22	0.33	0.40	0.74	0.06	0.20	0.09	0.02
1.0	0.17	0.22	0.30	0.44	0.06	0.18	0.05	0.02
1.5	1.93	2.74	2.77	3.83	0.09	0.17	0.17	0.03
2.0	12.90	14.72	15.12	20.20	0.24	0.22	0.78	0.12
2.5	13.13	13.60	13.92	17.01	0.25	0.19	0.91	0.18
3.0	15.27	13.28	12.69	13.66	0.28	0.30	0.91	0.21
3.5	9.38	7.20	7.12	6.78	1.65	1.97	1.09	0.53
4.0	7.91	5.43	4.25	4.63	4.50	4.90	1.75	1.23
4.5	2.33	3.08	3.12	5.65	7.58	7.85	4.04	5.81
5.0	2.34	3.08	3.12	5.66	7.59	7.86	4.04	5.81
5.5	2.04	2.23	0.57	0.80	7.59	8.29	2.96	6.34
6.0	2.04	2.24	0.57	0.81	7.59	8.29	2.96	6.35
6.5	1.17	1.39	0.56	0.54	5.06	5.73	1.61	6.34
7.0	1.17	1.40	0.57	0.54	5.06	5.74	1.62	6.35
7.5	0.87	1.73	0.57	1.08	2.53	2.55	1.08	4.75
8.0	0.87	1.74	0.57	1.08	2.53	2.55	1.08	4.76
8.5	1.17	0.78	1.13	1.88	1.26	2.54	0.54	3.70
9.0	1.17	0.78	1.13	1.88	1.27	2.55	0.54	3.70
9.5	0.87	1.40	0.70	2.69	0.63	1.91	3.50	2.64
10.0	0.88	1.40	0.70	2.70	0.63	1.92	3.50	2.65
10.5	1.23	1.16	0.76	1.28	3.63	2.36	0.26	2.16
11.0	1.23	1.17	0.77	1.29	3.64	2.37	0.27	2.16
11.5	0.97	1.19	0.85	1.37	3.77	2.68	0.27	2.16
12.0	0.97	1.20	0.86	1.37	3.78	2.69	0.27	2.17
12.5	0.97	1.19	0.64	1.09	3.77	2.46	0.27	1.97
13.0	0.97	1.20	0.65	1.10	3.78	2.46	0.27	1.97
13.5	1.21	1.19	0.85	1.37	3.99	2.68	0.27	2.16
14.0	1.21	1.20	0.86	1.37	4.00	2.69	0.27	2.17

*weight in grams

TABLE 8 (cont.)

CORE B2

Intervals (cm)

Ø	0-25	25-51	51-76	76-102	102-114	114-135	135-155
-5.0							
-4.5							
-4.0							
-3.5							
-3.0							
-2.5					0.41*		0.24*
-2.0					0.20		0.00
-1.5	0.05*	0.08*			0.14		0.00
-1.0	0.03	0.09	0.05*		0.16	0.04*	0.01
-0.5	0.02	0.07	0.02	0.02*	0.15	0.01	0.01
0.0	0.04	0.08	0.03	0.07	0.10	0.03	0.02
0.5	0.03	0.09	0.02	0.04	0.07	0.03	0.01
1.0	0.05	0.09	0.07	0.04	0.08	0.03	0.02
1.5	0.19	0.36	0.23	0.27	0.25	0.08	0.06
2.0	1.28	1.92	1.45	2.15	1.34	0.45	0.38
2.5	2.28	3.03	2.61	3.64	1.92	0.75	0.62
3.0	2.25	2.65	2.88	4.49	2.25	0.78	0.68
3.5	2.41	3.06	3.60	6.28	2.21	1.20	1.76
4.0	1.61	2.03	2.68	4.86	1.19	1.20	3.66
4.5	0.51	0.60	0.76	0.79	0.25	0.65	2.14
5.0	0.51	0.61	0.76	0.79	0.26	0.65	2.14
5.5	0.51	1.01	0.76	1.18	0.25	1.20	2.14
6.0	0.51	1.01	0.76	1.19	0.26	1.21	2.14
6.5	1.53	1.41	1.14	0.92	0.07	1.11	0.85
7.0	1.54	1.42	1.15	0.92	0.08	1.11	0.86
7.5	1.87	2.22	0.76	0.92	0.33	0.83	0.64
8.0	1.88	2.22	0.76	0.92	0.33	0.84	0.64
8.5	2.89	2.22	1.33	1.05	0.22	0.55	0.53
9.0	2.90	2.22	1.34	1.05	0.22	0.56	0.54
9.5	2.89	2.22	7.62	0.79	0.11	0.46	0.43
10.0	2.90	2.22	7.62	0.79	0.11	0.47	0.43
10.5	1.73	2.58	1.63	1.84	0.73	1.05	0.90
11.0	1.73	2.58	1.64	1.85	0.73	1.06	0.90
11.5	1.63	2.66	1.68	1.89	0.67	1.09	1.07
12.0	1.64	2.66	1.68	1.90	0.68	1.10	1.08
12.5	1.73	2.66	1.67	1.89	0.72	1.15	1.00
13.0	1.74	2.66	1.68	1.90	0.72	1.16	1.00
13.5	1.73	2.66	1.68	1.89	0.72	1.15	1.07
14.0	1.74	2.66	1.68	1.90	0.72	1.16	1.08

*weight in grams

CORE B2 (cont.)

TABLE 8 (cont.)

Intervals (cm)

Ø	155-183	183-216	216-229	229-249	249-279	279-305
-4.0						
-3.5			2.24*			
-3.0			0.00			
-2.5			1.54			
-2.0			0.33			
-1.5			0.36			
-1.0			0.12		0.01*	
-0.5			0.11		0.00	
0.0	0.01*	0.01*	0.10	0.01*	0.01	0.01*
0.5	0.02	0.02	0.09	0.02	0.02	0.02
1.0	0.02	0.02	0.09	0.02	0.02	0.02
1.5	0.02	0.02	0.07	0.03	0.02	0.03
2.0	0.03	0.03	0.07	0.04	0.06	0.04
2.5	0.10	0.39	0.11	0.06	0.11	0.23
3.0	0.42	2.14	0.20	0.12	0.93	2.64
3.5	1.29	2.08	0.36	0.18	4.02	12.79
4.0	2.18	1.51	0.41	0.37	5.40	12.30
4.5	1.78	1.64	0.58	0.87	4.02	1.42
5.0	1.78	1.64	0.58	0.87	4.02	1.43
5.5	2.89	3.75	2.03	4.70	6.12	2.23
6.0	2.90	3.75	2.04	4.71	6.13	2.24
6.5	1.11	4.22	1.64	3.31	2.29	0.91
7.0	1.12	4.22	1.65	3.32	2.30	0.92
7.5	2.00	2.81	1.26	2.26	1.34	0.81
8.0	2.01	2.81	1.26	2.27	1.34	0.82
8.5	2.45	1.40	1.16	1.57	0.76	0.61
9.0	2.45	1.41	1.16	1.57	0.77	0.61
9.5	1.33	1.40	0.77	0.87	0.76	0.51
10.0	1.34	1.41	0.78	0.87	0.77	0.51
10.5	2.82	2.14	1.01	1.37	0.89	0.73
11.0	2.83	2.14	1.02	1.38	0.90	0.73
11.5	2.50	2.02	0.98	1.34	1.02	1.02
12.0	2.50	2.02	0.99	1.35	1.03	1.02
12.5	2.62	2.02	0.98	1.34	0.89	0.89
13.0	2.63	2.02	0.98	1.35	0.90	0.89
13.5	2.75	2.02	0.98	1.34	1.02	1.02
14.0	2.75	2.02	0.98	1.35	1.03	1.02

*weight in grams

TABLE 8 (cont.)

CORE F3

Intervals (cm)

Ø	4-25	25-51	51-76	76-102	102-117	117-127	127-142
-4.0							
-3.5							
-3.0							
-2.5			0.30*				
-2.0		0.06*	0.06				
-1.5		0.20	0.25			0.14*	
-1.0	0.09*	0.06	0.08	0.10*	0.01*	0.04	
-0.5	0.12	0.11	0.11	0.11	0.04	0.01	
0.0	0.17	0.21	0.19	0.14	0.05	0.02	0.01*
0.5	0.10	0.10	0.13	0.07	0.03	0.02	0.02
1.0	0.08	0.05	0.09	0.05	0.03	0.02	0.02
1.5	0.16	0.13	0.08	0.15	0.16	0.10	0.14
2.0	0.72	0.81	1.01	1.10	2.25	2.45	3.90
2.5	2.55	2.82	3.64	3.98	10.73	16.63	25.23
3.0	2.33	2.33	2.83	3.35	9.01	11.29	12.63
3.5	1.74	1.73	1.85	2.35	5.43	4.76	4.72
4.0	1.09	1.14	1.33	1.34	2.04	1.80	1.74
4.5	1.11	1.14	1.18	1.15	0.76	0.12	0.33
5.0	1.12	1.15	1.19	1.15	0.77	0.12	0.34
5.5	1.95	2.00	1.78	1.72	1.33	0.95	1.00
6.0	1.95	2.01	1.78	1.73	1.34	0.96	1.00
6.5	1.70	1.72	2.07	2.01	1.14	0.71	0.77
7.0	1.70	1.72	2.08	2.02	1.15	0.72	0.78
7.5	2.78	2.86	2.97	2.30	1.72	0.71	0.66
8.0	2.79	2.87	2.97	2.30	1.72	0.72	0.67
8.5	3.62	4.58	4.45	4.32	2.29	0.95	0.55
9.0	3.62	4.58	4.45	4.32	2.29	0.96	0.56
9.5	4.45	10.31	5.04	4.32	3.63	0.83	0.66
10.0	4.46	10.31	5.05	4.32	3.63	0.84	0.67
10.5	2.85	1.24	3.15	3.34	2.04	1.87	1.66
11.0	2.86	1.24	3.15	3.34	2.05	1.87	1.66
11.5	3.22	1.68	3.40	3.22	2.06	1.95	1.87
12.0	3.23	1.69	3.41	3.22	2.06	1.95	1.87
12.5	3.06	1.51	3.22	3.22	2.06	1.95	1.68
13.0	3.07	1.52	3.23	3.22	2.06	1.95	1.69
13.5	3.06	1.68	3.22	3.22	2.06	1.95	1.87
14.0	3.07	1.69	3.23	3.22	2.06	1.95	1.87

*weight in grams

TABLE 8 (cont.)

CORE F3 (cont.)

Ø	Intervals (cm) 142-154	154-168	168-193	193-218	218-244	244-279
-4.0						
-3.5						
-3.0						
-2.5						
-2.0						
-1.5	0.01*					
-1.0	0.00		0.01*	0.04*	0.01*	
-0.5	0.00		0.02	0.02	0.01	
0.0	0.02	0.01*	0.04	0.07	0.02	
0.5	0.02	0.01	0.03	0.08	0.03	0.02*
1.0	0.02	0.02	0.05	0.13	0.03	0.05
1.5	0.05	0.03	0.15	0.23	0.11	0.08
2.0	1.21	0.82	0.23	0.28	0.27	0.10
2.5	18.17	18.12	0.45	0.34	0.37	0.14
3.0	17.98	17.49	0.56	0.39	0.33	0.16
3.5	6.07	7.01	0.60	0.51	0.29	0.20
4.0	1.99	2.33	0.47	0.74	0.25	0.16
4.5	0.40	0.79	0.22	2.02	1.06	0.99
5.0	0.40	0.79	0.23	2.02	1.06	1.00
5.5	0.93	1.24	1.00	5.73	4.58	3.31
6.0	0.93	1.24	1.00	5.73	4.59	3.31
6.5	1.06	1.13	1.11	4.04	3.52	4.96
7.0	1.07	1.13	1.12	4.05	3.53	4.97
7.5	1.06	1.69	1.33	4.38	4.58	5.95
8.0	1.07	1.70	1.34	4.38	4.59	5.96
8.5	1.86	2.03	0.83	6.74	5.64	5.62
9.0	1.86	2.04	0.84	6.74	5.64	5.63
9.5	1.59	1.47	0.44	4.38	5.29	12.24
10.0	1.60	1.47	0.45	4.38	5.29	12.25
10.5	1.67	0.84	0.12	1.12	2.60	0.00
11.0	1.67	0.85	0.12	1.63	2.61	0.00
11.5	1.57	0.70	0.17	1.59	2.72	0.00
12.0	1.58	0.70	0.18	1.60	2.72	0.00
12.5	1.57	0.70	0.14	1.60	2.54	0.00
13.0	1.58	0.70	0.14	1.60	2.54	0.00
13.5	1.57	0.70	0.17	1.60	2.72	0.00
14.0	1.58	0.70	0.18	1.60	2.72	0.00

* weight in grams

TABLE 8 (cont.)

CORE It2

Intervals (cm)

ø	28-142	142-183	183-285	285-287	287-318	318-323	323-335
-5.0	1.14*	54.16*	9.13*	4.87*	0.16*	28.06*	
-4.5						8.56	
-4.0						16.42	
-3.5		3.54		3.45		3.39	
-3.0		11.76	5.33	0.0		8.19	
-2.5		14.81	2.02	0.0		0.47	
-2.0		11.06	1.08	0.0		0.64	
-1.5	0.35	6.45	0.41	0.0		0.87	
-1.0	0.16	3.20	0.15	0.17		0.52	
-0.5	0.17	1.59	0.00	0.36	0.02	0.27	0.04*
0.0	0.17	0.89	0.02	0.24	0.03	0.33	0.08
0.5	0.09	0.45	0.01	0.19	0.02	0.28	0.04
1.0	0.08	0.26	0.04	0.23	0.02	0.22	0.05
1.5	0.12	0.15	0.07	0.23	0.07	0.28	0.09
2.0	0.17	0.10	0.07	0.25	0.10	0.25	0.11
2.5	0.21	0.10	0.10	0.28	0.15	0.27	0.14
3.0	0.21	0.11	0.26	0.27	0.17	0.26	0.17
3.5	0.34	0.22	1.25	0.26	0.17	0.28	0.25
4.0	0.45	0.42	1.53	0.20	0.22	0.21	0.26
4.5	0.62	0.76	1.77	0.18	1.75	0.19	0.66
5.0	0.62	0.76	1.78	0.19	1.75	0.20	0.67
5.5	1.86	2.73	6.75	0.45	5.95	0.49	1.65
6.0	1.86	2.74	6.75	0.46	5.96	0.49	1.66
6.5	2.79	6.69	6.39	0.73	5.95	0.68	2.32
7.0	2.79	6.69	6.40	0.73	5.96	0.69	2.32
7.5	4.65	2.73	5.68	1.55	6.30	1.66	5.63
8.0	4.66	2.74	5.69	1.55	6.31	1.67	5.63
8.5	4.96	0.76	3.91	1.82	4.90	2.35	7.29
9.0	4.97	0.76	3.91	1.83	4.91	2.35	7.29
9.5	4.03	0.30	4.62	1.55	3.15	1.66	5.51
10.0	4.04	0.31	4.62	1.55	3.16	1.67	5.52
10.5	3.08	4.71	1.54	1.77	1.67	6.76	2.51
11.0	3.09	4.71	1.54	1.78	1.67	6.77	2.52
11.5	3.07	4.90	1.68	1.89	1.78	6.99	2.36
12.0	3.07	4.90	1.69	1.90	1.78	6.99	2.37
12.5	3.07	4.72	1.49	1.89	1.78	6.99	2.36
13.0	3.07	4.73	1.50	1.90	1.78	6.99	2.37
13.5	3.07	4.90	1.68	1.97	1.78	6.99	2.36
14.0	3.07	4.90	1.69	1.97	1.78	6.99	2.37

*weight in grams

APPENDIX III

VARIATIONS IN SAND/SILT/CLAY PERCENTAGES WITH DEPTH FOR SELECTED CORES

TABLE 9

Sand/Silt/Clay Percentages

CORE A1

Interval (cm)	Sand	Silt	Clay
0-51	76.33%	11.83%	11.84%
51-107	82.57	8.44	8.99

CORE A3

Interval (cm)	Sand	Silt	Clay
0-114	80.35	9.83	9.82
114-165	68.21	17.03	14.76
165-191	71.90	26.41	1.69
191-198	13.16	40.08	46.76
198-203	47.03	21.96	31.01
203-224	12.53	31.24	56.23
224-249	33.69	28.42	37.89
249-267	30.60	27.44	41.96
267-279	11.38	54.54	34.08

CORE A5

Interval (cm)	Sand	Silt	Clay
0-51	73.47	13.26	13.27
51-81	67.83	17.67	14.50
81-89	77.49	11.26	11.25
89-132	67.51	14.77	17.72
132-165	10.27	52.27	38.46
165-198	12.65	54.59	32.76
198-206	17.98	53.69	28.33
206-254	3.28	59.11	37.61

CORE A7

Interval (cm)	Sand	Silt	Clay
0-51	36.43	29.76	33.81
51-97	48.69	21.99	29.32

TABLE 9 (cont.)

CORE B2

Interval (cm)	Sand	Silt	Clay
0-25	16.51	21.66	61.67
25-51	23.90	18.93	56.88
51-76	26.21	13.65	60.14
76-102	47.80	15.08	37.00
102-114	54.49	10.14	30.47
114-135	19.72	33.60	46.43
135-155	29.76	37.56	32.00
155-183	10.86	31.64	57.50
183-216	13.07	46.07	40.86
216-229	7.97	52.44	39.60
229-249	2.84	62.18	34.98
249-279	25.23	53.90	20.87
279-305	60.07	21.57	18.36
CORE F3			
4-25	13.68	23.31	63.01
25-51	14.69	22.92	62.04
51-76	16.49	21.59	58.33
76-102	19.39	20.10	60.39
102-117	44.32	14.47	41.17
117-127	63.02	7.71	29.04
127-142	70.39	7.61	22.00
142-154	61.96	9.86	28.13
154-168	67.78	13.86	18.36
168-193	21.06	51.91	26.81
193-218	5.03	46.33	48.22
218-244	2.77	39.85	57.38
244-279	1.56	45.27	53.17
CORE H1			
0-25	9.23	37.22	53.55
25-43	9.68	35.23	55.09
43-51	10.14	18.88	70.98
51-76	2.22	34.38	63.40
76-86	0.57	25.85	73.58
86-94	0.17	10.00	89.83
94-102	2.83	15.55	81.62
102-117	0.18	15.97	83.85
117-127	0.50	22.89	76.61
127-152	0.47	37.82	61.71
152-178	0.46	45.79	53.75
178-203	0.44	54.78	44.78
203-229	0.44	60.73	38.83
229-254	2.38	53.77	43.85
254-259	2.53	46.72	50.55
259-274	0.55	63.65	35.80
274-305	3.78	49.29	46.93

TABLE 9 (Cont.)

CORE IT2

Interval (cm)	Pebbles*	Sand	Silt	Clay
28-142		3.39	30.71	65.29
142-183	51.46	5.10	36.93	6.51
183-285		5.01	55.09	39.90
285-287	30.96	8.80	19.30	40.94
287-318		1.68	56.02	42.30
318-323	69.72	2.97	8.45	18.86
323-335		1.91	29.44	68.65

*Samples from this trench contained pebbles.

APPENDIX IV

CRITICAL LEVELS OF SIGNIFICANCE DERIVED FROM CROSS-ASSOCIATION OF TEXTURES AND MINERALS FROM SELECTED CORES

TABLE 10

Cross-Association of Textures

Cores Compared	Intervals Compared	Levels of Significance
A3 A5	0-279 cm 0-254 cm	6.18 $p<0.05$
A5 F3	0-205 cm 76-279 cm	2.83 $p<0.10$
A5 H1	0-254 cm 76-305 cm	6.22 $p<0.05$
A5 H1	0-254 cm 51-274 cm	6.22 $p<0.05$
A5 H1	0-254 cm 43-259 cm	3.19 $p<0.10$
B2 F3	0-249 cm 76-279 cm	12.43 $p<0.01$
B2 H1	0-305 cm 76-305 cm	5.00 $p<0.05$
B2 H1	0-330 cm 51-305 cm	6.76 $p<0.01$
B2 H1	0-368 cm 43-305 cm	8.66 $p<0.01$
B2 H1	0-393 cm 25-305 cm	4.55 $p<0.05$
F3 H1	4-279 cm 0-227 cm	3.05 $p<0.10$

The only levels of significance which are included in this appendix are those derived from comparisons involving significant lengths of each core.

The levels of significance shown are the result of the x^2 test.

TABLE 11

Cross-Association of Selected Minerals

Quartz

Cores Compared	Intervals Compared	Levels of Significance
A4 A6	0-315 cm 31-318 cm	7.50 p<0.01
A4 B2	76-315 cm 0-260 cm	2.16 p>0.10
A4 F3	31-315 cm 0-284 cm	3.15 p<0.10
A6 B2	30-412 0-395 cm	2.12 p>0.10
A6 F3	0-274 cm 4-284 cm	2.92 p<0.10
B2 F3	51-305 cm 0-284 cm	2.51 p>0.10

Montmorillonite

Cores Compared	Intervals Compared	Levels of Significance
A4 A6	0-315 cm 31-318 cm	11.17 p<0.01
A4 A6	0-315 cm 20-318 cm	4.80 p<0.05
A4 A6	0-315 cm 0-305 cm	4.80 p<0.05
A4 A6	31-315 cm 0-279 cm	5.93 p<0.05
A4 B2	0-315 cm 25-279 cm	8.58 p<0.01
A4 B2	0-315 cm 0-257 cm	3.30 p<0.10
A6 B2	0-412 cm 25-483 cm	5.32 p<0.05
A6 B2	20-412 cm 0-394 cm	8.99 p<0.01

TABLE 11 (cont.)

14Å Chlorite

A6	0-361 cm	3.77
B2	51-483 cm	$p<0.10$
A6	0-412 cm	3.06
B2	25-483 cm	$p<.010$
A6	20-412 cm	3.77
B2	0-394 cm	$p<0.10$

7Å Kaolinite/Chlorite

A6	0-412 cm	2.83
B2	25-483 cm	$p<0.10$
A6	20-412 cm	3.45
B2	0-394 cm	$p<0.10$

APPENDIX V

PEAK-HEIGHT INTENSITIES OF SELECTED MINERALS AS DERIVED FROM X-RAY DIFFRACTOGRAMS, FOR SELECTED CORES

TABLE 12

PEAK-HEIGHT INTENSITIES IN CENTIMETRES

CORE A4

Interval (cm)	Q*	F*	AS*	C*	Mo*	MI*	KC*	Ch*
0-32	23.0	10.2	0.4	0.2	0.0	0.5	0.3	0.0
32-61	24.3	12.5	0.0	0.6	0.0	0.6	0.3	0.0
61-86	17.8	2.9	0.1	0.5	0.2	0.8	0.5	0.2
86-112	20.0	1.7	0.0	0.2	0.2	0.9	0.6	0.3
112-137	15.0	4.9	0.0	0.1	1.0	1.4	1.0	0.4
137-163	7.7	1.1	0.0	0.3	1.4	2.0	1.6	0.5
163-188	7.7	1.1	0.0	0.3	0.5	1.7	1.5	0.1
188-213	9.4	1.8	0.0	0.3	3.5	3.9	2.0	1.0
213-224	11.4	1.3	0.0	0.3	3.0	5.2	1.8	0.7
224-239	8.2	0.5	0.0	0.2	4.5	1.3	0.5	0.0
239-257	6.8	0.4	0.0	0.2	3.0	1.0	0.4	0.0
257-264	17.1	2.8	0.0	0.3	1.9	4.5	0.4	0.0
264-269	21.6	0.4	0.0	0.1	1.6	0.7	0.3	0.0
269-297	25.4	0.5	0.0	0.1	1.5	1.1	0.3	0.0
297-315	25.5	0.7	0.0	0.1	3.0	1.2	0.4	0.0

CORE A6

Interval (cm)	Q*	F*	AS*	C*	Mo*	MI*	KC*	Ch*
0-20	9.9	0.8	0.0	0.2	0.0	0.1	0.0	0.0
20-31	13.4	1.4	0.0	0.1	0.0	0.1	0.0	0.0
31-51	17.0	2.2	0.0	0.9	0.0	0.5	0.3	0.0
51-76	12.2	1.6	0.0	0.3	0.0	0.6	0.3	0.0
76-107	10.4	1.6	0.0	0.6	0.4	1.0	0.7	0.2
107-112	6.0	1.2	1.6	0.9	0.2	0.6	0.6	0.1
112-137	8.8	1.7	0.0	0.8	0.8	1.2	1.0	0.3
137-163	7.3	1.4	0.2	0.7	0.3	0.7	0.6	0.1
163-188	6.6	1.0	0.0	0.6	0.2	0.4	0.4	0.0
188-213	8.3	1.4	0.0	0.6	0.7	1.3	1.1	0.3
213-239	7.0	0.9	1.1	0.6	0.5	1.2	0.9	0.2
239-254	7.8	1.2	0.0	0.5	0.8	1.7	1.1	0.3
254-274	8.0	1.5	1.8	0.8	0.4	0.7	0.5	0.2
274-279	9.9	1.6	0.9	0.4	0.4	0.6	0.6	0.1
279-305	8.7	2.6	1.3	0.5	0.3	0.7	0.5	0.0
305-318	7.7	0.8	1.2	0.5	0.6	0.7	0.5	0.2
318	6.6	0.7	0.8	0.4	0.2	0.6	0.3	0.0
318-343	8.0	0.7	0.6	0.5	0.3	0.7	0.6	0.1

*Q = Quartz
*F = Feldspar
*AS = Amorphous Silica
*C = Calcite
*Mo = Montmorillonite
*MI = Mica/Illite
*KC = 7Å Kaolinite/Chlorite
*Ch = 14Å Chlorite

TABLE 12 (Cont.)

CORE B2

Interval (cm)	Q*	F*	AS*	C*	Mo*	MI*	KC*	Ch*
0-25	10.4	0.9	1.7	0.3	0.2	0.2	0.2	0.0
25-51	7.0	1.3	4.5	0.2	0.0	0.2	0.2	0.0
51-76	5.9	1.3	4.3	1.0	0.0	0.2	0.0	0.0
76-102	4.0	0.9	5.6	0.8	0.0	0.1	0.2	0.0
102-114	9.9	2.3	1.5	0.9	0.1	0.3	0.2	0.0
114-117	2.2	0.7	1.3	0.4	0.0	0.0	0.2	0.0
117-135	9.7	1.1	3.0	1.5	0.3	0.3	0.4	0.1
135-155	12.3	1.5	2.1	1.3	0.7	0.4	0.5	0.1
155-160	12.2	3.6	0.4	1.2	0.7	0.8	0.7	0.2
160-163	4.5	1.2	1.7	0.6	0.0	0.2	0.2	0.0
163-183	12.2	3.6	0.4	1.2	0.7	0.8	0.7	0.2
183-216	9.2	1.2	0.2	1.0	0.5	0.5	0.5	0.2
216-229	8.1	1.8	0.9	0.7	0.2	0.4	0.4	0.1
229-254	14.1	3.5	0.2	0.7	0.4	0.9	0.6	0.2
254-257	13.2	8.3	0.7	0.9	0.5	0.7	0.5	0.2
257-279	8.0	1.3	2.3	0.4	0.1	0.2	0.1	0.0
279-305	10.5	1.2	2.6	0.6	0.3	0.2	0.2	0.1
305-330	10.0	1.0	0.2	0.5	0.1	0.1	0.1	0.0

CORE F3

Interval (cm)	Q*	F*	AS*	C*	Mo*	MI*	KC*	Ch*
0-4	11.3	1.6	0.0	0.3	0.8	1.0	0.3	0.0
4-25	12.3	3.7	0.0	0.2	1.3	1.1	0.4	0.0
25-51	12.4	2.7	0.0	0.4	1.7	1.2	0.3	0.0
51-76	14.2	3.6	0.0	0.3	1.6	1.0	0.4	0.0
76-102	11.3	3.4	0.0	0.3	2.8	1.7	0.5	0.0
102-117	10.3	4.5	0.0	0.2	2.7	1.0	0.5	0.0
117-127	14.6	4.4	0.0	0.9	4.0	0.9	0.5	0.0
127-142	23.0	9.4	0.0	0.2	3.3	0.7	0.6	0.0
142-153	15.1	5.0	0.0	0.5	3.3	0.8	0.5	0.0
153-168	17.3	3.4	0.0	0.2	3.3	0.9	0.4	0.0
168-193	2.7	0.0	0.0	1.8	0.4	0.0	0.0	0.0
193-218	19.8	0.3	0.0	0.2	1.9	2.3	0.0	0.0
218-244	19.1	0.3	0.0	0.2	3.4	2.8	0.4	0.0
244-284	22.8	0.6	0.0	0.3	3.5	2.7	0.5	0.0

CORE It2

Interval (cm)	Q*	F*	AS*	C*	Mo*	MI*	KC*	Ch*
28-142	9.3	0.4	0.0	0.5	0.1	0.7	0.5	0.0
142-183	2.3	0.5	0.0	6.5	0.0	0.3	0.4	0.0
183-285	12.2	1.9	0.0	1.3	1.5	2.4	2.2	0.4
285-287	3.9	0.4	0.0	0.8	0.2	0.9	0.5	0.2
287-318	8.3	1.3	0.0	1.0	0.7	1.8	1.5	0.3
318-323	3.3	0.5	0.0	0.5	0.2	1.1	0.6	0.2
323-335	11.0	1.5	0.0	1.0	0.6	2.3	1.9	0.3

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