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INTERRELATIONSHIPS BETWEEN GLACIALLY BURIED ORGANIC MATTER, THE BEDROCK SURFACE, AND THE PRESENT TOPOGRAPHY IN SOUTH-CENTRAL MICHIGAN: A CASE FOR MULTIPLE PALEOSURFACES

presented by

Bruce Lane Rhoads

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[signature]

Major professor

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By

Bruce Lane Rhoads

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ABSTRACT

INTERRELATIONSHIPS BETWEEN GLACIALLY BURIED ORGANIC MATTER, THE BEDROCK SURFACE, AND THE PRESENT TOPOGRAPHY IN SOUTH-CENTRAL MICHIGAN: A CASE FOR MULTIPLE PALEOSURFACES

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Well log reports of forty-six glacially buried Pleistocene organic deposits in south-central Michigan provide evidence of paleogeographic significance. Map comparisons are used to investigate interrelationships between the buried carbonaceous matter, the bedrock surface, and the present topography and landforms. No direct relationship exists between the regional configuration of the bedrock and the overall shape of the topography but local bedrock-landform associations are evident. The data also suggest that in the past the bedrock surface had a greater influence on the topography of the area. The process that perpetuated this widespread influence previously, however, appears eventually to have been restricted to locations on the present surface overlying the largest bedrock channels. Results of trend surface analysis indicate it is highly probable that the glacially buried carbonaceous deposits represent more than one paleosurface. These findings provide direct evidence for at least three and possibly several Pleistocene glacial events in south-central Michigan.

To my parents

whose support has made this all possible

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CHAPTER I

INTRODUCTION

Statement of Problem

Forty-six glacially buried Pleistocene organic deposits located within an area of south-central Michigan provide the basis for this research. The reports of carbonaceous material in the region are believed to (1) represent remnants of vegetation that accumulated (most likely at low topographic sites) on one or more ice-free paleosurfaces that (2) have been buried *in situ* by drift from an overriding ice sheet. The scarcity of reports describing non-*in situ* Pleistocene organic deposits tends to verify this assumption. But there is a possibility that some of the buried organic material may have been eroded by the ice and subsequently deposited along with glacial outwash. Dreimanis and Goldthwaite (1973, p. 90), however, studied trees buried by an advancing Pleistocene glacier in Ohio and Indiana and deduced that, if any of the organic matter was transported, it was not moved very far from its growth point. They also suggested that the limited, periglacial tree growth occurred mainly in valleys. All of these relationships, plus the relatively large number of reported carbonaceous zones in the area, provide evidence for one or more paleosurfaces that are suitable for analysis.

Objectives

The major objectives of this study are:

1) to map and describe the configuration of the bedrock surface within the study area

2) to indicate the relationships, if any, between the following:

   a) the bedrock surface and existing topography

   b) the bedrock surface and glacially buried organic deposits

   c) present surface features and glacially buried organic deposits

3) to determine, using trend surface analysis, whether the glacially buried organic deposits represent a single paleo-surface or multiple paleosurfaces

Justification

Pleistocene paleosurfaces can provide useful information for correlation of rock and soil stratigraphic units (Frye and Willman, 1960) and for determining the sequence of glacial events. White (1974, pp. 332-33) realized that these "contacts between drift sheets, are important paleogeomorphic elements for elucidation of Pleistocene history...." and he hoped (p. 333) that future research would involve "mapping and analysis of the paleosurfaces in drift sequences...." Horberg (1953, p. 8) called attention to the value of glacially buried organic deposits for differentiating drift sheets by including "extensive buried peat, wood, and other organic matter" and "relative positions of buried ... peat beds with reference to depth, elevation, stratigraphic interval and distance above bedrock" as two of six criteria for multiple glaciation.

A need for more research of the subsurface glacial drift in south-central Michigan has also been recognized. Farrand and Eschman, in their 1974 article summarizing current knowledge on the glaciation of the southern peninsula, stated (p. 39):

> Parts of the picture of pre-late Woodfordian stratigraphy in Michigan are coming to light, but the picture is still very fragmentary. No undisputed pre-Wisconsinan drift has been recognized, although it certainly must be present in the subsurface of those parts of the state [south-central] where the total drift sequence exceeds 500 feet [150 m].

They also point out (p. 39) that "subsurface information necessary for the delineation of lower surfaces is not yet adequate."

Rieck and Winters (1980, p. 87) realized the importance of glacially buried organic deposits to the understanding of Michigan glaciation:

> Moreover, they [glacially buried carbonaceous deposits] may provide additional data to support further recognition, formal establishment, and possible correlations of rock, soil, and time stratigraphic units on the basis of localized evidence from within the peninsula, a condition that, at present, is generally lacking for events that predate final glaciation of the state.

This study responds to these observations by determining whether one or more paleosurfaces are represented by the rather numerous and widespread glacially buried organic deposits in the study area. The results of the research will contribute to our knowledge of the subsurface drift sequence and pre-Woodfordian glacial chronology in south-central Michigan.

Statistical Comparison of Surface Configurations Using Trend Surface Analysis

Trend surface regression equation coefficients can be considered numerical descriptors of surface configurations.[1] Quantitative measures of similarity between surface shapes can be derived from these coefficients.

Miller (1964, pp. 676-77) suggested three ways of analyzing trend surface maps. These are "comparison of the dependent variable for fixed grid points," "direct comparison of the matrices," and graphic comparison of the equation coefficients.

Merriam and Sneath (1966) demonstrated a more sophisticated technique for determining the similarity between trend surfaces. They used the regression equation coefficients for the highest order fitted surfaces (excluding the base term) to compute two similarity measures--the correlation coefficient and taxonomic distance. These coefficients were first transformed so that higher terms of the equation contributed equally to the similarity measures as the lower terms.

In their example, third-degree trend surfaces were fitted to six geologic structural horizons in south-central Kansas. These surfaces were then grouped according to similarity of shape based upon both visual and statistical comparisons. Merriam and Sneath (p. 1113) found that "the grouping of surfaces with correlation coefficients and taxonomic distances substantiates the visual grouping completely." On the basis of these findings and conclusions, trend surface analysis

[1]Detailed discussions on trend surface analysis and its applications to geographic and geomorphic research are given in Chorley and Haggett (1965), Harbaugh and Merriam (1968), and Norcliffe (1969).

appears to be a reasonable and effective method for quantitatively describing and comparing surface configurations.

Study Area

The approximately 2700 km^2 study area includes parts of Clinton, Ionia, Montcalm, and Gratiot counties (Figure 1). The boundaries enclose 46 known glacially buried Pleistocene organic deposits including 22 referred to by Rieck and Winters (1980, p. 83, Figure 2B) as the Hubbardston cluster. The area is part of the Michigan physiographic province known as the Saginaw Lowland (Newcombe, 1933, p. 13, Figure 3). Undoubtedly, pre-Wisconsinan glaciation has occurred here (Dohr ahd Eschman, 1970, p. 159); however, no unequivocal evidence for such an event(s) has been identified. During the Wisconsinan stage, the area was affected by the southeast flowing Saginaw lobe of the Laurentide ice sheet. Final deglaciation of the region took place approximately 13,000-14,000 years ago to result in the Cary-Port Huron Interstade (Farrand and Eschman, 1974).

Literature Review

Glacially Buried Organic Deposits

Reports of organic matter within the glacial drift of Michigan have been few in number until recently. Most early findings were thought to represent remnants of the Sangamon Interglacial, thereby separating Wisconsinan from pre-Wisconsinan drift (Lane, 1899, p. 58-9; Leverett and Taylor, 1915, p. 192, 199; Sherzer, 1917, p. 8,

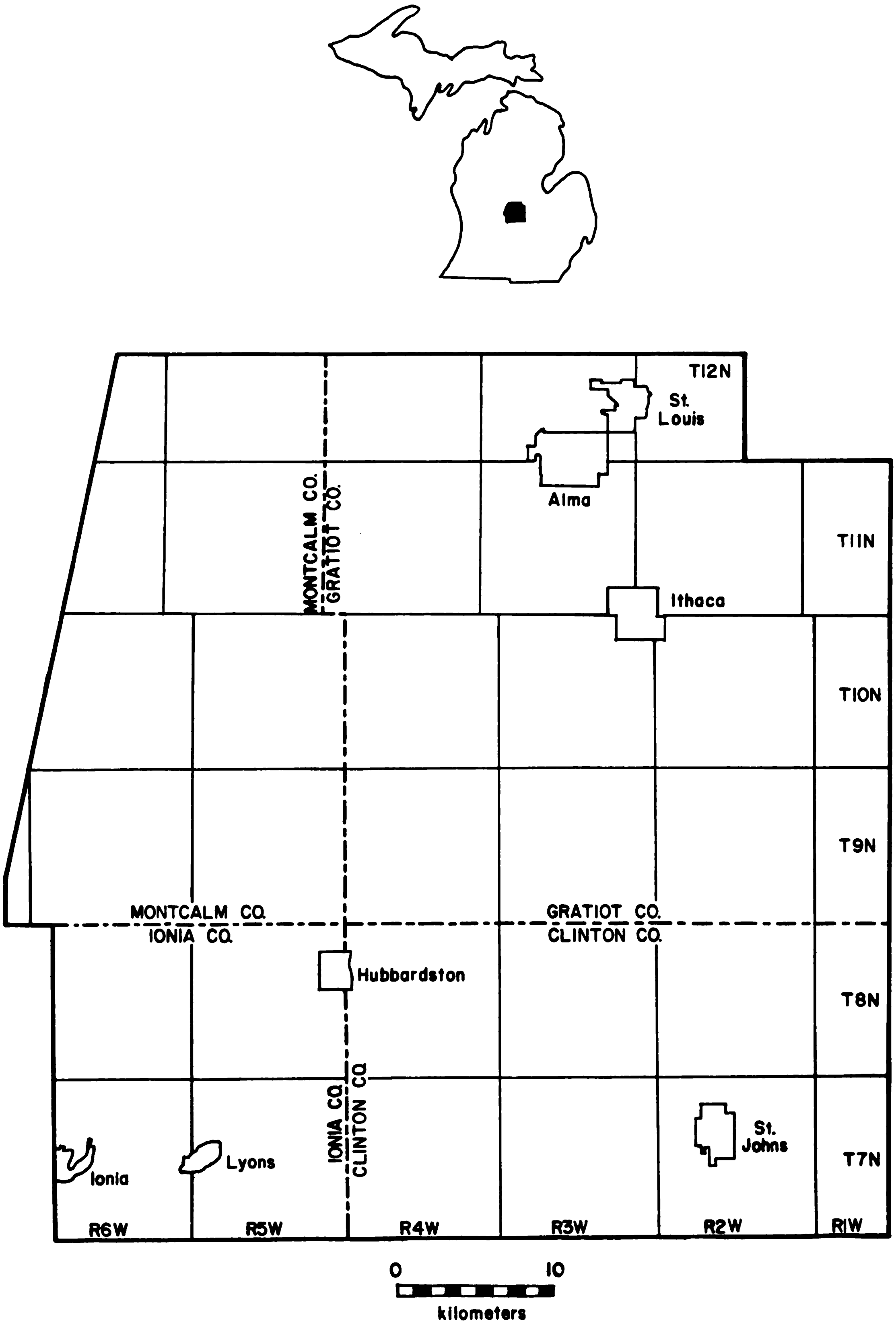

Figure 1. Study Area.

among others). Lately, an increase in the discovery, dating, and vegetal analysis of buried Pleistocene carbonaceous material has provided valuable information on the glacial chronology of Michigan.[2]

Within the study area samples of only one glacially buried organic deposit have been studied in detail. This material is from the Sanborn Farm site located within the SE¼ SE¼ NE¼ sec. 6, T. 8 N., R. 4 W. Clinton County (Appendix B, Well CL-5, and Figure 11). A sample of "wood and strongly humified organic sediment" from well cuttings recovered from a depth of 31.1 to 51.8 meters was radiocarbon dated as > 32,000 B.P. (Sullivan, Spiker, Rubin, 1970, p. 322). N. G. Miller (1973) analyzed the pollen assemblages of peat and clay samples from the carbonaceous horizon and found evidence indicative of a boreal environment. He (p. 222) tentatively correlated the samples with the John Ball Park buried organic deposits (Zumberge and Benninghoff, 1969) near Grand Rapids because of similarities in age and pollen composition. Miller further suggested (p. 222) a correlation with the mid-Wisconsinan Port Talbot Interstade (Dreimanis, Terasmae, and McKenzie, 1966) because the two Michigan pollen profiles closely resemble those of known Port Talbot age in Ontario.

As stated previously, Rieck and Winters (1980, p. 83) identified 22 glacially buried organic deposits (included in this study) within the study area. They suggested that more than one paleosurface may exist in the Hubbardston area due to the occurrence of organic

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[2]A complete synopsis of these discoveries is beyond the scope of this thesis. For further information, see Farrand and Eschman (1974), Rieck and Winters (1980), and Eschman (1980).

material at three distinctly different levels and one well log that reports two separate buried organic horizons.

The closest, dated sample of buried organic material outside of the study area is located approximately 20 km to the west on the Williams Farm in Otisco Township, Ionia County. Here, a piece of wood dated as > 30,000 B.P. (Crane and Griffin, 1961) was recovered from 26.5 m below the surface.

In summary, the finite ages of glacially buried Pleistocene carbonaceous matter within or near the study area are unknown; therefore, spatial or temporal associations between these deposits have not been established.

Interrelationships Between Glacially Buried Organic Deposits, Bedrock, and Surface Features

Rieck and Winters (1976, 1979, 1980) present evidence supporting the following interrelationships between buried organic deposits, the bedrock surface, and present surface features in south-central Michigan:

1) Glacially buried Pleistocene organic deposits tend to be located within or overlie valleys and low places on the buried bedrock surface.
2) Surface hydrographic features, especially the larger ones, tend to exist over bedrock valleys.

From these interrelationships, Rieck and Winters have hypothesized that low places on the preglacial surface were perpetuated during the Pleistocene so that to some degree present drainage channels conform with bedrock lows. Glacially buried organic deposits positioned between these corresponding features support the theory because characteristics of this material indicate that they probably accumulated in low, poorly drained topographic sites. They propose that ablation of ice buried in or over bedrock valleys may explain this phenomenon.

Rieck and Winters observed these interrelationships in areas of south-central Michigan where average drift thickness ranges from 20 to 40 m. This study will determine if these associations exist where the drift is much thicker and the underlying bedrock is at some places unconsolidated.

Bedrock Surface

Late in the 1800's J. W. Spencer (1891, p. 93), basing his study partially on a deep well near Alma that did not encounter bedrock, hypothesized that a large eastward-flowing preglacial river once existed in central Michigan. He thought that the Saginaw Lowland was the modern expression of this large bedrock valley. Mudge (1897, p. 384) agreed with Spencer and, on the basis of two borings near Ionia which struck bedrock at "moderate depths", placed the axis of the preglacial valley farther north than the present Grand River.

Spencer's interpretation was questioned by Lane (1899, p. 83), who maintained that the preglacial river drained not into Saginaw Bay but flowed westward between Ludington and Manistee toward the lowland now occupied by Lake Michigan. Because the Grand River channel is floored by bedrock near Ionia, he also dismissed Mudge's (1897) claim that the Grand River flows within a buried bedrock valley. The large preglacial valley is clearly shown on a bedrock surface map (contour interval 100 ft., 30.5 m) of the lower peninsula (Plate VI) included in Lane's report.

Leverett and Taylor (1915, p. 60) mentioned the Saginaw Lowland bedrock valley and reviewed its course. Their geologic map of the southern peninsula of Michigan (Plate II) shows 100 ft (30.5 m) contours on the bedrock surface and is based on a revised version of Lane's 1899 map.

Newcombe (1933, in pocket) constructed a more detailed bedrock topographic map with a contour interval of 100 ft. (30.5 m) that shows several tributaries to the main preglacial valley. An interesting feature of this map is a large enclosed depression on the valley floor that lies partially within the study area.

A bedrock surface map (contour interval 50 ft., 15.2 m) by Grant and Pringle (1943) depicts several enclosed basins along the large preglacial channel floor. The outline of this valley on their map is irregular and poorly defined.

Rhodehamel (1951) mapped the bedrock surface (contour interval 25 ft., 7.6 m) of five counties in the Saginaw Lowland adjacent to Saginaw Bay. A complex system of bedrock channels was described, the largest of which he named the Ancient Saginaw Valley. Rhodehamel (pp. 94-7) believed the gradient of this valley was toward the west and described its course in detail.

Rhodehamel (pp. 87-92) also recognized an angulate pattern of drainage on the bedrock surface in the Saginaw Lowland, with preferred orientation toward N 46°E and N 50°W. He attributed the cause of this pattern to a similar alignment of master joints revealed in carboniferous rocks at Grand Ledge, Eaton County. Rhodehamel also mentioned the absence of the angulate pattern where bedrock valleys are entrenched into unjointed post-Pennsylvanian "Red Beds". He pointed out, however, that, where streams have eroded through the "Red Beds" to the underlying jointed strata, the angulate pattern is evident.

More recent maps of the bedrock surface in or near the study area that were pertinent in this research include those by Moore (1959, Plate 2) of Shiawassee County and Vanlier, Wood, and Brunett (1973) of Clinton County. These maps also show an angulate bedrock valley pattern.

It is evident from this review that, although some data are available, no detailed bedrock topographic maps have been published for the area covered by this study.

Surface Morphology

Some aspects of the surface morphology within the study area have been described by Leverett and Taylor (1915, pp. 232-261). They associated morainal features of the area with either the western or southern margin of the Saginaw lobe. The West Branch-Gladwyn moraines of the lobe's west flank trend north of the Grand River valley, while those of the eastern margin, including the Owosso, Flint, St. Johns, Fowler, Lyons, and Ionia moraines, extend south and east of the channel. Included in their report are maps showing the surface morphology (Plate VII) and moraines (Plate XXXII) of the Lower Peninsula. Leverett (1924) later revised the surface morphology map although only minor changes are apparent for features within the study area.

Bretz (1951, 1953, 1964) published several articles that relate the Grand River channel to glacial lake levels in the Michigan and Huron-Erie basins. He not only described features directly associated with the river channel but also added to and reinterpreted Leverett and Taylor's observations of the surface morphology in the study area.

In 1955 a map of Michigan's surface formations, compiled by Martin (1955), was published. A list of principle sources of information included on the map indicates that much of it is based upon Leverett's earlier maps and field notes. For the study area, however, this map is more detailed than either of Leverett's maps, showing greater complexity in the outlines of surface morphologic features.

All the surface morphology maps currently available are based largely on field observations, and not rock and soil stratigraphy. Little to no subsurface information on Pleistocene sediments in the area is available.

CHAPTER II

GEOLOGY OF THE BEDROCK SURFACE, PLEISTOCENE DEPOSITS AND TOPOGRAPHY

Bedrock Geology

The study area is located south of the center of the Michigan structural basin. Three sedimentary rock units--the Saginaw Formation, the Grand River Formation, and the informally designated "Red Beds"--immediately underlie the glacial drift (Figure 2). The following is a brief discussion of the characteristics of these stratigraphic units.

Saginaw Formation

The Saginaw Formation consists of lenticular beds of sandstones, shales, limestones, and thin coal seams (Martin, 1936). A cyclical sedimentation origin has been suggested with a typical sequence composed of "a basal sandstone overlain successively by sandy shale, gray shale, underclay, coal, black shale, and limestone" (Kelly, 1936, p. 166). Locally, however, the upper beds of the formation may be missing. Although some controversy exists on the subject, the beds of the formation are believed to conform with the basinward dip of underlying strata (Kelly, 1936, pp. 214-5). The Saginaw is not known to be exposed anywhere within the study area.

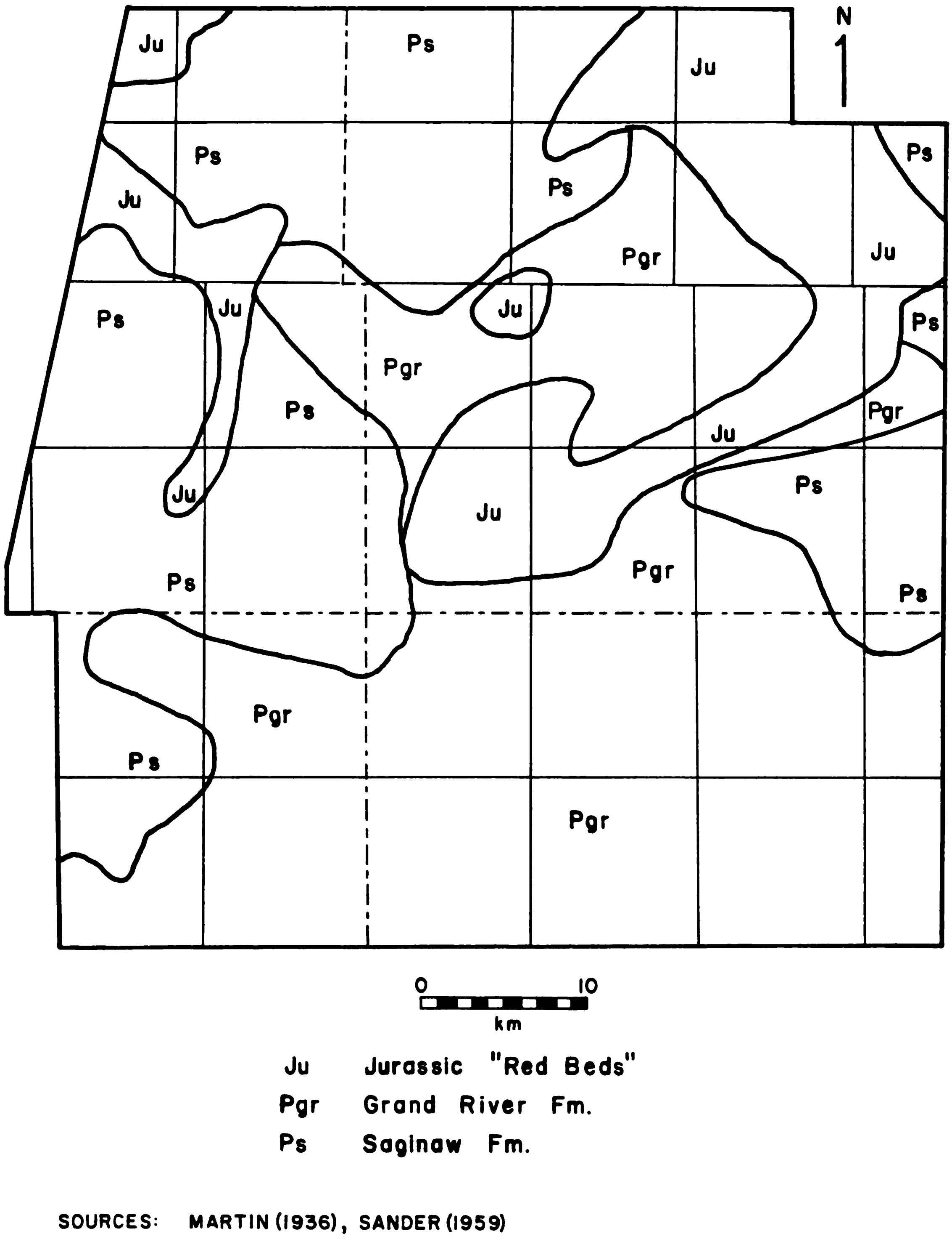

Figure 2. Bedrock Geology.

Grand River Formation

The Grand River Formation overlies the Saginaw and is comprised of the Woodville Sandstone, the Ionia Sandstone, and the Eaton Sandstone. Only the Ionia Sandstone has been identified in the subsurface within the area covered by this study. The only known outcrop of this bedrock is in a quarry in the west half of sec. 23, T. 7 N., R. 6 W. It reveals a 21 m thick "red or brown, fairly coarse-grained, cross-bedded sandstone with white or greenish gray spots and streaks" (Newcombe, 1933, p. 61). A similar sandstone "has been traced by well records across the central part of the state" (Newcombe, 1933, p. 61).

Jurassic "Red Beds"

The Jurassic "Red Beds", which lie unconformably between the Ionia Sandstone and Pleistocene deposits, are composed of "plastic red shale and clay, sandy shales with gypsum beds, streaks and nodules, and disseminated selenite, and red to greenish shales" (Martin, 1936). At some places these beds directly overlie the Saginaw Formation. No exposure of "Red Beds" is known to exist in Michigan. Prior to the late 1960's these red, poorly consolidated sediments were labeled as "Permo-Carboniferous". In the early part of the century, they were included in the Grand River Formation of Pennsylvanian age (Lane, 1909). Later, the possibility of a correlation with Permian "Red Beds" in the southwestern United States was suggested (Newcombe, 1933, p. 62). In 1969 a detailed palynological analysis of the "Red Beds" in Michigan indicated that they are middle to lower Upper Jurassic in age (Shaffer, 1969, p. 35).

Bedrock Surface

Data Compilation

Figure 3 shows the contoured bedrock surface within the study area, based on data for 610 locations. This information was obtained from oil, gas, and water well records on file at the Groundwater and General Geology units of the Geological Survey Division, Department of Natural Resources, State of Michigan. All available well logs for the area covered by this research were examined and considered for inclusion in construction of the bedrock surface map.

The "Red Beds" Problem

In 1933 Newcombe (1933, p. 62) stated "it is probable that because of their soft, plastic character and the resemblance to certain types of red lake clay and boulder clay these beds ["Red Beds"] have not been recorded in many wells. The exact limits of the area underlain by "Red Beds" is, therefore, not very accurately defined." Since the average thickness of these sediments is approximately 26.5 m and known thicknesses exceed 60 m, the failure to record their presence could result in gross inaccuracies of calculated bedrock surface elevations.

Shaffer (1969, p. 12) mentioned "extremely disparate thicknesses [of "Red Beds"] within very short distances, which may be only apparent because of poor quality data...." He also suggested (p. 12) that these variations in thickness could be due to extensive modification caused by "irregularities of the pre- "Red Beds" topography, by post- "Red Beds" and pre-Pleistocene erosion, and by Pleistocene glaciation."

Sander (1959, in pocket) constructed a map based on cuttings from 133 wells that shows the distribution of the "Red Beds" throughout the state. Figure 2 displays the portion of Sanders' map which lies within the study area. Figure 4 shows the bedrock lithology of the region, based on 441 well logs selected for this research, that report the color and texture of the bedrock. Comparison of these maps reveals that the extent of the "Red Beds" may be larger than is indicated by Figure 2.

In general, water well logs include more detailed descriptions of Pleistocene sediments than oil and gas logs; in many instances, only the word "drift" appears on the latter. Oil and gas companies are usually interested only in subsurface rock formations and generally do not take samples until bedrock is encountered. Therefore, water well logs are commonly more useful for determining the contact between the drift and the bedrock. But the sparcity of water wells that penetrate bedrock in the northern section of the study area contributes to the problem of accurately determining the extent and thickness of the "Red Beds" (Figure 5).

Criteria for Selecting Well Log Data

The following criteria were used to select the well log data used in this study:

1) Where records were abundant, all logs were reviewed, and the one with the most detailed stratigraphic description was selected for each section.
2) Detailed well logs that record "Red Beds" were selected, unless the log was inconsistent with other criteria.

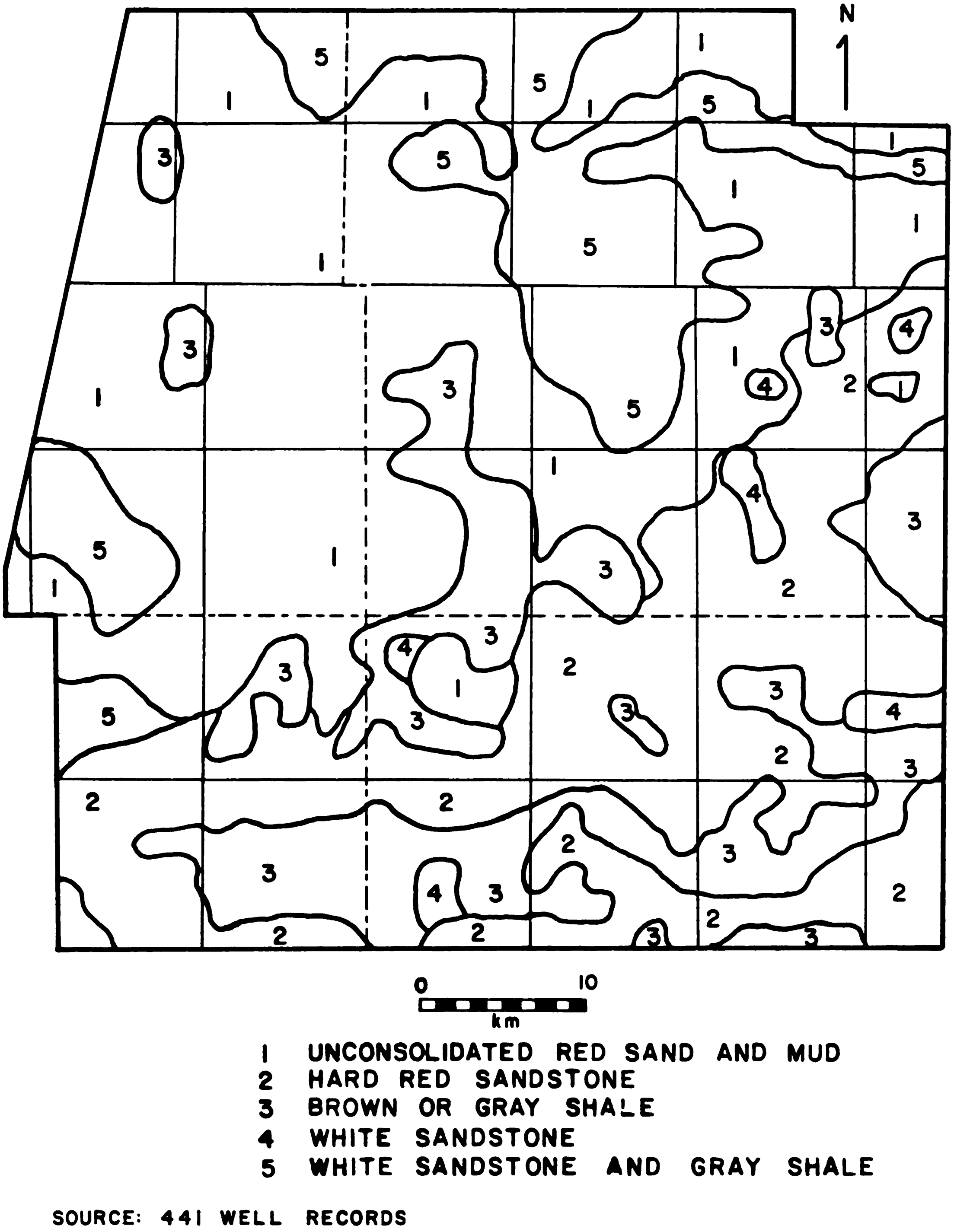

Figure 4. Bedrock Lithology.

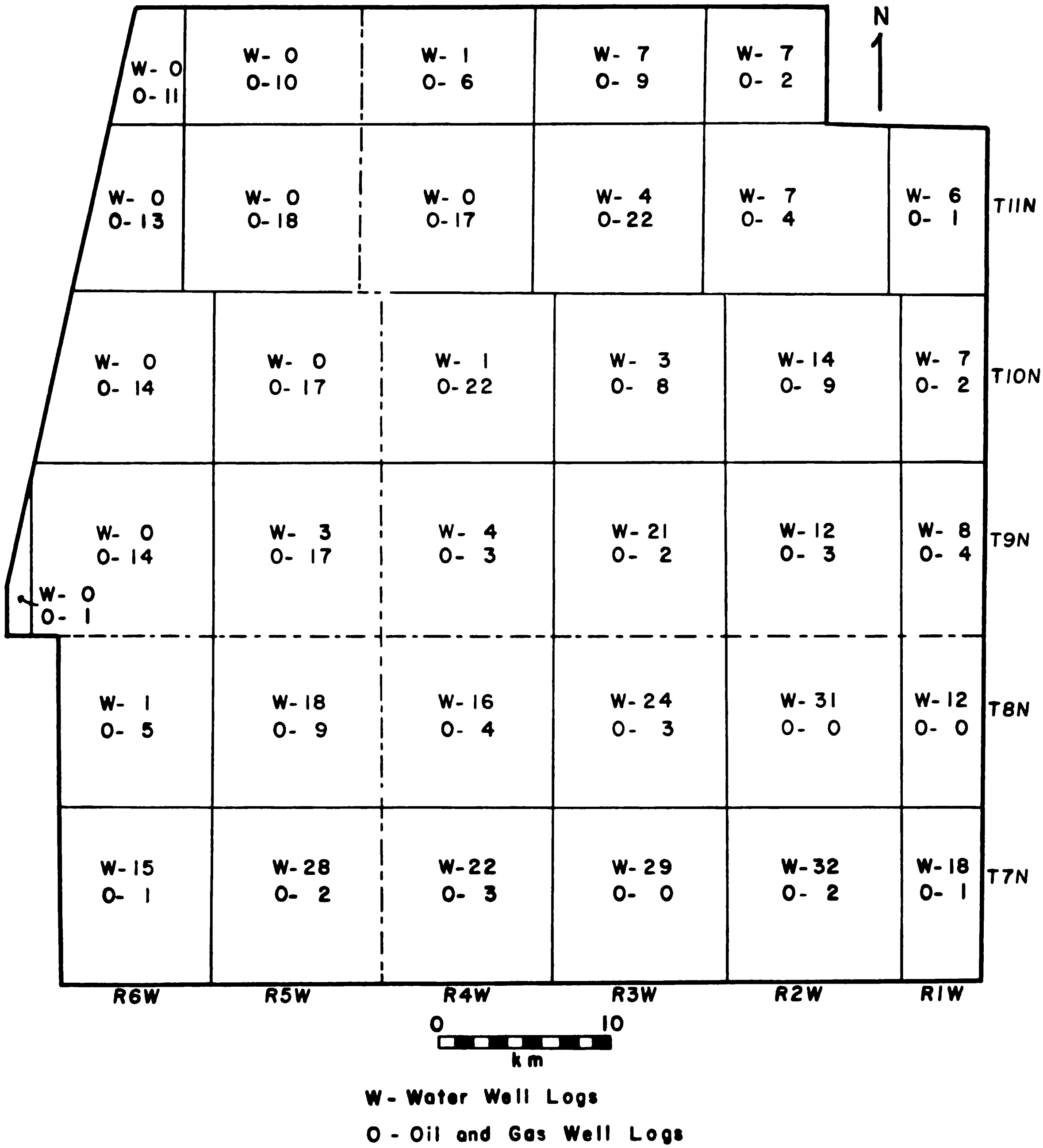

Figure 5. Distribution of Well Logs by Township.

3) Logs that do not report "Red Beds" were utilized, if records for nearby wells indicate these sediments are thin or absent.

4) Logs that report "Red Beds" were excluded, if logs closeby indicate they are absent. Conversely, logs without evidence of "Red Beds" were excluded if nearby logs include descriptions of them.

5) Any log with bedrock elevation data that was grossly inconsistent with records for nearby wells was eliminated from consideration.

Map Construction

The well locations were plotted by quarter sections on a base map with a scale of 1:170,000. Altitudes of the well heads were determined, using the most recent U.S.G.S. topographic maps. The bedrock surface elevation was calculated for each location on the basis of the well log data. Spatial coordinates (x,y) for each site were determined using Michigan State University's GTCO Datatizer. The Surface II computer software system (Sampson, 1978) was used to contour the bedrock surface. This computer-generated map was then drawn by a Calcomp 963 incremental pen plotter.

A second map of the bedrock surface was independently constructed by the more traditional manual method. The two maps were compared, and adjustments were made where judged appropriate. Figure 3 is therefore a synthesis of manual and mechanical interpretations of the data. Broken contour lines indicate areas where control is poor or the data is of lower reliability.

Characteristics of the Bedrock Surface

The bedrock surface shown in Figure 3 may be divided into two sections: the Southern Upland and the Northern Lowland. The boundary between the areas is transitional and does not correspond to an abrupt escarpment or lithologic change.

The Southern Upland underlies the Ionia, Clinton, and southeastern Gratiot counties portion of the study area. The region is generally located south of the 150 m contour line and is underlain by Ionia Sandstone and grey-black Saginaw shales. This bedrock upland reaches a maximum elevation of over 200 m in the extreme southeastern corner of the study area. No relationship is evident between variations in lithology and the location of high and low places on the bedrock surface of this highland.

The Northern Lowland lies north of the 150 m contour line and is generally underlain by "Red Beds". Several deeply incised bedrock valleys in the northern part of this lowland are floored by shales and sandstones of the Saginaw Formation. A linear ridge, which reaches a maximum elevation of approximately 180 meters, exists near the western edge of the region and may be a northern extension of the Southern Upland. The presence of grey-black Saginaw shales on the highest parts of this feature suggests it may be an erosional remnant or a reflection of a localized bedrock structure.

Trends and Patterns of Bedrock Valleys

The general trend of the bedrock valleys is northward, although there are local deviations due to the angulate pattern of these channels.

In the Northern Lowland the bedrock valleys are entrenched into the jointed Saginaw Formation and therefore display angularity (Figures 3 and 6). Some bedrock channel modification caused by Pleistocene glaciation may have taken place in this region. The direction of ice flow during the late Wisconsinan was from the northeast. If prior glaciations had similar flow directions, the northward-trending sections of the bedrock channels are oriented perpendicularly to these Pleistocene ice advances. Alteration of preglacial valley characteristics is possible if the overriding ice transported any unconsolidated "Red Beds" from the interfluves into these channels. The broad, poorly defined outlines of linear bedrock lows in this area may partially be due to such modification.

Bedrock valleys in the Southern Upland also show an angulate pattern; however, they are shorter, narrower, and better defined than those to the north (Figure 3 and 6). Glacial modification of these channels therefore appears to have been less effective, probably because of the more resistant bedrock underlying the region.

Major Buried Bedrock Valleys--Northern Lowland

Alma-St. Louis Valley

The Alma-St. Louis Valley (Figures 3 and 6) is the largest and best defined bedrock valley in the study area. The channel probably enters the region from the east at sec. 9, T. 11 N., R. 1 W.[3]

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[3]The Alma-St. Louis Valley may be an extension of Rhodehamel's (1951, p. 94-97) Ancient Saginaw Valley, which he terminated 3 miles due east of this location.

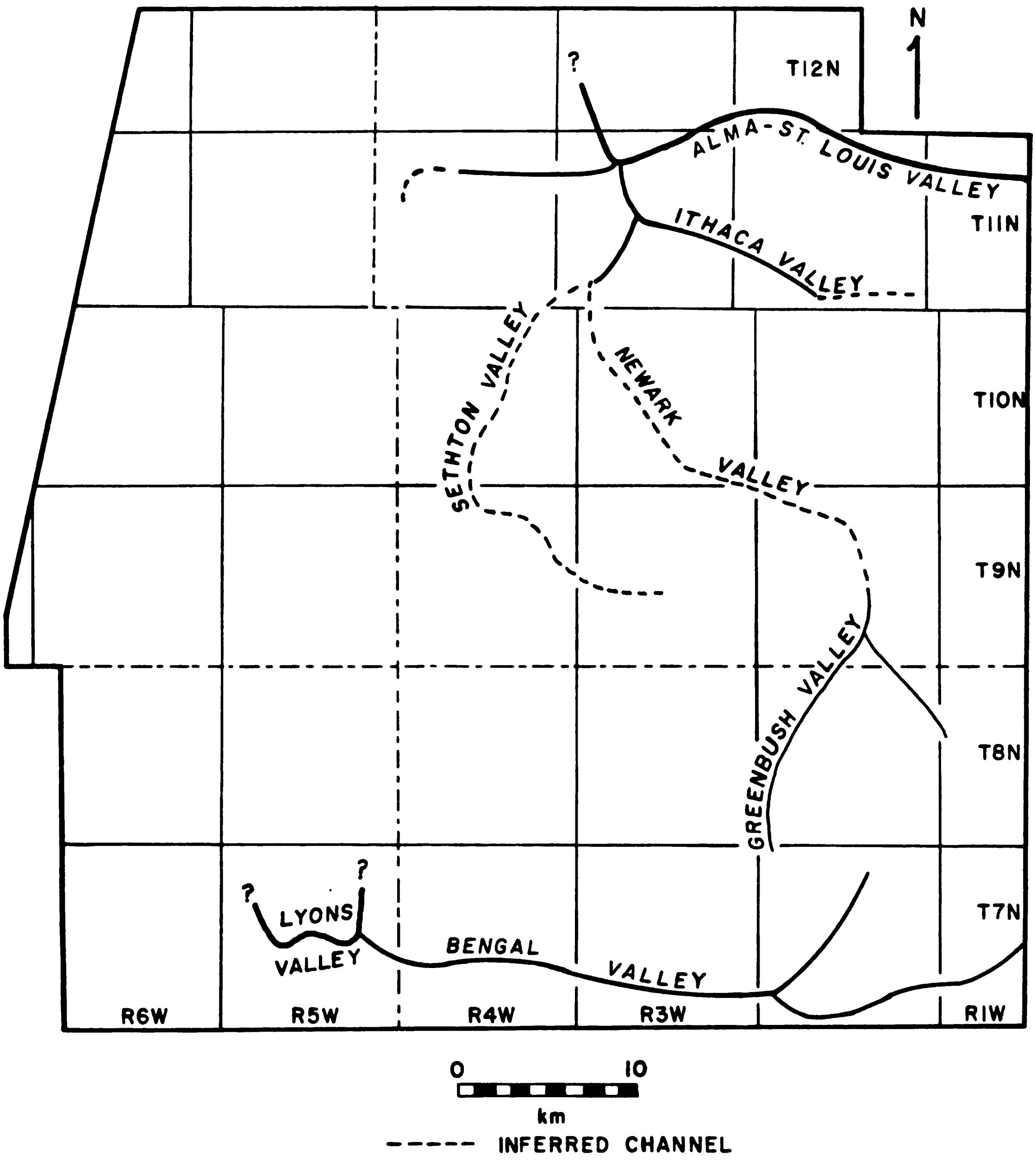

Figure 6. Major Bedrock Valleys.

The eastern portion of the valley is rather poorly defined but is believed to trend northwestward to sec. 31, T. 11 N., R. 1 W., where it turns toward the southwest.[4] Just west of Alma the valley bends sharply to the north-northwest, thereafter its course is unknown. This linear bedrock low appears to be floored by the Saginaw Formation along its entire course (Figures 4 and 6).

The Alma-St. Louis Valley is over 3 km wide throughout most of its 27 km course. To the east, the channel floor is 30 m lower than the surface of the adjacent bedrock; toward the west this figure increases to 60 m. Subtracting the former value from the latter and dividing this figure by the channel length results in a northwest trending gradient of 1.1 m/km.

Lowland Tributaries to the Alma-St. Louis Valley

Several tributaries appear to join the Alma-St. Louis Valley just southwest of Alma (Figures 3 and 6). These bedrock valleys are also entrenched into the Saginaw Formation and two of them, the Sethton and the Newark (Figure 6), may originate in the Southern Upland. For the most part these valleys are poorly defined and nondescript.

Major Buried Bedrock Valleys--Southern Upland

Greenbush Valley

The Greenbush Valley appears to originate somewhere within Greenbush Township (T. 8 N., R. 2 W.) and trends north-northeast

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[4]There is a possibility the course of the valley may be to the southeast, eventually joining the Newark Valley. The eastern extension of the main valley near Alma, would, therefore, be unknown.

(Figures 3 and 6). It merges with an apparent tributary valley at sec. 27, T. 9 N., R. 2 W. and may extend to the Newark Valley slightly north of this location. The channel is floored by the Ionia Sandstone and has a gradient of 2.6 m/km.

Bengal Valley

The Bengal Valley may have been the major preglacial drainage channel for the southeastern portion of the Southern Upland (Figures 3 and 6). It extends from T. 7 N., R. 2 W. westward to T. 7 N., R. 5 W. and is entrenched into Ionia Sandstone except for the eastern and western sections, which are floored by shales of the Saginaw Formation (Figures 4 and 6). The valley has an average gradient of .63 m/km. This figure, however, appears to increase greatly near sec. 24, T. 7 N., R. 5 W. where the channel connects with the Lyons Valley.

Lyons Valley

Evidence for a large valley exists in Lyons Township (T. 7 N., R. 5 W.), where data for nine closely spaced wells reveal a deep, narrow depression on the bedrock surface (Figures 3 and 6). The pattern of the contours indicates this feature makes a sharp, 180° turn with the direction of its gradient either to the northwest or northeast. Lack of data for this area make interpretations of valley trends tenuous, but it appears most likely that drainage was north-northeast, possibly extending to one of the lowland tributaries of the Alma-St. Louis Valley. As was mentioned previously, the trends and gradients of other bedrock valleys in the study area are northward toward the Alma-St. Louis Valley. Additionally, westward drainage off the southeastern portion of the Southern Upland and eastward drainage from the highland in T. 8 N., R. 5 W. indicates that a valley must have existed between these areas. Evidence for this proposed course of drainage is lacking however, because the elevations of the channel floor near Lyons are lower than any observed elevations between the Lyons Valley and the Alma-St. Louis Valley to the north.

Pleistocene Deposits

Drift Thickness

Drift thickness in the study area varies from a known maximum of 172.2 m in sec. 23, T. 12 N., R. 6 W. to less than 1 m in sec. 23, T. 7 N., R. 6 W., where the Ionia Sandstone is exposed in a quarry. Figure 7 shows the average glacial drift thickness in the region. This map is based on the mean thickness per township as determined from the 610 well logs. The drift thickness increases toward the northwest and is greatest over buried bedrock valleys situated beneath end moraines.

Subsurface Sediments

Attempts to correlate subsurface sediments using water well logs were unsuccessful. Logs for closely spaced wells describe decidedly different sediment sequences, indicating that the drift stratigraphy is quite complex. Driller inconsistencies in identifying drift sediment types may also contribute to this apparent complexity.

Well logs in the Southern Upland suggest that till is most commonly in contact with the bedrock surface. This sediment is often

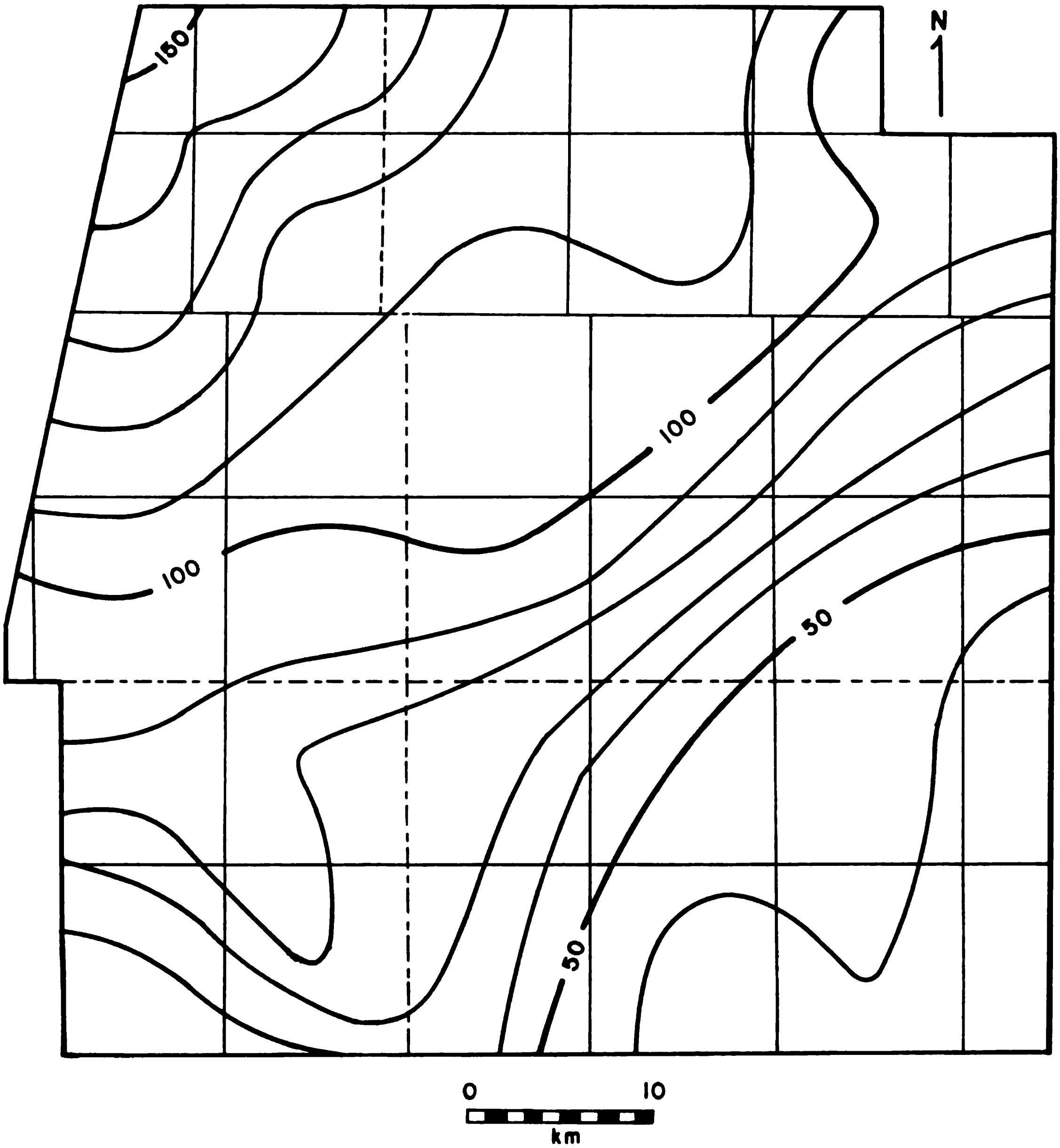

Figure 7. Average Drift Thickness.

described as "blue clay", "clay", or "clay and boulders" and is at some places underlain by a thin red sand layer which may or may not be part of the Pleistocene drift.

Determinations of basal sediment type in the Northern Lowland are complicated by unconsolidated bedrock and the abundance of less reliable oil and gas logs. More often than not, however, till seems immediately to overlie the bedrock. This till is most commonly described as "brown clay with boulders". In the eastern Saginaw Lowland Rhodehamel (1951, pp. 131-133) mentioned thick, bedded sequences of sand and gravel within buried bedrock valleys and boulder deposits lining their floors. Although there were more reports of basal sand and gravel in the incised Northern Lowland than to the south, no definite correspondence was evident between the location of wells recording these sediments and buried bedrock valleys.

Relationships Between the Bedrock Surface and Topographic Features

Bedrock Surface and Topography

Visual Comparison

The most recent U.S.G.S. quadrangles were used to develop a generalized map of the surface with a contour interval of 25 ft. (7.6 m). A metric topographic map was constructed by interpolating between these 25 ft. (7.6 m) isolines (Figure 8). A visual comparison was then made between this map and the bedrock surface map (Figure 3).

The present surface consists of two asymmetrical, west-to-east-sloping uplands separated by the westward-draining Maple and Grand Rivers (Figures 8 and 10). The lowest topography in the study area is located within the valleys of these two streams. The upland to the north is larger and reaches higher elevations than the highland in the southern portion of the region.

The bedrock surface, which has been previously described in detail, is basically an incline--sloping regionally from south to north (Figure 3). The lowest bedrock elevations are found along the northern boundary of the study region within the Alma-St. Louis Valley, in contrast with the high surface topography in this area.

Differences in direction of regional slope and location of uplands and lowlands indicate that little relationship exists between the general configurations of the bedrock surface and present topography.

Statistical Comparison

All data from the 610 well logs collected for this study were used in the trend surface analysis of the bedrock. Only 290 locations were needed to represent accurately the present surface because the exact nature of the topography in the study area is known. Before surfaces were fitted to these data, the spatial coordinates (x,y) for the well locations were standardized by subtracting the mean and dividing by the standard deviation, so that the resulting polynomial equations contained standardized regression coefficients or beta weights. Beta weights indicate the relative effect of each independent variable on the dependent variable, i.e., the influence of the spatial variables on the shape of the surface. Third-degree trend surfaces were then fitted to the 610 bedrock data values and the 290 surface elevations.

This degree of regression equation was used because higher order terms were not significant at the 95% confidence interval.

Tables 6 and 7 of Appendix A show the results of the analysis of variance for the two surfaces. Both the overall equations and individual components for the surfaces were significant at the 99% confidence interval. Relatively good fits (R^2) were obtained for both the bedrock surface and topography with 69% and 83% of the variance explained respectively.

Table 15, part a (Appendix A) shows the standardized regression coefficients (excluding the base) for the polynomial equations describing each surface. A correlation coefficient (R) of -.39 (Table 15, part b) for these equations substantiates the conclusion based on visual comparisons that little relationship exists between the configurations of the two surfaces.[5]

Bedrock and Surface Morphology

Figure 9 shows the surface morphology of the study area (Martin, 1955). The most prominent features are several concentric, arcuate recessional moraines that formed during deglaciation of the Saginaw lobe. Newcombe, Burgoyne, and Lindberg (1935, p. 1117), in a report on the glacial expression of bedrock structural features in Michigan, stated that the "constricting patterns of moraines marking the retreat of the Saginaw ice lobe show little, if any, reflection of structure beneath them." Comparison of Figures 3 and 9, however, reveals that

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[5]Only the correlation coefficient was used for the statistical comparison because Merriam and Sneath (1966) found that separate grouping of surfaces based on the correlation coefficient and taxonomic distance were identical.

two significant bedrock-surface morphology associations do exist.

The bends in the Lyons, Fowler, Flint, and Owosso moraines, which mark a change in their trends from north-south to east-west, coincide with the approximate boundary between the Northern Lowland and the Southern Upland (Figures 3 and 9). These bends also become more pronounced as bedrock elevations increase to the south. An expression of this bedrock highland probably retarded southward flow of the ice sheet and, therefore, influenced its lobate nature.

The inner member of the Outer West Branch Morainic System appears to overlie the western ridge of the Northern Lowland. This correspondence is not exact, however, particularly at the northern and southern ends of these linear features. The general coincidence of their positions may suggest an association between the bedrock and the position of this moraine. A topographic expression of the underlying linear bedrock high on a paleosurface prior to the last glaciation of this region may have served as a block to a minor readvance of the retreating ice margin.

If the above relationships are valid, then Newcombe et al. (1935) are incorrect in stating that there is no bedrock influence on the patterns of moraines produced by the Saginaw lobe.

Bedrock Surface and Surface Drainage Features

A map of the major streams in the study area constructed from the most recent U.S.G.S. topographic maps is shown in Figure 10. The divide between eastward and westward drainage to Lakes Huron and Michigan, respectively, lies within the region (Figure 10). Newcombe and others (1935, p. 1179) believed that the general location of this divide is related to an indefinite extension of a bedrock anticline that is known to exist southeast of the study area near Howell, MI. The pattern of present drainage was largely a product of late Wisconsinan glaciation, with modern streams conforming largely to courses of ice marginal glacial drainageways (Figures 9 and 10).

The major drainage channel in the Northern Lowland is the eastward-flowing Pine River (Figure 10). Its course does not appear to conform with underlying linear bedrock lows, although it does overlie the Alma-St. Louis Valley near sec. 4, T. 11 N., R. 3 W.[6] (Figures 3 and 10). Fish Creek in Montcalm County may not necessarily correspond to a bedrock valley, but it does tend neatly to avoid areas of higher bedrock associated with the western ridge of the Northern Lowland. Prairie Creek shows no preference for underlying bedrock lows.

The surface drainage divide appears generally to conform with bedrock highs near sec. 20, T. 10 N., R. 1 W., sec. 17 and sec. 28, T. 10 N., R. 2 W.; sec. 1, T. 10 N., R. 4 W. and the northern portion of the bedrock ridge near the study area's western border (Figures 9 and 10). Therefore, a relationship is suggested between the location of this divide and areas of elevated bedrock.

The Maple-Grand River system marks the course of the Glacial Grand River channel through which various glacial lakes in the Erie and Saginaw Lowlands drained. Leverett and Taylor (1915, p. 256) believed that this channel formed contemporaneously with the retreat of the Saginaw lobe because no westward projections of the moraines, except

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[6]The implications of this are discussed in Chapter III.

for the Owosso,[7] are noticeable where they cross the Maple or Grand Rivers. Bretz (1953, pp. 361-365), however, maintained the existence of a pre- late Wisconsinan Grand River valley. He recognized morainic topography descending the slopes of this valley almost to the level of the channel floor at several places along its length.

Within the study area the Maple River-Grand River system seems generally to coincide with the margin between the Northern Lowland and the Southern Upland. There is little evidence of a bedrock valley or linear low conforming to the course of this system, although sections of the Maple River do overlie the Lyons Valley and its possible north-eastern extension.[8]

The strongest indication of possible bedrock control on present drainage is the correspondence between the trends of Stoney Creek (on the present surface) and the underlying Bengal Valley (Figures 3, 6 and 10). Although the drift thickness between the floors of these two valleys is 40-50 m, it is far less than that beneath other major streams in the study area. Therefore, the relationship found by Rieck and Winters (1976, 1979) between bedrock valleys and surface streams in south-central Michigan may only exist within this region where the drift is relatively thin.

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[7]Leverett and Taylor (1915, pp. 257-258) argued that the channel that caused this projection of the ice margin was formed immediately prior to a minor readvance of the Saginaw lobe to the Owosso moraine position. Their evidence for this readvance was the observed cross-cutting relationship between the Flint and Owosso moraines just north of the Glacial Grand River valley.

[8]The implications of this are discussed in Chapter III.

CHAPTER III

RELATIONSHIPS BETWEEN GLACIALLY BURIED PLEISTOCENE ORGANIC DEPOSITS, THE BEDROCK SURFACE, AND TOPOGRAPHY

Characteristics of Glacially Buried Organic Deposits

Location and Distribution

Glacially buried Pleistocene organic matter is reported for 44 sites in the 2700 km^2 study area--an average of one site per 61 km^2 (Figure 11). Data for these deposits are derived from (1) 35 water well logs, (2) two oil and gas well logs, and (3) seven reports based on interviews with water well drillers.[9] (See Appendix B for detailed descriptions of this data.) All well log data were obtained from the files of the Groundwater and General Geology units, Geological Survey Division, Department of Natural Resources, State of Michigan.

Table 1 (on the following page) shows that these buried organic sites are concentrated in Gratiot and Ionia counties. The degree of site dispersion was computed using CENTRO, a program in Geosys Version 5 (Wittick, 1980). The results of this analysis are illustrated in

[9] Dr. Richard Rieck kindly supplied the author with the interview data derived from an extensive survey of water well drillers who operate within the study area.

Table 1. Distribution of Glacially Buried Organic Sites by County

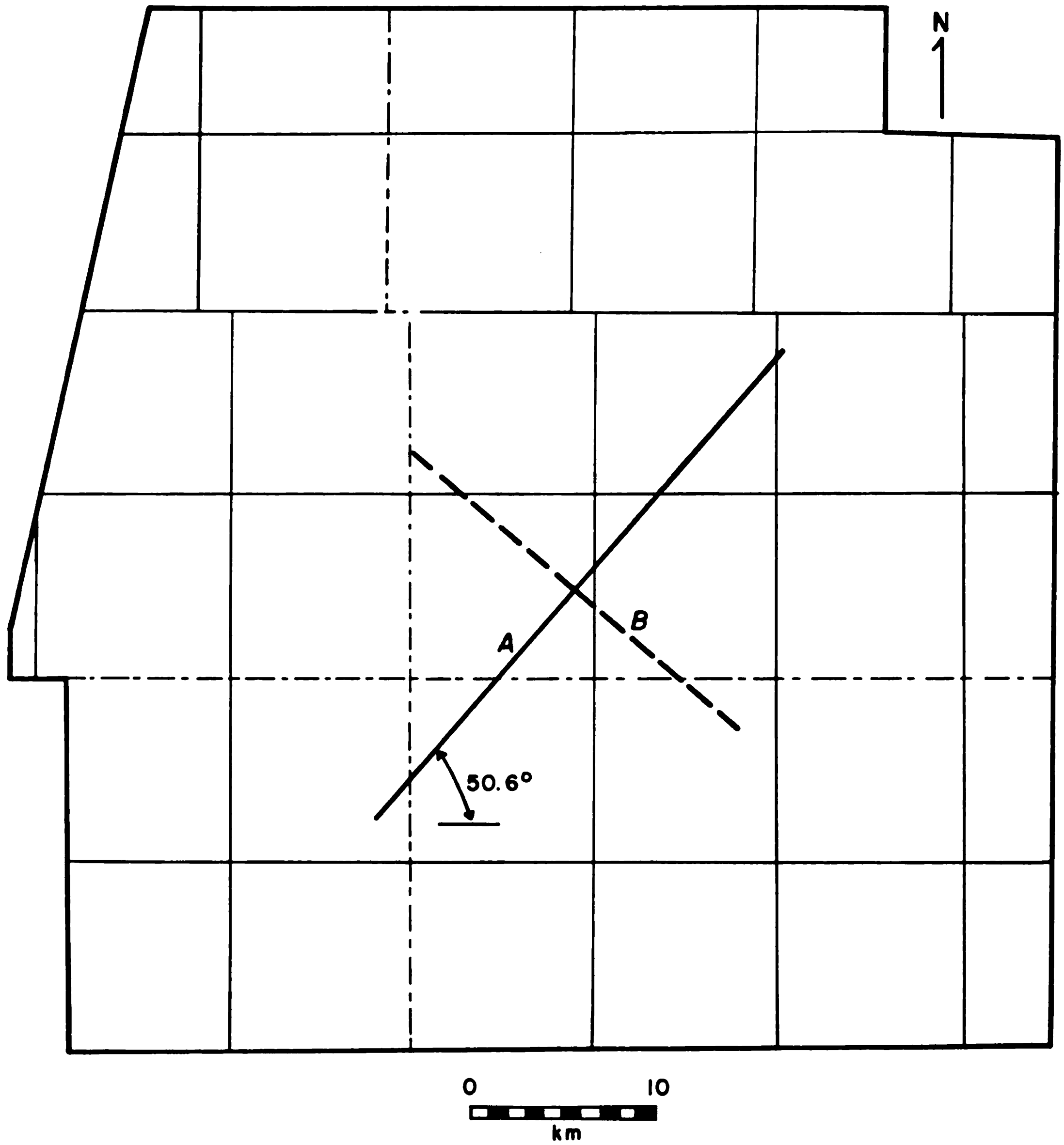
	GRATIOT	CLINTON	IONIA	MONTCALM
Glacially Buried Organic Sites	23	8	7	6
Area (km^2)	1182	615	330	577
Sites/km^2	1/51	1/77	1/47	1/96

Figure 12. The coefficient of circularity of .7 indicates that the distribution is more circular then linear. The northeast-southwest trend indicated in Table 1 is supported by an orientation angle of 50.6° for the elliptical buried organic site distribution.

A nearest neighbor analysis was performed to generate a distance matrix from which subclusters were identified. A "subcluster" is arbitrarily defined as consisting of more than three sites, each of which must be within 5 km of another site in the grouping. Two subclusters, the Hubbardston and Alma-St. Louis, shown enclosed by dashed lines on Figure 11, contain exactly one-half of the glacially buried organic deposit locations in the study area. The Hubbardston subcluster consists of 16 sites with an average distance to nearest neighbor (ADNN) of 1.5 km, while the Alma-St. Louis subcluster is comprised of six sites with an ADNN of 2.8 km.

Depth, Thickness, and Elevation

The glacially buried organic deposits are overlain by from 8.1 to 96.3 m of drift--their average depth, 40.9 m. Rieck (1976, p. 77) discussed the relationship between lithologic descriptions on well logs



A Major Standard Axis

B Minor Standard Axis

Coefficient of Circularity $\frac{A}{B}$ = .70

Figure 12. Orientation of Glacially Buried Organic Deposits.

and the identification of glacial till. Log records of "clay", "stoney clay", "sandy clay", "hardpan and stones", and "clay with boulders" are considered subsurface till layers based on his interpretations. All but two deposits appear to be covered by at least 10 m of till, while many well logs indicate that more than one such horizon may overlie the buried organic material.

Exact altitudes of buried organic deposits are somewhat difficult to determine because drillers usually record a zone where organic matter is mixed with sediment rather than the precise altitude of carbonaceous horizons. Within the area the thickness of these zones is generally one or two meters, but in a few wells it may exceed 20 m. Furthermore, it cannot be determined from most logs whether the organic material is distributed throughout these horizons or exists at a specific level within them. Collapse of organic matter into the well may also occur after the drill bit has passed the carbonaceous horizon, giving the logger a false impression of its thickness. Other factors which may have a complicating effect on the correct determination of original organic levels include possible erosion of upper parts of a horizon by overriding ice and compaction of organic deposits by both the ice sheet and the subsequent deposition of sediments.

For purposes of analysis in this study, the depth of a buried organic deposit is considered to be the vertical distance from the surface to the middle of the sediment horizon in which carbonaceous material is reported. The degree of error (the vertical distance from the middle to the top and bottom of the sediment layer) for these depths ranges from a maximum of ± 11.4 m to a minimum of ± 0.1 m with an average of ± 3.0 m.

Glacially buried organic matter altitudes were calculated for each site by subtracting the depth of the carbonaceous material from the elevation of the well head as determined from the most recent U.S.G.S. topographic maps. Figure 13 shows that the greatest concentration of buried organic deposit elevations is between altitudes of 180 m and 190 m. Two well logs Mt-3 and Gr-10 (Figure 11, Appendix B), report glacially buried organic matter at two separate levels.[10] Therefore, at the 44 sites in the area, there are actually 46 total occurrences of glacially buried organic matter.

<u>Driller Descriptions of the Buried Organic Deposits and Associated Sediments</u>

Many loggers use a variety of terms to describe the organic matter-sediment zones, particularly the thicker ones. Table 2 lists the words used by well drillers in descriptions of both the organic deposits and associated sediments (Appendix B contains detailed information on individual sites). Wood, sand, and coal are used most commonly in these descriptions. Wood is reported in 80% of the buried carbonaceous deposits, and sand constitutes the associated sediment in 74% of the sites. The high frequency of coal (59%) existing with these deposits is not readily explainable. A sample of material logged as coal was obtained from one driller, and it appeared to be identical to Paleozoic coal known to be associated with the bedrock in this part of Michigan. Rieck and Winters (personal communication) have observed the

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[10]These wells are discussed in greater detail in Chapter IV.

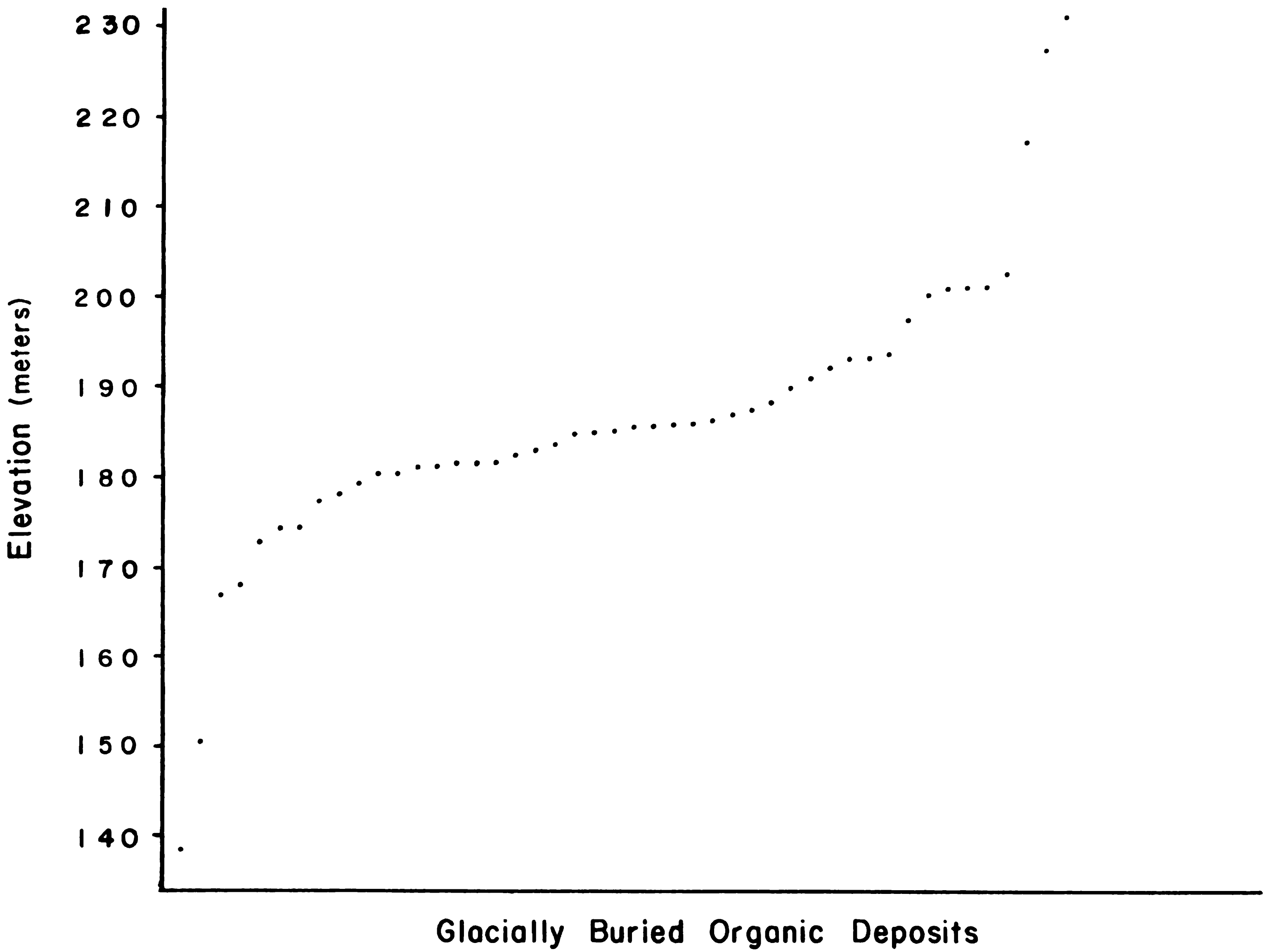

Figure 13. Ranking of Glacially Buried Organic Deposit Elevations.

Table 2. Frequency of Terms Used to Describe Organic Matter-Sediment Horizons

a) Total Frequency

Term	Rotten Vegetation	Muck	Peat	Marl	Grass	Shell	Wood	Gas	Coal	Sand	Clay	Gravel
Number of Times Used	2	7	3	2	2	1	37	4	27	34	7	7
Frequency	1.5%	5.3%	2.3%	1.5%	1.5%	0.7%	27.8%	3.0%	20.3%	25.6%	5.3%	5.3%

b) Total Frequency by Category

Sediment		Organic Matter		Miscellaneous	
Sand	71.0%	Wood	68.5%	Coal	87.0%
Gravel	14.5%	Muck	13.0%	Gas	13.0%
Clay	14.5%	Peat	5.6%		
		Marl	3.7%		
		Rotten Veg.	3.7%		
		Grass	3.7%		
		Shell	1.8%		

c) Frequency by Category per Observation

Sediment		Organic Matter		Miscellaneous	
Sand	74.0%	Wood	80.0%	Coal	59.0%
Gravel	13.0%	Muck	15.0%	Gas	9.0%
Clay	13.0%	Peat	7.0%		
		Marl	4.0%		
		Rotten Veg.	4.0%		
		Grass	4.0%		
		Shell	2.0%		

same relationships for samples from numerous sites in other areas of the state. Thus, the term is probably not used as a misnomer for peat or other unlithified organic matter. All logs but two, CL-7 and MT-2 (Appendix B), record a vegetal composition of the Pleistocene organic matter.

Glacially Buried Organic Deposits and the Bedrock Surface

Regional Relationships

The distribution of glacially buried organic deposits appears to be associated with the extent of bedrock lowlands in the study area (Figures 3 and 11). Only 5 (11%) of the 44 buried carbonaceous sites are underlain by bedrock above 150 m. Since 30 percent[11] of the bedrock surface area is higher than 150 m, 13 of the buried organic sites should be expected to overlie these areas if a random distribution is assumed. A one variable x^2 test shows that the difference between these observed and expected distributions is significant at the 98% confidence interval. If one considers that a greater number and higher percentage of wells penetrate the entire drift layer in these bedrock upland areas, this relationship becomes even more significant. In areas of deep drift and low bedrock surface elevations, where there are more reports of buried organic material, shallow drift aquifers are abundant. Therefore, many wells may be terminated before they reach any deeper carbonaceous deposits. Clearly, there is a relationship between areas with a relatively low bedrock surface and the location of glacially buried organic matter.

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[11]Area measurements were calculated using a polar planimeter.

The 50.6° orientation angle of the elliptical organic sites distribution described previously roughly parallels the trend of the nearby boundary between the Northern Lowland and Southern Upland (Figures 3 and 12). This correspondence is in agreement with findings by Rieck and Winters (1980, p. 76) that buried organic deposits are located near bedrock slopes or escarpments.

Localized Relationships

For areas where detailed bedrock maps are available, Rieck and Winters (1980, pp. 79-80) found that 70% of all known buried organic deposits are within or overlie bedrock valleys, which constitute only 20% of the preglacial surface. Of the 44 buried organic sites in the study area, 27 (60%) lie very near, over or within boundaries of known or inferred bedrock channels (Figures 3 and 11, Table 3). Because the outlines of some of these valleys are poorly defined, their proportion of the total bedrock surface cannot be precisely determined. Visual estimates, however, seem to be consistent with the findings of Rieck and Winters (1980).

Both buried organic deposit subclusters are situated almost entirely over bedrock lows (Figures 3 and 11). The Hubbardston subcluster generally overlies bedrock elevations less than 140 m (the height of the surrounding bedrock surface ranges from 170 to 140 m). None of these deposits lie above bedrock with a surface that exceeds 150 m and two occur where the uppermost underlying bedrock is < 130 m. Only site MT-5 does not overlie a bedrock low.

As mentioned in Chapter II, this linear bedrock depression near Hubbardston may represent the northern extension of the Lyons Valley.

Table 3. Organic Deposits Associated with Bedrock Lows

Sites	Over or Within Bedrock Low	Associated Bedrock Low
Hubbardston Subcluster		
CL-1	Over	
CL-5	Over	
CL-6	Over	
CL-7	Over	
CL-8	Over	Localized bedrock low
I-3	Over	extending northward
I-5	Over	from near Hubbardston,
I-6	Over	sec. 12 T8N R5W
I-7	Within	(Possible northern
MT-3	Over	extension of Lyons
MT-4	Over	Valley)
GR-3	Over	
GR-7	Over	
GR-10	Over	
GR-16	Over	
Alma-St. Louis Subcluster		
GR-4	Over	
GR-11	Over	Alma-St. Louis Valley
GR-12	Over	
GR-21	Over	
Unclustered Sites		
CL-4	Over	Bengal Valley
I-2	Over	Localized bedrock low
I-4	Over	Lyons Valley
I-1	Over	Small bedrock valley, possible tributary to Lyons Valley
GR-17	Over	Ithaca Valley
GR-9	Over	
GR-5	Over	Newark Valley
GR-22	Over	

The clustering of several organic deposits just east of a bedrock valley in Sec. 12, T. 8 N., R. 5 W. may indicate the presence of an underlying channel.

Four sites of the Alma-St. Louis subcluster overlie the Alma-St. Louis bedrock valley, which is incised to elevations < 70 m. The other two deposits in the subcluster, GR-18 and Gr-20, are situated over the slopes extending from a localized bedrock high north of the valley.

Table 3 summarizes the above information and reveals relationships between several unclustered organic sites and low areas or valleys on the bedrock surface. All but one of these deposits (1-7) are above or immediately adjacent to lows on the bedrock surface. Rieck and Winters (1979, pp. 286-287) have stated that "organic material within the drift overlying the bedrock valleys indicates the previous existence of low areas above and yet controlled by the underlying bedrock surface." At most places in the study area, low places on the present surface do not conform with (1) the trends of linear bedrock lows and (2) associated overlying glacially buried organic deposits. Therefore, the processes that perpetuated direct relationships between bedrock and surface topography here in the past must have ended sometime before or during the last glaciation.

Glacially Buried Organic Deposits and Surface Morphology

The actual and expected distributions of glacially buried organic sites were statistically compared to determine if a relationship exists between buried carbonaceous matter locations and surface morphologic features. The relative area for each type of glacial morphologic feature in the region was derived from Figure 9 by use of a polar planimeter (Table 4). Based on these percentages, the number of organic sites that would be expected to underlie each landform type was calculated, assuming a random distribution. The x^2 test was used to compare the expected vs. the actual number of sites underlying the various glacial morphologic features. The difference between these observed and expected values is significant at the 99% confidence interval (Table 4).

The major reasons for this difference are (1) the higher than expected number of sites (18 vs. 10) that underlie end moraines and (2) the relatively few sites (5 vs. 15) that are situated beneath ground moraine (Table 4, Figures 9 and 11). Because end moraines constitute only 23% of the total area, a relationship between these features and the glacially buried organic deposits is suggested. Glacial outwash channels and ponded water lake beds also appear to be associated with ice marginal positions (Figure 9). If these features are considered, the results are even more striking. These three landform types (end moraines, ponded water lake beds and outwash channels) comprise only 39% of the total area. Yet 75% (33) of the organic deposit sites are beneath them. Further investigations elsewhere may determine whether this curious relationship between ice marginal features and glacially buried organic deposits is unique to this study area.

Table 4. Actual vs. Expected Distributions of Glacially Buried Organic Deposits in Relationship to Surface Morphologic Features

	Ground Moraine	End Moraine	Outwash Aprons Glacial Channels	Lake Beds --sand	Lake Beds--Ponded Water	Water Laid Moraine	Sand Dunes (lake)
Area (km^2)	915	614	320	408	109	8	330
Percentage of total area	34%	23%	12%	15%	4%	1%	12%
Expected Distribution*	15	10	5	7	2	0	5
Actual Distribution*	5	18	8	1	7	0	5

^{2}Actual vs. Expected = 29.0

Difference is significant at the 99% confidence interval

*Expressed in number of glacially buried organic sites

Glacially Buried Organic Deposits and Surface Drainage

Only nine of the 44 (20%) buried organic sites are beneath present stream valleys.[12] Six additional wells are either within one-half mile of a major stream valley or are located in broad, shallow depressions drained by underfit streams. Therefore, at most, 34% of the known organic sites underlie the general position of stream valleys. Although the exact proportion that stream valleys contribute to the total area of the region was not determined, it is unlikely that the above percentage is significantly different than that resulting from a random distribution.

Interrelationships Between Glacially Buried Organic Deposits, Bedrock Valleys, End Moraines, and Present Drainage

Sixteen of the 18 (89%) sub-end moraine glacially buried organic sites and 25 of the 33 carbonaceous sites beneath ice marginal features are also located over or within bedrock lows (Figures 3, 9 and 11). Correspondence between sub-ice marginal organic matter locations and those overlying bedrock lows is complete in the Hubbardston subcluster. Here the trends of the Inner Member, West Branch moraine, and distal Fish Creek outwash channel parallel that of the underlying bedrock low. Elsewhere, the ice marginal features are oriented perpendicular to the

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[12]Restrictions in well data locations hindered the investigation of relationships between glacially buried organic deposits and surface drainage lines. Wells are not drilled within stream boundaries nor on the steep slopes associated with the Fish Creek and Maple-Grand River channels.

courses of underlying bedrock valleys and the buried organic deposits are found at the intersection of their trends. Furthermore, both the Pine and Maple-Grand Rivers traverse end moraines at such an intersection, suggesting bedrock control on surface drainage at these locations (Table 5, Figures 3, 9, 10 and 11). These rivers are the highest order streams in the study area, and the Lyons and Alma-St. Louis Valleys, whose trends they transect, are the largest and deepest bedrock channels.

Figure 14 illustrates the sequence of events that may have produced an interrelationships between bedrock valleys, present streams, end moraines, and glacially buried organic deposits. Perpetuation of a large bedrock low by ablation of stagnant ice trapped in this depression and subsequent paleosurface expressions of it may have (1) produced a low-lying paleotopographic site where organic matter could accumulate and (2) cause localized sagging in an end moraine produced by the last glaciation of the region. The morainic low would, in turn, be a preferential site for subsequent drainage to cut through this glacial feature. In this way the bedrock may have had an indirect, localized influence on the major drainage lines in the study area.

Table 5. Interrelationships Between Glacially Buried Organic Deposits, Bedrock Valleys, End Moraines and Surface Drainage

Location	Bedrock Valley	End Moraine	Stream	Organic Deposits
Intersection T12N R2W T11N R3W T12N R3W	Alma-St. Louis Valley	Inner and Middle Gladwyn Moraines	Pine River	Alma-St. Louis Subcluster Particularly GR-18, GR-11 and GR-21
T7N R5W	Lyons Valley	Inner Member, Outer West Branch Morainic System (Portland, Lyons)	Maple and Grand Rivers	I-4

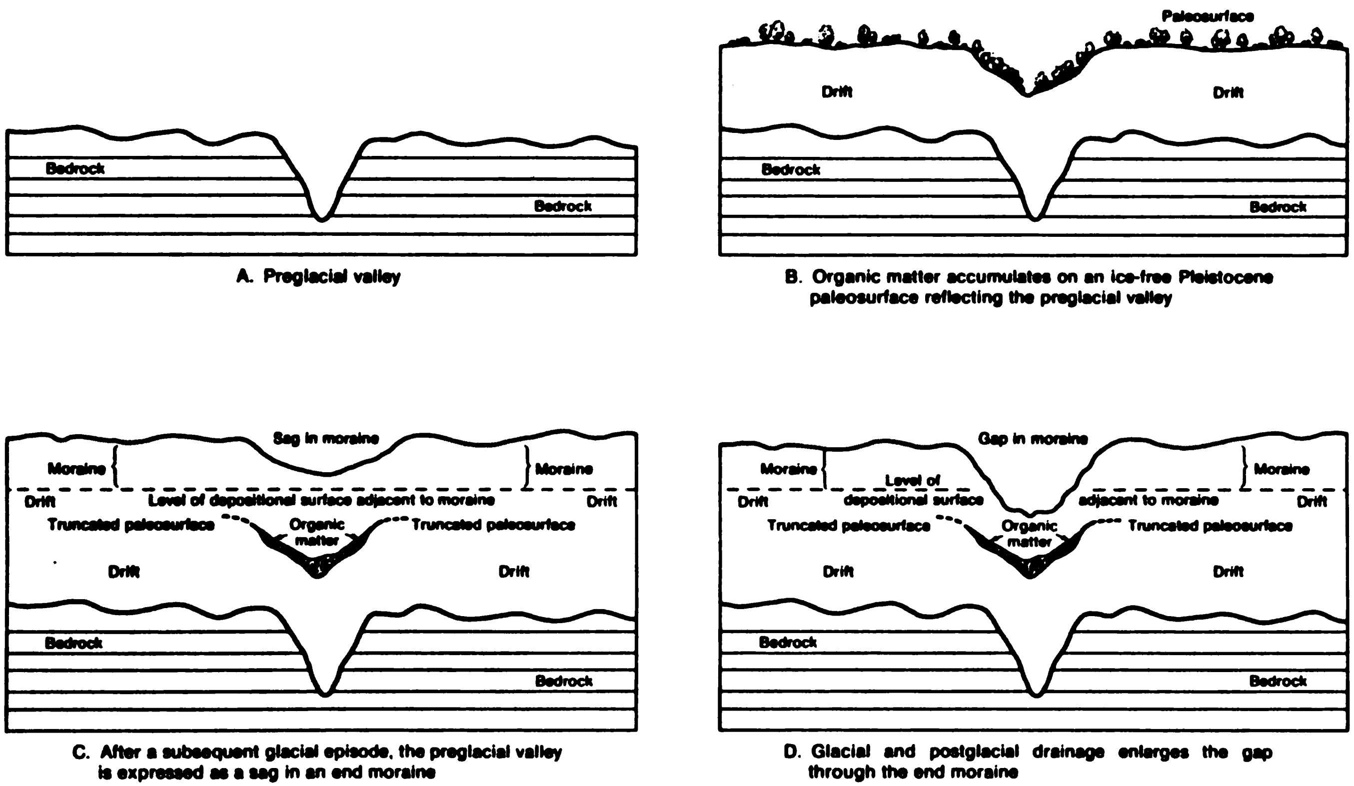

Figure 14. Idealized Interrelationships Between Bedrock Valleys, Organic Deposits, End Moraines, and Streams (After Winters and Rieck, in press).

CHAPTER IV

THE CASE FOR MULTIPLE PALEOSURFACES

Introduction

Trend surface analysis has been utilized to, among other things, reconstruct past erosional landscapes (Svensson, 1956; Monmonier, 1971). It has also been used in studies of glacial stratigraphy to map spatial gradations in textural and mineralogical characteristics of till (White, 1968; Gross and Moran, 1971). This research will employ trend surface analysis in another fashion to determine whether the areal and altitudinal arrangement of glacially buried organic deposits in south-central Michigan are indicative of one or more Pleistocene paleosurfaces.

Hypothesis and Methodology

It is proposed that 42 of the known glacially buried organic deposits in the study area define a single Pleistocene paleosurface. Trend surface analysis can be used to test this hypothesis by providing quantitative parameters for surfaces fitted to (1) altitudes of buried organic deposits and (2) elevation data for both the uppermost bedrock and present topography. Comparison of parameters for the two known surfaces to those for the hypothesized Pleistocene paleosurface provides a means for determining whether a valid polynomial trend equation can be fitted to the buried organic deposit data. Well logs GR-10 and MT-3, which report two separate carbonaceous zones, were excluded from the trend surface analysis because there was no adequate way for the Surface II computer program to accommodate more than one organic elevation per site.

Procedure

Third-degree trend surfaces were first fitted to the 610 known elevations for the bedrock surface and to 290 altitude locations on the present topography. Analysis was limited to a third-degree regression because higher degree components were not significant at the 99% confidence interval and contributed less than a 1% increase in explained variance.

Next, third-degree surfaces were fitted to 42 bedrock elevations and 42 topographic sites with the same geographic locations as the buried organic sites. Correlation coefficients, which provide a measure of shape similarity between surfaces, were calculated from the standardized regression coefficients[13] to determine if 42 data points can adequately depict the configuration of the two surfaces defined by 610 and 290 data locations.

As stated previously, the glacially buried organic deposits probably accumulated within low, protected sites on a paleolandscape.

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[13]See Chapter III for a definition of these measures.

The question may be raised whether a limited random sample of topographic lows defines a surface, and if so, is it representative of the actual configuration of the topography. To test this notion, elevations of present organic soils, which by their nature form in low, poorly drained areas, were derived from the most recently published Soil Conservation Service Soil Survey Manuals and U.S.G.S. topographic maps. An initial data base of 397 elevation sites was gathered, from which 42 data points were randomly selected. Third-degree trend surfaces were fitted to both (397 and 42) of these data sets, and the degree of correlation between them determined. Finally, a third-degree trend surface was fitted to the 42 glacially buried organic deposit elevations.

Results

Tables 6-11 in Appendix A shows the analysis of variance for the various fitted surfaces. The overall equations and individual components for Bedrock (610), Surface (290) and Surface Organics (397) are all significant at the 99% confidence interval. The third-degree regression equations for Bedrock (42), Surface (42) and Surface Organics (42) are also significant at the 99% level, but their cubic components are only marginally significant, possibly because of their smaller degrees of freedom.

For all of these equations the linear components explain approximately half of the total variance, the quadratic components from 15-30%, while the cubic components contribute only minor amounts of explained variance. The goodness of fit of the surfaces varies from 69% (Bedrock 610) to 83% (Surface 290) explained variance.

Table 15, Appendix A shows (1) the standardized regression coefficients for the resulting third degree trend equations and (2) the correlation coefficients measuring the degree of association between the surfaces. High correlations exist between the larger data set surface configurations and their 42 point counterparts, indicating that small data samples may adequately define the general configuration of a topographic surface. Furthermore, because the Surface Organics (42) and Surface (290) equations are highly correlated, the shape defined by a small, random distribution of low topographic sites appears to mirror the configuration of the actual topography. Figures 15-20 are perspective diagrams of the third-degree surfaces and present visual confirmation of the statistical comparison.

The third-degree trend surface fitted to the glacially buried organic deposit elevations contrasts greatly with the quantitative characteristics of the various bedrock and present surfaces described above (Table 12, Appendix A). The surface is a poor fit, accounting for only 36% of the total variance, and both the overall equation and individual components are insignificant or highly questionable. In particular, the linear components have an extremely low significance and explain less than 1% of the total variance. The organic deposit elevations, therefore, do not display a regional trend. Both the significance level and explained variance increase in the higher degree terms, but this probably reflects the greater random complexity of the elevations only. Thus it appears that a single valid surface cannot be fitted to the 42 glacially buried organic deposit elevations.

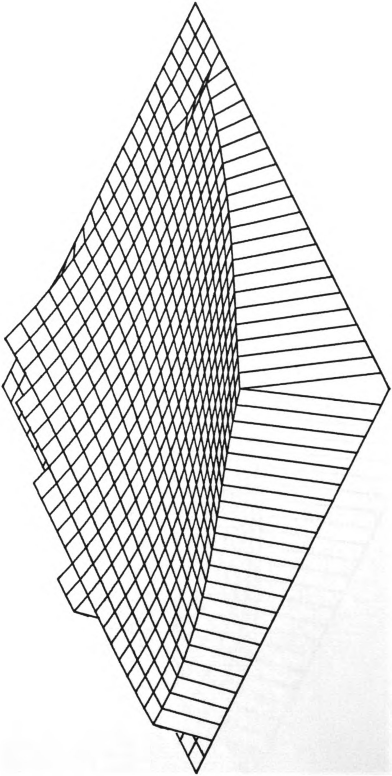

Figure 15. Third-degree Trend Surface--Bedrock (610)   (Viewed from the southeast)

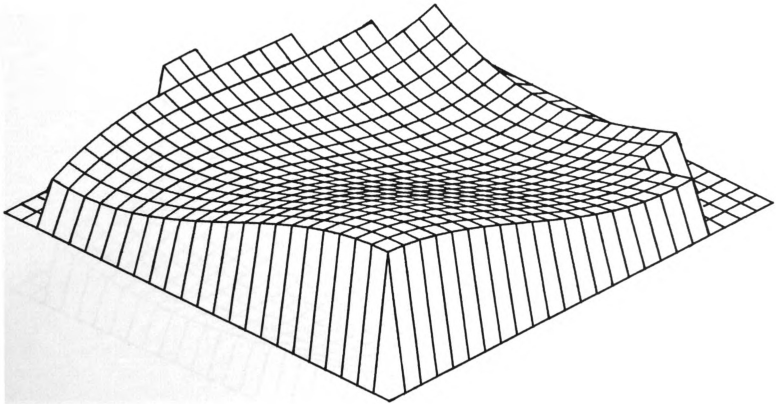

Figure 16. Third-degree Trend Surface--Bedrock (42) (Viewed from the southeast)

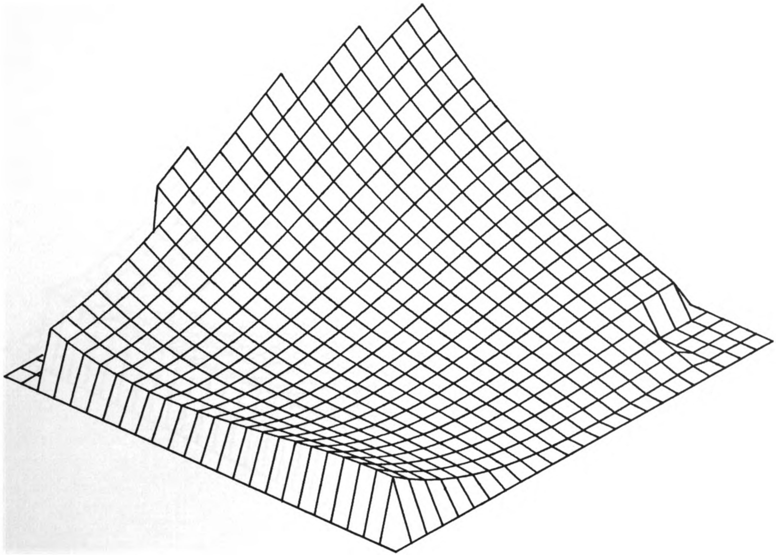

Figure 17. Third-degree Trend Surface--Surface (290) (Viewed from the southeast)

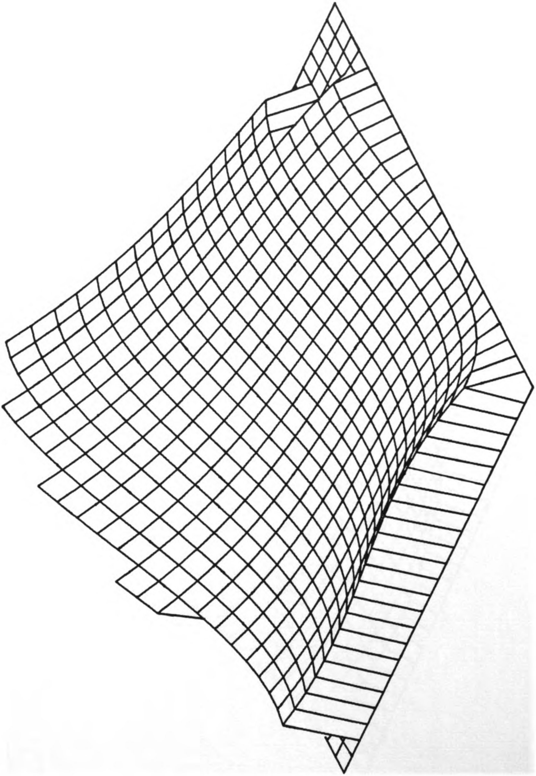

Figure 18. Third-degree Trend Surface--Surface (42) (Viewed from the southeast)

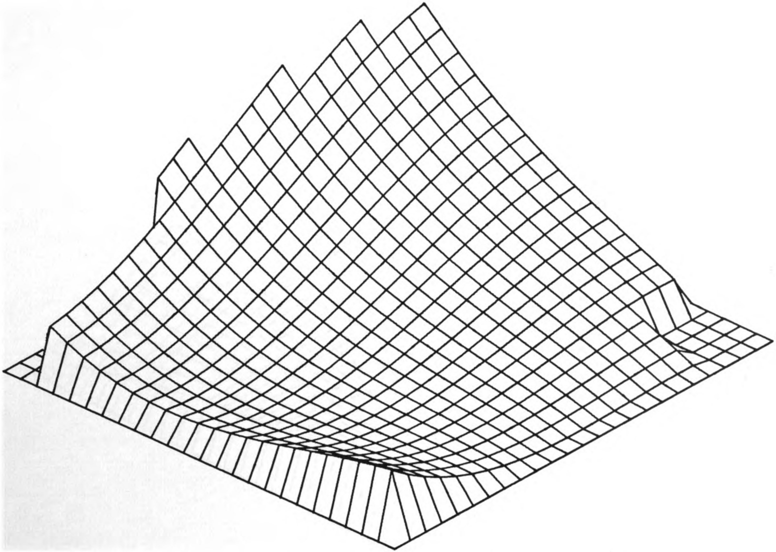

Figure 19. Third-degree Trend Surface--Surface Organics (397) (Viewed from the southeast)

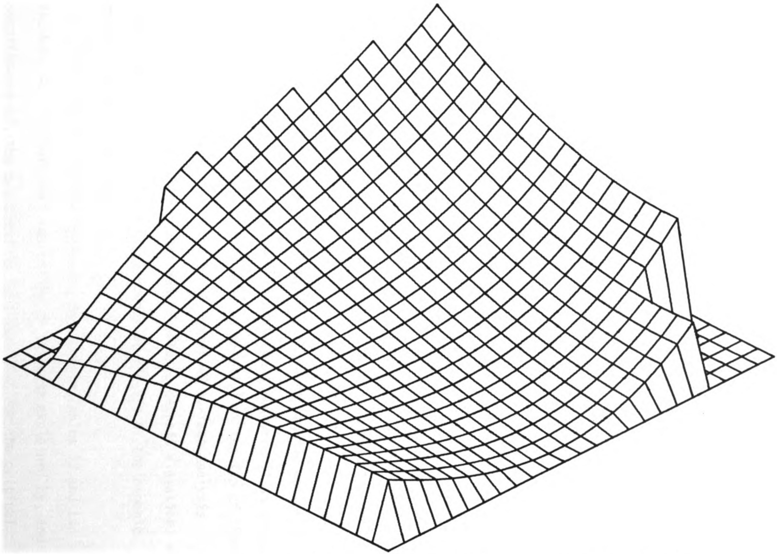

Figure 20. Third-degree Trend Surface--Surface Organics (42) (Viewed from the southeast)

To further substantiate this conclusion, two additional trend surface analyses of modified buried organic matter data sets were performed. Figure 21 shows the elevation distribution for the 42 glacially buried carbonaceous deposits. The altitudinal distribution is rather continuous from 165 to 204 m; however, two extreme elevations are separated from this uninterrupted linear cluster by more than 10 m at both its high and low ends. Inspection of the trend surface residuals reveals that these four extreme values (I-7, GR-22, CL-4, MT-6) are major sources of unexplained variation. Therefore, a trend surface analysis was performed excluding these values to determine if they contributed greatly to the poor fit and possibly represent higher and lower paleosurfaces of differing ages.

As mentioned in Chapter III, the buried carbonaceous deposit elevations were calculated using the vertical distance to the middle of the organic matter-sediment zones because of difficulties in exact depth determinations. It seems unlikely that the organic matter in these horizons is located below this elevation; however, it is possible that drillers penetrate the carbonaceous material at the top of these zones. Therefore, the sensitivity of the trend surface analysis results to differing interpretations of organic deposit elevations was tested by fitting a surface to altitudes at the top of the organic matter-sediment horizons.

The results of these analyses are shown in Tables 13 and 14 Appendix A. For both surfaces the total variance explained by, and significance of, the equations is less than that for the original buried organic surface (Table 12). Therefore, the poor fit of the

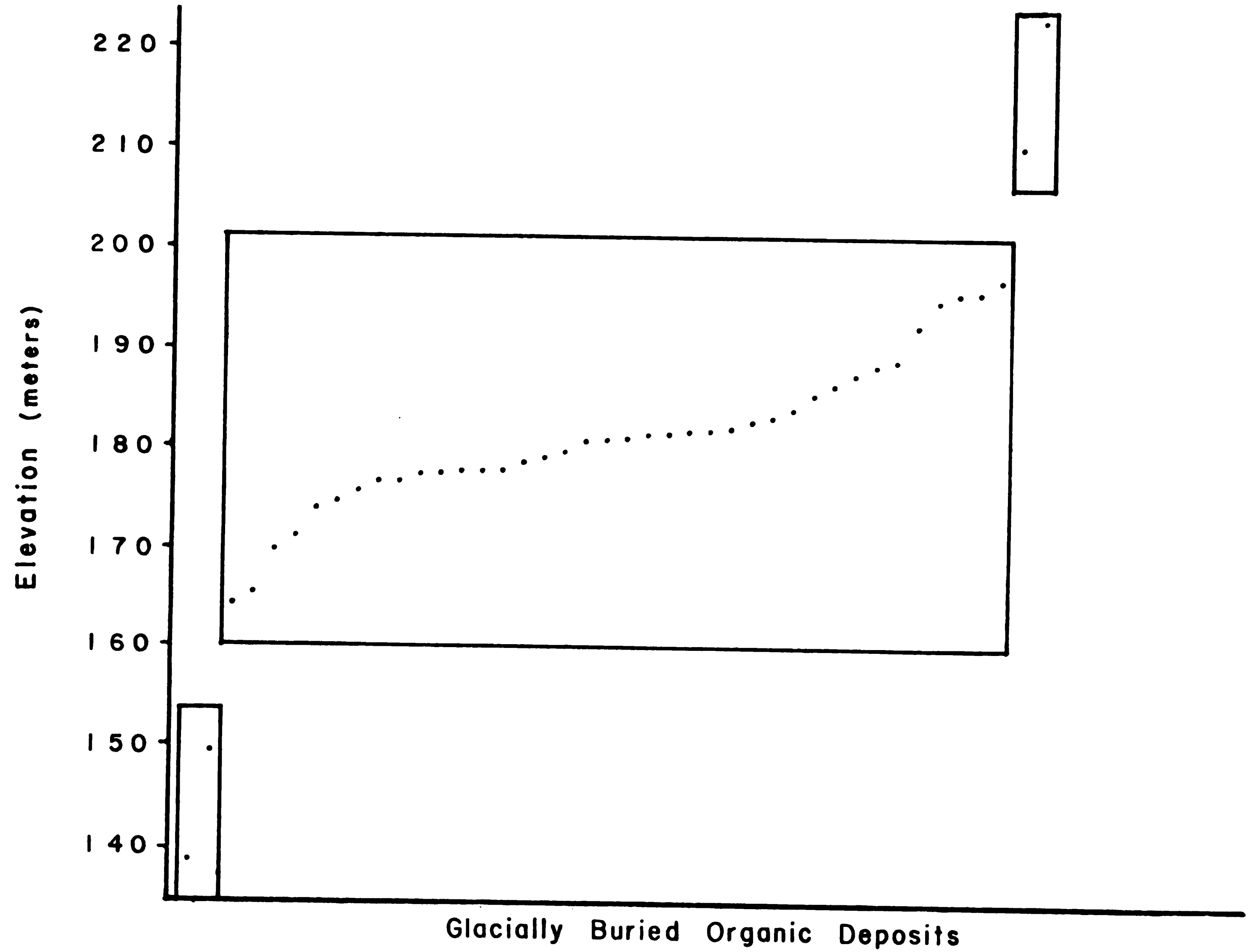

Figure 21. Extreme Organic Deposit Elevations.

buried carbonaceous deposit surface (based on 42 sites) appears to be the result of local altitudinal variations and is not caused by extreme values. Additionally, possible errors in depth and elevation calculations for the organic matter do not appear to affect the goodness of fit.

Conclusions

If the glacially buried organic deposits define a surface, it is a highly complex one, drastically different from either the deeply dissected bedrock surface or the immature, poorly drained present landscape. It would have virtually no regional trend indicating the lack of even an immature regional drainage network. This seems unlikely because some of the carbonaceous deposits in the area are over 20 m thick, implying a long ice-free accumulation period. The results of the trend surface analysis strongly suggest that the glacially buried organic matter in the study area represents more than one paleosurface.

Supporting Evidence for More Than One Paleosurface

Well Logs Reporting Two Separate Organic Zones

Logs for wells MT-3 and GR-10 (Appendix B, Figure 11), which report two separate buried organic deposits, provide the strongest supporting evidence for the presence of more than one glacially buried paleosurface in the area. Both of these sites are part of the Hubbardston subcluster.

Log MT-3 records a mucky organic zone containing wood that is 3 m thick and centered on an elevation of 202.7 m. Six meters of brown clay separate this horizon from 1.2 m of sand, muck, and clay at an altitude of 194.0-195.2 m. This brown clay is probably till and most likely represents a glacial event. The lower of these two organic deposits represented on log MT-3 is 6 m higher than the elevations of five glacially buried carbonaceous deposits within 3.5 km of this site. And reports from five well logs for these nearby locations show no evidence for multiple ice-free episodes post-dating glacial sediments immediately overlying the organic horizons. It appears that site MT-3 is temporally unrelated to these other closeby deposits.

Well GR-10 reports a 4.5 m sand and gravel stratum containing wood and coal centered on 229.0 m separated from 6.0 m of muck, peat, and gravel at 172.3 to 178.3 m by 13.7 m of sandy gray clay and 35.4 m of brown clay and stone. Again the intervening material appears to be till. Neither of the organic deposit elevations from this log correspond closely to altitudes of nearby buried carbonaceous horizons. The uppermost organic deposit is 15 m higher than a small group of three buried carbonaceous zones with relatively high elevations located 6 to 10 km to the east (Figure 11). In fact this superior carbonaceous deposit at site GR-10 is both the highest and shallowest in the study area. The second organic deposit recorded on well log GR-10 is more than 20 m below those to the east and is approximately 12 m lower than the elevations of three Hubbardston subcluster deposits 5 km to the south (Figure 11).

Figure 22 shows that the uppermost carbonaceous deposit at site MT-3 is approximately 30 m below the highest organic matter reported

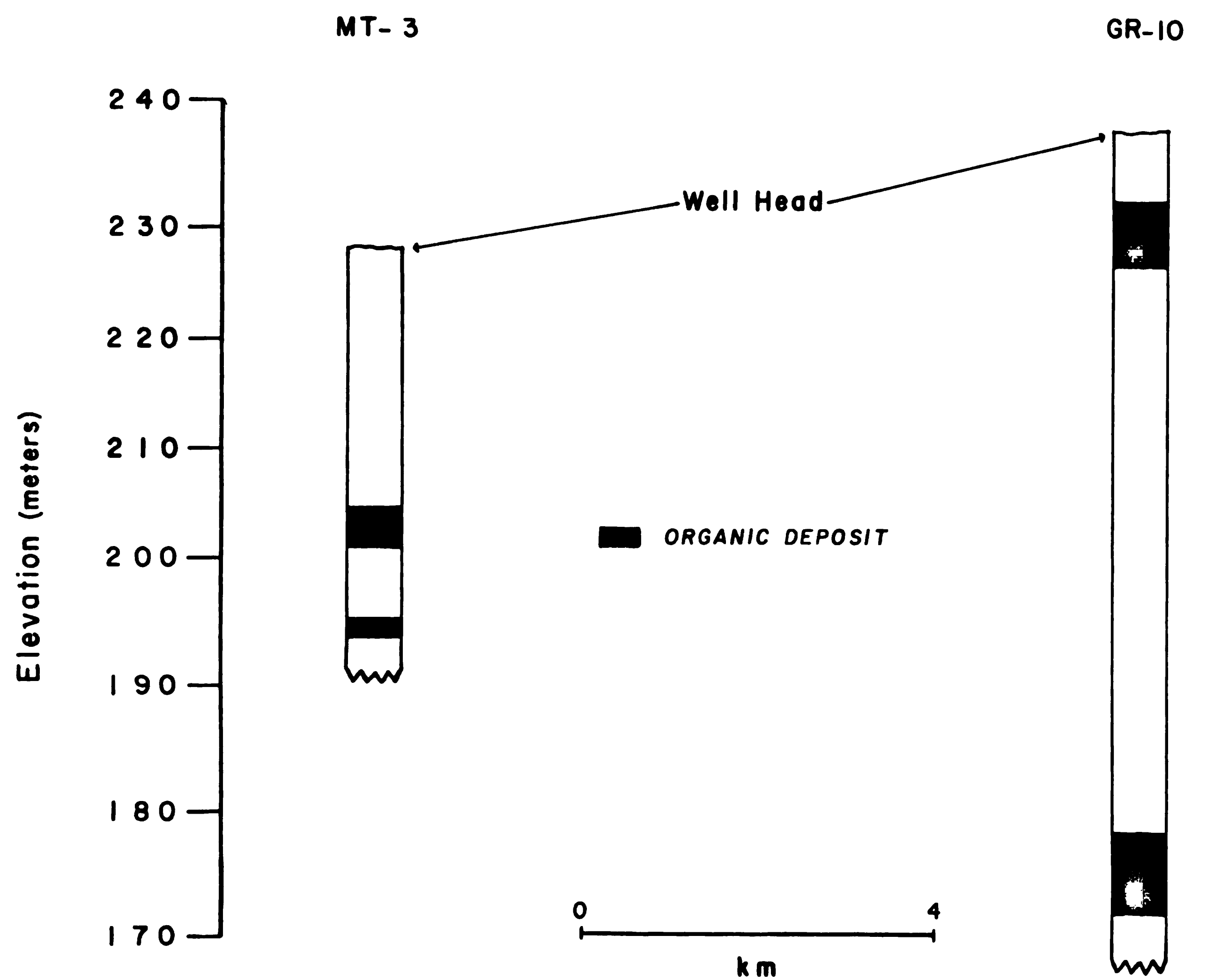

Figure 22. Diagram of Well Logs Reporting Two Separate Organic Horizons.

at location GR-10. Conversely, the inferior carbonaceous horizon at MT-3 is about 20 m above the lower organic stratum reported on log GR-10. Therefore, an inversion of the paleotopography would have had to occur between the respective organic material formation episodes for the upper and lower buried carbonaceous horizons at these two sites to be correlated with each other. Because an event of this nature seems unlikely, the two organic deposits recorded on log MT-3 do not appear to be temporally associated with those reported for site GR-10.

Anomalous Organic Deposit Elevations

Several glacially buried organic deposit altitudes show great discrepancy with elevations of nearby intradrift carbonaceous material. The greatest elevation anomaly is between records for site I-7 and known horizons of closeby organic deposits in the Hubbardston subcluster (Figure 11). At an elevation of 138.7 m, the carbonaceous material at site I-7 is more than 40 m lower than organic matter approximately 2 km to the east. Sites GR-17 and GR-9 are only a few hundred meters apart, yet the elevations of these carbonaceous deposits differ by 20 m. Reported altitudes of organic material in the Alma-St. Louis subcluster vary greatly and do not appear to display a localized slope. Wells GR-20 and GR-18 are less than 2 km apart, yet calculated elevations for these buried organic deposits differ by 30 m.

Observed differences between altitudes of closely spaced organic soils at low places on the present surface generally do not exceed 10 m. If existing topography is representative of that for a buried Pleistocene paleosurface, the altitudinal variation of glacially buried carbonaceous horizons cited above (also believed to have formed at low places) appear greater than is reasonable to expect within the terrain of a "youthful" glaciated landscape.

Implications

In summary, the glacially buried organic material in the study area represents at least two and possibly several Pleistocene paleosurfaces. This conclusion is based upon:

1) A third-degree trend surface fitted to the glacially buried carbonaceous deposits that explained only a low percentage of total variance and was of little significance when compared to statistical parameters for polynomial regression equations fitted to existing surfaces.
2) Two logs reporting separate organic deposits at different altitudes that correlate poorly with each other and with nearby elevations of carbonaceous matter.
3) Unreasonable elevation anomalies that exist between closely spaced organic deposits.

Therefore, the subsurface Pleistocene sediments must consist of a minimum of three drift sheets separated by two paleosols. And these provide evidence for several glacial episodes and at least two ice-free intervals that occurred in south-central Michigan during the Pleistocene.

CHAPTER V

SUMMARY AND CONCLUSIONS

The major findings of this research, as they relate to the objectives presented in Chapter I, are summarized below.

The first objective is "to describe and map the general configuration of the bedrock surface within the study area." A map constructed from data for 610 well logs shows that the shape of the bedrock surface in the region is basically a simple incline. From an upland in the south the bedrock surface slopes northward to an indistinct, northeast-southwest-trending boundary with the Northern Lowland. The Southern Upland is underlain by both the Ionia Sandstone and shales of the Saginaw Formation. The Northern Lowland, which is underlain by unconsolidated Jurassic "Red Beds", is incised by several large bedrock valleys that are floored by sandstones and shales of the Saginaw Formation. The preglacial drainage of both the Southern Upland and Northern Lowland appears to have been toward the north.

Objective 2 (a) is "to indicate the relationships, if any, between the bedrock surface and the present surface features." Both visual and statistical comparisons have shown that no direct relationship exists between the regional configuration of the bedrock surface and the overall shape of the present topography. Certain specific associations are evident, however, between the bedrock and surface landforms. The 90° bends in the end moraines of the study area are situated above the approximate bedrock boundary between the Southern Upland and Northern Lowland. Furthermore, a correspondence exists between the positions of the Inner Member, Outer West Branch Moraine and an underlying bedrock ridge in the Northern Lowland. These associations suggest that areas of elevated bedrock within the study region may have retarded minor readvances of the most recent ice sheet during deglaciation of the area and thus influenced the development and positioning of end moraines. Only in the extreme southeastern section of the area where the drift is thinnest is there evidence for a coincidence between the linear trends of bedrock channels and present stream valleys.

Objective 2 (b) is "to indicate the relationships, if any, between the bedrock surface and the glacially buried organic deposits." Regionally, the locations of glacially buried carbonaceous deposits are significantly more abundant over areas with a relatively low bedrock surface. Locally over half of the carbonaceous matter sites are situated above buried bedrock valleys. Therefore, if this organic material accumulated at low places on a Pleistocene paleosurface(s), a bedrock influence on the paleotopography is suggested. But because low places on the present surface generally do not conform with trends of bedrock channels and the organic deposits overlying these valleys, the processes that perpetuated a direct relationship between the bedrock and surface topography in this region previously must not have been effective during the last deglaciation.

Objective 2 (c) is "to indicate the relationships, if any, between the surface features and the glacially buried organic deposits." This research has shown that there is a spatial association between the locations of buried organic deposits and ice marginal morphologic features. Many of these buried carbonaceous sites also overlie bedrock valleys that are oriented perpendicular to the trends of the overlying end moraines. Both the Pine and Maple Rivers traverse end moraines at an intersection between these three features (bedrock channels, organic matter, and end moraines), suggesting a perpetuated bedrock influence on surface drainage.

The last objective is "to determine, using trend surface analysis, whether the glacially buried Pleistocene organic deposits represent a single paleosurface or multiple paleosurfaces." This study has shown that it is highly probable that the glacially buried organic deposits represent more than one paleosurface. This conclusion is based on:

1) A third-degree trend surface fitted to the glacially buried carbonaceous deposits that explained only a low percentage of total variance and was of little significance when compared to statistical parameters for polynomial regression equations fitted to existing surfaces.
2) Two logs reporting separate organic deposits at different altitudes that correlate poorly with each other and with nearby elevations of carbonaceous matter.
3) Unreasonable elevation anomalies that exist between closely spaced organic deposits.

These findings provide direct evidence for at least three and possibly several Pleistocene glacial episodes that occurred in the study area.

Evaluation of Methodology

The comparative methodology employing trend surface analysis demonstrated in this study is useful as a preliminary investigative procedure in glaciated areas where data on the subsurface drift are lacking. It provides information on the relative number of glacial events that occurred in a region which in turn can serve as a basis for further research of subsurface sediment sequences.

The buried organic matter data set should be as large as possible to avoid misleading results. The number of data locations used in this study was marginal for a third-degree trend surface analysis. This is apparent from the lower significance levels for the higher order terms in the 42 point control data sets for the existing surfaces. Emphasis should be placed on high significance levels to avoid the error of accepting a good fit that is a chance occurrence.

The technique is effective for disproving the existence of a single paleosurface because a poor fit provides strong evidence against the reality of such a surface. If a good fit is obtained, however, it does not necessarily mean that the data define a single paleosurface. Additional evidence, such as radiocarbon dates, are needed to confirm its existence.

Suggestions for Further Research

Several problems deserving further research became evident during the course of this study. A planned and systematic drilling program should be developed in the study area to determine the subsurface till stratigraphy and to recover, analyze, and radiocarbon date samples of glacially buried organic material. Such a study would provide detailed information on the glacial chronology for this part of the state. The relationship observed between bends in end moraines and underlying areas of elevated bedrock should be investigated elsewhere to determine if it is unique to this region. Because the exact nature and pattern of preglacial drainage in the central portion of Michigan is unknown, a need also exists for more detailed mapping of the bedrock surface in adjacent areas.

APPENDICES

APPENDIX A

RESULTS OF TREND SURFACE ANALYSIS: ANALYSIS OF VARIANCE AND CORRELATION COEFFICIENTS

APPENDIX A--RESULTS OF TREND SURFACE ANALYSIS: ANALYSIS OF VARIANCE AND CORRELATION COEFFICIENTS

Table 6. Bedrock (610)

Source	df	SS	MS	F	Sign.
Total, 610 points	609	443570			
Linear Components	2	237316	118658	349.0	99%
Deviations Linear	607	206254	340		
$R^2 = .54$					
Quadratic Components	3	65647	21882	94.0	99%
Deviations Quadratic	604	140607	233		
$R^2 = .14$					
Cubic Components	4	3168	792	3.5	99%
Deviations Cubic	600	137439	229		
$R^2 = .01$					
All Components	9	306131	24014	148.0	99%
Deviations	600	137439	229		
$R^2 = .69$					

Table 7. Surface (290)

Source	df	SS	MS	F	Sign.
Total, 290 points	289	123928			
Linear Components	2	65886	32943	163.0	99%
Deviations Linear	287	58042	202		
$R^2 = .53$					
Quadratic Components	3	35142	11714	145.0	99%
Deviations Quadratic	284	22899	81		
$R^2 = .28$					
Cubic Components	4	1823	456	11.0	99%
Deviations Cubic	280	11427	41		
$R^2 = .02$					
All Components	9	102851	11428	152.0	99%
Deviations	280	21076	75		
$R^2 = .83$					

APPENDIX A--continued

Table 8. Bedrock (42)

Source	df	SS	MS	F	Sign.
Total, 42 points	41	13975			
Linear Components	2	6541	3271	17.1	99%
Deviations Linear	39	7433	191		
$R^2 = .47$					
Quadratic Components	3	3206	1069	9.1	99%
Deviations Quadratic	36	4227	117		
$R^2 = .23$					
Cubic Components	4	964	241	2.4	90%
Deviations Cubic	32	3264	102		
$R^2 = .07$					
All Components	9	10712	1190	11.7	99%
Deviations	32	3263	102		
$R^2 = .77$					

Table 9. Surface (42)

Source	df	SS	MS	F	Sign.
Total, 42 points	41	9425			
Linear Components	2	4812	2406	20.4	99%
Deviations Linear	39	4614	118		
$R^2 = .51$					
Quadratic Components	3	1978	659	9.0	99%
Deviations Quadratic	36	2634	73		
$R^2 = .21$					
Cubic Components	4	723	181	3.0	95%
Deviations Cubic	32	1911	60		
$R^2 = .08$					
All Components	9	7513	835	13.9	99%
Deviations	32	1911	60		
$R^2 = .80$					

APPENDIX A--continued

Table 10. Surface Organics (397)

Source	df	SS	MS	F	Sign.
Total, 397 points	396	161359			
Linear Components	2	81192	40596	200.0	99%
Deviations Linear	394	80167	203		
R^2 = .50					
Quadratic Components	3	45187	15062	169.2	99%
Deviations Quadratic	391	34979	89		
R^2 = .28					
Cubic Components	4	3014	754	9.1	99%
Deviations Cubic	387	31966	83		
R^2 = .02					
All Components	9	129393	14377	174.0	99%
Deviations	387	31966	83		
R^2 = .80					

Table 11. Surface Organics (42)

Source	df	SS	MS	F	Sign.
Total, 42 points	41	12914			
Linear Components	2	6766	3383	21.4	99%
Deviations Linear	39	6148	158		
R^2 = .52					
Quadratic Components	3	3267	1089	13.6	99%
Deviations Quadratic	36	2880	80		
R^2 = .26					
Cubic Components	4	589	147	2.1	88%
Deviations Cubic	32	291	72		
R^2 = .04					
All Components	9	10623	1180	16.4	99%
Deviations	32	2291	72		
R^2 = .82					

APPENDIX A--continued

Table 12. Glacially Buried Organic Deposits (42)

Source	df	SS	MS	F	Sign.
Total, 42 points	41	8751			
Linear Components	2	33	17	.1	<25%
Deviations Linear	39	8718	224		
R^2 = .01					
Quadratic Components	3	1045	348	1.6	75%
Deviations Quadratic	36	7673	213		
R^2 = .12					
Cubic Components	4	2051	512	2.9	95%
Deviations Cubic	32	5621	176		
R^2 = .24					
All Components	9	3130	348	2.0	90%
Deviations	32	5621	176		
R^2 = .36					

Table 13. Glacially Buried Organic Deposits (38)

Source	df	SS	MS	F	Sign.
Total, 38 points	37	2764			
Linear Components	2	119	59	.8	50%
Deviations Linear	35	2645	76		
R^2 = .04					
Quadratic Components	3	270	90	1.2	50%
Deviations Quadratic	32	2376	74		
R^2 = .10					
Cubic Components	4	408	102	1.4	75%
Deviations Cubic	28	1968	70		
R^2 = .15					
All Components	9	796	89	1.3	50%
Deviations	28	1968	70		
R^2 = .29					

APPENDIX A--continued

Table 14. Top of Organic Sediment Zone (42)

Source	df	SS	MS	F	Sign.
Total, 42 points	41	9310			
Linear Components	2	52	26	.1	<25%
Deviations Linear	39	9258	237		
R^2 = .01					
Quadratic Components	3	972	324	1.4	50%
Deviations Quadratic	36	8287	230		
R^2 = .10					
Cubic Components	4	2068	517	2.7	90%
Deviations Cubic	32	6219	194		
R^2 = .22					
All Components	9	3091	343	1.8	75%
Deviations	32	6219	194		
R^2 = .33					

APPENDIX A--continued

Table 15. Standardized Regression Coefficients and Correlations Between Surfaces

a) Standardized Third-degree Trend Surface Regression Equation Coefficients

	Bedrock (610)	Bedrock (42)	Surface (290)	Surface (42)	Surface Organics (397)	Surface Organics (42)
Linear	9.75	13.44	-9.37	-9.74	-14.25	-17.81
Components	-21.90	-25.94	8.55	16.61	16.99	6.81
	4.29	5.82	3.95	1.84	6.19	2.27
Quadratic	-8.74	-5.11	-9.71	-6.60	-8.52	-8.01
Components	1.41	1.23	4.91	2.59	2.30	4.51
	-1.89	-3.04	-1.72	-1.93	-1.71	.17
Cubic	1.12	2.86	1.07	1.63	-.02	2.74
Components	.81	1.38	.78	.81	1.03	4.31
	1.24	3.71	-1.99	-4.63	-2.49	2.18

b) Correlation Coefficients Showing the Degree of Association Between Surfaces

Bedrock (610) Bedrock (42)	R = .99	Surface (290) Surface Organics (397)	R = .94
Surface (290) Surface (42)	R = .90	Surface (290) Surface Organics (42)	R = .88
Surface Organics (397) Surface Organics (42)	R = .84	Bedrock (610) Surface (290)	R = -.39

APPENDIX B

WELL RECORD DATA FOR GLACIALLY BURIED ORGANIC DEPOSITS

APPENDIX B--WELL RECORD DATA FOR GLACIALLY BURIED ORGANIC DEPOSITS

Table 16. Glacially Buried Organic Deposits

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller & Date Completed
Clinton County						
CL-1	NW¼NW¼NW¼ sec. 19 T8N R4W	214.9	27.4	187.5	6.0 m gray sand w/large amount of wood	Parks Well Dlg. 10/14/66
CL-2	NW¼NW¼SW¼ sec. 7 T8N R3W	219.5	33.2	186.3	1.8 m fine sand w/wood and coal	R. Oberlitner 8/24/74
CL-3	NW¼SW¼SW¼ sec. 26 T8N R2W	219.7	26.2	193.5	1.2 m fine sand w/wood and coal	R. Oberlitner 2/3/75
CL-4	NE¼SE¼NE¼ sec. 25 T7N R2W	228.6	9.4	219.2	6.1 m fine sand w/wood and coal	R. Oberlitner 5/10/78
CL-5	SE¼SE¼NE¼ sec. 6 T8N R4W	224.0	41.4	182.6	20.7 m wood, coal and decayed grass	F.M. and C.S. Oberlitner 10/67
CL-6	SW¼ sec. 6 T8N R4W	225.0	40.2	184.8	5.8 m wood and muddy sand .6 m water, sand and gas	L. S. Weber 10/53
CL-7	NW¼NW¼NW¼ sec. 6 T8N R4W	233.2	54.9	178.3	clam shell	R. Oberlitner[@]
CL-8	NE¼NE¼NE¼ sec. 7 T8N R4W	231.6	36.6	195.1	gas and compacted grass	R. Oberlitner[@]

APPENDIX B--continued

Table 16 (cont'd)

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller & Date Completed
Ionia County						
I-1	SE¼SE¼SW¼ sec. 20 T8N R5W	240.8	73.2	167.6	3.0 m fine sand w/wood and coal	R. Oberlitner 5/18/70
I-2	SE¼SE¼NE¼ sec. 32 T7N R6W	237.8	46.6	191.2	15.2 m sand and decayed vegetation	Seese Well Dlg. 10/28/77
I-3	SW¼SE¼SE¼ sec. 12 T8N R5W	213.4	26.3	187.1	1.5 m wood, coal and muck	R. Oberlitner 7/7/78
I-4	NW¼NW¼SE¼ sec. 16 T7N R5W	213.4	30.7	182.7	3.0 m fine sand w/wood and coal	R. Oberlitner 7/25/78
I-5	NW¼NE¼NW¼ sec. 13 T8N R5W	218.8	35.2	183.6	22.8 m muck, peat, coal and wood	R. Oberlitner 8/4/78
I-6	NW¼SE¼SE¼ sec. 12 T8N R5W	217.9	30.6	187.2	9.4 m wood, coal, muck and sand; 7.6 m marl	R. Oberlitner 5/15/80
I-7	S½NW¼SW¼ sec. 12 T8N R5W	214.9	76.2	138.7	Twigs, bark, wood and gas	Oberlitner[@]

APPENDIX B--continued

Table 16 (cont'd)

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller & Date Completed
Montcalm County						
MT-1	SW¼SW¼SW¼ sec. 13 T12N R6W	288.6	96.3	192.3	1.2 m peat, shale, soft black	Theodore Oil Co. 1934
MT-2	NE¼NW¼SW¼ sec. 1 T9N R6W	247.9	67.5	180.3	4.6 m marl, sandy	Lima Dlg. Co. 1936
MT-3	NE¼SE¼NW¼ sec. 24 T9N R5W	228.7	26.0	202.7	2.7 m muck or organic deposit w/some wood	F.M. and C.S. Oberlitner 2/9/68
			34.1	194.6	1.2 m sand w/muck and clay	
MT-4	NW¼SE¼ sec. 12 T9N R5W	231.7	43.4	188.2	.3 m coarse gravel, medium to coarse sand, trace of rotten vegetation	Francis Engin. Co.
MT-5	SW¼SW¼SW¼ sec. 26 T9N R5W	233.1	46.2	186.9	10.0 m fine sand w/wood and coal	R. Oberlitner 2/28/75
MT-6	SE¼SE¼NE¼ sec. 25 T9N R7W	256.0	32.6	233.4	6.1 m fine sand w/wood and coal	R. Oberlitner 1/17/78

APPENDIX B--continued

Table 16 (cont'd)

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller & Date Completed
Gratiot County						
GR-1	NE¼NW¼NW¼ sec. 25 T10N R4W	231.6	29.0	202.6	wood on top of 16.5 m sand horizon	F.M. and C.S. Oberlitner 11/68
GR-2	SW¼SW¼SW¼ sec. 29 T10N R3W	222.5	21.1	201.8	.9 m gravel w/wood and coal	R. Oberlitner 3/17/72
GR-3	SW¼SE¼SW¼ sec. 7 T9N R4W	234.7	46.0	188.7	9.4 m sandy gray clay w/wood	R. Oberlitner 7/11/72
GR-4	NW¼NW¼NW¼ sec. 28 T12N R3W	234.7	55.6	179.1	4.6 m clay, sand w/wood and coal	R. Oberlitner 8/8/74
GR-5	NW¼NE¼NE¼ sec. 21 T10N R3W	225.6	31.1	194.5	12.5 m fine sand w/wood and coal	R. Oberlitner 8/15/74
GR-6	SW¼SE¼NW¼ sec. 29 T10N R1W	207.3	32.1	175.2	3.7 m fine sand w/wood and clay	R. Oberlitner 1/27/75
GR-7	SW¼SE¼SW¼ sec. 30 T9N R4W	239.2	53.3	186.0	3.0 m sand w/wood and coal	R. Oberlitner 2/13/76

APPENDIX B--continued

Table 16 (cont'd)

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller * Date Completed
<u>Gratiot County</u> cont'd						
GR-8	NE¼NE¼SE¼ sec. 27 T10N R2W	210.3	24.2	186.1	3.4 m fine sand w/wood and coal	R. Oberlitner 5/27/78
GR-9	NE¼NW¼NE¼ sec. 25 T11N R3W	246.9	64.6	182.3	2.4 m sand and coal w/wood fragments	R. Oberlitner 5/17/78
GR-10	NW¼NE¼SW¼ sec. 29 T10N R4W	237.7	8.1	229.6	4.6 m sand and gravel w/wood and coal	R. Oberlitner 8/12/78
			62.4	175.3	6.1 m muck, peat and gravel	
GR-11	NW¼NE¼NE¼ sec. 35 T12N R3W	224.6	25.6	199.0	4.9 m thin layers of sand and clay w/wood and coal	R. Oberlitner 3/13/79
GR-12	SE¼NE¼SE¼ sec. 30 T12N R2W	228.6	39.0	189.6	15.2 m fine muddy sand w/wood and coal	R. Oberlitner 3/26/79
GR-13	NW¼NW¼NW¼ sec. 28 T11N R1W	215.8	33.6	182.2	2.7 m sand w/wood and coal	R. Oberlitner 6/1/79

APPENDIX B--continued

Table 16 (cont'd)

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller & Date Completed
<u>Gratiot County</u> cont'd						
GR-14	NE¼NW¼NE¼ sec. 19 T10N R1W	212.8	44.0	168.8	2.7 m sand layers in clay w/wood	R. Oberlitner 8/3/79
GR-15	SW¼NE¼SE¼ sec. 30 T9N R3W	221.0	39.6	181.4	6.1 m fine muddy sand w/wood and coal	R. Oberlitner 8/7/79
GR-16	NE¼NE¼SE¼ sec. 8 T9N R4W	231.6	44.8	186.8	6.1 m sand and gravel w/wood and coal	R. Oberlitner 10/4/79
GR-17	SW¼SW¼SE¼ sec. 24 T11N R3W	245.3	42.5	202.8	2.1 m fine sand w/wood and coal	R. Oberlitner 7/22/80
GR-18	NW¼SW¼SW¼ sec. 24 T12N R3W	231.6	57.9	173.7	6.1 m sand, clay and wood	Herron Well Dlg. 10/2/80
GR-19	SE¼NE¼NE¼ sec. 31 T9N R3W	213.4	29.2	184.1	11.6 m fine muddy sand w/wood and coal	R. Oberlitner 6/25/81
GR-20	NW¼NE¼ sec. 23 T12N R3W	228.6	24.4	204.2	coal and wood at the top of a gravel formation	C. Oberlitner@
GR-21	NE¼NE¼NW¼ sec. 3 T11N R3W	223.7	41.1	182.6	wood in 14.0 m gravel zone	Brewer@

APPENDIX B--continued

Table 16 (cont'd)

Well	Location	Surface Altitude (meters)	Depth* (meters)	Organic Zone Altitude* (meters)	Organic Material and Associated Sediments	Driller & Date Completed
Gratiot County cont'd						
GR-22	SE¼SE¼SE¼ sec. 35 T10N R3W	227.0	76.2	151.0	muck and sand	F. Oberlitner[@]
GR-23	SW¼SE¼SW¼ sec. 20 T9N R1W	201.2	19.8	181.4	9.1 m sand w/wood and coal	R. Oberlitner[@]

*Calculated from middle of organic matter-sediment horizon.

[@]Interview.

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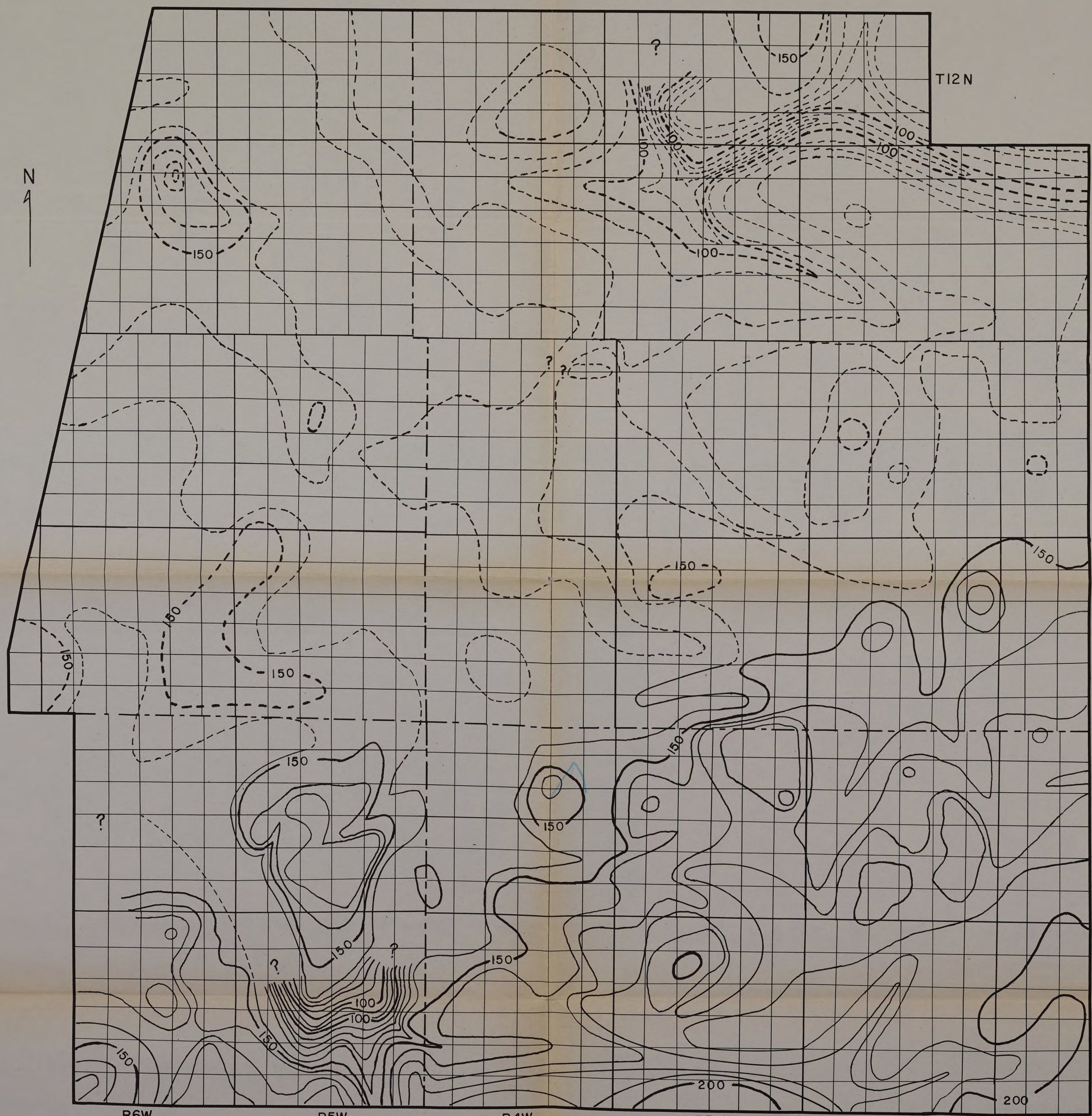
FIGURE 3. BEDROCK SURFACE



---- CONTOUR IN AREA WITH FEWER WELL RECORDS

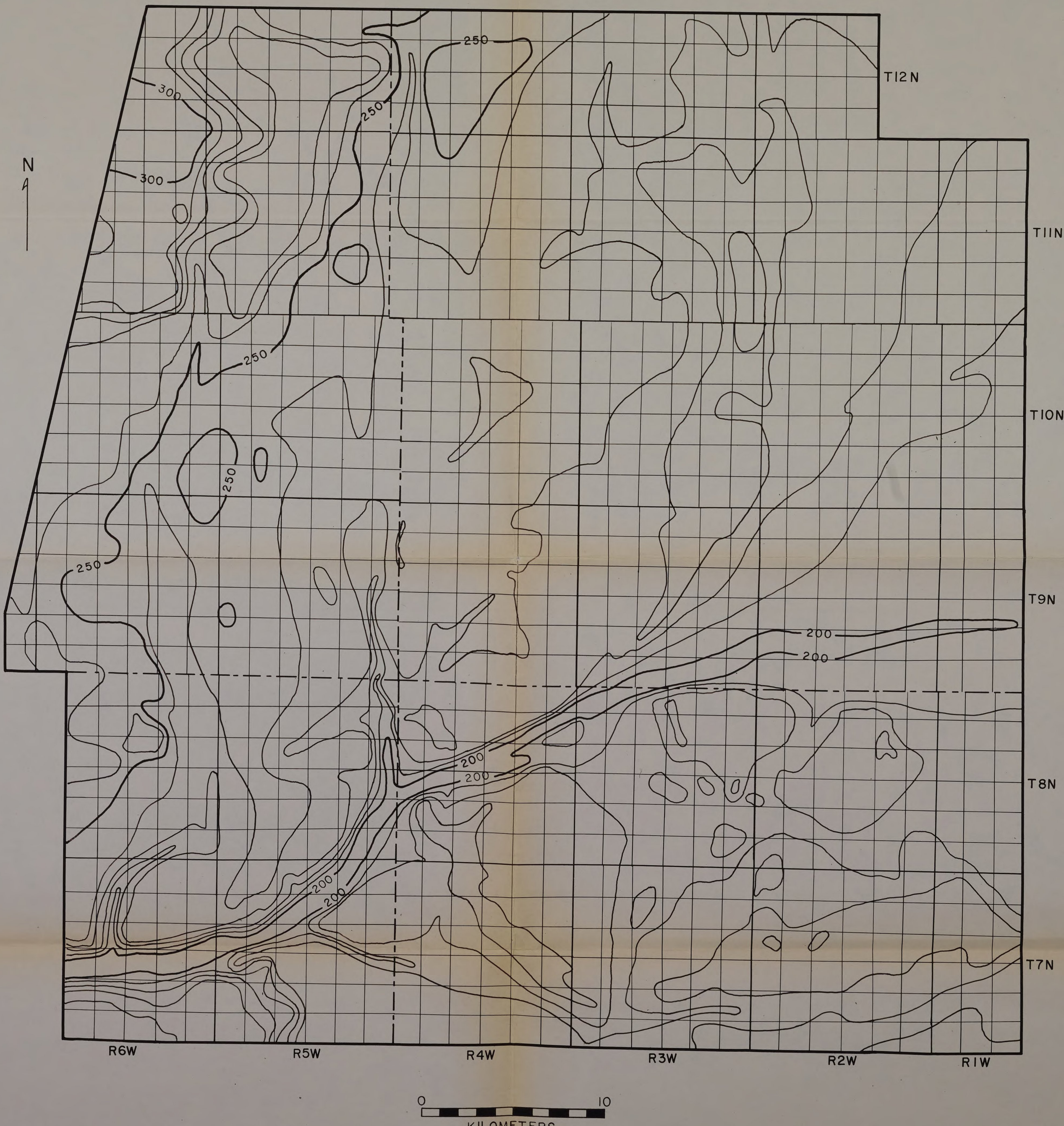
0 10 KILOMETERS

— CONTOUR IN AREA WITH NUMEROUS WELL RECORDS

CONTOUR INTERVAL 10 METERS

(ALTITUDES IN METERS ABOVE MEAN SEA LEVEL)

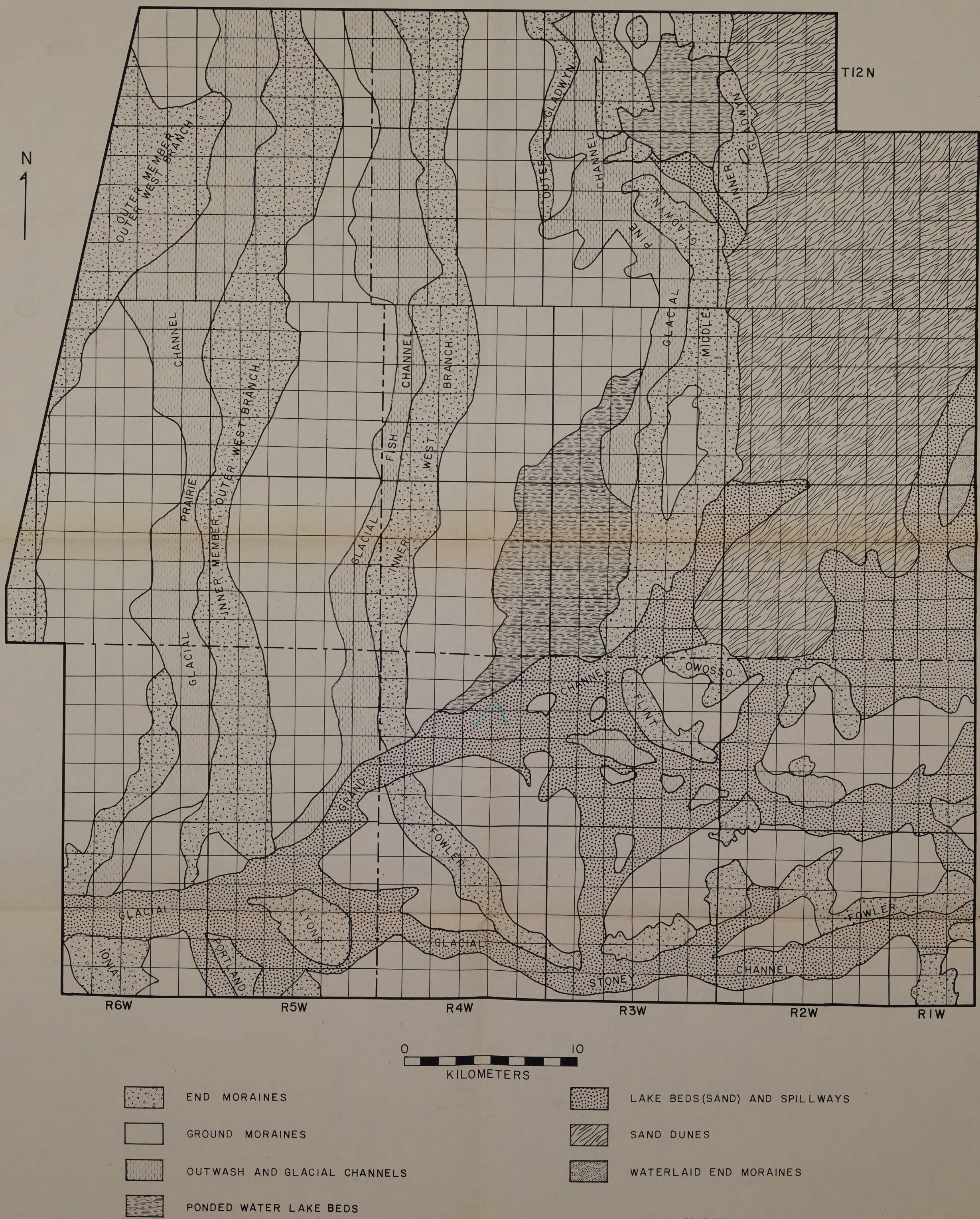
FIGURE 8. TOPOGRAPHY



CONTOUR INTERVAL 10 METERS

(ALTITUDES IN METERS ABOVE MEAN SEA LEVEL)

FIGURE 9. SURFACE MORPHOLOGY



SOURCES: LEVERETT AND TAYLOR (1915), BRETZ (1953), MARTIN (1955)

FIGURE 10. SURFACE DRAINAGE

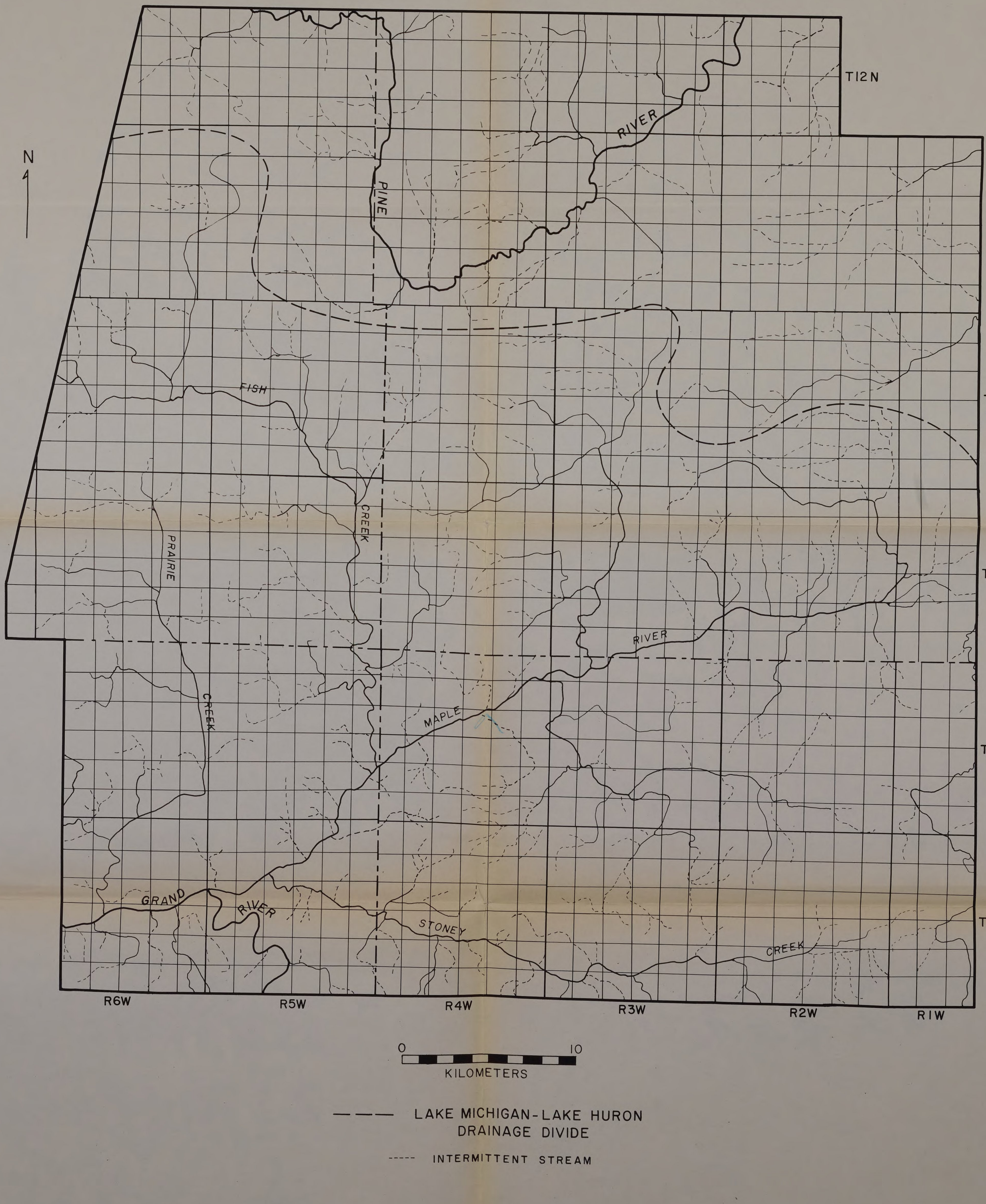
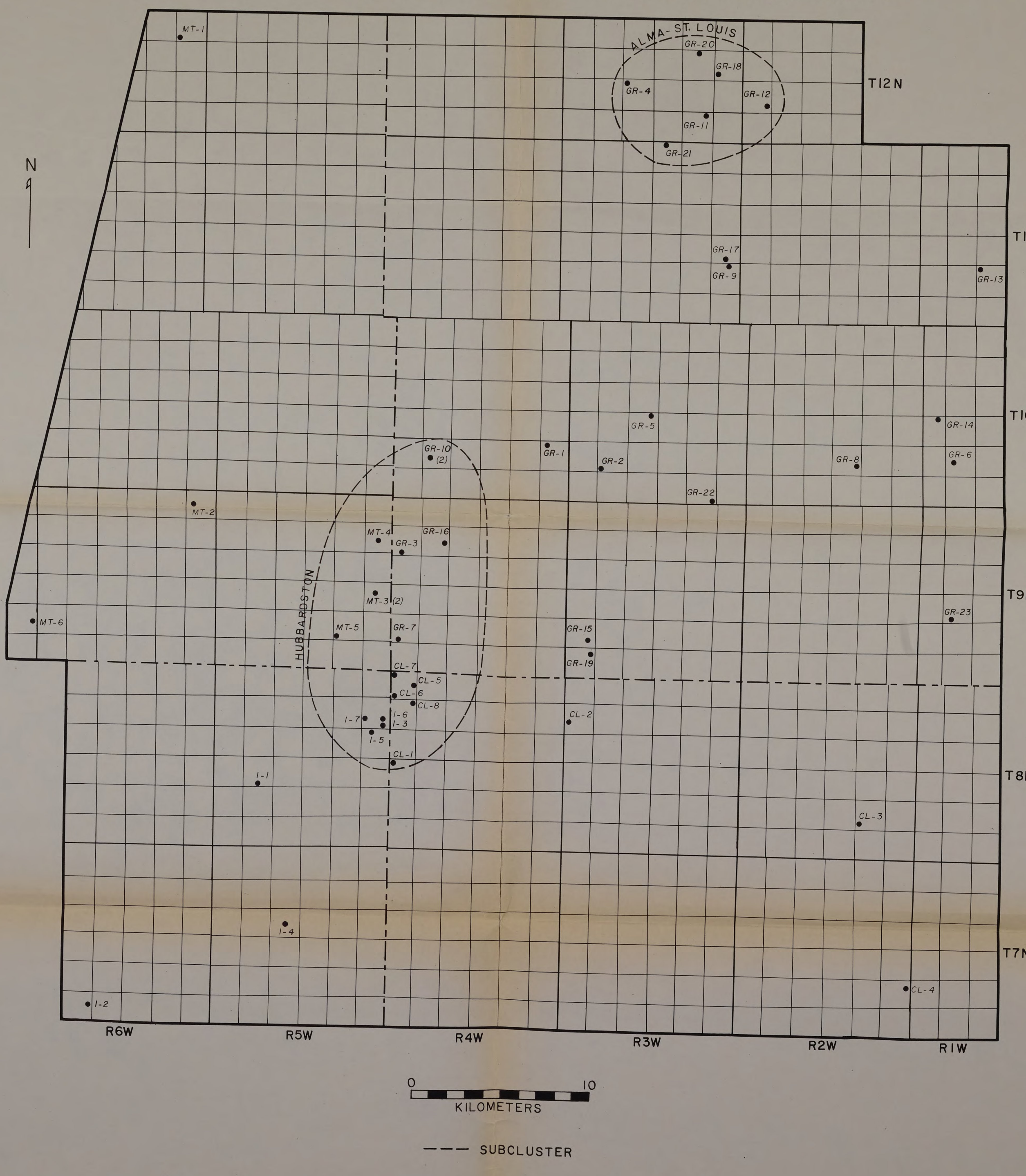
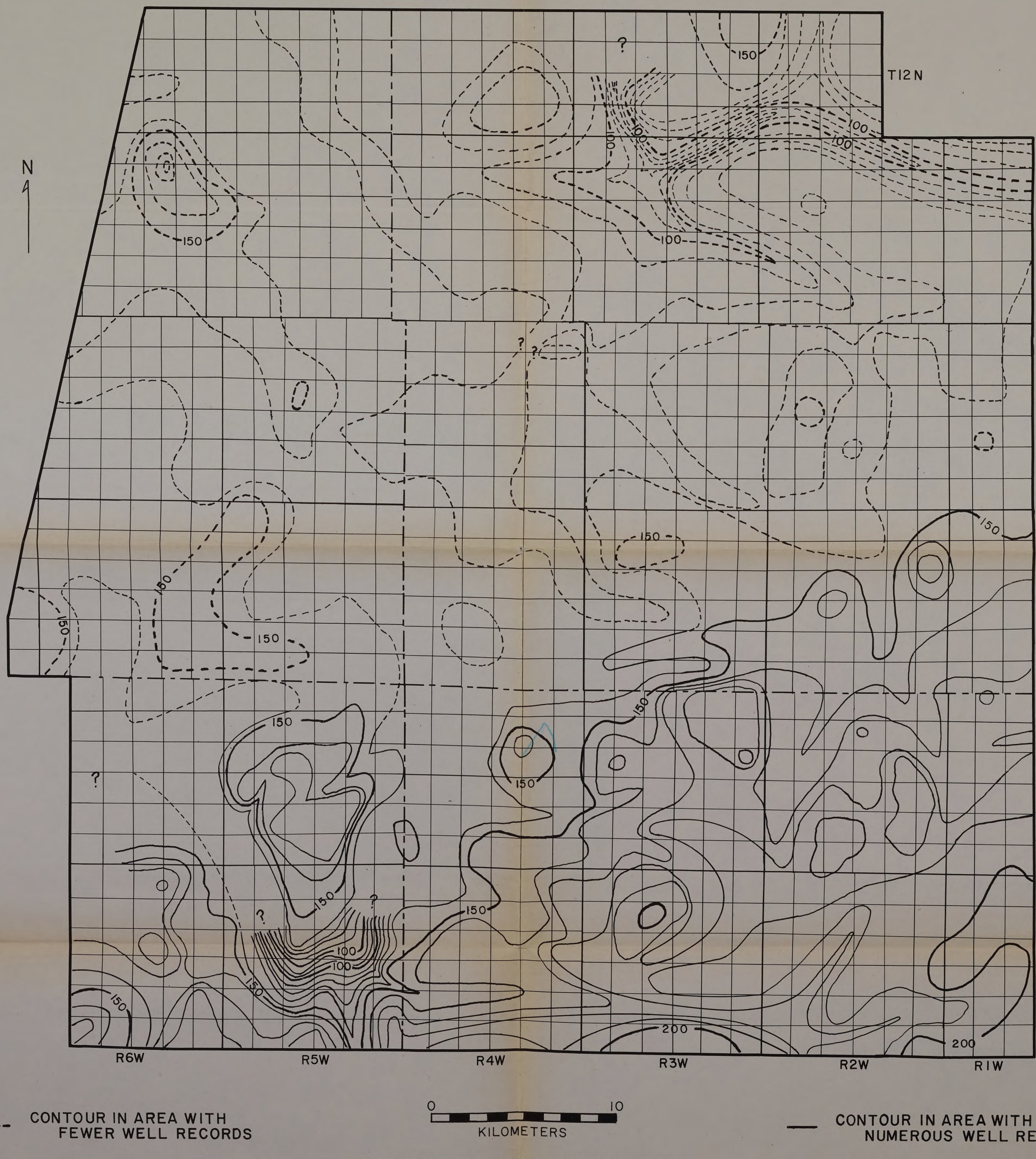


FIGURE 11. GLACIALLY BURIED ORGANIC DEPOSITS



SOURCE: SEE APPENDIX B

FIGURE 3. BEDROCK SURFACE



---- CONTOUR IN AREA WITH FEWER WELL RECORDS

— CONTOUR IN AREA WITH NUMEROUS WELL RECORDS

CONTOUR INTERVAL 10 METERS

(ALTITUDES IN METERS ABOVE MEAN SEA LEVEL)

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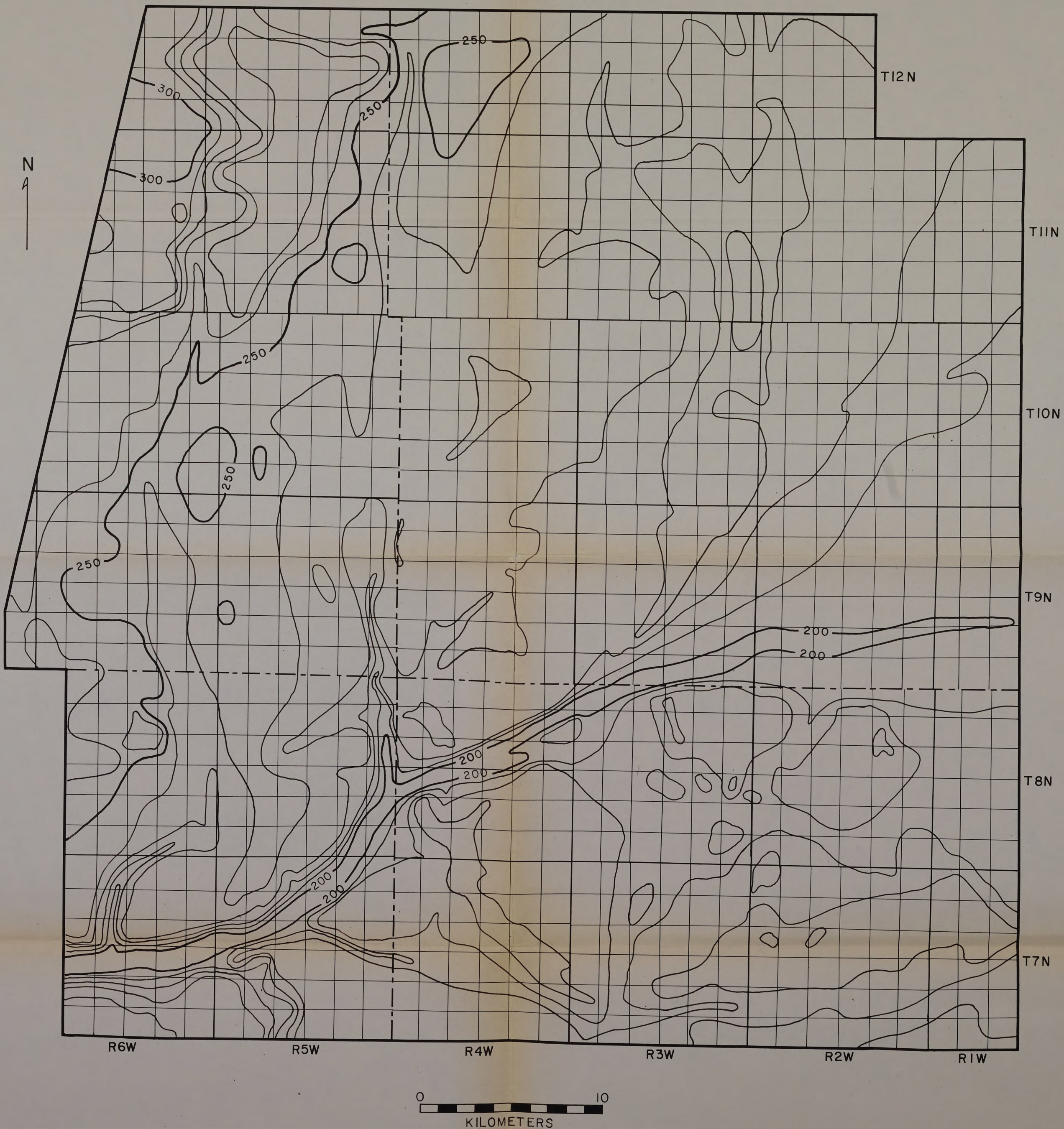
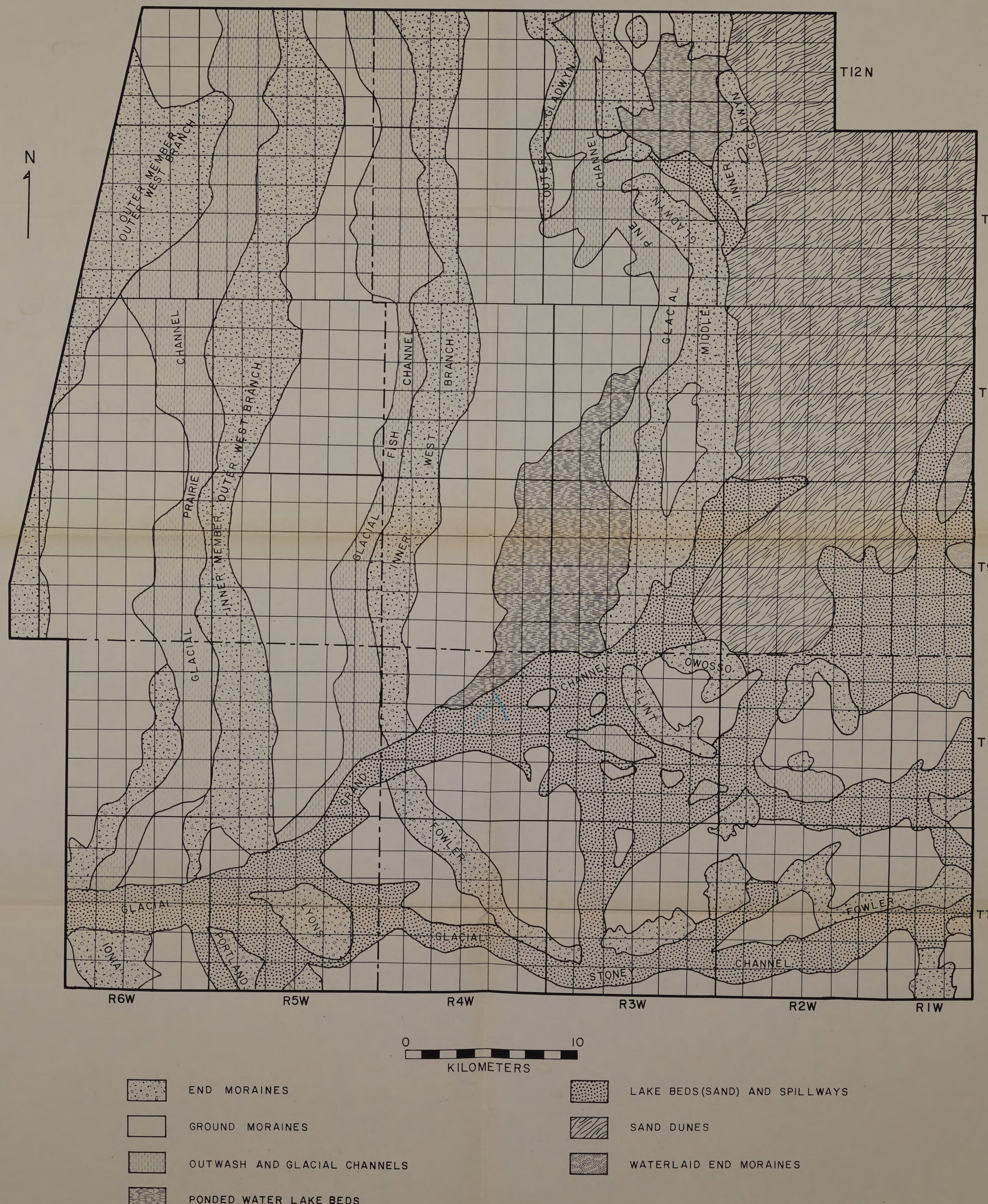


CONTOUR INTERVAL 10 METERS

(ALTITUDES IN METERS ABOVE MEAN SEA LEVEL)

FIGURE 9. SURFACE MORPHOLOGY



SOURCES: LEVERETT AND TAYLOR (1915), BRETZ (1953), MARTIN (1955)

FIGURE 10. SURFACE DRAINAGE