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THE GLACIAL GEOMORPHOLOGY OF AN INTERLOBATE AREA IN SOUTHEAST MICHIGAN: RELATIONSHIPS BETWEEN LANDFORMS, SEDIMENTS, AND BEDROCK

By

Richard Louis Rieck

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ABSTRACT

THE GLACIAL GEOMORPHOLOGY OF AN INTERLOBATE AREA IN SOUTHEAST MICHIGAN: RELATIONSHIPS BETWEEN LANDFORMS, SEDIMENTS, AND BEDROCK

By

Richard Louis Rieck

This dissertation is concerned with the relationships between glacial landforms, glacial sediments, and the bedrock in and near an interlobate area in southeast Michigan. The examination of well records provided a data base for mapping the bedrock surface and supplied information on the area's glacial history. Analyses of the clay mineralogy of drift samples, using X-ray diffraction and other characteristics such as pebble lithology, color, fabric, and texture of tills, were made to identify lobe provenance. Investigations were made to determine the location of the surficial drift contact and the nature of deglaciation. Landform assemblages were identified by field investigation and study of topographic maps and air photos.

The Kalamazoo Moraine of the Saginaw Lobe and the Mississinewa Moraine of the Huron-Erie Lobe (possibly correlative with the Mississinewa Moraine of Indiana and Ohio) merge near the Washtenaw-Jackson county boundary. An Interlobate Moraine Tract is situated at the confluence of the moraines, and the Grass Lake outwash plain exists in the reentrant between them. Bedrock configuration influenced certain aspects of both the larger and smaller elements of the topography. A bedrock-surface map constructed from 1,482 data points shows that the two moraines are associated with the flanks of a subsurface bedrock tableland. Seven valleys, deeply buried by glacial drift and incised into the bedrock appear to be the result of fluvial erosion. Oxidized drift and organic

material that underlie unoxidized till in these valleys indicate a non-glacial episode of considerable length and provide evidence of multiple glaciation. Numerous linear lakes and streams are located on drift above the buried valleys and may be due to the ablation of buried stagnant-ice masses.

Drifts of the Saginaw and Huron-Erie Lobes are so similar in the area it may be difficult, if not impossible, to identify the lobe provenance of a till sample on the basis of such characteristics as color, pebble lithology, or texture. X-ray diffraction data of clay from forty-nine till samples and twelve glaciofluvial and glaciolacustrine samples indicate that lobe provenance may ordinarily be determined with a high degree of confidence. Magnesium-saturated, glycerol-solvated, basally oriented clays of all thirteen till samples studied from the Kalamazoo Moraine, areas proximal to it, and the associated portion of the Interlobate Morainic Tract had 7Å/10Å peak height ratios of 0.91 or more. Twenty-one of twenty-two till samples from the Mississinewa Moraine, areas proximal to it, and the associated portion of the Interlobate Tract had 7Å/10Å peak height ratios of 0.90 or less. Saginaw Lobe drift produces higher ratios than Huron-Erie drift, probably due to the presence of larger relative amounts of kaolinite. On the basis of clay mineralogy the surficial drift contact in the Interlobate Tract appears to be sharp, with little or no interdigitation of tills.

Flow till is widely distributed in the Kalamazoo Moraine and associated portion of the Interlobate Tract. It is probably present in Huron-Erie deposits as well. The presence of considerable amounts of flow till provides sedimentological evidence that ice stagnation was common during deglaciation.

Both moraines appear to be accumulations of drift deposited primarily in contact with stagnant, rather than active, ice. The Kalamazoo Moraine has a well-developed outwash apron which terminates at an ice-contact slope as much as 150 feet (45 m) high. Latitudinal zonation in the moraine is marked by (1) linear depressions and ridges immediately proximal and parallel to the crest of the outwash apron, (2) a zone of lakes and bogs, and (3) a northern tract of linear depressions also oriented parallel with the crest. The Mississinewa Moraine is separated into two portions by the lowland of Mill Creek and conspicuous zonation is lacking. However, eskers and a smaller tract of linear depressions do exist.

The Blue Ridge Esker trends across the Grass Lake Plain, and on the basis of sedimentary and morphologic evidence it apparently formed near the interlobate contact. Tributary eskers, physically connected with Blue Ridge and displaying a dendritic pattern, are associated with specific features in both moraines, indicating contemporaneous formation. The Grass Lake Plain is also directly related to the moraines. Thus, it appears likely that, as the moraines were formed by meltwater streams at the inactive margins of the lobes, a superglacial outwash plain and an englacial or subglacial esker system were formed distally to the moraines in contact with stagnant ice. Subsequent ablation of this stagnant ice caused superimposition of the glaciofluvial sediments on the subjacent material, including the esker system, to form a collapsed outwash plain.

Ice-contact slopes at the confluence of the two moraines prove that their distal portions are time-correlative. A similar situation within the Interlobate Tract probably indicates that the medial or proximal portions of the moraines are also time-correlative.

Two distinct landform assemblages are located in the Interlobate Morainic Tract. Groups of linear depressions with uniform orientation, ice-contact outwash fans, and large ice-contact channel fillings are associated with the Saginaw Lobe portion of the tract; crevasse fillings and groups of linear depressions with dissimilar intergroup orientations are characteristic of the Huron-Erie portion. These assemblages are probably due to differing conditions in the stagnant ice of the two lobes. A line separating the two landform assemblages is almost coincident with the boundary separating drift samples with 7Å/10Å peak height ratios of 0.91 or more and 0.90 or less. Thus, the evidence from two separate and distinct lines of investigation (sediments and landforms) indicates a similar location for the surficial interlobate contact. In addition, flow till, ice-contact slopes, and certain landforms indicate that stagnant-ice conditions prevailed during deglaciation.

Of general interest is the finding that in certain areas the study of morphology may yield results at least as useful as those provided by investigation of sediment characteristics. Hence, those who are concerned with the nature of glaciated areas may benefit from using morphological techniques as well as those that provide other meaningful information.

To my loving wife

Renate

for her sacrifices and support

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I wish to express my deepest and most sincere gratitude to my major professor, Dr. H. A. Winters, for his patient guidance, advice, and constructive criticism at all stages of this study. I am indebted to the following faculty members- Dr. D. Brunnschweiler and Dr. J. R. Harman of the Department of Geography, and Dr. H. D. Foth and Dr. D. L. Mokma of the Department of Crop and Soil Sciences. They graciously served as members of my doctoral committee and gave freely of their time and counsel. I also wish to thank Dr. M. M. Mortland of the Departments of Crop and Soil Sciences and Geology for his advice and interest; the Department of Crop and Soil Sciences for laboratory space and equipment; the Department of Geography for funding the computer mapping and Mr. D. Batkins for programming assistance; Dr. C. E. Prouty and the Department of Geology for supplying well cuttings; Dr. W. A. Kneller, Department of Geology, University of Toledo, for discussions and maps; the United States Geological Survey for the loan of F. Leverett's field notebooks and maps; Dr. A. Dreimanis and Dr. R. M. Quigley of the University of Western Ontario for their discussions and interest; Mr. M. Fox of Napoleon, Mr. D. Lindemann of Dexter, and Mr. M. Meabon of Pinckney for well logs and information on buried organic matter; and Mr. D. P. Lusch and Mr. R. L. Dodson of the Department of Geography for their many hours of discussion both in the field and office.

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Chapter 1

INTRODUCTION

Statement of Problem

This study is concerned with the nature and relationships of the glacial landforms and sediments at and near a segment of the Saginaw and Huron-Erie interlobate area in southeastern Michigan.[1] The major objectives of this study are listed below:

1. To determine what relationship, if any, exists between the nature of the bedrock surface beneath the drift and the glacial landforms of the study area;
2. to describe the characteristics, extent, and contact relationships of the surficial drifts associated with the Saginaw and Huron-Erie Lobes and to specify on what basis the drifts may be identified and delineated;
3. to determine the characteristics and assemblages of the various landforms in and near the interlobate area;
4. to determine, on the basis of landforms and sediments, the nature of deglaciation in the area and its effects upon the landscape.

Definition, Concepts, and Techniques

Chamberlin (1883A, p. 276) introduced the term "interlobate moraine" for a feature formed "by two glaciers pushing from opposite directions" and (1883B, p. 301) "by the joint action of two glacial lobes pushing their marginal moraines together, and producing a common

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[1]The study area is defined on page 8 and illustrated in Figures 1 and 2.

one along the line of their contact."

Modern definitions of interlobate moraines by Thornbury (1969, p. 381) and Flint (1971, p. 200) do not emphasize quite as strongly the requirement that interlobate moraines be formed by lobes in contact with one another. Nevertheless, relatively strict definitions such as these present problems in application. For example, if the lobes part slightly and are separated by an open valley when drift deposition takes place, is the feature formed an interlobate moraine? Alden (1918, p. 309) considered such a situation in the Kettle Interlobate Moraine of Wisconsin and stated that "no strictly interlobate deposition took place." Alden (1918, pp. 275, 308) also noted areas in the Kettle Moraine where one of the lobes continued to hold a stable marginal position and deposit drift after the margin of the other lobe had begun to retreat. Here the compound feature formed is not entirely interlobate in origin as a portion of it was deposited after the lobes were no longer in contact. Black (1970, p. 37) hypothesizes that much of the Kettle Moraine was deposited not at the contact of two lobes but rather at the outer margins of the active ice which were separated by a zone of stagnant ice.

Chamberlin (in Alden, 1918, p. 14) realized that interlobate areas may be complex and noted, "There are grades and degrees of interlobateness and corresponding degrees of interlobate moraines." Therefore, a narrow definition of the term "interlobate moraine" is of limited value especially in areas where the chronological details of deposition are not clear. Consequently, a more general definition of interlobate moraine will be used for this dissertation: a drift accumulation deposited in or near the reentrant between (two) lobes of ice; it may have formed at a time when both glaciers were in contact or when the active ice margin(s) had retreated a distance of one to several miles (1.6 to several kilometers), exposing a narrow zone between them.

In this study the geomorphic characteristics of a complex area are described and interpreted on the basis of the nature of the topography and characteristics of the underlying sediments. The related concepts of morphostratigraphic units and rock-stratigraphic units are also utilized in this investigation because they are concerned with the stratigraphic significance of form and sediment (Frye and Willman, 1962). Both concepts have been applied in studies in other areas (for example, see Willman and Frye, 1970) and have provided a workable basis for extensive investigations of glacial landforms and sediments. The nature of rock-stratigraphic and morphostratigraphic units is discussed below along with the techniques which provide the data used to identify such units.

Rock Stratigraphy

The American Commission on Stratigraphic Nomenclature Code (1961, p. 649) has defined a rock-stratigraphic unit as "a subdivision of the rocks in the earth's crust and delimited on the basis of lithologic characteristics. . . . Rock-stratigraphic units are recognized and defined by observable physical features rather than by inferred geologic history." Willman and Frye (1970, p. 45) state that in reference to the Pleistocene the purpose of rock-stratigraphic classification is to "deal with the surficial deposits . . . on the basis of their physical characteristics, to identify and map the different types of rock units, and to understand their variations and interrelations." Rock-stratigraphic units have been formally defined in such nearby states as Illinois, Indiana, and Ohio (for example, see Willman and Frye, 1970; Wayne, 1963; and Goldthwait and others, 1965). However, little work has been done on defining rock-stratigraphic units in Michigan. This study will provide at least a partial basis for the identification of two rock-stratigraphic units that exist within the area investigated.

One of the principal objectives of the rock-stratigraphic portion of this investigation is to locate the surficial drift contact of the Saginaw and Huron-Erie Lobes. Till is generally deposited at or very near the place it was released from glacial ice.[2] Therefore, if a surficial till body situated near the drift contact can be identified as to its provenance, it will provide evidence that ice from a particular lobe occupied that location or was very close by during final deglaciation of the area. With a sufficient number of such sites it may be possible to delineate the surficial contact between Saginaw and Huron-Erie drift.

Till Texture

Grain-size analysis has long been used as a basis for the description and differentiation of tills in the Midwest and other areas (see discussion by Dreimanis and Goldthwait, 1973, p. 75) and is one of the criteria that may be used to define rock-stratigraphic units. Textural analyses of surficial sediments from within the study area have been performed in conjunction with soil surveys and the investigation of glaciofluvial sediments, but to the author's knowledge none have been

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[2] An exception would be till that sloughed off an ice margin and moved downslope before final deposition. Such a till body would have moved only a short distance. Till transported by an iceberg in a water body deposited far from the point of calving from the glacier is another exception.

determined solely for the differentiation or correlation of tills. Therefore, one objective of this dissertation is to consider till differentiation by using textural analysis.

Stone Lithology

Identification of the lithology of sedimentary particles is a well-established technique that has been used to determine the provenance of glacial till (Flint, 1971, pp. 174-75). Anderson (1957) did this for stones within Saginaw and Huron-Erie tills along two traverses which were located a considerable distance from the drift contact. This dissertation provides data on the lithology of certain coarse clastics from the area shown on Figure 2.

Till Fabric

The orientation of clastic particles within till is referred to as its fabric and may be useful to determine the former flow direction of glacial ice associated with the sediment. Very few fabric determinations have been published for Michigan tills, and none of these are from the area considered in this investigation. This study utilizes a number of till-fabric determinations to provide a better understanding of the relationships between ice-flow directions and environment of till deposition in and near the Saginaw/Huron-Erie interlobate area in a portion of southeastern Michigan.

X-Ray Diffraction of Clays

X-ray diffraction techniques have been used in numerous studies to differentiate glacial sediments. For example, studies published by the Illinois Geological Survey have utilized clay-mineralogy data to differentiate drifts of differing ages and extent (see discussion by Frye, 1968). Also an interlobate contact between two surficial tills in Illinois has been located, partially through the use of clay mineralogy (Castillon, 1972).

The mineralogical characteristics of Michigan tills are not well known. The only detailed study (Mahjoory, 1971) of which the author is aware utilized X-ray diffraction to determine clay mineralogy in soil lithosequences and toposequences in areas of Michigan not shown on Figure 2. X-ray diffraction techniques are used in this dissertation to provide a basis for identification and differentiation of Saginaw and Huron-Erie tills in southeastern Michigan.

Morphostratigraphy

Frye and Willman (1962) have defined a morphostratigraphic unit as "a body of rock that is identified primarily from the surface form it displays; it may or may not transgress time throughout its extent." The use of morphostratigraphic units may provide increased detail and understanding in Pleistocene studies and complement time, soil, and rock-stratigraphic units. No formal morphostratigraphic units have been defined in Michigan. This study will define the extent of two moraines that converge to form an interlobate area, and these may provide a basis for the future definition of morphostratigraphic units.

Map and Air Photo Interpretation

Topographic maps and air photos are useful tools for the glacial geomorphologist, and both have been utilized in this study. They provide insights into aspects of spatial and hypsometric relationships that are difficult to observe directly in the field. The largest-scale topographic maps available and 1:15,840 scale air photos (stereo coverage) were used in the investigation.

Justification

Interlobate regions and their associated drift contacts are extensive and constitute a significant portion of the glaciated area in the Midwest. The landforms and their assemblages in these areas have received relatively little attention, and in the only extensive study on the topic in the Saginaw/Huron-Erie interlobate area of Michigan Kneller (1964) grouped at least seven separate landforms into one mapping unit.

Problems related to the study area and the need for further research have been recognized previously. For example, in their study of the Ann Arbor quadrangle Russell and Leverett (1908, p. 5) stated,

> The features built along the line of retreat of the junction of the ice lobes are complicated and their study in detail will probably help to show the mode of development of interlobate moraines. Indeed, the portion of the interlobate tract that falls within the limits of this quadrangle not only well illustrates in its variety of topographic features the character of the great belt of which it forms a part, but serves as a fair sample of the usual diversity of interlobate areas in other places.

In a review article on the Pleistocene of Michigan and Indiana Wayne and Zumberge (1965, p. 71) wrote,

> Interpretation of the history of deposition of the complex intermingling of tills, outwash sediments, and lake deposits in the northern part of Indiana and in southern Michigan posed problems for Leverett, which have not been worked out adequately to this day. Typical tills from the three lobes can be distinguished without difficulty, but in the interlobate areas where they intertongue with each other, their identification becomes increasingly difficult.

Kneller (1964, p. 26) called for work associated with the tills of the area by stating that "more detailed study of till lithologies is needed to define any stratigraphic relationships existing between Saginaw and Erie lobe deposits."

This investigation utilizes several techniques to determine the relationships that exist between glacial topography and the underlying sediments. The results may provide information on the nature of deglaciation in the area, its effects on the landscape, and, in turn, how it may have been affected by the underlying bedrock. In addition, the findings may also add significantly to our knowledge of landforms, drifts, and drift contacts in and near interlobate areas and of certain relationships between the Saginaw and Huron-Erie Lobes.

Study Area

The study area is centered at the contact of Saginaw and Huron-Erie drift (Figure 1) and contains about 400 square miles (1,000 square km).[3] Two topographic trends, interpreted as moraines by early workers, converge at Leverett Hill[4] in northwest Washtenaw County (Figure 2). One of these trends northeast from the city of Jackson and has been named the Kalamazoo Moraine (Leverett and Taylor, 1915, p. 189) of the Saginaw Lobe. The other feature trends north-northeast from near Norvell and has been mapped by the same workers as a moraine of the Huron-Erie Lobe. Adjacent to Leverett Hill, their point of confluence, is a plexus of forms, interpreted by Russell and Leverett (1908, p. 5) as an interlobate morainic tract that extends northeast about 12 miles (20 km) to Pinckney in Livingston County. An outwash plain, the Grass Lake Plain, has been mapped in the reentrant between the morainal trends.

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[3]Approximate metric equivalents will be given throughout this report.

[4]A feature unnamed on the Stockbridge quadrangle and located in portions of secs. 28, 32, and 33, T. 1 S., R. 3 E. and sec. 5, T. 2 S., R. 3 E. This informal designation of "Leverett Hill" is given only to facilitate identification and is not formally proposed as a geographic name. As shown on the Stockbridge quadrangle, Sugarloaf Hill is a knob on the west flank of Leverett Hill.

Figure 1. Location of the Study Area

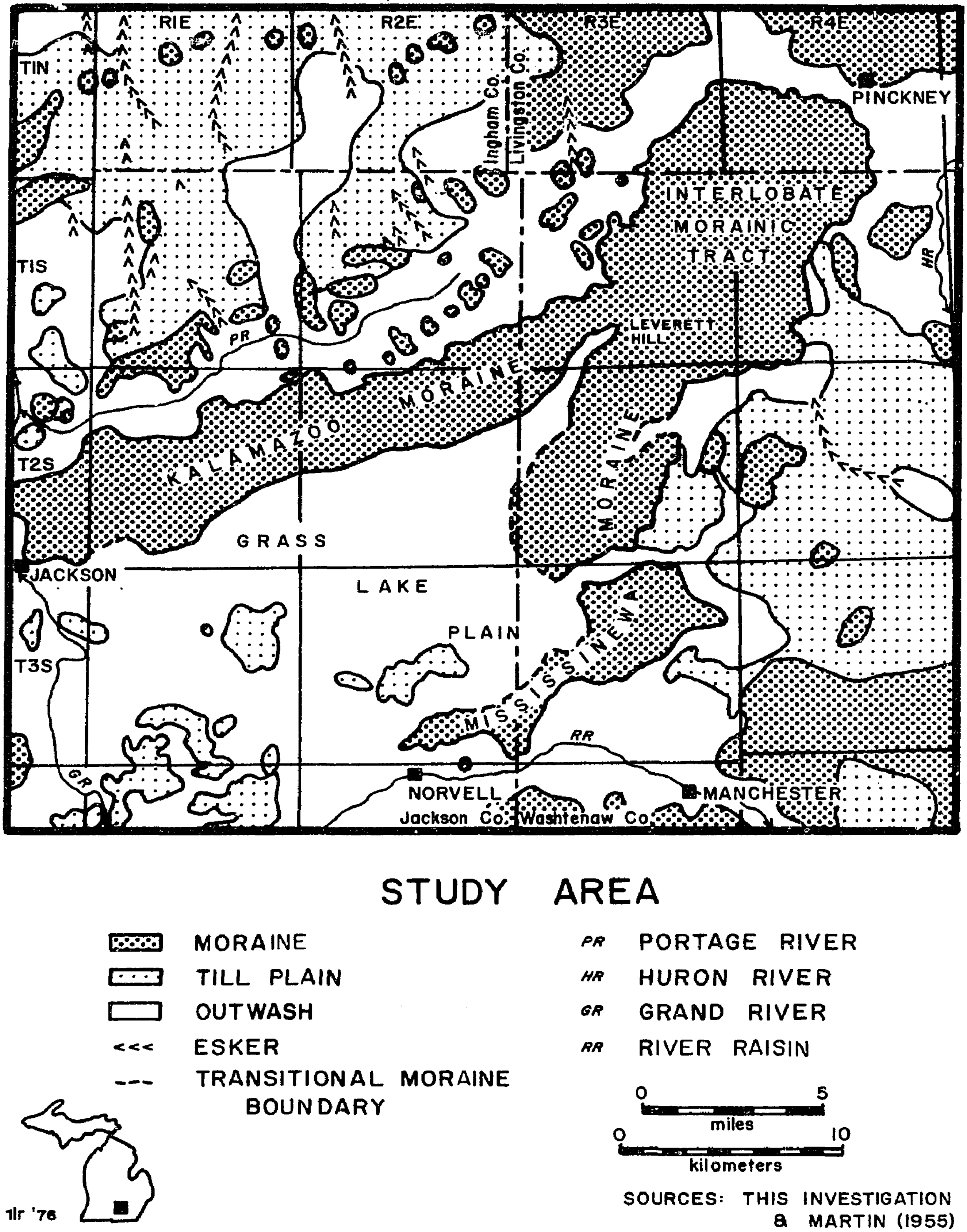

Figure 2. Study Area

Literature Review

Written Material- Study Area

In general, nineteenth-century works that treated the study area were concerned with reconnaissance mapping of surface formations at a statewide scale. Studies from the early part of the twentieth century which treated individual landforms were apparently based on a deglaciation model which did not include several aspects of ice stagnation. The most recent works dealing with the area concentrated on sand and gravel characteristics or subsurface stratigraphy and treated landforms to a lesser degree. Only works that contributed significantly to the writer's understanding of the area are cited in the following chronological review of written material.

In 1876-77 and 1883 Chamberlin presented short descriptions of the landforms in the area and in the latter publication (1883A) introduced the term "interlobate moraine." Frank Leverett, who began field work in the area in 1887 and returned intermittently for over fifty years, compiled many field notes that are on file at the United States Geological Survey library in Denver. A number of these notebooks were obtained on loan. In addition, a limited number of his field notes have been transcribed and are in the library of the Michigan Geological Survey in Lansing. Alfred Lane noted the sandy nature of the moraines in the area and also the effect of ice-margin movement on interlobate reentrants (1899).

Shortly after the turn of the century Frank Leverett, either alone or in collaboration with others, authored several publications treating the glacial landforms and geology of the study area. They include (1) the Ann Arbor Folio of the Geologic Atlas Series (Russell and

Leverett, 1908, and reprinted in a revised edition in 1915), which dealt with the Ann Arbor quadrangle (1:125,000) and included a part of the Interlobate Morainic Tract considered in this study; (2) a publication on surface geology and agricultural conditions in Michigan (1912, revised and reprinted in 1917), which referred to the moraine trending northeastward from Jackson as the Jackson Moraine; (3) and the most important, his monograph with Taylor, published in 1915, concerning in part the Pleistocene formations of Michigan. This is the only publication to provide a description and interpretation of the entire study area both in restricted and regional perspectives. In the monograph Leverett interpreted the north-northeast-trending moraine as part of the Mississinewa[5] Moraine of Ohio and Indiana, associated with the Huron-Erie Lobe and correlative with the Jackson Moraine of the Saginaw Lobe, which he renamed "Kalamazoo" (p. 189).

Several features within the study area were investigated in the 1920s and 1930s. Scott's 1921 volume on the inland lakes of Michigan presented an interpretation of the origin and history of several lakes in the interlobate area. Newcombe and Lindberg (1935) suggested a possible relationship between bedrock features and surficial topography in southeastern Michigan. And a glacial history of streams in and near the study area was the topic of a paper by Bay (1938).

New evidence bearing on the glacial history and geomorphology of southeastern Michigan and the study area was introduced in a 1960

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[5]Leverett and Taylor (1915) and Martin (1955) referred to this moraine as the Mississinewa. Later workers, Zumberge (1960) and Wayne and Zumberge (1965), have deferred using this name until the question of correlation with the Mississinewa of Indiana and Ohio is answered. The term "Mississinewa Moraine" will be used in this investigation, but it should be noted that the problem recognized by Wayne and Zumberge has not been resolved.

article by Zumberge. He stated that some of Leverett's field notes indicate that ice of the Erie Lobe overrode Saginaw drift in northeastern Indiana. Zumberge also reported that till of the Erie Lobe overlies Saginaw till at a place about 10 miles (16 km) south of Norvell in Lenawee County, Michigan. If Zumberge's interpretation is correct, it indicates that at one time the Saginaw Lobe held a position farther to the east than that indicated in Leverett and Taylor (1915). To explain this situation, Zumberge postulated a retreat of the Saginaw ice margin accompanied or followed by a westward advance of the Erie Lobe, resulting in the deposition of Erie till over the Saginaw drift. A review article by Wayne and Zumberge (1965) reiterated both this interpretation and Zumberge's belief that regional correlation of the Mississinewa with other Huron-Erie moraines to the southwest was impossible at that time due to the lack of field data from Branch, Hillsdale, and Lenawee Counties.

Kneller (1964) investigated the sand and gravel deposits of Washtenaw County and on the basis of pebble lithology was able to distinguish two lithologic groups which he interpreted as being Saginaw and Huron-Erie drifts. He concluded that exposures within a number of gravel pits in the eastern part of the county revealed Huron-Erie till overlying Saginaw gravel, in agreement with Zumberge's interpretation. Kneller did not discuss the Mississinewa Moraine, but did state (p. 35) that "Moraine-like ridges composed of stratified drift . . . formed . . . in the reentrant angle between the Saginaw and Huron-Erie lobes." These ridges are situated in T. 1 S., R. 3 E. and T. 3 S., R. 3 E., the townships in which the Mississinewa Moraine is located. He also stated (p. 36) that the pebble lithology in these ridges is intermediate between the assemblages characteristic of both lobes.

Written Material- Other Interlobate Areas

Several studies from other portions of the Midwest provide valuable information on interlobate landform assemblages and deglaciation processes. Some of these also treat drift discrimination in interlobate areas.

In 1918 Alden authored a comprehensive work describing the results of his reconnaissance of the Kettle Interlobate Moraine in Wisconsin. This remains one of the most notable works available on interlobate moraines of the Midwest and describes a number of landforms that exist in and near the former reentrant between the Green Bay and Lake Michigan Lobes.

Black (1969) summarized many of Alden's previous findings regarding the Kettle Interlobate Moraine and in the following year (1970) prepared a field-trip guide on the Kettle Moraine, in which he postulated a sequence of events involving glacial thrust-faulting and the eventual formation of superglacial drift to explain the parallel moraines with medial lowland observed within the area of Kettle Moraine State Park.

In a study detailing the glacial geomorphology of a quadrangle in the Lake Michigan-Saginaw interlobate area of southwestern Michigan, Folsom (1971) discovered abundant evidence of ice stagnation. He, as well as Black (1970), noted that an interlobate contact may be marked by two sets of hills bordering an intervening lowland. Concurrently Shah (1971) utilized relative proportions of lithologic types within glaciofluvial deposits to delineate the contact of Lake Michigan and Saginaw drifts. Folsom and Shah independently suggested a similar location for the interlobate contact within a certain area of southwestern Michigan.

Castillon (1972) investigated the relationship between till fabric and landforms in an interlobate area in east-central Illinois. He found that the till fabrics associated with two moraines converging at a low angle tend to be parallel with the long axes of the features rather than being perpendicular as one might expect. He was able to differentiate and delineate the surface drift contact by using X-ray diffraction to determine the clay mineralogy of the tills in the moraines.

Maps

Early landform maps of the study area were very generalized and were produced at a relatively small scale. Some of these maps by Chamberlin (1876-77 and 1883) and Taylor (1897) show a single Saginaw/Huron-Erie interlobate moraine extending from Indiana to the vicinity of Lapeer, Michigan.

The first glacial-landform map of the Lower Peninsula was published at a scale of 1:2,000,000 and was included in an 1899 water-supply paper by Lane (Leverett, 1904, p. 107). Lane showed certain converging features in the study area in approximately the location of the major moraines as subsequently mapped, but the legend described them as the "overwash and interlobate gravels" of a "dissected sand and gravel plain."

The first rather detailed surface-formation map (1:375,000) of the Lower Peninsula was by Nellist (1907) and shows converging landforms in southeastern Michigan in a pattern similar to that which appears on most later maps. The legend identifies such features as "gravelly or sandy moraines." In the following year, and also seven years later, the Ann Arbor Folio by Russell and Leverett (1908 and 1915) was published and contained a surface-formation map (1:125,000) showing a portion of the interlobate moraine extending northeast from Pinckney. The most conspicuous landforms shown within this area are two moraines labeled "Interlobate Moraine, Saginaw Lobe" and "Interlobate Moraine, Huron-Erie Lobe," which are separated by the lowland of the Huron River.

A map of the Lower Peninsula (1:1,000,000) by Leverett (1912) depicted the converging moraines in the study area as bordered by both outwash and till plains. Plate 32, accompanying Leverett and Taylor's 1915 monograph, is a map (1:2,000,000) that clearly identifies the converging trends as the Kalamazoo and Mississinewa morainic systems. A later surface-formation map by Leverett (1924), at a scale of 1:750,000, shows slight modification from the 1915 map, but the overall pattern remains essentially unchanged. A number of Leverett's field maps of differing dates are on file at the United States Geological Survey library in Denver. Three of the maps, at scales of 1:63,360, 1:85,000, and 1:178,200, showing portions of the study area, were obtained on loan. Some of Leverett's manuscript maps of the area are on file at the Michigan Geological Survey in Lansing and in the Department of Geology at the University of Michigan in Ann Arbor. These are colored landform maps on topographic-map bases and have various dates associated with them.

A Jackson County soil survey (Veatch, Trull, and Porter) was published in 1930, although the map accompanying it is dated 1926.[6] A soil-survey map for Livingston County (Wheeting and Bergquist, 1928) has recently been updated by a detailed soil survey (Engberg and Austin, 1974), although only advance sheets were available during the field-mapping and data-analysis phase of this investigation. The Washtenaw County soil map of 1930 (Veatch, Wheeting, and Bauer) has also been recently updated

[6] A detailed survey of the county is in progress, but not enough has been completed to aid substantially in this investigation.

by a detailed soil survey. Here, too, advance sheets were utilized.

Since the 1930s the Michigan Department of Natural Resources has produced hydrographic maps of many of the lakes in the study area. These maps may be useful in determining bottom trends and provide data indicative of minimum thickness for ice blocks which eventually melted to form lakes.

Martin's (1955) 1:500,000 surface-formation map is probably the most-cited glacial map of the state at this time. This map shows a pattern in the study area similar to that first presented by Nellist in 1907. A chart on Martin's map correlates the Saginaw Lobe's Kalamazoo Moraine with the Mississinewa Moraine of the Erie Lobe. A number of Martin's manuscript maps (on topographic-map bases) are available for inspection at the Michigan Geological Survey.

The converging moraines of the study area are clearly shown on a map by Zumberge dated 1960. On this map he identified the Kalamazoo Moraine of the Saginaw Lobe, but did not name the converging moraine of the Huron-Erie Lobe. In the same year Kunkle (1960) produced a surface-formation map of Washtenaw County showing, but not naming, this same Huron-Erie moraine.

Kneller included a surface-formation map superimposed on a 1:62,500 topographic-map base in his 1964 investigation. Although recognizing the presence of kames, kame terraces, interlobate kame moraines, eskers, crevasse fillings, outwash fans, and outwash cones in the accompanying text, Kneller did not differentiate the features on his map but included them in a group labeled "ice contact deposits."

Wayne and Zumberge (1965) provided a map which again shows two converging morainal trends within the study area. However, the moraine associated with the Huron-Erie Lobe was not named, and only the part of the Kalamazoo Moraine associated with the Lake Michigan Lobe was labeled.

Summary

The pre-1900 works dealing with the study area provided a historical perspective on the subject of interlobate areas. Leverett and Taylor's monograph (1915) presented a synthesis of the deglaciation of the region at both local and regional scales. Leverett's field notes were especially helpful in providing information on exposures which are no longer available and for descriptions of areas which in the past were under cultivation but are now wooded, obscuring vision. In addition, his unpublished notes contained an interpretation of the drift-contact location in the Interlobate Morainic Tract. Recent studies treating other drift-contact areas were helpful in providing insights on differing interlobate situations. Recent works concerned with the study area provided quantitative data on the sediments and suggest a possible local history for late Wisconsinan events.

Chapter 2

THE BEDROCK AND ITS SURFACE CHARACTERISTICS

Bedrock Maps

Maps of the bedrock and its surface were published for part or all of the study area by Russell and Leverett (1908 and 1915) and Leverett and Taylor (1915), but these were based on rather limited data. The two maps by Russell and Leverett, with approximate scales of 1:500,000 (1908) and 1:390,000 (1915), also show a number of spot altitudes on the bedrock surface. Leverett and Taylor's 1915 map is at a scale of 1:1,000,000 and depicts the bedrock surface with 100-foot (30.5-m) contours. A "Bedrock Map of the Southern Peninsula" (1:500,000) by Martin, published in 1936, most probably represents an improvement over the earlier maps. It shows the lithology, age, and the general northeast-southwest trend of bedrock formations that are believed to exist beneath the drift within the study area. In the east and southeast portions of the area Martin mapped the uppermost preglacial bedrock as the Mississippian Coldwater Shale. Her map shows successively younger Mississippian formations toward the west-- the Lower Marshall and Napoleon Sandstones and scattered bodies of the Michigan Formation and Bayport Limestone. Still farther west Martin mapped the Pennsylvanian Parma Sandstone and Saginaw Formation. An incomplete, unpublished manuscript map of the bedrock surface of Jackson and Calhoun Counties by Barwick (1958) is on file at the Geological Survey of Michigan in Lansing. On the basis of interviews with water-well drillers Barwick obtained information on 363 wells in the Jackson County portion of the study area. He plotted well depth, bedrock lithology, and driller's name at the appropriate location on the 1:63,360 map. In 1959 Moore completed a thesis concerned with Livingston and Shiawassee Counties, including subcrop maps, contour maps of the bedrock surface, and drift isopach maps, all at a scale of 1:63,360. Kunkle (1960) constructed bedrock-lithology, bedrock-surface, and drift-thickness maps for all of Washtenaw County and a small portion of Livingston County. The portion of Kunkle's map showing the westernmost two ranges of townships in Washtenaw County (288 square miles, or 745 sq km) was based on 11C well logs with seven additional logs from Livingston County. His subcrop map shows that the contact between Coldwater Shale and the Michigan-Marshall Formation is located approximately along the eastern boundary of Tps. 1-2 S., R. 3 E.

Bedrock Characteristics of the Area

County maps of the bedrock surface completed prior to this study were based on no more than a few hundred well records and interviews. Kunkle (1960) had data from 117 points in a portion of Livingston County and the western two ranges of townships of Washtenaw County. In the Livingston County portion of the study area Moore (1959) compiled data from 84 points. In addition to these 201 data points, appropriate well records and information on file at the Geological Survey of Michigan which dealt with the study area were investigated. Furthermore, published and unpublished sources of information were consulted, and a limited number of interviews conducted. This resulted in a more than sevenfold increase (from 201 to 1,482) in the number of well logs available for map construction (see Appendix A for details of well-record data).

Bedrock Geology

Figure 3 depicts the bedrock lithology of the area as determined by the data from 1,482 points. Due to the limited descriptions of water-well records, only lithologic units, not rock-stratigraphic units, are shown on the map.

Bedrock Surface

The bedrock surface of the region may be divided into three northeast-southwest-trending sections (Figures 3 and 4). These are (1) an area in the southeast, generally below the 850-foot (259.1-m) contour and underlain by the Coldwater Shale; (2) a higher (850 to 1,050 feet, or 259.1 to 320.0 m) surface underlain by sandstone within the central portion of the study area;[1] and (3) a slightly lower tract in the northwest with a surface altitude of 800 to 950 feet (243.8 to 289.6 m) underlain by shale, sandstone, and limestone. A number of buried bedrock valleys apparently begin on or near the sandstone tableland and trend southeast to the shale lowland.

Russell and Leverett (1908, p. 3) stated that the sandstone tableland has an east-facing escarpment with the top of the sandstone 100 to 200 feet (30 to 60 m) higher than the Coldwater Shale on the southeast. Details of Figure 4 indicate that the term "escarpment" may not be entirely appropriate because in most locations the contact between sandstone and shale is marked by a moderately sloping surface rather than a steep or abrupt slope as the term "escarpment" might indicate.

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[1]Russell and Leverett (1908, pp. 2-3) named this the "Marshall tableland," as it is a high area of relatively low relief underlain, at least in part, by the Marshall Sandstone. In this study the term "tableland" will be used, but, because the Marshall Formation is not the only rock unit involved, it will be identified as the "sandstone tableland."

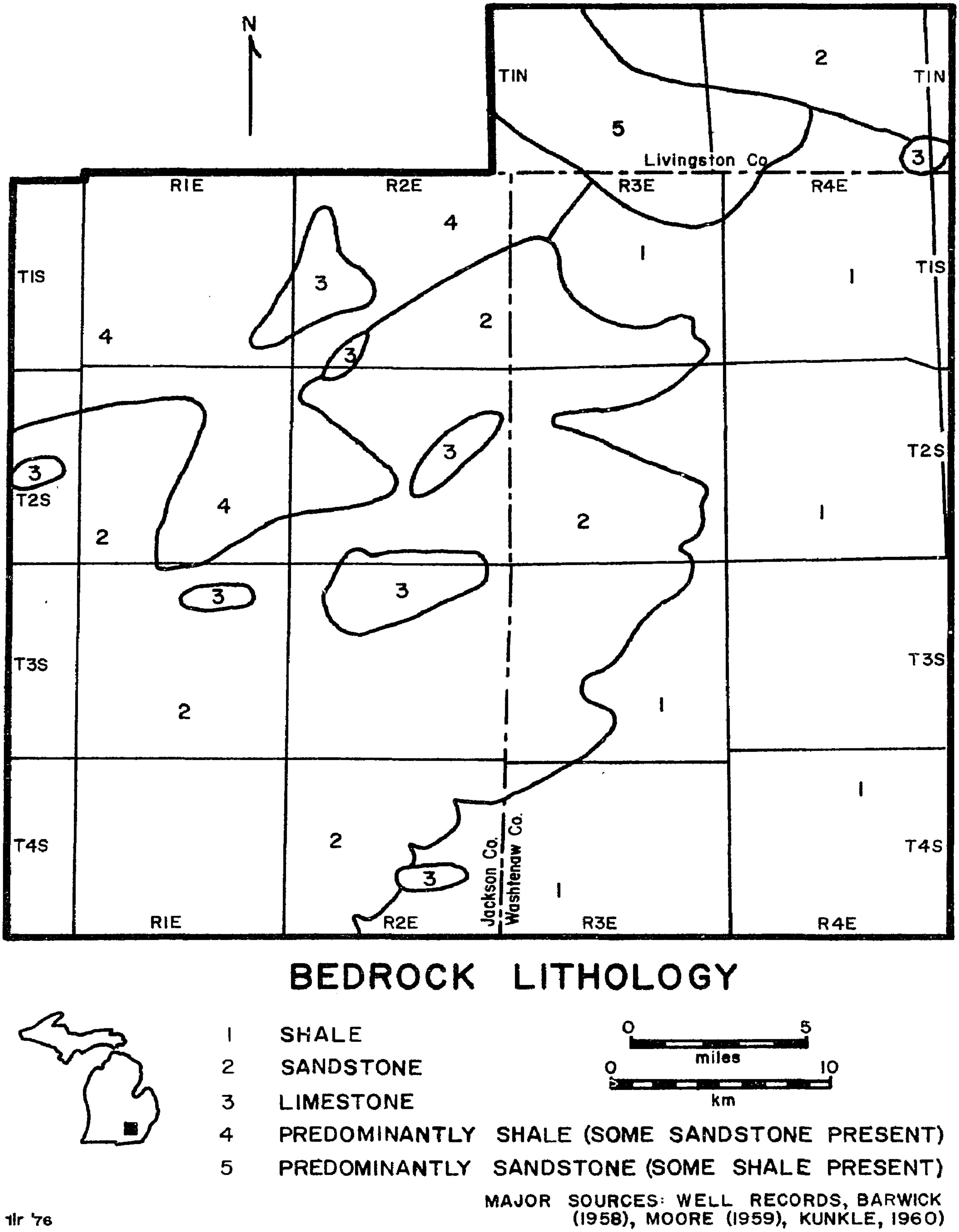

Figure 3. Bedrock Lithology

However, there is little doubt that the average altitude of the sandstone surface is well over 100 feet (30 m) higher than that of the lower area to the southeast underlain by shale.

Relationship of Bedrock Surface to Topography

The sandstone tableland, outlined by the 900-foot (274.3-m) contour, is a blunt, wedge-shaped feature with its apex to the northeast. A comparison of Figures 4 and 8 shows that a strong relationship exists between this higher bedrock surface and the present landscape. From Jackson to Leverett Hill the distal flank of the Kalamazoo Moraine nearly coincides with the 900-foot (274.3-m) contour of the bedrock surface. Although not as well defined as the distal side of the Kalamazoo Moraine, the outer flank of the Mississinewa Moraine is also very near the location of the 900-foot (274.3-m) bedrock contour. Thus, it may be concluded that the two moraines are situated on the north and east edges of the sandstone bedrock high and that the tableland itself underlies the Grass Lake Plain and associated areas of till plain.[2]

Major Buried Bedrock Valleys

A number of well-developed valleys, trending southeast, are associated with the surface of the bedrock underlying the drift (Figures 4 and 5). The pattern of these buried valleys and their tributaries indicates a fluvial origin. They were probably formed, for the most part, in preglacial time, though glacial modification and interglacial erosion may have taken place. The largest valley systems appear to originate within the sandstone, and, if this interpretation is correct, the

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[2]The relationship between bedrock features, the moraines, and the Grass Lake Plain will be described in greater detail in Chapter 4.

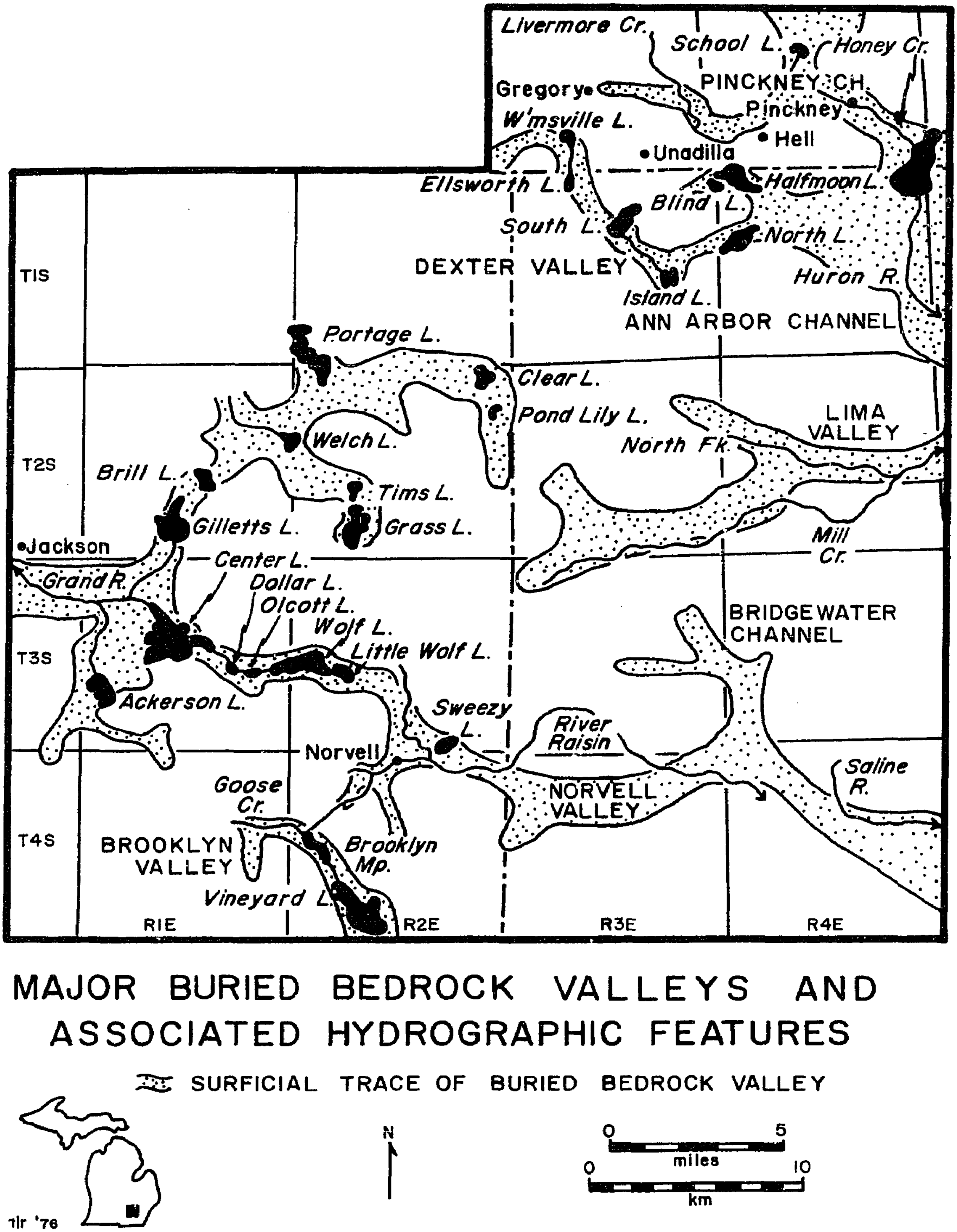

Figure 5. Major Buried Bedrock Valleys and Associated Hydrographic Features

streams that cut them flowed southeast to the lowland underlain by Coldwater Shale. Figure 4 reveals that at least two of the valleys have nearly right-angle turns along their courses and that many of the tributary valleys have trends normal to those of the main channels, giving the appearance of a somewhat angular drainage pattern.

Location and Pattern of the Valleys

Rhodehamel (1951) reported an angular pattern of bedrock valleys in the subsurface of the Saginaw Lowland of Michigan. He noted (p. 90) that Kelly had described a system of intersecting joints within Carboniferous rocks at Grand Ledge with trends of about N. 50° E. and N. 50° W. Rhodehamel concluded that the buried bedrock valleys in the Saginaw area had trends similar to the joints described by Kelly. In those areas where Carboniferous rocks do not subcrop, but are covered by younger, possibly unjointed rocks, the bedrock valley pattern does not exhibit angular drainage (Rhodehamel, pp. 90-91). This suggested to Rhodehamel that joints controlled, or at least strongly affected, the development of the bedrock valleys. Ferris, Burt, Stramel, and Crosthwaite (1954, p. 34) suggested that an angular drainage pattern may be present on the bedrock surface of Oakland County. Kunkle's 1960 bedrock surface map for Washtenaw County displays well-developed northeast-southwest and northwest-southeast angularity. Vanlier, Wood, and Brunett (1973) produced a bedrock-surface map for Eaton, Ingham and Clinton Counties, which also shows an angular drainage pattern with similar trends. If a fracture system exists in Jackson and Washtenaw Counties, it may have been an important factor in the development of the angular system of bedrock channels. The fracture pattern in the sandstone at Napoleon and research by Prouty (1975) support this interpretation, but with the limited data available no definite conclusions can be drawn at this time.

Ice flow from the Erie basin probably tended to parallel the trend of the bedrock valleys and may have resulted in a certain amount of widening and deepening in some places. However, the narrow, angular nature of some channels within areas of sandstone may indicate that the amount of glacial modification was minimal. Furthermore, organic matter and material interpreted as oxidized till are present at depth in certain buried valleys and suggest that at least sometimes deposition, not erosion, was dominant there during glaciation.[3]

The age (or ages) of the bedrock valleys is not definitely known. If the interpretation that buried oxidized till exists in the valleys is correct, the valleys must predate that till and may therefore be preglacial in age. It is also possible that they are, at least in part, Pleistocene in age and may have continued to develop or experience modification during Pleistocene time before (final) burial. Kunkle (1960, p. 72) noted that certain bedrock valleys in Washtenaw County are similar in size to the Teays and Mahomet Valleys of Indiana and Illinois. He considered (p. 122) the possibility that they may all be of approximately the same age, which is "thought to be Tertiary or early Quaternary."

Major Buried Bedrock Valleys and Associated Hydrographic Features

Seven major buried bedrock valleys are identified on Figures 4 and 5 and are named for their proximity to geographic features. In most parts of the study area the bedrock surface is overlain by more than 50

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[3]The organic matter and oxidized till(?) are discussed in detail in Chapter 3.

feet (15 m) of drift. However, the bottoms of the valleys are often 150 feet (45 m) lower than the surface of neighboring bedrock, resulting in an overlying drift thickness of more than 200 feet (61 m) in some places. Nevertheless, these bedrock valleys buried beneath the drift appear to have had some influence on hydrographic features at the surface. This is evidenced by a number of streams and lakes that are located directly above them (Figure 6). Descriptions of the valleys and their associated hydrographic relationships are given below.

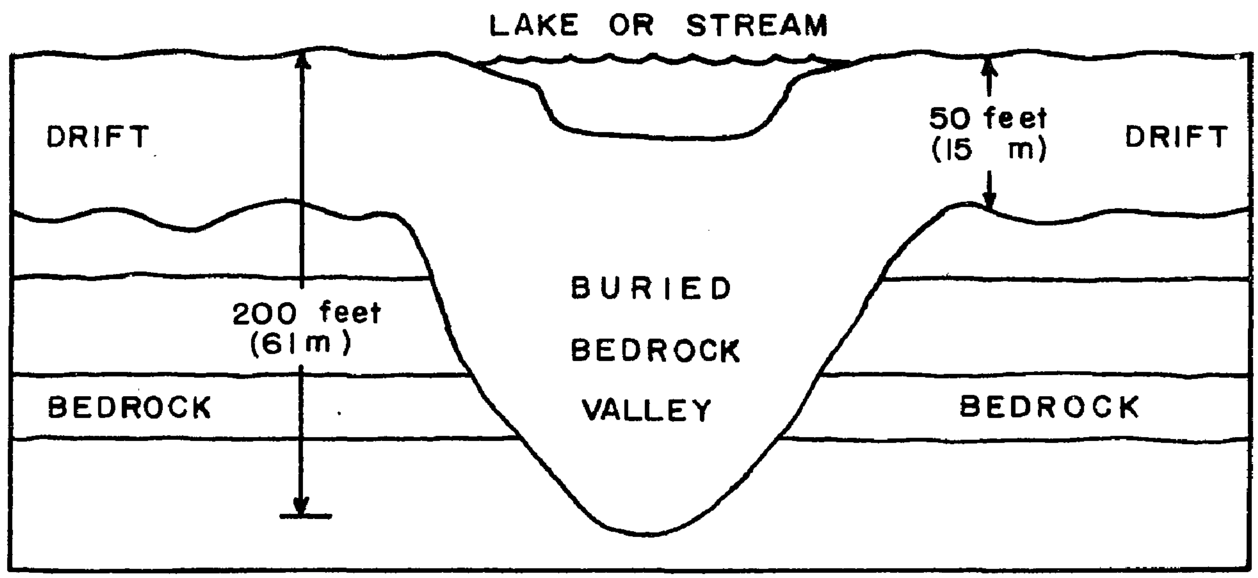

Figure 6. Generalized Cross-Section of the Buried Bedrock Valley-Hydrography Relationship

Brooklyn Valley

Brooklyn valley is located primarily in the southwest portion of T. 4 S., R. 2 E., and originates near Brooklyn within the sandstone tableland (Figures 4 and 5). An apparent lack of headwater tributaries may be the result of an insufficient number of well records to define fully the drainage pattern. Near Brooklyn the bottom of the valley is more than 150 feet (45 m) lower than the surface of the adjacent sandstone, but farther southeast it is only about 100 feet (30 m) lower than the surface of the Coldwater Shale.

Although drift associated with the Brooklyn valley is more than 150 feet (45 m) thick in some places, Vineyard Lake and Brooklyn Mill Pond directly overlie the feature, and both lakes are elongated in the same direction as the bedrock channel (Figure 5). A segment of Goose Creek also coincides with the surficial trace of the buried bedrock valley.

Norvell Valley

The largest buried bedrock valley within the study area is the Norvell valley. The feature originates on the sandstone tableland and trends southeast past Norvell (Figures 4 and 5). In places it is more than one mile (1.6 km) wide and has been eroded more than 150 feet (45 m) below the surface of the adjacent bedrock. The maximum thickness of the overlying drift is more than 200 feet (60 m) in some places. Two angular changes in the course of the subsurface valley exist near Wolf Lake, and tributaries join the main channel at approximately right angles. As mapped, the valley trends southeast across the northeast corner of T. 4 S., R. 2 E., although it is possible it may trend south across the center of T. 4 S., R. 2 E. to connect with Brooklyn valley.

Sweezy Lake and almost all of River Raisin and its northern tributaries in Jackson County are associated with unconsolidated sediments that overlie the lower course of the Norvell valley or its southern tributaries. A chain of lakes and streams that extend across the Grass Lake Plain also coincides with the surficial trace of the buried Norvell valley. These water bodies include Wolf and Little Wolf Lakes, Olcott and Little Olcott Lakes, Dollar Lake, Center Lake, and the stream flowing west from Center Lake. This stream joins the Grand River near the eastern city limits of Jackson. From here the Grand River follows a course associated with the location of the Norvell valley for a distance of about two miles (3.2 km) to the western limit of Figures 4 and 5. Ackerson Lake and the stream flowing north from it, Gilletts Lake and the stream flowing south from it, and Brill Lake all have positions that coincide with the surficial traces of tributaries to the main channel that exists deep in the subsurface.

Bridgewater Channel

A well-defined southeastward-trending buried bedrock channel is located in T. 4 S., R. 4 E., Bridgewater Township, and T. 3 S., R. 4 E., of Washtenaw County. Kunkle (1960, p. 70) recognized this feature and named it the Bridgewater channel. The valley is 100 to 150 feet (30 to 45 m) deeper than the nearby bedrock surface, and the drift thickness associated with it is locally more than 200 feet (60 m). Two of the three valleys tributary to the Bridgewater channel begin on or near the sandstone tableland. The confluence of Norvell valley and Bridgewater channel is located in Sec. 6, T. 4 S., R. 4 E.

There is probably less surface expression of the Bridgewater channel than of any other major buried bedrock valley in the study area. Only the headwaters of the Saline River[4] and a small segment of the River Raisin near Manchester are located on the drift surface above the buried bedrock valley.

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[4]Kunkle (1960, p. 71) previously noted this relationship.

Lima Valley

The subsurface Lima valley trends eastward beneath T. 2 S., R. 4 E., Lima Township, toward the Ann Arbor channel, which was identified by Kunkle (1960). It is rather broad and shallow, although drift thickness associated with it is more than 100 feet (30 m). Its tributaries follow the dominant regional pattern of northeast-southwest and northwest-southeast trends. A southern tributary originates within the sandstone tableland and displays an angular course change near its confluence with the northern tributary. Most wells in T. 2 S., R. 4 E. are developed in drift, so the exact course of this portion of the valley is not known with certainty. The limited data available suggest that it is very broad here and only slightly lower than the nearby bedrock surface.

A portion of the North Fork of Mill Creek is situated directly above the buried Lima Valley. In addition, a considerable reach of Mill Creek trends parallel to the buried valley and is less than one mile (1.6 km) to the south of the poorly defined portion of the feature.

Dexter Valley

This valley trends southeastward beneath the northern portion of Washtenaw County and is named for Dexter Township, T. 1 S., R. 4 E. It may originate in Ingham County a short distance northwest of Stockbridge. Vanlier, Wood, and Brunett (1973) identify a bedrock valley that trends southeast near Stockbridge and extends to the southeast corner of Ingham County. Figures 4 and 5 show the Dexter valley trending generally southeastward from near the point common to Ingham, Livingston, Jackson, and Washtenaw Counties. Although the valleys on Vanlier, Wood, and Brunett's map and Figure 4 of this study do not appear to connect when the maps are juxtaposed, there seems little doubt they are related to each other in some manner. The bottom of Dexter valley is approximately 100 feet (30 m) lower than the surface of the adjacent bedrock, and total drift thickness associated with the channel is more than 150 feet (45 m). Two angular course changes exist along the trend of the valley--one west of Unadilla and another just north of Island Lake. Dexter valley is probably a major headwater tributary to the Ann Arbor channel (see discussion in Kunkle, 1960, p. 70).

South and Island[5] Lakes and the unnamed stream connecting them are situated on drift that overlies the buried bedrock valley, as is North Lake.[6] In addition, Williamsville and Ellsworth Lakes and the stream connecting them also seem to be associated with the channel. Blind and Halfmoon Lakes may be associated with a northern tributary to the valley.

Pinckney Channel

A buried bedrock valley which originates beneath the town of Gregory trends eastward. In secs. 28 and 29, T. 1 N, R. 4 E., its exact course is unknown, although it may connect with a buried valley in sec. 22 trending east and southeast beneath the towns of Hell and Pinckney. Moore (1959, p. 22) labeled this the Pinckney channel. The bottom of the valley is more than 100 feet (30 m) below the surface of the nearby bedrock, and total drift thickness associated with the feature is more

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[5]Kunkle (1960, p. 47) identified a "Lyndon tributary channel," and, as mapped by him, this bedrock feature trends southwest-northeast across the S½, T. 1 S., R. 3 E. The existence of the valley was not confirmed by this investigation; however, the two-mile (3.2 km)-long segment of Dexter valley beneath North and Island Lakes does correspond with a portion of Kneller's "Lyndon tributary channel."

[6]The steep, subaerial slope in the S½ sec. 13, T. 1 S., R. 3 E. which is situated along a westward extension of the North Lake lowland, may also be associated with the Dexter valley.

than 150 feet (45 m). Pinckney channel is probably a headwater tributary to the Ann Arbor channel (see discussion in Kunkle, 1960, p. 70). Honey Creek from School Lake to a point east of Pinckney and a portion of Livermore Creek coincide with the surficial trace of the buried bedrock valley.

Ann Arbor Channel

Dexter valley and Pinckney channel apparently merge in the E½, T. 1 S., R. 4 E. to form the Ann Arbor channel. Kunkle (1960, p. 70) named this bedrock valley and mapped it as trending southeast, extending past the city of Ann Arbor. His map indicates that the valley bottom is more than 160 feet (49 m) below the surface of the nearby bedrock in T. 1 S., R. 4 E., with the total thickness of drift overlying the valley bottom more than 200 feet (60 m).[7] Without doubt it was one of the major streams of the area before burial. Kunkle (1960, p. 71) noted that the Huron River is located along the surficial trace of this buried bedrock valley.

Relationship Between Buried Bedrock Valleys and Hydrography

A number of buried bedrock valleys, interpreted to be of fluvial origin but possibly modified by glaciation, trend southeast beneath the drift of the study area. Despite burial these valleys appear to have influenced present hydrography because a number of lakes and streams are situated directly above their courses (Figures 5 and 6).

Drift thickness in most of the area is 50 feet (15 m) or more. Bottoms of the valleys are often 150 feet (45 m) below the surface of

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[7] In T. 2 S., R. 5 E., Kunkle shows the bottom of the buried valley to be more than 240 feet (73 m) below the nearby bedrock surface.

nearby bedrock, resulting in local drift thicknesses of more than 200 feet (60 m). At certain places both organic matter and material interpreted as oxidized till exist within the unconsolidated sediments overlying the bedrock floors of the buried valleys.[8]

Surficial expression of the buried valleys is primarily limited to the presence of lakes and streams located along the traces of the subsurface channels.[9] The Wolf Lake-Center Lake-Grand River chain of features associated with the Norvell valley (Figure 5) is probably the most striking example in the study area of the close relationship between the extent of buried bedrock valleys and certain hydrographic features. Conversely, there is little or no surface expression of segments of some channels, such as the northern tributaries of the Bridgewater channel.

There is a tendency for hydrographic features associated with bedrock valleys to be best developed in those areas where the bottoms of the valleys are considerably lower than nearby bedrock surfaces. Where the buried valleys are incised less deeply in the bedrock, hydrographic features directly above the valleys are not as conspicuous.

A satisfactory explanation of the genesis of the buried bedrock valley and hydrography relationship must therefore account for, at the least, two phenomena. First, the surficial expression of the buried bedrock valleys is not uniform and may vary from one reach of a valley

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[8]See Chapter 3 for a discussion of the unconsolidated sediments associated with the buried bedrock valleys and also drift thickness in the study area.

[9]In many portions of the area surficial streams trend across bedrock divides and seem unaffected by the bedrock surface. An example of such a situation is where Portage River flows across the trace of a bedrock divide in Tps. 1-2 S., R. 1 E. Newcombe and Lindberg (1935, p. 1181) discussed the relationship between lakes and the Marshall Sandstone but did not consider the relief on the bedrock surface.

to another. Second, a horizon in the drift of the buried valleys seems to mark a period of subaerial exposure. This suggests that a subsequent glacial advance buried the valleys and the sediments in them. Nevertheless, surficial expression of the valleys is present in the form of lakes and streams on the drift surface. Due to the buried oxidized till and organic matter, any explanation of the bedrock-hydrography relationship would need to account for surficial expression of the bedrock valleys through at least two glacial episodes.

One hypothesis which explains the bedrock valley-hydrography relationship involves buried ice that may have been associated with the channels during glaciation(s). Subsequent ablation would have lowered any sediments overlying the ice, thus predisposing these lineations to become drainage lines or lakes. This ice could have been buried in or over the bedrock valleys (1) by chance or (2) by subglacial expression of the valleys, permitting ice to be lodged in their deeper portions.[10] In the first situation depressions would be distributed in a random pattern after ablation, the individual features would be irregular in shape, and they would lack a preferred orientation. In the second case depressions would have preferred shapes, locations, and orientations related to the depth and trend of the related bedrock valleys. As some lakes of irregular shape and orientation are found overlying the buried bedrock channels, it seems possible that they may have formed by random burial of ice blocks; however, many streams and linear lakes are found directly above buried bedrock valleys and seem associated with them.

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[10] Ferris, Burt, Stramel, and Crosthwaite (1954, p. 31-34) suggested a third possibility--that masses of buried ice may be due to ponded proglacial water bodies in preexisting drainage systems being overridden and frozen by the advancing glacier.

Hydrographic maps indicate apparent ice-contact slopes beneath the waters of Wolf, Patterson, South, Blind, and Halfmoon Lakes. These steep slopes are also parallel to the buried bedrock channels beneath the lakes.[11] In addition, Kunkle (1960, p. 72) noted that the Fort Wayne Moraine seems to extend westward a distance along the surficial trace of the Ann Arbor channel. He suggested that a valley may have existed in the drift overlying the bedrock channel, allowing ice of the last advance to flow in that linear feature and deposit the westward extension of the moraine near Dexter.

Thus, many aspects of the bedrock valley-hydrography relationship may be explained if it is assumed that ice was buried in or above portions of the subsurface channels. In general, related hydrographic features are situated over the deeper portions of the bedrock valleys. Apparently these locations were preferred sites for masses of stagnant ice. The orientation of linear lakes, their bottom trends, apparent ice-contact slopes, and streams are all generally parallel with underlying bedrock valleys and may be explained by ablation of ice blocks buried in the drift filling of the deeper portions of the valleys, predisposing certain sites to become drainage lines or lakes. This process does not require unique conditions and probably was effective during more than one glacial episode, as is indicated by the buried organic matter and possible oxidized till found in the valleys.

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[11] Ferris, Burt, Stramel, and Crosthwaite (1954, p. 31 and 34) noted similar steep slopes in some lakes of Oakland County and stated (p. 34) that such lakes "may be related to the bedrock surface of the area."

Chapter 3

CHARACTERISTICS, DISTRIBUTION, AND STRATIGRAPHIC SIGNIFICANCE OF THE GLACIAL SEDIMENTS

Introduction

This chapter is concerned with the sedimentary characteristics of certain Quaternary deposits.[1] Drift thickness in the area varies from almost zero in a few places to over 200 feet (60 m) in others. Subsurface drift stratigraphy appears complex in terms of both sediment type and contact relationships. With the exception of loess all types of sediments commonly associated with glaciation were recognized at the surface in the study area. Till, including flow till, is common, and glaciofluvial sediments, some of which were deposited in contact with ice, underlie large portions of the area. Glaciolacustrine silts and clays exist within and near the Interlobate Morainic Tract.

Different procedures and techniques were utilized to determine the characteristics of the surficial drift sheets recognized. These included the use of soil maps and the determination of till fabric, color, texture, and clast lithology. Certain aspects of the clay mineralogy of the sediments were analyzed to identify the different surficial drift sheets within the area. This identification was possible because till and some other deposits from both the Saginaw and Huron-Erie Lobes appear to have distinctive clay mineralogies that ordinarily permit recognition of the provenance of a drift sample.[2]

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[1]See Appendices for field and laboratory procedures.

[2]The drift contact suggested by morphology is very similar to that determined by clay mineralogy. This congruity of evidence provided by dissimilar methods of investigation is striking and lends credence to the results of both.

Drift Thickness

Leverett and Taylor (1915, p. 199) noted that within the area glacial deposits thought to be associated with the Huron-Erie Lobe tend to be somewhat thicker than those of the Saginaw Lobe. Kunkle (1960) and Moore (1959) prepared drift-thickness maps for Washtenaw and Livingston Counties, respectively, with a total of 201 well records for the 363 survey sections (Figure 7) which are east of the Jackson County boundary. Figure 7, showing the east half of Jackson County plus portions of Livingston and Washtenaw Counties, is based on these records and data from an additional 1,281 points (total=1,482). The map was compiled, then computer plotted, and finally manually modified in a manner similar to Figure 4.[3]

It is apparent from Figure 7 that deposits proximal to the Kalamazoo Moraine are considerably thinner than the drift immediately to the east of the Mississinewa Moraine (Table 1). In fact, mean drift thickness north of the Kalamazoo Moraine is about 80 feet (24.4 m) but averages approximately 180 feet (54.9 m) south and east of the Mississinewa Moraine.[4]

Mean drift thickness beneath the Kalamazoo Moraine west of Leverett Hill averages about 100 feet (30.4 m), and beneath the Mississinewa Moraine south of Leverett Hill it is approximately 115 feet (35.1 m). Drift thickness is therefore only slightly greater beneath the Kalamazoo Moraine than in the area proximal to it and is much greater proximal to the Mississinewa Moraine than it is underlying that feature. The west

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[3]As described in Appendix A.

[4]These mean values are based on Figure 7 and were calculated by averaging the drift thickness at the center of each survey section.

portion of the Interlobate Morainic Tract has a mean drift thickness of about 110 feet (33.5 m). Within the east part of the tract the thickness of the drift averages 145 feet (44.2 m). On the basis of these figures it is obvious that in those areas where Saginaw drift is at the surface the depth to bedrock tends to be less than in those with surficial Huron-Erie drift.

Table 1. Average Drift Thickness in Study Area

	Kalamazoo Moraine	Mississinewa Moraine
Proximal to	80 feet (24.4 m)	180 feet (54.9 m)
Beneath	100 feet (30.4 m)	115 feet (35.1 m)

Interlobate Morainic Tract

Areas with Surficial Saginaw Drift	110 feet (33.5 m)
Areas with Surficial Huron-Erie Drift	145 feet (44.2 m)

Grass Lake Plain Area

Including Norvell Valley	80 feet (24.4 m)
Not Including Norvell Valley	75 feet (22.9 m)

In the Grass Lake Plain area[5] the mean drift thickness is about 75 feet (22.9 m) if the effects of the Norvell bedrock valley are removed. At least some of the trends of the major buried bedrock valleys are apparent on Figure 7, but are not as well defined as on Figure 4, "Bedrock Surface."

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[5]This tract is located in the reentrant between the two moraines north of the T. 3 S.-T. 4 S. township line and east of Jackson.

Subsurface Sediments

Study of more than 1,000 well records indicates the drift stratigraphy of the area is complex. The only fairly consistent subsurface relationship noted was that till immediately overlies the bedrock surface in many places. An attempt was made to correlate subsurface sediments, but this effort was generally unsuccessful because most of these sediments seem to be of limited horizontal extent. Evidence for this is that records of very closely spaced wells are commonly quite different. Nevertheless, a few generalizations may be made on the sequence of sediments in the subsurface.

Subsurface Sediments in the Area of the Kalamazoo Moraine

Numerous well records indicate that till and glaciofluvial materials are present in approximately equal quantities both at and beneath the surface of the northern portions of the Kalamazoo Moraine. However, well records, existing road cuts, and scattered gravel pits indicate glaciofluvial materials to be predominant in the uppermost 30 to 50 feet (9.1 to 15.2 m) of the crest or southern portion of the moraine.

Because of the nature of descriptions on many of the well records, it is often difficult to interpret the difference between till and shale (see Appendix A). Consequently it is not possible to state exactly with what frequency till is in contact with bedrock, but it is estimated that, in 60 to 70 percent of all wells which reach bedrock beneath the Kalamazoo Moraine, till is the basal glacial sediment.

Sediments Beneath the Mississinewa Moraine

Well records are not as numerous for the area of the Mississinewa Moraine, but those available indicate a greater abundance of till present both at the surface and at depth beneath the northern portion of the moraine than beneath the Kalamazoo Moraine. To the south the presence of sand and gravel is more common. Possibly 80 to 85 percent of the records of wells which were drilled into bedrock beneath the Mississinewa Moraine indicate that till immediately overlies the bedrock surface.

Sediments Beneath the Interlobate Morainic Tract

Both well records and soil maps indicate that the preponderance of surficial material in the Interlobate Morainic Tract is sand and gravel, although there are some areas underlain by till. Most well records note the presence of this sand and gravel to a depth of 20 to 40 feet (6.1 to 12.2 m). Below this level till is reported to be more common, and approximately 75 percent of the well records used in map construction of the Interlobate Morainic Tract indicate that till is in contact with the underlying bedrock.

Sediments Beneath the Grass Lake Plain Area

Soil maps and most well records indicate sandy or gravelly material at, and near, the surface of much of the Grass Lake Plain area. However, significant amounts of till are recorded at depths of about 30 to 50 feet (9.1 to 15.2 m). This may represent basal till overlain by outwash sediments because kettles here are generally no deeper than 30 to 40 feet (9.1 to 12.2 m). Approximately 70 to 75 percent of the records of wells that penetrate bedrock beneath the Grass Lake Plain area indicate that till immediately overlies bedrock.

Organic Matter and Oxidized Till(?) in the Subsurface

Organic deposits within glacial sediments in the subsurface do not appear to be common in southeastern Michigan although reports of such materials do exist. Sherzer (1917, p. 8) noted the presence of a buried soil at a depth of 85 feet (25.9 m) in Macomb County. Leverett and Taylor (1915, pp. 192, 290) reported buried soils in Eaton and St. Clair Counties and mentioned (p. 199) extensive swamp deposits at the base of Wisconsin(an)(?) till in Hillsdale County about 30 miles (48 km) southwest of the study area. Russell and Leverett (1908, pp. 4-5) reported large quantities of pre-Wisconsin(an) till in the Ann Arbor quadrangle, but they knew of no soils buried in the subsurface there.

Recently, additional evidence has become available primarily due to drilling operations. Both Chang (1968) and VanWyckhouse (1966) studied engineering test-boring samples from two sites in Detroit. They concluded that a number of tills were present in the subsurface and that a "Lower Drift" is either Illinoian or preclassical Wisconsin(an) in age. Kunkle (1960, p. 30) noted references to two or three buried tills on well records from sites in eastern Washtenaw County. He was able to separate an "upper Cary till" from a "lower pre-Cary till" on the basis of a number of criteria, two of which were the presence in the subsurface of "a red (oxidized?) clay or sand" and "a change from soft clay to hard clay" (pp. 31-32).

A number of professional water-well drillers have developed wells in the area, and of the four interviewed three[6] indicated they had

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[6]Personal communications, Messrs. Melvin Fox of Napoleon, December 30, 1974, Marshall Meabon of Pinckney, December 17, 1974, and Dale Lindemann of Dexter, December 17, 1974.

obtained wood from depths greater than 40 feet (12.2 m).[7] On well records till is commonly described as clay or stony clay.[8] Oxidized sediments apparently are most often described by drillers as red or brown, and unoxidized sediments as blue or gray in color. Wells with organic matter and red and brown clays and stony clays in the subsurface exist at a number of places within and very near the study area. Almost without exception these sites are associated with bedrock valleys or low areas on the bedrock surface. Organic matter or oxidized sediments found in the subsurface beneath unoxidized sediments interpreted as till imply a former weathering surface that has been buried by deposits from a subsequent glacial advance.[9]

Interlobate Morainic Tract and Vicinity

The strongest evidence for a paleo-drift surface is in the vicinity of Pinckney. Well records and interviews with drillers indicate that in this area red and brown clay and stony clay, wood, muck, peat, reeds, and even a snail shell have been recovered from beneath blue and gray clay

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[7] These drillers do not ordinarily report organic matter on their records.

[8] See discussion on well-record interpretation in Appendix A.

[9] Because it has been stated that circulating ground water may cause subsurface chemical changes (Boulton, 1972, p. 389), well records with reports of red sands and gravels at depth were not considered as their relatively high permeability might permit large quantities of ground water to flow through them. Some red and brown clays at depth may be due to ground-water circulation, but the presence of organic matter associated with such sediments at depth seems to indicate that at least some are the result of subaerial, not ground-water, weathering. It is assumed that the red or brown color is due to secondary chemical changes after deposition and is not a primary characteristic. In addition, those records indicating organic matter and red and brown clays beneath sand and gravel were not considered because the uppermost material may represent postglacial fluvial deposits.

and stony clay at depths ranging from 62 to 115 feet (18.9 to 35.1 m) (Table 2).

Meabon and Lindemann indicate[10] that wood is most common in the subsurface just east of the Huron River in T. 1 S., R. 5 E. and is also found in T. 1 N., R. 4 E. and T. 1 N., R. 5 E. Lindemann also stated he recovered wood from a well in T. 1 S., R. 4 E.

In this area the subsurface altitude of the top of the red and brown clay and organic matter varies from 785 to 850 feet (239.3 to 259.1 m), and the existing topographic surface averages about 900 feet (274.3 m). In five wells thickness of the buried and apparently oxidized material was recorded as 6, 8, 11, 11, and 20 feet (1.8, 2.4, 3.3, 3.3, and 6.1 m). These should be considered minimum thicknesses because it cannot be determined to what degree subsequent glacial erosion may have removed material. The fact that paleosols are not common indicates that some erosion probably did take place. If the interpretation that these are subaerially oxidized zones is correct, they can be interpreted as representing a nonglacial episode of considerable length, because oxidation depths on the upper surface of Wisconsinan tills in the area averages about 20 feet (6.1 m).

Grass Lake Plain Area

There are reports of red and brown clay at depth near Wolf Lake, located about 15 miles (24 km) to the southwest of the Interlobate Morainic Tract (Table 3). Records from two wells located above the buried Norvell valley (secs. 20 and 21, T. 3 S., R. 2 E.) indicate that the top of 5 to 10 feet (1.5 to 3.0 m) of red and brown sandy and

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[10] Personal communications, December 17, 1974.

Table 2. Buried Organic Matter and Oxidized Sediments in Interlobate Morainic Tract and Vicinity

Well Location	Surface Altitude Ft. (m)	Depth Ft. (m)	Subsurface Altitude Ft. (m)	Evidence	Source and Driller
T. 1 S., R. 5 E.					
SE¼SE¼SW¼ sec. 10	900 (274.3)	62 (18.9)	838 (255.4)	8 ft. (2.5 m) red clay, with wood immediately above it in blue clay	Record & interview, Lindemann
#Secs. 11 and 12	900 (274.3)	50 (15.2)	850 (259.1)	reeds beneath sand and gravel	Interview Meabon
SW¼NW¼NE¼ sec. 15	900 (274.3)	90 (27.4)	810 (246.9)	11 feet (3.3 m) red clay	Record Lindemann
SE¼SE¼NW¼ sec. 18	900 (274.3)	112 (34.1)	788 (240.2)	wood and peat with H_2S odor immediately beneath blue clay	Record & interview, Lindemann
T. 1 N., R. 4 E.					
NE¼NW¼SW¼ sec. 9	915 (278.9)	65 (19.8)	850 (259.1)	20 feet (6.1 m) brown gravelly clay	Record Brown Bros.
SE¼NE¼NE¼ sec. 14	930 (283.5)	92 (28.0)	838 (255.4)	11 feet (3.4 m) brown gravelly clay	Record Fulmer
SW¼NW¼SW¼ sec. 23	900 (274.3)	115 (35.1)	785 (239.3)	5 ft. (1.5 m) wood & bark with snail shell in sand, clay and stones	Record Interview Meabon

Table 2 (cont'd.)

Well Location	Surface Altitude Ft. (m)	Depth Ft. (m)	Subsurface Altitude Ft. (m)	Evidence	Source and Driller
<u>T. 1 N., R. 4 E.</u> (cont'd)					
#NW¼NW¼NW¼ sec. 26	900 (274.3)	48 (14.6)	852 (259.7)	7 feet (2.1 m) of wood (pine?) beneath sand and gravel	Interview Meabon
NW¼SE¼SW¼ sec. 35	870 (265.2)	80 (24.4)	790 (240.8)	6 feet (1.8 m) brown clay and gravel	Record Brown Bros.
<u>T. 1 S., R. 4 E.</u>					
NE¼SW¼SE¼ sec. 12	?	?	?	wood at ? depth	Interview Lindemann

= beneath sand and gravel

Table 3. Buried Organic Matter and Oxidized Sediments in Grass Lake Plain Area

Well Location	Surface Altitude Ft. (m)	Depth Ft. (m)	Subsurface Altitude Ft. (m)	Evidence	Source and Driller
T. 4 S., R. 2 E.					
NE¼NE¼NE¼ sec. 24	1,000 (304.8)	84 (25.6)	916 (279.2)	19 feet (5.8 m) of red clay	Record, Brewer
NE¼SE¼SW¼ sec. 28	970 (295.7)	40 (12.2)	930 (283.5)	10 feet (3.0 m) of marl & sand, 4 feet (1.2 m) marl and gravel	Record Sprunger
T. 3 S., R. 2 E.					
NW¼SW¼NE¼ sec. 20	960 (292.6)	55 (16.8)	905 (275.8)	10 feet (3.0 m) hard brown gravelly "shale"	Record Fox
NE¼NE¼SW¼ sec. 21	965 (294.1)	70 (21.3)	895 (272.8)	5 feet (1.5 m) brown sandy clay	Record Fox
T. 3 S., R. 1 W.					
@NE¼SE¼NE¼ sec. 1	960 (292.6)	20 (6.1)	940 (286.5)	8 feet (2.4 m) muck	Record Washburn

@ = apparently beneath post-glacial deposit gravelly clay beneath blue and gray gravelly clay is at an altitude of about 900 feet (274.3 m) approximately 60 feet (18.3 m) below the surface.

Another record from a well located along the surficial trace of the Brooklyn valley (sec. 28, T. 4 S., R. 2 E.) notes marl at a depth of 40 feet (12.2 m) beneath blue clay. Also, the record for a well located three miles (4.8 km) to the east (sec. 24, T. 4 S., R. 2 E.) in a tributary to the Norvell valley indicates that the top of 19 feet (5.8 m) of red clay is at a depth of 84 feet (25.6 m) beneath a body of blue clay.

Area Proximal to the Kalamazoo Moraine

Four wells with rather unusual records exist in the E½, T. 1 S., R. 1 W. and W½, T. 1 S., R. 1 E. (Table 4). All indicate what is apparently the upper part of an oxidized till (red and brown clay) at depths from 48 to 83 feet (14.6 to 25.3 m), most with overlying blue or gray clay. However, thickness of the material interpreted to be oxidized till is great and varies from 27 to 44 feet (8.2 to 13.4 m). If this is subaerially oxidized material and was not affected by circulating ground water, it might represent a very long weathering interval.

Just to the west of the study area in sec. 17, T. 1 S., R. 1 W. wood has been reported at a depth of 88 feet (26.8 m), overlain by sediment interpreted to be till. This is the only record observed from Jackson County which notes the presence of wood at depth.

Significance of the Buried Organic Matter and Oxidized Sediments

The widespread distribution of red and brown clays, peat, wood, and marl in the subsurface indicates the presence of at least one older drift sheet whose surface was exposed to the atmosphere for a period of time. These older sediments do not appear to form a continuous layer because

Table 4. Buried Organic Matter and Oxidized Sediments Proximal to the Kalamazoo Moraine

Well Location	Surface Altitude Ft. (m)	Depth Ft. (m)	Subsurface Altitude Ft. (m)	Evidence	Source and Driller
<u>T. 1 S., R. 1 W.</u>					
SE¼NE¼SW¼ sec. 1	930 (283.5)	83 (25.3)	847 (258.2)	31 feet (9.4 m) red clay	Record Hart
SW¼SW¼NW¼ sec. 17	950 (289.6)	88 (26.8)	862 (262.7)	2 feet (0.6 m) wood	Record, Intrvw. Fox
<u>T. 1 S., R. 1 E.</u>					
SE¼SW¼SE¼ sec. 9	950 (289.6)	48 (14.6)	902 (274.9)	27 feet (8.2 m) hard brown clay	Record Fox
SW¼SW¼SW¼ sec. 17	955 (291.1)	83 (25.3)	872 (265.8)	34 feet (10.4 m) red clay	Record Hart
NE¼SE¼NE¼ sec. 30	965 (294.1)	48 (14.6)	917 (279.5)	44 feet (13.4 m) red clay	Record Hart
#NE¼SE¼NE¼ sec. 31	949 (289.3)	45 (13.7)	904 (275.5)	10 feet (3.0 m) muck and sand	Record, Oil well permit # 2631

= beneath sand and gravel

they are found almost exclusively in the drift associated with bedrock valleys and low areas on the bedrock surface. Many well logs indicate a number of separate till layers at depth in the eastern portion of the study area, and Kunkle (1960) mapped the surface of a buried older drift sheet in eastern Washtenaw County but no well record studied showed convincing evidence of more than one weathered zone.

Surficial Sediments

The bulk of the characteristics of certain surficial sediments--till color, clay mineralogy, texture, fabric, pebble and boulder lithology, and boulder distribution was determined by field observation, field sampling, and laboratory analyses. Details of these procedures are discussed in the appendices. The following discussion on the soils of the study area is based on available soil maps as modified by field observations.

Drift Associated with Kalamazoo Moraine and Related Portions of Interlobate Morainic Tract

Soils as an Indicator of Parent Material

Soil maps were completed for Washtenaw, Livingston, and Jackson Counties in the 1920s and 1930s, and all seem to be based on similar mapping criteria. Recent and more detailed soil maps are also available for Washtenaw and Livingston Counties. By comparing the newer maps and older maps of these counties, it is possible to recognize what soil series are present in the older, more generalized mapping units. On this basis it is possible to identify those soil series which will probably appear on the new soil map for Jackson County[11] by using the older

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[11]Field work has begun on a detailed soil survey for Jackson

map as a base. The map accompanying the 1930 Jackson County Soil Survey (Veatch, Trull, and Porter) indicates that most of the soil in the northern (proximal) two-thirds of the Kalamazoo Moraine is Hillsdale sandy loam, which is interpreted to have till as the parent material (Figure 8). The recent soil surveys from Washtenaw and Livingston Counties indicate that Fox, Spinks, and Boyer soils, interpreted to have glaciofluvial sediments as parent material, may also exist within areas that previously have been mapped as Hillsdale sandy loam. This is corroborated by personal field observation.

Bellefontaine sandy loam soil was associated with a series of gravelly knobs located along the highest (southern) part of the moraine on the 1930 soil map. It is also apparent that Boyer, Fox, Spinks-Oakville, and Boyer-Oshtemo soils may be expected to exist within areas formerly mapped as Bellefontaine. The parent material of all these soils is interpreted to be glaciofluvial sands and gravels. According to the 1930 soil survey, Plainfield loamy sand and Newton loam are scattered in small tracts throughout the moraine and are thought to be developed on glaciofluvial materials. Rifle peat and Greenwood peat have been mapped in certain poorly drained depressions.

Spinks, Boyer, Oshtemo, Oakville, and Fox soils exist on the large area of glaciofluvial sediments on the Saginaw Lobe side of the Interlobate Morainic Tract. Smaller areas of Miami and Kidder soils, which have till as parent material, exist primarily north of Patterson Lake. Sisson, Kibbie, and Colwood soils formed on bodies of lacustrine clay and silt in the Interlobate Morainic Tract. These lake deposits may also

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County, but insufficient mapping has been completed to be of significant use in this investigation.

underlie areas more recently mapped as Miami. For example, at least a portion of the large tract mapped as Miami soil west of Patterson Lake is actually derived from a lacustrine deposit, and not till as shown on the recent soil map of Livingston County.

Clay Mineralogy

One of the basic techniques utilized in this investigation was X-ray diffraction to determine certain aspects of clay mineralogy of samples from various locations in the area. A total of sixty-six samples was examined by this method (Figure 9 and Appendix B). Of these, sixty-one were obtained from glacial deposits and included forty-nine till, nine glaciofluvial, and three glaciolacustrine samples. Five samples of bedrock (three shale and two sandstone) were also analyzed. Samples of both basal and flow till were analyzed as was till from the crests of the Blue Ridge and Goose Lake Eskers. In addition, clay from glaciofluvial materials within these eskers and from beneath the surface of the Mississinewa Moraine was also X-rayed. Sediments from many parts of the study area were investigated,[12] and a number of samples from near the surficial Saginaw/Huron-Erie drift contact were collected and analyzed because the clay mineralogy of a drift sample proved to be a reliable indicator of its lobe provenance. In fact, of all the lithologic characteristics examined in this investigation, clay mineralogy was the most consistent and reliable property by which the provenance of a drift sample could be determined.

The clay mineralogy of thirteen surficial till samples from the Kalamazoo Moraine, from associated portions of the Interlobate Morainic

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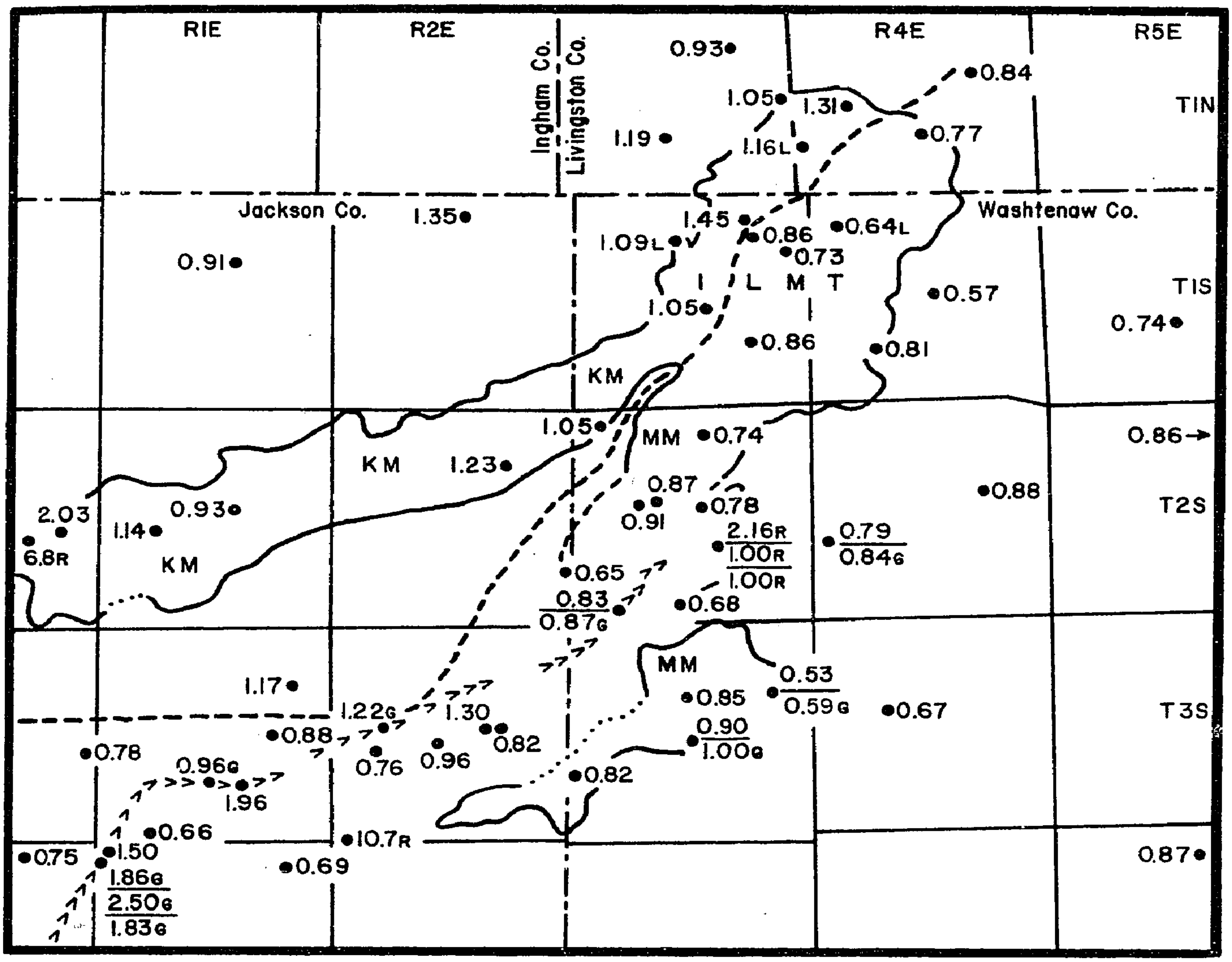
[12]Two samples (numbers 227 and 228) from the surface of the Fort Wayne and Outer Defiance Moraines were also studied.



SITES AND RATIOS FOR X-RAY DIFFRACTION SAMPLES

KM KALAMAZOO MORAINE- SAGINAW LOBE

MM MISSISSINEWA MORAINE- HURON-ERIE LOBE

ILMT INTERLOBATE MORAINIC TRACT

<<< ESKER

--- SURFICIAL DRIFT CONTACT

7Å/10Å RATIOS FOR SAMPLES OF:

1.23	TILL
1.23G	GLACIOFLUVIAL MATERIAL
1.23L	GLACIOLACUSTRINE MATERIAL
1.23R	BEDROCK
1.23 / 1.23G	TILL STRATIGRAPHICALLY ABOVE GLACIOFLUVIAL MATERIAL

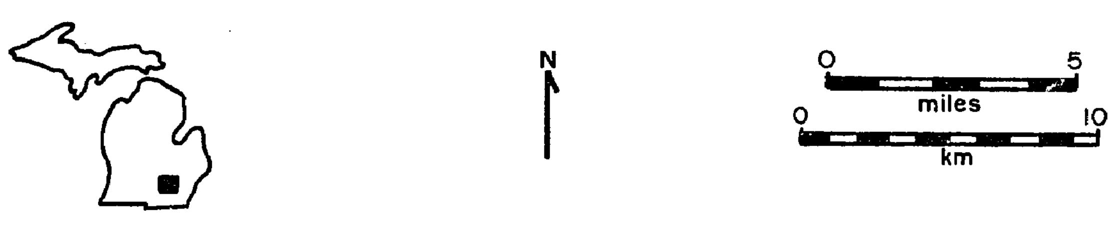


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Figure 9. Sites and Ratios for X-Ray Diffraction Samples

Tract, and from the area immediately to the north were analyzed according to the procedures described in Appendix B. Peak heights on the X-ray diffractograms were measured, and 7Å/10Å ratios calculated. All thirteen of these till samples yielded ratios of 0.91 or more and were collected from sites north and west of a line connecting Leverett Hill, Riley Hill, Stofer Hill, Russell Hill,[13] the east end of Patterson Lake and Pinckney[14] (Figure 10).

The range of the 7Å/10Å ratios for 13 sites is 1.12 with values varying between 2.03 at site 72 (NW¼SW¼NW¼ sec. 24, T. 2 S., R. 1 W.) and 0.91 at site 129 (NW¼SE¼SE¼ sec. 10, T. 1 S., R. 1 E.). It is possible that the rather high value of 2.03 may be due to the influence of local bedrock overlain by relatively thin drift located just to the north of the sample site (Figure 7). Sandstone (probably from the Pennsylvanian Saginaw Formation) is also reported both at the surface along the Grand River about one mile (1.6 km) to the west of site 72 (Leverett, field notebook 274, p. 86 and Martin and Straight, 1956, p. 235) and 1.5 miles (2.2 km) to the north in the bed of Portage River (Leverett, notebook 275, p. 95). Analysis of a sample of the sandstone bedrock (number 229, NW¼SW¼NW¼ sec. 26, T. 2 S., R. 1 W.), probably from the Saginaw Formation (Martin and Straight, 1956, p. 235) and collected from a road cut along I-94 about 1.5 miles (2.2 km) from site 72, indicates a very

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[13]A flat-topped hill located in sec. 1, T. 1 S., R. 3 E. which is unnamed on the Stockbridge quadrangle. The name "Russell Hill" is applied to this feature for identification purposes only and is not proposed as a formal geographic name. This hill has ice-contact slopes on three sides and is situated between Bruin and Blind Lakes.

[14]This boundary line is also important morphologically and will be discussed in the following chapter.

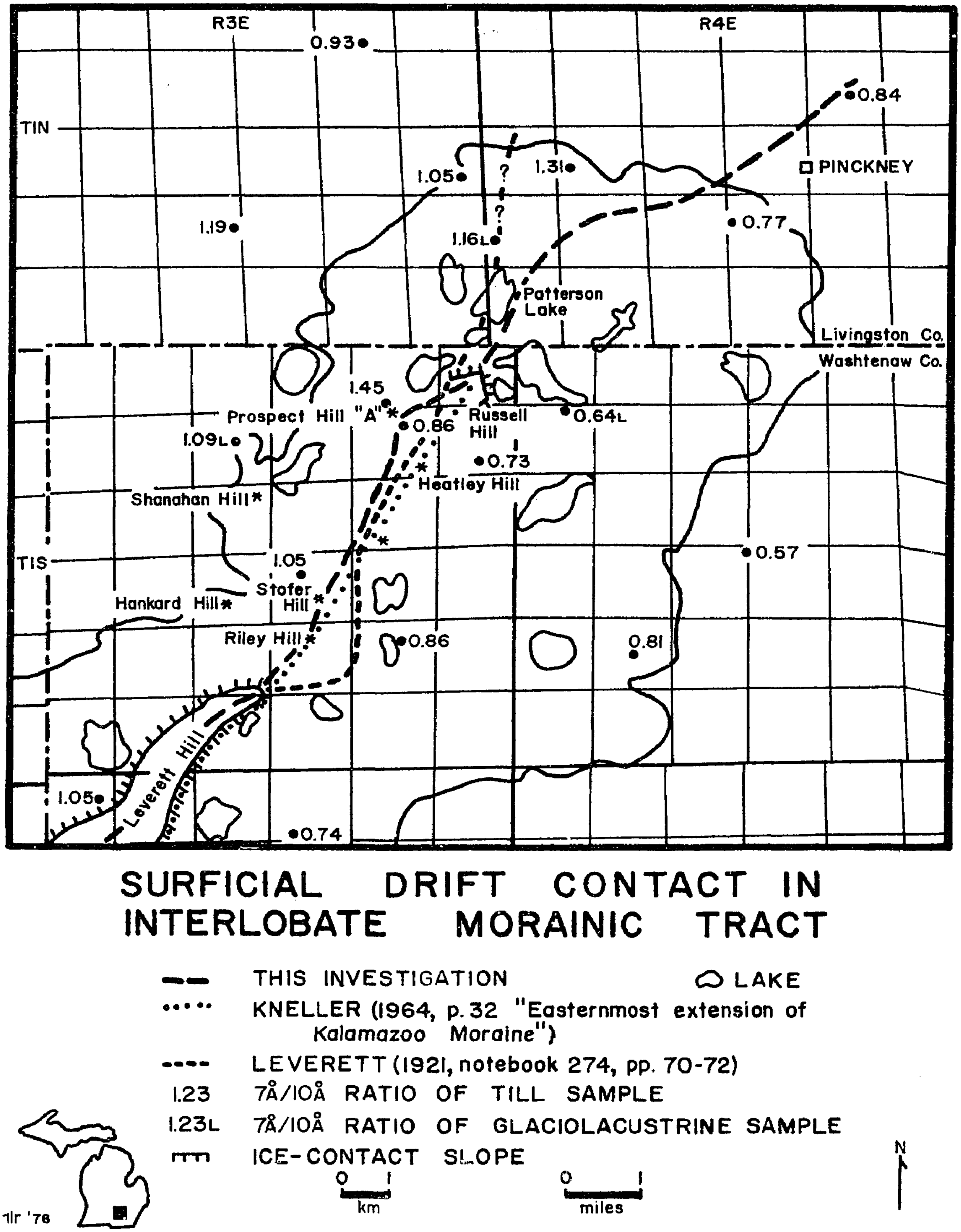

Figure 10. Surficial Drift Contact in Interlobate Morainic Tract

large amount of kaolinite causing the 7Å/10Å ratio to be 6.77.[15] If significant amounts of local bedrock with these characteristics were incorporated into the till collected at site 72, it could well have increased the associated 7Å/10Å ratio from a somewhat lower figure to the high value of 2.03. Furthermore, 7Å/10Å ratios tend to be higher at each site where local bedrock is near the surface. Thus, the interpretation that the clay mineralogy of the local sandstone influenced the characteristics of the till appears reasonable. It is important to note that, even with these variations that may be related to local conditions, the utility of identifying Saginaw Lobe till by means of clay mineralogy is not diminished.

Till Color

The color of oxidized, unleached till from the surface of the Kalamazoo Moraine is rather uniform. Of seventeen samples described using the Munsell system of classification, thirteen were 10YR 7/3 or 10YR 7/4 (very pale brown) (Appendix C). Moist colors were also quite uniform, as twelve of the samples were 10YR 5/4 or 10YR 5/6 (yellowish brown). The few exceptions did not follow a consistent pattern.

Till Texture

Till associated with the surface of the Kalamazoo Moraine, its proximal areas, and portions of the Interlobate Morainic Tract tends to be relatively coarse in texture, although it is slightly finer to the north of the moraine. Mean texture (Appendix D) for eleven till samples from the moraine is sandy loam (sand 58%, silt 25%, clay 17%), and for four till samples north of Portage River it is sandy clay loam (sand

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[15]This sample produced such a high 7Å peak at a scale factor of 8 that it was necessary to rerun the sample at a scale factor of 16.

47%, silt 27%, clay 26%).[16] It should be noted that these are mean figures and individual samples may vary considerably from these values (Figure 11). Examples of this dispersion are sample 85 (silty clay), sample 129 (clay), and sample 183 (loamy sand). Nevertheless, most samples are located within the sandy loam portion of the textural triangle.

The sandy nature of the till may be due, at least in part, to the presence of sandstone both beneath and proximal to the moraine. Leverett and Taylor (1915, pp. 190–91) have noted that till in the Kalamazoo Moraine is rather sandy where underlain by sandstone.

Pebble Lithology

The lithology of 500 pebbles collected at five sites (Appendix E) is somewhat similar to findings reported by Anderson (1957) and Kneller (1964). Minor variations between studies shown on Figure 12 are not unexpected because (1) Anderson studied pebbles from till at sites along the axis of the Saginaw Lobe 30 to 35 miles (46 to 56 km) to the west of the study area, (2) Kneller studied pebbles in outwash deposits (rather than till) in and near the study area, (3) this investigation was concerned only with pebbles from till in the study area, and (4) both Anderson's and Kneller's data are based on well over 1,000 pebbles for each lobe. Pebble counts for this investigation are based on 500 clasts for the Saginaw Lobe and 400 for the Huron-Erie Lobe.

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[16] All textures are based on the U.S. Department of Agriculture textural triangle (Soil Survey Staff, 1951, p. 209).

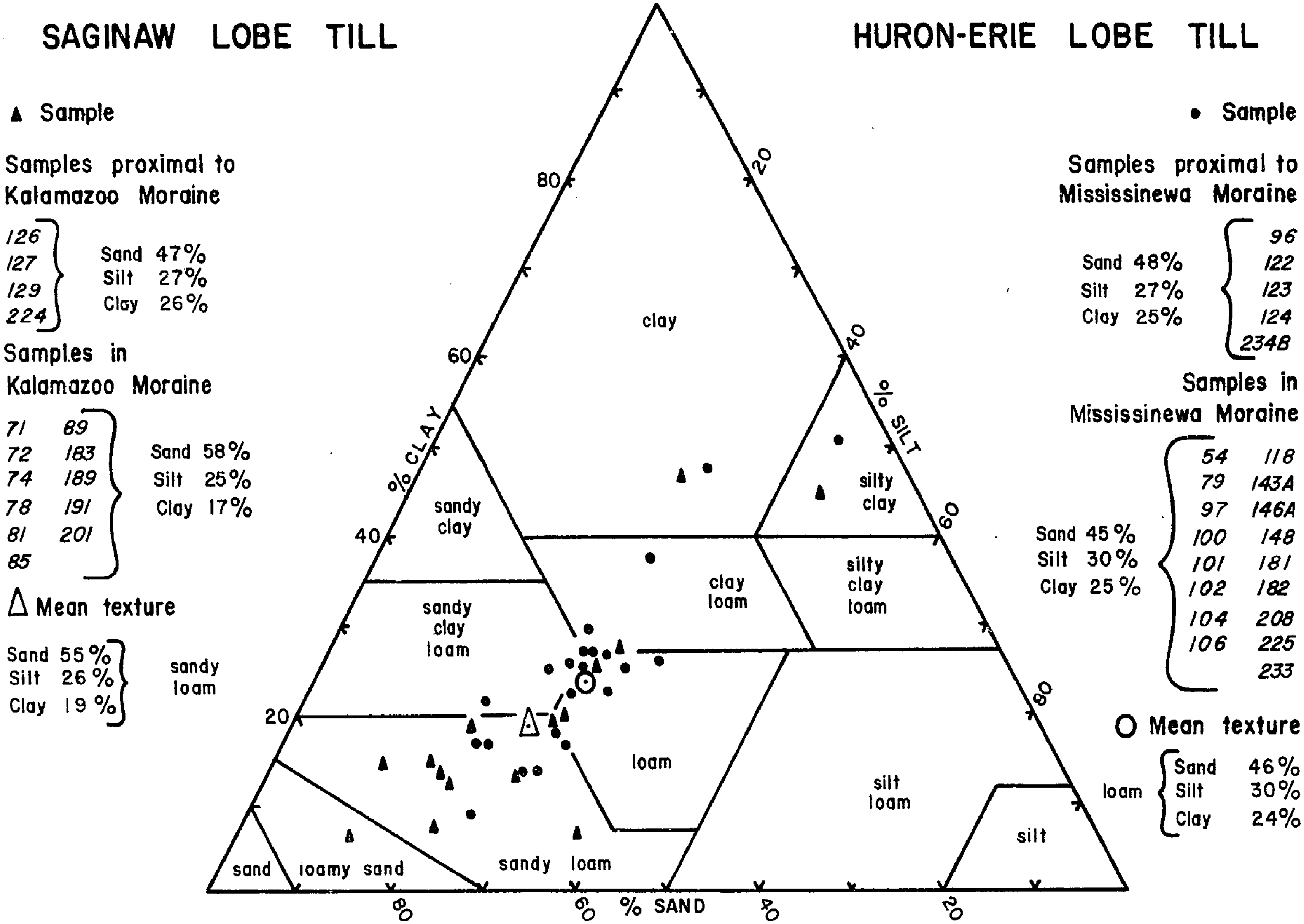

Figure 11. Textures of Tills in and Proximal to Moraines

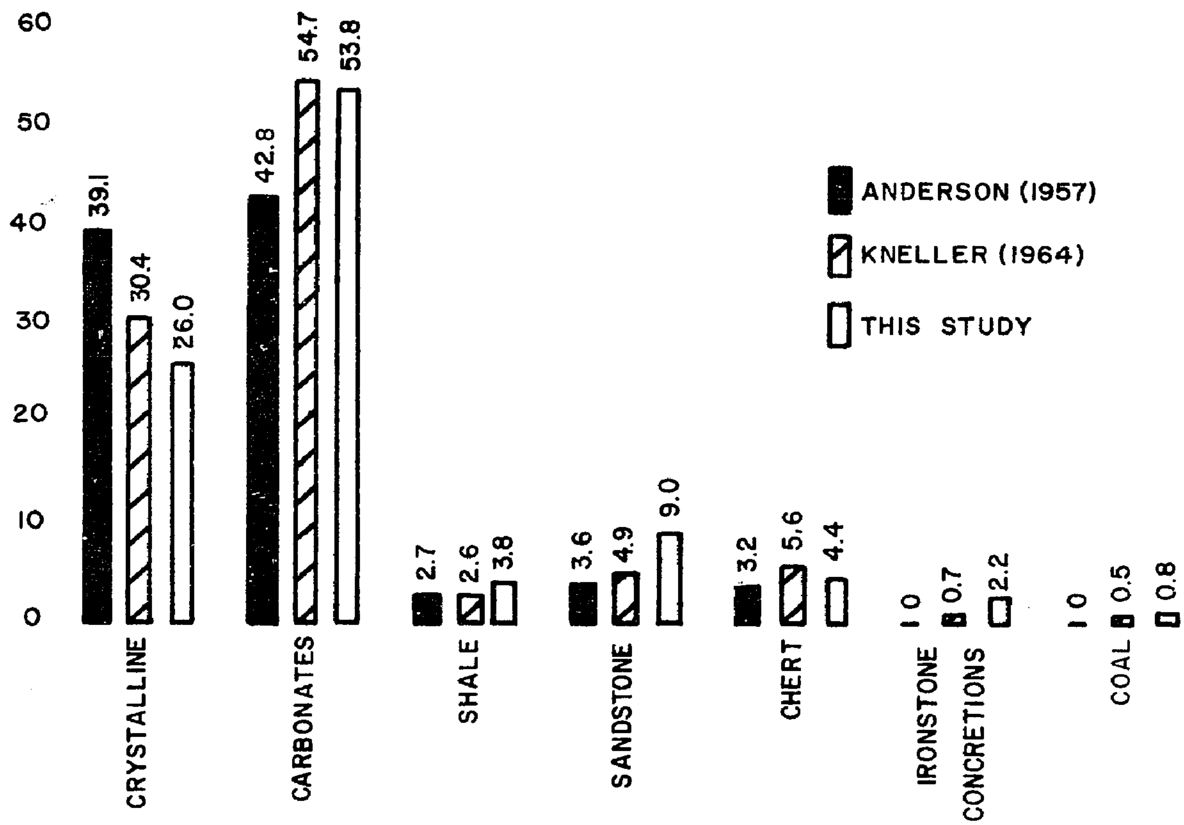

Figure 12. Pebble Lithology of Saginaw Drift in and near Study Area

The greatest variation in results of the three investigations is revealed in the crystalline[17] and carbonate fractions. Anderson listed the crystalline stones as consisting of 39.1% of all pebbles in samples of Saginaw till, and pebble counts from this study indicate that the value is 26.0%, for a difference of 13.1%. Kneller lists the carbonate fraction as 54.7%, and Anderson indicates it to be 42.8%, or a difference of 11.9%. In all other fractions the differences between studies were considerably less than 10%.[18]

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[17] The American Geological Institute Dictionary of Geological Terms, 1962, defines "crystalline" as a "general term for igneous and metamorphic rocks as opposed to sedimentary."

[18] Anderson's data (1957, p. 1439) in Figure 12 do not include 8.7% in his "other clastic" fraction. Kneller's data (1964, Table 2) in Figure 12 do not include 0.6% in his "others," "krag," and "armored mud balls and till clods" fractions.

Leverett and Taylor (1915, p. 200) noted the presence of coal in Saginaw drift. The coal is most likely derived from local Carboniferous bedrock.[19] Many of the pebble-sized coal fragments in the drift were weaker than the till matrix and tended to crumble when touched. This characteristic complicated measurement somewhat because coal pebbles were reduced in size regardless of the care exercised in excavation. Consequently the actual percentage of coal in Saginaw Lobe till is somewhat more than the 0.8% shown on Figure 12, but it clearly forms only a small portion of Saginaw Lobe drift.

Boulder Lithology

Identification of the lithology of 601 boulders on the surface of the Kalamazoo Moraine provided data quite different from that obtained from pebble counts (Table 5 and Appendix E). Crystalline boulders are by far the most common type (97.3%), and sedimentary rocks are quite rare (2.7%). Although present, red jasper conglomerate[20] boulders are not common (0.3%). Slawson (1933, p. 551) stated that more red jasper conglomerate boulders were transported by Saginaw ice than by Huron-Erie ice. This study does not confirm his conclusion. A tillite(?)[21] was considerably more common in the cobble fraction than in the boulder fraction where it is 4.0% of the total. In a stone fence in NE¼ sec. 11, T. 2 S., R. 2 E. (site 169), 16% of the boulder fraction and an even higher

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[19] Several records from wells in the study area report coal at the bedrock surface.

[20] Rounded white quartzite and red jasper clasts in a matrix of white quartzite. A number of these boulders were observed as yard decorations but were not included in Table 5.

[21] Greenish-gray to light greenish-gray matrix with angular to subrounded crystalline clasts. This rock is discussed in Lindsey, 1969.

percentage of the cobble fraction consist of tillite(?). A cause for this large amount of tillite(?) in a restricted area is not obvious, and no similar concentrations were found anywhere in the study area. The large numbers of rocks involved and their drab appearance seem to indicate that they are very near their point of release from the ice and were not transported here over great distances for decorative purposes.

Table 5. Lithology of Surficial Boulders on Saginaw Drift

	Total	Total Crystalline	Crystalline [Excluding Tillite(?) & R.J.C.]	Tillite(?)	Red Jasper Conglomerate	Sandstone	Carbonate
Number	601	585	559	24	2	15	1
Percent	100.0	97.3	93.0	4.0	0.3	2.5	0.2

Boulder Distribution

Boulders are most common in the Kalamazoo Moraine from the longitude of Gilletts and Brill Lakes eastward to Leverett Hill (Figure 13). Although Leverett reported a number of boulders west of Brill Lake (notebook 31, p. 92), very few were observed there during this study. Leverett and Taylor (1915, p. 190) also reported boulders "in great numbers" along the southern or high portion of the moraine. In this investigation some boulders were seen along the highest points of the moraine but many more are visible in its northerly portions. Very few boulders exist at the surface in the Portage River lowland, but they are common to the north on higher topography. Relatively few surficial boulders exist on the Saginaw side of the Interlobate Morainic Tract. However, one

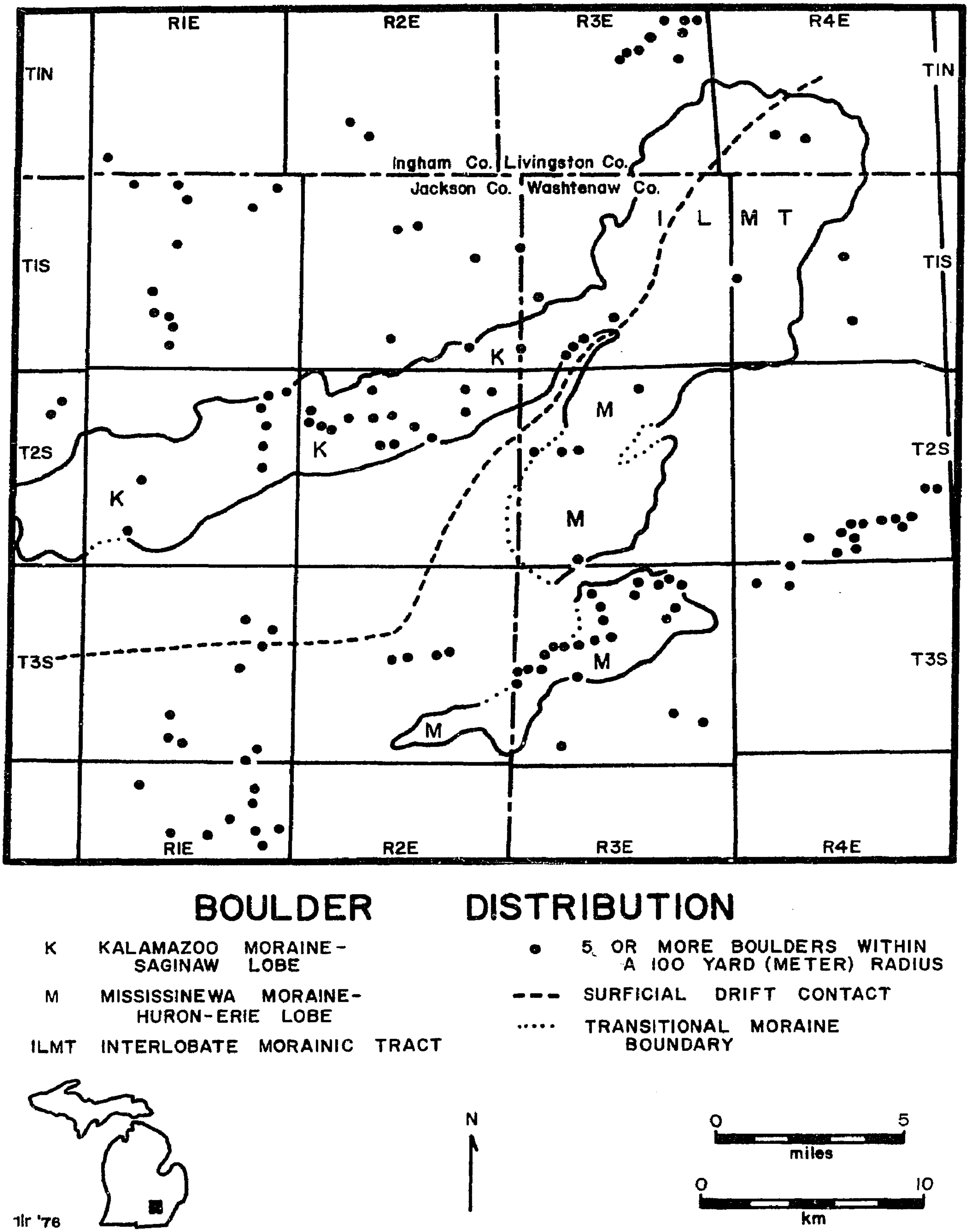

Figure 13. Boulder Distribution

water-well driller, Marshall Meabon of Pinckney, stated that boulders are quite common in the subsurface on the north sides of hills in the northern portion of the Interlobate Morainic Tract.[22]

Till Fabric

Till fabric is the spatial orientation of clasts included in the till matrix and has been used in numerous studies to determine former ice-flow direction. With the exception of morainal trend and orientation of proximal eskers, little evidence exists that provides a direct basis for determining the direction of ice flow during deposition of the Kalamazoo Moraine. To supplement this morphological evidence with lithologic data, the orientation of the long axis of certain stones in till was determined at five sites within the moraine (Figure 14 and Appendix F).[23] These sites are located at approximately 3- to 5-mile (4.8 to 8.0 km) intervals along the trend of the moraine at appropriate exposures of till. Three of the analyses are based on fifty pebbles each (sites 76-- SW¼NW¼SE¼ sec. 10, T. 2 S., R. 2 E., 78-- SE¼SE¼NE¼ sec. 6, T. 2 S., R. 3 E., and 81-- SE¼SE¼SW¼ sec. 15, T. 2 S., R. 1 E.). Twenty-five clasts were used to measure the fabric at site 81A, located only a few yards (meters) away. Due to the extreme scarceness of stones of the appropriate shape at site 74 (NW¼SW¼NE¼ sec. 20, T. 2 S., R. 1 E.), the fabric is based on thirty-one clasts.

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[22] Personal communication, December 17, 1974.

[23] A search was also made for striations on bedrock surfaces in the moraine. The only known site where the bedrock surface may be observed is a road cut at the intersection of I-94 and M-106 (site 229, NW¼SW¼NW¼ sec. 26, T. 2 S., R. 1 W.) in the city of Jackson. Inspection of the exposure failed to reveal any striations. Leverett also unsuccessfully searched for striations on bedrock surfaces in Jackson (notebook 161, p. 12).

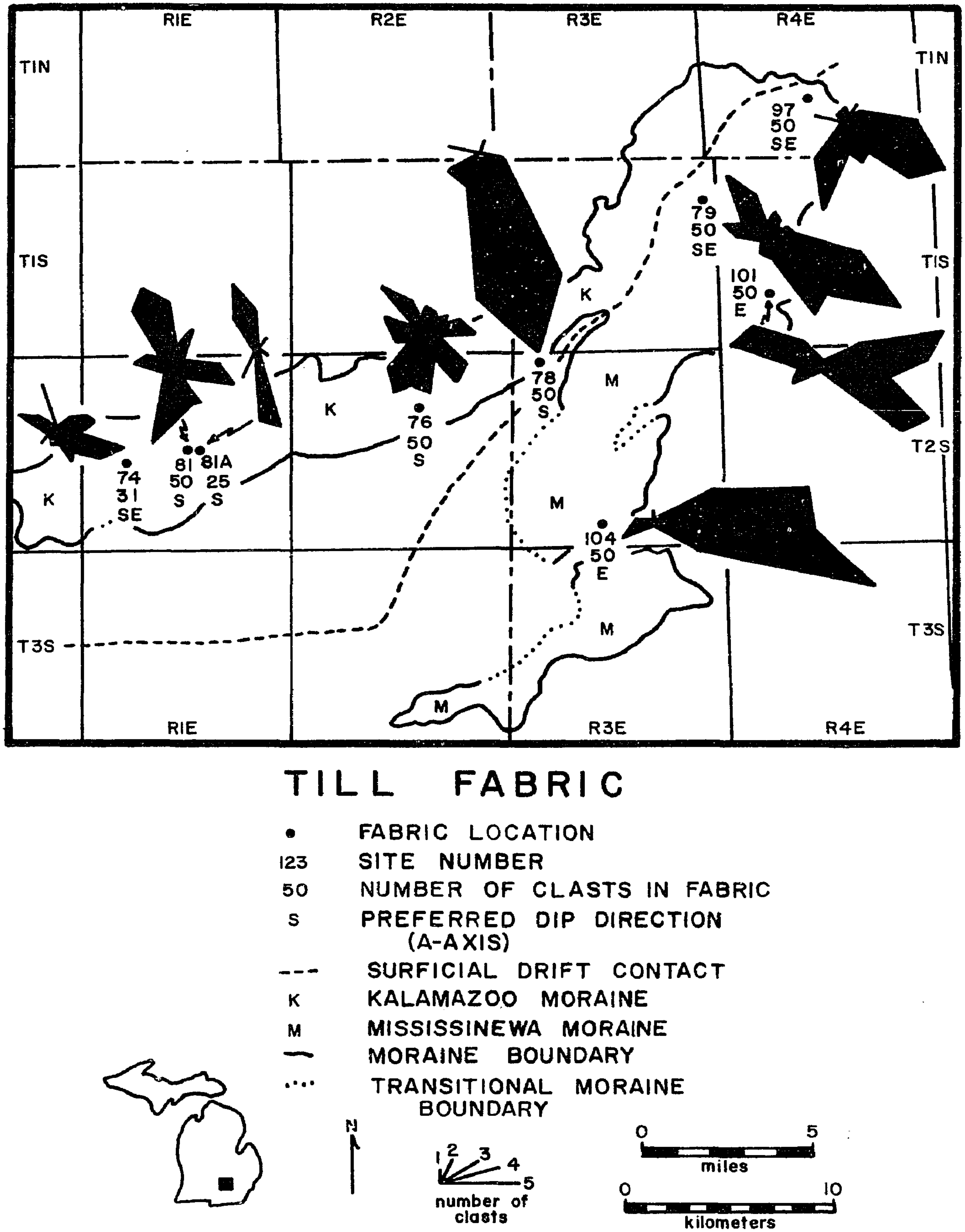

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Figure 14. Till Fabric

The situation and characteristics of the till bodies in which the fabrics were determined appear quite similar. All are near the surface--often near ice-contact slopes-- are rather thin, and are of sandy loam texture. Sandy lenses and horizons are visible within the till bodies, and glaciofluvial sediments exist beneath the till at four of the five sites.

The fabric patterns (Figure 14) vary from unimodal to multimodal and are primarily oriented transverse, but not normal, to the trend of the Kalamazoo Moraine. In every case preferred dip of the stones is to the south or southeast,[24] suggesting former ice flow from that quadrant and deposition by Huron-Erie ice. However, the regional trend of the moraine, the slope of its associated outwash apron, pebble lithology, and clay mineralogy of the till all clearly indicate that the Kalamazoo Moraine is a depositional feature formed by the Saginaw Lobe, not by the Huron-Erie Lobe as the till-fabric patterns seem to indicate. This apparent inconsistency may be resolved and the fabrics made more meaningful if consideration is given to the possibility that the sediment is flow till. The characteristics and significance of flow till are discussed below.

Flow Till

Boulton (1972, p. 379) recognizes three types of glacial till and defines them as

> (a) flow till, released supraglacially and undergoing subsequent deformation as a result of subaerial flow: (b) melt-out till, released either supraglacially or subglacially from stagnant ice beneath a confining overburden, and in which some of the original englacial features are preserved: (c) lodgement till, deposited

[24]A number of studies have shown that clasts tend to have an up-glacier dip. See Goldthwait (1971) for examples of such work.

beneath actively moving ice and undergoing deformation as a result of the shear imposed by this ice.

In the last two decades flow till has been recognized and described by a number of writers-- including Hartshorn (1958), Kaye (1960), Boulton (1968, 1971, and 1972), and Marcussen (1973, 1975)-- in such widely separated areas as Massachusetts, Rhode Island, Spitsbergen, Britain, and Denmark. Boulton's work on the subject is probably the most detailed to date and is concerned primarily with the flow tills forming at present on Spitsbergen. Because the glaciers of that island are outlet glaciers, the characteristics of associated flow tills may not be strictly comparable to those of Pleistocene continental glaciers. Yet if observations of flow till forming at present are used in conjunction with what is known of Pleistocene flow tills, a general pattern seems clear.

Boulton (1968, p. 410) states that flow till may be formed (1) when the margin of a glacier is in compression due to the overriding of bedrock obstacles, (2) with a decrease in slope of the glacier bed, or (3) with stagnation of ice at the margin. In each of these situations till may be carried along debris bands that may extend to the surface of the ice. Ablation of the ice matrix releases the sediment. Water may be abundant in such a superglacial environment, and the saturated till may move downslope due to gravity in a series of flows, coming to rest in lower areas which often contain previously deposited glaciofluvial or glaciolacustrine sediments. Inversion of the surface may take place as a result of the ablation of buried ice, and eventually the till-capped glaciofluvial or glaciolacustrine sediments may be associated with the higher portions of the present landscape. In the past such a situation, where till overlies hills of sand and gravel, would often have been interpreted as evidence of the readvance of active ice rather than mass movement of till from a mass of stagnant, or dead, ice (Boulton, 1972, pp. 380, 384).

During downslope movement and deposition of flow till a number of characteristics may be established. According to Boulton (1971, p. 58), when the till is first released by melting, it has a fabric inherited from the time it was situated in englacial debris bands. However, during downslope movement a new fabric is generated in which the long-axis orientation of elongate clasts tends to parallel the greatest surface slope present during deposition (Boulton, 1971, p. 58).[25] The dips of long axes are generally upslope in relation to the plane of deposition (Boulton, 1968, p. 397).[26]

The stratigraphic relationships of flow till to neighboring sediments can be quite variable, from complex interfingering of flow till and outwash (Marcussen, 1973, p. 217) to a simple cap of flow till on other sediments (Boulton, 1968). Flow till may be found in both concordant and discordant relationships with glaciofluvial and glaciolacustrine sediments. Most commonly the contact between it and subjacent sediments is reported to be sharp and planar, but gradational contacts have been observed (Boulton, 1968, p. 400).

Hartshorn (1958, p. 481) and Boulton (1968, pp. 406, 411) have noted the resistant, "overconsolidated" nature of many flow tills. In the past this resistant character has been attributed to subglacial compaction by some, but both of these writers believe that it is due to subaerial drying.

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[25]It should be noted that the present surface configuration may not be that which prevailed during till deposition.

[26]The plane of deposition may not necessarily be horizontal.

The texture of flow till can be variable, depending somewhat on the initial composition of the till as it ablated from debris bands. The upper portion of the till subjected to subaerial processes tends to have some of the finer material removed by running water and wind, but much of the till beneath the surface may retain its original texture. These coarser surface layers of till may be subsequently covered by another flow till, resulting in a somewhat stratified appearance. Sandy surface layers may also be incorporated within the moving till mass to form sandy lenses or pods oriented approximately in the direction of movement. Some flow tills which were not long exposed to the atmosphere may be massive with no sandy horizons or lenses, but oriented pebbles may create a linear appearance. The combined visual effect of the stones, lenses, and pods can be quite striking, causing exposures of some flow tills to resemble lithified sedimentary rock (see Kaye, 1960, figures 51, 52, and 57). Kaye applied the term "stratified till" to such deposits.

Boulton has described flow till associated with hummocky moraines in Spitsbergen, and Kay recognized this type of sediment associated with an ablation moraine in Rhode Island. Both hummocky and ablation moraines may be associated with stagnant ice. Most of the flow-till sections studied by Hartshorn (1958, p. 481) and Marcussen (1973) were in ice-contact features which are found predominantly in landscapes deposited in the presence of stagnant ice.

In summary, the rather variable nature of flow till in terms of fabric, texture, appearance, and relationship to other sediments precludes positive identification on the basis of only one or two characteristics. Therefore, the key element in the identification of flow till is a consideration of till structure, stratigraphic position and associations, geomorphic situation, and relationship to ice-contact slopes

(Hartshorn, 1958, p. 481, and Marcussen, 1973, p. 229).

Flow Till in the Kalamazoo Moraine and Associated Areas of the Interlobate Morainic Tract

Application of the criteria and principles discussed in the preceding section makes it possible to demonstrate that flow till exists at many places in the Kalamazoo Moraine and associated portions of the Interlobate Morainic Tract.[27] Probably the best exposure of flow till in the Kalamazoo Moraine is in a pit at the north end of Brill Lake (site 81-- SE¼SE¼SW¼ sec. 15, T. 2 S., R. 1 E.). In the vertical exposure on the east side of the pit, 8 to 12 feet (2.4 to 3.7 m) of massive till (unit A) overlies 0.5 to 1.0 foot (15 to 30 cm) of sand (unit B); beneath this is 8 to 12 feet (2.4 to 3.7 m) of till (unit C) containing numerous subhorizontal sandy lenses and layers that may be traced laterally for more than 75 feet (22.9 m), overlying 10 feet (3.0 m) of coarse sand (unit D) with beds dipping south (Figures 15 and 16). This basal sand extends at least 10 feet (3.0 m) beneath the floor of the pit.[28]

The upper till (unit A) is massive and possesses the "overconsolidated" state described by Hartshorn (1958, p. 477) and Boulton (1968, pp. 406, 411) that is interpreted to be characteristic of flow till. Repeated blows with a pick-mattock are required to dislodge material. Fracture of the till is in the form of "sheets" up to eight inches (20.3 cm) thick that spall off, resulting in a smooth, vertical face (Figures 16-19).[29] This surface appears typical of relatively fresh exposures

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[27]Kneller (1964, p. 34) previously recognized the presence of flow till in Washtenaw County in Huron-Erie Lobe landforms.

[28]Interview with owner, Mr. Stanley Szymczyk, July 25, 1974.

[29]Occasionally the till shatters into thumb-sized shards.

of flow tills in the area and has been observed in several other exposures. Hartshorn (1958, p. 478) describes an exposure of flow till which had stood in a vertical face for at least eight years. At some locations within the Brill Lake pit the massive till displays subhorizontal lineations due to the presence of pebbles, many of them striated, and very thin sandy partings (Figures 17 and 18).

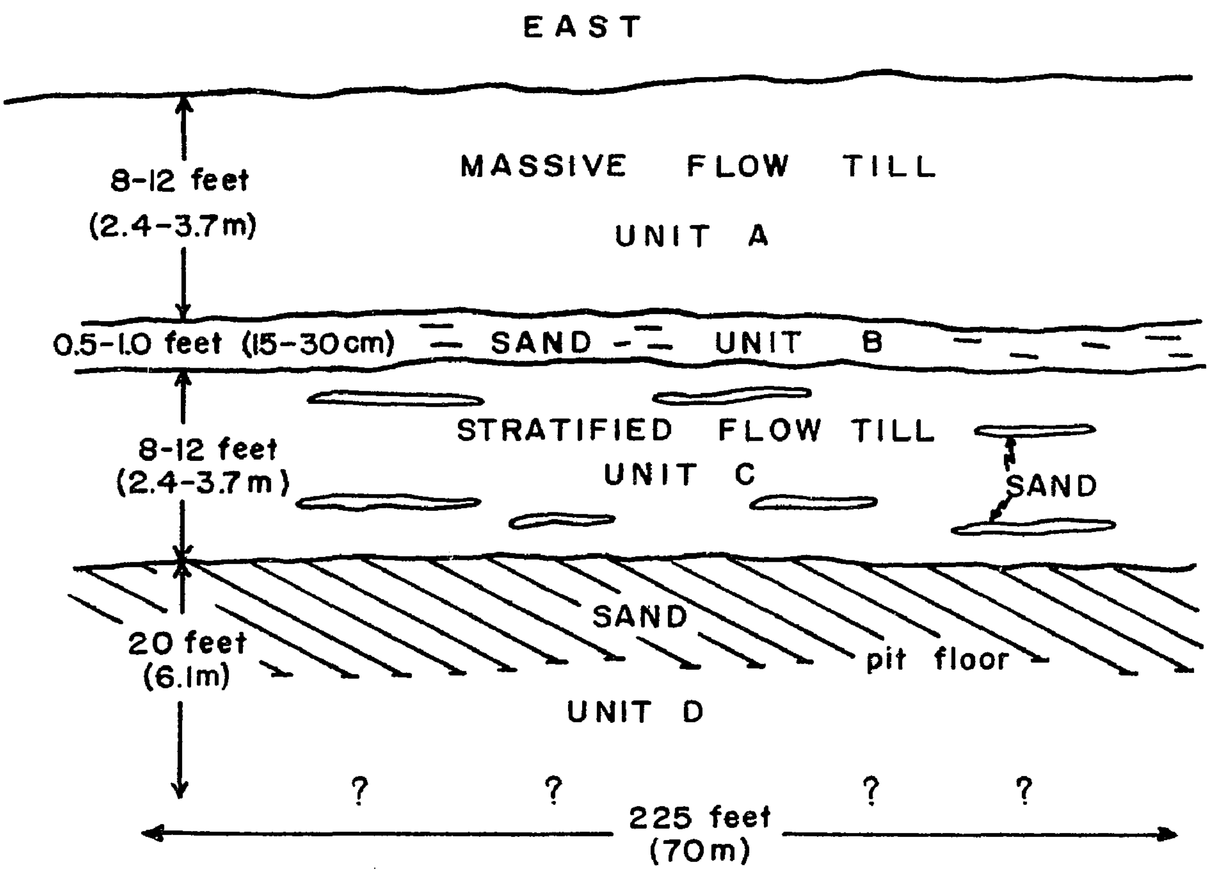

Figure 15. Stratigraphy at Brill Lake Pit (Site 81)

A 0.5- to 1-foot-thick (15.2 to 30.5 cm) sand horizon (unit B) separates the massive upper till (unit A) from a lower till (unit C) having a pronounced stratified appearance. Fluvial bedding is evident in unit B, including two channel fillings which consist of bedded sand that is graded from coarse to fine from the bottom upward.

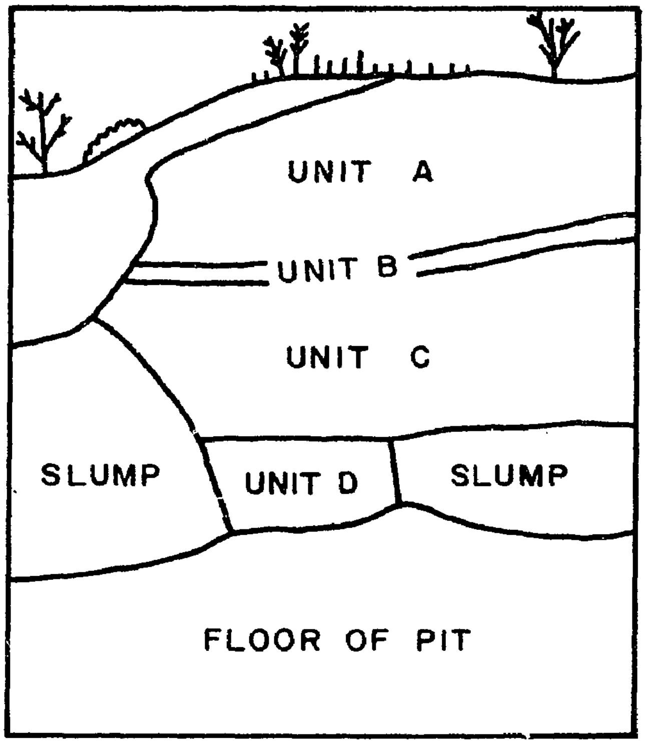

Figure 16. Exposure in East Wall of Brill Lake Pit. This is the type section for Brill Lake till showing--
unit A, massive flow till;
unit B, layer of bedded sand;
unit C, stratified flow till;
unit D, bedded sand.
Note smooth vertical face of the 30-foot-high (9.1 m) exposure.
October 25, 1973.

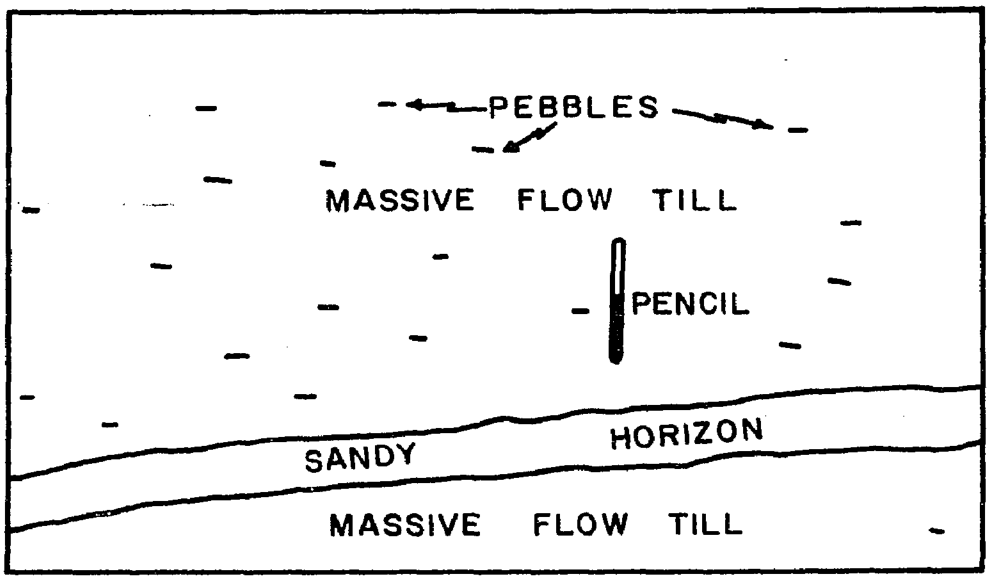

Figure 17. Close-up of Massive Flow Till. Note numerous sub-horizontal pebbles parallel to the single 2-inch-thick (5.1 cm) sandy horizon. Several of the pebbles are striated. Pencil is 5 inches (12.7 cm) long. West wall of Brill Lake pit. October 23, 1973.

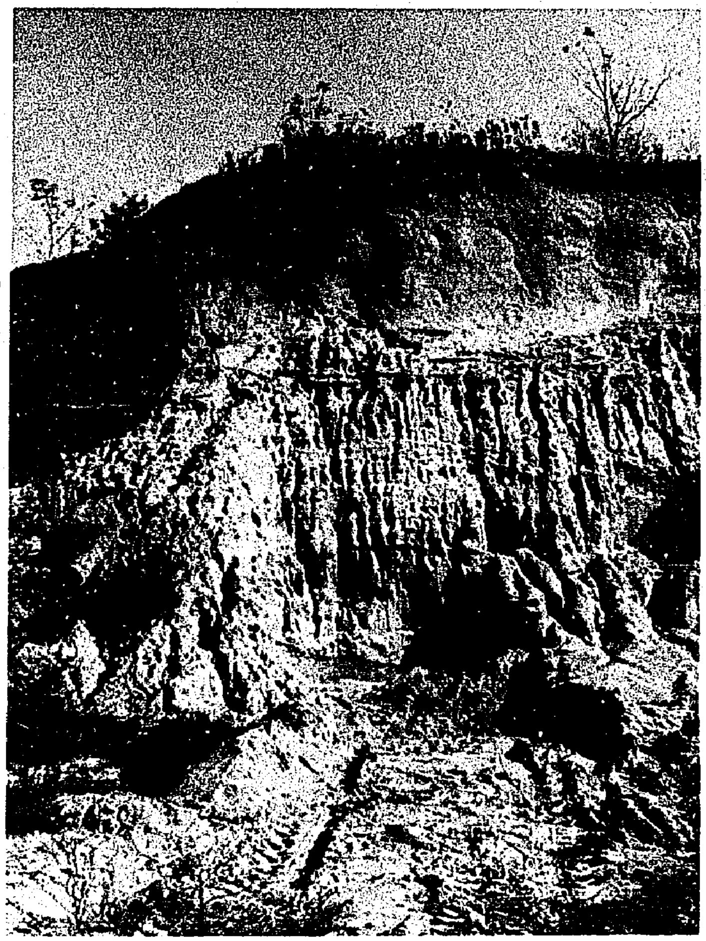

Figure 16.

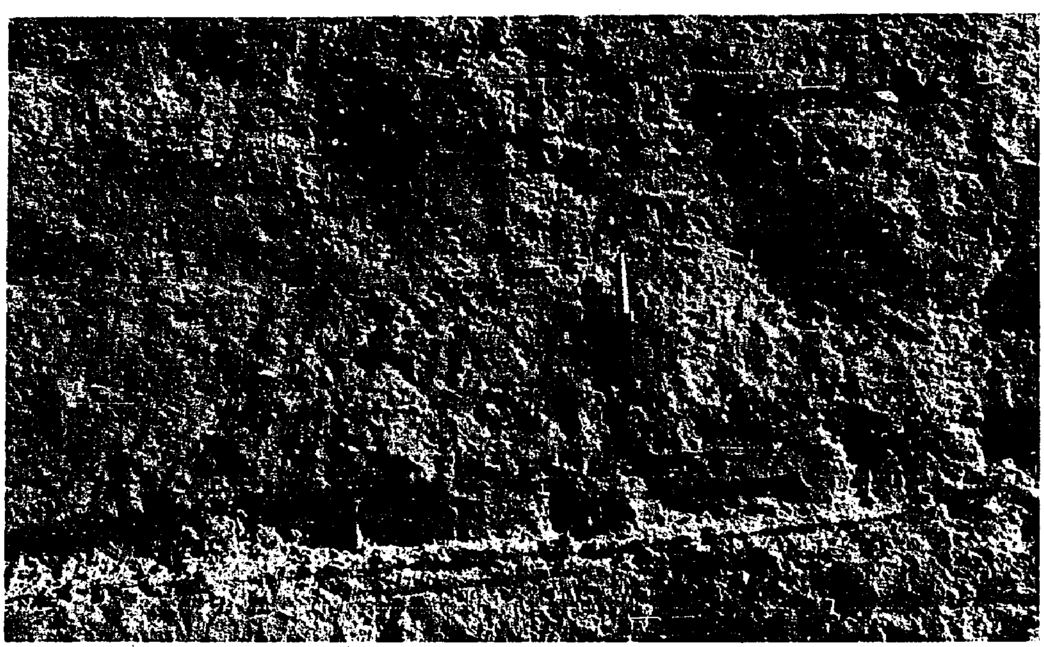

Figure 17.

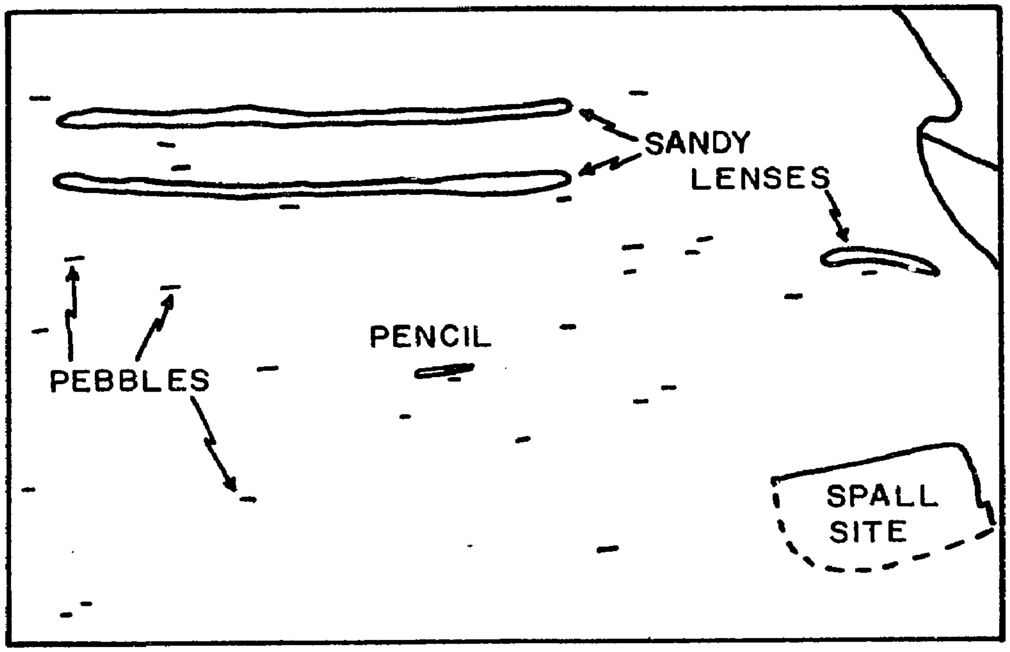

Figure 18. Massive Flow Till. A few very thin sandy lenses and a number of subhorizontal striated pebbles are shown. Note smooth vertical face and site where a sheet of till 2 inches thick (5.1 cm) spalled off due to repeated blows with a pick-mattock. Pencil is 5 inches (12.7 cm) long. East wall of Brill Lake pit. July 7, 1974.

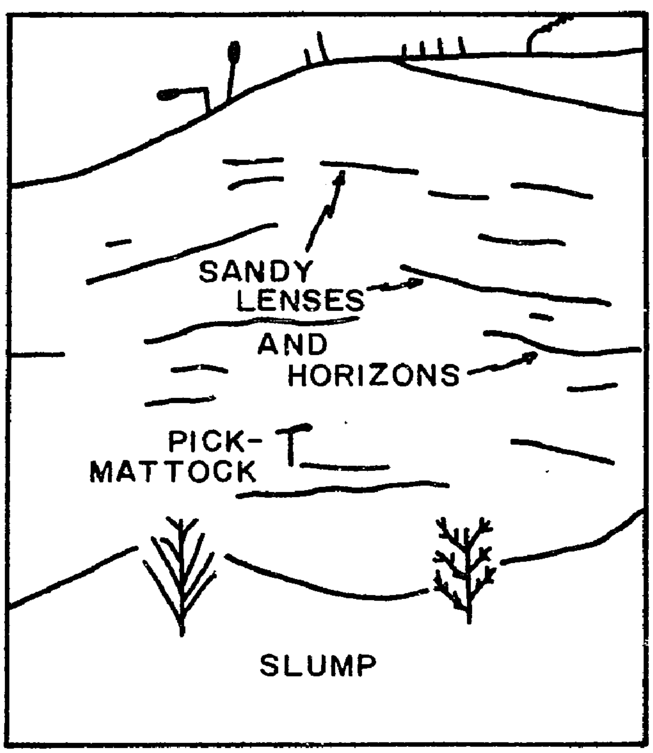

Figure 19. Stratified Flow Till. Note subhorizontality of numerous sandy horizons and lenses up to 3 inches (7.6 cm) thick. Face had been exposed at least one year when photo was taken. Note smooth, vertical face. Pick-mattock is 18 inches (45.7 cm) long. Northeast wall of Brill Lake pit.
July 25, 1974.

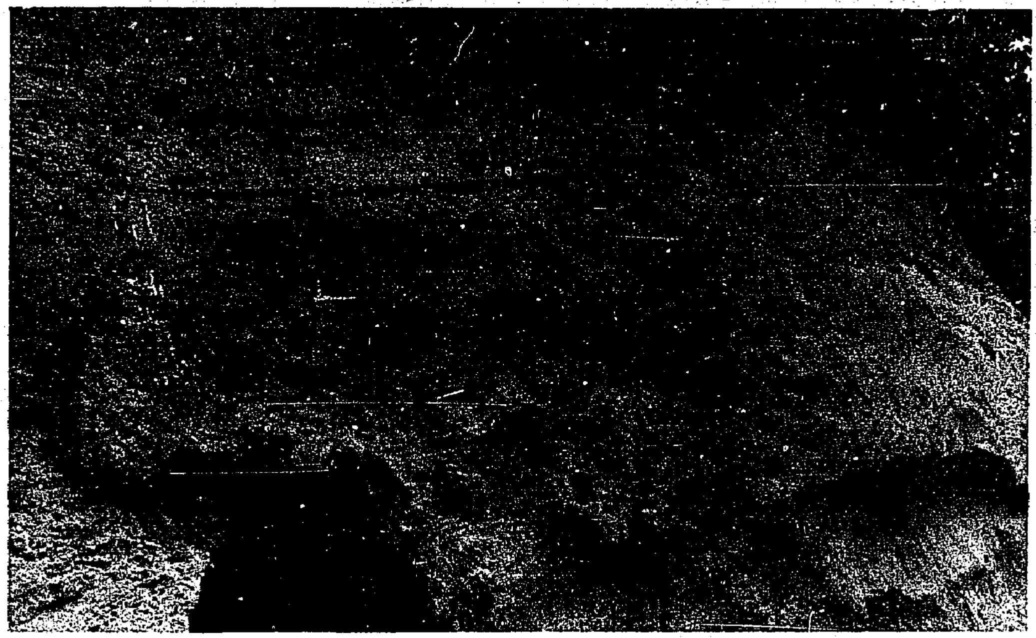

Figure 18.

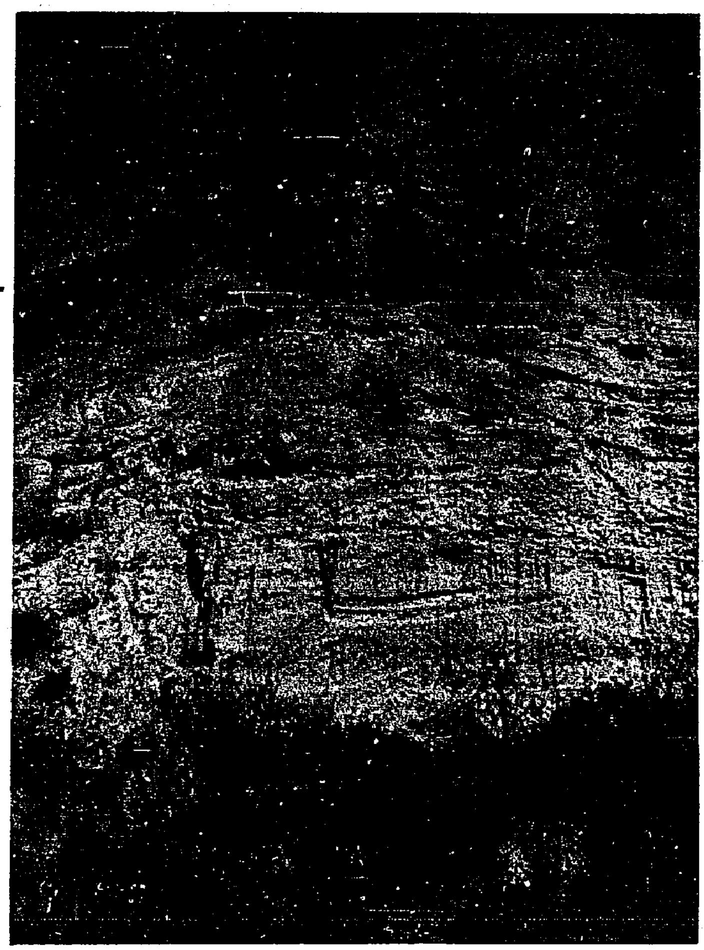

Figure 19.

On the basis of the preceding evidence, it seems likely that unit A is a massive flow till, not greatly modified by subaerial washing, that was deposited upon unit B. Unit B represents an earlier phase when glaciofluvial conditions predominated.

The lower till, unit C, contains many sand lenses, sand partings, and sandy horizons (some with bedding clearly visible).[30] Most of the sandy horizons are subhorizontal and roughly parallel to the present topographic surface. The till is coarser and contains more pebbles than unit A. Kaye (1960, Figures 51 and 52) shows two tills with very similar appearance which he labeled "stratified till." He believed that these tills had moved downslope under the influence of gravity and were flow tills. It seems probable that unit C consists of a series of flow tills which had been exposed to meltwater before and after flow had taken place. The coarser texture and greater abundance of clasts is most likely due to meltwater removing the finer fractions of the till.

Both Boulton (1968, p. 408) and Marcussen (1973, p. 222) have observed exposures which show interfingering of flow till and outwash sediments. They interpret this as flow till deposited simultaneously or penecontemporaneously with outwash. These authors have also described exposures revealing flow till conforming with, truncating, and grading into sediments with which they are in contact (Boulton, 1968, p. 400 and Marcussen, 1973, p. 221). The Brill Lake pit (site 81) has examples of all these relationships. An exposure along the north side of the pit reveals interfingered till and water-deposited sands. One of the till bodies truncates the bedding in the lower portion of an outwash sequence (Figures 20 and 21). Although the contact between till and outwash is

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[30]Figure 19 shows similar till elsewhere in the pit.

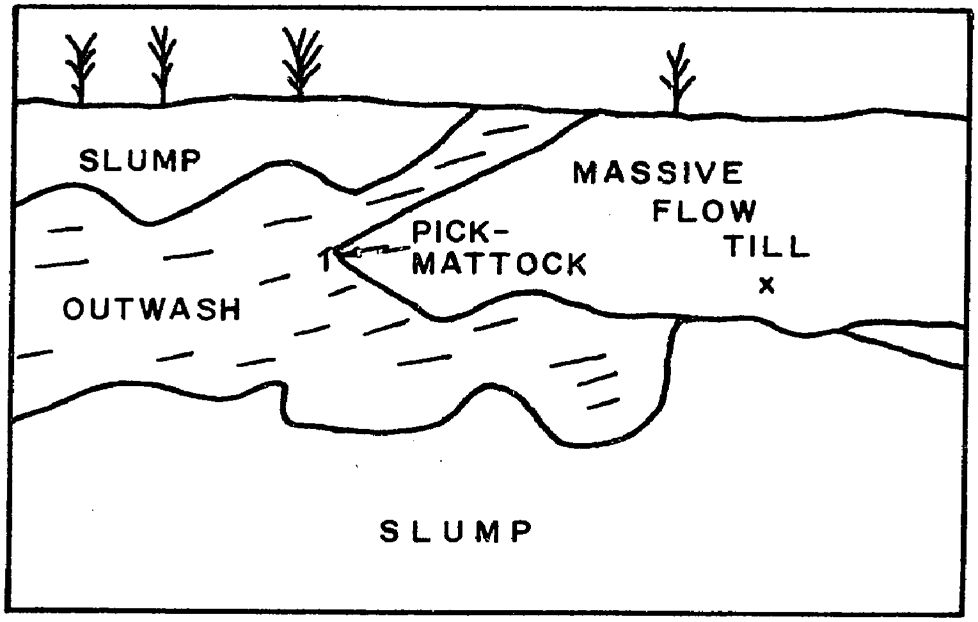

Figure 20. Interfingering of Massive Flow Till and an Unbroken Outwash Sequence. Till has been moistened to emphasize tonal difference between it and outwash. Till fabric 81 was measured at "X." Site of fabric 81A is just off picture to right. Pick-mattock is 18 inches (45.7 cm) long. Exposure in north wall of Brill Lake pit. July 25, 1974.

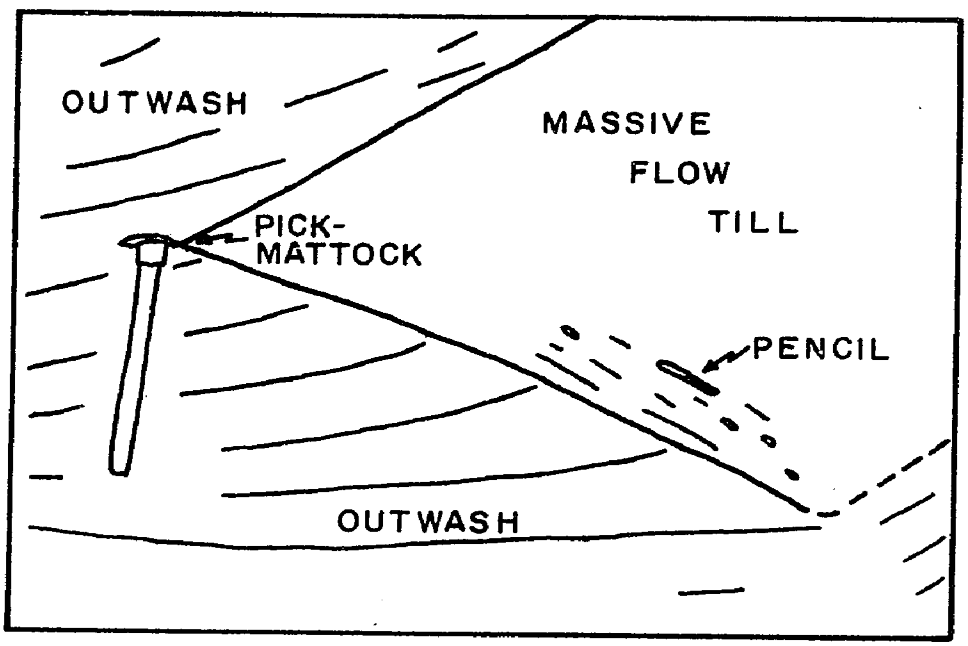

Figure 21. Close-up of Exposure in Figure 20. Bedding in outwash is truncated by till in lower part of photo but is conformal with it in upper part. The outwash bedding appears to represent an unbroken depositional sequence. Note the stratification in the till near pencil. A portion of the till has been moistened to clarify the till/outwash contact. July 25, 1974.

Figure 20.

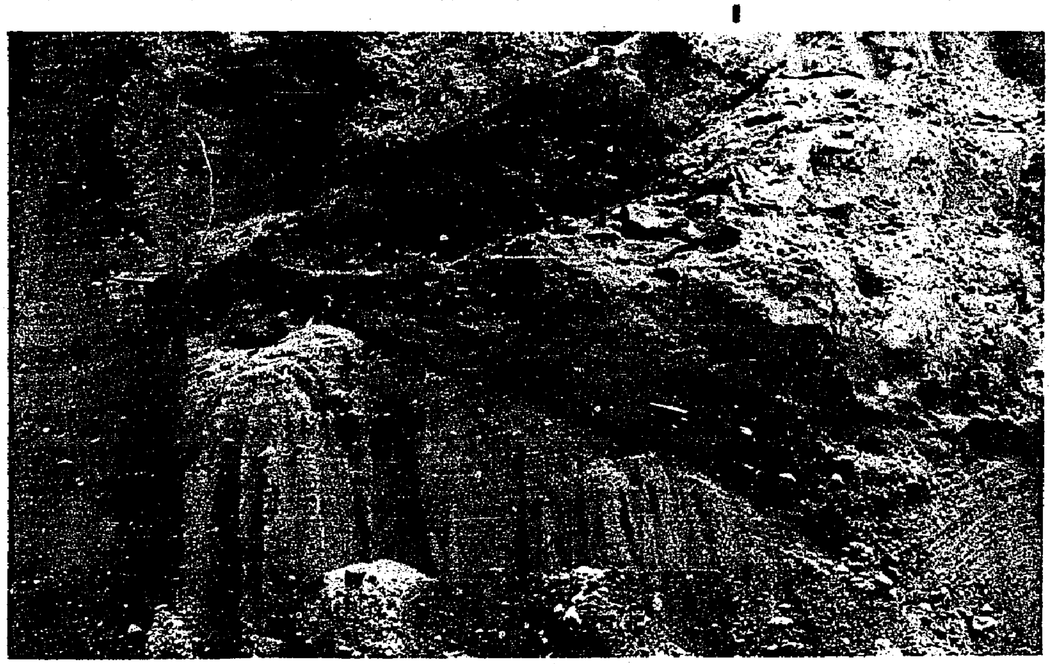

Figure 21.

sharp and undeformed, the lower portion of the till displays stratification locally and in one location grades into underlying sediments.

On the basis of the (1) sand lenses and horizons, (2) "overconsolidated nature," (3)vertical faces in exposures, (4) high stratigraphic position, (5) till fabrics, (6) interfingering with outwash, and (7) proximity to an ice-contact slope (less than 100 yards or 91 m away), it is apparent that flow till is present in the pit.

Prospect Hill "A" (S½SE¼SW¼ sec. 2 and N½NW¼ sec. 11, T. 1 S., R. 3 E.)[31] is a large kame located just west of Russell Hill. Air photos and topographic maps show a 10- to 15-feet-deep (3.0 to 4.6 m) draw trending northeast down the flank of Prospect Hill "A." A portion of the gravel pit at site 183 (SW¼SE¼SW¼ sec. 2, T. 1 S., R. 3 E.) intersects the draw, and the resulting exposure reveals till up to 10 feet (3.0 m) thick on the side of the draw. The till is very sandy (loamy sand) and displays smooth vertical faces in the pit. The till spalls off the face in sheets and is generally massive and relatively stone-free, but those sandy horizons and striated pebbles present are parallel to the contact with the subjacent sand and gravel. Small drag structures in the sand and gravel indicate that the till moved obliquely downward toward the center of the draw. The preferred orientation of fifteen pebbles within the bottom part of the till was also transverse to the maximum slope of walls of the draw. On the basis of this evidence, it appears reasonable to conclude that flow till moved down the flanks of Prospect Hill"A" and flowed obliquely into a preexisting valley on the slopes of the feature.

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[31]A number of features named "Prospect Hill" are located in the study area. Those discussed in this dissertation will be identified by a letter; thus, this feature is Prospect Hill "A."

A somewhat similar situation exists at site 161 (N$\frac{1}{2}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 7, T. 2 S., R. 2 E.), where a vertical 25-foot-high (7.7 m) face in a gravel pit exposes 10 feet (3.0 m) of till with smooth vertical faces, subhorizontal sandy lenses, and striated pebbles overlying 15 feet (4.6 m) of sand and gravel. A 4-foot-deep (1.2 m) channel at the top of the sand and gravel is filled with till. It appears that flow till completely filled the small channel and buried the sand and gravel, obscuring any of its surface characteristics. Marcussen (1973, pp. 222-23) noted a similar situation in Denmark.

The maximum thickness of flow till observed in the study area was about 25 feet (7.6 m) at site 81 near Brill Lake. Boulton (1968, p. 391) reports a maximum thickness of 5 meters (16.4 ft) for flow till on Spitsbergen, and Marcussen (1973, p. 229) observed a deposit 7 meters (23 ft) thick in Denmark. Kaye (1960, p. 357) does not list the maximum thickness for flow till in his area of study but does include a photograph of this material in an exposure which appears to be 15 to 20 feet (4.5 to 6 m) in height. Flow till is generally found on the higher portions of the landscape in the study area, and in most exposures it is both uppermost and the last glacial sediment deposited, although in some cases 1 or 2 feet (0.3 or 0.6 m) of sand covers the till.[32]

Flow till may be recognized quite easily in large exposures where both structure and stratigraphy are visible (Figure 22 and Appendix G). In small exposures it is generally not possible positively to identify flow till, although in some cases a probable recognition may be made.[33]

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[32]Almost no exposures or excavations were found in the lower portions of the landscape, so the presence or absence of flow till in such locations cannot be confirmed.

[33]Positive identification does not appear possible from auger borings or well records.

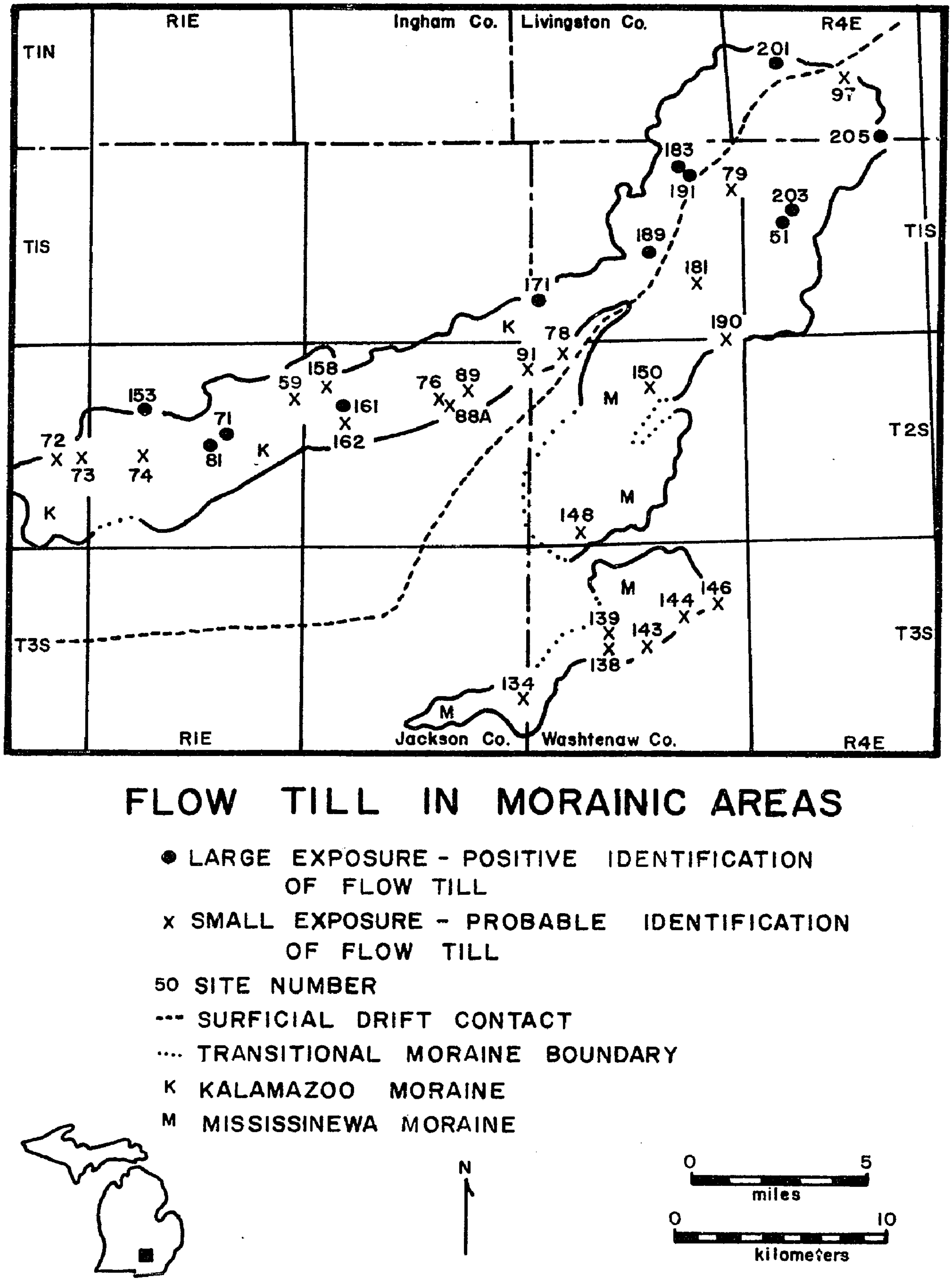

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Figure 22. Flow Till in Morainic Areas

In the portion of the Kalamazoo Moraine and associated area of the Interlobate Morainic Tract which extends from Jackson to Pinckney, twenty-one large exposures were studied during this investigation. Flow till was positively identified in nine of these exposures, and probable identification was made in four.[34] Thus, of the twenty-one large exposures suitable for study, flow till is thought to be present in thirteen, or 62% of the total. Data from soil maps and observations made in numerous road cuts also indicate the probability that flow till is widely distributed in the Kalamazoo Moraine and associated portions of the Interlobate Morainic Tract.

In summary, flow till appears to be a widespread sediment at the surface within the Kalamazoo Moraine and is very similar to that previously reported in the literature. For example, both massive and stratified types of flow till were recognized in the area. In addition, most of the major characteristics of flow till were observed, such as (1) interfingering with glaciofluvial sediments, (2) orientation of striated pebbles parallel to the direction of movement, (3) presence of sandy lenses and horizons, (4) sharp planar contacts with subjacent materials, (5) "overconsolidated" nature when dry, (6) smooth vertical faces in relatively fresh exposures, (7) presence in higher topographic positions within the landscape, (8) association with ice-contact slopes, and (9) till fabric parallel to maximum surface slopes. The presence of this flow till in the Kalamazoo Moraine indicates that at least a portion of that feature was deposited in an environment in which ice stagnation was very common.

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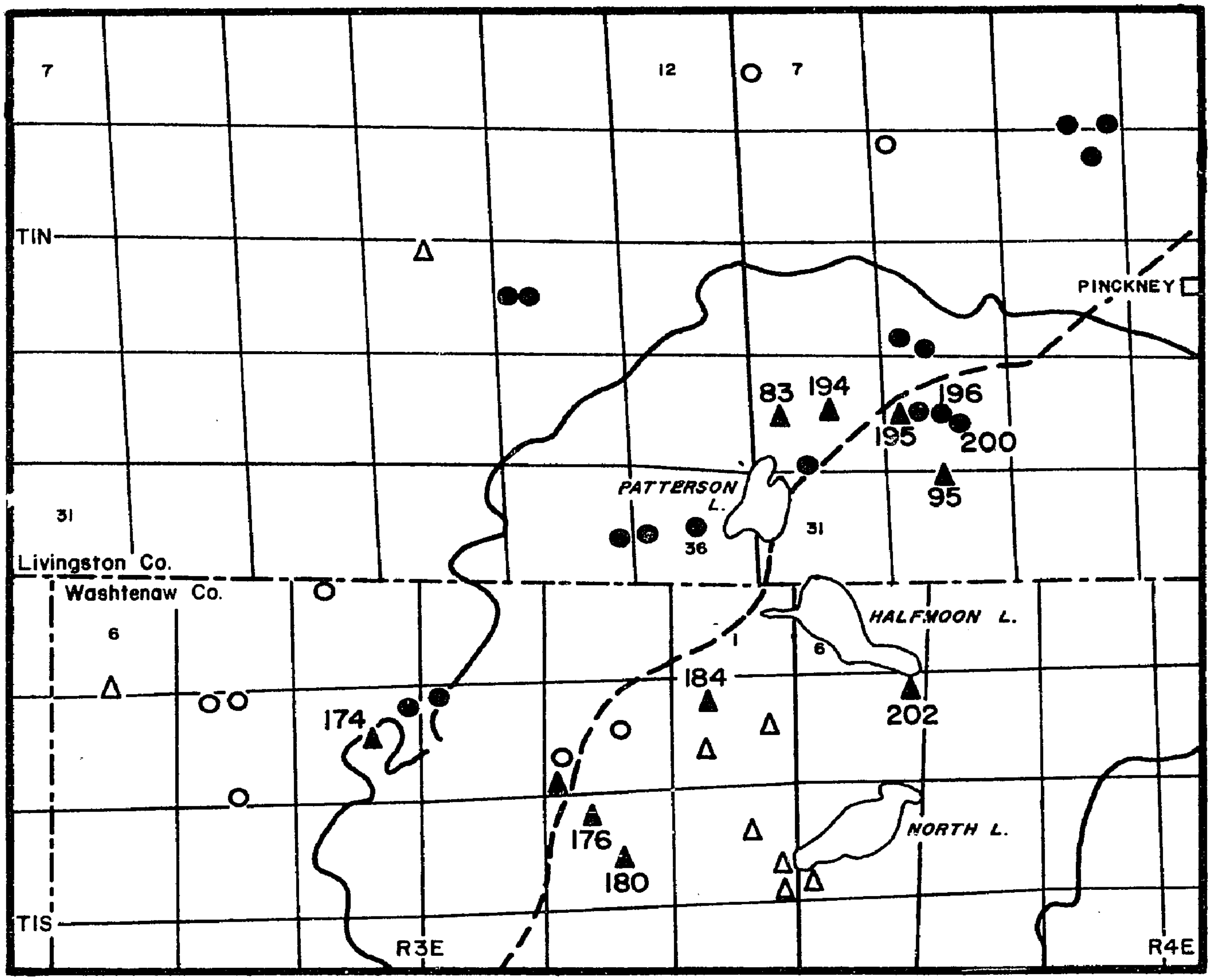
[34]Considerable slumping at four of the sites precluded positive identification of flow till.

Lacustrine Sediments

Deposits of pebbleless clays and silts exist at various places in the Saginaw Lobe portion of the Interlobate Morainic Tract and also within and north of the drainageway at Pinckney (Figure 23). Mechanical analysis of samples 83 (NE¼NW¼SW¼ sec. 30, T. 1 N., R. 4 E.) and 174 (SW¼SW¼NE¼ sec. 9, T. 1 S., R. 3 E.) yielded textures of clay and silty clay, respectively. The sediments are generally massive, although bedding is visible locally. The bedding, fine texture, and scarcity of pebbles all indicate a lacustrine origin.

Maximum thickness of the sediments was observed at site 83, where a road cut exposed 10 to 15 feet (3.0 to 4.5 m) of the material.[35] Sand often exists above and below the lacustrine sediments, and very fine sand partings are visible within the deposits at some places. In many exposures the sediment is massive, and at some locations bedding is visible but no rhythmites were observed. Not all visible bedding planes were horizontal; for example, steep dips and deformation may be observed at sites 174 and 194 (SW¼SW¼NE¼ sec. 30, T. 1 N., R. 4 E.). At site 195 (SW¼SW¼NE¼ sec. 30, T. 1 N., R. 4 E.) a 1.5-foot-thick (0.5 m) layer of lacustrine sediment is faulted with a 3-foot (1 m) vertical displacement. The silt and clay deposits are often near ice-contact slopes. Because these sediments were always observed in contact with sands and gravels, and never with adjacent or overlying till, it is reasonable to conclude that deformation is due to an ice-contact origin and is not the result of a readvance and overriding of the ice.

[35] This must be considered a minimum thickness because the sediments extend to an unknown depth below the road grade.



LACUSTRINE SEDIMENTS

● DEPOSIT ALTITUDE ≤930 FEET (283.5 M), EXAMINED IN DETAIL

▲ DEPOSIT ALTITUDE ≥930 FEET (283.5 M), EXAMINED IN DETAIL

○ DEPOSIT ALTITUDE ≤930 FEET (283.5 M), LOCATION FROM SOIL MAP

△ DEPOSIT ALTITUDE ≥930 FEET (283.5 M), LOCATION FROM SOIL MAP OR LEVERETT FIELD NOTEBOOK

-- SURFICIAL DRIFT CONTACT

~ INTERLOBATE MORAINIC TRACT BOUNDARY

123 SITE NUMBER

0 1 MILE

0 1 KM

N

Figure 23. Lacustrine Sediments

Clay mineralogy and geomorphic findings indicate that the Saginaw/ Huron-Erie drift contact is about 0.7 miles (1.1 km) east of site 83 and approximately 1.8 miles (2.9 km) east of site 174 (Figures 10 and 23). X-ray diffraction of samples from these sites yielded relatively high 7Å/10Å ratios (1.16 and 1.09, respectively), which are indicative of Saginaw Lobe provenance and imply that here there was little or no mixing of sediment-laden meltwater from the two lobes during the time the lacustrine sediments were deposited. Had there been such extensive mixing, one would expect the 7Å/10Å ratios to be nearer the 0.91 value which separates Saginaw and Huron-Erie drift. Since this is not the case, the watersheds of the ice-contact lakes in which the sediments were derived and deposited were most likely quite small.

Recent soil maps show Sisson, Kibbie, or Colwood soils (lacustrine parent materials) developed on several of the silt and clay deposits.[36] As noted previously in this chapter (p. 50), some of the soils associated with the lacustrine sediments observed are also mapped as Miami (till parent material) on the modern soil surveys.

In this study it was not feasible to determine the exact distribution of the lacustrine sediments in and near the Interlobate Morainic Tract for the following reasons.

1. The number of exposures available for observation were limited.
2. Recent soil maps of the area are at too small a scale (1:15,840) to show many of the soils associated with lacustrine deposits, as they tend to be rather small.

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[36] Arkport soils are believed to have both lacustrine and outwash sediments as parent materials and are present in the interlobate area. This soil series is not shown on Figure 23 because none of the twenty-seven silt and clay deposits observed were mapped as Arkport by recent soil surveys.

3. Some of the lacustrine deposits which are large enough to be shown on soil maps are classified as Miami soils which have till as parent material.

4. Some lacustrine deposits have a cover of sand which may exceed 5 feet (1.5 m) in thickness and therefore were probably not detected during soil mapping.

Leverett wrote (notebook 275, p. 92) that when the ice margin melted north into T. 1 N., R. 1 W., an outwash apron with an altitude of about 930 feet (283.5 m) was deposited just north of Rives Junction in the Grand River valley, partially filling it. He believed that this apron acted as a threshold ponding the waters to the south at a level of 930 feet (283.5 m)[37] until it was trenched by river erosion and that the resulting lake covered a considerable area north of the Kalamazoo Moraine.[38] Furthermore, he considered the possibility that this ponding at 930 feet (283.5 m) may also have affected portions of the Interlobate Morainic Tract.

Of the eighteen bodies of lacustrine sediment observed on the Saginaw Lobe side of the Interlobate Morainic Tract, four were at altitudes higher than 930 feet (283.5 m) (Figure 23). This suggests that, if the ponding envisioned by Leverett did take place, not all, and possibly none, of the lacustrine sediments are necessarily associated with it. Those silt and clay bodies with altitudes greater than 930 feet (283.5 m) appear to be associated with small ice-contact lakes with limited

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[37]Marginal notes in Leverett's hand on Rives Junction and Stockbridge topographic maps on file at the Geological Survey of Michigan.

[38]A lake with dimensions of at least 2 miles (3.2 km) by 10 miles (16 km) could be expected to have formed beaches. Although a search was made for such features, especially on air photos, none were located.

watersheds, and not the large lake Leverett hypothesized for the Grand and Portage River drainage areas. If this large lake did exist, some of the lacustrine sediments at or below 930 feet (283.5 m) may have been associated with small ice-contact ponds separated from the large lake by stagnant ice. X-ray diffraction data from sediments collected at altitudes of less than 930 feet (283.5 m) may provide evidence of whether or not the lake existed and if sediment-laden meltwaters from both lobes flowed into it.

Brill Lake Till--Characteristics and Type Section

One of the most important sediments in the area is the flow till exposed at Brill Lake (hereafter referred to informally as the Brill Lake till) because it is believed representative of much of the surficial till of the Saginaw Lobe in the Kalamazoo Moraine and associated areas of the Interlobate Morainic Tract between Jackson and Pinckney.

In most exposures of the study area this surficial Brill Lake till overlies, or is intercalated with, outwash of the Saginaw Lobe. The type section is in a pit at the north end of Brill Lake (site 81, SE¼SE¼SW¼ sec. 15, T. 2 S., R. 1 E.), where 12 feet (3.7 m) of massive flow till overlies 12 feet (3.7 m) of stratified flow till, which is underlain by at least 20 feet (6.1 m) of outwash sands.[39] Brill Lake till has only been recognized at, or very near, the surface, and the maximum observed thickness was 25 feet (7.5 m). Oxidized and unleached, it is a very pale brown (dry) or yellowish brown (moist). Texture of the till is variable but most commonly is sandy loam. Sand lentils and

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[39] Other representative sections are at site 183 (SW¼SE¼SW¼ sec. 2, T. 1 S., R. 3 E.), site 191 (SE¼SE¼SW¼ sec. 2, T. 1 S., R. 3 E.), and site 161 (N½SE¼SE¼ sec. 7, T. 2 S., R. 2 E.).

sandy horizons are common. Orientation of certain elongate stones within Brill Lake till may be quite variable at some locations and generally reflect its flow-till origin. Glaciolacustrine sediments are found in contact with outwash associated with the Brill Lake till. With the exceptions of a higher crystalline content and a lower shale content, pebble lithology of the till is quite similar to that of the till associated with the Mississinewa Moraine to the east and south (see description of Chelsea till in this chapter). X-ray diffraction of clays from the till matrix, and also of associated lacustrine clays, always yields a distinctive 7Å/10Å peak height ratio of 0.91 or more which serves to identify its Saginaw Lobe provenance. Detailed information on the Brill Lake till and its distribution is presented in this chapter and Appendix B.

Drift Associated with Mississinewa Moraine and Related Portions of Interlobate Morainic Tract

Soils as an Indicator of Parent Material

The soils in the higher, proximal portions of the Mississinewa Moraine (Boyer, Fox, Spinks, and Owosso) are developed largely on sands and gravels. On the lower, distal portions of the moraine, till parent materials are more common (Miami, Conover, Kidder, and Hillsdale soils).

Soils of the Huron-Erie segment of the Interlobate Morainic Tract are in general coarse-textured, having glaciofluvial parent materials. However, finer-textured soils derived from till are slightly more common here than in the Saginaw Lobe sector. Along the surficial Huron-Erie/Saginaw drift contact, soils associated with glaciofluvial materials are predominant (Boyer, Spinks, and Fox) although small soil bodies developed on till are present (Miami, Conover, Brookston, and Kidder). On the eastern margin of the Interlobate Morainic Tract, soils associated with glaciofluvial materials (Boyer, Oshtemo, Fox, and Spinks-Oakville) are most common, but soils with till parent material (Miami, Kidder, Riddles) are more widespread than to the west near the interlobate drift contact.

Clay Mineralogy[40]

Twenty-two till samples from the Mississinewa Moraine, associated portions of the Interlobate Morainic Tract, and the area immediately to the east were analyzed according to the procedures described in Appendix B. Twenty-one of the samples produced 7Å/10Å ratios or 0.90 or less, and all samples were from sites located east and south of a line connecting Leverett, Riley, Stofer, and Russell Hills, the east end of Patterson Lake, and Pinckney (Figures 9 and 10).[41] The range of the 7Å/10Å ratios is 0.38, with the highest being 0.91 from site 225 (SE¼NE¼SE¼ sec. 17, T. 2 S., R. 3 E.) and the lowest being 0.53 from site 146 (SW¼SW¼SW¼ sec. 12, T. 3 S., R. 3 E.).

X-ray diffraction of clays extracted from four samples of glaciofluvial sediments from beneath the surficial till of the Mississinewa Moraine produced data quite similar to that of samples from surficial till. At site 234 (SW¼SE¼SW¼ sec. 19, T. 2 S., R. 4 E.), proximal to the moraine, the surficial till has a 7Å/10Å ratio of 0.79, and the clays removed from the underlying glaciofluvial sediments at a depth of 20 feet (6.1 m) have a value of 0.84. At site 146 the surficial till ratio was 0.53, and clays from the glaciofluvial material beneath at a depth

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[40]A total of twenty-four till, four bedrock, and four glaciofluvial 7Å/10Å ratios was determined for this portion of the study area.

[41]All thirteen surficial till samples analyzed from sites proximal to, and in, the Kalamazoo Moraine and associated portions of the Interlobate Morainic Tract had 7Å/10Å ratios of 0.91 or more.

of more than 10 feet (3 m) yielded a ratio of 0.59. Till from a sample site on the crest of the Goose Lake Esker (site 148-- NW¼SE¼SW¼ sec. 32, T. 2 S., R. 3 E.) produced a ratio of 0.83, and clays from the underlying glaciofluvial material, a ratio of 0.87. Site 143 (NW¼NW¼NW¼ sec. 22, T. 3 S., R. 3 E.) produced a surficial till ratio of 0.90, and clays from glaciofluvial materials 8 feet (2.4 m) below the surface, a ratio of 1.00. On the basis of this evidence, it seems reasonable to conclude that most of the buried glaciofluvial materials near the surface are of Huron-Erie provenance.

If a planimetric outline of the Mississinewa Moraine is projected downward to the bedrock surface, it will encircle portions of the Upper Mississippian Michigan and Marshall Formations (primarily sandstones). A sample of Mississippian Napoleon Sandstone, a part of the Marshall Formation, was collected in a quarry in the town of Napoleon within a few hundred yards (m) of its type section. The clay minerals removed from this sample (number 230-- SE¼SE¼SW¼ sec. 31, T. 3 S., R. 2 E.) gave a 7Å/10Å ratio of 10.7 (scale factor 16).

Two samples (numbers 227-- NW¼NW¼SE¼ sec. 3, T. 4 S., R. 5 E., and 228-- SW¼SE¼SW¼ sec. 12, T. 2 S., R. 6 E.) of surficial till from the Outer Defiance and Fort Wayne Moraines of the Huron-Erie Lobe, 15 miles (25 km) to the east of the Mississinewa Moraine, produced 7Å/10Å ratios of 0.87 and 0.86. If it is assumed that samples 227 and 228 are representative of Huron-Erie till to the east, any incorporation of Napoleon Sandstone as the lobe moved westward would likely cause 7Å/10Å ratios to increase resulting in values of more than 0.90. If this reasoning is correct, it may be concluded that during deposition of the Mississinewa Moraine Huron-Erie ice was probably not generating drift from the underlying sandstone.

Another local bedrock unit was analyzed to determine what effect it might have on the Huron-Erie Lobe till. Lower Mississippian Coldwater Shale subcrops east of the Mississinewa Moraine, but is not known to be exposed anywhere in the study area. Three samples of the shale were obtained from the well-cuttings library of the Michigan State University Department of Geology. The oil well from which the cuttings were derived is located in W½SE¼SE¼ sec. 22, T. 2 S., R. 3 E. (site 235, permit number 11655). The Coldwater Shale is 617 feet (188.1 m) thick here, and X-ray samples 235A, B, and C were taken 27 feet (8.2 m), 117 feet (35.7 m), and 457 feet (139.3 m) from the top of the shale on the assumption that because of the regional structural pattern sample 235A would be somewhat similar to shale subcropping just to the east of the moraine, that sample 235B might be representative of shale subcropping somewhat farther east, and that sample 235C is similar to shale subcropping about 15 miles (24 km) to the east (approximately beneath Ann Arbor). Clays from these samples produced 7Å/10Å ratios of 2.16 (235A), 1.00 (235B), and 1.00 (235C).[42] The variation between clay samples from bedrock (7Å/10Å ratios of 1.00 or more) and surficial till (7Å/10Å ratios of 0.90 or less) may indicate that in this area Huron-Erie ice was not in contact with Coldwater Shale during deposition of the surficial till of the Mississinewa Moraine. This would be possible if a subsurface drift sheet which predates surficial tills protected the bedrock from ice of the last advance. Leverett and Taylor (1915, p. 199), Russell and Leverett (1908, pp. 4-5), and Kunkle (1960, p. 29) discussed a hard till found at depth in Washtenaw

[42]Chung (1973) determined that 7Å/10Å ratios decreased with depth in Coldwater Shale in the central part of Michigan also.

County which they considered to be pre-Wisconsin(an) or early Wisconsin(an) in age. The presence of wood, peat, and apparent oxidized till in the subsurface in and near the study area, as discussed earlier in this chapter, also suggests the presence of an older drift sheet in the subsurface. Thus, the possibility exists that the characteristic 7Å/10Å ratio of surficial Huron-Erie drift in this part of the Mississinewa Moraine may be due to one or both of the following conditions:

1. An older subsurface drift sheet may have protected the Coldwater Shale and Mississippian sandstone from ice of the last advance preventing incorporation into the till and a consequent increase in 7Å/10Å ratio.
2. The incorporation of a portion of this subsurface drift sheet may have caused surficial tills in the moraine to have 7Å/10Å ratios somewhat lower than those on the surface of the Fort Wayne and Outer Defiance Moraines.[43]

Till Color

The color of dry, oxidized, unleached till from the Mississinewa Moraine is very uniform, with twenty of the twenty-three samples investigated having colors of 10YR 7/3 or 10YR 7/4 (very pale brown). Moist colors are also very similar, with eighteen of the samples 10YR 5/4 (yellowish brown) or 10YR 4/4 (dark yellowish brown) (Appendix C).

Till Texture

On the whole, unleached surficial tills associated with the Mississinewa Moraine are medium-textured (Figure 11). Mean texture of all till samples in and proximal to the Mississinewa is loam (sand 46%,

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[43]Assuming this subsurface drift has a low 7Å/10Å ratio.

silt 30%, clay 24%). Mean texture of five samples from sites located proximal to the moraine is slightly coarser (sandy clay loam, sand 48%, silt 27%, clay 25%) than samples from seventeen sites within the moraine (loam, sand 45%, silt 30%, clay 25%). It should be noted these are mean figures and that individual samples may differ considerably from these values.

Pebble Lithology

The lithology of 100 pebbles collected from Huron-Erie till at each of the four sites where till fabric was determined within the Mississinewa Moraine is quite similar to that reported in previous studies by Anderson (1957) and Kneller (1964). Figure 24 shows that the greatest variation in results of the three studies was in the carbonate fraction: Anderson's data indicate a value of 64.3%, and data from this investigation indicate a value of 52.2%, or a difference of 12.1%. With this exception the variation between all other lithologic fractions was considerably less than 10%.[44]

Shale exists in moderate amounts in the till and is most commonly dark brown in color. This contrasts markedly with samples of Coldwater Shale from well cuttings, which tend to be light to medium gray.

Only rarely are fragments of coal found, and these are generally too small and fragile to excavate and measure. This observation agrees with Kneller's (1964) low value of 0.2% coal (Figure 24) for Huron-Erie drift.[45]

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[44]Kneller's data (1964, Table 2) does not include 0.4% in his "others" and "armored mud balls and till clods" fractions.

[45]Morse (1970, p. 19) stated that coal is an "indicator lithology" for Saginaw drift. Both Kneller's work and this study show that coal is also present in Huron-Erie drift but is less common than in Saginaw drift.

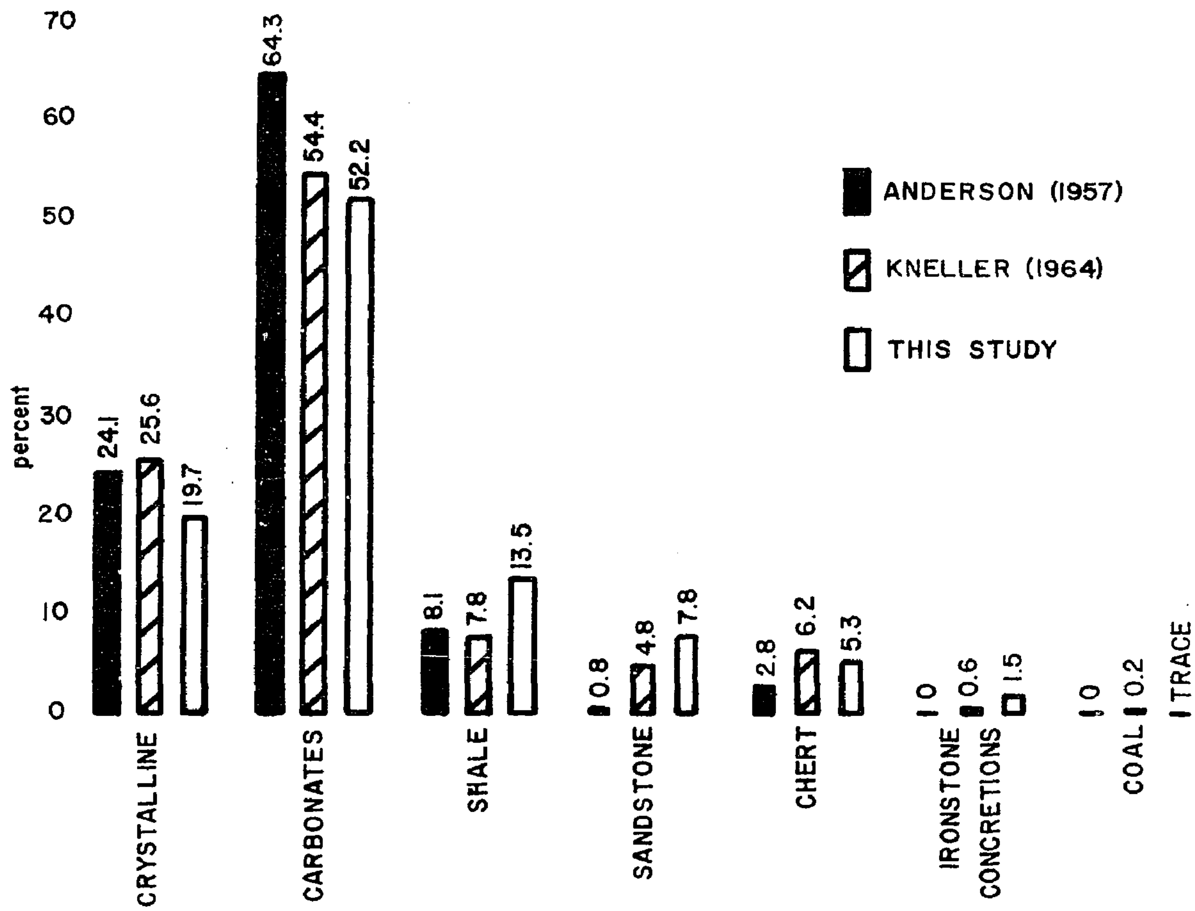

Figure 24. Pebble Lithology of Huron-Erie Drift in and near Study Area

Boulder Lithology

Lithologic classification of 632 boulders at the surface within the Mississinewa Moraine produces results strikingly different from lithologic data on pebbles from till in the same area (Figure 24 and Table 6). Although crystalline lithologies make up less than one-fifth of the pebbles identified (19.7%), they represent well over 99% of all boulders observed on the moraine. Russell and Leverett (1908, p. 12) and Sherzer (1917, p. 18) note that most surficial boulders in the Huron-Erie Lobe portions of southeastern Michigan are crystalline. Red jasper conglomerate and tillite(?) boulders make up less than 2% of the total (see discussion on p. 59).

Table 6. Lithology of Surficial Boulders on Huron-Erie Drift

	Total	Total Crystalline	Crystalline [Excluding Tillite(?) & R.J.C.]	Tillite(?)	Red Jasper Conglomerate	Carbonate	Sandstone
Number	632	630	618	10	2	2	-
Percent	100.0	99.7	97.8	1.6	0.3	0.3	-

Boulder Distribution

The only major concentration of boulders in the Mississinewa Moraine is south of Mill Creek (Figure 13). It is a linear tract of boulders distal to the Sharon Short Hills and trends northeast-southwest across the northern half of T. 3 S., R. 3 E. In places this line of boulders appears to be associated with meltwater channels that extend west on the flank of the moraine to the Grass Lake Plain. For the most part, the remaining boulders in the moraine are widely scattered.

Till Fabric

Till fabrics determined at three sites within Huron-Erie Lobe till show well-developed orientations (sites 79, 101-- NE¼NW¼SE¼ sec. 29, T. 1 S., R. 4 E., and 104-- SW¼NE¼SW¼ sec. 33, T. 2 S., R. 3 E.), and a fourth (97) has an irregular, multimodal pattern (Figure 14). The primary modes of fabrics 101 and 104 are oriented normal to the Mississinewa Moraine and associated areas of the Interlobate Morainic Tract. Preferred dips at these sites are to the east and southeast and may indicate flow from that quadrant.

Site 79 (NW¼SW¼SE¼ sec. 12, T. 1 S., R. 3 E.) is located in a road cut near the crest of a linear feature trending N. 60° E. that is probably associated with final ice disintegration. In the exposure approximately 5 feet (1.5 m) of till overlies at least 4 feet (1.2 m) of sand. Although the well-developed till-fabric orientation with a preferred southeast dip suggests that the till may be basal, the form and stratigraphy of the feature indicate the probability that it is flow till.

The fabric at site 97 (NW¼SW¼NW¼ sec. 27, T. 1 N., R. 4 E.), from a till exposure in a small ridge with ice-contact slopes trending N. 55° E., is rather unusual. The till contains loamy sand and sandy loam lenses, and its fabric has similarities to the fabric at site 78 of the Saginaw Lobe, which is interpreted to be a flow till. Like the Saginaw Lobe site, the long axis of almost every clast in the fabric has a southerly dip, yet there is also a pronounced transverse mode directed to the southwest. Although the primary mode is nearly normal to nearby ice-contact slopes, it is also nearly parallel to fabrics 101 and 104 of the Huron-Erie Lobe, which are interpreted to be representative of basal till. Thus, the evidence is contradictory whether the sediment at the site is basal or flow till and whether the fabric is due directly to glacial deposition or the downslope movement of material induced by gravity.

The absence of large exposures in the Huron-Erie portion of the Interlobate Morainic Tract or in the Mississinewa Moraine limits the possibility of recognizing the extent of flow till in the area (see discussion on pp. 78-80). Flow till is positively recognized at only three sites (Figure 22). From the limited evidence available, it appears that it may not be as common as in the Kalamazoo Moraine. Kneller (1964,

p. 30) concluded that much of the surficial till overlying sand and gravel in T. 2 S., R. 3 E. and T. 3 S., T. 3 E. is either flow till or ablation till. However, until more data are available, the characteristics, extent, and distribution of flow till in the Mississinewa Moraine and associated areas of the Interlobate Morainic Tract will not be known.

Lacustrine Sediments

Deposits of almost stone-free silt and clay which are ordinarily of limited extent are scattered throughout the Huron-Erie side of the Interlobate Morainic Tract (Figure 23). They are located at, or within 2 miles (3.2 km) of, the surficial Saginaw/Huron-Erie drift contact, and most exposures of this clay and silt have maximum dimensions of less than 100 yards (m). On soil maps the deposits are most often associated with Kibbie, Sisson, or Colwood soils. The maximum observed thickness was 8 feet (2.4 m) at site 95(NW¼NW¼NE¼ sec. 32, T. 1 N., R. 4 E.). However, the deposit could be thicker because an unknown amount also exists below the lower limit of the exposure. At every location where visible, the subjacent material is sand and gravel. In some places the deposits are overlain by a thin layer, generally 3 feet (0.9 m) or less, of sand.

Hand-texturing of numerous samples in the field and laboratory analysis of sample 202 all indicated fine textures (silty clay loam, sand 4.3%, silt 61.1%, clay 34.6%). Pebbles are very rare in these sediments, and no clasts larger than about 2 inches (5.1 cm) were observed. Fine texture, the absence of large numbers of pebbles, and an occasional observation of bedding indicate a lacustrine origin. If this interpretation is correct, the pebbles may have been deposited from the melting of floating drift-laden ice in a lacustrine environment.

A sample of lacustrine sediment from site 202 (SE¼NE¼NE¼ sec. 7, T. 1 S., R. 4 E.), with an altitude of 935 feet (285.0 m) and located 1.5 miles (2.4 km) east of the surficial Saginaw/Huron-Erie drift contact, yielded a 7Å/10Å ratio of 0.64, well within the range of values associated with Huron-Erie drift (Figures 10 and 23). This may indicate that the watershed of the water body in which the sediments were deposited was of limited extent and probably did not receive sediment-laden meltwater from nearby Saginaw Lobe ice.

At site 196 (SE¼SE¼NW¼ sec. 29, T. 1 N., R. 4 E.) (altitude 915 feet or 278.9 m) an exposure of massive silts and clays, at least 3.5 feet (1.1 m) thick and 50 feet (15.2 m) long, is juxtaposed with a 10-foot-wide (3.0 m) body of fine sand which is in turn flanked by a 15-foot-wide (4.5 m) body of sand and gravel (Figure 25). Contacts between the units are sharp, rather than gradational, and almost vertical, with a lack of distinct bedding in the sand and gravel. Considerable deformation was also observed about 100 yards (m) to the southeast at site 200 (SW¼SW¼NE¼ sec. 29, T. 1 N., R. 4 E.) (altitude 925 feet or 281.9 m). Here massive lacustrine sediment is in contact with a body of fine sand. Where visible, beds in the sand have dips varying from horizontal to 80°, and an extension of the main body of lacustrine sediment protrudes about 3 feet (0.9 m) down into the sand as if faulted into position. On the basis of this evidence it seems likely the situation at site 196 is due to postdepositional faulting and subsidence of the sediments of a small ice-contact lake.[46] An ice-contact origin is also probable at site 200 because a number of nearby depressions appear to mark the former

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[46] The sharp, vertical contacts between sand and gravel, fine sand, and lacustrine sediments give little support to an interpretation of the deposit representing a horizontal facies change.

location of ice blocks. Similar relationships are visible in several other exposures in the area.

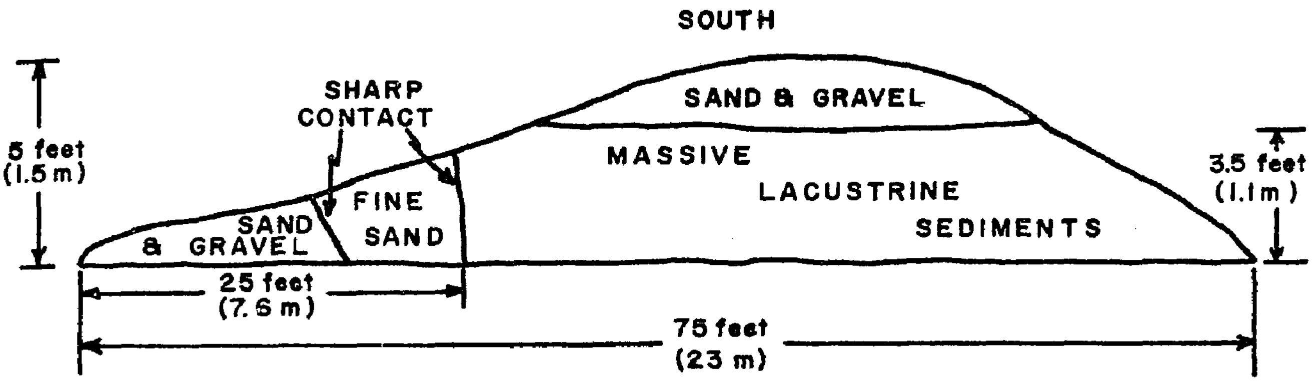

Figure 25. Section in a Deposit of Lacustrine Sediments (Site 196)

In 1921, when Leverett investigated the formations of the Stockbridge quadrangle, much of the land was in private ownership and under cultivation. He was able to observe (notebook 274, pp. 69-70) "clay" between Halfmoon and North Lakes associated with the tops and flanks of hills and also in intervening depressions. Elevations of the bottoms of the depressions are from 920 to 930 feet (280.4 to 283.5 m). He noted a knoll 30 feet (9.1 m) high (crest altitude 960 feet or 292.6 m) in the CE½ sec. 12, T. 1 S., R. 3 E. that was covered with "clay" and a similar knoll in NE¼ sec. 13. One mile (1.6 km) to the east, near the south shore of Halfmoon Lake, a similar situation was discovered during the course of this investigation (site 202-- SE¼NE¼NE¼ sec. 7, T. 1 S., R. 4 E.). A lengthy road cut on the flanks of a hill reveals 6 feet (1.8 m) of pebble-free silty clay loam (sand 4.3%, silt 61.1%, clay 34.6%) with the material extending below road grade. Near the crest of the hill the top of the deposit of fine sediment is at an altitude of about 940 feet (286.5 m), and at the base of the hill at about 910 feet (277.4 m). Although occasional fine sand partings are visible in the lacustrine sediments, they are generally massive.

In the Huron-Erie portion of the Interlobate Morainic Tract nine deposits of lacustrine sediments were studied during field work for this investigation. Of these nine sites five (95-- N¼C sec. 32, T. 1 N., R. 4 E., 176--CNE¼NW¼ sec. 14, T. 1 S., R. 3 E., 180-- N½NW¼SE¼ sec. 14, T. 1 S., R. 3 E., 184--CNW¼ sec. 12, T. 1 S., R. 3 E., and 202) were situated above 930 feet (283.5 m) and so cannot be directly related to Leverett's hypothesized ponding of the Grand and Portage River lowlands (see pp. 84-85).[47] The 7Å/10Å ratio at site 202 seems to indicate that the watersheds for these small ice-contact lakes were limited in area. Unfortunately, no 7Å/10Å ratios of lacustrine sediments are available for any sites at, or below, 930 feet (283.5 m). Therefore, it is not possible at this time to suggest if any mixing of sediments and meltwater from the Saginaw and Huron-Erie Lobes took place near the drift contact in the hypothesized ponded waters-- if indeed the ponding extended that far east.

Chelsea Till-- Characteristics and Type Section

The till exposed near Chelsea (hereafter informally referred to as the Chelsea till) is thought to be representative of the surficial till of the Huron-Erie Lobe in the Mississinewa Moraine and associated areas of the Interlobate Morainic Tract between Norvell and Pinckney.

Chelsea till is often overlain by up to 5 feet (1.5 m) of outwash sediments. The type section is in a road cut 3 miles (4.8 km) northeast of Chelsea on the proximal side of the Huron-Erie portion of the Interlobate Morainic Tract (site 101-- NE¼NW¼SE¼ sec. 29, T. 1 S., R. 4 E.).

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[47]Sites 180 and 184 are at altitudes of between 960 and 970 feet (292.6 and 295.7 m).

Here a thin layer of sand overlies 8 feet (2.5 m) of sediment interpreted to be lodgement till. A flow till facies of Chelsea till is also present in the area. Chelsea till has only been recognized at or very near the surface. When oxidized and unleached, it is, according to the Munsell notation, a very pale brown (dry) or yellowish brown (moist). Texture of the till is rather variable but is commonly loam. The maximum observed thickness was 14 feet (4.3 m). Fabrics in Chelsea lodgement till indicate ice flow from the east and southeast. Pebble lithology of Chelsea till resembles that of Brill Lake till of the Saginaw Lobe (see description of Brill Lake till in this chapter), although the crystalline fraction is somewhat less and the shale content somewhat more in the Chelsea till. X-ray diffraction of clays from the till matrix, and also of associated lacustrine clays, yields a distinctive 7Å/10Å peak height ratio of 0.90 or less, which serves to identify its Huron-Erie Lobe provenance. More detailed information on Chelsea till and its characteristics in the study area is given in this chapter and Table 10.

Comparison of Brill Lake and Chelsea Tills

The color and boulder lithology of the Brill Lake and Chelsea tills are so similar it is not possible to identify the lobe provenance of till samples on the basis of these characteristics. Although Brill Lake till samples are often somewhat coarser than Chelsea till samples, it does not appear feasible positively to identify all, or even most, till samples on the basis of texture. A similar situation may hold if attempts are made to identify individual till samples on the basis of pebble lithology.

The primary modes of fabrics determined in Brill Lake till are not ordinarily well developed, and clasts tend to be horizontal or have a predominant down-glacier dip. This is most likely the result of down-slope movement as flow till and much of the Brill Lake till is believed to be flow till. Some till fabrics from deposits of Chelsea till have similar characteristics and may also represent flow till. However, other fabrics determined in Chelsea till have well-developed primary modes with a predominant up-glacier dip and are thought to represent lodgement till. Lodgement till is probably more common in Chelsea than in Brill Lake till.

All thirteen samples of Brill Lake till and two samples of associated lacustrine sediment that were X-rayed had 7Å/10Å ratios of 0.91 or more. Of the twenty-two samples of Chelsea till and one sample of associated lacustrine sediment that were analyzed, twenty-two had 7Å/10Å ratios of 0.90 or less. Thus, the clay mineralogies of the Brill Lake and Chelsea tills are distinctively different and provide a basis for identification in areas where drift thickness is at least 20 feet (6.1 m) or so. On the basis of the clay mineralogy a line may be drawn connecting Leverett, Riley, Stofer, and Russell Hills, the east end of Patterson Lake, and Pinckney, which is interpreted to represent the surfical contact between Saginaw and Huron-Erie drift. Topographic information is given in Chapter 4 which also indicates that the interlobate contact is located along this line.

Drift Associated with Grass Lake Plain and Related Areas

Soils as an Indicator of Parent Material

A 1930 soil survey by Veatch, Trull, and Porter resulted in a map which shows most of the Grass Lake Plain as having Fox and Plainfield soils. Comparison of more recent soil surveys in Washtenaw and Livingston Counties with surveys completed in these counties at about the same time as the 1930 Jackson survey indicates that Boyer, Oshtemo, and Spinks soils are also likely to be included in the old Fox mapping unit. On this basis it may be reasonable to conclude that sand and gravel is very common on the Grass Lake Plain, as all the soil series mentioned above have outwash as parent materials (Figure 8). The older Jackson County survey indicates that Hillsdale soils, interpreted to have till parent materials, exist primarily south of Wolf Lake. The limited work completed on a modern survey indicates that Riddles soils, with till parent material, are also present in the area. Rifle peat is the most common organic soil on the Grass Lake Plain and is found in undrained depressions and along drainage lines.

Clay Mineralogy

Till is not common on the surface of the Grass Lake Plain north of Center Lake, but it is exposed over considerable areas in the south. Twelve till samples from the plain were X-rayed; seven have 7Å/10Å ratios greater than 0.91, and five have ratios less than 0.90. Of the samples with a ratio more than 0.91 one is from north of Wolf Lake (Figure 26), two are from the vicinity of Willow Creek, and two are from the crest of the Blue Ridge Esker. One of the samples with a 7Å/10Å ratio less than 0.90 is from a site north of Wolf Lake, two are from the vicinity of Willow Creek, and four are from locations on either side of the Blue Ridge Esker.

Two samples, number 132 (SW¼NW¼SW¼ sec. 12, T. 3 S., R. 1 E.) and 213 (SW¼NW¼SE¼ sec. 14, T. 3 S., R. 1 E.), are from tills located north of Wolf Lake and produce 7Å/10Å ratios of 1.17 and 0.88, respectively. This indicates that the drift contact is situated just north of Wolf Lake somewhere between these two samples. Topographic evidence,

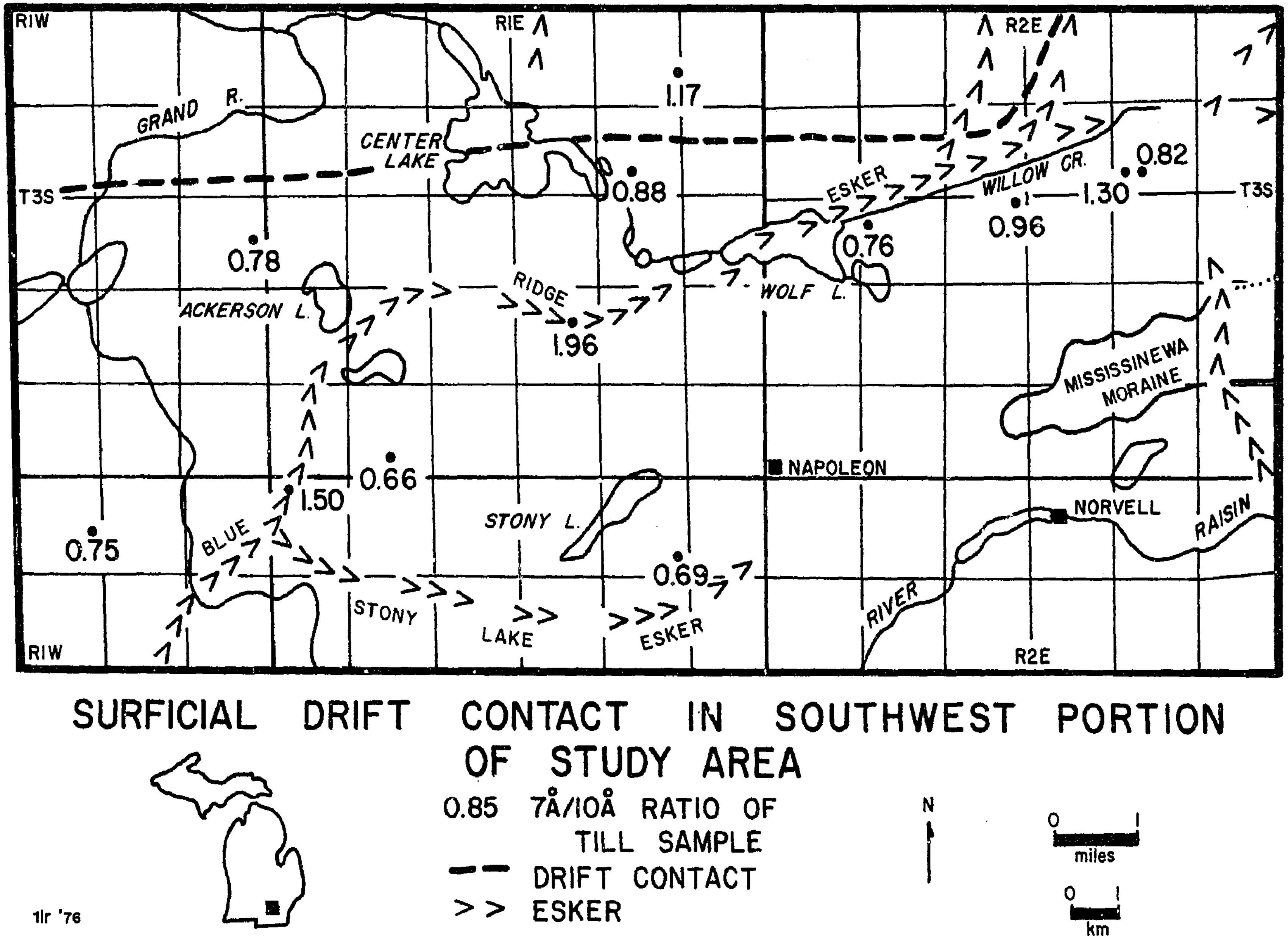

Figure 26. Surficial Drift Contact in Southwest Portion of Study Area

consisting of the slopes of the outwash surfaces associated with the Kalamazoo and Mississinewa Moraines, support this interpretation.

Four till samples, numbers 218 (NE¼NE¼SE¼ sec. 3, T. 4 S., R. 1 W.), 223 (SE¼SE¼NE¼ sec. 24, T. 3 S., R. 1 W.), 217 (NW¼SW¼SE¼ sec. 32, T. 3 S., R. 1 E.), and 133 (NE¼SE¼SE¼ sec. 2, T. 4 S., R. 1 E.), obtained from exposures near the Blue Ridge Esker, all produce 7Å/10Å ratios indicating Huron-Erie provenance (0.75, 0.78, 0.66, and 0.69, respectively). This seems to indicate that the esker was deposited in Huron-Erie ice but close to the interlobate contact. However, two till samples from the crest of the esker, 219 (SW¼SE¼NE¼ sec. 27, T. 3 S., R. 1 E.) and 220 (SE¼NE¼NW¼ sec. 6, T. 4 S., R. 1 E.), yield ratios of 1.96 and 1.50, respectively. These very high ratios appear to indicate Saginaw Lobe provenance. Thus, four till samples from sites north, northwest, west, and east of the esker indicate Huron-Erie provenance, and two till samples from the crest of the esker seem to indicate Saginaw provenance. It is not possible at this time to explain this seemingly anomalous situation. Any explanation must consider the fact that two till samples from the crest of the esker have very high 7Å/10Å ratios, suggesting Saginaw Lobe provenance, and four samples of till from either side of the esker have ratios of less than 0.90, indicating Huron-Erie provenance.

In an attempt to determine the lobe provenance of the finer esker sediments clay was removed from five glaciofluvial samples collected at three sites along the trend of the esker (site 212-- NE¼SE¼SW¼ sec. 17, T. 3 S., R. 2 E., site 216A-- NE¼SE¼NE¼ sec. 28, T. 3 S., R. 1 E., and site 220-- SE¼NE¼NW¼ sec. 6, T. 4 S., R. 1 E.). X-ray diffraction data from these samples show 7Å/10Å ratios of 1.22, 0.96, 1.86, 2.50, and 1.83 (Figure 9). These ratios appear to indicate a Saginaw provenance for the clays in the glaciofluvial sediments. However, the ratios are so high it seems more likely that considerable kaolinite from sandstone boulders in the esker is dispersed in the sediments so as to preclude certainty about lobe provenance of the sediments on the basis of clay mineralogy.

X-ray diffraction data were obtained from four samples of till exposed approximately 3 miles (4.8 km) north of Norvell (Figure 26). Peak height ratios indicate that two of these samples, 211 (NE¼SW¼NW¼ sec. 20, T. 3 S., R. 2 E.) and 226A (NE¼SE¼SW¼ sec. 14, T. 3 S., R. 2 E.) (0.76 and 0.82, respectively), are associated with deposition by the Huron-Erie Lobe. The remaining samples 231 (NE¼NE¼NE¼ sec. 21, T. 3 S., R. 2 E.) and 226 (NW¼SE¼SW¼ sec. 14, T. 3 S., R. 2 E.) yield ratios of 0.96 and 1.30, respectively. These higher ratios seem to imply a Saginaw Lobe provenance. However, two water-well records on file at the Geological Survey of Michigan and interviews conducted by Frank Leverett (notebook 166, p. 70) indicate that sandstone is within 5 feet (1.5 m) of the surface nearby (Figure 7). The proximity to Huron-Erie samples 211 and 226A and the slope of the outwash surfaces suggests that samples 226 and 231 may actually be Huron-Erie tills that have an unusually high kaolinite content because of the influence of local bedrock. Samples 226 and 231 seem to be the only till analyzed in which there is strong evidence of local bedrock altering the 7Å/10Å ratio of Huron-Erie Lobe till to resemble that of Saginaw Lobe till.[48]

The northernmost till sample on the Grass Lake Plain has a 7Å/10Å ratio indicative of a Saginaw Lobe origin, and most of the other tills on the plain have ratios suggesting Huron-Erie Lobe provenance. Because of

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[48]Such evidence is lacking for the till samples from the crest of the Blue Ridge Esker.

the scarcity of till on portions of the plain and the proximity of bedrock to the surface in some places, it does not seem possible to trace the drift contact across the entire Grass Lake Plain on the basis of the clay mineralogy of tills. However, on the basis of geomorphology it is probable that the drift contact in T. 3 S., R. 1 E., is located between sites 132 and 213 (Figure 26).

Till Color

Eight of the twelve till samples from the Grass Lake Plain area have Munsell colors of 10YR 7/3 or 10YR 7/4 (very pale brown) when dry, and ten have colors of 10YR 5/4 (yellowish brown) and 10YR 4/4 (dark yellowish brown) when moist (Appendix C). As in the nearby moraines it is not possible on the Grass Lake Plain to differentiate Saginaw and Huron-Erie Lobe tills on the basis of color.

Till Texture

Figure 27 indicates that most of the till samples from the Grass Lake Plain have textures similar to those of the Huron-Erie Lobe in the Mississinewa Moraine (Figure 11). This is in general agreement with peak height ratios, which also indicate that most of the samples are of Huron-Erie provenance. Nevertheless, it is not possible positively to differentiate lobe provenance of surficial tills on the Grass Lake Plain on this basis.

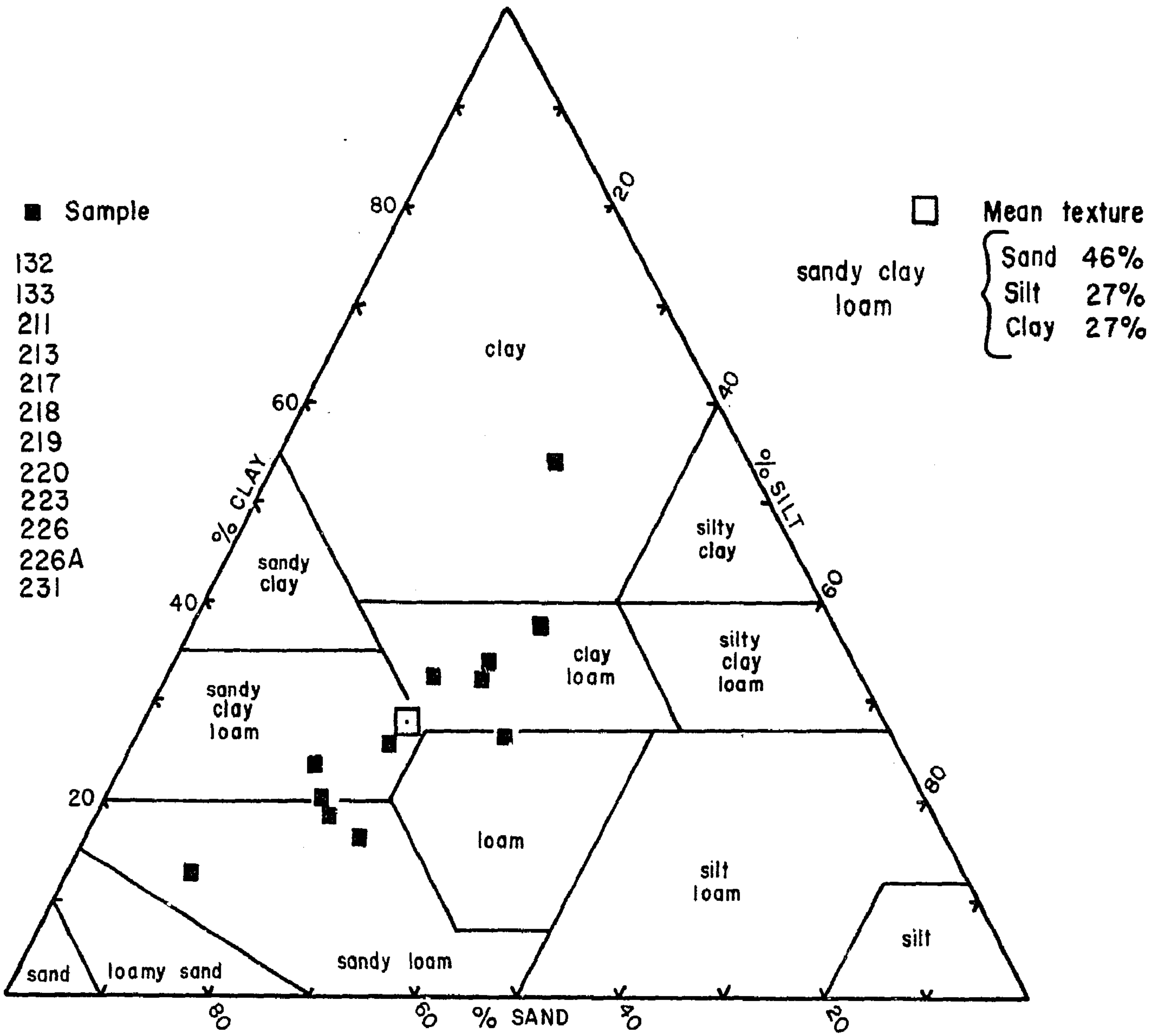

Figure 27. Textures of Tills on and near Grass Lake Plain

Boulder Distribution

Boulders exist in moderate numbers in T. 4 S., R. 1 E., and in the southern portion of T. 3 S., R. 1 E. (Figure 13). No obvious pattern to the distribution exists except that boulders are almost always associated with areas underlain by till. In his field notes Leverett (notebook 166, p. 69 and notebook 299, p. 38) reported a "boulder strip" south of Wolf Creek[49] trending eastward in secs. 13, 14, 15, 16, 20, 22, and 23, T. 3 S., R. 2 E. Although a careful search was made both in the field and on air photos, the presence of the concentration cannot be completely confirmed because boulders were observed in secs. 14, 15, and 16 only.

Absence of Striations

Sandstone bedrock is very near the surface at Napoleon, and although Leverett (notebook 32, p. 59) reported that the surface of the bedrock in the local quarries was smooth, as if glaciated, he did not observe any striations. During this investigation a search was made for striations in two quarries on the east side of Napoleon (SE¼SE¼SW¼ sec 31, T. 3 S., R. 2 E. and site 230-- NE¼NE¼NW¼ sec. 6, T. 4 S., R. 2 E.), but none were found.

Till on Crests of Eskers

At three sites (219-- SW¼SE¼NE¼ sec. 27, T. 3 S., R. 1 E.;220-- SE¼NE¼NW¼ sec. 6, T. 4 S., R. 1 E.; and 221-- SE¼SW¼NW¼ sec. 6, T. 4 S., R. 1 E.) on the Blue Ridge Esker and at one (214-- NW¼NE¼SW¼ sec. 11, T. 4 S., R. 1 E.) on the Stony Lake Esker, till was observed on the esker crests. The till is generally massive and spalls off in sheets when struck, but not as readily as in the Brill Lake till type section. The

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[49]Labeled "Willow Creek" on the Manchester quadrangle.

long axis of many of the pebbles is subhorizontal, but few sandy horizons are visible. Structures that might be associated with ice shove are generally lacking in both the till and subjacent sand and gravel. Flint (1928, p. 411) has stated that till on the crests of eskers is not uncommon. Such till is generally thought to be from the ice overlying the eskers. Maximum observed thickness of the till was 7 feet (2.1 m) at site 220.

Rock-Stratigraphic Units

Defining informal rock-stratigraphic units on the Grass Lake Plain is considerably more difficult than in the nearby moraines because exposures of till north of Wolf Lake are limited in number and because south of Wolf Lake the proximity of sandstone to the surface appears to influence the clay mineralogy of some till deposits. However, it does seem possible to identify the lobe provenance of till on the plain with some degree of confidence by using analyses of clay mineralogy and landforms.

Surficial till associated with the Saginaw Lobe exists only in the northern portion of the Grass Lake Plain and is hereafter informally referred to as the Grass Lake till-Saginaw Lobe. Although slightly older, it is very similar to the Brill Lake till. The surficial till of the Huron-Erie Lobe is located only in the southern portion of the plain and is hereafter referred to informally as the Grass Lake till-Huron-Erie Lobe. It is slightly older and has somewhat more variable characteristics than the Chelsea till, although these two tills are basically very similar.

Chapter 4

GLACIAL LANDFORMS

Introduction

The study area may be divided into four morphologic sections: (1) Kalamazoo Moraine, (2) Mississinewa Moraine, (3) Interlobate Morainic Tract, and (4) Grass Lake Plain area (Figure 2). Each of these sections and their distinctive surficial characteristics are described in this chapter, and a genesis suggested for many of the individual landform types.

In his report accompanying the Glacial Map of Canada, Prest (1968, p. 8) used the term "kame moraine" to

> signify an ice-marginal complex including many kames, and a predominance of glaciofluvial deposits as compared to till. The term is applicable to some end moraines and many interlobate moraines. . . . Such moraines cover large areas and probably due to infilling of depressions by glaciofluvial deposits may not look like moraine on air photos.

Prest's definition is used in this dissertation and is applied to the portions of the Kalamazoo Moraine and Interlobate Morainic Tract in the study area.[1]

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[1]Flint (1971, p. 199) has defined a moraine as "an accumulation of drift deposited chiefly by direct glacial action, and possessing initial constructional form independent of the floor beneath it." It was shown in the previous chapter that the surficial sediments of the Kalamazoo Moraine consist largely of glaciofluvial sediments and flow till. Many declivities interpreted to be ice-contact slopes exist within the feature and appear to be associated with the deposition of drift in the presence of stagnant, not active, ice. Furthermore, the underlying bedrock has had a strong influence on the formation of the moraine. Thus, if Flint's definition is used, the linear feature trending northeast from Jackson to Leverett Hill cannot be considered a moraine at all. Similarly, Boulton (1972, p. 385) might consider the portion of the Kalamazoo Moraine under study to be an "inverted fluvio-lacustrine mold of an ice-cored moraine."

Relationship Between Bedrock Surface and the Kalamazoo Moraine

Although it is reasonable to conclude that climatic conditions and general regimen were major factors influencing the Saginaw Lobe, the exact postioning and configuration of this part of the Kalamazoo Moraine is believed to be closely associated with the nature of the underlying bedrock surface. It is evident from Figures 4 and 8 that the distal boundary of the moraine very nearly coincides with the trace of the 900-foot (274.3 m) bedrock-surface contour. North of this contour the bedrock surface is generally at an altitude of less than 900 feet (274.3 m), and to the south, on the sandstone tableland, it is at an altitude of 900 to 1,000 feet (274.3 to 304.8 m). Thus, the planimetric outline of the moraine is located above the lower altitude bedrock and trends along the northern edge of the buried sandstone tableland, and the Grass Lake Plain is situated above the higher altitude bedrock.

Kalamazoo Moraine

The segment of the Kalamazoo Moraine which trends northeast from Jackson to Leverett Hill is about 15 miles (24 km) long and 3 to 5 miles (4.8 to 8.0 km) wide. Local relief[2] in this Saginaw Lobe moraine increases from between 50 to 100 feet (15.2 to 30.5 m) in the west near Jackson to 230 feet (70.1 m) in the east near Leverett Hill (Figure 28). Maximum altitudes in the moraine also tend to increase eastward from about 1,020 (310.9 m) near Jackson to 1,164 feet (354.8 m) at Prospect Hill "B" (SW¼SE¼ and SE¼SW¼ sec. 1, T. 2 S., R. 2 E.) (Figure 29).

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[2] The amount of relief in a survey section as determined from topographic and hydrographic maps.

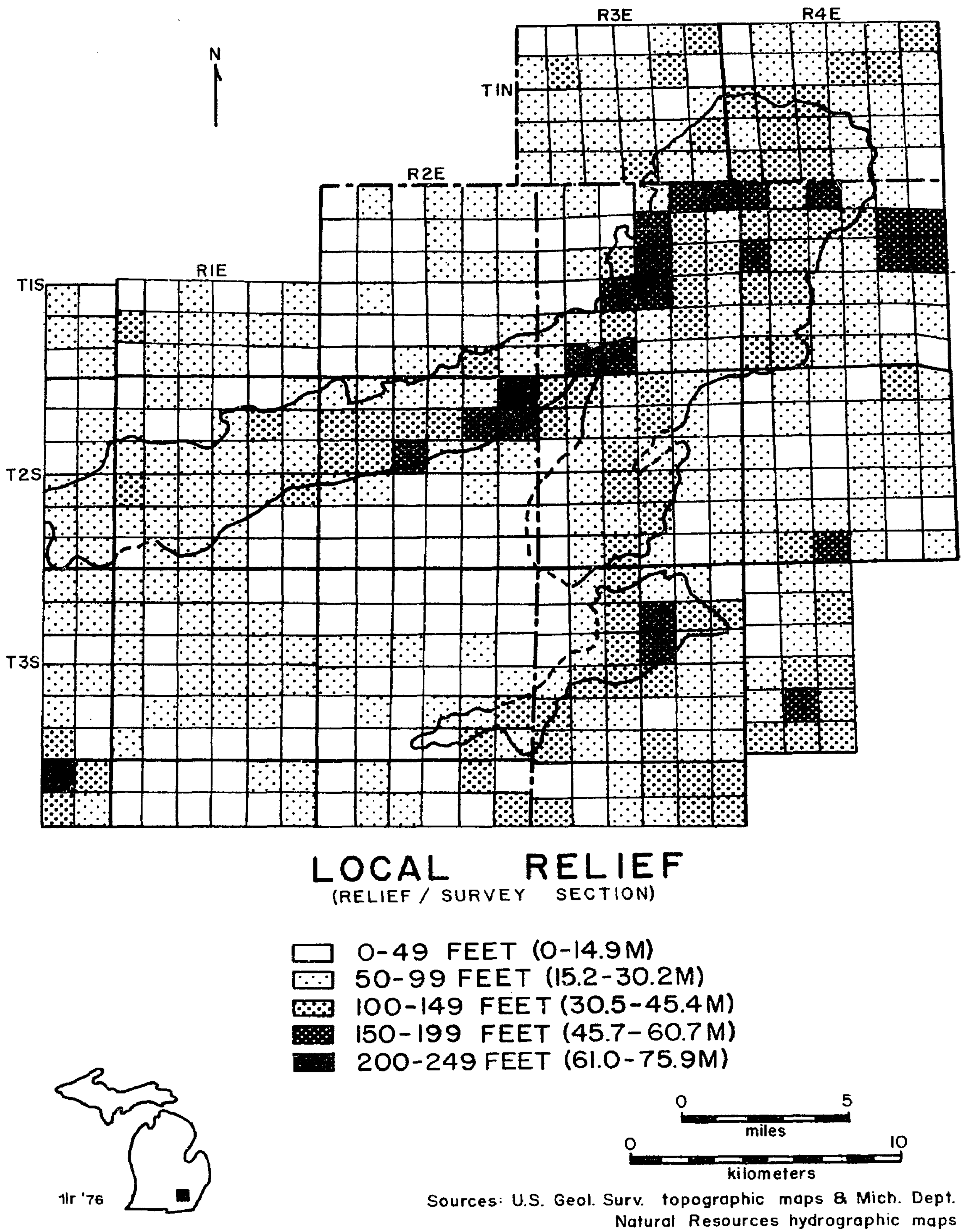

Figure 28. Local Relief

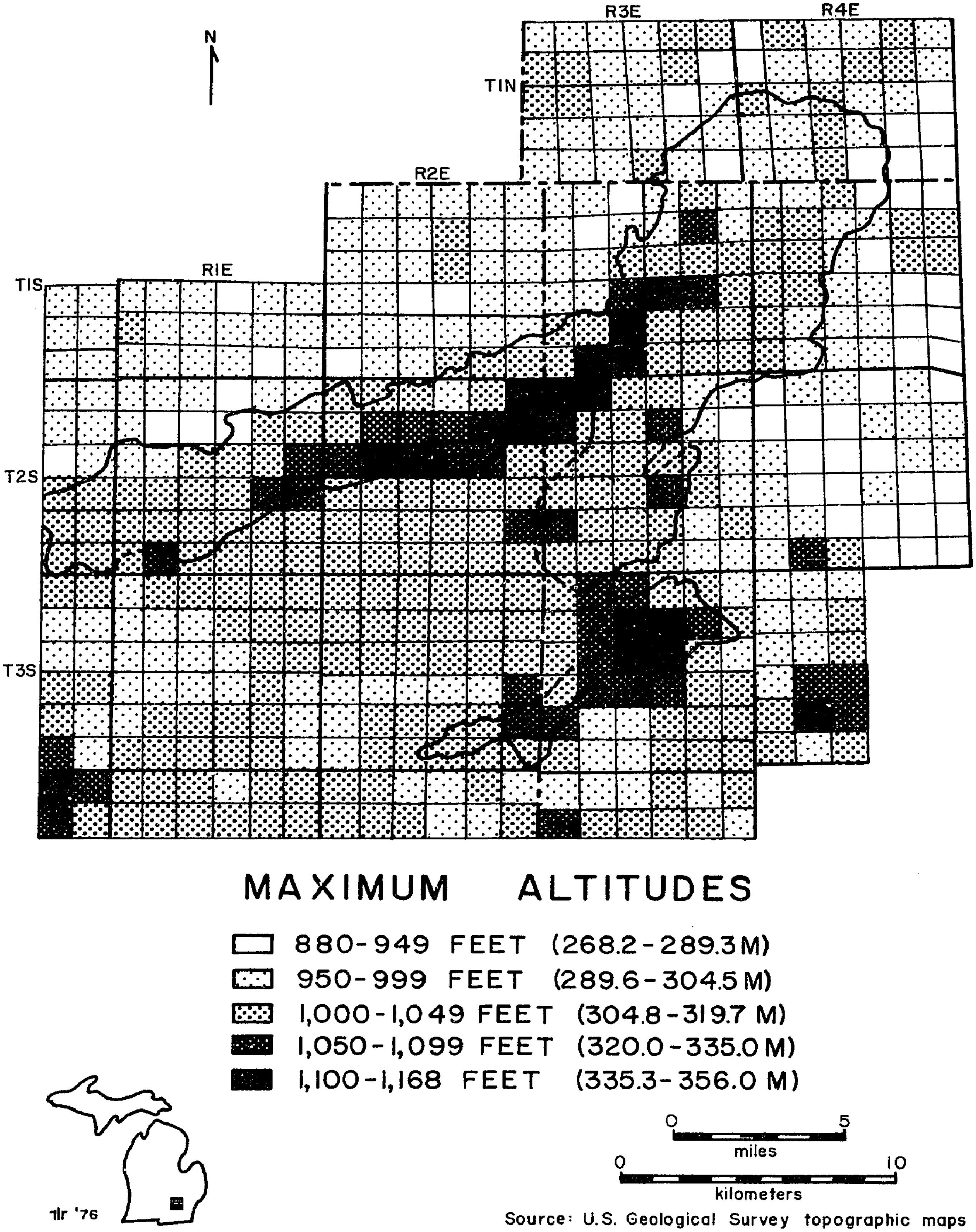

Figure 29. Maximum Altitudes

West of Brill Lake the surface of the moraine is rather irregular with little zonation of features apparent. East of the lake[3] the Kalamazoo Moraine may be divided into four latitudinal zones: (1) crest area, (2) zone of linear depressions and ridges, (3) zone of lakes and bogs, and (4) northern zone of linear depressions (Figure 30). A fifth zone, the Portage River lowland, is recognized north of the moraine. Each of the zones has a distinctive landform assemblage. In the following sections these zones will be described and an interpretation of their genesis presented.

Crest Area

More than 60 percent of the survey sections along the crest, or southern portion, of the Kalamazoo Moraine have altitudes of 1,050 feet (320.0 m) or more and are thus well above the level of the adjacent Grass Lake Plain, which has an altitude of 1,000 to 1,030 feet (304.8 to 313.9 m). West of Brill Lake the crest is lower than 1,050 feet (320.0 m), is not well defined, and is difficult to identify at some places because it tends to be only a few feet (m) higher than the general level of the Grass Lake Plain (Figure 29). East of Brill Lake the crest of the moraine is higher, and well defined, and an apron-like surface underlain by sand and gravel slopes to the south, merging with the Grass Lake Plain at an altitude of about 1,020 to 1,030 feet (310.9 to 313.9 m).[4] The crest is commonly bounded on the north by a very steep, east-west-trending, north-sloping declivity which may be well over 100 feet (30.5

[3]The longitude of Brill Lake also marks the separation of other characteristics of the moraine which will be considered later in this chapter.

[4]Steep-sided depressions may locally obscure this relationship.

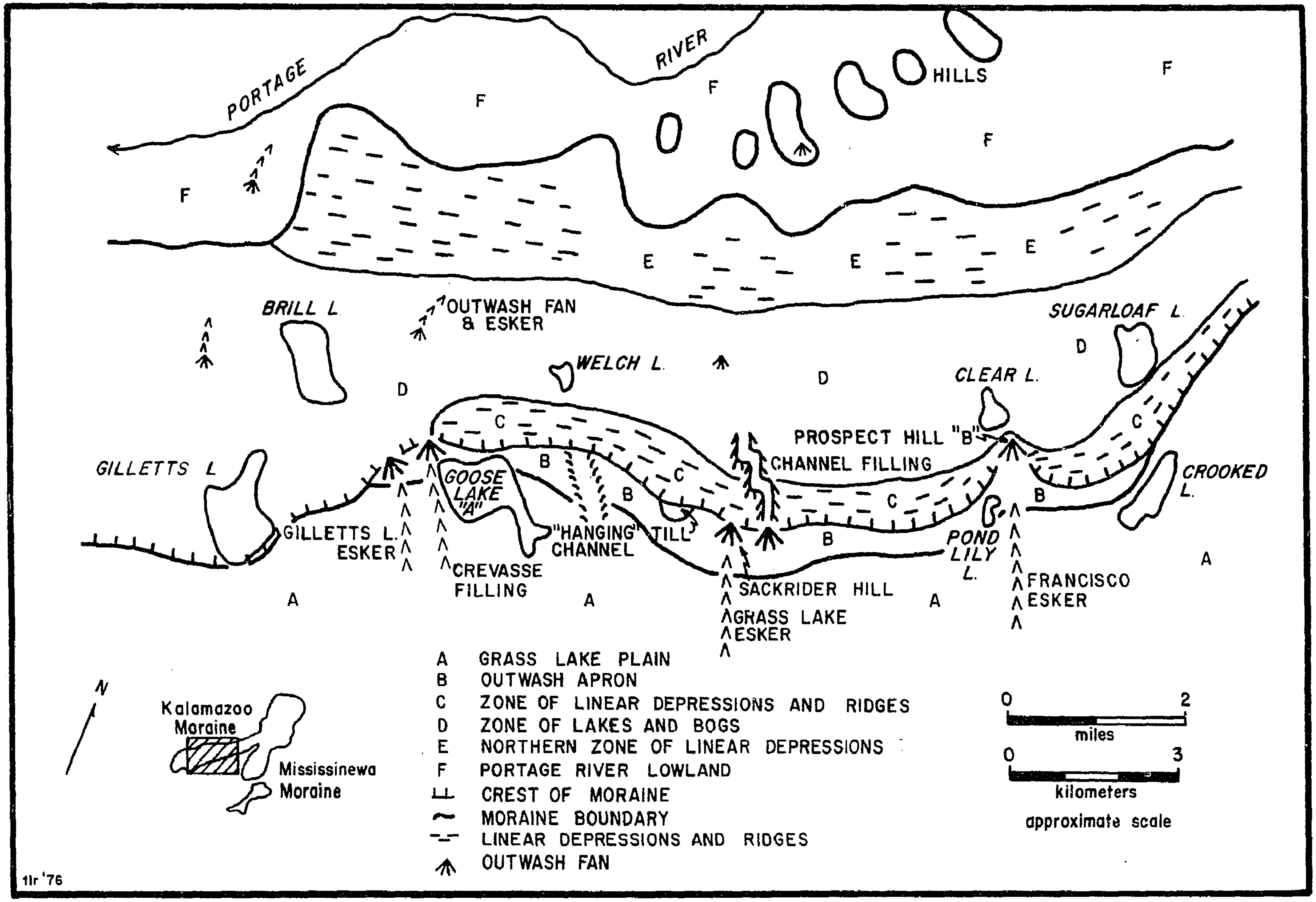

Figure 30. Diagram of a Portion of the Kalamazoo Moraine

m) high (Figures 31 and 32).

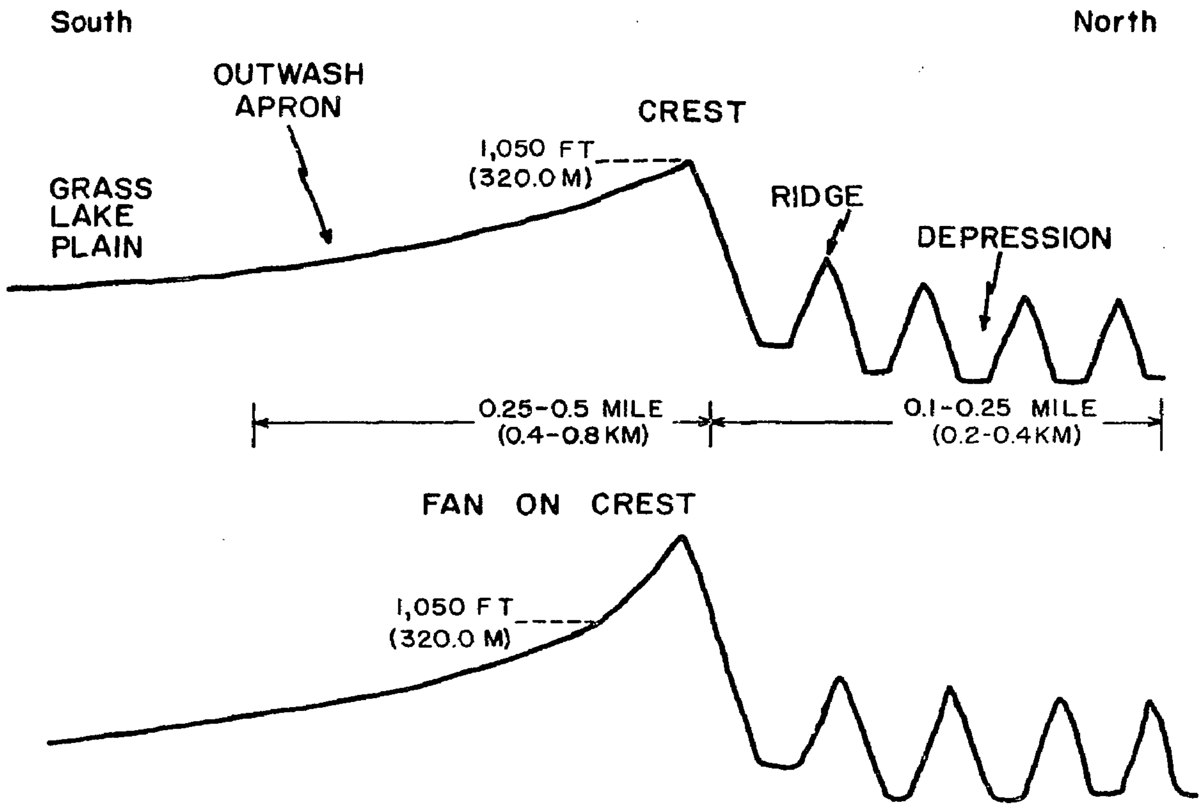

Figure 31. Schematic Profiles of Kalamazoo Moraine Crest Area, East of Brill Lake

On the basis of sediment, form, and regional relationships it seems clear that the sand-and-gravel surface which slopes south from the crest should be interpreted as an outwash apron formed by numerous streams depositing glaciofluvial materials as they flowed from the surface of the glacier.[5] The crest and outwash apron are not conspicuous west of Brill Lake, where bedrock altitudes are generally less than 900 feet (274.3 m), but are well developed east of Brill Lake where the substrate is at higher altitudes.

[5] See Thwaites (1963, p. 52) for a discussion on how the outwash apron associated with the moraine may be distinguished from the Grass Lake Plain.

The east-west-trending declivity which slopes to the north from the crest is ordinarily very steep and is inclined 27 to 29^{o} from the horizontal at both Sackrider Hill and Prospect Hill "B." It is interpreted to be an ice-contact slope which marks the approximate location where glaciofluvial sediments were deposited against ice of the Saginaw Lobe. Only a few very shallow gullies, probably due to man-induced erosion, are visible on the slope. Okko (1962, pp. 37-38) states that ice-contact slopes unmarked by fluvial erosion are evidence of deposition by subaerial streams because subglacial streams would likely erode channels on the proximal slopes. Thus, it appears that the outwash apron was deposited an an alluvial fan at the ice margin.

A number of gravelly knobs, such as Prospect Hill "B" and Sackrider Hill, are located along the crest (Figure 30) and form the highest points in the moraine with maximum altitudes of more than 1,050 feet (320.0 m). These asymmetric, cone-shaped features appear to mark the sites where especially large streams deposited sand and gravel at the margin and built outwash fans above the surface of the outwash apron.[6] The steep northern slopes of the fans indicate an ice-contact origin. In most places there is little or no morphological evidence of these superglacial streams in the present landscape, but in the N½ sec. 16, T. 2 S., R. 2 E., a large, relatively flat feature trending south merges with such a fan. Flanked by steep, apparent ice-contact slopes with several angular bends along its course the feature is interpreted to be a large channel filling marking the course of a subaerial stream which supplied sediment to the fan. The county soil survey (Veatch, Trull, and Porter, 1930) indicates that a portion of the feature is covered with Hillsdale sandy loam, a

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[6]These fans are also discussed in the section of this chapter concerned with the Grass Lake Plain.

soil interpreted to have till as parent material. This may be a cap of flow till, or, as the old Hillsdale mapping unit may include large amounts of glaciofluvial materials, it may mark bodies of flow till on the surface of the channel filling.

Although glaciofluvial processes appear to have been predominant on the outwash apron of the Kalamazoo Moraine, Hillsdale soil with till parent material has been mapped (Veatch, Trull, Porter, 1930) in the W½ sec. 17 and E½ sec. 18, T. 2 S., R. 2 E. just west of Sackrider Hill. On air photos this lobe-shaped area contrasts with its surroundings due to lesser micro-relief. It is the only known deposit of till on the surface of the apron. There is no indication of a readvance of the ice which would permit deposition of basal till on the outwash apron, but there is abundant evidence of stagnant ice in the area. Because this till is on the crest of the moraine, it cannot represent a postglacial mass movement deposit from a higher area. The topographic position, smooth surface, and lobate form of this unit indicate that it is flow till which postdates accumulation of the outwash apron but predates the ablation of ice at the ice-contact slope proximal to the crest. Hester and DuMontelle (1971, pp. 367-82) discuss similar features associated with the Shelbyville Moraine in Illinois and state that they represent lobes of flow till deposited during deglaciation of the moraine.

About 1 mile (1.6 km) west of Sackrider Hill a channel 30 to 40 feet (9.1 to 12.2 m) deep extends down the south-sloping sand and gravel apron into the SE¼ sec. 19, T. 2 S., R. 2 E. The channel originates at the steep north-facing slope of the crest where its bottom is 40 feet (12.2 m) above a linear depression. Limited numbers of considerably smaller features are also visible along the crest of the moraine. One of these, a 5-foot-deep (1.5 m) channel, trends southeast down the slope of Prospect Hill "B." All of these channels are well developed, even at the crest. This indicates that they were eroded by streams flowing off the Saginaw Lobe after most of the apron had been deposited but before deglaciation was complete.

Zone of Linear Depressions and Ridges

East of Brill Lake a number of linear depressions and ridges are located immediately to the north of the crest (Figure 31). These features are oriented parallel to the trend of the moraine. Most commonly a sharp-crested sand-and-gravel ridge is separated from the crest by one of the linear depressions. A series of three or four additional sand-and-gravel ridges and linear depressions may be located to the north. Small lakes or bogs are often located in the depressions.[7] These linear features are very striking in the field, on topographic maps, and especially on air photos. All the ridges and depressions form a zone which is approximately 0.5 miles (0.8 km) wide (Figure 30).

The linear depressions are somewhat variable in size but average about 200 to 250 feet (61 to 76 m) in width and 1,000 to 1,300 feet (305 to 396 m) in length although a few exceed 2,000 feet (610 m). The dimensions of the ridges also vary, but commonly they are 200 to 300 feet (61 to 93 m) wide and 1,200 to 1,300 feet (366 to 396 m) long, although some are larger. Bottoms of the depressions may be 50 to 100 feet (15.2 to 30.5 m) lower than adjacent ridge tops with relief increasing eastward toward Leverett Hill.

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[7]Boulders may be visible on the flanks of ridges or in dry linear depressions, but no regular pattern is discernible.

According to Charlesworth (1957, p. 416), steep-sided ridges and depressions with trends parallel to the kame moraines in which they are situated are common (see also Boulton, 1972; Bogacki, 1973; and Galon, 1973). Generally these moraines contain large amounts of sand and gravel, and the ridges and depressions are believed to be due to deposition of glaciofluvial materials in contact with fractured, stagnant ice (Virkkala, 1963, p. 28; Fogelberg, 1970, p. 38; and Boulton, 1972, pp. 385-86). In the study area the ridges have steep slopes, sharp crests, relatively uniform dimensions, symmetrical form and they lack erosional channels on their slopes. Their presence in a linear zone 0.5 miles (0.8 km) wide and 10 miles (16.0 km) long parallel to the crest of the moraine indicates that they were deposited by meltwater in a fracture zone in stagnant ice at the margin of the Saginaw Lobe. Adjacent linear depressions mark the former positions of ice blocks between the fractures.

This zone of linear depressions and ridges is best developed east of Brill Lake, where nearby bedrock has altitudes of 900 feet (274.3 m) or more. The zone is either very poorly developed, or not present, west of the lake where bedrock altitudes are generally less than 900 feet (274.3 m).

The causes of crevasse systems parallel to, or very near, the margins of ice sheets are not always clear although some are associated with the underlying bedrock surface. For instance, Fogelberg (1970, pp. 44, 65) cites numerous examples of linear ridges which are thought to have formed in crevasse systems at the edge of stagnant ice masses on high bedrock surfaces. Also Virkkala (1963, pp. 46-47, 70) notes that linear ridges of sand and gravel deposited in crevasses parallel to the ice margin are most common on the down-glacier sides of bedrock lows.

The zone of ridges and linear depressions in the Kalamazoo Moraine is also situated on the down-glacier side of a low-altitude bedrock area where the bedrock surface rises to a rather high altitude under the Grass Lake Plain. There is also evidence of the former presence of large blocks of stagnant ice on the Grass Lake Plain very near the Kalamazoo Moraine. Thus, it seems likely the bedrock surface was responsible, at least in part, for the crevasse system thought to have been present at the stagnant margin of the Saginaw Lobe. The difference topography east and west of Brill Lake also seems to be related to the altitude of the bedrock surface. Fogelberg (1970, p. 78) made a similar observation about the Second Salpausselka of Finland when he stated that "deglaciation of the different marginal sections depended on variations in the topography of the substratum; this had important effects on the geomorphological activity of the ice margin and the meltwater."

Zone of Lakes and Bogs

Five lakes in the Kalamazoo Moraine between Jackson and Leverett Hill have surface areas greater than 110 acres (44.5 ha) (Table 7). With the exception of Gilletts Lake[8] all of the lakes are located about 0.5 miles (0.8 km) north of the crest of the moraine and form a zone about 1 mile (1.6 km) wide which has more lakes and bogs and fewer high-relief features than areas to the north or south (Figure 30). All five of the lakes have a neighboring lake to the north or south, either in the moraine or on the Grass Lake Plain.

Relief in this zone is generally subdued, and most of the higher features which are present seem to be associated with the zones to the

[8]Spelling of this name is variable-- "Gilletts," "Gillett's," "Gillett," and "Gillette." "Gilletts" seems to be preferred locally.

south or north. Ice-contact slopes and flow till are common in this zone.

Table 7. Large Lakes and Their Neighboring Lakes

	Neighboring Lake	
Large Lake	In Kalamazoo Moraine	In Grass Lake Plain
Sugarloaf	--	Crooked
Clear	--	Pond Lily
Welch	--	Goose "A"[9]
Brill	Gilletts	--
Gilletts	Brill	--

The presence of ice-contact slopes, flow till, and large lakes and the relatively low altitude (940 to 960 feet or 286.5 to 292.6 m) of much of this area indicate that a zone of stagnant ice was present during final deglaciation. Most of the lakes are 20 feet (6.1 m) or less in depth; and, according to hydrographic maps, at least three-- Brill, Clear, and Welch-- seem to have ice-contact slopes below the surface of the water. Although some of the lakes appear to have formed by ablation of buried ice associated with bedrock valleys (see Figure 5), some are situated over areas of high bedrock altitude. This may mean that their bottoms mark the approximate altitude of the base of the Saginaw Lobe during moraine deposition.

On the basis of the few available exposures, the higher features in the zone seem to be kames, for they consist primarily of ice-contact stratified drift deposited by meltwater flowing south or west. Some of

[9] Sec. 24, T. 2 S., R. 1 E.

these kames have flow till at the surface.

Boulton (1968, p. 410) has stated that flow till may be formed when an ice margin is in compression due to (1) overriding of a bedrock obstacle, (2) stagnation of ice at the margin, and (3) decrease in the slope of the glacier bed. It has been shown (1) that the Kalamazoo Moraine is situated adjacent to a bedrock high; (2) that numerous ice-contact features, generally interpreted to be indicative of stagnant ice, are present at and near the crest of the moraine and in the zone of lakes and bogs; and (3) that the bedrock surface in the area tends to rise to the south-- a gradient up which the Saginaw Lobe had to flow. Boulton indicates that any one of the three conditions is sufficient to permit flow-till formation, and it has been shown that all three probably existed in the study area during deposition of the Kalamazoo Moraine. This helps to account for the widespread distribution of flow till believed present in the area (Figure 22).

Asymmetric fan-shaped features of glaciofluvial materials with very steep slopes on their northern sides are located in this and subsequent zones to the north and will be discussed in this section. The features resemble the high, fan-shaped hills along the crest of the moraine but are smaller. Three of these smaller fans have narrow ridges of sand and gravel trending into their steep northern slopes. All these features are interpreted to be outwash fans which were deposited in contact with stagnant ice by meltwater streams. Their consistent southward slope indicates that the source of the meltwater was generally to the north. Those fans with associated ridges may mark the location of small esker streams and their deltas.

Northern Zone of Linear Depressions

North of the lake zone, on the proximal side of the moraine, is a tract about 1 mile (1.6 km) wide in which surficial till is more common than in the zone along the crest.[10] Linear depressions with steep slopes are present here but tend to be smaller and not quite as well developed as in the zone near the crest. The orientation of these northern depressions is generally parallel to the moraine. The linear depressions to the east, near the meridian of Leverett Hill, are quite obvious on air photos but are somewhat less conspicuous on topographic maps and are more difficult to observe in the field than are the larger depressions to the west or to the south in the zone near the crest. Accompanying high-relief ridges are rare, but an area north of Goose Lake "A" and west of Welch Lake contains a number which are up to 50 feet (15.2 m) in height.

Although somewhat similar in appearance to the zone of linear depressions and ridges near the crest, this zone differs from it in several ways: (1) ridges are not as pronounced; (2) although the linear depressions are distributed in a zone parallel to the crest of the moraine, the individual depressions tend to be concentrated in four groups; (3) a well-developed outwash apron is not present; (4) flow till is more common here than in the crest area.

Apparently the northern zone of linear depressions was formed in a manner somewhat similar to that of the zone of linear depressions and ridges to the south near the crest. However, the fractures in the ice

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[10]Figure 8 is based on the 1930 soil survey map, which shows most of the zone as Hillsdale sandy loam (till parent material). As noted previously in Chapter 3, the old Hillsdale mapping unit contains considerable amounts of sand and gravel.

may not have been as deep or deposition may have been less because the ridges between the depressions are not well developed. The bedrock surface beneath this portion of the moraine is generally well below 900 feet (274.3 m) in altitude(Figure 4). However, a few outliers of the sandstone tableland are present in the subsurface. Three of the four groups of depressions that exist in the area are situated above these outliers and seem to be associated with them. It appears likely that these local bedrock highs caused the ice of the Saginaw Lobe to fracture, permitting the accumulation of sediments within crevasses.

Although a well-developed outwash apron is not associated with the zone, two kame-like features consisting primarily of glaciofluvial sediments are located at the north end of Clear Lake and about 1.5 miles (2.4 km) west of Brill Lake. Both appear to have an ice-contact origin and are oriented parallel to the crest of the moraine.

Flow till is more common at the surface here than in the vicinity of the crest. This indicates that till was present on the surface of stagnant blocks of ice in the area and perhaps that glaciofluvial deposition was not predominant in this zone as it was in the zone of linear depressions and ridges to the south, where the ridges are larger, flow till is less common, and an outwash apron is present.

Portage River Lowland

The Portage River lowland is a tract 1 to 3 miles (1.6 to 4.8 km) wide and more than 15 miles (24 km) long north of the Kalamazoo Moraine (Figure 30). Its average altitude in the east is about 930 feet (283.5 m) and about 920 feet (280.4 m) in the west where the Portage River flows into the Grand River north of Jackson. Leverett referred to this feature as the "Portage Swamp" (Leverett and Taylor, 1915, p. 197).

The landforms situated on the lowland west of the longitude of Brill Lake are considerably different from those east of that line.

A feature as much as 30 feet (9.1 m) high, 800 feet (245 m) wide, and 0.5 miles (0.8 km) long is located in sec. 8, T. 2 S., R. 1 E., west of Brill Lake. It is underlain by till with numerous cobble-sized clasts on the surface and slopes to the north. Three channels, up to 12 feet (3.7 m) deep, trend down the north-sloping surface. Ground silos in the feature expose large amounts of flow till. Steep marginal slopes on the south indicate an ice-contact origin, and the morphology suggests that it is a deposit of flow till which moved downslope off a nearby block of stagnant ice.[11] The three channels appear to "hang" and suggest that meltwater flowed over the till feature from nearby stagnant ice after it was deposited. This is the only large landform in the study area thought to consist almost entirely of flow till.

A number of hills of both high and low relief exist on the lowland east of Brill Lake. These features are aligned in a linear fashion nearly parallel to the Kalamazoo Moraine (Figures 2 and 30), and they appear to merge with the moraine in sec. 6, T. 2 S., R. 2 E. According to the soils map (Veatch, Trull, and Porter, 1930), till is quite common on the surface of the hills. Linear depressions are almost totally lacking in the lowland, and the hills have fewer very steep slopes than in any of the zones to the south. East of the longitude of Brill Lake the landscape is more like the area to the north, near the Charlotte Moraine, than the topography west of Brill Lake or in the Kalamazoo Moraine. Furthermore, if the line of hills is traced eastward, it merges

[11] A small outwash fan and associated feeding esker are located immediately to the east and also indicate the presence of stagnant ice.

with a spur of the Charlotte Moraine a few miles west of Pinckney. All of these factors suggest a different mode of deglaciation here than in the Kalamazoo Moraine, where stagnation seems to have prevailed. It appears that this zone marks a position held by an active ice margin for a relatively short time and which in its subsequent retreat may have left isolated blocks of stagnant ice. This margin seems to have been more active in the east than in the west, where there is evidence of stagnation.

Relationship of Bedrock Surface and Mississinewa Moraine

A comparison of Figures 4 and 8 shows that the Mississinewa Moraine is located along the south and east flanks of the buried sandstone tableland. This correspondence in shape and location is so similar, even in certain details, that the relationship is almost certainly not coincidental.

The trace of the 900-foot (274.3 m) bedrock-surface contour is situated very close to the distal edge of the moraine.[12] One of the highest points on the buried tableland is in sec. 8., T. 3 S., R. 3 E. and is within 1 mile (1.6 km) of the change in trend of the moraine near Mill Creek. In fact, this bedrock high probably deflected ice flow and, in conjunction with the regime of the Huron-Erie Lobe and the relatively steep eastern flank of the sandstone tableland, helped determine the location of the Mississinewa Moraine.

The Mill Creek lowland also appears to be associated with the bedrock surface, for the surficial trace of the southern tributary of the

[12] The distal edge of the Kalamazoo Moraine is also situated along the surficial trace of the 900-foot (274.3 m) bedrock contour.

buried Lima valley (Chapter 2) is situated along the lowland.[13] As mapped on Figures 2 and 8, the southwestern terminus of the Mississinewa Moraine in the study area is located where the trend of the moraine intersects the surficial trace of the 900-foot (274.3 m) bedrock contour.

The difference in topography north and south of Mill Creek may be partially the result of differences in bedrock configuration beneath the two areas, just as the bedrock seems to have caused differences in morphology east and west of Brill Lake in the Kalamazoo Moraine. The sandstone tableland beneath the southern part of the Mississinewa Moraine rises more abruptly from the shale lowland than in the north, because it is 4 miles (6.4 km) or less between the 800- and 900-foot (243.8 and 274.3 m) bedrock contours in the south and almost twice that distance in the north. Furthermore, the 900-foot (274.3 m) bedrock contour trends northeast-southwest across T. 3 S., R. 3 E., and may have been oriented almost normal to Huron-Erie ice flow. In T. 2 S., R. 3 E. the contour trends north-south and may only have been oriented obliquely to the ice flow.

Mississinewa Moraine

The portion of the Mississinewa Moraine within the study area is about 17 miles (27 km) long and trends north-northeast from a point near Norvell to the north-central portion of T. 3 S., R. 3 E., where it bears north toward Leverett Hill (Figure 2). The width of this Huron-Erie Lobe moraine varies from about 0.25 miles (0.4 km) to 4 miles (6.4 km), and local relief is from less than 50 feet (15.2 m) near Norvell to more than 180 feet (54.9 m) in the Sharon Short Hills (Figure 28). Maximum

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[13] Few well records are available in this area. The bedrock contours in secs. 4, 5, and 6, T. 3 S., R. 3 E., are shown on Figure 4 exactly as calculated by the computer and have not been hand-modified.

amounts of local relief tend to be located near the crest, which is situated along the proximal (east and southeast) side of the moraine. Maximum altitudes in the south near Norvell are about 960 feet (292.6 m), rise to a maximum of approximately 1,140 feet (347.5 m) in the Sharon Short Hills, and decrease to about 1,025 feet (312.4 m) near Leverett Hill (Figure 29). Much of the moraine north of Mill Creek and also near Norvell is only slightly higher than the Grass Lake Plain, and a considerable portion of it is lower. The moraine merges with the Grass Lake Plain, commonly very gradually, at altitudes of 980 to 1,020 feet (298.7 to 310.9 m) in the south and approximately 1,020 feet (310.9 m) in the north. The Mississinewa Moraine may be divided into north and south sections, which are separated by Mill Creek (Figures 32 and 33).

Southern Section of Mississinewa Moraine

The highest point in this portion of the Mississinewa Moraine, with an altitude of 1,140 feet (347.5 m), is along the crest in the Sharon Short Hills (Figure 29). This site is part of an apron of outwash and till in secs. 16, 17, 18, 19, and 20, T. 3 S., R. 3 E., which merges gradually with the Grass Lake Plain. Although the surficial till here has a lobelike shape, it is dissimilar to the till on the outwash apron of the Kalamazoo Moraine. Differences include greater relief (40 feet or 12.2 m) in a quarter-section, numerous boulders, and meltwater channels which tend to converge to the west.

South of Mill Creek a number of linear depressions and ridges of sand and gravel are proximal to the crest of the moraine and parallel to its trend.[14] The ridges are sharp-crested, approximately 200 feet (61

[14] These features resemble the linear depressions and ridges proximal to the crest of the Kalamazoo Moraine.

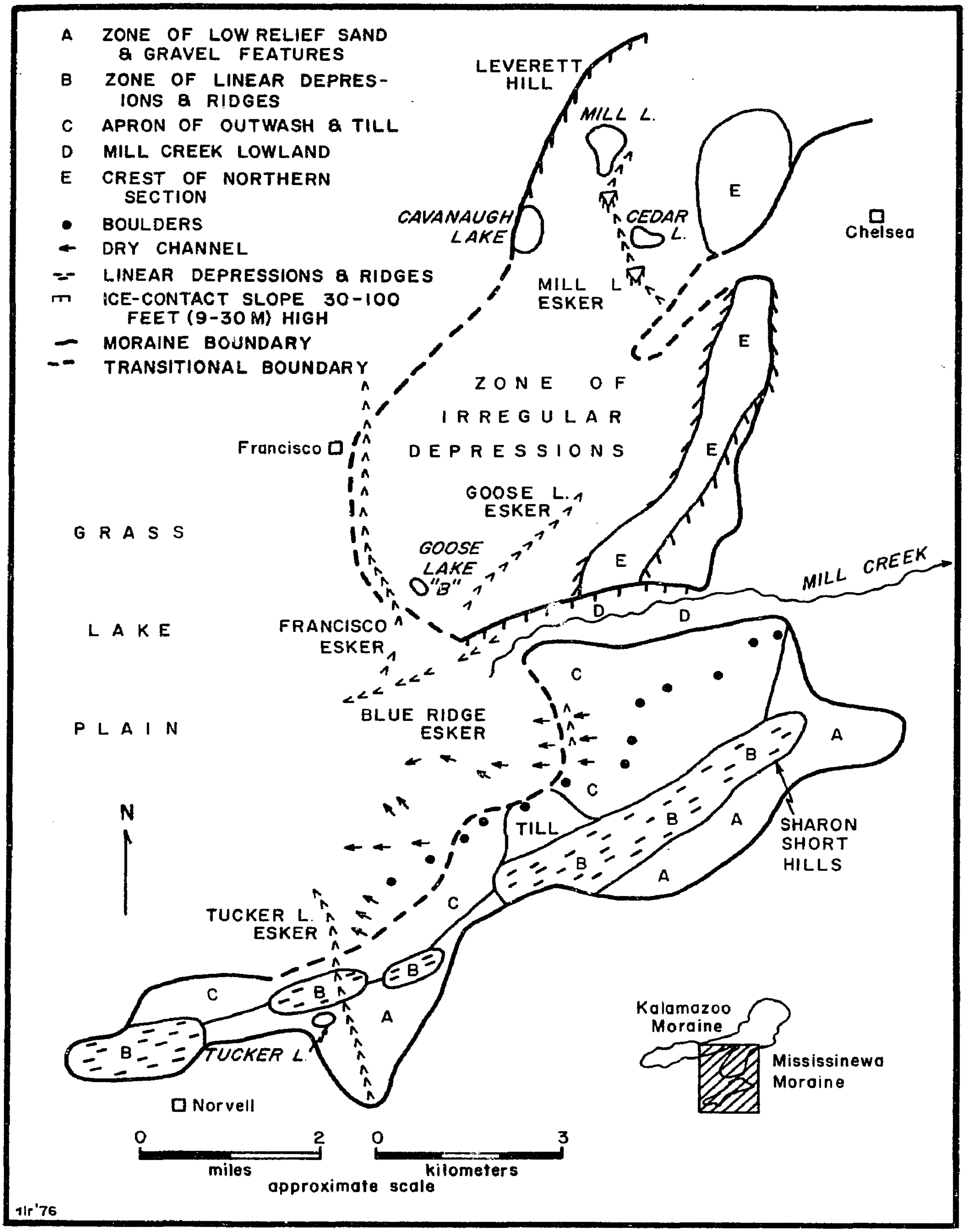

Figure 33. Diagram of a Portion of the Mississinewa Moraine

m) wide, and up to 1,500 feet (460 m) long, but average perhaps 800 to 1,000 feet (245 to 305 m). Depressions are about as long and wide as the ridges. Relief from the bottom of a depression to the crest of an adjacent ridge averages 50 feet (15.2 m) or less. The discontinuous zone of linear depressions and ridges is about 0.5 miles (0.8 km) wide.

The form, materials, local relationships, and bedrock conditions associated with portions of the Kalamazoo Moraine and the Sharon Short Hills of the Mississinewa Moraine are so alike that they suggest similar origins. Landforms and sediments indicate that both were deposited in and near a fracture zone along an ice margin and that both have associated outwash aprons which grade into the Grass Lake Plain. However, there are enough differences to indicate that the details of deglaciation in both areas were somewhat different. This is evidenced by the absence of outwash fans along the crest of the Mississinewa Moraine. Also, the zone of linear depressions and ridges associated with this moraine is not as continuous nor as well developed as that in the Kalamazoo Moraine. Finally, since the linear ridges and depressions are located in a single zone, there appears to have been only one fracture zone in the Huron-Erie Lobe and three in the Saginaw Lobe during deposition of the moraines.

Although not as widespread as in the Kalamazoo Moraine, there is evidence of stagnant ice in the Mississinewa Moraine. The crest of an esker-like ridge situated in a steep-walled depression in the E½ sec. 8, T. 3 S., R. 3 E., is lower in altitude than the nearby surface of the outwash apron. Two meltwater channels on the apron east of the depression in sec. 9 appear to continue into sec. 8 on the west side of the depression. These channels apparently had no effect on the crest altitude of the ridge. This suggests that the ridge formed beneath a mass of stagnant ice and that meltwater streams flowed across the top of the ice. In addition to this ridge and the zone of linear depressions and ridges proximal to the crest, there is additional evidence of stagnation in and near the Mississinewa Moraine. A steep-sided ridge of sand and gravel 40 feet high (12.2 m) trends completely through the moraine near Tucker Lake onto the Grass Lake Plain. It is almost 3 miles (4.8 km) long and may extend farther to the south of River Raisin. Too long and sinuous to be a crevasse filling, it is interpreted as an esker and will be referred to as the Tucker Lake Esker. West of the esker the evidence of ice stagnation, both in and distal to the moraine, is even more common and is in the form of steep, ice-contact slopes in glaciofluvial sediments.

Northern Section of Mississinewa Moraine

Variations in trend of the Mississinewa Moraine in T. 3 S., R. 3 E., give it a concave westward form (Figure 33). In fact, this concavity is so pronounced that the segment south of Mill Creek is oriented nearly normal to the segment north of Mill Creek.

Mill Creek flows northeast in a lowland that extends northeastward from the Grass Lake Plain and bisects the moraine.[15] The altitude of the lowland is approximately 1,000 feet (304.8 m) at the Grass Lake Plain-moraine contact and about 940 feet (286.5 m) at the proximal side of the moraine. It is 0.5 to 0.75 miles (0.8 to 1.2 km) wide, is underlain by much organic soil, and has a very steep and linear north flank which varies from 30 to 60 feet (9.1 to 18.3 m) in height. The south flank of the lowland is not as precipitous.

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[15] Both Willow Creek and the Blue Ridge Esker trend southwestward along the extension of the lowland onto the Grass Lake Plain.

The Mill Creek lowland has characteristics of both a subglacial drainageway and a lowland associated with a buried bedrock valley. The eastward gradient of about 15 feet per mile (2.9 m per km), opposite to the flow direction of glacial meltwater, suggests that it does not have a subaerial origin. Linear sand-and-gravel ridges within the lowland that appear to be the head of the Blue Ridge Esker indicate a subglacial origin. However, the width of the feature, the pronounced ice-contact slope on the north, and the presence of the southern tributary of the buried Lima valley beneath the lowland (Figure 5) seem to indicate a collapse origin due to the ablation of buried ice. It may well be that it has a dual origin with both glaciofluvial erosion and collapse involved in its genesis.

North of Mill Creek lowland the nature of deglaciation appears to have been considerably different than in the Sharon Short Hills to the south. For a distance of 4 miles (6.4 km) north of the creek the crest of the moraine is at an altitude of about 1,030 to 1,060 feet (313.9 to 323.1 m). Here, ice-contact slopes are visible on both the proximal and distal sides; few, if any, linear depressions exist; and no well-defined outwash apron is apparent. A tract 2 to 3 miles (3.2 to 4.8 km) wide, with hills 30 to 50 feet (9.1 to 15.2 m) higher than the numerous adjacent kettles, is located between the crest and the Grass Lake Plain.[16] In fact, much of this portion of the moraine has an altitude from 20 to 80 feet (6.1 to 24.4 m) lower than the surface of the Grass Lake Plain.[17]

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[16]Leverett (notebook 274, p. 75) mapped the Grass Lake Plain-Mississinewa Moraine boundary partially on the basis of the number of kettles present. He considered those areas with many depressions to be morainic and those with relatively few to be outwash plain.

[17]For a discussion of such situations see Thwaites (1963, p. 43).

This suggests that deposition took place in contact with stagnant ice. With final ablation the ice blocks formed the kettles which are so common in this area and which may be as large as half a survey section. The western edge of this tract is indicated by a considerable decrease in the number of ice-contact depressions along a line trending north from Mill Creek along the county line to Francisco and thence northeast to the southeast flank of Leverett Hill. This line almost certainly marks the margin of the Huron-Erie Lobe when Leverett Hill was formed.

Southwest of Chelsea a lowland, 0.25 miles (0.4 km) wide, breaches the crest of the moraine. It has a slope to the east of 15 feet per mile (2.9 m per km), and along its southwestward extension a 30 foot (9.1 m) high ridge of sand and gravel trends southwest past Goose Lake "B"[18] to within 0.5 miles (0.8 km) of the Blue Ridge Esker which trends west from the Mill Creek lowland. The lowland near Chelsea is interpreted to have formed as a subglacial drainageway due to its eastward slope and the associated sand-and-gravel ridge which is believed to be an esker and is here named the Goose Lake Esker. The stream which deposited the esker may also have supplied meltwater and sediments to the Francisco Esker, as the two eskers seem to have been part of an integrated drainage system and may have had their confluence at the S¼C sec. 31, T. 2 S., R. 3 E.

North of the lowland the crest of the moraine is less well defined and is in the form of several sand-and-gravel knobs with altitudes of 1,030 to 1,040 feet (313.9 to 317.0 m). A large sand-and-gravel ridge trends northwest past Cedar and Mill Lakes in secs. 4, 9, 15, and 16, T. 2 S., R. 3 E. Two relatively flat, delta-shaped features are situated

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[18] SE¼ sec. 31, T. 2 S., R. 3 E.

along its length. This feature is too long to be a crevasse filling and is interpreted to be an esker with two deltas or outwash fans along it. It will be referred to as the Mill Lake Esker.

Relationship of Bedrock Surface and Interlobate Morainic Tract

Almost all of the bedrock surface northwest of a line connecting Leverett Hill, Russell Hill, and Pinckney has an altitude of 800 feet (243.8 m) or more. Much of the bedrock surface southeast of this line is at an altitude of less than 800 feet (243.8 m) (Figures 4 and 32).

Leverett Hill is situated in the angle between the Kalamazoo and Mississinewa Moraines. Its location within 0.5 miles (0.8 km) of the apex of the buried, wedge-shaped, sandstone tableland suggests that both bedrock configuration and altitude were important factors in determining the location of the interlobate contact in the study area. Interpretation of both drift and landform characteristics indicate that surficial phenomena associated with the Saginaw Lobe in the Interlobate Morainic Tract are generally situated over higher bedrock areas. The converse is true for surficial phenomena associated with the Huron-Erie Lobe.

Interlobate Morainic Tract

The Interlobate Morainic Tract is a rectangular-shaped area about 5 miles (8.0 km) wide and 12 miles (20 km) long which trends northeast from Leverett Hill to Pinckney. Maximum local relief is 180 feet (54.9 m) at Stofer Hill (Figure 28). Mean local relief is about 115 feet (35.1 m). Associated with this relatively high local relief are numerous steep slopes believed to be of ice-contact origin. The Interlobate Morainic Tract is bounded on three sides by low altitude, low relief areas about 1 mile (1.6 km) wide which are underlain by sand and gravel (Figure 8).

The highest altitudes in the tract tend to be located along a series of hills which trends north and includes Leverett Hill-- 1,120 feet (341.1 m), Riley Hill-- 1,040 feet (317.0 m), Stofer Hill-- 1,100 feet (335.3 m), Heatley Hill[19]-- 1,020 feet (310.9 m), and Russell Hill-- 970 feet (295.7 m) (Figures 32 and 34). These features separate the tract into two areas-- a northwest zone which is slightly more than 1 mile (1.6 km) in width and a southeast zone which is 3 to 4 miles (4.8 to 6.4 km) wide. About 1 mile (1.6 km) to the west of these hills is a second line of hills which trends northeast. It marks a continuation of the northern zone of linear depressions of the Kalamazoo Moraine into the Interlobate Morainic Tract as a series of hills which includes Hankard Hill[20]-- 1,086 feet (331.0 m), Shanahan Hill-- 1,040 feet (317.0 m), and Prospect Hill "A"-- 1,050 feet (320.0 m). This linear series of features trends toward the northwest flank of Russell Hill. The steep slopes and existence of several gravel pits in these features indicate they are ice-contact in origin and are kames. In addition, this section also contains several groups of linear depressions[21] with northeast-southwest orientation that strongly resemble similar features in the northern zone of linear depressions in the Kalamazoo Moraine.

A high-altitude, relatively flat, linear hill north of Pinckney (SW¼ sec. 14 and SE¼ sec. 15, T. 1 N., R. 4 E.) is composed of sand and

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[19]A steep-sided hill in SE¼ sec. 11, T. 1 S., R. 3 E. which is unnamed on the Stockbridge quadrangle. This name is applied for identification purposes only and is not formally proposed as a geographic name.

[20]A steep-sided hill in SW¼ sec. 21, T. 1 S., R. 3 E. which is unnamed on the Stockbridge quadrangle. This name is applied for identification purposes only and is not formally proposed as a geographic name.

[21]These depressions are located at or near the surficial trace of the 900-foot (274.3 m) bedrock contour where it indicates the presence of outliers of the sandstone tableland.

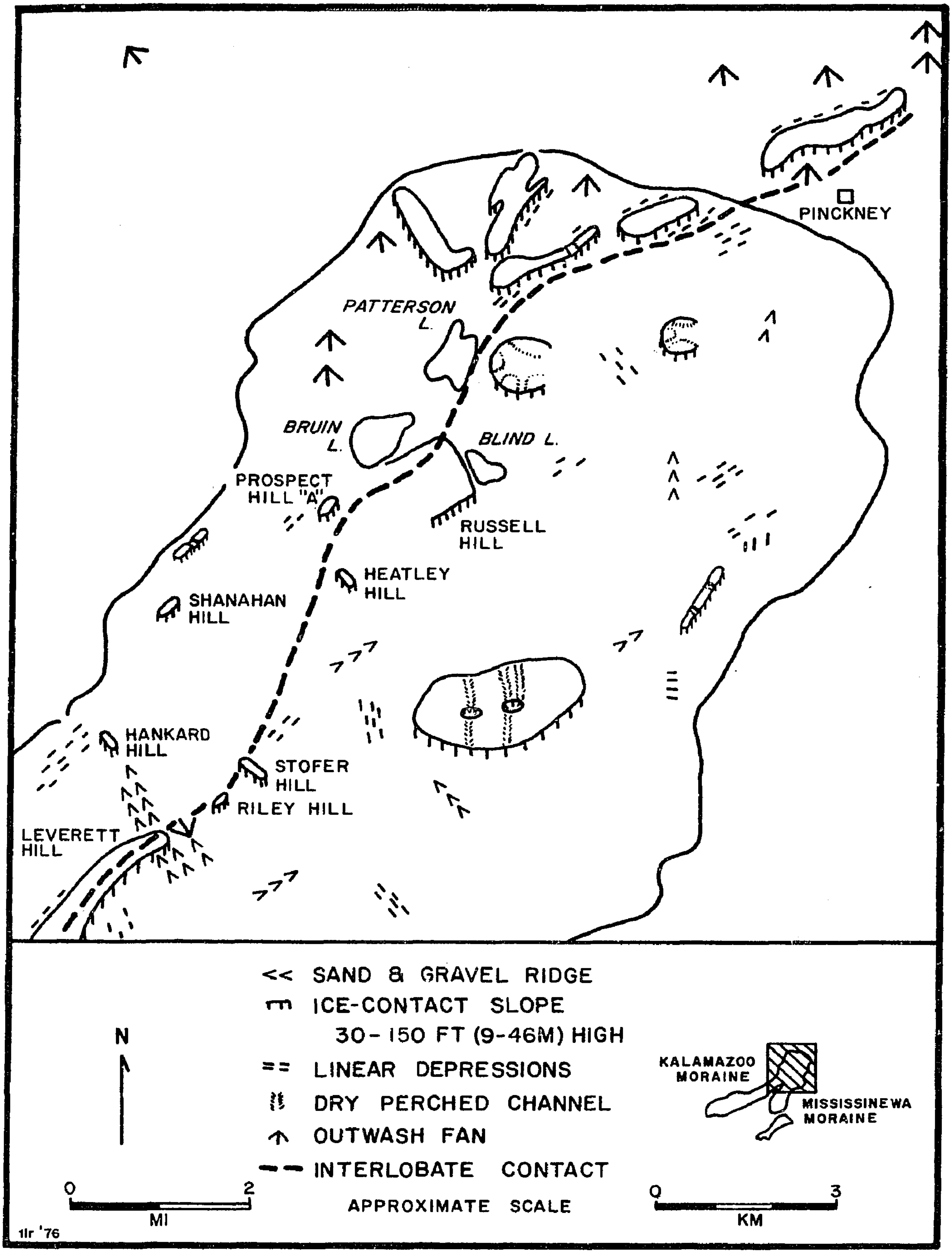

Figure 34. Diagram of Interlobate Morainic Tract

gravel, has very steep flanks and a number of linear depressions on its margins (Figure 34). Similar features are located to the southwest in secs. 20 and 21, T. 1 N., R. 4 E. and secs. 29 and 30, T. 1 N., R. 4 E. All three of these flat-topped features are about 0.2 miles (0.3 km) wide, trend approximately northeast-southwest, and are located in the northwest portion of the Interlobate Morainic Tract. The linear depressions on the margins of these channel fillings are oriented parallel to the long axis of the larger features and probably mark the former sites of narrow, stagnant ice masses that were buried by glaciofluvial sediments. There is a possibility that these channel fillings may all have been deposited by the same southwest-flowing superglacial stream for they form a 6-mile (9.6 km) long, discontinuous, southwest-sloping surface as much as 1,000 feet (305 m) wide which is bounded by ice-contact slopes. Crest altitude at the north end near Pinckney is 1,000 to 1,010 feet (304.8 to 307.8 m), and at Patterson Lake it is about 970 feet (295.7 m). Two similar features are located in sec. 19, T. 1 N., R. 4 E. and secs. 24 and 25, T. 1 N., R. 3 E. and may mark the location of tributaries to the trunk stream which flowed almost exactly along the interlobate contact.

Groups of linear depressions are located in both the northwest and southeast portions of the Interlobate Morainic Tract. Those in the northwest have northeast-southwest orientations and are associated with the extension of the northern zone of linear depressions into the tract. Linear depressions are distributed throughout the southeast portion of the tract. Here intragroup orientations are generally parallel to one another, but intergroup orientations are generally dissimilar. These depressions are most probably due to the burial of fractured, stagnant ice by glaciofluvial sediments. The intragroup similarities and intergroup dissimilarities in depression orientations suggest that the fractures may have been determined by local conditions in the ice sheet. On the other hand, the tendency for the depressions to have northeast-southwest or northwest-southeast orientations (Figures 32 and 34) may indicate some sort of regional structural control in the ice sheet. In any case, the exact cause of this situation is not clear and does not seem to be related to the underlying bedrock.

Four fan-shaped features on the northwest side of the Interlobate Morainic Tract and five more to the north near Pinckney have steep northern slopes and relatively smooth surfaces dipping more gently to the south. These sand-and-gravel features resemble small outwash fans in the Kalamazoo Moraine described previously. Only one similar feature is thought to exist in the southeast portion of the tract, and it is located only 0.25 miles (0.4 km) east of Leverett Hill in SW¼SW¼SW¼ sec 27, T. 1 S., R. 3 E. Here the gentle slope is to the west and the steep slope to the east.[22] These features are interpreted as small ice-contact outwash fans. With the exception of the single fan east of Leverett Hill, all slope south and indicate a Saginaw Lobe source of meltwater.

Numerous narrow linear ridges are located in the Interlobate Morainic Tract. These features are ordinarily quite straight and any changes in trend are angular. Because of this, their steep flanks, and the presence of large amounts of sand and gravel in them, they are

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[22] Three sewage lagoons are now situated on what was the gently sloping surface; however, the steep slope is still present as is a feeding esker trending into it from the east. Its unmodified form is clearly visible on air photos XT-3DD-6, -7, -8 (Agricultural Stabilization and Conservation Service, October 1, 1963) which were exposed before the lagoons were excavated.

interpreted as crevasse fillings.

There seem to be significant differences in the distribution of landforms in the Interlobate Morainic Tract. For example, the landform assemblage which includes the large channel fillings, small outwash fans, and linear depressions with a consistent northeast-southwest trend is located in the northwest portion of the tract. Another assemblage including larger crevasse fillings and the groups of depressions with large amounts of intergroup orientation variability is located in the southeast. A number of features are located in a narrow zone that separates the northwestern landform assemblage from the southeastern. A consideration of these features may help to explain the distributional characteristics of the two assemblages.

Riley, Stofer, and Heatley Hills are located along this boundary zone and appear to be composed primarily of sand and gravel. Their steep slopes and linear forms suggest they are ice-contact accumulations of glaciofluvial materials which were probably deposited in openings enlarged by melting along fractured zones or surfaces in stagnant ice. Leverett Hill is situated at the southwest end of this line of hills, and Russell Hill is at the northeast end. There are a number of striking similarities between these two features. (1) Both are underlain by glaciofluvial sediments. (2) Both have ice-contact flanks on three sides. (3) Both slope to the southwest indicating that the meltwater streams which formed them also flowed in that direction. (4) The zone of linear depressions and ridges along the crest of the Kalamazoo Moraine may be traced into the northwest flank of Leverett Hill and the Hankard-Shanahan-Prospect Hill "A" series of features, and the extension of the northern zone of linear depressions of the Kalamazoo Moraine may be traced to the northwest flank of Russell Hill.

On the basis of form, sediments, and regional trends, it is clear that Leverett Hill is a large outwash fan which marks the contact of the Saginaw and Huron-Erie Lobes during a phase of the deglaciation sequence. It is also clear that the northwest flank of Russell Hill is associated with a marginal position of the Saginaw Lobe. Furthermore, if the trend of the Mississinewa Moraine is extended north from Leverett Hill, it intersects the northeastern flank of Russell Hill. Thus, the similarities in form, sediments, and geomorphic relationships indicate that Russell Hill is also an outwash fan that marks the contact of the Saginaw and Huron-Erie Lobes for a period of time during deglaciation and that it postdates Leverett Hill. If this is correct, it is likely that the Riley-Stofer-Heatley series of hills between these two interlobate outwash fans probably formed in association with a stagnant-ice zone along, or very near, the interlobate contact.[23] Both Leverett (notebook 274, pp. 71-72) and Kneller (1964, p. 32) came to essentially the same conclusion (Figure 10).

On the basis of this evidence, it may be concluded that landform assemblages in the Interlobate Morainic Tract were formed under varied conditions as a consequence of their association with ice of different lobes. The northwest assemblage, including channel fillings, small outwash fans, and linear depressions with similar orientations, was deposited in contact with Saginaw Lobe ice. The southeast assemblage, including crevasse fillings and groups of linear depressions with dissimilar orientations, was formed in Huron-Erie Lobe ice.

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[23]It should be noted that the surficial drift contact, as defined by 7Å/10Å ratios, is also situated along this line.

Relationship of Bedrock Surface and Grass Lake Plain and Associated Areas

In general, the Grass Lake Plain and associated areas are underlain by the buried sandstone tableland, which has altitudes of 900 to slightly more than 1,000 feet (274.3 to 304.8 m). The relatively low amounts of surficial relief on much of the Grass Lake Plain is probably due, at least in part, to the subdued relief of the bedrock surface beneath it. A primary factor in the formation of the Center Lake-Wolf Lake chain of lakes is the buried Norvell valley, which is incised 100 to 150 feet (30.5 to 45.7 m) into the sandstone and trends southeast beneath the area from Jackson past Norvell (Chapter 2).

Grass Lake Plain and Associated Areas

The Grass Lake Plain and associated areas form a southwesterly sloping surface with an altitude of 1,050 to 1,100 feet (320.0 to 335.3 m) on Leverett Hill to approximately 950 feet (289.6 m) south of Jackson (Figures 29 and 35). A low-lying tract with an altitude of about 960 feet (292.6 m) trends northwest past Norvell to Jackson and contains a series of lakes-- the Center Lake-Wolf Lake chain.

The plain merges with the Mississinewa Moraine on the east and southeast (Figure 32) at altitudes of about 980 to 1,020 feet (298.7 to 310.9 m), and to the north the Kalamazoo Moraine outwash apron merges with the plain at altitudes of about 1,020 to 1,030 feet (310.9 to 313.9 m). The plain slopes to the south from the Kalamazoo Moraine and west and north from the Mississinewa Moraine. The surficial sediments on these aprons and the margins of the plain are rather coarse with considerable amounts of gravel including large cobbles. However, with increasing distance from the moraines the surficial sediments become

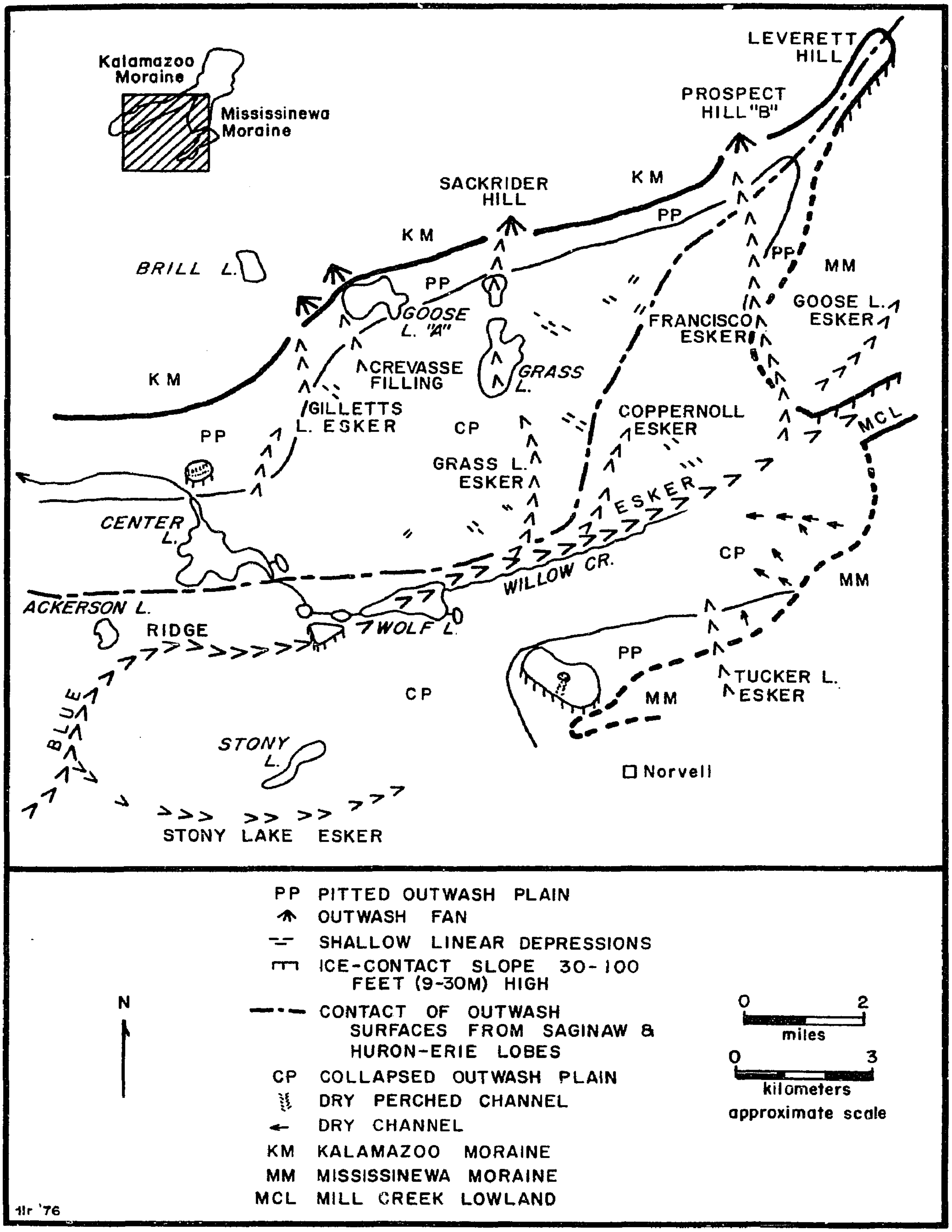

Figure 35. Diagram of Grass Lake Plain and Associated Areas

finer until little gravel is present. This indicates that the Grass Lake Plain is an outwash plain associated with both the Kalamazoo and Mississinewa Moraines. The contact of the two outwash surfaces which slope away from the moraines is interpreted to mark the boundary between surficial drift of the Saginaw and Huron-Erie Lobes. It is situated approximately along a line bearing southwest from Leverett Hill to the center of T. 3 S., R. 2 E. and then westward, separating the N½ and S½, T. 3 S., R. 1 E. (Figures 9 and 35).

Local relief on the plain (Figure 28) is generally less than 50 feet (15.2 m), but near the Center Lake-Wolf Lake chain of lakes it is somewhat greater, partially due to the depth of the lakes.[24] A tract about 1 mile (1.6 km) wide immediately distal to the Kalamazoo Moraine has 50 to 100 feet (15.2 to 30.5 m) of relief and steep-sided depressions which may be as large as a survey section. A similar zone is present distal to the Mississinewa Moraine, especially in the south near Norvell. This tract with numerous deep depressions on the outer margins of the plain shows abundant evidence of stagnant ice. Several crevasse fillings and eskers trend across the tract and will be discussed in detail below. Boulders are present in some of the depressions (Leverett notebook 32, p. 19) but are absent on the higher outwash surfaces. Till is visible in an exposure at the bottom of one of the depressions (NW¼NE¼SW¼ sec. 22, T. 2 S., R. 2 E.). In addition, topographic profiles show that the higher outwash marks the remnants of a surface which slopes gently from the moraines. On the basis of this evidence, the marginal tract is

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[24]According to the hydrographic map, Wolf Lake is as much as 45 feet (13.7 m) deep.

is interpreted as a pitted outwash plain.[25]

Leverett Hill is a southwest-sloping sand-and-gravel feature approximately 2.5 miles (4.0 km) long, about 0.5 miles (0.8 km) wide, and more than 150 feet (45.7 m) high in places. It is situated in the narrow reentrant between the Kalamazoo and Mississinewa Moraines and has very steep slopes on its northwest, northeast, and southeast flanks. Leverett Hill is the highest point on the Grass Lake Plain, and its steep flanks indicate that it is an ice-contact feature (Figure 35). The southwest slope, sediments, and location at the northeast terminus of the Kalamazoo Moraine and the north end of the Mississinewa Moraine show that it is a large outwash fan deposited by meltwater in a former reentrant between the Saginaw and Huron-Erie Lobes. The meltwater which deposited it flowed to the southwest and onto the lower portion of the Grass Lake Plain.

Several straight, steep-sided sand-and-gravel ridges at the west end of Goose Lake "A" are interpreted as crevasse fillings which were deposited in association with stagnant ice that existed on the distal side of the Kalamazoo Moraine. A nearby ridge trends south from sec. 26, T. 2 S., R. 1 E. to Sec. 10, T. 3 S., R. 1 E. This discontinuous feature, here named the Gilletts Lake Esker, has some of the characteristics of a crevasse filling, but its somewhat sinuous nature and length indicate that it probably is an esker. The Grass Lake Esker (Keifenheim, 1974, p. 22), extended in this study, trends south near the town of Grass Lake. Air photos and hydrographic maps indicate that segments of the esker are also present on the bottoms of Grass and Tims Lakes.

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[25]See discussion in Thwaites, 1926, for a discussion of such features.

Leverett (notebook 166, p. 63) examined an exposure in the ridge which revealed dipping beds that provide evidence that the esker stream flowed to the south. Another esker, here named the Francisco Esker, trends south along the Jackson-Washtenaw boundary at the distal margin of the Mississinewa Moraine. The Gilletts Lake, Grass Lake, and Francisco Eskers all originate distal to large outwash fans on the crests of the Kalamazoo Moraine.[26] It appears that superglacial streams deposited the outwash fans but that the continuation of the drainage became subglacial. The result was a number of streams that formed the eskers flowing south beneath stagnant ice. The deposition of the sediments was probably contemporaneous with the deposition of outwash on the upper surface of the stagnant ice. A fourth esker, here named the Coppernoll Esker, is rather short (secs. 3, 10, and 16, T. 3 S., R. 2 E.) and does not appear to originate near the Kalamazoo Moraine.[27] The three easternmost eskers are all tributaries to the Blue Ridge Esker and tend to parallel that feature a short distance before merging with it. All the eskers associated with the Kalamazoo Moraine have adjacent low-lying tracts which are interpreted as esker troughs. The Goose Lake and Tucker Lake Eskers associated with the Mississinewa Moraine (pp. 131, 133) cannot be traced to a merger with the Blue Ridge, but their trends and proximity strongly suggest that they did supply meltwater and sediments to that feature. A third esker associated with the Huron-Erie Lobe, the Stony Lake Esker

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[26] Prospect Hill "B," Sackrider Hill, and a large hill near Brill Lake.

[27] Although portions of all these eskers are easily recognized in the field and on topographic maps, other parts are apparent only with close stereoscopic inspection of air photos. This may be due to more complete burial during superimposition of the superglacial outwash.

(Keifenheim, 1974, p. 31), extended in this study, is physically connected with the Blue Ridge Esker (SE¼NW¼SW¼ sec. 6, T. 4 S., R. 1 E.). This contact indicates that both features were deposited at the same time.

Small depressions are present locally on the low-relief, central portion of the plain; and even on the flattest area (N½, T. 3 S., R. 2 E.) groups of very shallow, parallel, linear depressions trending northwest-southeast and northeast-southwest are visible on air photos (Figure 35). These patterns have little resemblance to erosional features and appear to have been caused by the deposition of outwash on stagnant, fractured ice.

At least three eskers and associated troughs trend across the plain. It is apparent that the eskers were not formed prior to the outwash plain because the troughs would then have subsequently filled with outwash and would no longer be visible. Apparently the eskers and associated troughs were formed beneath a thin sheet of stagnant ice and the outwash laid down on top of the ice. Subsequent ablation of the stagnant ice resulted in the superimposition of the outwash upon the underlying materials. Thus, on the basis of (1) the groups of linear depressions and (2) the presence of eskers and associated troughs, the low-relief portion of the Grass Lake Plain is interpreted as a collapsed outwash plain. Considering the plain, Leverett (Leverett and Taylor, 1915, p. 197) also concluded that "only a small portion of its surface is up to the plane of deposition."

The sand-and-gravel ridges in the Mill Creek lowland (p. 132) extend southwest along the north side of Willow Creek as a series of short segments spaced at intervals of 1,000 feet (305 m) or more. West of sec. 11, T. 3 S., R. 2 E. the ridge segments are wider and higher, may be more than 0.5 miles (0.8 km) long, and are separated by only small gaps. The hydrographic map for Wolf Lake indicates that ridge segments are also present below the surface of the water. Immediately west of the lake a segment of the ridge is almost 0.5 miles (0.8 km) wide and has very steep slopes. It is not well defined in sec. 28, T. 3 S., R. 1 E.,[28] but from sec. 29, T. 3 S., R. 1 E. it extends southwest as a conspicuous, steep-sided ridge more than 50 feet (15.2 m) high and is labeled "Blue Ridge" on topographic maps. Crest altitude near the Mill Creek lowland is about 1,000 feet (304.8 m), and at the southwest it is well over 1,050 feet (320.0 m).

Blue Ridge is an esker which was deposited by a stream flowing west and southwest.[29] It may be considered the trunk esker in the area and received sediments and meltwater from at least four, and probably all seven, of the eskers shown on Figure 35.

On the basis of pebble and cobble lithology, Keifenheim (1972, p. 42) concluded that the esker sediments are more closely associated with the Saginaw, rather than the Huron-Erie, Lobe. The lithology of 564 boulders in gravel pits along the esker was determined during this investigation and was found to be quite different than data on pebble lithology because 80% of the boulders and only 13% of the pebbles were

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[28]The 1930 soil survey indicates a narrow band of Bellefontaine sandy loam (sand and gravel parent material) in this section along the extension of the ridge. A gravel pit in this band (site 216-- NE¼SE¼NE¼ sec. 28, T. 3 S., R. 1 E.) confirms the presence of sand and gravel.

[29]In his monograph with Taylor (1915, p. 203) Leverett originally applied the name "Ackerson Esker" to this feature, but it is now commonly referred to as the "Blue Ridge Esker." He mapped it as far east as the west end of Wolf Lake. Later workers (Rieck, 1972, and Keifenheim, 1974) have mapped it extending 3 miles (4.8 km) east of the lake. As interpreted in this investigation, it originates in the Mill Creek lowland in SE¼ sec. 6, T. 3 S., R. 3 E., 7 miles (11.2 km) east of the lake.

sandstone (Appendix E). Most of the sandstone resembled well-record descriptions of the local sandstone.[30]

On the basis of morphology of the Grass Lake Plain and 7Å/10Å ratios of clays from near the esker (Figure 26), it seems likely that the section of the Blue Ridge Esker from west of the meridian of Norvell to Ackerson Lake formed very near the interlobate contact but in ice of the Huron-Erie Lobe. There are numerous reports[31] on "interlobate eskers" from Finland. However, the lobes between which these eskers formed were small, only 10 to 15 miles (16 to 24 km) wide or less and protruded just a short distance from the margin of the Scandinavian ice sheet. Buddington and Leonard (1962, p. 15) mapped an esker in the Adirondacks which was deposited between lobes which were somewhat larger. Wilson (1939, p. 124) and Stoelting (1970) described interlobate eskers which formed between major lobes in Canada and Wisconsin, respectively, but reported none which had tributary eskers from both lobes merging with the trunk, interlobate, esker. Thus, the Blue Ridge seems to be a rather unusual esker because it was formed in close proximity to a significant interlobate contact and has connecting tributary eskers associated with both lobes. This indicates that stagnant ice from the Saginaw and Huron-Erie Lobes was present over a large portion of the Grass Lake Plain during deglaciation.

Features Located in More Than One Physiographic Section

Two distinct types of landforms are located in several portions of the study area. One is a linear sand-and-gravel feature, often

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[30] See also Dorr and Eschman, 1971, p. 156.

[31] Some of these include Repo, 1960, pp. 12-13; Aartolahti, 1972, p. 62; and Okko, 1962, p. 39.

flat-topped, with steep flanks and a dry channel or notch transverse to its long axis (Table 8). Some of the ridges have been breached completely, others have not.[32] Examples of these features are found in the Kalamazoo Moraine, Interlobate Tract, and the Grass Lake Plain. Due to their sediments and steep flanks, the breached and notched ridges probably represent crevasse or channel fillings with postdepositional glaciofluvial erosion. After the ridges were deposited and a portion of the adjacent stagnant ice had melted, superglacial streams probably flowed across the features, eroding some of the sediments. The depth of the eroded channels was determined by the length of time that the streams flowed in those locations. If the superglacial environment was relatively stable, the streams may have flowed long enough to completely breach the ridge; if not, only a notch was eroded.

The second type of landform is a high, relatively flat, sand-and-gravel feature with steep flanks, which may have any shape from almost circular to irregular. A dry channel may trend across it from one side to another. This channel ends abruptly at an ice-contact slope and is not graded to the surrounding lowland. Such features are located on the Grass Lake Plain and in the Interlobate Morainic Tract. A variation is a high, flat feature with a dry depression on top and an associated dry channel which trends across the flat area toward lower ground. These features are also located in the Interlobate Morainic Tract and on the Grass Lake Plain. Genesis of the flat-topped features and their channels was probably similar to that of the breached and notched ridges except that deposition evidently took place in some sort of perforation in the

[32]They resemble wind and water gaps which are found in bedrock ridges.

Table 8. Locations of Landforms Situated in More Than One Morphologic Area

<u>Breached and Notched Ridges</u>

Section	T.	R.	Morphologic Area
29	1N	4E	Interlobate Morainic Tract
35	1S	2E	Kalamazoo Moraine
10	1S	4E	Interlobate Morainic Tract
9	1S	4E	Interlobate Morainic Tract
16	1S	4E	Interlobate Morainic Tract
16	2S	1E	Kalamazoo Moraine
27	2S	1E	Kalamazoo Moraine
33	2S	1E	Grass Lake Plain
3	2S	2E	Kalamazoo Moraine

<u>Channeled Plateaus-- Lacking Depressions</u>

31	1N	4E	Interlobate Morainic Tract
33	1N	4E	Interlobate Morainic Tract
4	3S	1E	Grass Lake Plain

<u>Channeled Plateaus-- With Depressions</u>

24	1S	3E	Interlobate Morainic Tract
19 & 30	1S	4E	Interlobate Morainic Tract
28	3S	2E	Grass Lake Plain

ice rather than in a crevasse. The origin of the channels associated with the depressions is not as obvious. Perhaps the depressions mark the former locations of ice blocks which protruded above the sediments and the channels may have been eroded by the meltwater from the ice blocks. However, the depth of the channels, 20 feet (6.1 m) or more, seems to preclude this. There is a possibility that the depressions are the former locations of springs and mark the point of escape of subglacial meltwater under hydrostatic pressure.

The presence of the breached ridges and channeled plateaus in the Kalamazoo Moraine, in the Interlobate Morainic Tract, and on the pitted portion of the Grass Lake Plain indicates that large amounts of stagnant ice were present in these areas for a sufficient time to permit glaciofluvial erosion to take place after deposition of the sediments. The lack of such features in the Mississinewa Moraine indicates that stagnant ice was not as prevalent or did not remain for as long a time as in the other areas.

Chapter 5

DEGLACIATION OF THE STUDY AREA

Morphologic Factors Influencing Deglaciation

The final deglaciation of southeastern Michigan is significantly associated with the characteristics of the underlying bedrock. The surface basins now occupied by Lakes Erie and Huron served as the axes of flow for the Huron-Erie Lobe during late Wisconsinan time. Also, during the process of deglaciation active ice remained in these lower areas after the nearby higher tracts had been deglaciated. The "Thumb" of Michigan is underlain by bedrock with a surface of sufficiently high altitude to present an obstacle to the movement of glacial ice and deflect a portion of the Huron Lobe into the Saginaw Lowland, forming the Saginaw Lobe (Figure 1) (Horberg, 1956, p. 105). The former contact between the Saginaw and Huron-Erie Lobes is marked by an interlobate drift contact that is believed to be located approximately above this bedrock high of regional extent. The correspondence of the higher bedrock surface and the drift contact of the different lobes indicates (1) that the surface configuration of the bedrock served to separate the ice into two lobes and (2) that its high altitude resulted in a comparatively thinner cover of overlying ice and consequently early deglaciation.

Bedrock altitude influenced both the regional patterns of ice flow and the local deglaciation of the study area. The highest bedrock surface in the area is associated with a buried sandstone tableland located along the southwest extension of the bedrock high in the Thumb. Evidence indicates that ice above the sandstone tableland thinned and eventually stagnated. At the same time the ice in nearby areas probably remained active because of lower altitude of the subglacial surface and greater thickness of the glacier. Shearing of the active glaciers over the stagnant ice resulted in the deposition of sediments such as basal till, meltout till, flow till, and glaciofluvial materials in the areas where the Kalamazoo and Mississinewa Moraines and the Grass Lake Plain were in the process of formation.

Possible Changes in the Position of the Interlobate Contact Through Time

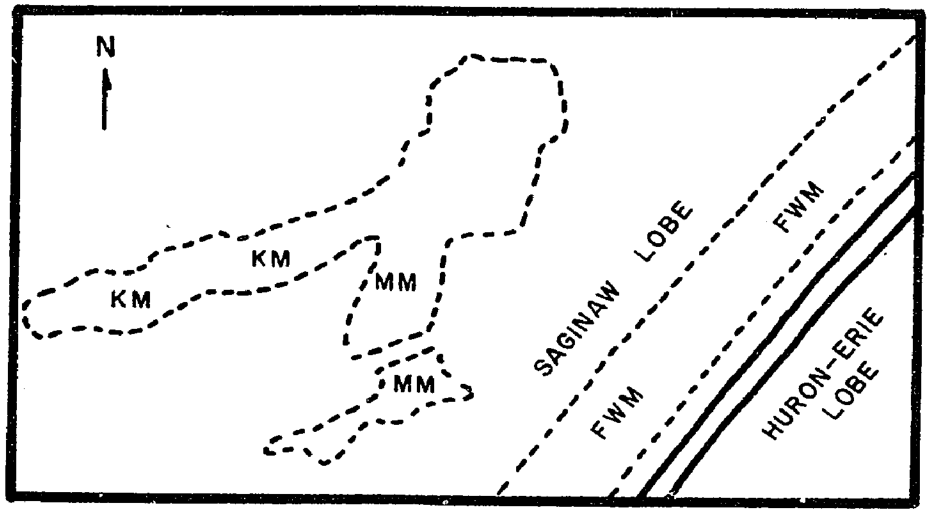
The exact positions of the margins of the Saginaw and Huron-Erie Lobes prior to the final deglaciation of the study area are not known. On the basis of previous works and findings in this study, it is not clear whether the interlobate contact always trended across the study area or was located elsewhere.

Study of interlobate areas in Wisconsin (Black, 1969, p. 105) and Ontario (Westgate and Dreimanis, 1967, p. 1143) indicates that the location of interlobate contacts may shift somewhat with time prior to deglaciation. Zumberge (1960, pp. 1182-83) and Wayne and Zumberge (1965, p. 72) state that clay-rich Huron-Erie till is stratigraphically above sandy till of the Saginaw Lobe in Lenawee County, Michigan, just a few miles (km) south of the study area. If this interpretation is correct,[1] it indicates that the Huron-Erie Lobe advanced into an area formerly covered by the Saginaw Lobe. Although indicating that his evidence "is not compelling," Kneller (1964, pp. 25-26, 35-36) interpreted many

[1]The textures of both Saginaw and Huron-Erie Lobe tills in the study area tend to be rather variable (Figure 11), and identifying the lobe provenance of a till strictly on the basis of texture may not necessarily yield reliable results. Therefore, the possibility exists that the sediments described by Zumberge and Wayne may only represent coarse and fine facies of Huron-Erie Lobe till.

gravel deposits in Washtenaw County, as far east as the Fort Wayne Moraine, as exhibiting Saginaw Lobe pebble lithology and to be overlain by Huron-Erie Lobe till.

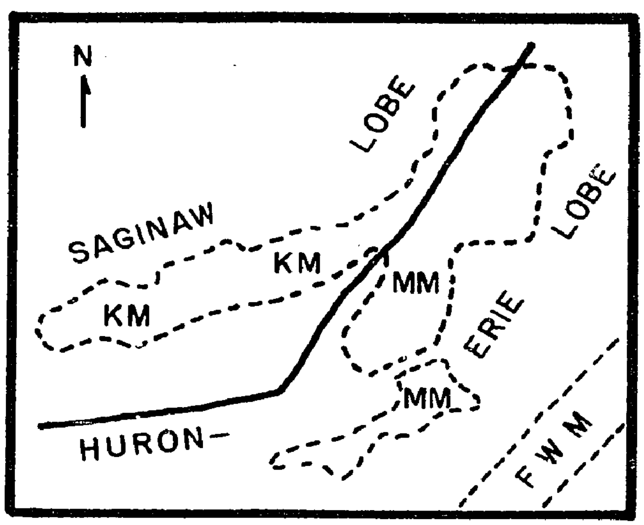
As a test of this interpretation, samples of till and underlying outwash were obtained from two such sites (234-- SW¼SE¼SW¼ sec. 19, T. 2 S., R. 4 E.;and 146-- SW¼SW¼SW¼ sec. 12, T. 3 S., R. 3 E.; Kneller's sites 22 and 18, respectively) and studied by X-ray diffraction. Clay-sized particles from the till and outwash at site 234 produced 7Å/10Å peak height ratios of 0.79 and 0.84, respectively, indicating a Huron-Erie Lobe provenance for both sediments. Conversely, pebble-count data from the site "strongly suggests" (Kneller, 1964, Table 1) that the outwash deposit is of Saginaw provenance. The till and subjacent outwash at site 146 yielded 7Å/10Å ratios of 0.53 and 0.59, respectively, also clearly indicative of Huron-Erie Lobe provenance. Interpretation of the pebble lithology of this deposit is inconclusive and does not permit assigning a lobe provenance to the outwash (Kneller, 1964, Table 1). A third site (143-- NW¼NW¼NW¼ sec. 22, T. 3 S., R. 3 E.) with till stratigraphically above outwash, and not studied by Kneller, produced 7Å/10Å ratios of 0.90 and 1.00, respectively. This suggests that the sediments are Huron-Erie till over Saginaw Lobe outwash. Thus, 7Å/10Å ratios at this site seem to indicate that the margins of the Saginaw and Huron-Erie Lobes were, for a time, located farther to the east near the Fort Wayne Moraine, possibly as shown on Figure 36. Peak height ratios at the other two sites support the interpretation that the margins were located as shown on Figure 37. Further investigation is needed to solve this problem and to determine whether the Saginaw and Huron-Erie margins changed position significantly before the ice along the final



LOBE MARGIN
KM KALAMAZOO MORAINE
MM MISSISSINEWA MORAINE
FWM FT. WAYNE MORAINE
--- MORAINE BOUNDARY

0 5 mi APPROXIMATE SCALE 0 10 km

Figure 36. Possible Location of Saginaw and Huron-Erie Lobe Margins Prior to Cessation of Flow



LOBE MARGIN
KM KALAMAZOO MORAINE
MM MISSISSINEWA MORAINE
FWM FT. WAYNE MORAINE
--- MORAINE BOUNDARY

0 5 mi APPROXIMATE SCALE 0 10 km

Figure 37. Location of Saginaw and Huron-Erie Lobe Margins at Cessation of Flow

interlobate contact stagnated and ablated.[2]

Phases of Deglaciation

The final events in the deglaciation of the study area took place in several phases beginning with the deglaciation of the terrain overlying the sandstone tableland. Subsequently the events moved north and east with the retreat of the margins of the Saginaw and Huron-Erie Lobes. The deglaciation process may be divided into five phases:

1A. Formation of the Grass Lake Plain[3]

1B. Formation of the distal flanks of the moraines

2. Formation of the proximal flanks of the moraines

3. Retreat of the margins from the moraines

4. Completion of the deglaciation process

5. Postglacial modification of the landscape

Phase 1A-- Formation of the Grass Lake Plain

Topographic profiles show that the crest elevations of the higher hills on the Grass Lake Plain are successively lower to the south from the crest of the Kalamazoo Moraine and to the west and northwest from the Mississinewa Moraine. On this basis the hills are interpreted to represent remnants of a former surface of glaciofluvial deposition associated with the two moraines (Figure 38). In addition, the average grain size of sediments associated with the plain tends to decrease with

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[2]Although the spatial relationships of the two lobes are not clear during this prelude to deglaciation, their relative positions can be delimited with much more confidence during several of the succeeding events.

[3]Phases 1A and 1B were essentially contemporaneous and are presented separately to simplify the description of the deglaciation sequence.

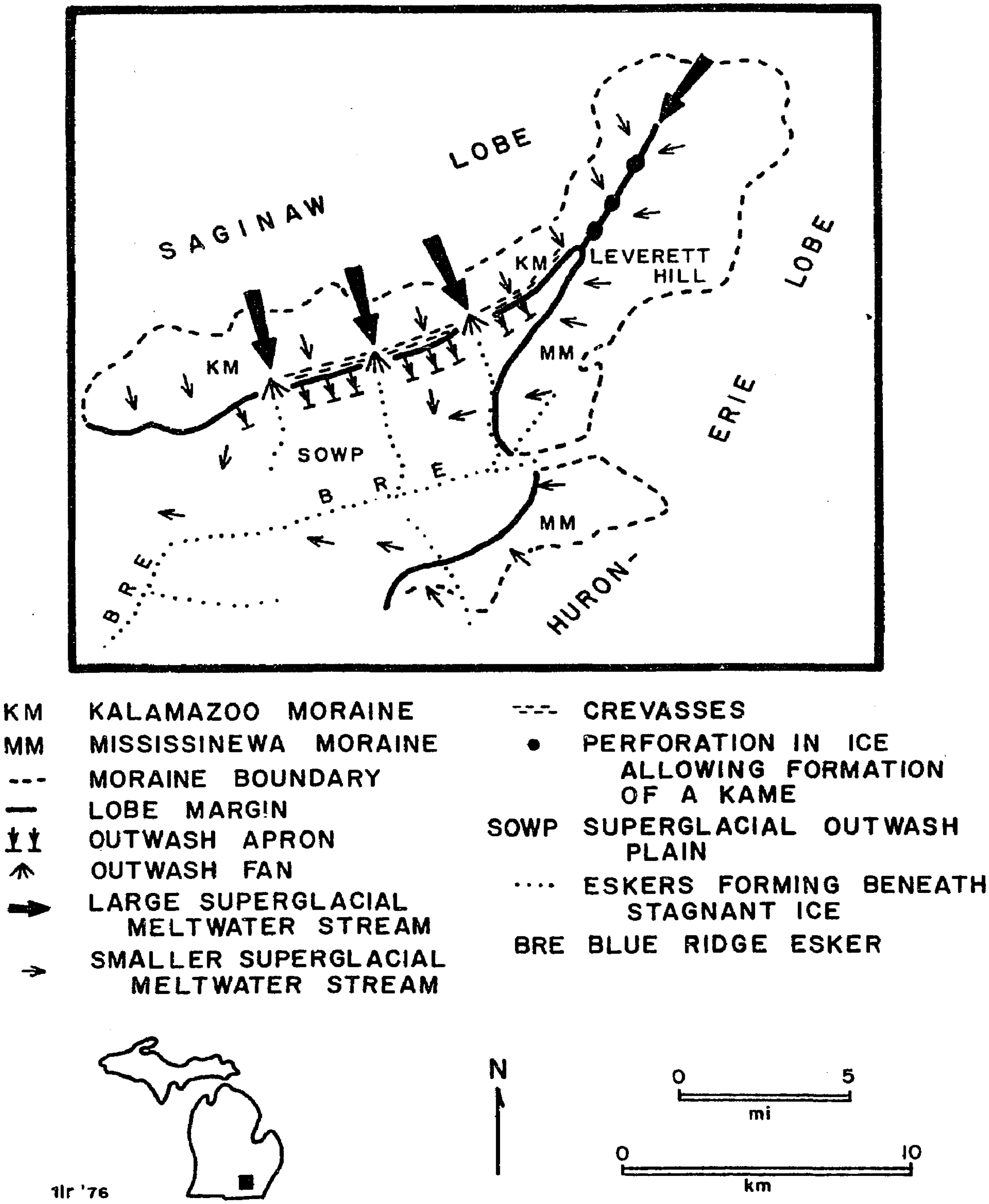

Figure 38. Phases 1A and 1B

distance from the moraines. Both of these lines of evidence indicate that the Grass Lake Plain is a complex outwash plain formed concomitantly with the Kalamazoo and Mississinewa Moraines.

Evidence that masses of stagnant ice existed in the Grass Lake Plain area at the time the sediments were deposited is widespread and is illustrated by the following:

1. The Wolf Lake-Center Lake chain of lakes indicates that stagnant ice was associated with the Norvell bedrock valley.
2. Numerous depressions are present on the periphery of the Grass Lake Plain.
3. Ice-contact features such as breached and notched ridges and channeled plateaus exist within the plain.
4. Shallow linear depressions exist even on the flattest portions of the plain, indicating that sand and gravel was deposited in contact with stagnant ice.
5. Perhaps the strongest evidence for the existence of widespread stagnant ice is the presence of the Blue Ridge Esker and associated tributary eskers which form a dendritic pattern trending across the entire plain.[4] The areal pattern and the interrelated nature of the eskers indicate the presence of an integrated drainage system in and beneath stagnant ice of both the Saginaw and Huron-Erie Lobes.

The relationship of eskers and associated esker troughs to the Grass Lake Plain also indicates that it is not simply an outwash plain deposited in an area containing previously formed eskers. If such were the case, the esker troughs would have been filled by the subsequent

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[4] It is generally conceded that most eskers form in contact with stagnant, not active, ice (Embleton and King, 1968, p. 389).

glaciofluvial deposition which formed the plain. Instead, the troughs, and other evidence for glacial stagnation discussed previously, indicate that glaciofluvial sediments from the moraines were deposited on a thin sheet of stagnant ice[5] penecontemporaneously with the formation of the Blue Ridge Esker and its tributary segments (Figures 38 and 39). Subsequent ablation of the ice superimposed the superglacial sediments onto the subjacent material and eskers, preserving the subglacial forms even though covering them with a veneer of sediments (Figure 40). The ablation of the ice and lowering of the superglacial sediments onto the subjacent material also formed the Grass Lake Plain, which is probably best described as a collapsed outwash plain.

Phase 1B-- Formation of the Distal Flanks and Medial Portions of the Moraines and Leverett Hill

Contemporaneously with the formation of the superglacial outwash plain, numerous superglacial meltwater streams deposited the outwash apron of the Kalamazoo Moraine. In addition, several large superglacial meltwater streams formed the outwash fans which are built up above the general level of the apron (Figures 31 and 38). These larger streams then drained southward within and beneath the stagnant ice of the Grass Lake Plain and were associated with the formation of the Gilletts Lake, Grass Lake, and Francisco Eskers. Their configuration shows that each of these streams joined the trunk esker stream which formed the Blue Ridge Esker. The close association of the outwash fans and the eskers, and the location of the fans on the outwash apron, which in turn grades into the Grass Lake Plain, indicate that all of the features formed at

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[5] Relations of the eskers and features in the moraines (discussed in Phase 1B) indicate that the subglacial drainage which deposited the eskers was probably flowing at the same time the superglacial outwash plain was being deposited.

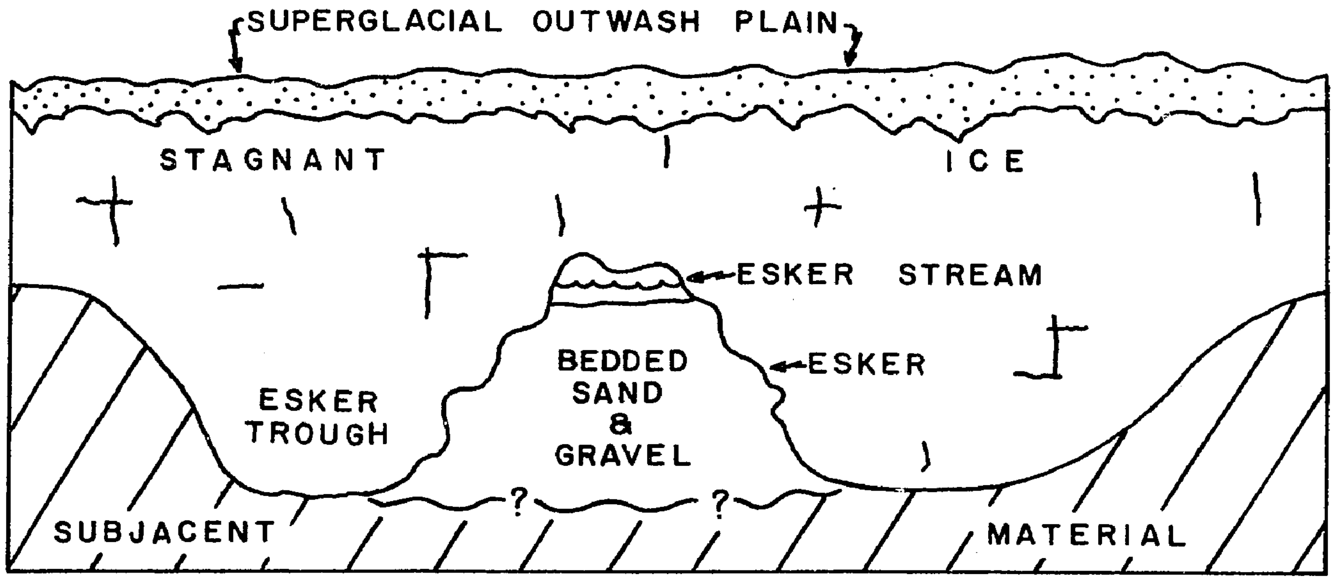

Figure 39. Simultaneous Formation of Superglacial Outwash Plain and Esker

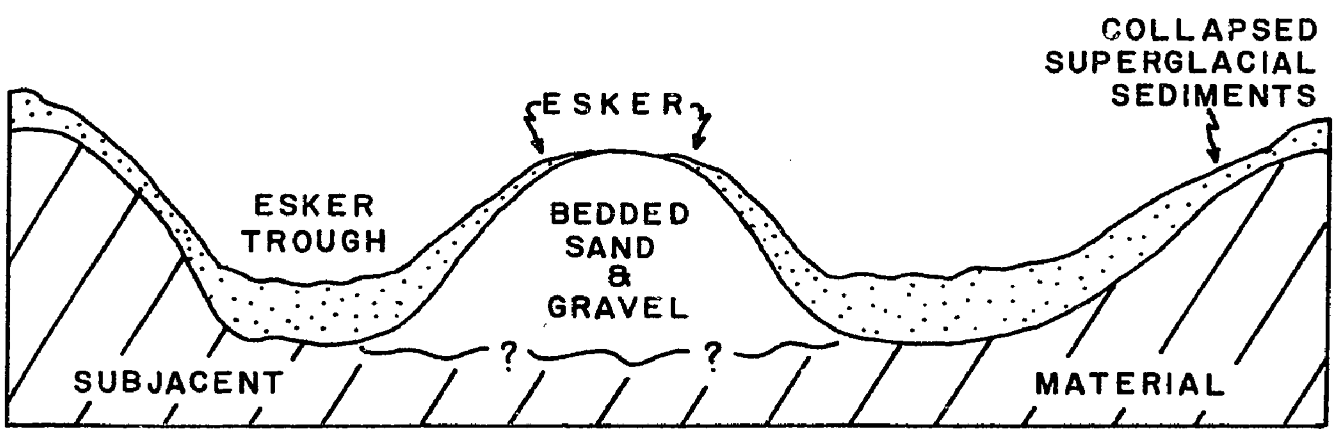

Figure 40. Site of Figure 39 After Deglaciation

approximately the same time.

Simultaneously, fractures in the ice parallel to and near the Saginaw Lobe margin were enlarged, and glaciofluvial sediments were deposited within them. With deglaciation these crevasse fillings became ridges, and the adjacent masses of ice melted to form a zone of linear depressions and ridges proximal to the crest of the Kalamazoo Moraine.

At this time a large tract of stagnant ice was situated to the north in an area that was to become the zone of lakes and bogs in the medial portion of the moraine. Glaciofluvial sediments deposited in scattered perforations in the ice eventually formed kames. Lakes and bogs mark the former location of larger ice masses which persisted long enough to prevent significant amounts of deposition. Along the contact between active and stagnant ice, probably located a short distance to the north, shearing of ice resulted in the formation of englacial debris bands. Subsequent ablation of the ice matrix permitted water-saturated meltout till to move downslope as flow till, which was then deposited on the kames after glaciofluvial deposition had slowed or ceased.

Subaerial glaciofluvial processes were also important along the margin of the Huron-Erie Lobe, resulting in the deposition of large amounts of sand and gravel in contact with stagnant ice. In addition, subglacial streams deposited the Goose Lake, Tucker Lake, and Stony Lake tributary eskers and the Blue Ridge trunk esker. The upstream portion of the Blue Ridge Esker was probably formed at this time by subglacial meltwater flowing west out of the Mill Creek lowland. The intricate association of all the eskers with features in both the Kalamazoo and Mississinewa Moraines and the association of the outwash plain with the moraines clearly show that this assemblage of features was formed at about the same time and reflects different aspects of the subglacial and superglacial drainage systems of the two glaciers.

The location of Leverett Hill at a reentrant site between the two lobes, its gradual slope to the southwest, and the steep ice-contact slopes on its northwest and southeast flanks indicate that the meltwater and sediments which formed it were supplied by both lobes. This is apparent because the continuous ice-contact slope near the crest of the Kalamazoo Moraine merges with a similar slope on the northwest flank of Leverett Hill. Also, the ice-contact slope on the southeast flank of Leverett Hill merges with the ice-contact slopes along the distal flank of the Mississinewa Moraine, proving those portions of the two moraines to be truly time-correlative.[6]

There is also evidence that a tract of stagnant ice was situated along the interlobate contact to the northeast of Leverett Hill and perforations in it were filled with glaciofluvial materials. When exposed by ablation, these features resulted in kame-like forms now known as Riley, Stofer, and Heatley Hills.

Phase 2-- Formation of the Proximal Flanks of the Moraines and Russell Hill

The northern zone of linear depressions in the Kalamazoo Moraine, Hankard and Shanahan Hills, Prospect Hill "A," and several sets of linear depressions in the Interlobate Morainic Tract form a zone which is aligned with, and in proximity to, the northwest flank of Russell Hill (Figure 41). If the crest of the Mississinewa Moraine is extended north into the Interlobate Morainic Tract, it is in line with the

[6]Farrand and Eschman (1974, p. 38) state that the Mississinewa and Kalamazoo Moraines were formed about 14,800 years ago.

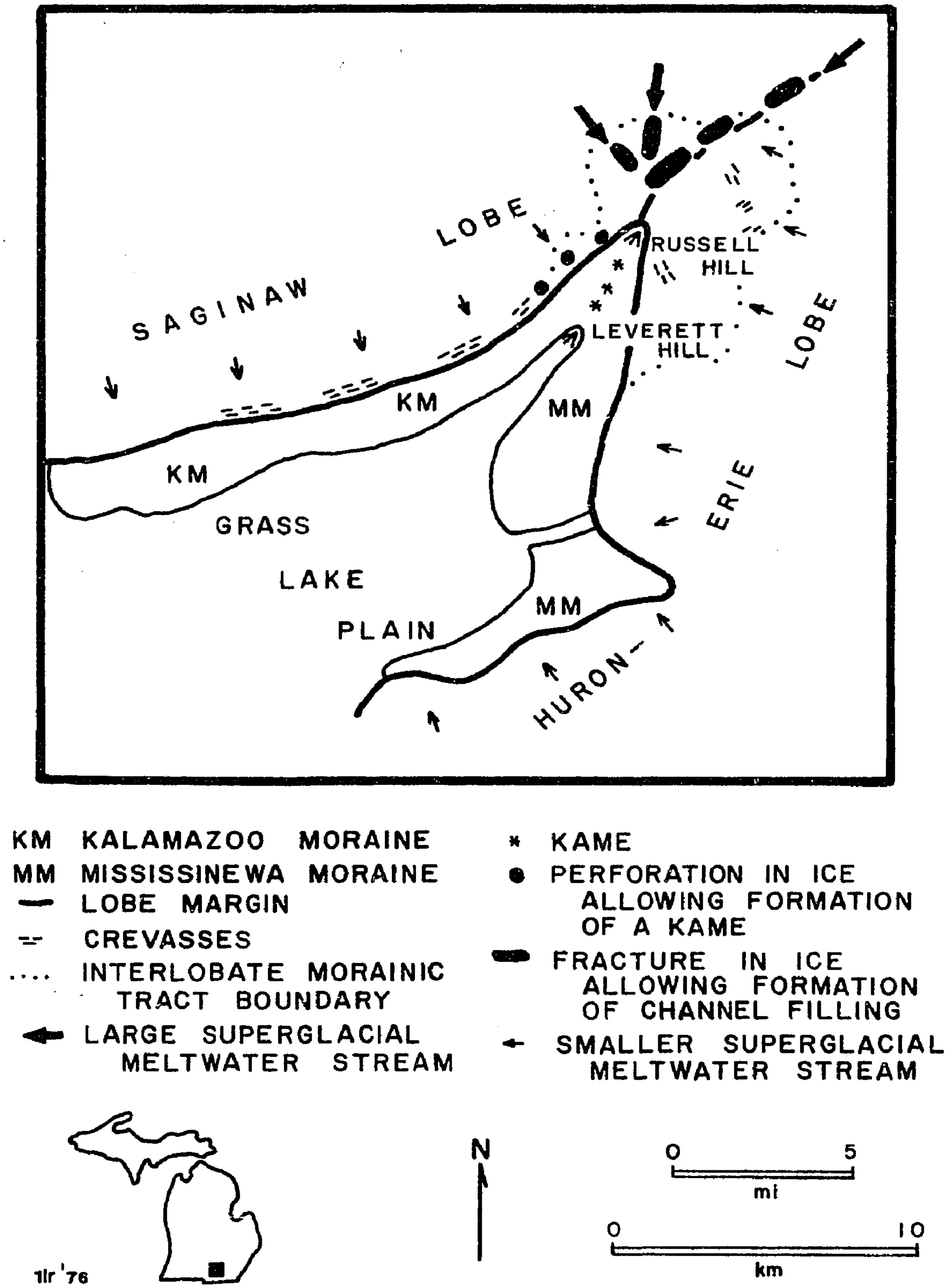

Figure 41. Phase 2

northeast flank of Russell Hill. These spatial and morphologic relations, X-ray diffraction data on clay-sized particles, associated sediment type, southwest slope, and ice-contact flanks of Russell Hill closely resemble those of Leverett Hill and indicate a similar genesis for the two features. Thus, it is reasonable to conclude that Russell Hill was formed by meltwater deposition at a location between stagnant masses of ice associated with the Saginaw and Huron-Erie Lobes. Upstream from this reentrant sediment-laden meltwater flowed on stagnant ice in the zone of the interlobate contact, enlarging fractures and depositing the sediments that now form the chain of large channel fillings located between Pinckney and Russell Hill.[7]

The two different landform assemblages in the Interlobate Tract--channel fillings and outwash fans in the Saginaw Lobe portion and crevasse fillings and intragroup variability of linear depression orientation in the Huron-Erie portion-- indicate that conditions were somewhat different on either side of the interlobate contact. However, conditions were not entirely dissimilar because both portions of the Interlobate Morainic Tract have (1) ice-contact glaciolacustrine sediments, (2) large amounts of ice-contact glaciofluvial sediments and (3) an abundance of ice-contact slopes, indicating the existence of a stagnant-ice environment. The dry perched channels and breached ridges in the area clearly indicate that stagnant ice supported superglacial streams capable of erosion after deposition of the sediments.

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[7]The corresponding landforms associated with Leverett Hill are kamelike, are considerably smaller, and include Riley, Stofer, and Heatley Hills.

Phase 3-- Retreat of the Margins from the Moraines

During this phase of the deglaciation sequence,[8] the outermost ice of the Saginaw Lobe was stagnant in the western portion of the study area but active in the east (Figure 42). West of Brill Lake numerous ice-contact slopes, an ice-contact feature comprised primarily of flow till, and an outwash fan appear to be indicative of deposition in association with stagnant ice. East of Brill Lake, on the Portage River lowland, a linear series of hills with large amounts of surficial till and a general lack of ice-contact slopes were probably formed by an active Saginaw Lobe margin.

A somewhat similar situation may have existed in the Huron-Erie Lobe. The linear depressions and ridges in the Sharon Short Hills indicate deposition in crevassed, stagnant ice. A bouldery tract trends northeast-southwest across Tps. 2 and 3 S., R. 4 E.,[9] and if extended, this tract intersects the Sharon Short Hills, which have a similar northeast-southwest trend. Several hills and meltwater channels are also associated with the bouldery tract. Thus the margin of the Huron-Erie Lobe may have been stagnant near the Sharon Short Hills but active to the northeast.[10] Russell and Leverett (1908, p. 6) made a somewhat

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[8]The contact between the Saginaw and Huron-Erie Lobes was not located in the study area in this phase and does not seem to be marked by converging, contiguous morphologic features (see Russell and Leverett, 1908, and Leverett notebook 188, p. 33). For this reason it is not possible to state with certainty whether the landforms associated with the two ice margins described below were deposited at exactly the same time.

[9]Russell and Leverett (1908) also map this tract continuing north along the west bank of the Huron River to a point 3 miles (4.8 km) northwest of Dexter. Although a search was made for boulders in this area, few were found.

[10]The Lima Esker trends southeast-northwest across T. 2 S., R. 4 E. Its orientation indicates former ice flow most probably to have been

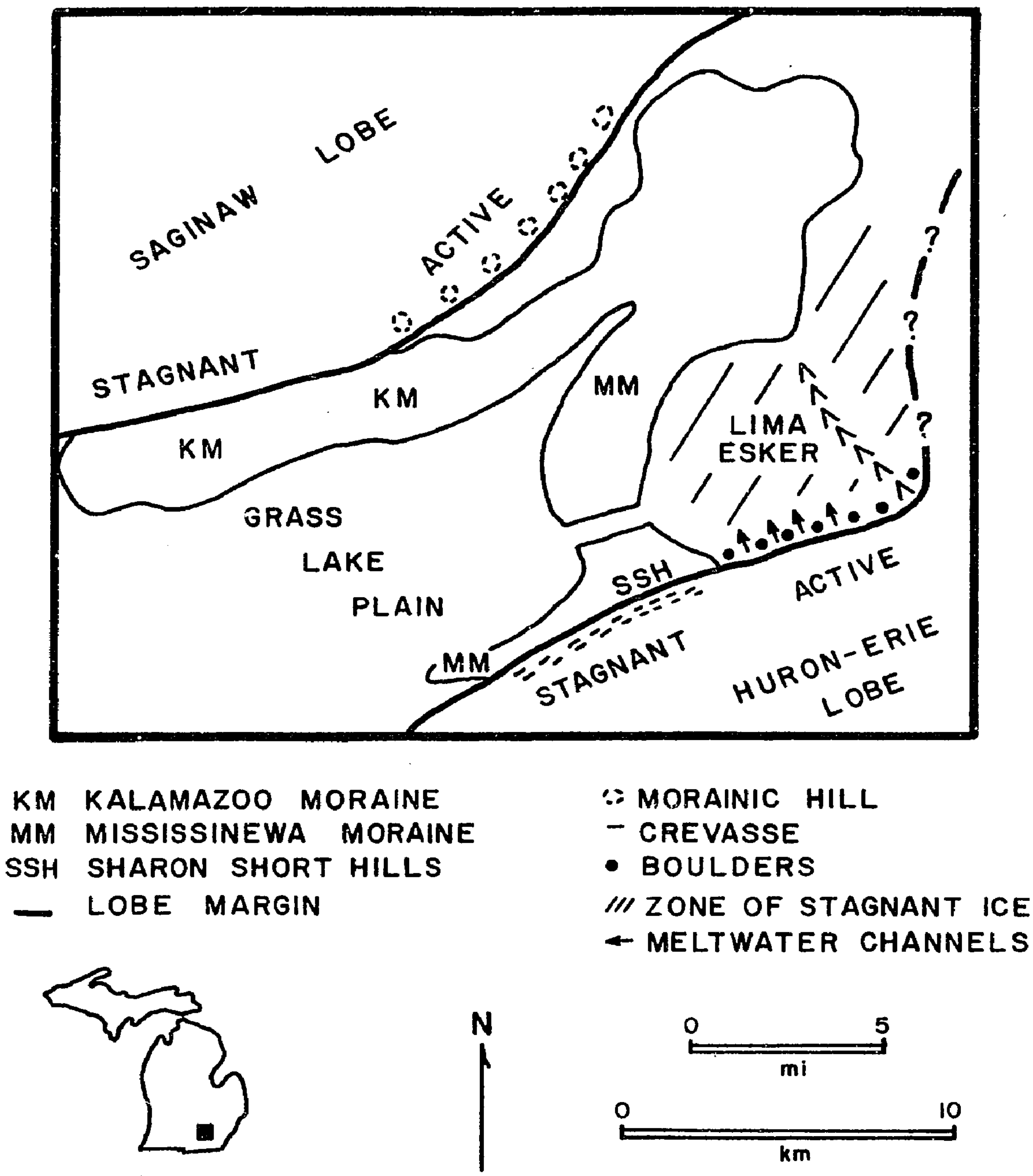

Figure 42. Phase 3

similar interpretation and stated that the bouldery tract may mark a "brief halt" in the retreat of an active margin of the Huron-Erie Lobe.

Phase 4-- Completion of the Deglaciation Process

There is evidence for at least two marginal positions of the Saginaw Lobe in the area to the north of the Kalamazoo Moraine (Figure 43). Study of topographic maps and air photos, as well as field reconnaissance, indicates the presence of linear tracts of higher-relief topography, which may be interpreted to be morainic in origin.[11] If this interpretation is correct, it indicates that the margin of an active glacier may not have continuously retreated to a position marked by the Charlotte Moraine (the next Saginaw Lobe moraine to the north) but may have halted temporarily at least twice or even readvanced. Eskers, which are evidence of stagnant ice, also exist in the area. This indicates that marginal stagnation took place after deposition of both the bouldery, undulating tracts and that the eskers were then formed in the stagnant ice masses.

The exact position of the Huron-Erie Lobe margin during this phase is not known. With the exception of the bouldery tract near the Lima Esker described previously, there is little evidence of ice-marginal deposition in the territory between the Mississinewa Moraine and the adjacent moraine to the east (the Fort Wayne Moraine).

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southeast-northwest, but it also indicates the former presence of stagnant ice distal to the bouldery tract. It may be that a mass of stagnant ice was present from the proximal side of the Mississinewa Moraine to the bouldery tract which was deposited by an active ice margin. Retreat of this active margin with little stagnation probably took place until the position of the Fort Wayne Moraine was reached.

[11] Leverett (notebooks 31, p. 84; 160, p. 98; 275, pp. 89,93) made a similar interpretation and also recorded the presence of numerous boulders in these tracts.

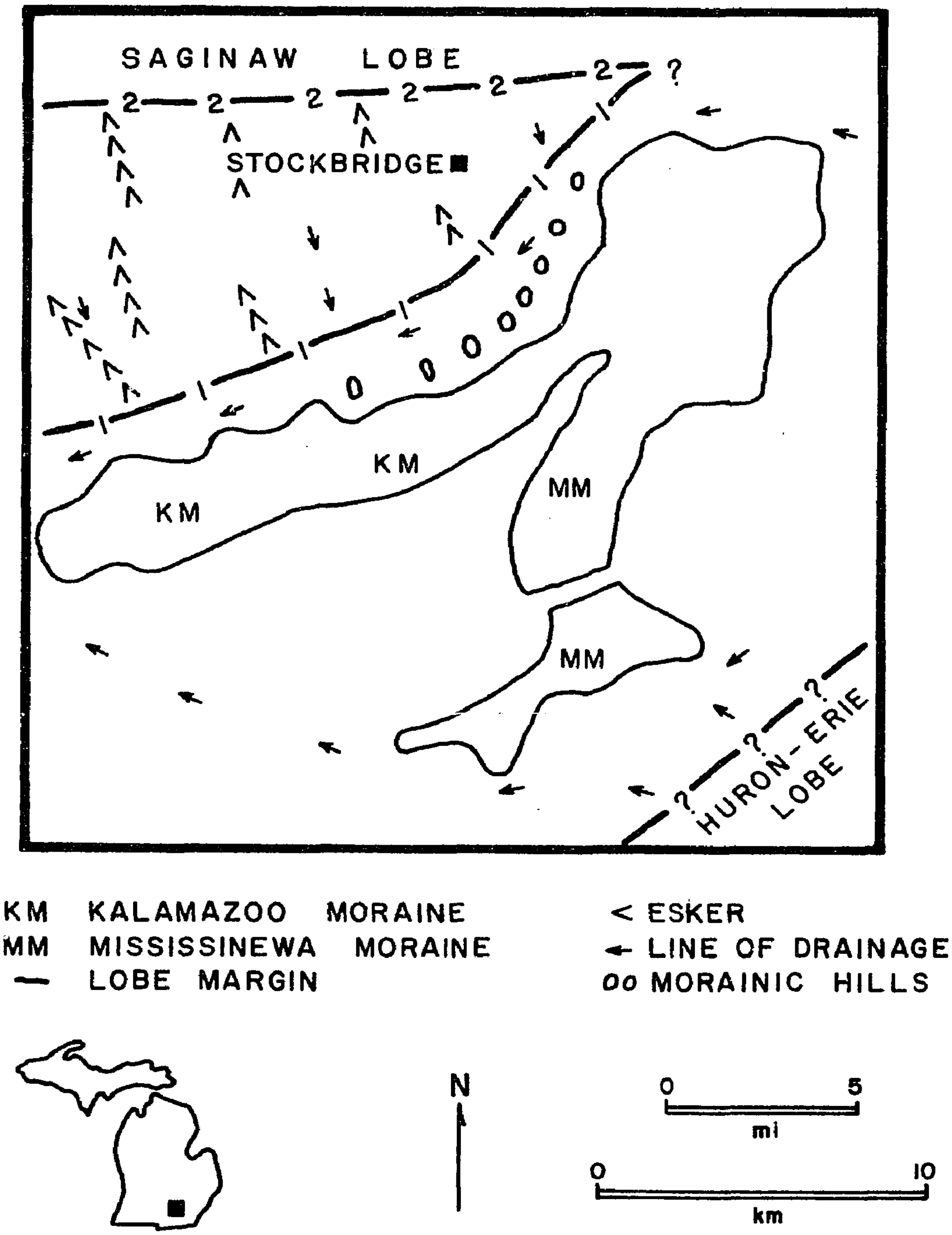

Figure 43. Phase 4

The ablation of buried ice took place during all of the four phases of deglaciation. It is known that the ablation rate of buried ice may be quite slow (Embleton and King, 1968, p. 394, and Flint, 1971, p. 213). Blind, Halfmoon, and South Lakes in the Interlobate Morainic Tract are all more than 80 feet (24.4 m) deep. If the masses of ice which melted to form these and other depressions were buried beneath drift, the ablation process may have required a considerable time span before the melting of all the glacial ice was complete. Until all this buried ice melted, the glacial landscape was still in the process of formation, even though the margins of the glaciers may have retreated significant distances and were no longer altering the topography or directly depositing material in the area.

As the margins of the Saginaw and Huron-Erie Lobes reached the positions now marked by the Charlotte and Fort Wayne Moraines, meltwater continued to drain through certain parts of the study area. Drainage from the interlobate contact, located to the northeast, flowed southwest along the present course of the Huron River and then west along the channel at Pinckney and the Portage River lowland to the Grand River. Meltwater from the Charlotte Moraine flowed south before merging with this line of drainage. Large amounts of meltwater which drained, in part, northwest along the lowland between Norvell and Jackson were associated with the deposition of surficial materials on the Fort Wayne Moraine. In addition, with final deglaciation and the removal of certain ice barriers, the direction of flow of several rivers, such as the Grand and Raisin, was reversed, and they began draining in the directions prevailing today.

Phase 5-- Modification of the Landscape Since Deglaciation

Postglacial modification of the landscape since deglaciation has been relatively minor. The numerous lakes and swamps indicate that integration of drainage is not well developed. Entrenchment along the major streams of the area is generally limited to 30 feet (9.1 m) or less and may be partially the result of glaciofluvial erosion. Marl has formed in some of the lakes (Russell and Leverett, 1908, p. 13), and organic matter in the form of muck and peat has partially filled some of the poorly drained depressions. Leaching of carbonates in the drift has lowered the surface altitude a few feet (1 m) but it certainly has not significantly affected the landforms. Slope modification appears to have been minimal, and most ice-contact slopes are well defined and at, or near, the angle of repose.

Chapter 6

CONCLUSIONS AND IMPLICATIONS

This dissertation has four major objectives, set forth in Chapter 1. The conclusions of this investigation are presented below as they relate to these objectives.

The first objective (p. 1) is "To determine what relationship, if any, exists between the nature of the bedrock surface beneath the drift and the glacial landforms of the study area." Findings of this study indicate that the character of the bedrock surface has had a significant effect on the glaciation of the area. The remarkable correspondence in shape and location of the moraines, even in certain details, with the north and east sides of the buried sandstone tableland is an illustration of the influence the bedrock surface has had on the larger geomorphic features of the area. The location, shape, and trend of certain streams and lakes above deeply buried bedrock valleys show that the bedrock surface has also influenced some of the smaller components of the existing topography to a considerable degree. It seems quite likely that in some locations masses of ice were buried within the confines of the bedrock valleys and later melted to influence the hydrography of the area. Apparently buried ice also protected organic matter and subaerially oxidized drift located in the lowest portions of the landscape which existed prior to the latest glaciation of the area. Therefore, not only did the configuration of the bedrock surface serve to influence the location of the two moraines and several hydrographic features, but it also was responsible for the preservation of certain sediments thus proving multiple glaciation of the area.

The second purpose of this dissertation is "To determine the characteristics, extent, and contact relationships of the surficial drifts associated with the Saginaw and Huron-Erie Lobes and to specify on what basis the drifts may be identified and delineated." Most of the physical characteristics of drifts associated with the two lobes are so similar that it is very difficult or even impossible to identify and differentiate many samples of drift and their lobe provenance. However, this study has established that the clay mineral suites associated with the two lobes are sufficiently different that the lobe provenance of a drift sample may ordinarily be determined with a high degree of confidence by means of X-ray diffraction. It was established that the 7Å/10Å peak height ratio for Saginaw Lobe drift is 0.91 or greater and is 0.90 or less for Huron-Erie drift. This fact may prove to be very helpful at the Saginaw/Huron-Erie interlobate contact in other areas where morphologic evidence for the location of the contact is obscure. Within the Interlobate Morainic Tract the drift contact may be delineated in a detailed fashion and apparently there is little or no interdigitation of the two drifts at the surface.

Another objective of this thesis is "To determine the characteristics, relationships, and assemblages of the various landforms in and near the interlobate area." Research has shown that one landform assemblage consisting of outwash apron, outwash fans, and linear depressions and ridges exists within the Kalamazoo Moraine. Outwash fans, large channel fillings and linear depressions trending northeast-southwest are characteristic of the Saginaw Lobe portion of the Interlobate Morainic Tract. The Huron-Erie Lobe segment of the Interlobate Morainic Tract has crevasse fillings and also linear depressions with large amounts of intergroup orientation variability. Distinctive landforms in the Mississinewa Moraine include eskers, drainageways, numerous small dry channels, and limited numbers of linear depressions and ridges. The most conspicuous landform assemblage of the Grass Lake Plain is the complex system of trunk esker (Blue Ridge) joined by a number of tributary eskers extending from both moraines. Two landform types are distributed throughout much of the study area and may be described as breached and notched ridges and channeled plateaus. Areal relationships and characteristics of certain landforms in the area prove that the distal portions of the Kalamazoo and Mississinewa Moraines are time-correlative and strongly suggest that the medial or proximal portions of the moraines are also time-correlative.

The final stated purpose of this dissertation is "To determine, on the basis of landforms and sediments, the nature of deglaciation in the area and its effects on the landscape." The distinctive landform assemblages in the area most likely are the result of differing conditions in the Saginaw and Huron-Erie Lobes. The prevalence of ice-contact slopes indicates that stagnant ice was widespread during deglaciation. Eskers located both north and south of the Mill Creek lowland and the Sharon Short Hills in the Mississinewa Moraine, kames, channel fillings, crevasse fillings and similar features in the Interlobate Morainic Tract are also evidence of stagnant ice. Furthermore, the Kalamazoo Moraine is not simply an end moraine formed by an active glacier. It is, at least for the most part, an accumulation of glaciofluvial sediments and flow till deposited in contact with stagnant ice. Southward-draining superglacial streams formed an outwash apron on the distal side of the moraine, and especially large streams deposited outwash fans that may be traced to the crest of the moraine. These streams and subglacial meltwater from the area of the Mississinewa Moraine flowed south and west and established a drainage system in and beneath stagnant ice of both lobes. The Blue Ridge Esker and its tributary eskers on the Grass Lake Plain are associated with features in both moraines and are the product of these streams. Conversely, active ice was probably responsible for the linear groups of hills and boulders in the area proximal to the moraines. Thus, although some secondary characteristics are due to active ice, the basic nature of the landscape was determined largely by the stagnant ice conditions which prevailed during the final deglaciation of the area.

In recent years study of the rock-stratigraphy of glacial sediments has been given increasing attention and has resulted in significant findings. Numerous separate and significant drift sheets have been identified in many areas and each may be associated with several moraines. At the same time, landforms may have become "less 'interesting'" (White, 1973, p. 26) to some as attention was concentrated more and more on rock-stratigraphy (White, 1973, pp. 26-27) in the belief that sedimentary characteristics provide more reliable results. Frye and Willman (1962) recognized the possible significance of landforms in the study of Pleistocene stratigraphy with their proposal to formally recognize morphostratigraphic units within stratigraphic nomenclature. In fact, in situations where the rock-stratigraphy is similar or identical over extensive areas the details of deglaciation may be best revealed by the nature of topographic forms and their related sediments.

This dissertation has clearly demonstrated that for an area in southeastern Michigan it is possible to map an interlobate contact by means of both morphology and rock-stratigraphy. In fact, the results obtained by (1) mapping of landforms and (2) analysis of clay minerals by X-ray diffraction are corroborative indicating that, in some areas at least, the careful study of surface form may be at least as revealing as the investigation of sediment characteristics. In addition, it has been shown that certain topographic characteristics are also indicative of the nature of deglaciation in the area. It is evident that several modes of investigation may provide more reliable results than one. Hence, those who are concerned with the nature of glaciated areas should consider use of all proven techniques which deal with morphology as well as those that provide meaningful information regarding sediments.

Suggestions For Further Research

During the course of this investigation it became clear that certain topics merit additional consideration. (1) Radiocarbon dating of samples of the deeply buried organic matter may provide information on the age of the weathering surface(s?) found in the bedrock valleys and supply additional information on the glacial chronology of the area. (2) Study of topographic maps suggests that several of the northeast-southwest and northwest-southeast trending lakes and streams of south-central Michigan, such as in Branch and Kalamazoo Counties, seem to have characteristics similar to the Wolf Lake-Center Lake chain of features in the study area. Thus, they may also be associated with buried bedrock valleys. Construction of bedrock maps for that and similar areas may reveal a bedrock valley-hydrography relationship and possibly the existence of buried oxidized drift and organic matter. (3) The use of 7Å/10Å peak height ratios appears to be a powerful tool for differentiating Saginaw and Huron-Erie drift in Jackson and Washtenaw Counties.

If this 7Å/10Å relationship is applicable outside the study area, and limited evidence presented by Mahjoory (1971) and Ogunbadejo and Quigley (1974) seem to support this possibility, it may be possible to identify the Saginaw/Huron-Erie drift contact in other portions of the state where morphological evidence is not clear-cut, such as in Hillsdale and Branch Counties. (4) By applying the X-ray diffraction technique to the clay-sized particles in subsurface till in the study area, it may be possible to determine the relationships between the Saginaw and Huron-Erie Lobes during the time preceding final deglaciation of the area. (5) Sediments recognized in the study area and limited reconnaissance of the Saginaw/Huron-Erie interlobate area in eastern Livingston and western Oakland Counties indicate the presence of considerable quantities of flow till. Mapping the distribution of this sediment will help to determine the nature of the deglaciation environment. (6) Large channel fillings, breached and notched ridges, channeled plateaus, crevasse fillings, and small outwash fans similar to those of the study area are evident on topographic maps of eastern Livingston and western Oakland Counties. Thus, the distribution of these landforms is not limited to the study area and further study and mapping of them are needed to determine if the characteristic assemblages are present elsewhere along the Saginaw/Huron-Erie drift contact.

APPENDICES

APPENDIX A

COMPILATION AND CONSTRUCTION OF BEDROCK-SURFACE AND DRIFT THICKNESS MAPS

Map Compilation

Figures 3, 4, and 7, showing bedrock lithology, bedrock surface, and drift thickness, respectively, are based on data from 1,482 points. Of these, 893, or 60 percent, represent well records on file at the Water and Environment Section of the Geological Survey of Michigan in Lansing. Most are water-well records dating from the late 1960s to the present, although some oil and gas wells are also included. Data from the remaining 589 points are from the several sources listed on Table 9.

Data were obtained from three or four records per survey section within much of the area. In those sections where wells are numerous, one record from each quarter-section was selected, if possible. In areas where a major valley exists on the bedrock surface, as many as ten records per section were utilized, if available, to delineate better the nature and extent of the feature.

Most of those who have developed water wells within the area have had little or no formal training in the technical interpretation of sediment type and characteristics, and as a result their well records may be difficult to interpret. For example, many records list "gravelly clay," "sandy clay," "gravelly shale," "stony clay," or simply "clay" at the surface. By comparing these records with information from soil maps and personal observation, it is apparent that the sediment described with these terms is glacial till. Consequently, when drillers have recorded "gravelly shale," "stony clay," or a similar sediment, that unit is interpreted most likely to be till.

Table 9. Well Record Data Sources

Township	Range	Total number of data points	Records from Michigan Geol. Survey	Barwick (1958)	Interviews	F. Leverett field notes	Martin & Straight (1958)	Moore (1959)	Kunkle (1960)
				JACKSON COUNTY					
*1S	1W	40	28	12	-	-	-	-	-
1S	1E	99	63	36	-	-	-	-	-
1S	2E	60	27	31	2	-	-	-	-
*2S	1W	41	24	15	-	-	2	-	-
2S	1E	108	69	36	1	2	-	-	-
2S	2E	75	45	30	-	-	-	-	-
*3S	1W	48	29	19	-	-	-	-	-
3S	1E	177	118	59	-	-	-	-	-
3S	2E	124	89	32	2	1	-	-	-
*4S	1W	29	19	10	-	-	-	-	-
4S	1E	130	86	36	2	4	2	-	-
4S	2E	89	40	47	2	-	-	-	-
TOTAL		1,020	637	363	9	7	4	-	-
				LIVINGSTON COUNTY					
*1N	3E	83	47	-	-	-	-	35	1
*1N	4E	66	36	-	-	-	-	28	2
*1N	5E	54	33	-	-	-	-	17	4
TOTAL		203	116	-	-	-	-	80	7
				WASHTENAW COUNTY					
1S	3E	63	42	-	-	1	-	4	16
1S	4E	19	10	-	-	-	-	-	9
2S	3E	49	26	-	-	-	-	-	23
2S	4E	29	12	-	-	-	-	-	17
3S	3E	43	31	-	3	-	-	-	9
3S	4E	20	11	-	1	-	-	-	8
4S	3E	8	2	-	-	-	-	-	6
4S	4E	28	6	-	-	-	-	-	22
TOTAL		259	140	-	4	1	-	4	110
		1,482	893	363	13	8	4	84	117

* only a portion of township mapped

Drillers commonly report "shale" in the subsurface underlain by considerable amounts of sand and gravel. Almost certainly this "shale" is a resistant till overlying glaciofluvial materials.

In the interpretation of well records it is particularly difficult to identify a contact between till and shale. Some of the drillers in the area are aware of this problem but are probably not always successful in differentiating drift and bedrock.[1] A few of the oil-well records prepared by geologists examining cuttings indicate that they too experience occasional difficulty in identifying a till-shale contact.[2]

Drillers do not ordinarily case water wells for more than a short distance following penetration of bedrock. Therefore, the casing length of a well was sometimes used as a guide to help differentiate till and shale. On this basis it is assumed that the stratum in which the casing is terminated is bedrock and that overlying units are drift, even though identified as various types of "shale" by the driller. This assumption is supported by the observation that water-well drillers' "gravelly shale" is most often till, and review of well records also indicates that such a term is usually applied to units in the cased portions of wells. Conversely, sandstone and limestone units are only rarely cased. Therefore, in certain circumstances the use of water-well-casing data seems to serve as a useful guide in differentiation of till and shale on well records where the contact between drift and bedrock is not obvious. The practice is not without limitations, however, because at least two

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[1]Personal communications, Messrs. Dale Lindemann, December 17, 1974, and Melvin Fox, December 30, 1974.

[2]In Oakland County, Ferris, Burt, Stramel, and Crosthwaite (1954, p. 34) also remarked on the difficulty of recognizing the drift/bedrock contact in areas underlain by Coldwater Shale.

well records indicated the presence of wood in "shale" in uncased sections of wells. This suggests that at least in some circumstances resistant tills may not be cased by water-well drillers and are identified as "shale" on the well record.

Map Construction

The geographic location of each well was determined to the nearest ten acres and then identified by arbitrary grid coordinates. Altitude of the well head was determined from the most recent U.S. Geological Survey topographic map, and subsequently bedrock-surface altitude was calculated. Grid coordinates, drift thickness, and bedrock-altitude data were punched on data cards and submitted to the Michigan State University Control Data Corporation 6500 Series computer. The General Purpose Contouring Program (GPCP), developed by California Computer Products (Calcomp), was used. This program generates gridded data from information distributed at arbitrary points (well locations) by constructing a smooth surface passing through every data point. Contours are generated on that surface at the mesh points of the regular grid constructed by the computer. A Calcomp 963 incremental pen plotter constructed the maps at a scale of 1:63,360. The maps were then manually modified on the assumption that karst development was not a significant process affecting the bedrock surface. It is estimated that the position of about 80 percent of the contour lengths on Figure 4 and 98 percent of those on Figure 7 are shown exactly as calculated and drawn by the computer.

APPENDIX B

MINERALOGY OF CLAY-SIZED PARTICLES IN CERTAIN SAMPLES

The mineralogy of the sediments was examined by X-ray diffraction of oriented clay (less than 2 microns) samples from forty-nine till, nine glaciofluvial, three glaciolacustrine, three shale, and two sandstone specimens. Although the general procedures were the same for all specimens, the details of treatment varied slightly with sediment type. The major steps of the laboratory procedure (modified from Jackson, 1956) for till and glaciolacustrine sediments are described below in (1). Treatment of glaciofluvial sediments, sandstone, and shale is covered in (2), (3), and (4), respectively.

(1) Oxidized, unleached (presence of carbonates was determined in the field by treatment with 10% HCl), air-dry till or glaciolacustrine samples were passed through a 2 mm sieve after gentle crushing. Soluble salts and carbonates were removed by adding 1N sodium acetate (buffered to pH 5 with acetic acid) and heating the suspension for thirty minutes. Organic matter was removed by treatment with hydrogen peroxide (30%) and heating the suspension for thirty minutes. Free iron oxides were removed by reacting the samples with sodium citrate-bicarbonate-dithionite at 80°C. The sample was then transferred to a sedimentation cylinder and distilled water added. After thorough agitation with a plunger, the sample was permitted to stand twenty-four hours. A siphon removed the less-than-2-micron portion of the suspension. This fractionation was repeated once. A porous porcelain plate was placed on a vacuum flask, vacuum applied, and treated clay suspension deposited on the

plate. The clay film was leached with 0.1N magnesium chloride (10% glycerol by volume). The film was then washed with 10% glycerol, air-dried, and stored overnight in a dessicator. The sample was then ready for analysis as a magnesium-saturated, glycerol-solvated, basally-oriented film.

(2) Clay was obtained from oxidized, unleached glaciofluvial samples by wet-sieving (#300 sieve) and collecting the wash water which contained the clay in suspension. The suspension was suction-filtered through #50 filter paper. The solids trapped on the paper were then treated as outlined in (1).

(3) Clay was obtained from sandstone by gently crushing bedrock samples. The sediment was passed through a #300 sieve and then treated as outlined in (1).

(4) Clay was obtained from shale by gently crushing well cuttings. The sediment was placed in water, disaggregated with a sonifier, and then treated as outlined in (1).

The oriented samples were then placed in the X-ray diffractomator of the Department of Crop and Soil Sciences and exposed to nickel-filtered copper radiation. The resulting diffractograms are reproduced in Figure 44. The 7Å and 10Å peak heights were determined and the 7Å/10Å peak height ratios were calculated (Table 10).

Kaolinite, chlorite, vermiculite, and illite are the predominant clay minerals in the samples. Illite produces a 10Å peak, and the remaining clays produce a 7Å peak. The intensity of the 7Å peak is the result of the vermiculite, chlorite, and kaolinite either individually or in combination. Therefore, the 7Å/10Å ratio is not a complete mineralogical characterization but is only used to group the samples investigated. Because the diffraction intensities are obtained from the same diffractogram and a ratio of the intensities is utilized, comparisons can be made between different diffractograms without the use of an internal standard. In their study of the clay minerals of the Neuse River estuary in North Carolina, Griffin and Ingram (1955, p. 199) used peak height ratios and stated,

> It is realized that the use of intensities of (001) lines as a measure of absolute clay mineral abundances is open to many uncertainties; but as all the samples were handled in the same manner and as only ratios of intensities were used, the results ...are considered to be significant.

Till samples 122 (Huron-Erie Lobe) and 127 (Saginaw Lobe) received further treatment. They were potassium-saturated with 1N potassium chloride, dried, and X-rayed (Figure 44). This was followed by heating to 300°C and X-raying. After heating to 550°C, the samples were allowed to cool and then X-rayed once again. After heating to 550°C, the 7Å peak was very much reduced in intensity, indicating the presence of considerable amounts of kaolinite in relation to illite. On the basis of samples 122 and 127 it appears likely that Saginaw Lobe till tends to have larger relative amounts of kaolinite than Huron-Erie Lobe till and consequently higher 7Å/10Å peak height ratios.

The Student's t test was applied to determine if there are two populations present in the surficial till samples from the two moraines, their proximal areas, and associated portions of the Interlobate Morainic Tract. Test results indicate that two populations are present at a significance level of 0.0005.

TABLE 10. CLAY MINERALOGY, TEXTURE, & COLOR OF SELECTED SEDIMENTS

Site Number	1/4	1/4	1/4 Section	Section	Township	Range	Sediment Type	7Å Peak Height A	10Å Peak Height A	7Å/10Å Peak Height Ratio	Texture	% Sand	% Silt	% Clay	Color-Dry	Color-Moist
															10YR	
54	NW	NW	NW	30	3S	3E	T	27	33	0.82	sandy loam	53	31	16	7/3	5/4
71	NW	SE	SE	15	2S	1E	T	25	27	0.93	loam	42	32	26	7/4	5/4
72	NW	SW	NW	24	2S	1W	T	63	31	2.03	sandy loam	68	17	15	7/6	5/6
74	NW	SW	NE	20	2S	1E	T	25	22	1.14	sandy loam	59	28	13	7/2	5/4
76	SW	NW	SE	10	2S	2E	T	–	–	–	–	–	–	–	7/4	5/3
78	SE	SE	NE	6	2S	3E	T	41	39	1.05	sandy loam	53	29	18	6/4	5/4
79	NW	SW	SE	12	1S	3E	T	22	30	0.73	sandy loam	61	22	17	7/4	5/4
81	SE	SE	SW	15	2S	1E	T	–	–	–	sandy loam	71	21	8	7/4	5/6
83	NE	NW	SW	30	1N	4E	L	51	44	1.16	clay	3	26	71	7/3	5/4
85	SE	NW	SE	24	1N	3E	T	43	41	1.05	silty clay	11	44	45	7/3	5/4
89	SW	SE	NW	11	2S	2E	T	32	26	1.23	sandy loam	62	20	18	7/3	4/3
91	SE	SE	SE	1	2S	2E	T	–	–	–	–	–	–	–	7/3	5/4
96	NW	NW	SE	14	1N	4E	T	27	32	0.84	clay loam	33	30	37	7/4	6/4
97	NW	SW	NW	27	1N	4E	T	23	30	0.77	loam	41	34	25	7/4	5/4
100	NW	NW	NW	22	1S	4E	T	20	35	0.57	clay loam	43	28	29	7/3	4/4
101	NE	NW	SE	29	1S	4E	T	33	41	0.81	loam	45	29	26	7/3	6/3
102	SW	SE	SW	3	2S	3E	T	28	38	0.74	loam	45	29	26	6/3	4/4
104	SW	NE	SW	33	2S	3E	T	19	28	0.68	clay loam	42	31	27	7/3	5/4
106	SE	SE	SE	9	3S	3E	T	29	34	0.85	loam	45	33	22	7/4	5/4
118	NE	SW	SW	15	2S	3E	T	28	36	0.78	clay	21	32	47	7/3	5/4
122	SE	SE	NE	17	3S	4E	T	32	48	0.67	sandy loam	53	30	17	7/4	5/4
123	NE	NE	SW	14	2S	4E	T	22	25	0.88	sdy. cl. loam	49	25	26	7/4	5/6
124	SW	SW	SW	22	1S	5E	T	25	34	0.74	loam	46	29	25	6/3	4/3
126	SE	SW	SE	11	1N	3E	T	25	27	0.93	loam	51	30	19	7/3	5/4
127	SW	NE	NE	3	1S	2E	T	74	55	1.35	loam	5	30	25	7/3	5/4
129	NW	SE	SE	10	1S	1E	T	31	34	0.91	clay	25	29	46	6/4	4/4
132	SW	NW	SW	12	3S	1E	T	49	42	1.17	sandy loam	59	22	19	6/6	4/4
133	NE	SE	SE	2	4S	1E	T	31	45	0.69	clay	18	28	54	7/3	4/4
143A	NW	NW	NW	22	3S	3E	T	36	40	0.90	sdy. cl. loam	48	27	25	7/4	5/4
143B	NW	NW	NW	22	3S	3E	O	27	27	1.00	–	–	–	–	–	–
146A	SW	SW	SW	12	3S	3E	T	20	38	0.53	sdy. cl. loam	58	20	22	7/3	5/4
146B	SW	SW	SW	12	3S	3E	O	17	29	0.59	–	–	–	–	–	–
148	NW	SE	SW	32	2S	3E	T	29	35	0.83	loam	49	29	22	6/4	5/4
148A	NW	SE	SW	32	2S	3E	O	14	16	0.87	–	–	–	–	–	–
174	SW	SW	NE	9	1S	3E	L	48	44	1.09	silty clay	2	53	45	7/3	5/4
181	SE	SW	NE	26	1S	3E	T	36	42	0.86	sandy loam	59	28	13	7/4	5/4
182	SW	NW	NE	11	1S	3E	T	43	50	0.86	silty clay	5	44	51	7/3	5/4

TABLE 10. (cont'd.)

Site Number	1/4	1/4	1/4 Section	Section	Township	Range	Sediment Type	7Å Peak Height ▲	10Å Peak Height ▲	7Å/10Å Peak Height Ratio	Texture	% Sand	% Silt	% Clay	Color-Dry	Color-Moist
															10YR	
183	SW	SE	SW	2	1S	3E	T	42	29	1.45	loamy sand	81	13	6	7/4	5/4
189	NW	SE	NW	22	1S	3E	T	41	39	1.05	sandy loam	67	20	13	7/4	5/6
191	SE	SE	SW	2	1S	3E	T	–	–	–	sandy loam	56	38	6	7/3	5/4
201	NE	NE	SW	20	1N	4E	T	43	32	1.31	sandy loam	73	12	15	7/3	6/6
202	SE	NE	NE	7	1S	4E	L	27	42	0.64	sty. cl. loam	4	61	35	7/4	5/4
208	SE	NE	SE	25	2S	2E	T	19	29	0.65	sandy loam	57	30	13	7/4	4/4
211	NE	SW	NW	20	3S	2E	T	38	50	0.76	clay loam	35	31	34	7/3	5/4
212	NE	SE	SW	17	3S	2E	O	28	23	1.22	–	–	–	–	–	–
213	SW	NW	SE	14	3S	1E	T	36.5	41.5	0.88	sandy loam	58	24	18	7/6	5/4
216	NE	SE	NE	28	3S	1E	O	22	23	0.96	–	–	–	–	–	–
217	NW	SW	SE	32	3S	1E	T	23	35	0.66	clay loam	37	31	32	6/4	5/4
218	NE	NE	SE	3	4S	1W	T	30	40	0.75	clay loam	28	35	37	7/3	5/4
219	SW	SE	NE	27	3S	1E	T	43	22	1.96	loam	38	36	26	7/4	5/4
220	SE	NE	NW	6	4S	1E	T	45	30	1.50	sandy loam	75	12	13	7/4	5/4
221A	SE	SW	NW	6	4S	1E	O	26	14	1.86	–	–	–	–	–	–
221B	SE	SW	NW	6	4S	1E	O	60	24	2.50	–	–	–	–	–	–
221C	SE	SW	NW	6	4S	1E	O	33	18	1.83	–	–	–	–	–	–
223	SE	SE	NE	24	3S	1W	T	36	46	0.78	clay loam	41	26	33	7/3	5/4
224	SE	SE	NE	28	1N	3E	T	37	31	1.19	sandy loam	68	19	13	7/3	5/4
225	SE	NE	SE	17	2S	3E	T	20	22	0.91	sandy loam	66	25	9	7/3	5/4
226	NW	SE	SW	14	3S	2E	T	43	33	1.30	sdy. cl. loam	49	26	25	7/3	6/3
226A	NE	SE	SW	14	3S	2E	T	41	50	0.82	sdy. cl. loam	58	19	23	6/3	4/4
227	NW	NW	SE	3	4S	5E	T	46	53	0.87	clay loam	31	32	37	7/4	5/3
228	SW	SE	SW	12	2S	6E	T	30	35	0.86	clay	29	30	41	7/3	5/3
229	NW	SW	NW	26	2S	1W	SS	88●	13●	6.77	–	–	–	–	–	–
230	NE	NE	NW	6	4S	2E	SS	43●	4●	10.7	–	–	–	–	–	–
231	NE	NE	NE	21	3S	2E	T	46	48	0.96	sandy loam	57	27	16	7/4	6/4
233	NW	SW	SW	16	2S	3E	T	40	46	0.87	loam	37	37	26	7/3	5/4
234B	SW	SE	SW	19	2S	4E	T	26	33	0.79	sandy loam	61	23	16	7/4	5/4
234C	SW	SE	SW	19	2S	4E	O	32	38	0.84	–	–	–	–	–	–
235A		SE	SE	22	2S	3E	SH	78	36	2.16	–	–	–	–	–	–
235B		SE	SE	22	2S	3E	SH	34	34	1.00	–	–	–	–	–	–
235C		SE	SE	22	2S	3E	SH	43	43	1.00	–	–	–	–	–	–

▲ - Scale Factor 8
● - Scale Factor 16

T- Till
O- Outwash

L- Glaciolacustrine
SS- Sandstone

SH- Shale

EXPLANATION OF DATA IN FIGURE 44

Sixty-six of the seventy-two X-ray diffractograms shown in Figure 44 represent magnesium-saturated (Mg sat), glycerol-solvated, basally-oriented films. The remaining six diffractograms represent samples given additional potassium saturation (K sat) and heat treatment (300^{o} and $550^{o}C$) and are labeled accordingly. Seventy of the seventy-two diffractograms were traced with a scale factor setting of 8 and the remaining two diffractograms had a setting of 16. These two samples are marked with a "*."

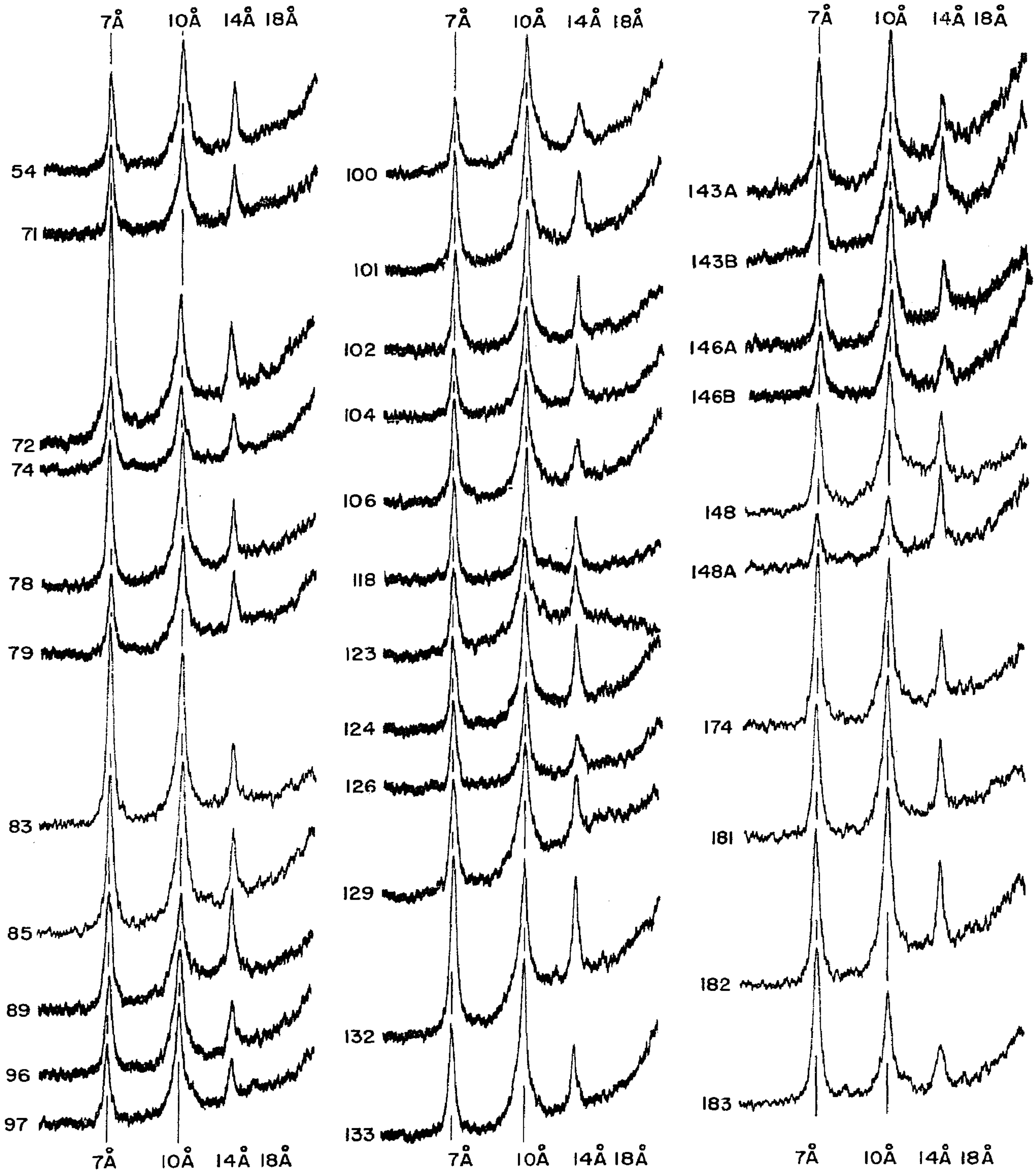


FIGURE 44. X-RAY DIFFRACTOGRAMS

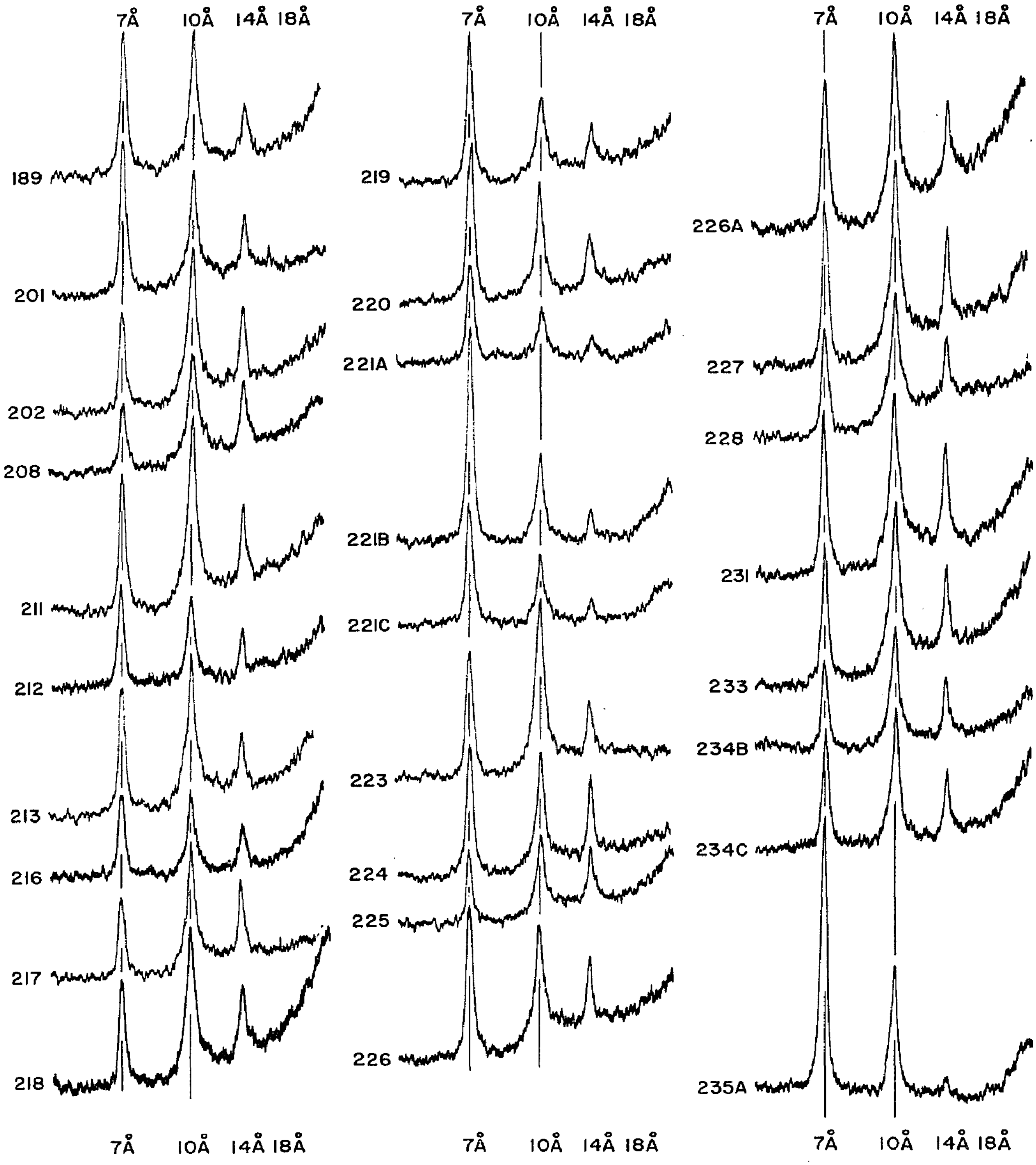
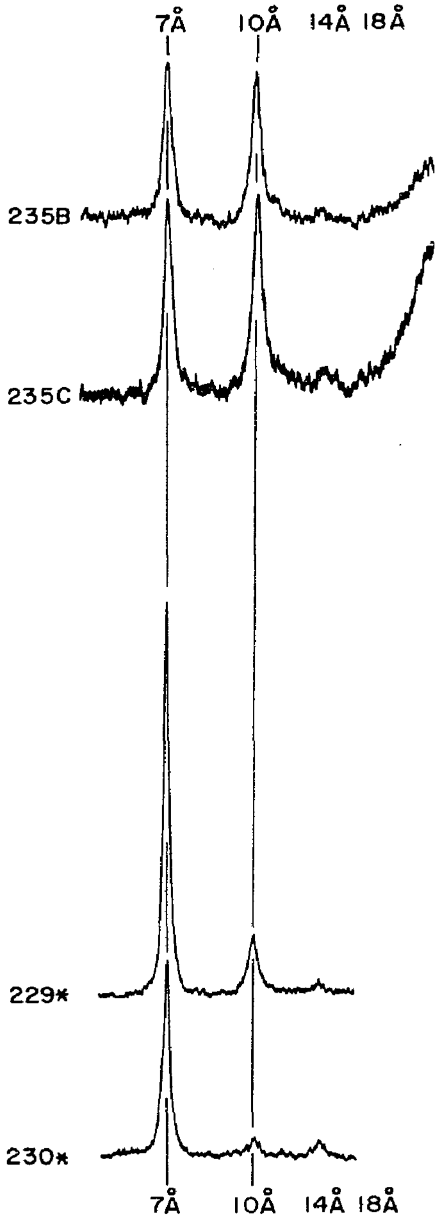


FIGURE 44. (CONT'D.)



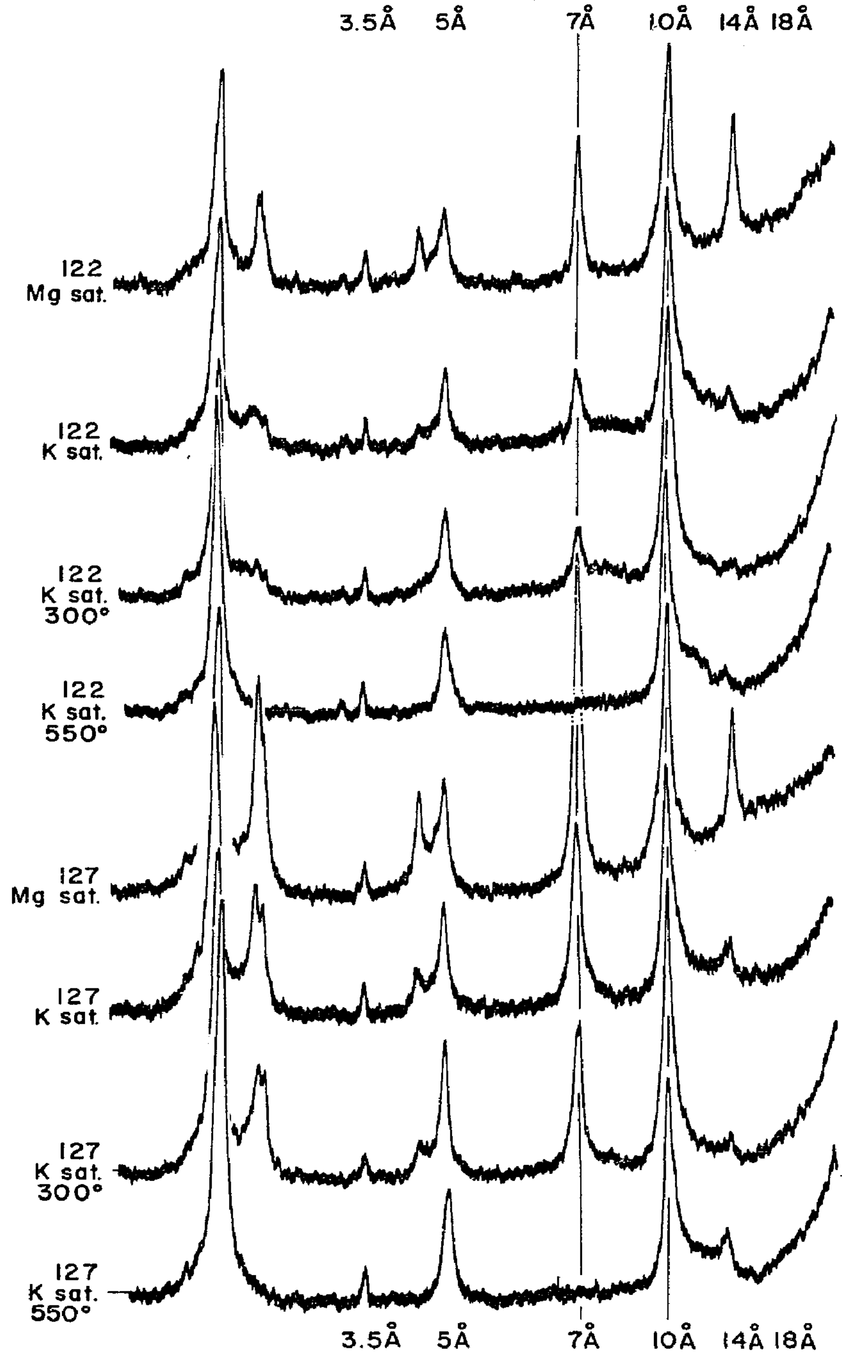


FIGURE 44 (CONT'D.)

APPENDIX C

TILL COLOR

The color of till samples, both moist and dry, was determined using the Munsell system. It was necessary to air-dry several samples in the laboratory before a dry color determination could be made. Tables 11 and 12 present the results of the investigation of till color and are constructed as a page from the Munsell book. Table 10 lists the color of each till sample studied.

Table 11. Color of Brill Lake and Chelsea Till Samples

HUE 10YR

VALUE	CHROMA 2	3	4	6	
7	1	8 *10*	5 *10*	1	Dry
6		*2*	2 *1*		Dry
6		*1*	*2*	1	Moist
5		1	10 *15*	3 *1*	Moist
4		1 *1*	1 *3*		Moist

Number of samples of Brill Lake till (Saginaw Lobe)

Number of samples of Chelsea till (Huron-Erie Lobe)

Table 12. Color of Grass Lake Till Samples

HUE 10YR

VALUE \ CHROMA	2	3	4	6	
7		5	3	1	Dry
6		1	1	1	Dry
6		1	1		Moist
5			7		Moist
4			3		Moist

Number of samples of Grass Lake till

APPENDIX D

TEXTURAL ANALYSIS

The hydrometer method of textural analysis was utilized in this investigation. A textural-analysis subsample was gently crushed, passed through a 2 mm sieve, and two 40 gram samples removed. Sample A was weighed, dried overnight in a 105°C oven, and reweighed to determine moisture content. Sample B was transferred to a milkshake mixer containing a 5% hexametaphosphate (Calgon) solution and distilled water. After soaking for ten minutes, the sample was mixed for five minutes, transferred to a sedimentation cylinder, and distilled water added. The cylinder was transferred to a constant-temperature room. After coming to temperature overnight, the solution was agitated with a plunger, the hydrometer inserted, and read after forty seconds. Another reading was taken after two hours. The results are presented in Table 10 and Figures 11 and 27.

APPENDIX E

LITHOLOGICAL CLASSIFICATION OF STONES

Pebbles

The first 100 1.0-to-2.5 cm-long (0.4 to 1.0 in) pebbles located during till-fabric determination were bagged for laboratory analysis.[1] Any of these pebbles which were blade- or rod-shaped were also included in the till-fabric analysis.

In the laboratory each pebble was broken, examined with a hand lens, and classified according to lithology (Table 13, Figures 12 and 24). Sedimentary pebbles were also tested for the presence of carbonates with a 10% hydrochloric acid solution.

Boulders

Wherever five or more boulders approximately 50 cm (18 in) or more in diameter were observed within 100 to 150 m (yds) of one another, the location was noted (Figure 13). Ornamental boulders near residences were not included. A total of 1,233 surficial boulders were identified and classified in terms of lithology at 19 sites (Table 14). A total of 564 boulders exposed during extraction operations in the Blue Ridge Esker were also identified and classified (Table 15).

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[1]Anderson (1957, p. 1417) found this size fraction to be the most diverse and most suitable to determine the lobe provenance of till samples.

TABLE 13. PEBBLE LITHOLOGY OF STUDY AREA TILLS

Site Number	1/4	1/4	1/4 Section	Section	Township	Range	Number of Pebbles	% Crystalline	% Carbonate	% Shale	% Sandstone	% Chert	% Ironstone Concretions	% Coal
BRILL LAKE TILL (SAGINAW LOBE)														
81	SE	SE	SW	15	2S	1E	100	28	53	6	8	3	2	–
74	NW	SW	NE	20	2S	1E	100	23	55	3	7	4	5	3
76	SW	NW	SE	10	2S	2E	100	27	47	3	16	5	1	1
78	SE	SE	NE	6	2S	3E	100	20	60	7	7	5	1	–
127	SW	SW	NE	3	1S	2E	100	32	54	–	7	5	2	–
Total pebbles or *Mean %*							500	*26.0*	*53.8*	*3.8*	*9.0*	*4.4*	*2.2*	*0.8*
CHELSEA TILL (HURON-ERIE LOBE)														
79	NW	SW	SE	12	1S	3E	100	12	56	7	19	5	1	–
97	NW	SW	NW	27	1N	4E	100	27	30	25	9	9	–	–
101	NE	NW	SE	29	1S	4E	100	24	62	7	1	3	3	–
104	SW	NE	SW	33	2S	3E	100	16	61	15	2	4	2	–
Total pebbles or *Mean %*							400	*19.7*	*52.2*	*13.5*	*7.8*	*5.3*	*1.5*	*tr*

TABLE 14. LITHOLOGY OF SURFICIAL BOULDERS

Site Number	1/4	1/4	1/4 Section	Section	Township	Range	TOTAL	Total Crystalline	Crystalline [Excl. Tillite(?) & R.J.C.]	Tillite(?)	Red Jasper Conglomerate	Sandstone	Carbonate
ON BRILL LAKE TILL (SAGINAW LOBE)													
88	NW	NE	NE	15	2S	2E	34	34	34	–	–	–	–
155		C	SW	12	2S	1E	39	39	38	–	–	–	–
156	SW	NW	NW	13	2S	1E	77	76	75	1	–	1	–
157	SE	NE	NW	7	2S	2E	57	54	54	–	–	3	–
158	NE	SE	NW	7	2S	2E	8	8	8	–	–	–	–
159		C	SE	7	2S	2E	11	9	9	–	–	2	–
161	NE	SE	SE	7	2S	2E	25	19	19	–	–	5	1
163	SE	NE	NW	16	2S	2E	71	70	69	1	–	1	–
164			C	8	2S	2E	37	37	36	1	–	–	–
166	SW	SW	NE	9	2S	2E	99	96	94	1	1	3	–
167	SW	NE	SW	10	2S	2E	24	24	23	1	–	–	–
169	SW	NE	NE	11	2S	2E	119	119	100	19	–	–	–
				TOTAL			601	585	559	24	2	15	1
				%			*100.0*	*97.3*	*93.0*	*4.0*	*0.3*	*2.5*	*0.2*

Site Number	1/4	1/4	1/4 Section	Section	Township	Range	TOTAL	Total Crystalline	Crystalline [Excl. Tillite(?) & R.J.C.]	Tillite(?)	Red Jasper Conglomerate	Sandstone	Carbonate
ON CHELSEA TILL (HURON-ERIE LOBE)													
55	NW	NW	SW	19	3S	3E	100	100	97	3	–	–	–
141	NE	NW	NE	19	3S	3E	110	110	109	1	–	–	–
145	NW	SW	NW	2	3S	3E	34	34	33	–	1	–	–
149	SE	SE	SE	32	2S	3E	26	25	24	1	–	–	1
186	SW	NW	SE	3	2S	3E	106	105	105	–	–	–	1
206	SE	NW	NE	16	3S	3E	83	83	82	–	1	–	–
207	NW	NW	SW	17	3S	3E	173	173	168	5	–	–	–
				TOTAL			632	630	618	10	2	–	2
				%			*100.0*	*99.7*	*97.8*	*1.6*	*0.3*		*0.3*

TABLE 15. STONE LITHOLOGY OF BLUE RIDGE ESKER

						THIS STUDY					KEIFENHEIM (1974)												
						BOULDERS					COBBLES							PEBBLES					
1/4	1/4	1/4 section	Section	Township	Range	Site number	Number of clasts	% Crystalline	% Sandstone	% Carbonate	Site number	Number of clasts	% Crystalline	% Sandstone	% Carbonate	% Shale	% Other	Number of clasts	% Crystalline	% Sandstone	% Carbonate	% Shale	% Other
NE	SE	SW	17	3S	2E	212	71	13	86	1	1	100	41	18	40	2	1	100	37	4	53	-	6
SW	SE	NE	27	3S	1E	219	85	12	87	1	2	100	50	19	29	2	-	100	36	15	40	5	4
NE	SE	NE	28	3S	1E	216	100	14	84	2	3	100	40	13	45	1	1	100	18	11	66	1	4
NE	SE	NW	31	3S	1E	222	127	32	67	1	-	-	-	-	-	-	-	-	-	-	-	-	-
SE	NE	NW	6	4S	1E	220	181	17	80	3	4	100	26	34	36	4	-	100	31	26	40	1	2
SE	SW	NW	6	4S	1E	-	-	-	-	-	5	100	33	28	38	-	-	100	33	13	42	2	10
SW	NE	SE	11	4S	1W	-	-	-	-	-	6	100	28	29	41	2	-	100	33	9	48	6	4
Total clasts or *Mean* %							564	*18*	*80*	*2*		600	*36*	*24*	*38*	*2*	*tr*	600	*31*	*13*	*48*	*3*	*5*

APPENDIX F

TILL FABRIC

The till-fabric methodology is basically that developed by Holmes (1941). The working face was on or near a hilltop in unleached till (as determined by 10% hydrochloric acid) at a depth of 1.2 m (4 ft) or more to minimize the effects of frost heave and mass movement (Harrison, 1957). A horizontal surface about 30 to 45 cm (12 to 18 in) square was cleared with a mattock, and pebbles were exposed by carefully scraping off thin layers of till with the blade of a spatula. Blade-and rod-shaped clasts (long [A] axis to medium [B] axis ratio of at least 3:2) have been shown to yield the most reliable results (Drake, 1974, p. 250) and were the only shapes considered in this study.[1] Only stones with long axes of 1.0 to 10.0 cm (0.4 to 3.9 in) were used; stones touching one another were rejected. When a suitable clast was located which appeared to be of appropriate size and shape, an aluminum knitting needle was carefully aligned with the long axis of the clast. The pebble was then removed from the till matrix, measured with a vernier caliper to the nearest millimeter (0.04 in), and if the proper size and shape, its dimensions were recorded (Tables 16 to 24). Dip of the needle was then determined to the nearest degree and bearing to the nearest five degrees with a Brunton compass. At no time was it necessary to sample through a vertical distance of more than 0.3 m (1 ft). Seven fabrics were measured which consist of fifty pebbles; one fabric consists of thirty-one pebbles; and one fabric consists of twenty-five pebbles.

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[1]It should be noted that this shape restriction may cause the mensuration procedure to be quite lengthy. At sites with tills that are not particularly stony, such as those in the study area, ten to fifteen hours may be required to measure a fifty-pebble fabric.

The lithology of the clasts was determined in the laboratory by the method outlined in Appendix E. Bearings of the long axes of clasts were plotted on rose diagrams in groups with fifteen-degree intervals (Figure 14). These diagrams show horizontal orientation and direction of dip of the long axes of the clasts. Dipping stones were plotted at full value, and horizontal stones were plotted at half values in opposite directions in the manner used by Wright, 1962.

EXPLANATION OF DATA IN TABLES 16 TO 24

Orientation of long (A) axis given in degrees. Bearings are in relation to true north based on 2^{o}W magnetic declination.

Dimensions of pebbles' A, B, and C axes given in millimeters.

Dip of long (A) axis given in degrees.

LAV-- Long (A) axis vertical, therefore orientation data is for medium (B) axis.

Table 16. Till-Fabric Data for Site 74

Site 74   Location NW¼SW¼NE¼ sec. 20, T. 2 S., R. 1 E. (roadcut)

Topography Kalamazoo Moraine   Altitude 980 ft (298.7 m)

Depth of Leaching 38 in (96 cm)   Analysis Depth 8 ft (2.4 m)

Pebble Number	Dimensions			Orient.	Dip
1	40	18	8	N60W	0
2	25	16	11	N60W	20NW
3	28	16	10	N65W	25NW
4	33	22	12	S75E	12SE
5	44	22	18	S80E	32SE
6	12	8	6	S70E	30SE
7	18	7	7	N80E	8NE
8	13	9	5	S40E	10SE
9	11	7	4	S45W	8SW
10	10	4	4	N15W	5NW
11	13	7	4	N65E	5NE
12	20	9	9	N85E	23NE
13	19	13	4	N75W	0
14	15	10	7	N15W	LAV
15	28	14	10	N80E	0
16	22	14	11	S25E	16SE
17	14	9	5	S75E	37SE
18	18	11	7	S70E	18SE
19	62	26	24	S30E	4SE
20	82	54	30	S60E	4SE
21	20	10	7	N15W	0
22	19	12	9	S60E	48SE
23	18	12	7	N50W	0
24	26	15	11	N20W	10NW
25	12	8	3	N20W	11NW
26	12	8	4	N40W	2NW
27	15	10	5	N55E	36NE
28	22	10	7	N75E	15NE
29	11	6	5	S	7S
30	32	19	17	S55E	19SE
31	12	8	6	N50E	15NE

Table 17. Till-Fabric Data for Site 76

Site 76 Location SW¼NW¼SE¼ sec. 10, T. 2 S., R. 2 E. (roadcut)

Topography Kalamazoo Moraine Altitude 970 ft (295.7 m)

Depth of Leaching 50 in (1.27 m) Analysis Depth 5.5 ft (1.6 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions			Orient.	Dip
1	13	8	5	S5W	5SW	26	15	6	6	S25E	25SE
2	17	9	3	N5E	5NE	27	15	4	3	W	5W
3	10	5	5	E	0	28	21	11	8	N5W	36NW
4	12	6	5	S5E	32SE	29	13	9	5	S65W	37SW
5	10	6	5	S50W	30SW	30	10	5	3	S25E	5SE
6	20	11	8	S40W	24SW	31	10	6	5	N10E	0
7	13	8	6	N50W	22NW	32	13	9	3	S5W	4SW
8	12	7	4	N50W	28NW	33	19	11	9	E	16E
9	27	5	3	N70W	2NW	34	11	5	4	N45E	0
10	21	12	8	N45W	3NW	35	13	6	4	S80W	3SW
11	13	7	5	N25W	0	36	20	9	6	S20W	43SW
12	12	6	5	S75W	10SW	37	12	7	4	N25W	LAV
13	13	4	3	S25W	31SW	38	12	7	5	N80W	7NW
14	13	7	5	S45E	56SE	39	12	5	3	N30W	2NW
15	12	7	4	N25W	LAV	40	12	8	3	N25E	0
16	14	8	4	N20W	0	41	12	7	5	S35W	8SW
17	14	9	6	S10W	39SW	42	12	8	6	S15W	5SW
18	20	11	5	N80E	46NE	43	11	4	3	N35E	2NE
19	16	6	5	N75E	28NE	44	11	7	3	S40E	55SE
20	18	12	8	N85W	5NW	45	15	10	5	N50W	15NW
21	14	6	4	S50W	17SW	46	12	5	5	N15E	33NE
22	18	10	5	N35W	0	47	10	4	2	S25W	16SW
23	25	12	6	N45E	3NE	48	10	7	4	S85W	48SW
24	12	8	4	N20W	0	49	11	7	4	S	8S
25	13	6	6	N80W	34NW	50	17	7	7	N45W	0

Table 18. Till-Fabric Data for Site 78

Site 78 Location SE¼SE¼NE¼ sec. 6, T. 2 S., R. 3 E. (roadcut)

Topography Kalamazoo Moraine Altitude 1000 ft (304.8 m)

Depth of Leaching 36 in (0.9 m) Analysis Depth 59 in (1.5 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions			Orient.	Dip
1	15	9	8	S10E	30SE	26	13	7	8	S35E	45SE
2	11	6	5	S5E	22SE	27	23	14	12	S5W	65SW
3	20	10	9	S15E	14SE	28	21	12	6	S20E	30SE
4	17	11	3	N20E	0	29	11	7	5	S20E	54SE
5	29	17	8	S35E	15SE	30	11	6	2	S55E	11SE
6	12	8	6	S20E	14SE	31	10	6	5	S35W	3SW
7	12	8	6	S75E	25SE	32	13	9	4	S40W	2SW
8	16	10	8	S25E	44SE	33	19	13	5	S15E	25SE
9	15	9	4	S50W	11SW	34	21	14	4	S5E	34SE
10	16	11	8	S5E	43SE	35	11	6	5	S35E	14SE
11	14	8	5	N10E	0	36	15	10	6	S25E	52SE
12	18	12	8	S5E	24SE	37	10	6	6	S35W	41SW
13	12	8	7	S	63S	38	13	6	5	S20E	47SE
14	18	9	7	S40E	21SE	39	10	5	5	N70W	17NW
15	20	13	11	S30E	44SE	40	24	16	8	S30E	26SE
16	11	6	4	S5W	4SW	41	15	10	8	S40E	28SE
17	20	13	10	S15E	45SE	42	35	23	17	S60E	21SE
18	29	15	11	S10E	35SE	43	13	7	6	S10E	36SE
19	12	7	5	S35E	28SE	44	12	8	6	S20E	31SE
20	18	9	9	S5E	34SE	45	19	13	12	S35E	62SE
21	15	10	9	S15W	45SW	46	28	17	11	N70W	6NW
22	11	6	4	S20E	10SE	47	12	7	6	S25E	3SE
23	25	17	12	S10E	54SE	48	12	7	7	S50E	4SE
24	14	9	5	S15E	44SE	49	10	6	5	S5E	21SE
25	11	5	4	S5E	63SE	50	10	6	4	S40E	40SE

Table 19. Till-Fabric Data for Site 79

Site 79 Location NW¼SW¼SE¼ sec. 12, T. 1 S., R. 3 E. (roadcut)

Topography Interlobate Morainic Tract Altitude 940 ft (286.5 m)

Depth of Leaching 37 in (0.9 m) Analysis Depth 4 ft (1.2 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions			Orient.	Dip
1	26	11	6	S55E	28SE	26	20	12	8	N85E	43NE
2	16	10	9	N35W	0	27	16	9	6	S45E	21SE
3	12	7	4	N80W	0	28	30	14	11	N20W	30NW
4	11	6	4	S30E	15SE	29	21	14	7	S80E	32SE
5	16	10	3	S50E	21SE	30	28	14	11	S65E	24SE
6	30	20	10	S50E	15SE	31	15	9	6	N25W	22NW
7	11	7	5	N50W	5NW	32	15	11	8	N60E	12NE
8	25	16	10	N60W	26NW	33	14	9	6	S30E	30SE
9	29	15	11	S65E	54SE	34	10	6	3	N40W	2NW
10	28	15	9	N70E	0	35	14	8	6	N20E	2NE
11	18	11	8	N15E	23NE	36	14	7	2	N35W	0
12	20	10	10	S80E	40SE	37	18	12	8	N30E	54NE
13	26	15	12	S35E	21SE	38	13	8	5	N10E	0
14	13	7	5	S60E	28SE	39	36	23	18	S75E	38SE
15	22	10	9	N30W	0	40	19	10	10	S55E	23SE
16	24	15	13	N70W	8NW	41	15	10	9	N75W	15NW
17	18	12	8	S45E	42SE	42	18	12	4	N30W	15NW
18	12	6	4	N25W	0	43	13	8	8	S50E	44SE
19	17	9	7	S75E	5SE	44	28	15	8	S60E	10SE
20	15	7	5	S20E	35SE	45	13	7	5	S85E	20SE
21	22	14	9	N75E	0	46	21	13	13	S55E	19SE
22	18	9	7	S55E	8SE	47	15	9	6	S65E	37SE
23	31	18	11	S5W	9SW	48	11	7	5	S70E	37SE
24	20	13	11	N35W	25NW	49	23	14	13	N70W	0
25	24	12	7	S25E	28SE	50	16	10	10	N20W	14NW

Table 20. Till-Fabric Data for Site 81

Site 81 Location SE¼SE¼SW¼ sec. 15, T. 2 S., R. 1 E. (pit)

Topography Kalamazoo Moraine Altitude 960 ft (292.6 m)

Depth of Leaching ? (topsoil removed) Analysis Depth about 6 ft (2 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions			Orient.	Dip
1	10	7	4	N10W	40NW	26	10	4	3	S30E	4SE
2	10	5	4	N5W	27NW	27	12	7	5	S10E	6SE
3	13	9	5	S80E	5SE	28	18	10	6	N70W	0
4	11	7	3	N85E	20NE	29	11	7	4	S15E	2SE
5	18	10	3	S10W	22SW	30	17	11	5	S80E	28SE
6	30	11	4	N5E	1NE	31	15	10	7	N60W	0
7	25	13	7	N35W	15NW	32	16	8	7	S30W	6SW
8	17	11	9	N20W	55NW	33	21	12	9	N35W	0
9	10	6	4	N30W	27NW	34	20	10	6	S15W	12SW
10	32	13	11	S80W	18SW	35	10	6	3	N85E	35NE
11	15	10	6	N	0	36	17	10	8	N30W	8NW
12	17	10	6	N55E	2NE	37	13	5	4	N30E	5NE
13	15	10	4	N15E	5NE	38	17	9	6	N	13N
14	26	17	8	S15W	3SW	39	24	16	5	N35E	17NE
15	15	9	6	N	2N	40	10	5	4	E	5E
16	11	5	2	S5W	15SW	41	27	18	11	S20E	7SE
17	10	6	4	S40E	2SE	42	24	14	10	S	9S
18	20	10	6	N15W	7NW	43	17	9	3	S20W	10SW
19	16	9	6	S40E	21SE	44	11	5	3	S5E	12SE
20	15	7	1	N20W	5NW	45	13	7	7	N10W	17NW
21	28	14	13	S40E	18SE	46	13	7	4	N30E	13NE
22	16	8	6	N75E	8NE	47	17	6	4	N70W	0
23	11	5	2	N30W	0	48	12	8	4	N15W	4NW
24	23	11	8	S10W	11SW	49	25	14	4	N30W	0
25	15	8	6	S75E	11SE	50	13	7	6	N55W	24NW

Table 21. Till-Fabric Data for Site 81A

Site 81A Location SE¼SE¼SW¼ sec. 15, T. 2 S., R. 1 E. (pit)

Topography Kalamazoo Moraine Altitude 960 ft (292.6 m)

Depth of Leaching ? (topsoil removed) Analysis Depth about 6 ft (2 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions	Orient.	Dip
1	12	7	6	S15E	7SE				
2	25	16	10	S10E	1SE				
3	16	7	6	N25W	5NW				
4	11	5	3	N20W	3NW				
5	16	11	10	N35E	24NE				
6	37	21	13	N10W	4NW				
7	16	7	5	N35E	0				
8	11	7	4	S25W	3SW				
9	10	6	3	N	22N				
10	18	12	7	S60E	9SE				
11	18	12	8	S	8S				
12	15	9	8	N5W	0				
13	12	6	4	N15W	11NW				
14	21	13	10	S15E	3SE				
15	24	15	12	S	14S				
16	15	9	4	N35W	0				
17	11	7	3	N10W	8NW				
18	18	10	5	S15E	6SE				
19	18	11	10	S35W	2SW				
20	11	6	5	S5W	3SW				
21	18	9	8	S	4S				
22	22	12	8	N15W	5NW				
23	10	6	3	N5E	3NE				
24	15	10	5	N15W	0				
25	22	7	7	N10W	0				

Table 22. Till-Fabric Data for Site 97

Site 97 Location NW¼SW¼NW¼ sec. 27, T. 1 N., R. 4 E. (roadcut)

Topography Interlobate Morainic Tract Altitude 950 ft (289.6 m)

Depth of Leaching 30 in (0.76 m) Analysis Depth 9 ft (2.7 m)

Pebble Number	Dimensions			Orient.	Dip
1	15	10	6	S	10S
2	14	9	6	S20W	16SW
3	29	12	8	N30E	LAV
4	21	14	9	S5E	34SE
5	12	8	5	S15W	3SW
6	33	19	14	N85E	17NE
7	15	10	7	S25W	6SW
8	14	8	7	S10W	36SW
9	12	7	5	S40E	41SE
10	23	13	9	N5W	11NW
11	19	12	6	N65E	31NE
12	21	12	8	S55E	28SE
13	29	11	5	N75W	40NW
14	20	13	4	S45W	27SW
15	18	11	6	S30W	25SW
16	13	9	5	N15W	13NW
17	11	4	3	S85E	44SE
18	17	9	7	N30E	46NE
19	16	11	7	S35E	35SE
20	18	12	5	S85E	33SE
21	11	7	5	S20W	7SW
22	12	8	7	S70E	40SE
23	17	8	5	S80E	16SE
24	17	10	9	S35W	32SW
25	11	7	3	S60E	35SE
26	21	14	12	S65E	45SE
27	23	8	8	S40E	55SE
28	28	19	11	S55E	41SE
29	20	12	5	S60E	4SE
30	17	9	7	S70E	56SE
31	22	9	6	N50W	8NW
32	19	7	6	S15W	40SW
33	13	8	5	S75E	36SE
34	12	8	4	S20E	8SE
35	19	12	10	S45E	12SE
36	11	7	4	S40E	26SE
37	12	7	4	S10E	45SE
38	18	12	8	S60E	58SE
39	12	7	6	S45E	17SE
40	28	14	5	N35W	19NW
41	25	16	13	S15W	49SW
42	20	13	10	S35E	41SE
43	23	12	8	N75E	20NE
44	27	17	13	S55W	34SW
45	15	9	6	S75E	38SE
46	17	10	6	S65E	39SE
47	22	15	10	N80W	24NW
48	14	9	9	S70E	3SE
49	13	7	7	S20E	44SE
50	13	8	2	S85E	30SE

Table 23. Till—Fabric Data for Site 101

Site 101 Location NE¼NW¼SE¼ sec. 29, T. 1 S., R. 4 E.(roadcut)

Topography Interlobate Morainic Tract Altitude 945 ft (288.0 m)

Depth of Leaching 30 in (0.76 m) Analysis Depth 6 ft (1.8 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions			Orient.	Dip
1	38	25	13	N55W	18NW	26	16	10	4	N80E	30NE
2	23	11	6	N85W	0	27	23	13	9	S70E	20SE
3	20	13	8	E	48E	28	13	8	6	N40W	0
4	13	9	7	N60E	35NE	29	20	10	6	S85E	12SE
5	36	22	13	N85W	0	30	10	5	3	N75E	11NE
6	10	6	5	S55E	30SE	31	16	8	7	S85W	5SW
7	12	9	5	N65W	0	32	12	7	6	N55W	0
8	12	7	3	N65E	0	33	12	7	5	N55W	0
9	25	15	11	N80W	10NW	34	13	7	4	S50E	28SE
10	15	9	4	S45E	28SE	35	12	8	5	N70W	0
11	15	9	7	N80E	28NE	36	12	8	5	N60W	0
12	23	12	10	E	0	37	11	7	7	S60E	15SE
13	14	9	8	N50W	0	38	51	30	18	N75E	26NE
14	15	10	6	N80W	0	39	24	14	13	S60E	36SE
15	20	12	11	S55W	15SW	40	25	13	12	N80E	37NE
16	12	7	3	N70E	15NE	41	30	15	13	N45W	0
17	26	22	14	S55E	8SE	42	13	7	4	N55W	2NW
18	13	8	6	N80E	9NE	43	11	7	4	N55W	0
19	14	8	8	N85W	0	44	14	8	4	N35W	0
20	15	9	8	E	10E	45	10	5	5	S45E	21SE
21	15	10	7	N70W	0	46	17	10	7	N80W	0
22	13	7	6	N80W	5NW	47	16	10	9	N50W	0
23	22	12	11	N75W	0	48	21	13	11	N70E	0
24	13	7	5	N45W	0	49	11	7	5	N75W	20NW
25	11	6	5	N60W	0	50	23	14	10	S40E	38SE

Table 24. Till-Fabric Data for Site 104

Site 104 Location SW¼NE¼SW¼ sec. 33, T. 2 S., R. 3 E.(roadcut)

Topography Mississinewa Moraine Altitude 990 ft (301.8 m)

Depth of Leaching 33 in (0.84 m) Analysis Depth 4.5 ft (1.6 m)

Pebble Number	Dimensions			Orient.	Dip	Pebble Number	Dimensions			Orient.	Dip
1	10	6	5	S75W	8SW	26	16	10	7	N55E	0
2	17	10	6	N80E	41NE	27	18	10	6	S80E	15SE
3	30	20	5	N75E	46NE	28	18	10	6	S75E	14SE
4	26	15	5	N85E	41NE	29	28	17	12	S80E	35SE
5	17	9	7	S60W	30SW	30	16	8	6	S80E	15SE
6	17	10	4	S70E	45SE	31	18	12	7	N80E	23NE
7	11	5	4	S75E	35SE	32	24	14	12	N85E	0
8	15	10	9	N55E	37NE	33	11	7	5	N85W	0
9	20	11	3	N60W	LAV	34	70	45	25	E	29E
10	18	12	8	N65E	50NE	35	25	14	13	S80E	35SE
11	16	9	6	E	45E	36	20	11	7	S70E	16SE
12	24	12	11	N5W	25NW	37	33	21	17	N75E	18NE
13	15	11	8	S85E	21SE	38	15	9	7	S70E	31SE
14	14	9	6	S75E	35SE	39	17	11	8	S65E	12SE
15	12	8	4	N50E	41NE	40	24	9	7	S60W	6SW
16	41	28	15	N60E	38NE	41	48	28	21	N75E	15NE
17	19	6	4	N80E	22NE	42	16	7	7	N75E	0
18	12	7	3	S60E	20SE	43	12	8	5	N70E	33NE
19	27	12	10	S80E	14SE	44	20	13	8	N60E	36NE
20	57	28	11	N85E	8NE	45	64	43	31	N80E	30NE
21	14	9	7	N85E	28NE	46	18	10	6	S85E	10SE
22	12	6	4	E	17E	47	16	6	5	N75E	10NE
23	11	7	4	S65E	13SE	48	19	12	8	S70E	22SE
24	15	4	4	N75W	0	49	19	12	9	S80E	18SE
25	14	8	5	S70E	55SE	50	16	11	7	E	45E

APPENDIX G

LOCATIONS OF SELECTED FLOW-TILL SITES

A positive or probable identification of flow till has been made at each of the sites listed below. Additional site locations are presented in Chapter 3 and Figure 22.

Table 25. Locations of Selected Flow-Till Sites

Site Number	
51	NW¼SE¼NW¼ sec. 17, T. 1 S., R. 4 E.
59	SE¼NW¼SE¼ sec. 12, T. 2 S., R. 1 E.
73	NW¼SW¼NW¼ sec. 24, T. 2 S., R. 1 W.
88A	NW¼SE¼SE¼ sec. 10, T. 2 S., R. 2 E.
134	NE¼SE¼SE¼ sec. 25, T. 3 S., R. 2 E.
138	SW¼SW¼SW¼ sec. 16, T. 3 S., R. 3 E.
139	NW¼SW¼SW¼ sec. 16, T. 3 S., R. 3 E.
144	NW¼SW¼NW¼ sec. 14, T. 3 S., R. 3 E.
150	SW¼NE¼NW¼ sec. 10, T. 2 S., R. 3 E.
158	NE¼SE¼NW¼ sec. 7, T. 2 S., R. 2 E.
171	NE¼SW¼SW¼ sec. 30, T. 1 S., R. 3 E.
190	NE¼NE¼NW¼ sec. 1, T. 2 S., R. 3 E.
203	NE¼SE¼NW¼ sec. 17, T. 1 S., R. 4 E.
205	SW¼SW¼SW¼ sec. 35, T. 1 N., R. 4 E.

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FIGURE 4. BEDROC

(ALTITUDES IN FEET ABOVE ME

FEET	METERS
650	198.1
700	213.4
750	228.6
800	243.8
850	259.1
900	274.3
950	289.6
1000	304.8
1050	320.0

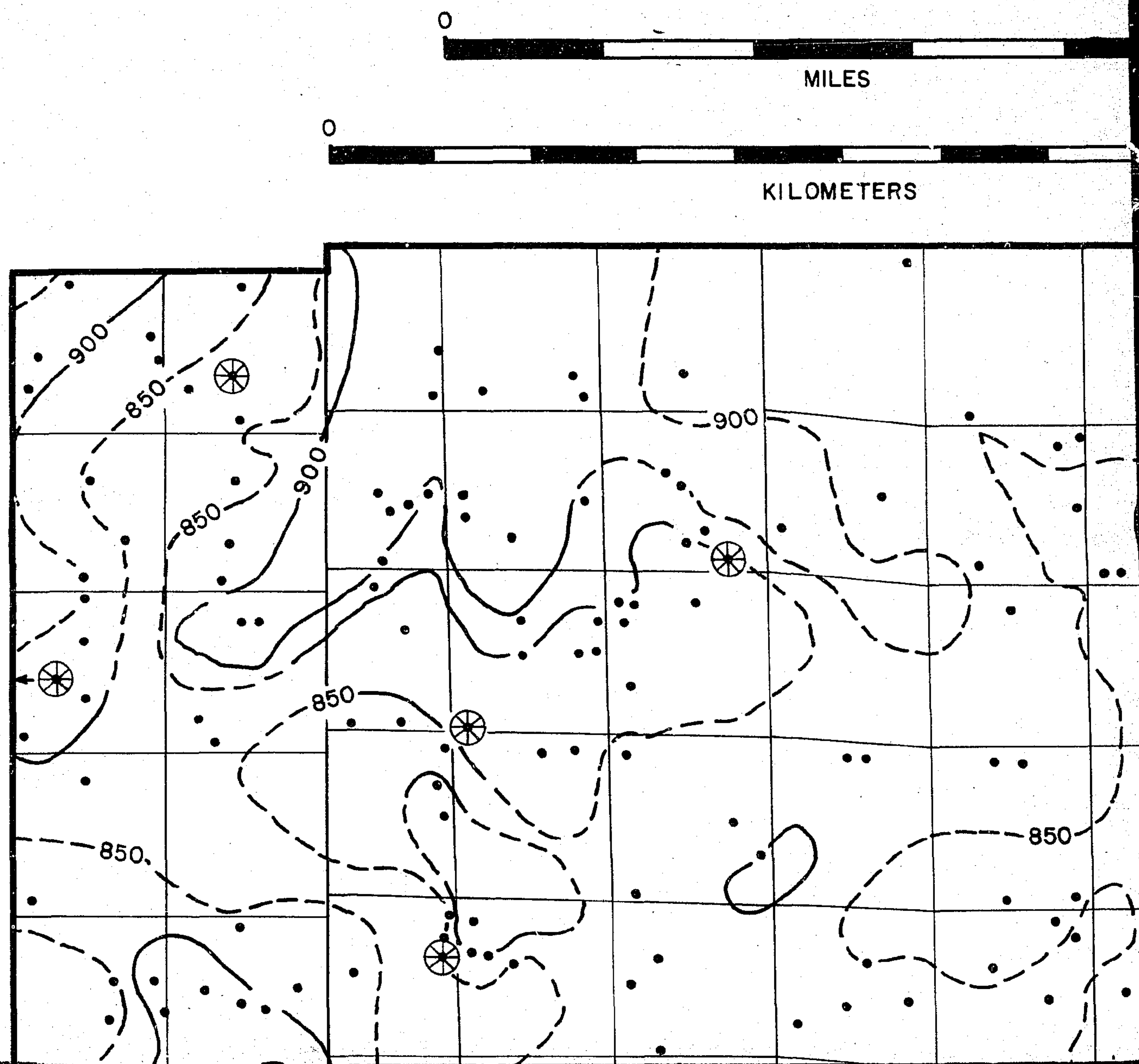
• WELL DATA SITE

— CONTOUR IN AREA W
NUMEROUS WELL R

-- CONTOUR IN AREA W
FEWER WELL REC

⊛ WEATHERED ZONES 8
MATTER WITHIN DR
OVERLYING BEDROC

CONTOUR INTERVAL 50 FE



4. BEDROCK SURFACE

S IN FEET ABOVE MEAN SEA LEVEL)

WELL DATA SITE

CONTOUR IN AREA WITH NUMEROUS WELL RECORDS

CONTOUR IN AREA WITH FEWER WELL RECORDS

WEATHERED ZONES & ORGANIC MATTER WITHIN DRIFT OVERLYING BEDROCK

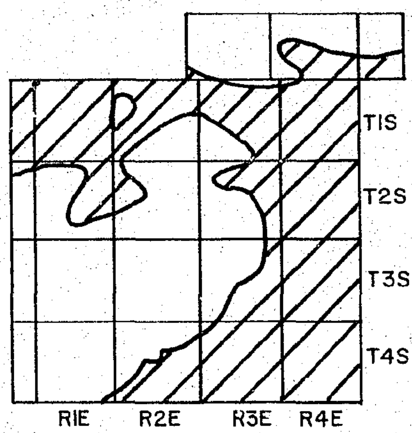
TOUR INTERVAL 50 FEET (15.2 M)

5

MILES

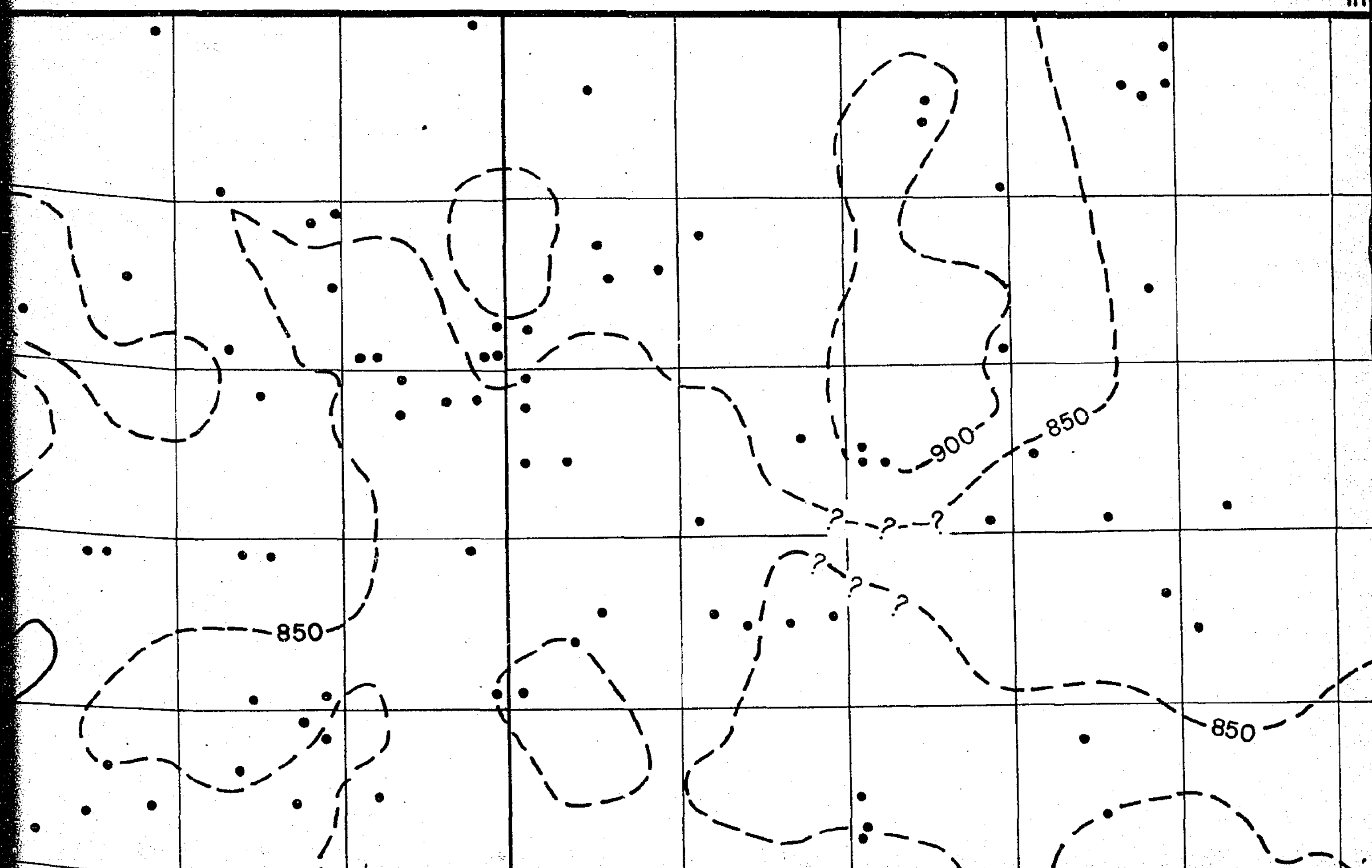
10

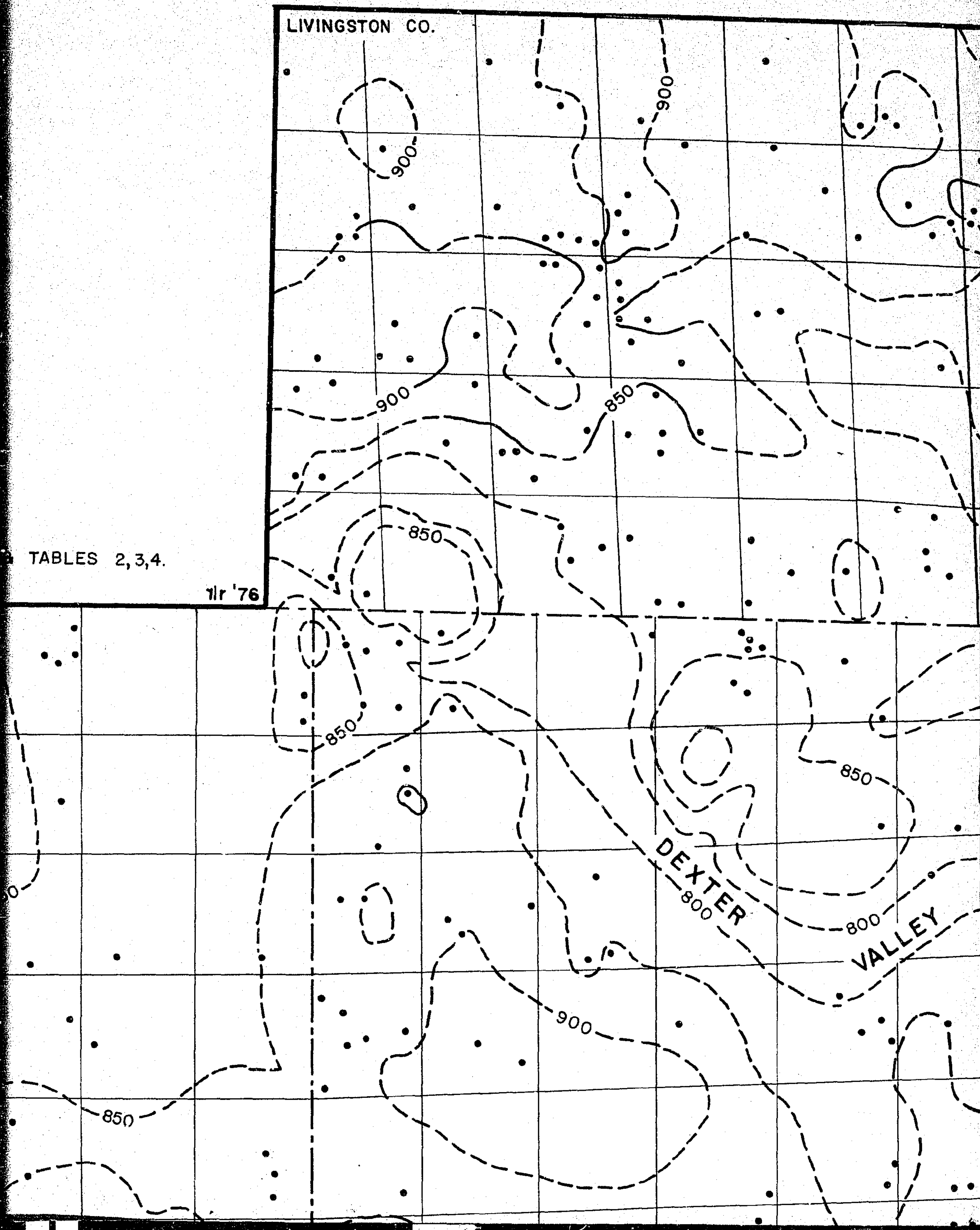
KILOMETERS



CONTOURS MAY BE PARTIALLY ON RESISTANT TILL

SOURCES: SEE APPENDIX A & TABLES 2, 3, 4.





LIVINGSTON CO.
900
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850
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850
850
800
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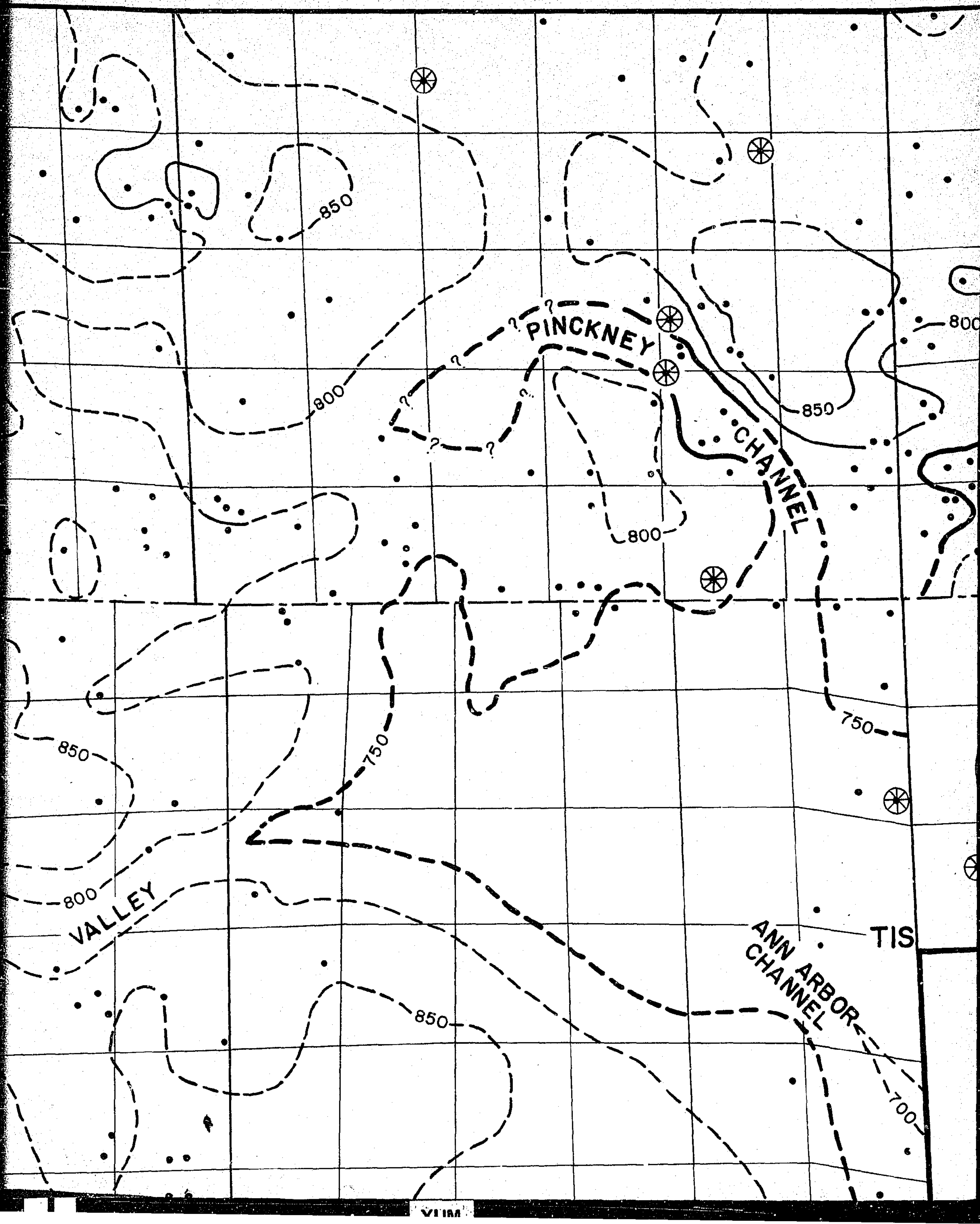
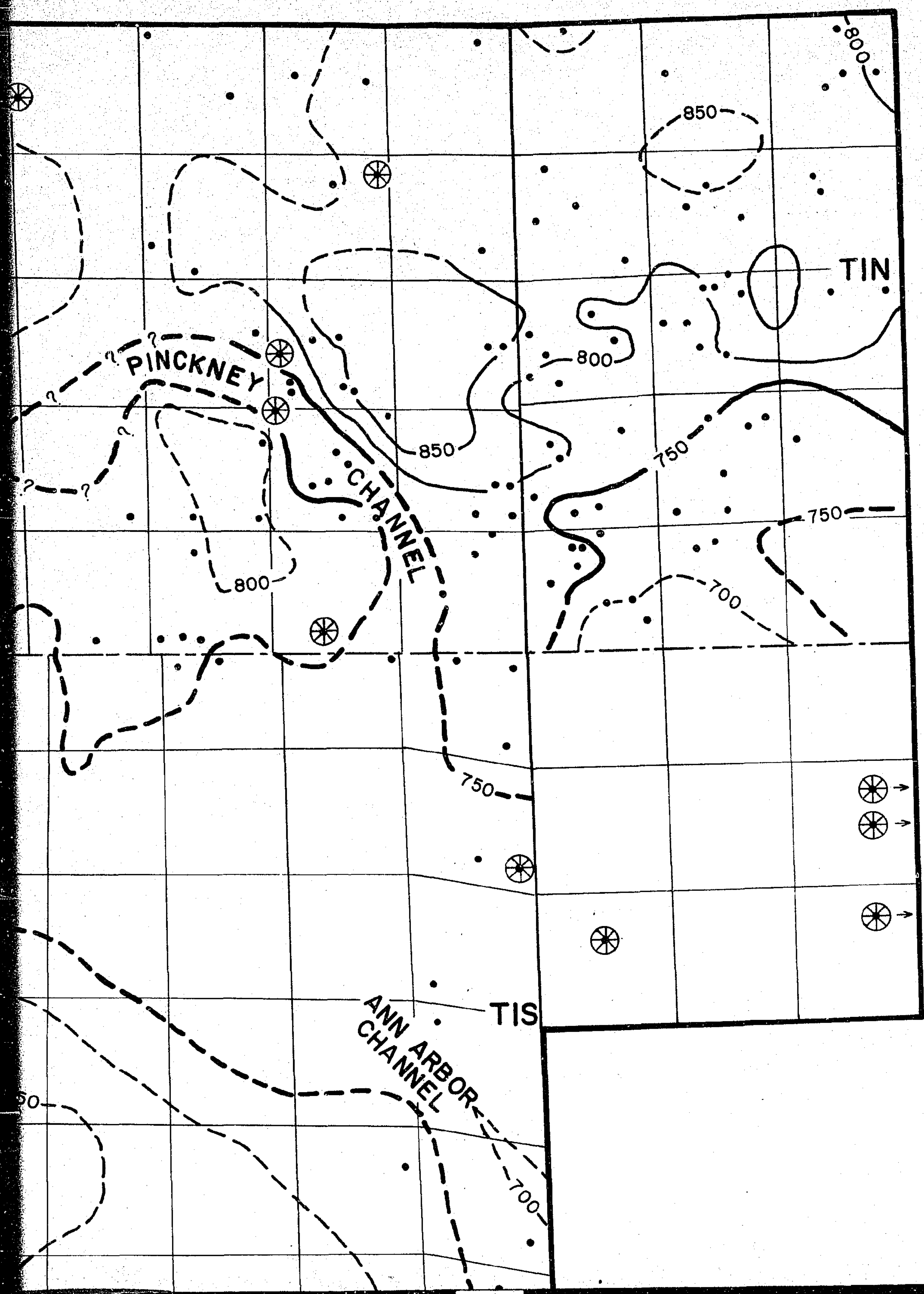
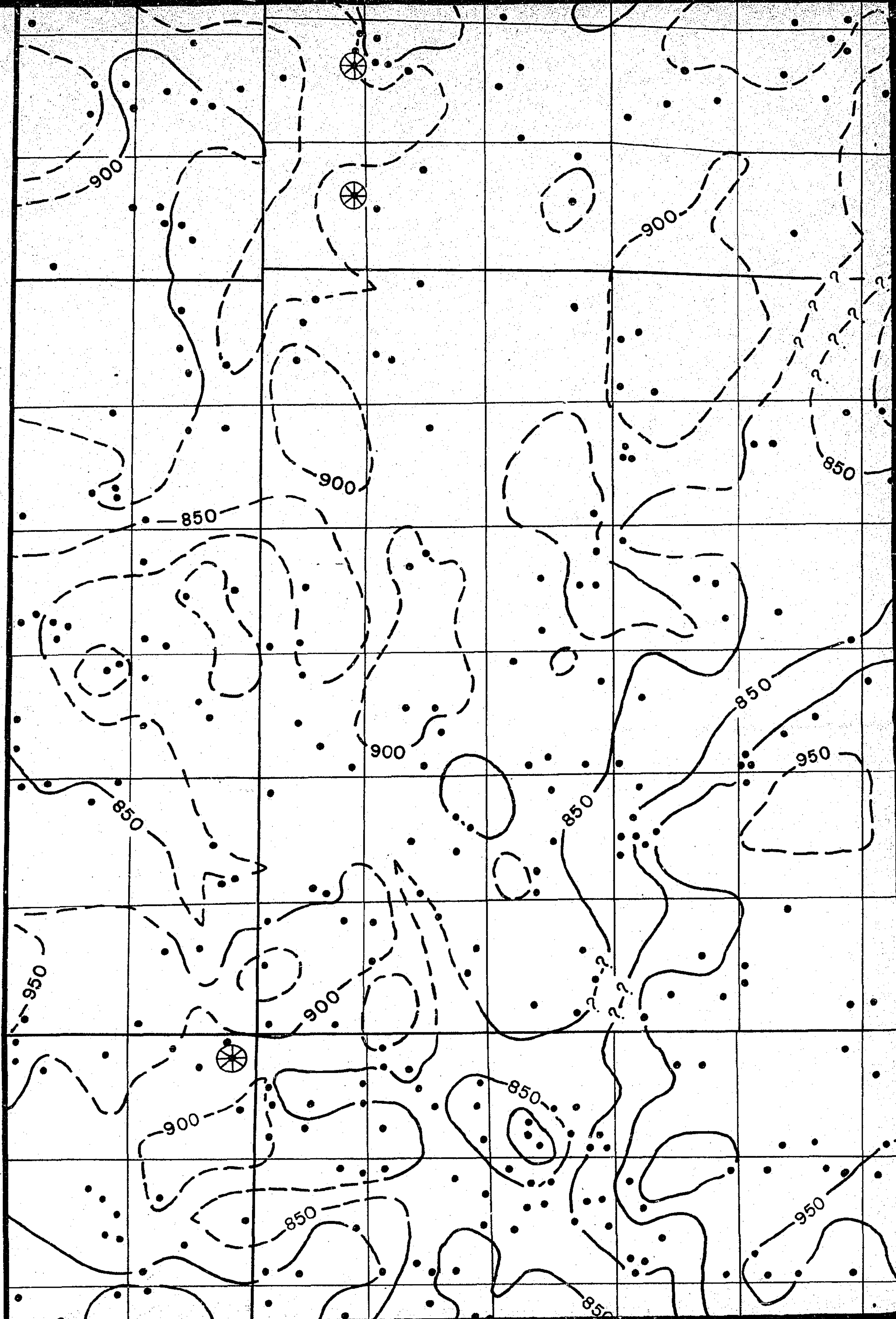
900
850
DEXTER
VALLEY
TABLES 2,3,4.
1lr '76


PINCKNEY
CHANNEL
VALLEY
ANN ARBOR
CHANNEL
TIS
850
800
750
700



PINCKNEY CHANNEL
ANN ARBOR CHANNEL
TIN
TIS
850
800
750
700
XUM



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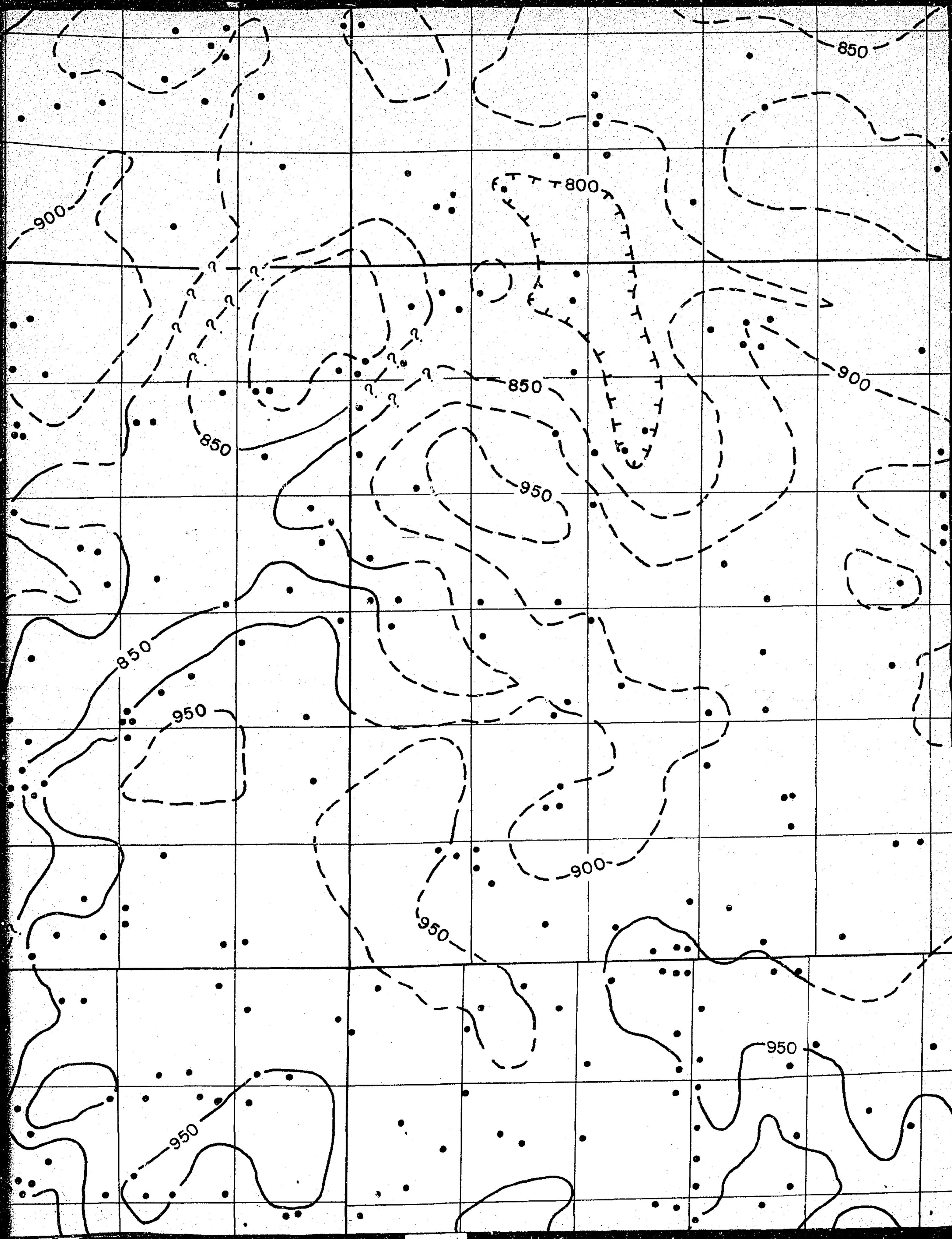

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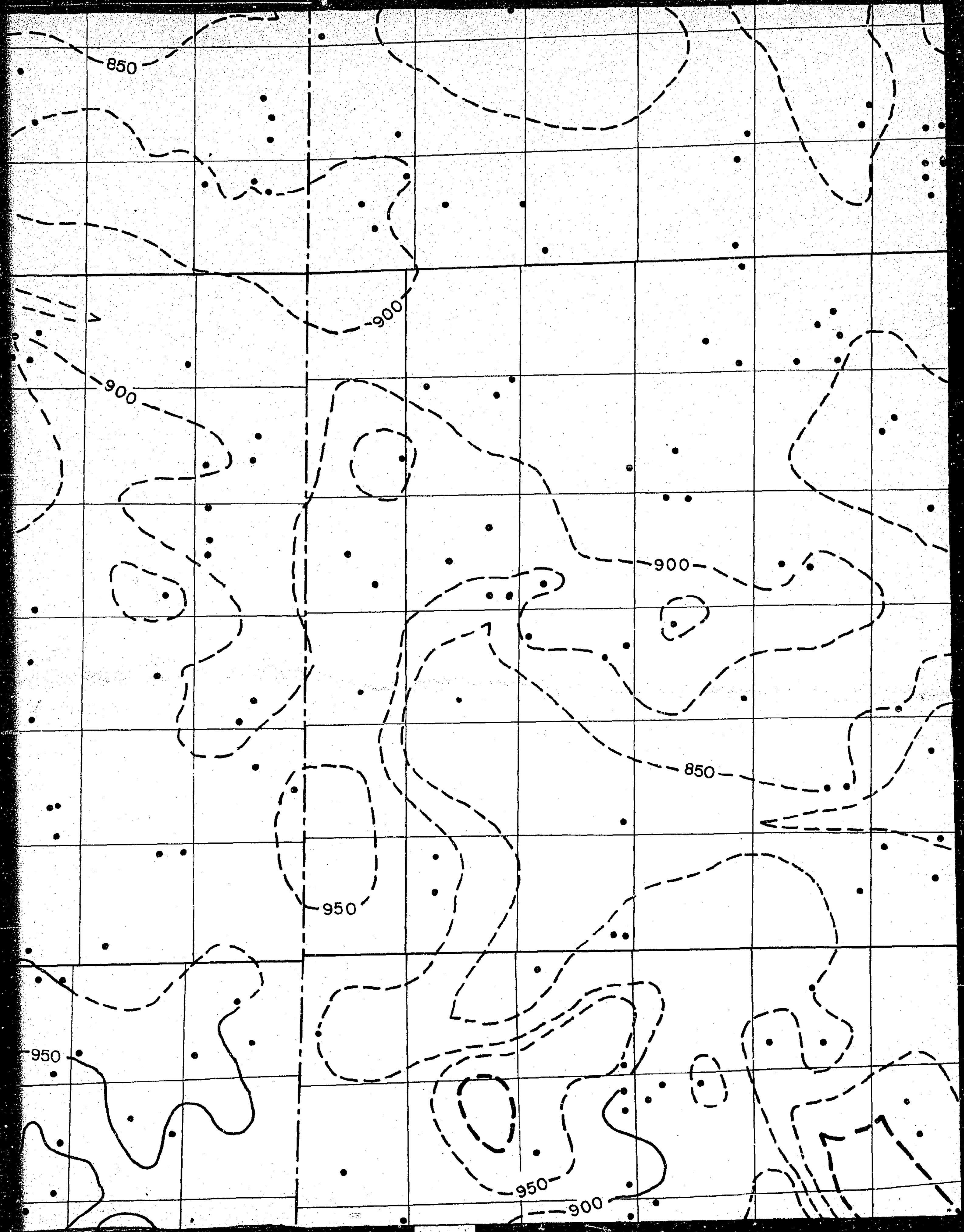

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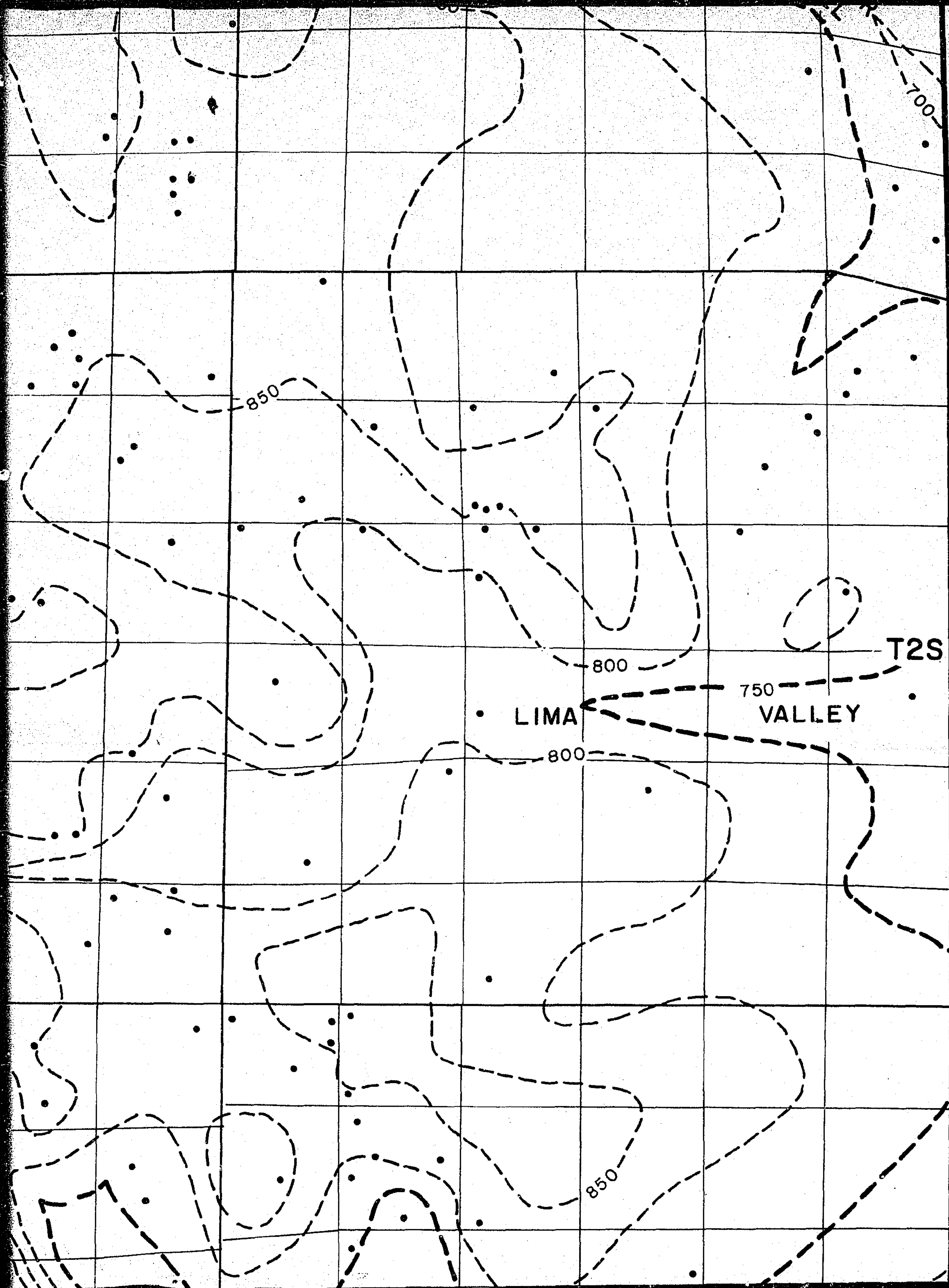
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LIMA
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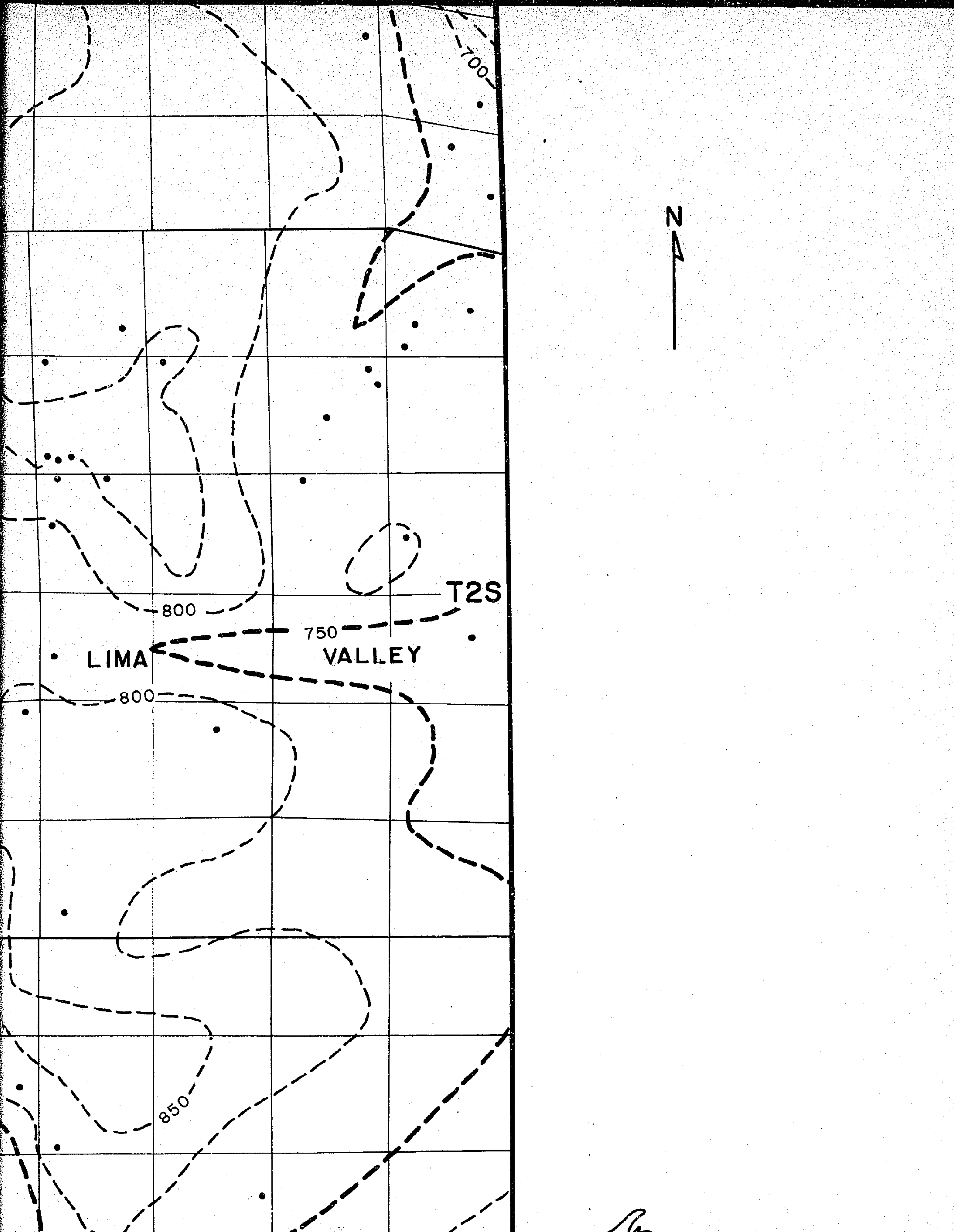

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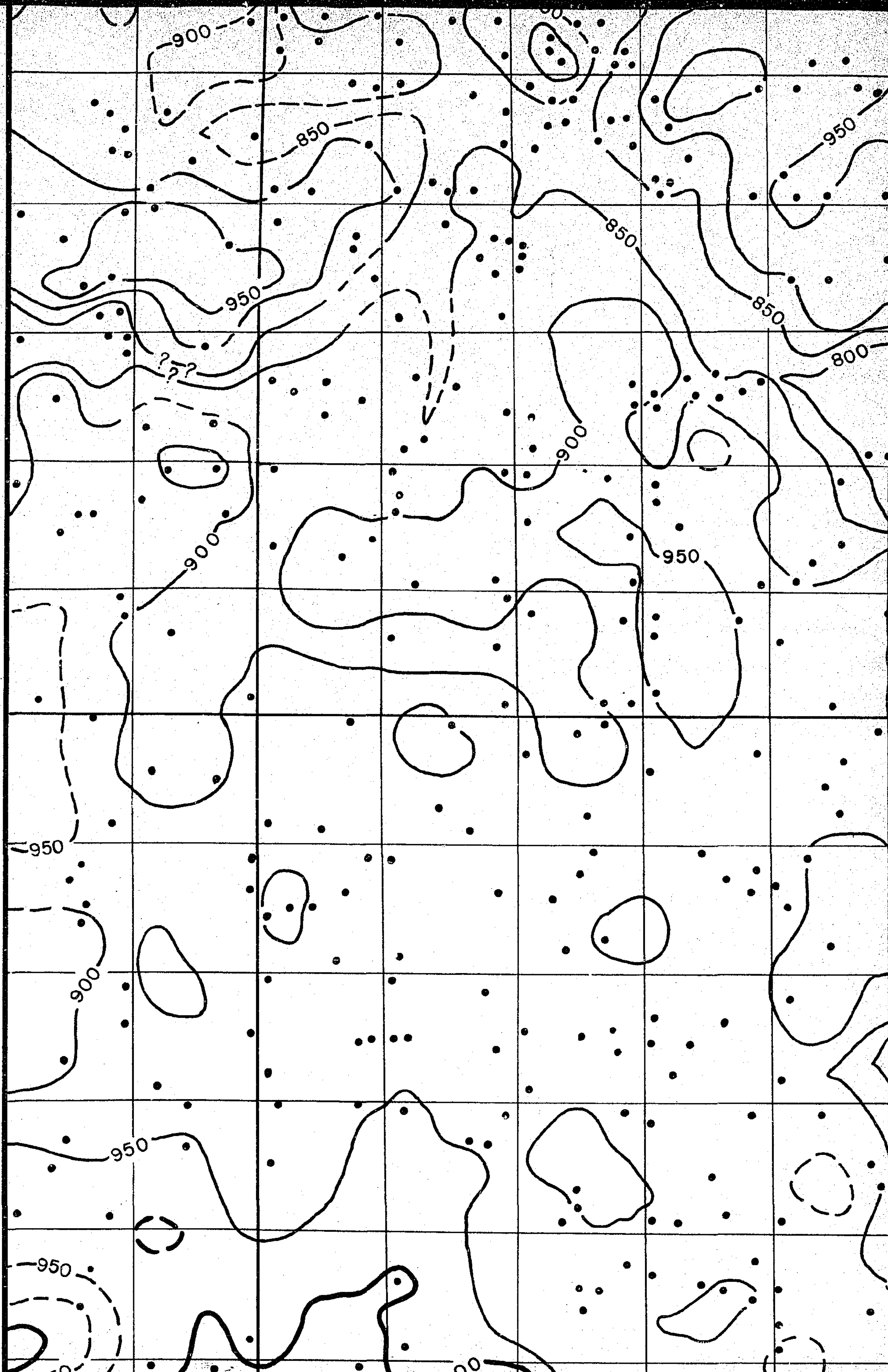

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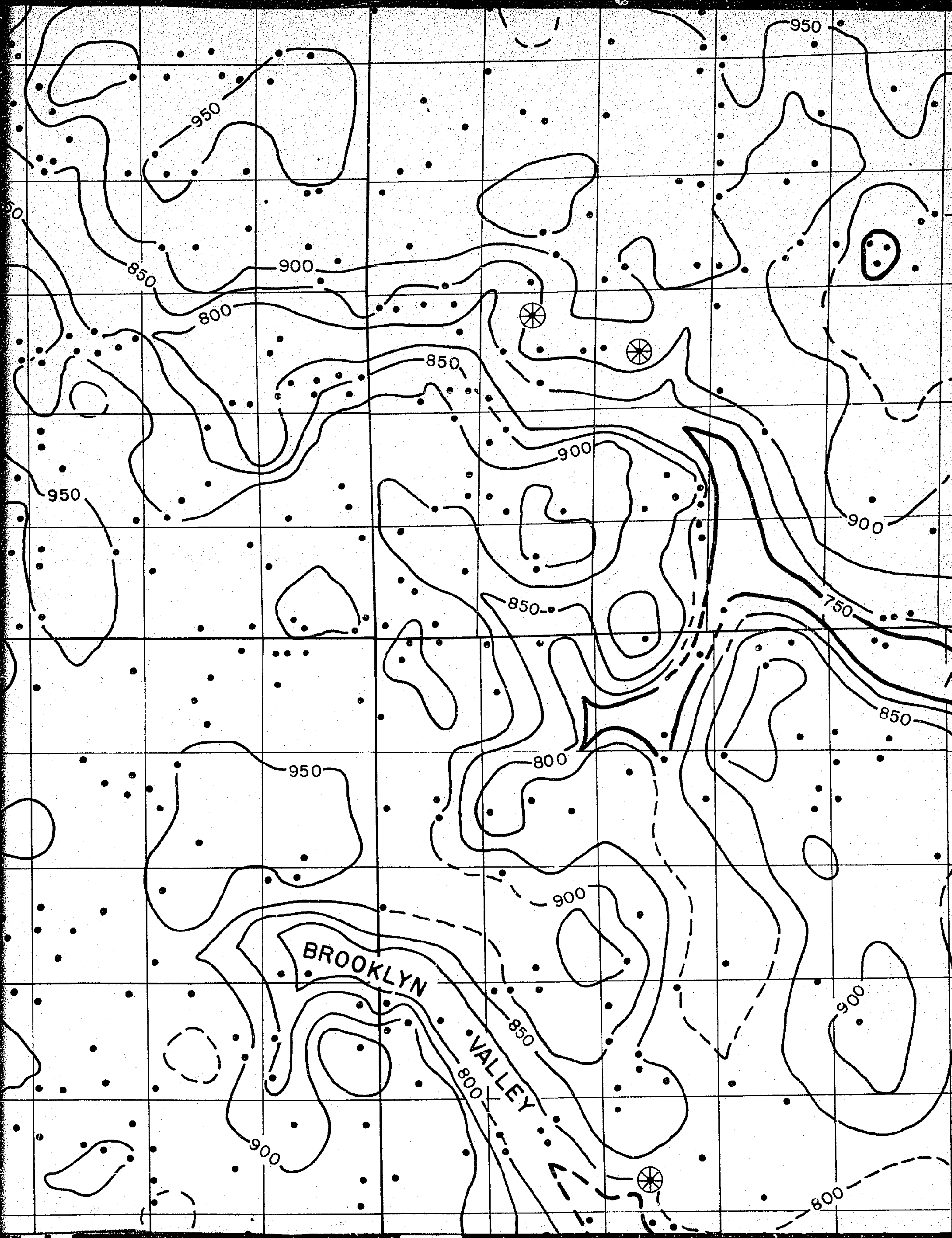
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BROOKLYN
VALLEY
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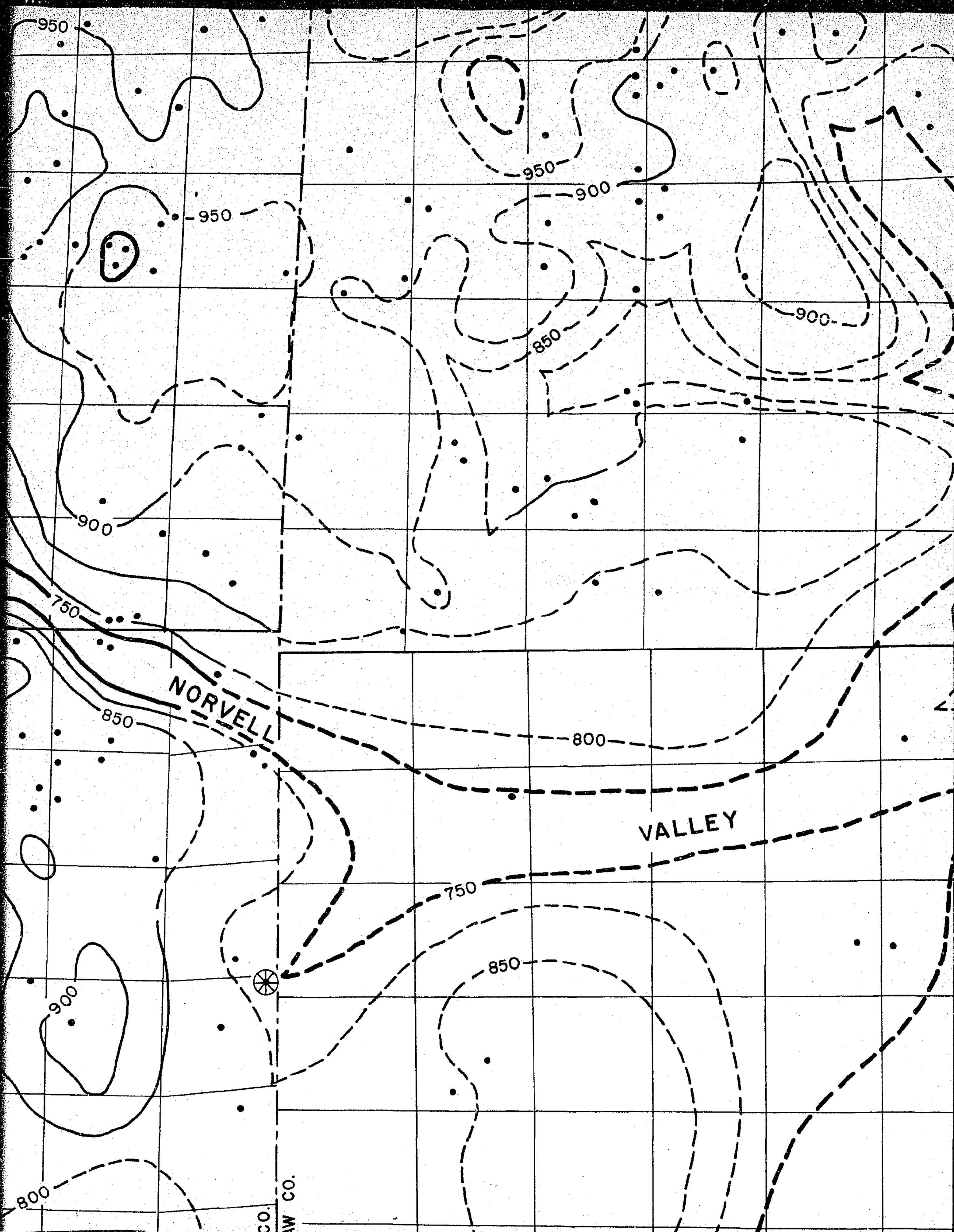
XUM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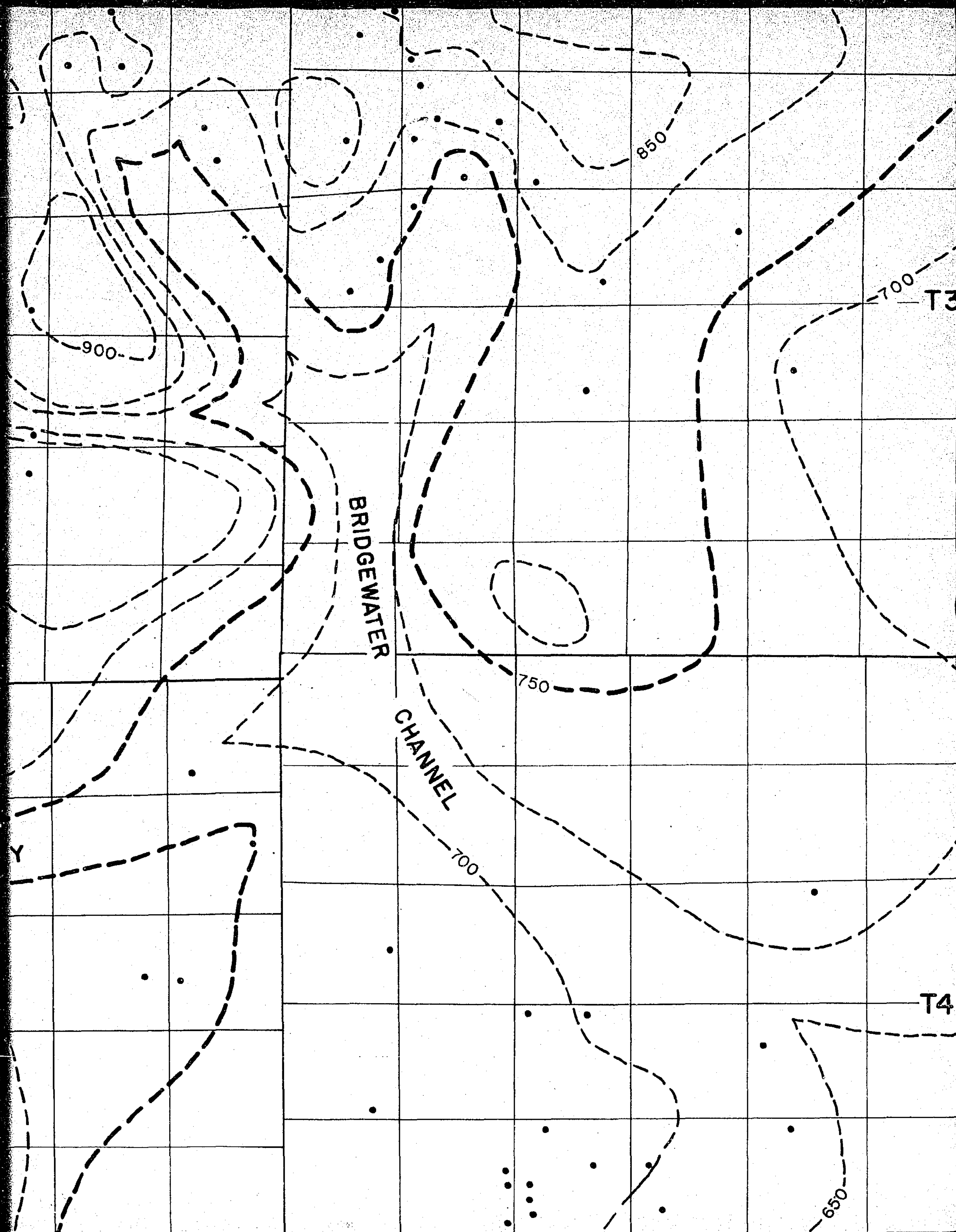
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T3
BRIDGEWATER
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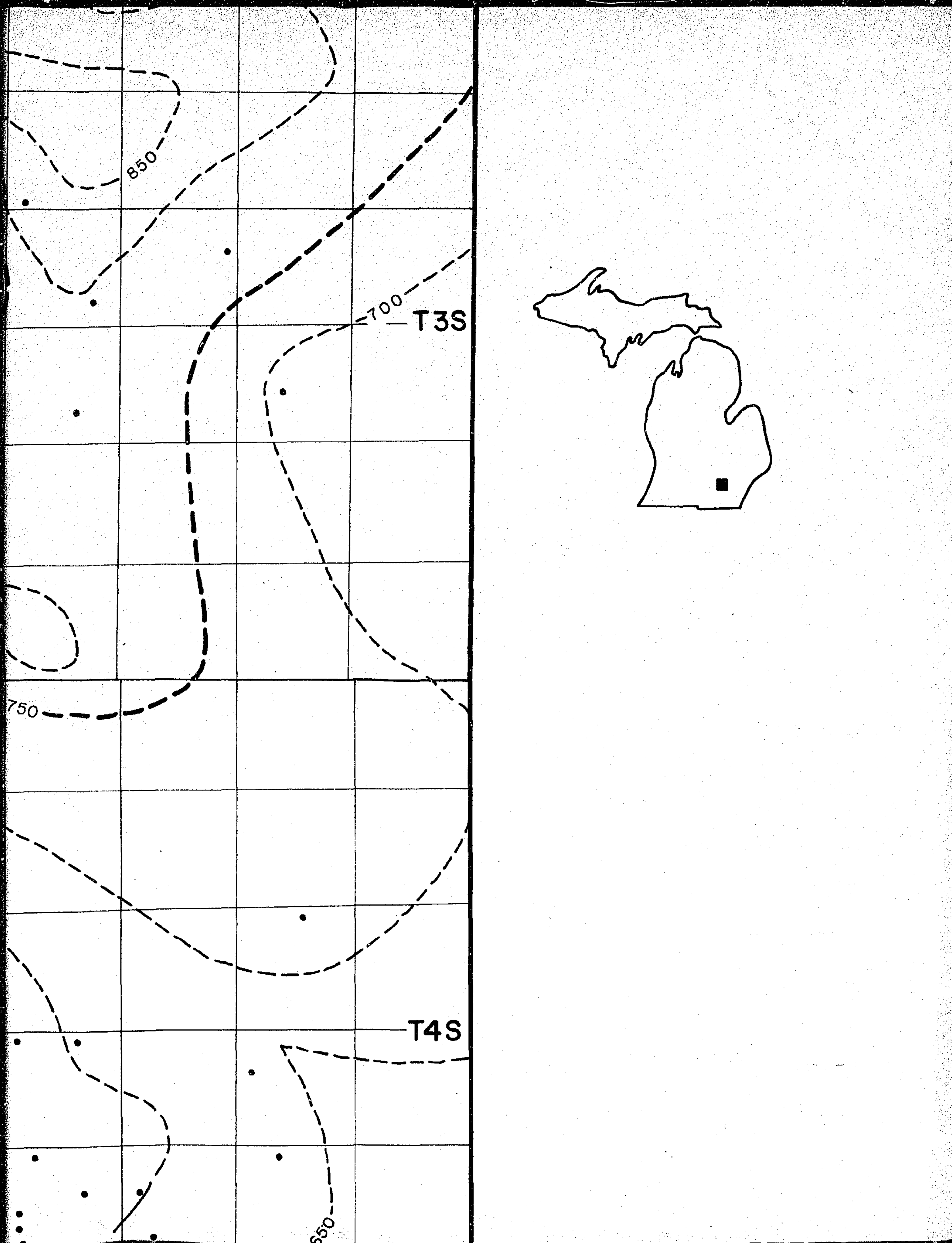

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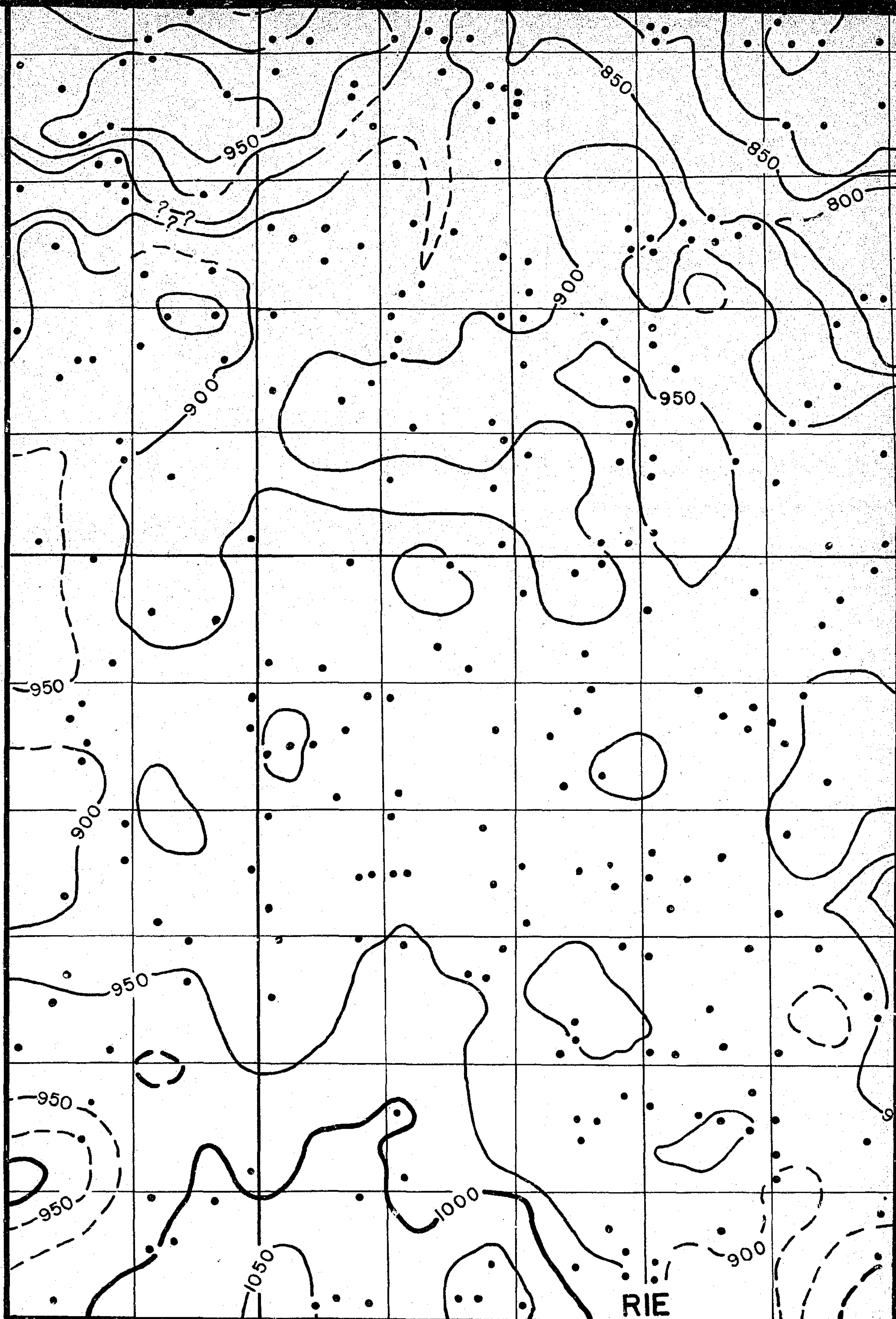
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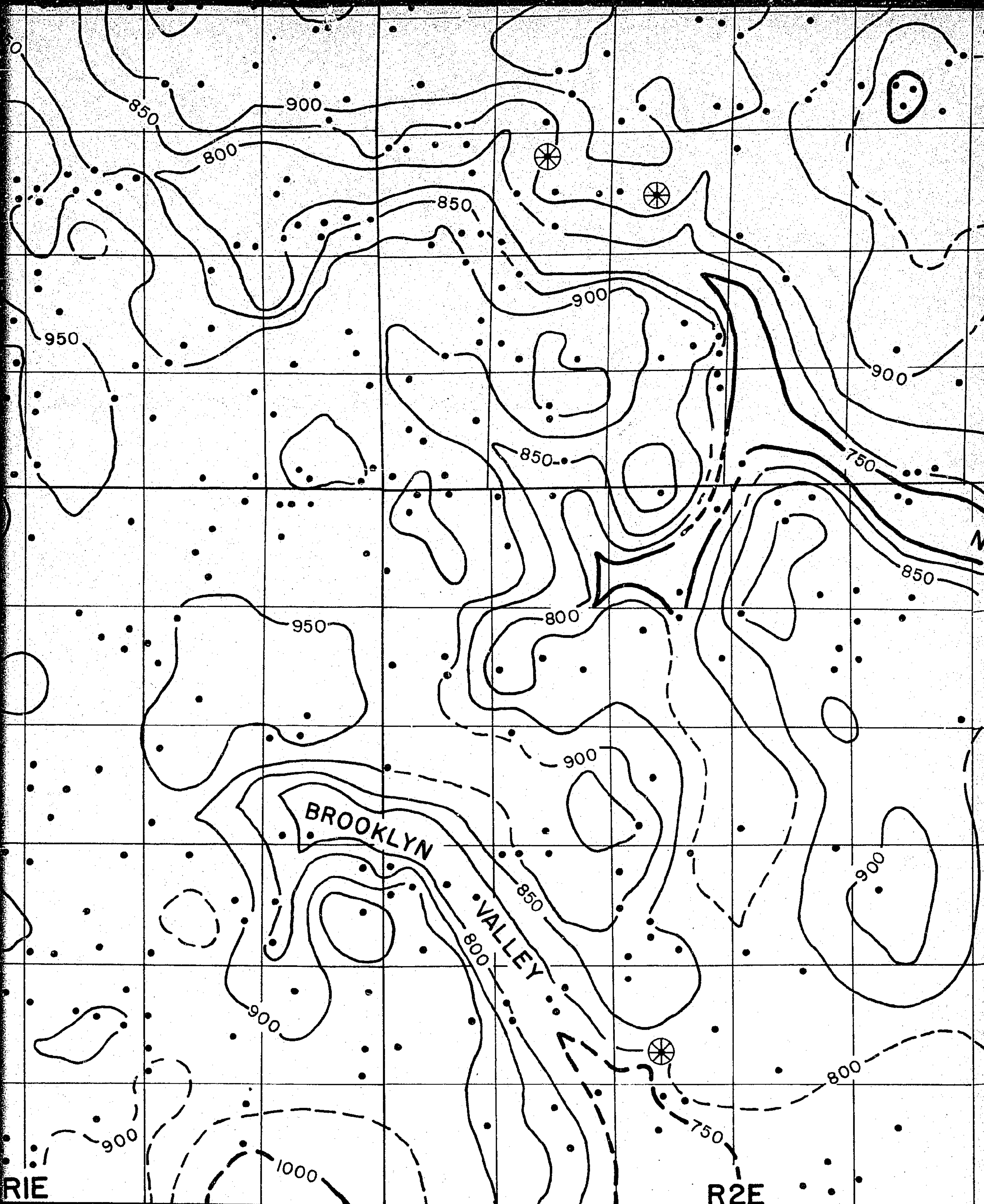

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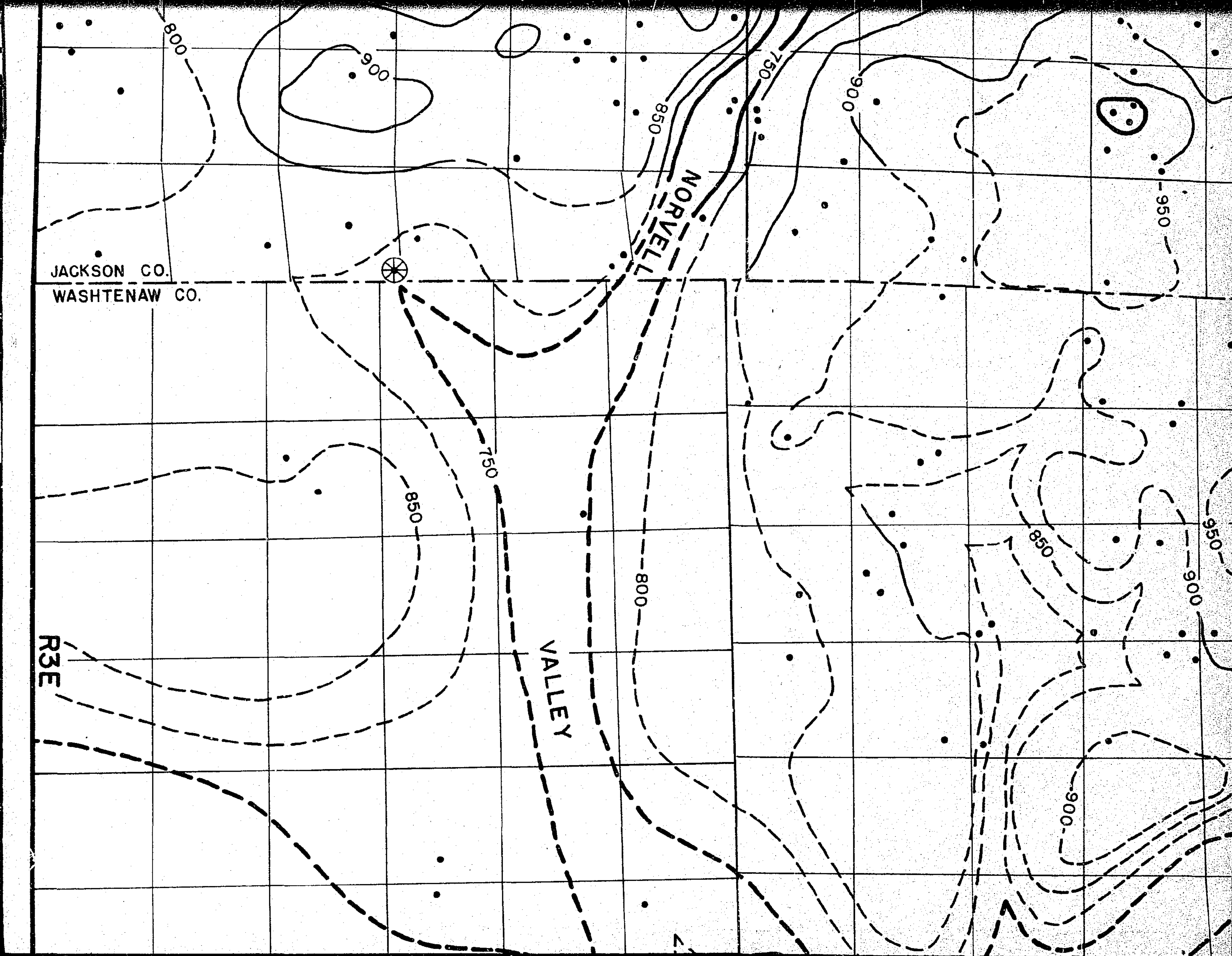
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JACKSON CO.
WASHTENAW CO.
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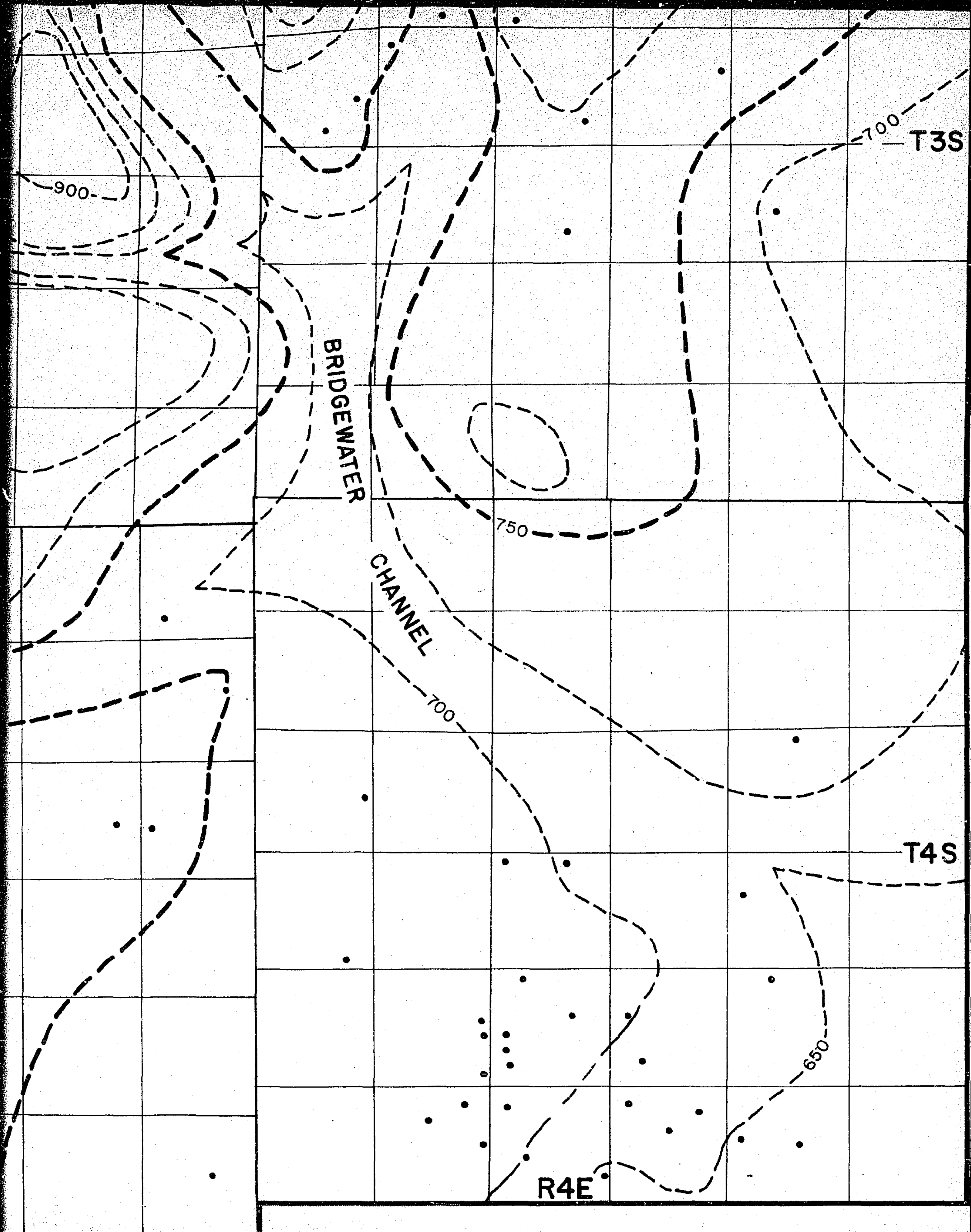

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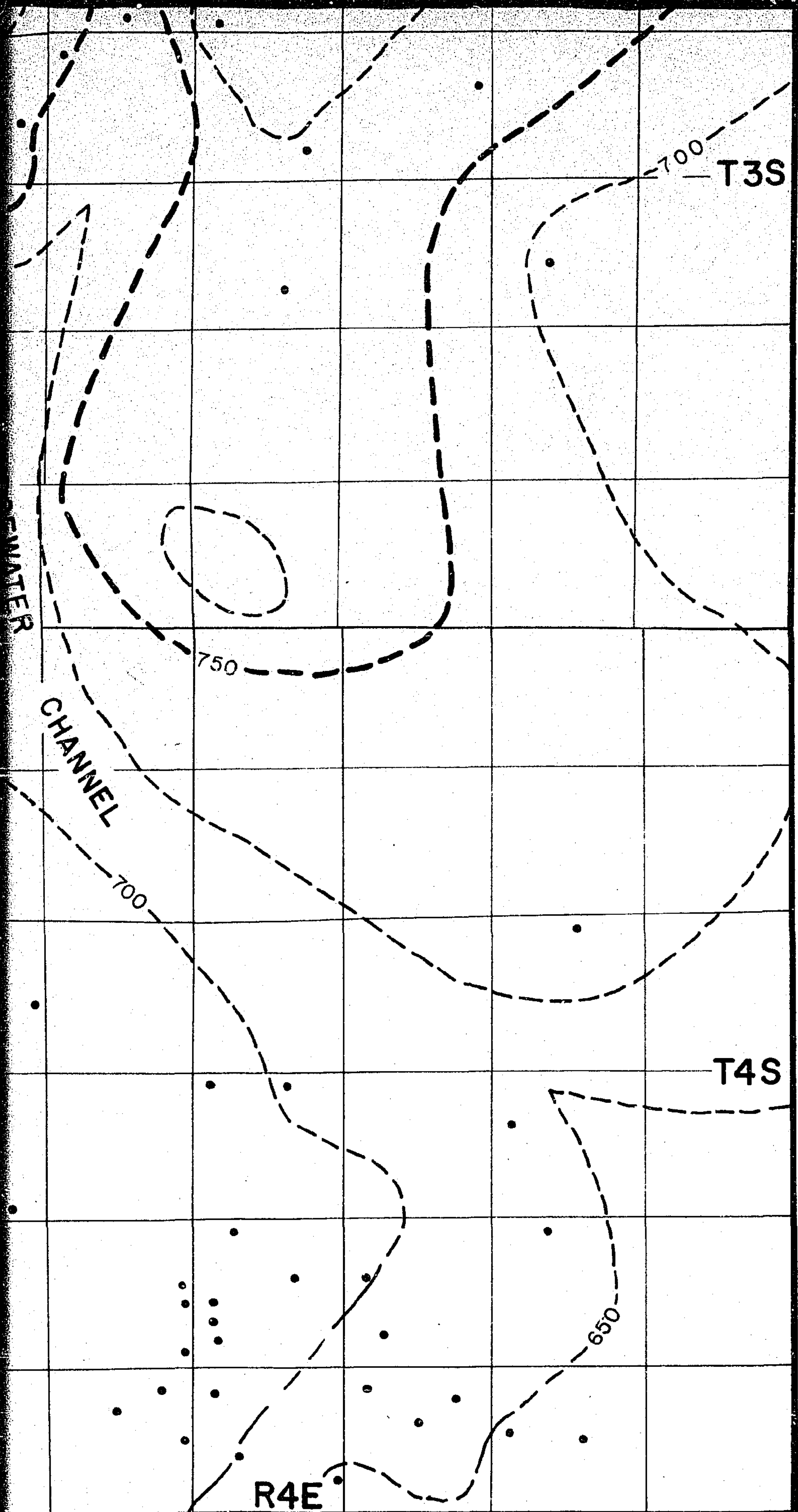


XUM

FIGURE 7. DRIFT

(IN FEET

FEET	METERS
0	0
50	15.2
100	30.5
150	45.7
200	61.0
250	76.2
300	91.4

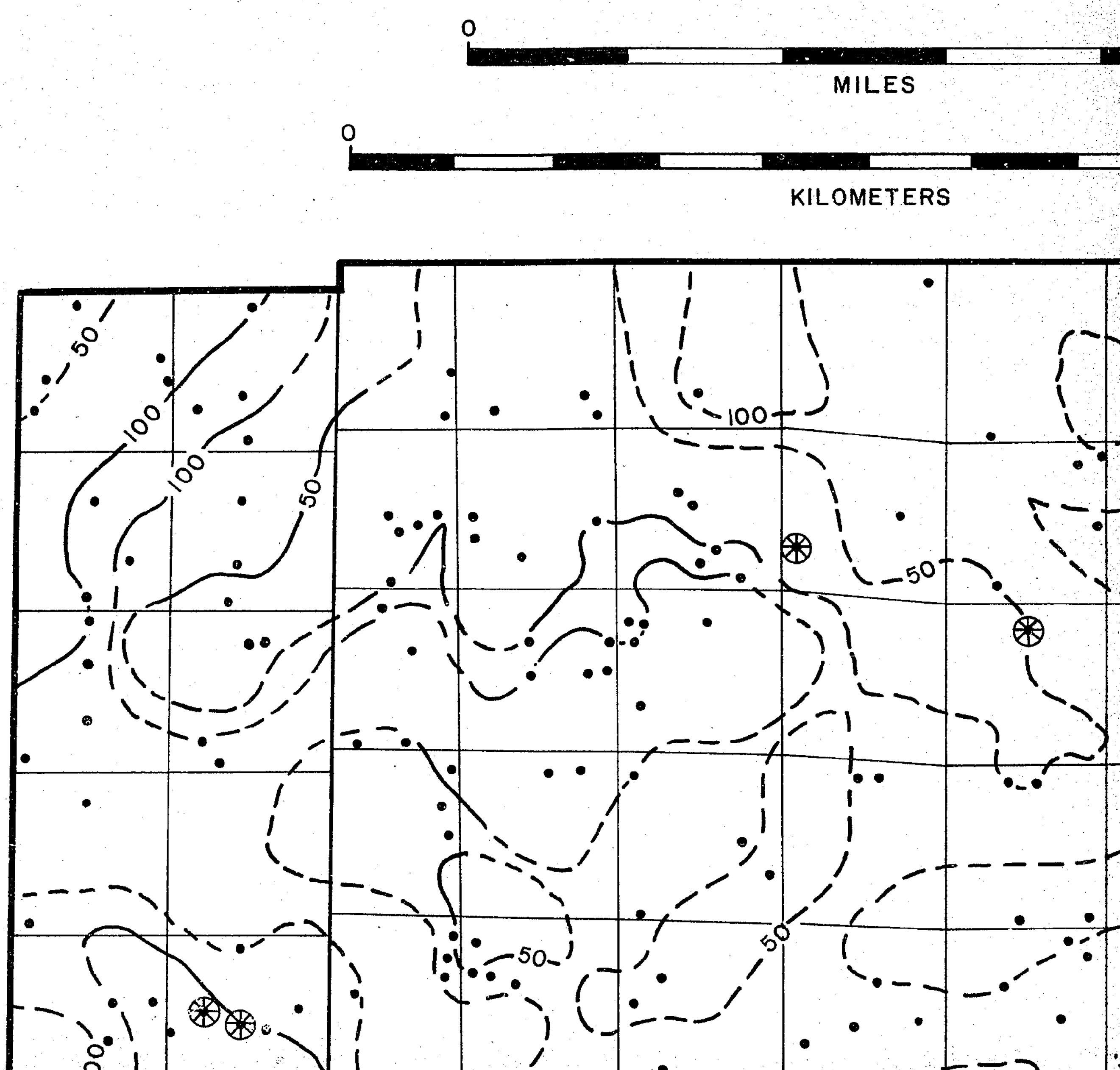
• WELL DATA SITE

CONTOUR IN AREA W
NUMEROUS WELL

CONTOUR IN AREA W
FEWER WELL REC

WELL WITH BEDROCK
20 FEET (6.1 M) OF

CONTOUR INTERVAL 50 FE



XUM

7. DRIFT THICKNESS
(IN FEET)

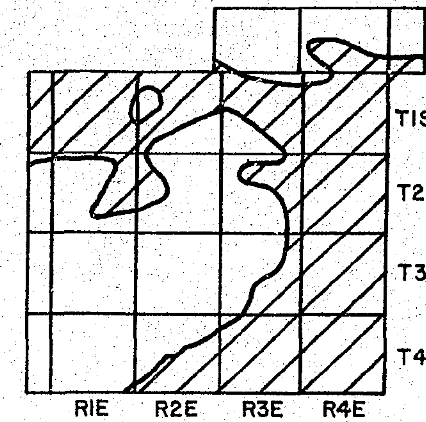
LL DATA SITE

NTOUR IN AREA WITH
UMEROUS WELL RECORDS

NTOUR IN AREA WITH
EWER WELL RECORDS

LL WITH BEDROCK WITHIN
O FEET (6.1 M) OF SURFACE

INTERVAL 50 FEET (15.2 M)



▨ DRIFT THICKNESS MAY BE GREATER THAN INDICATED DUE TO RESISTANT TILL DIRECTLY OVERLYING BEDROCK IN THE SUBSURFACE

5

MILES

10

OMETERS

SOURCES: SEE APPENDIX A.

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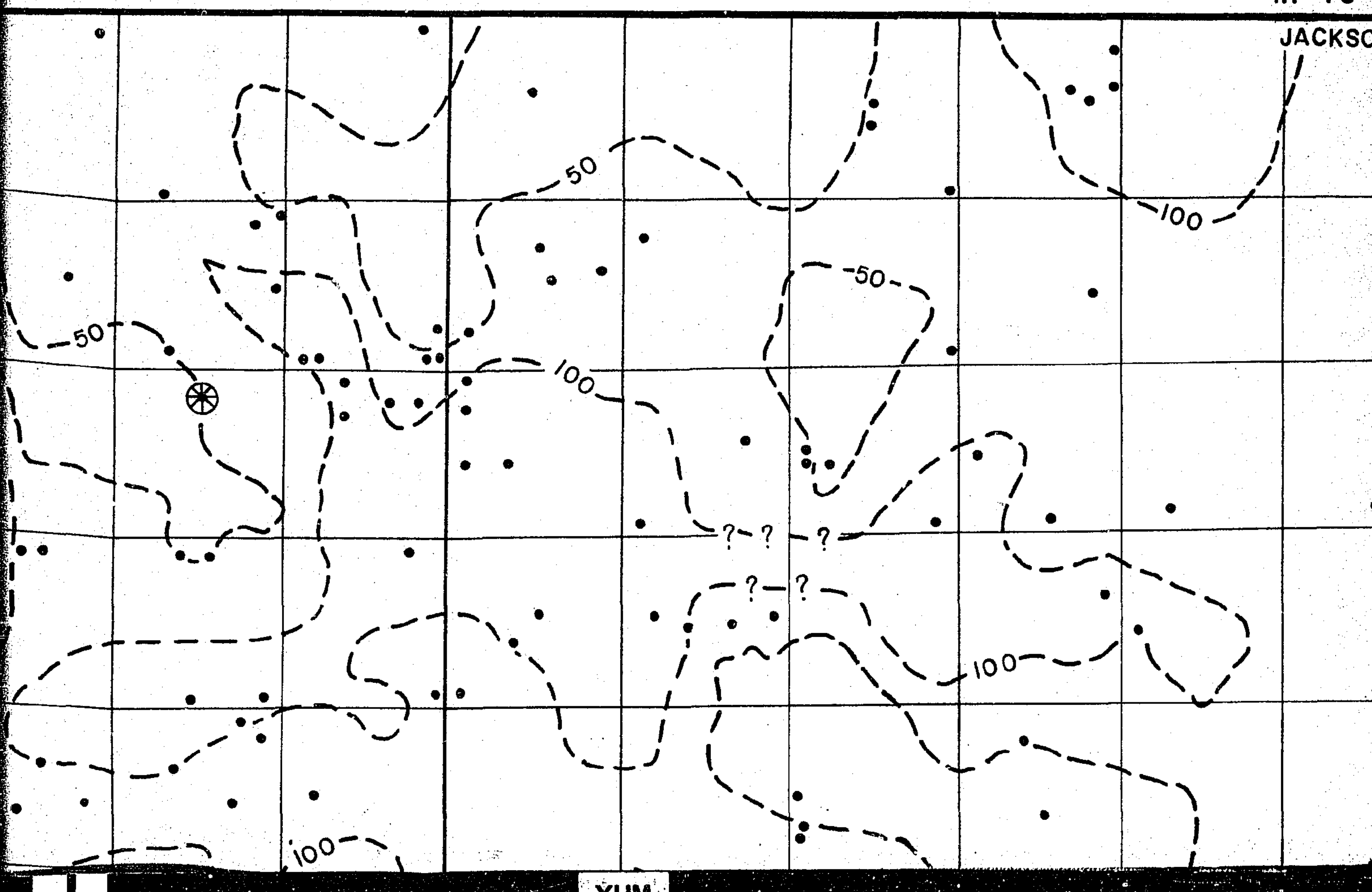

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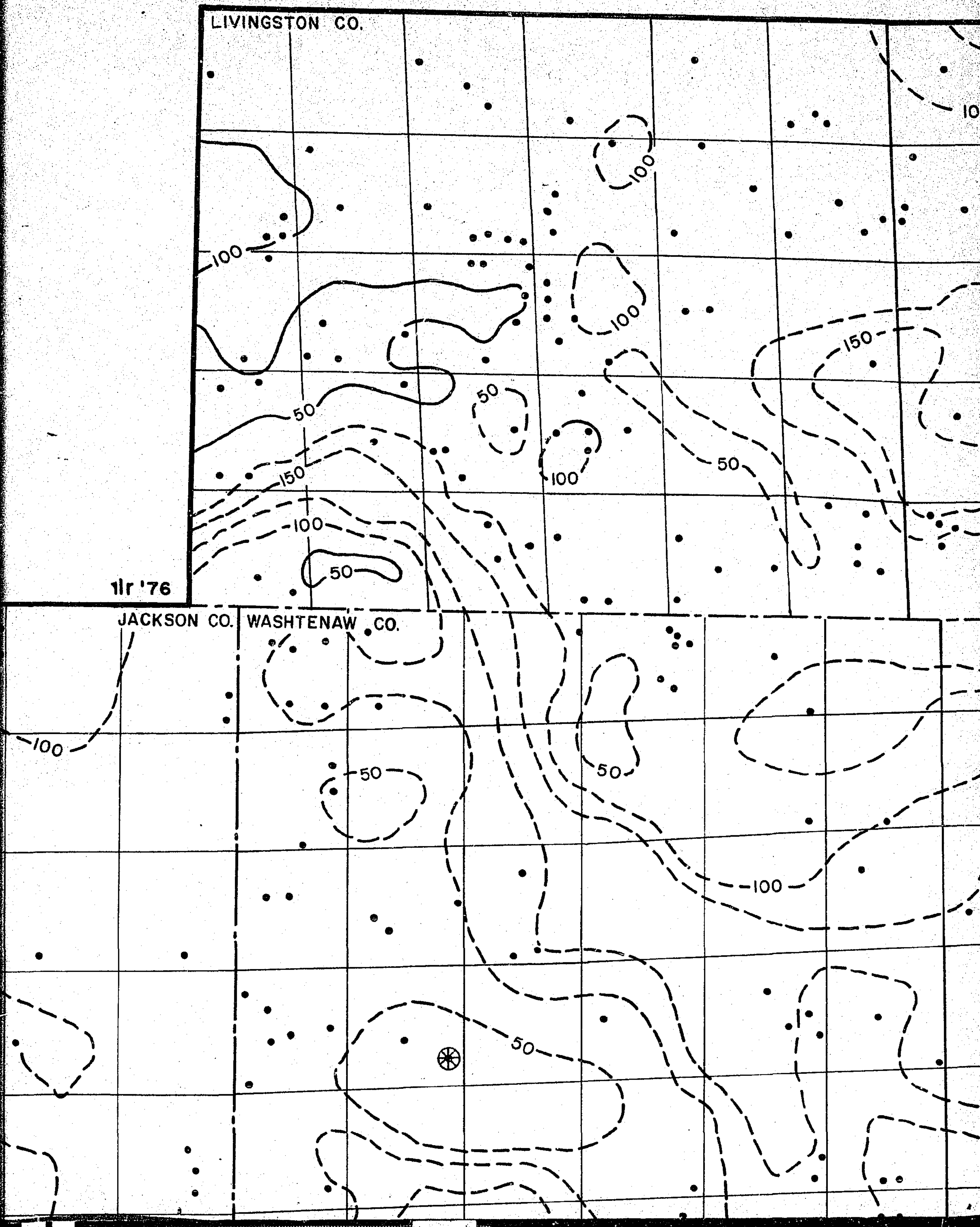
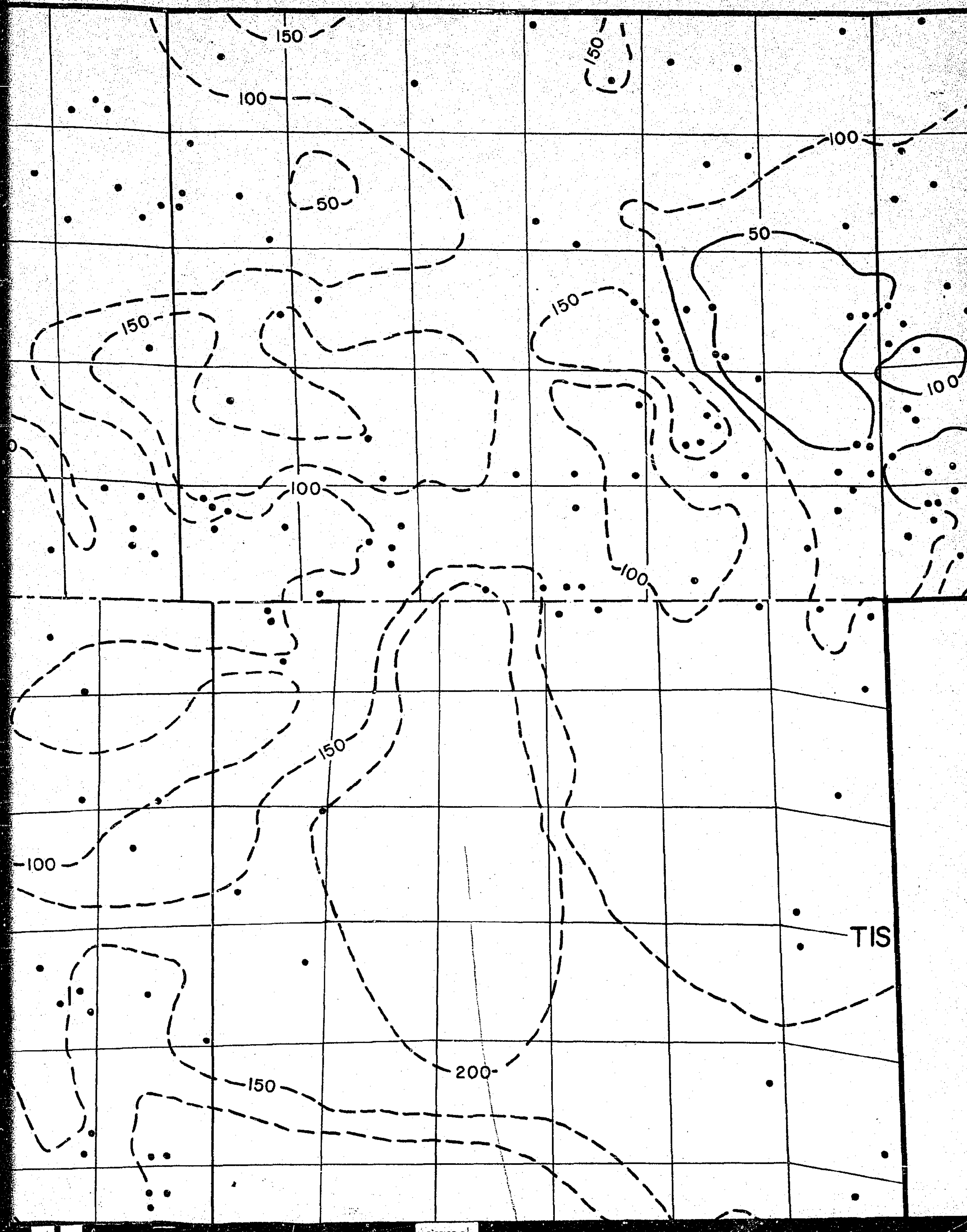

LIVINGSTON CO.
1lr '76
JACKSON CO.
WASHTENAW CO.
50
100
150
XUM



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TIS
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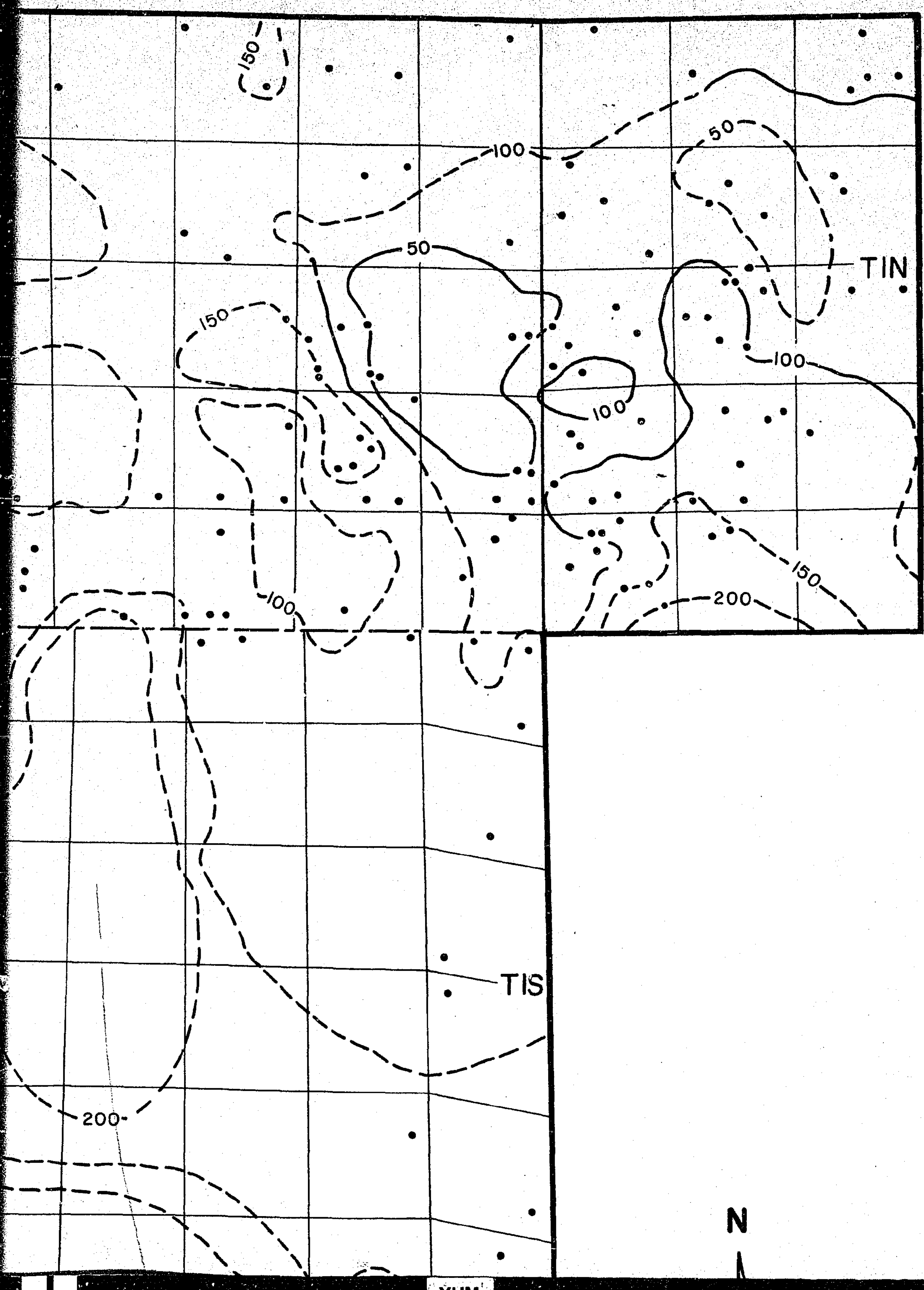
200
150
XUM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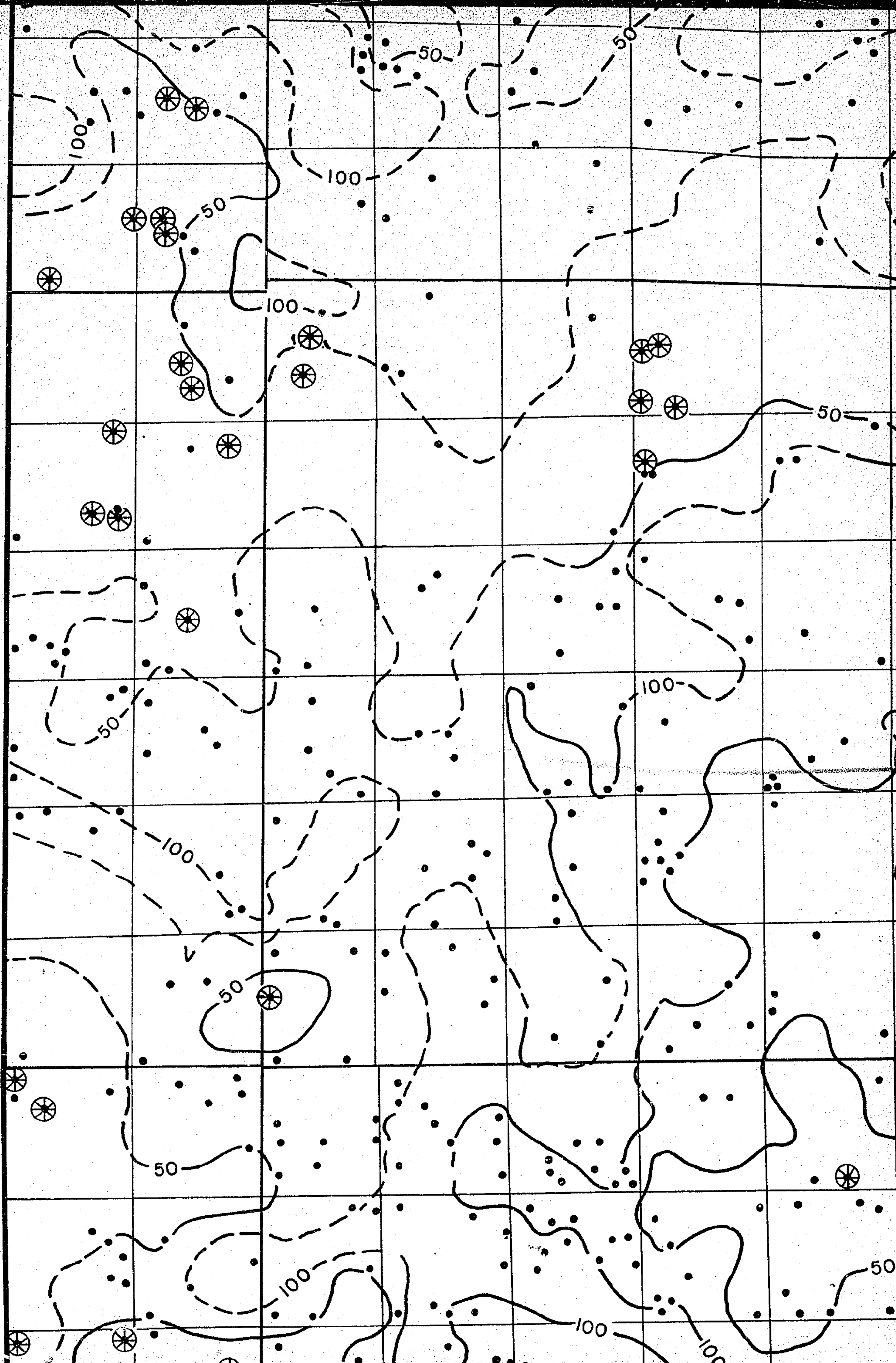

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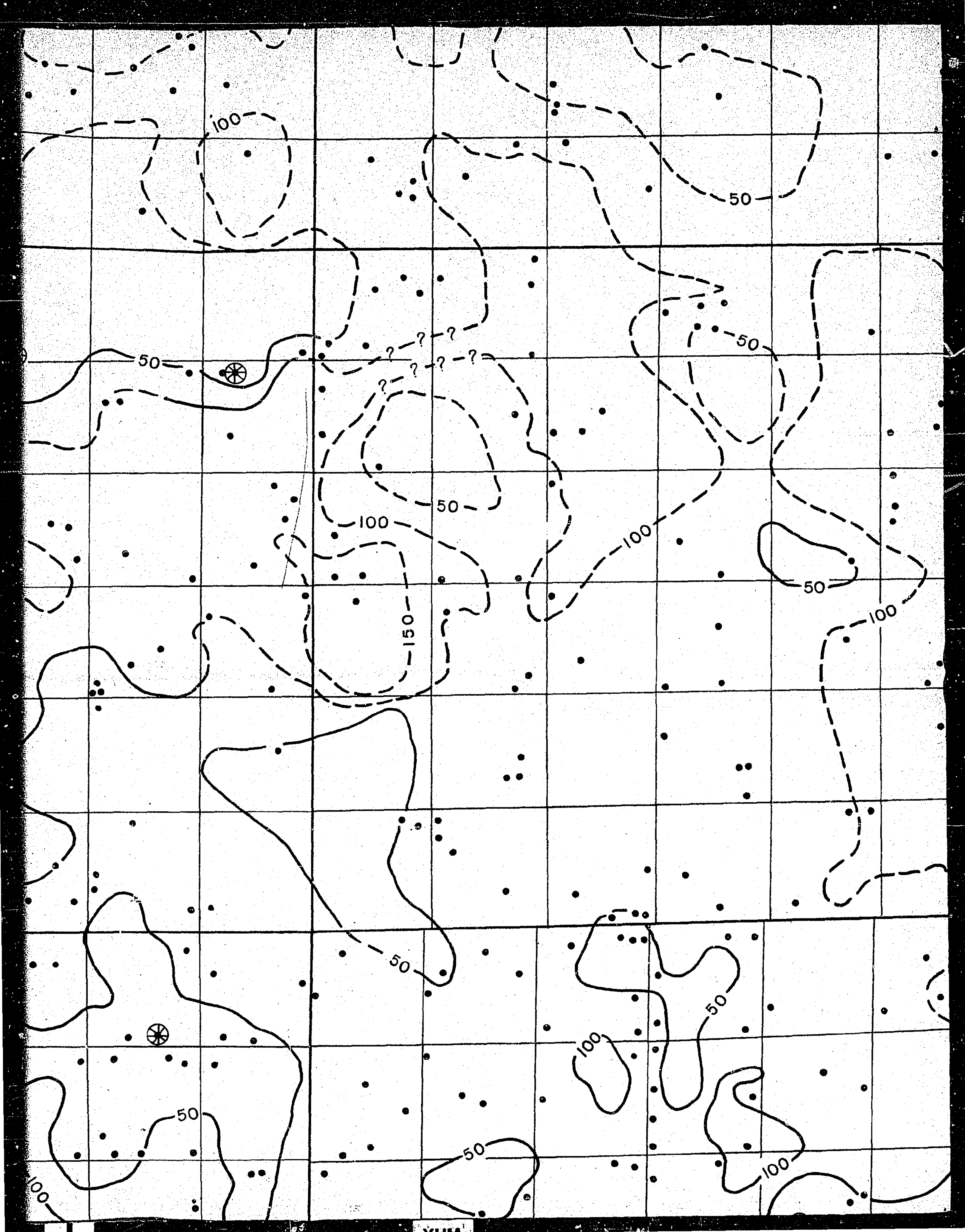
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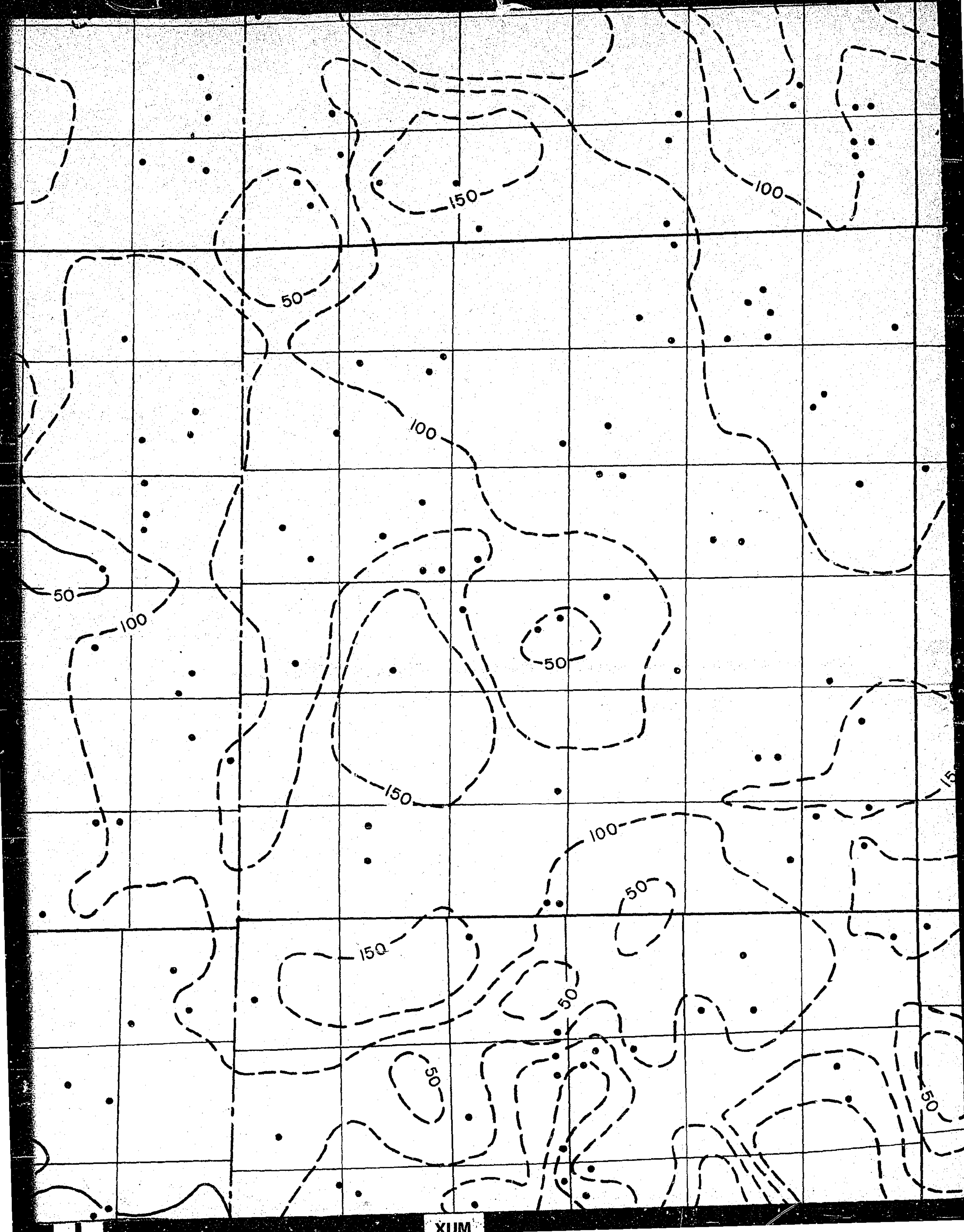
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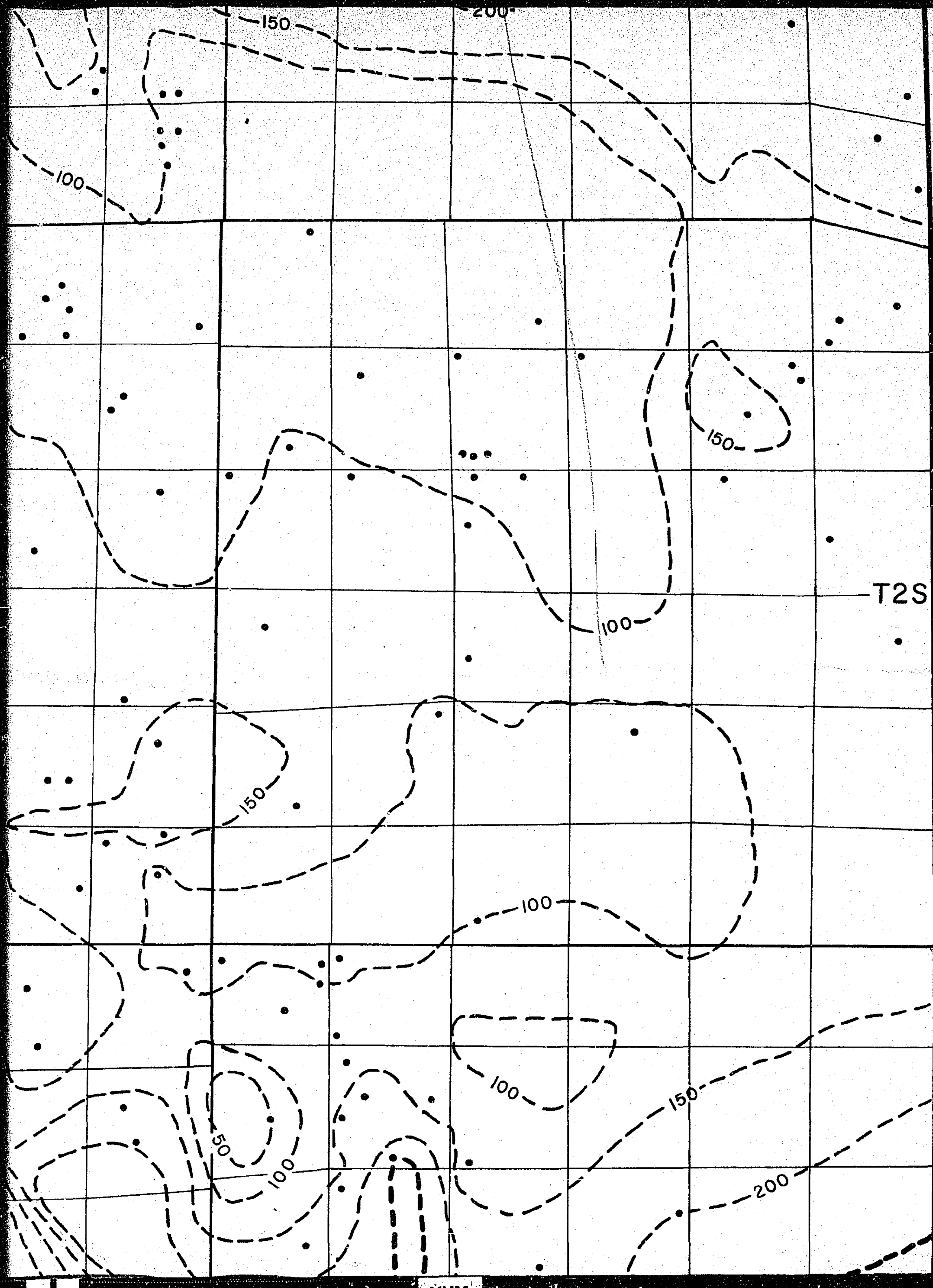
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T2S
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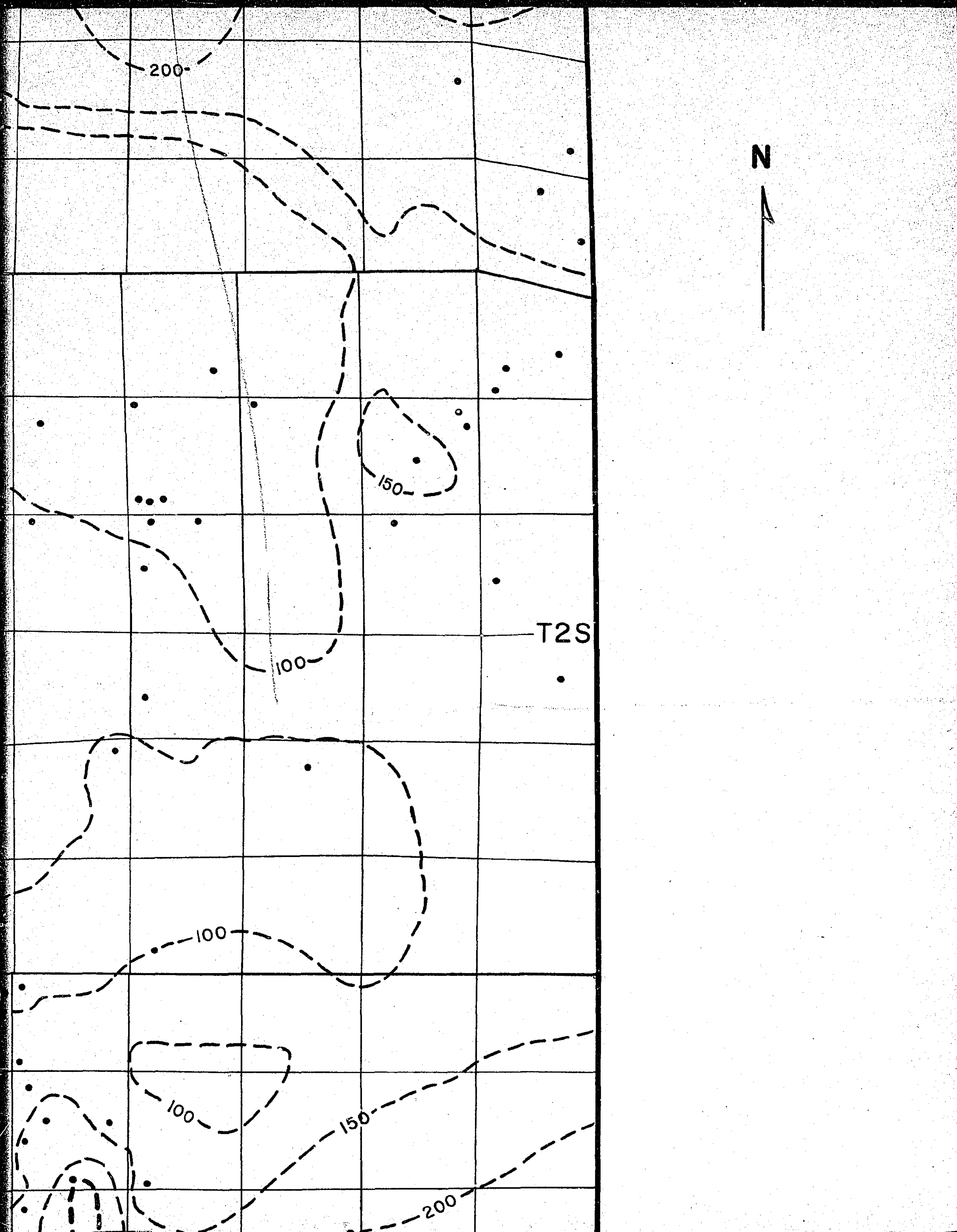
XUM



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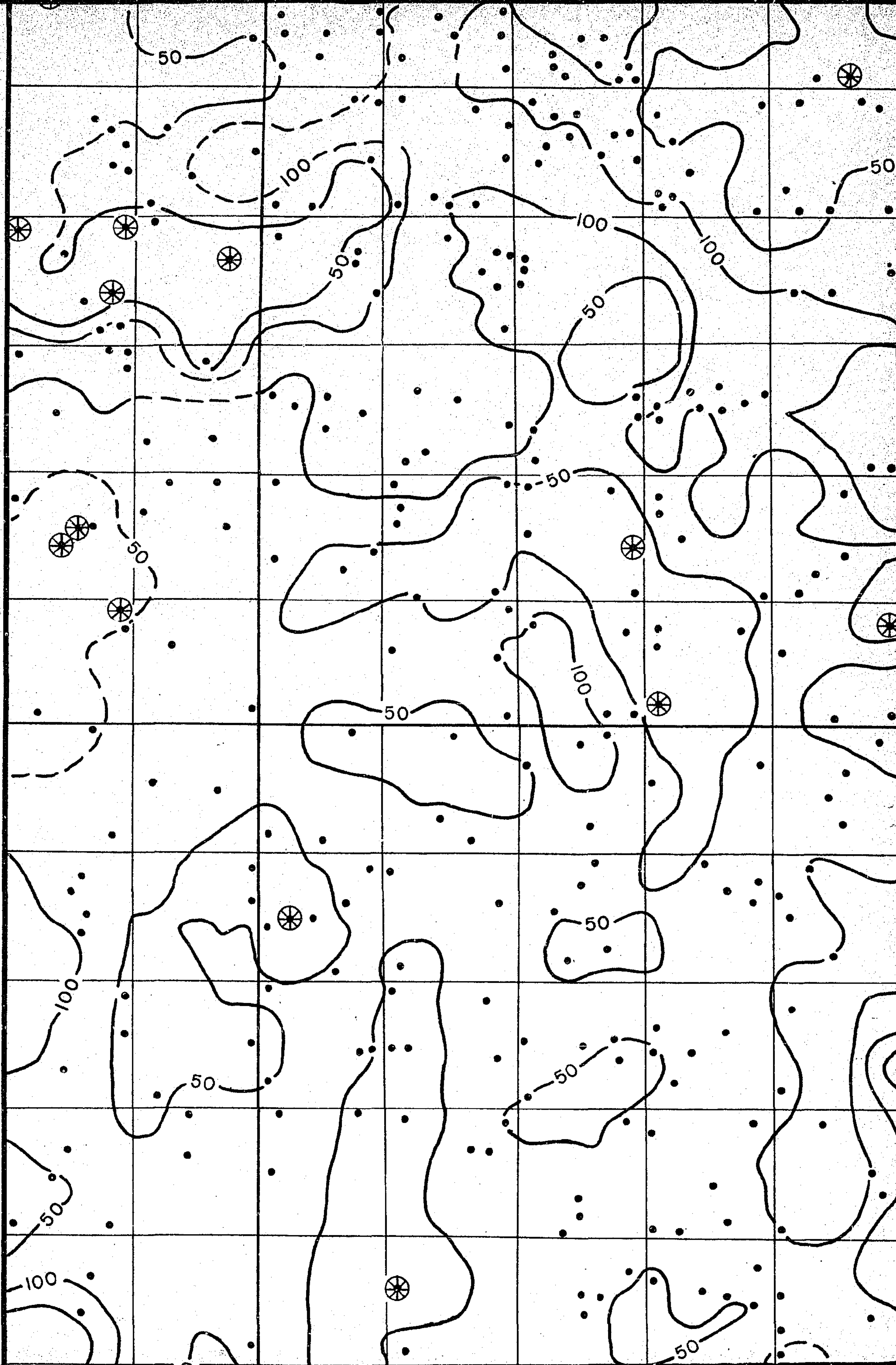

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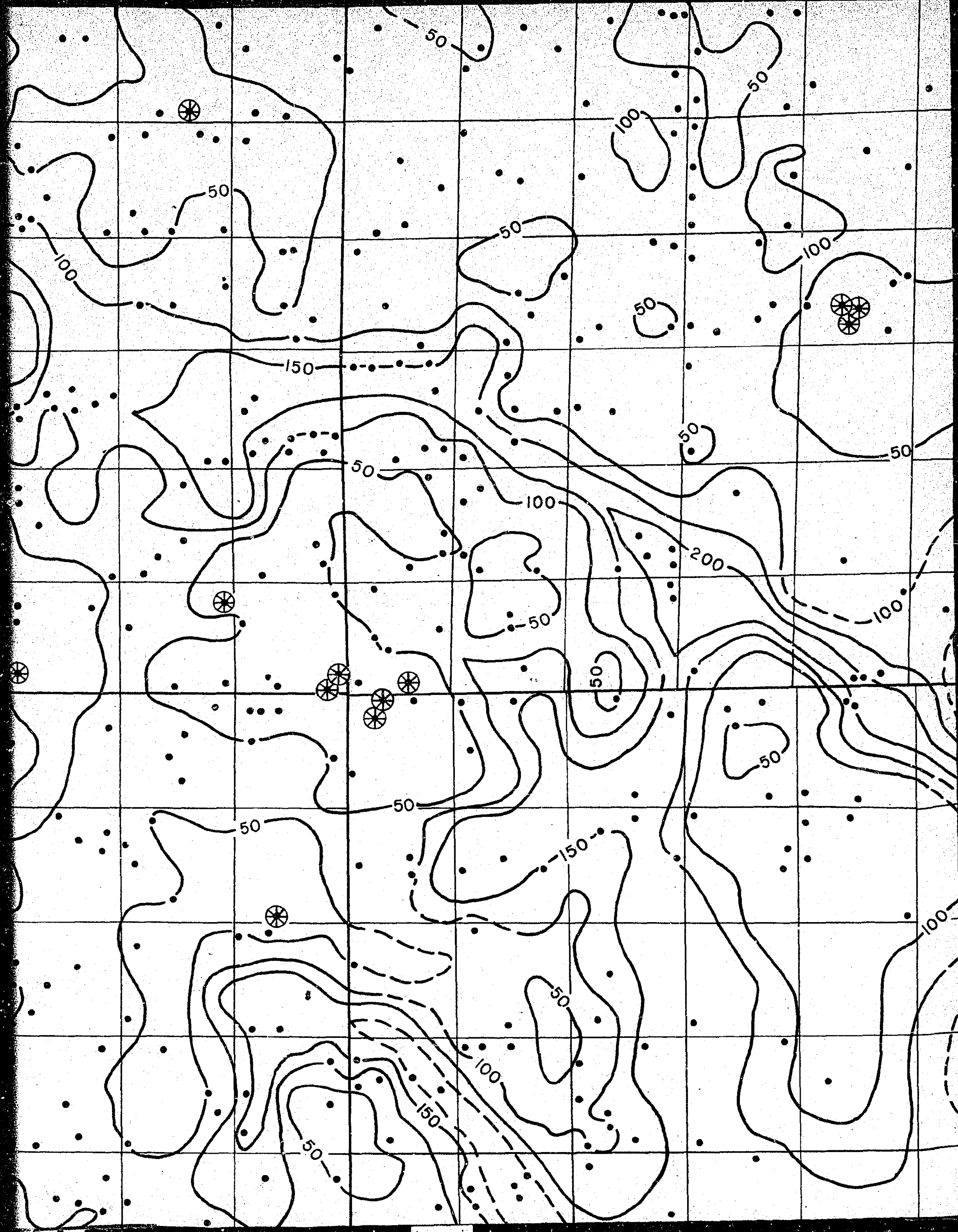
50
100
150
200
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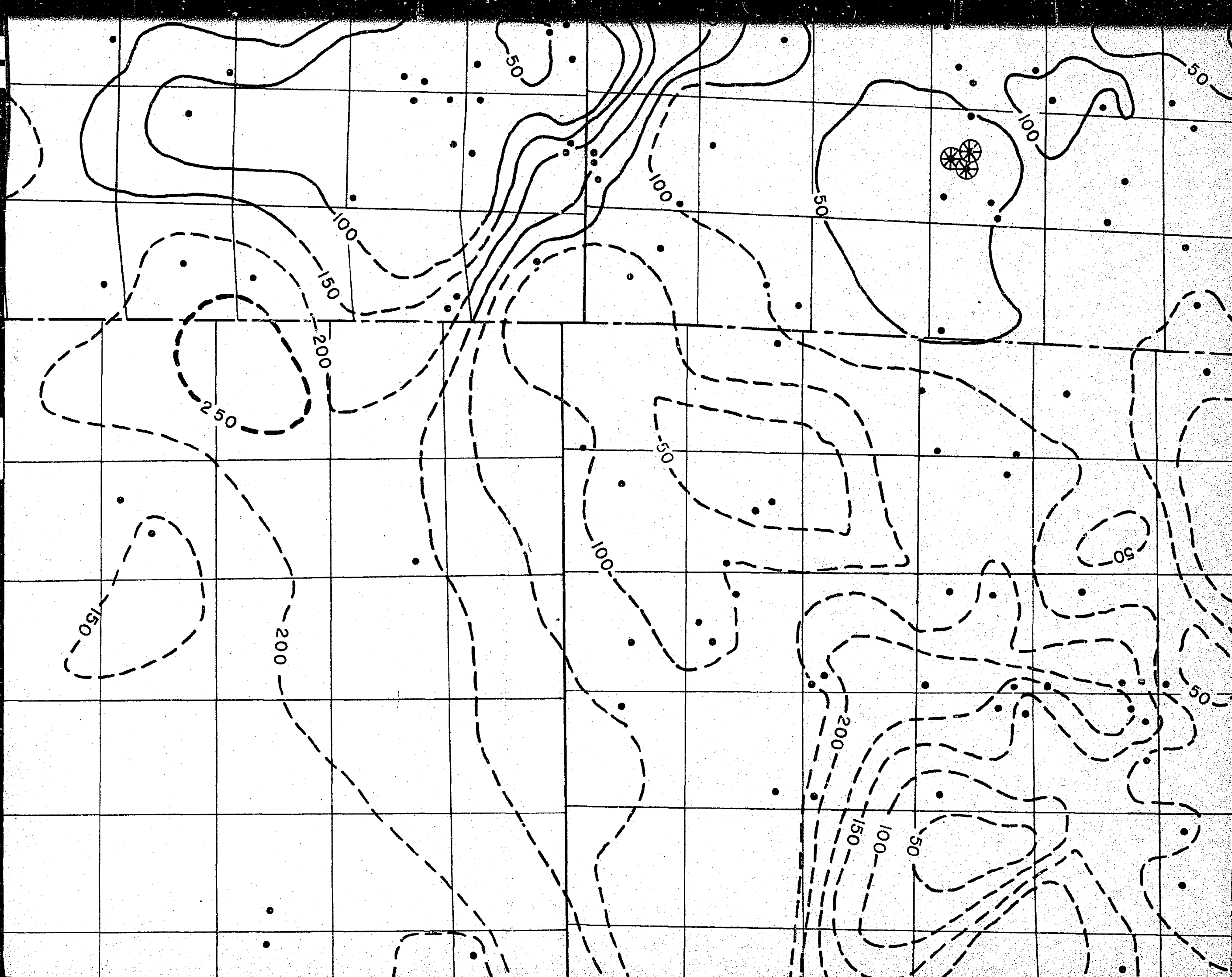
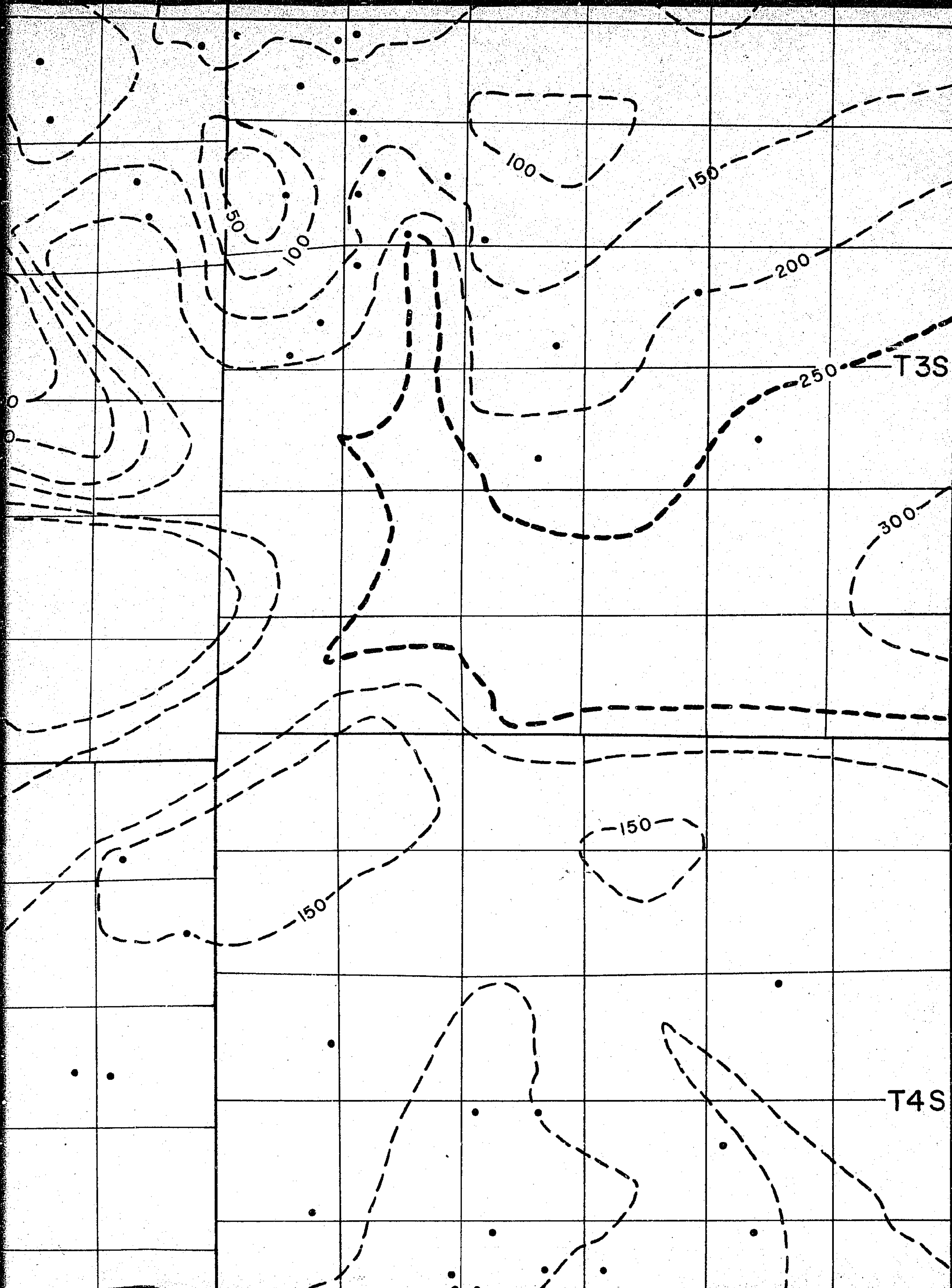
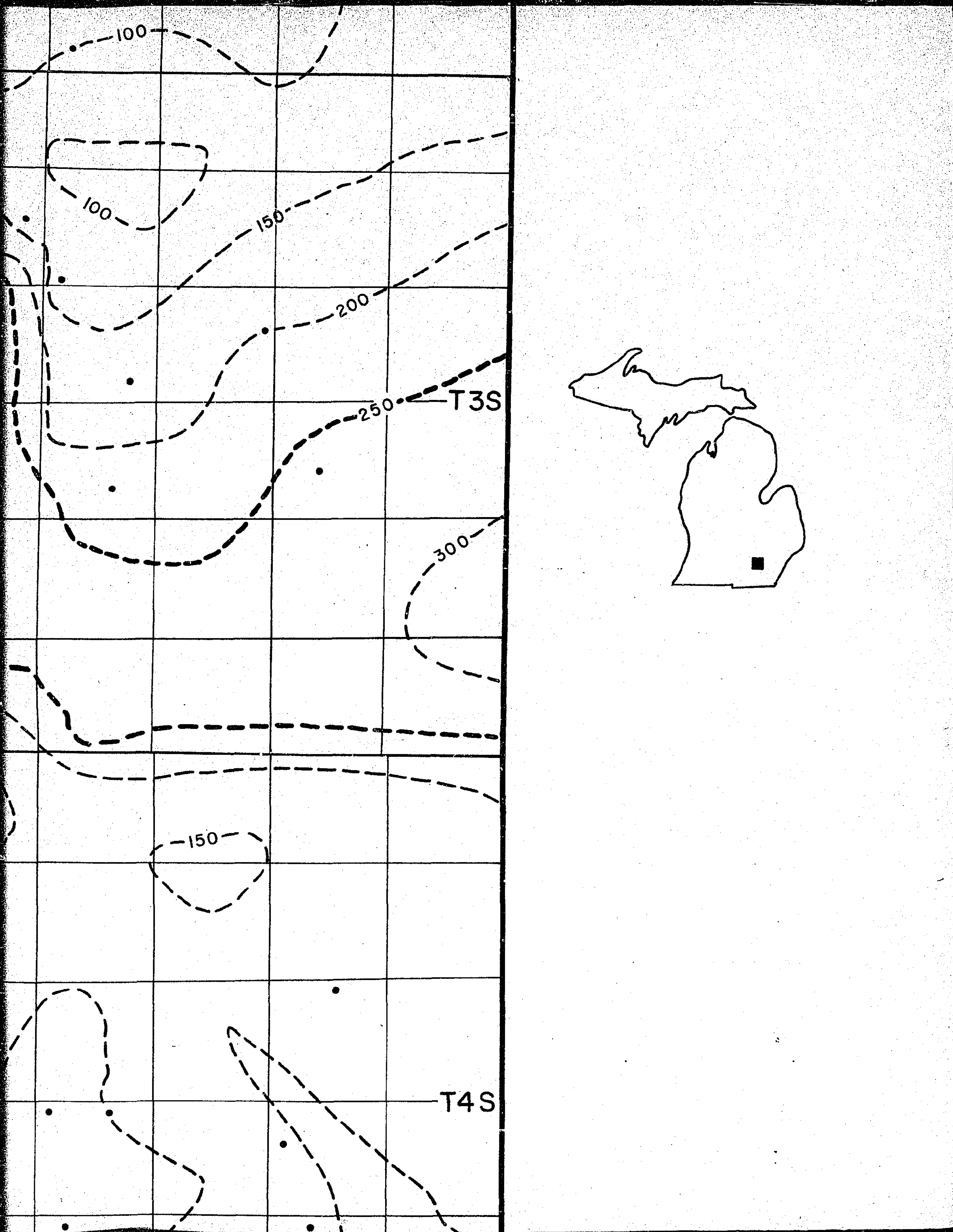


50
100
150
200
250

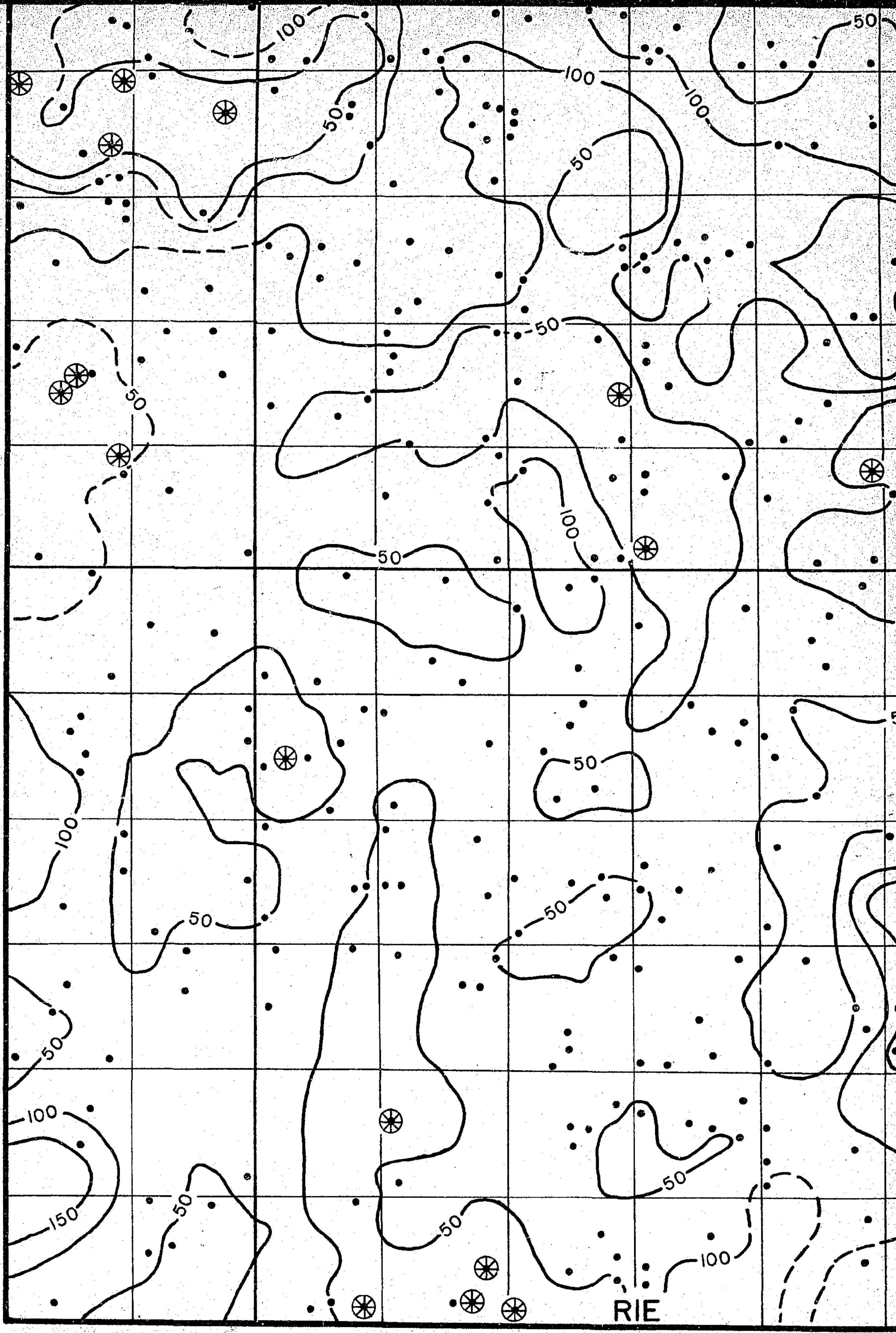
XUM



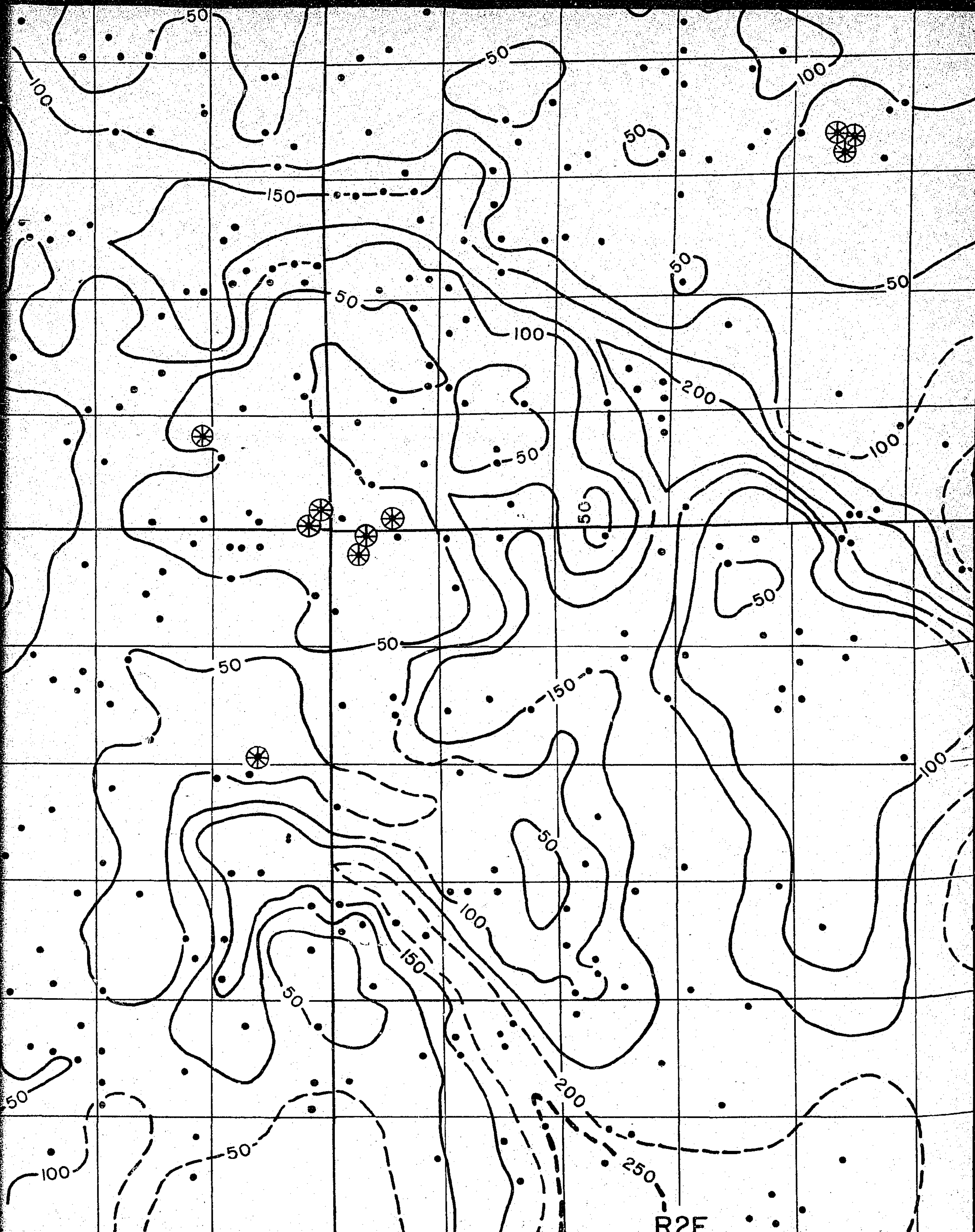
XUM



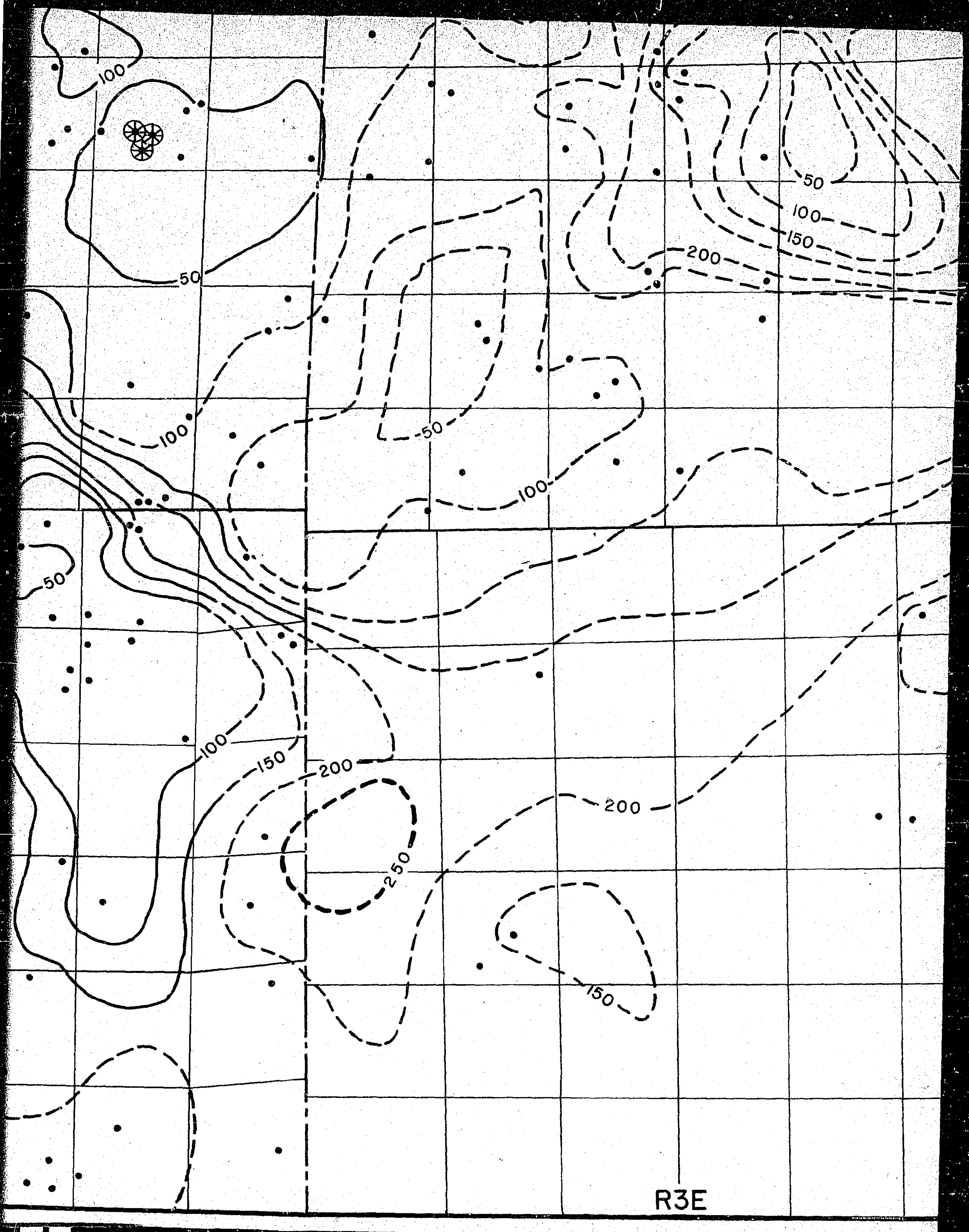
XUM

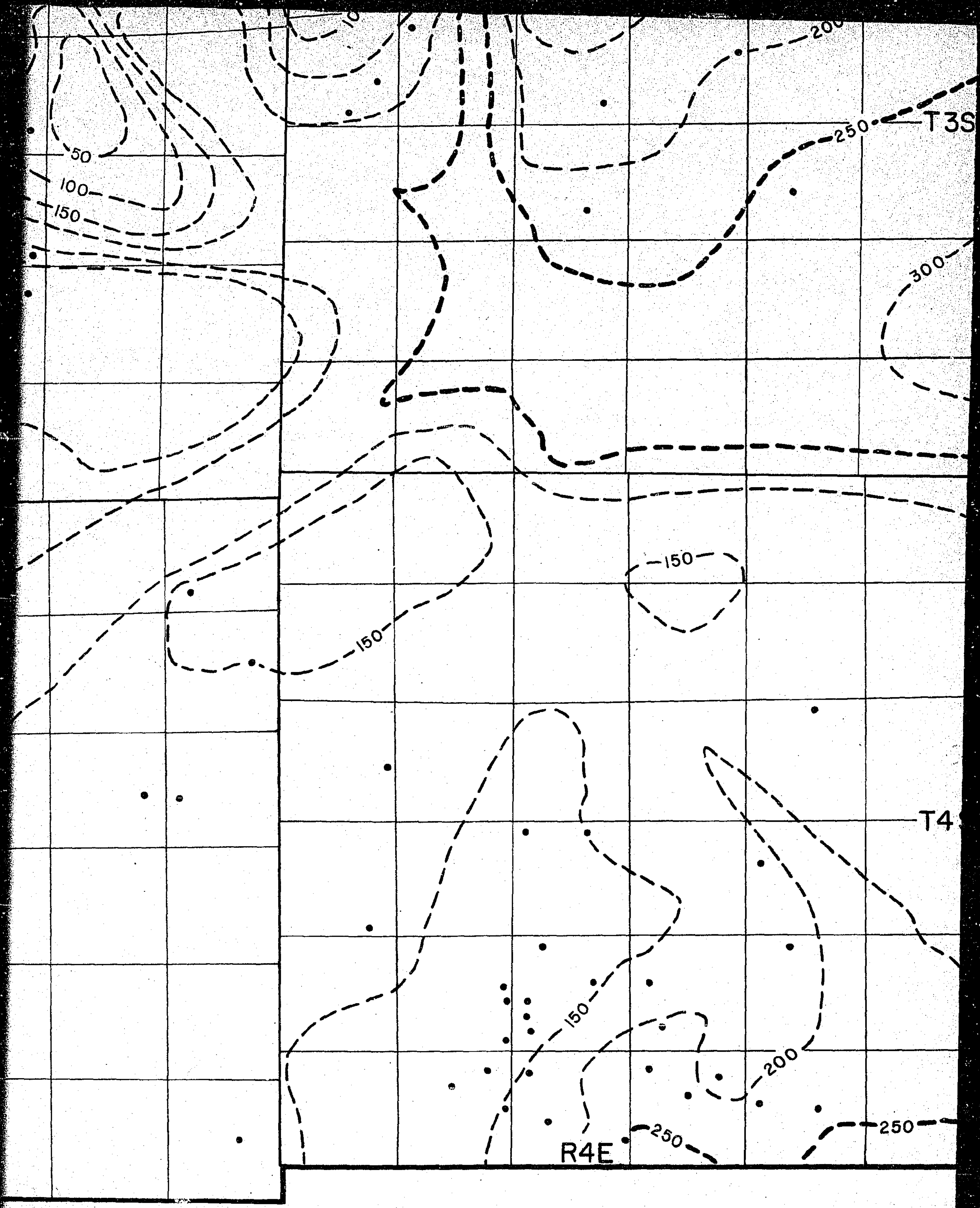


RIE
XUM

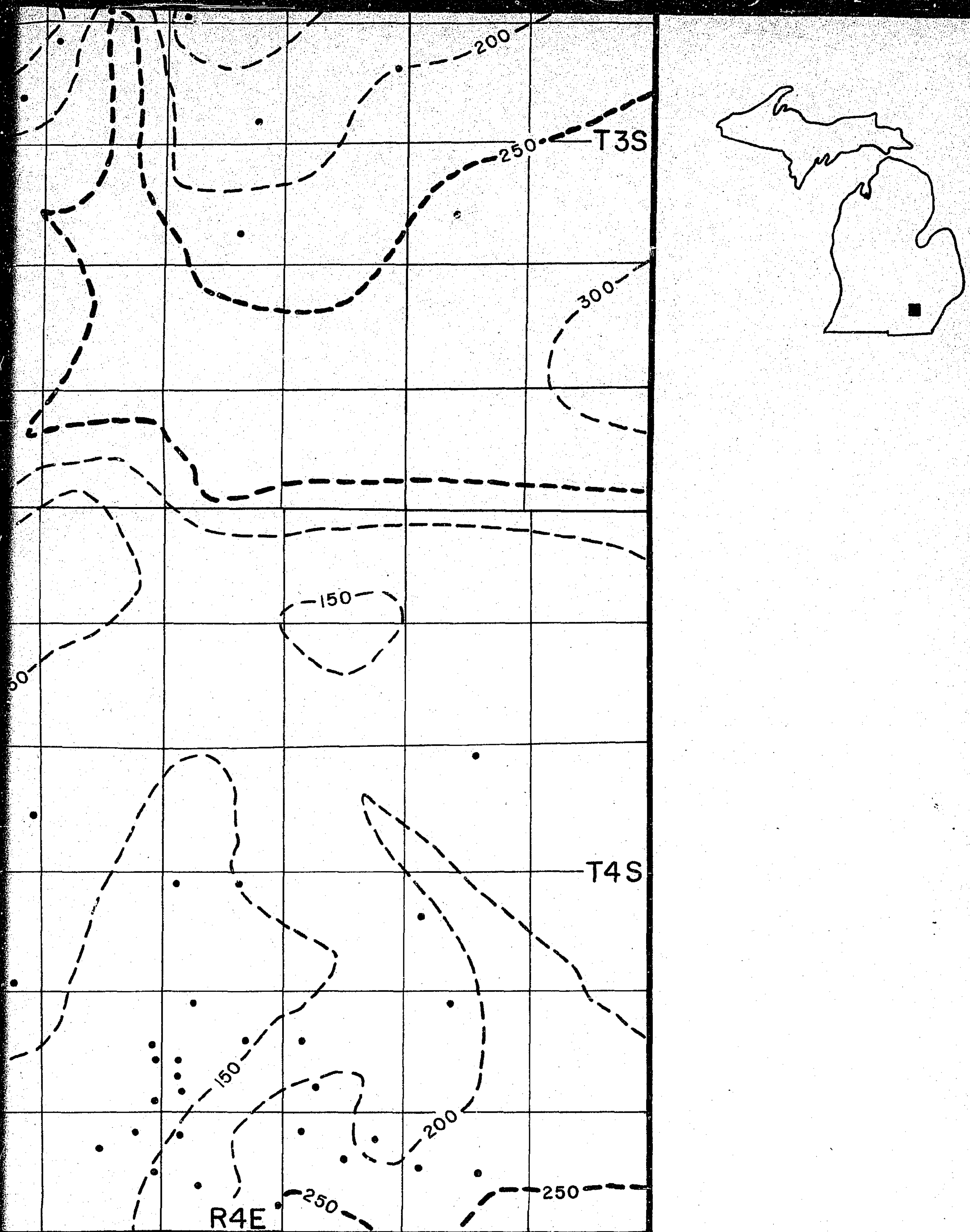


XUM


50
100
150
200
250
R3E
XUM



50
100
150
200
250
T3S
300
150
150
T4S
150
200
250
R4E
250



200
250
T3S
300
150
T4S
150
200
250
250
R4E

FIGURE 8. SEDIM

Qsl PREDOMINANTLY GLACIOFLUVIAL SEDI
[10 M] PER QUARTER-SECTION)

Qsh PREDOMINANTLY GLACIOFLUVIAL SEDI
[10 M] PER QUARTER-SECTION)

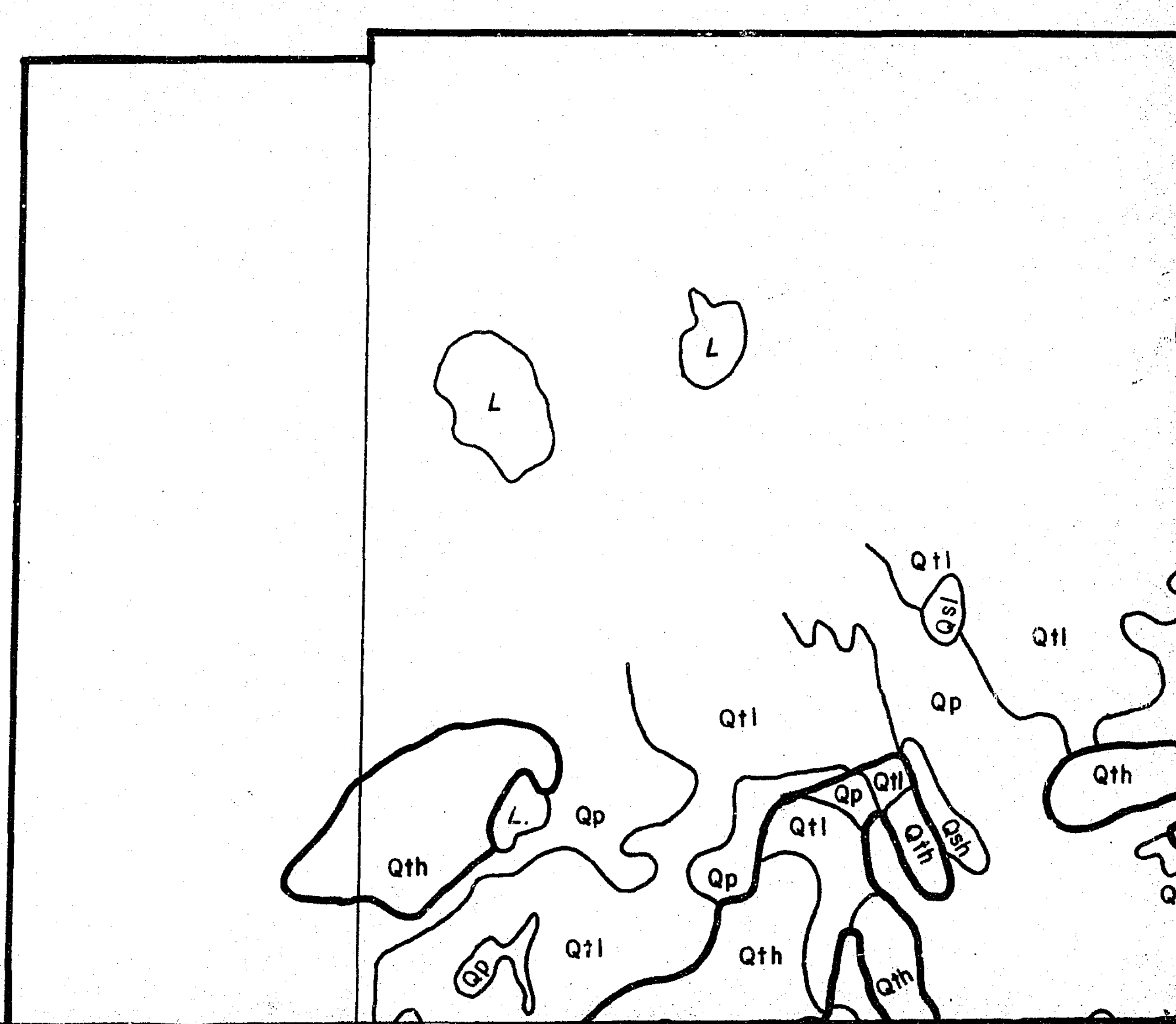
Qtl PREDOMINANTLY TILL (BUT LOCALLY
SEDIMENTS MAY BE PRESENT), L
PER QUARTER-SECTION)

Qth PREDOMINANTLY TILL (BUT LOCALLY
SEDIMENTS MAY BE PRESENT), HI
PER QUARTER-SECTION)

Qp PALUDAL SEDIMENTS, LOW RELIEF

FOR LOCATION OF GLACIOLACUSTRINE

POSTGLACIAL FLOODPLAIN SEDIMENT



GURE 8. SEDIMENTS AND RELIEF

LY GLACIOFLUVIAL SEDIMENTS, LOW RELIEF (LESS THAN ABOUT 30 FEET
QUARTER-SECTION)

LY GLACIOFLUVIAL SEDIMENTS, HIGH RELIEF (MORE THAN ABOUT 30 FEET
QUARTER-SECTION)

Y TILL (BUT LOCALLY CONSIDERABLE AMOUNTS OF GLACIOFLUVIAL
MAY BE PRESENT), LOW RELIEF (LESS THAN ABOUT 30 FEET [10 M]
ER-SECTION)

Y TILL (BUT LOCALLY CONSIDERABLE AMOUNTS OF GLACIOFLUVIAL
MAY BE PRESENT), HIGH RELIEF (MORE THAN ABOUT 30 FEET [10 M]
ER-SECTION)

MENTS, LOW RELIEF

OF GLACIOLACUSTRINE SEDIMENTS. SEE FIGURE 23

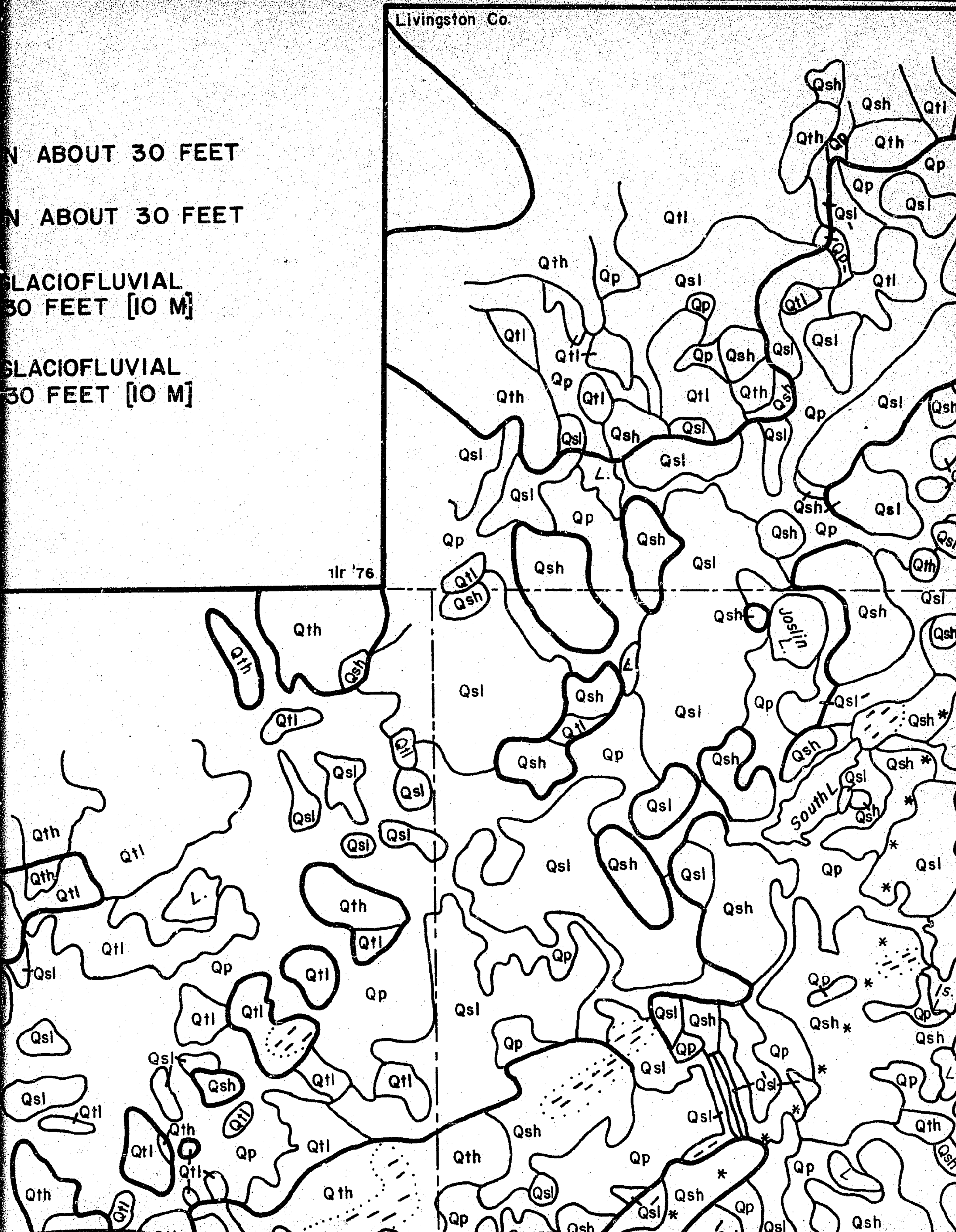
FLOODPLAIN SEDIMENTS NOT SHOWN

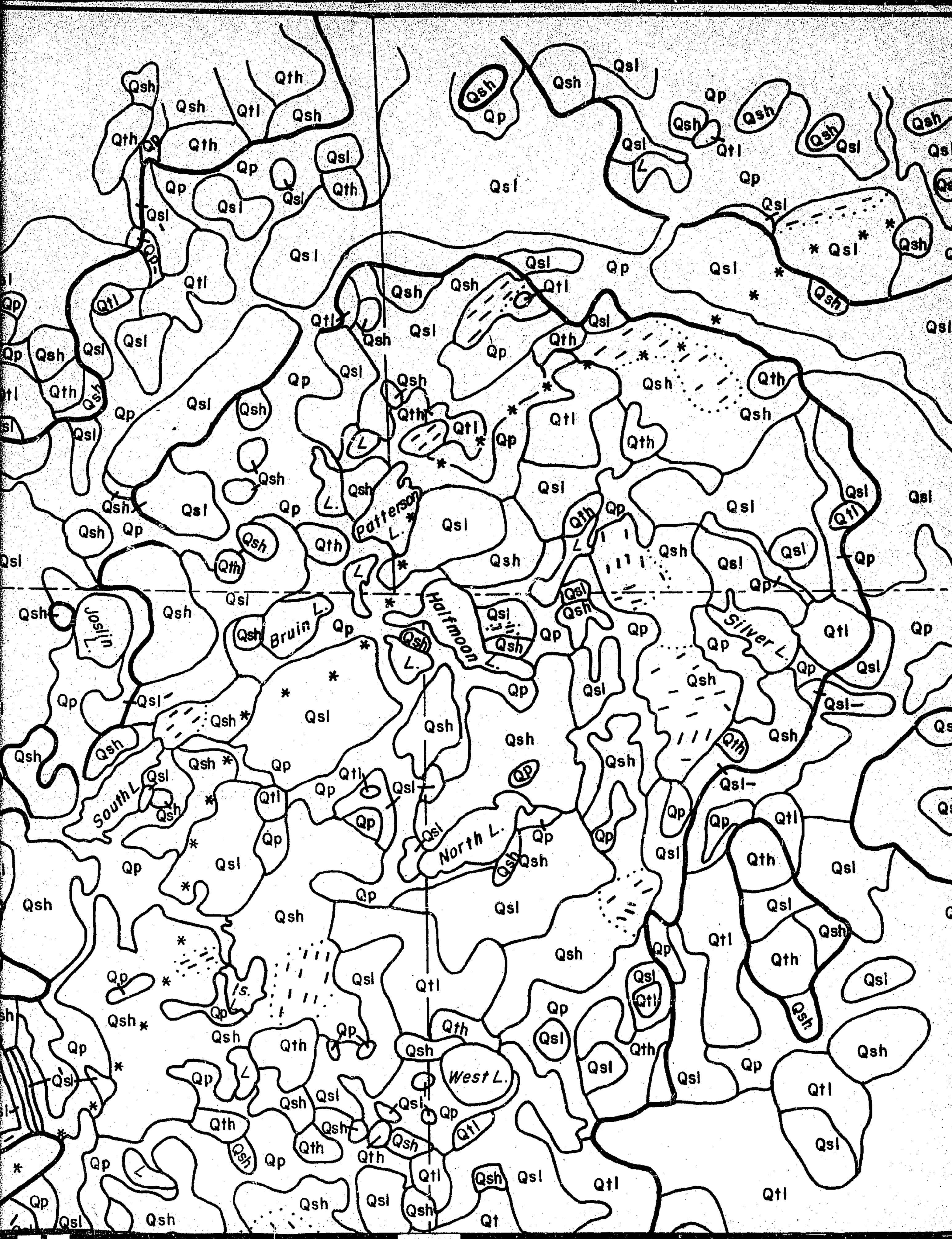
N ABOUT 30 FEET

N ABOUT 30 FEET

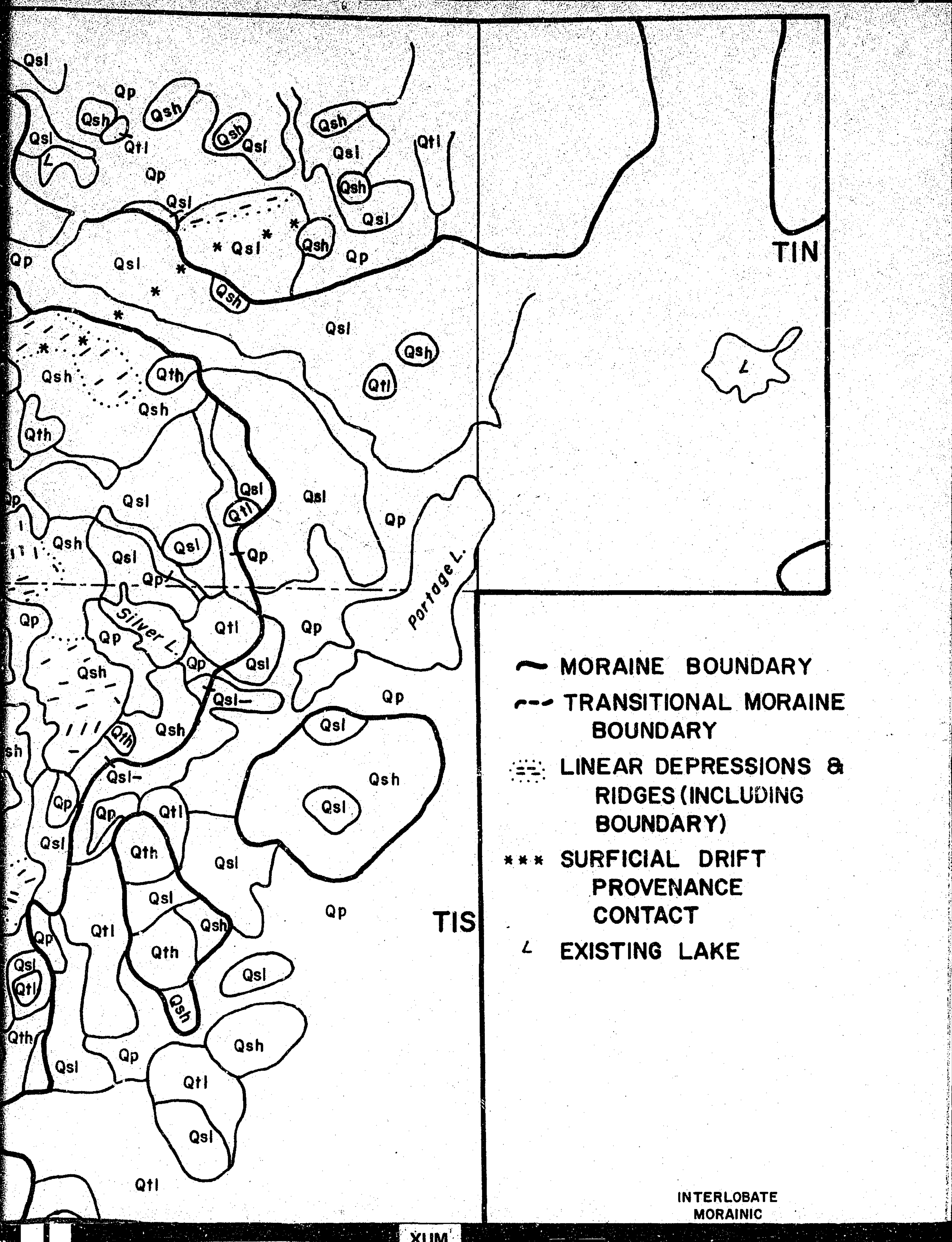
GLACIOFLUVIAL
30 FEET [10 M]

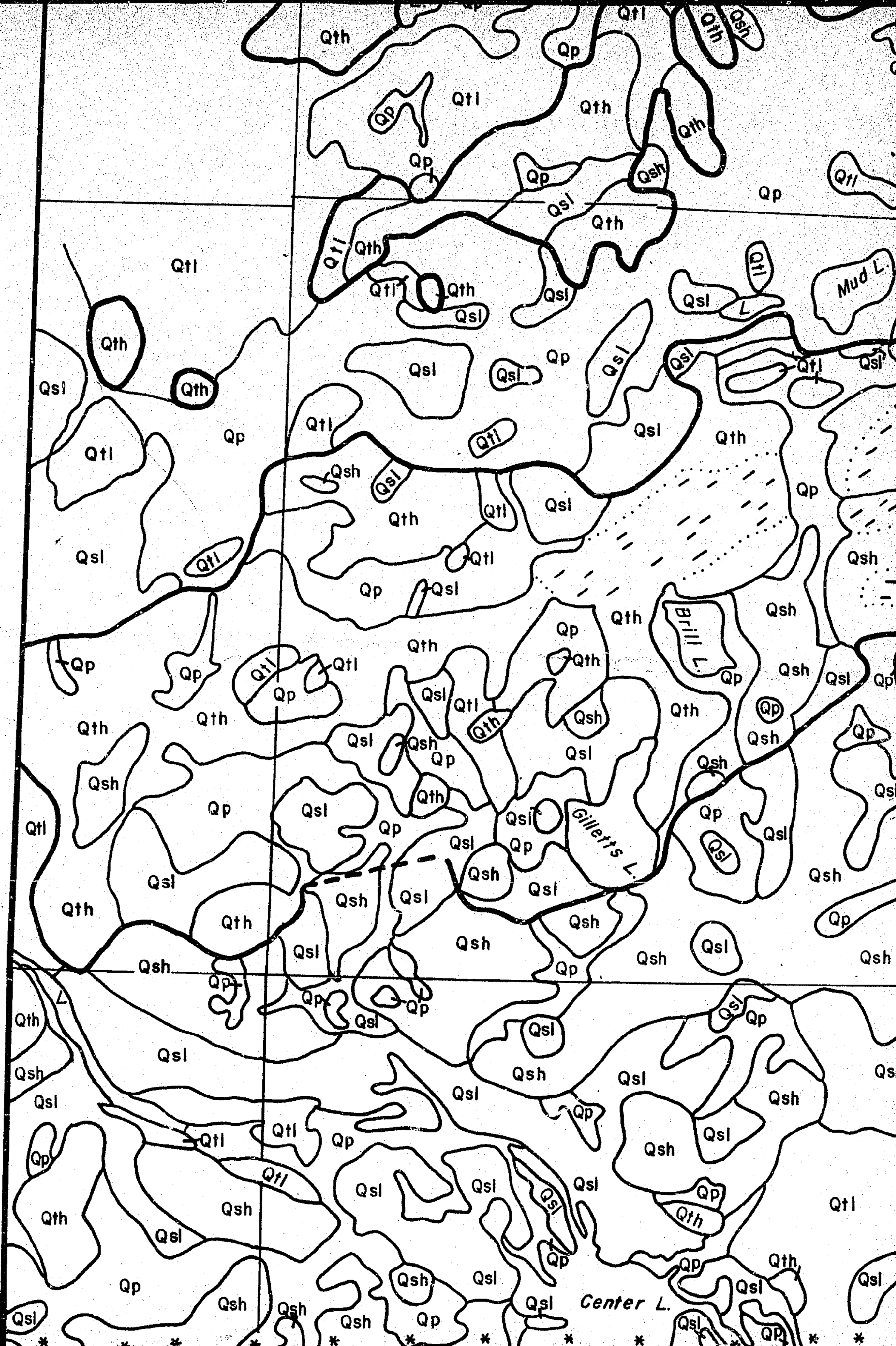
GLACIOFLUVIAL
30 FEET [10 M]



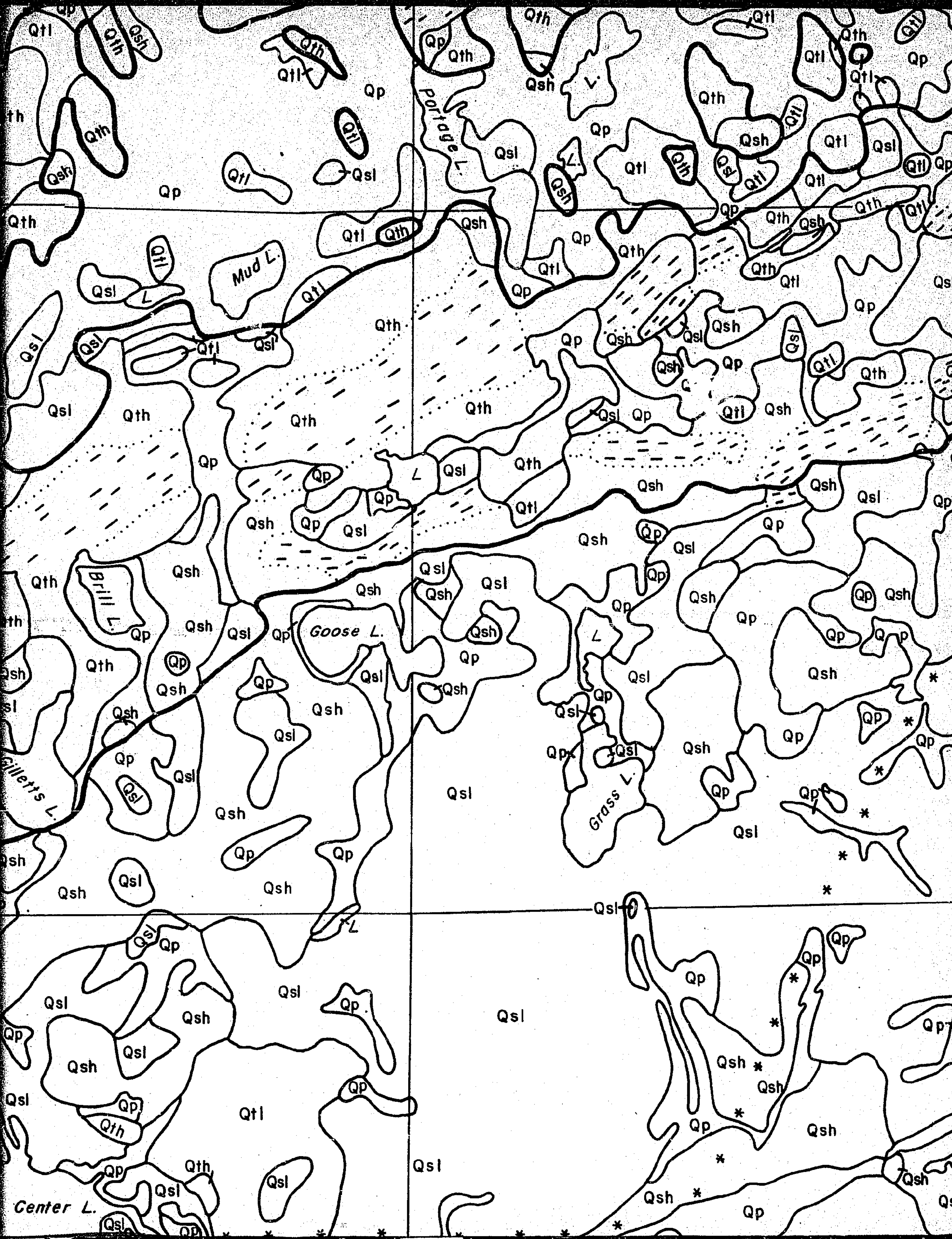

Patterson L.
Joslin L.
Bruin L.
Halfmoon L.
Silver L.
South L.
North L.
West L.
Is.

XUM

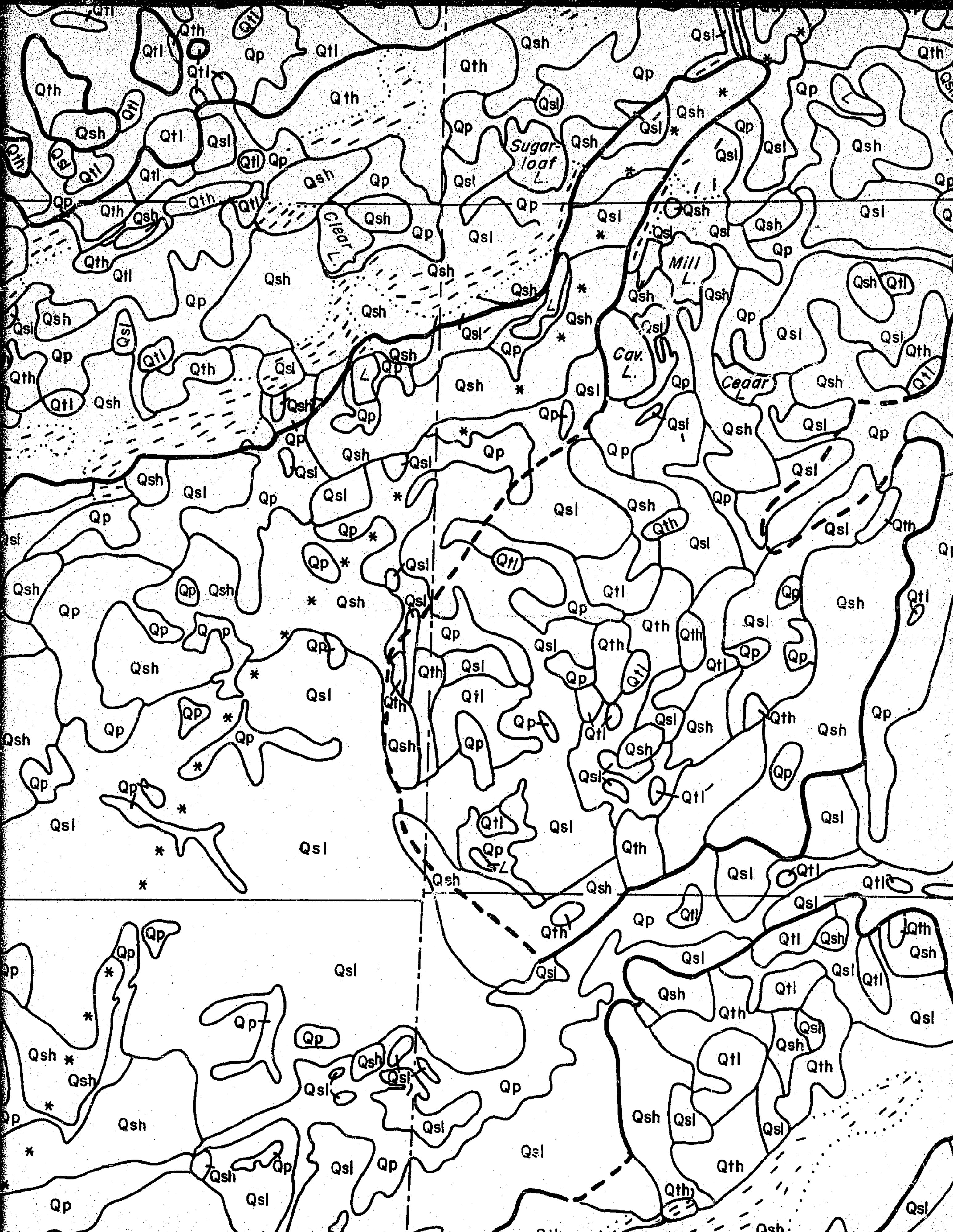

TIN
TIS
Portage L.
Silver L.
Qsl
Qsh
Qp
Qtl
Qth
MORAINE BOUNDARY
TRANSITIONAL MORAINE BOUNDARY
LINEAR DEPRESSIONS & RIDGES (INCLUDING BOUNDARY)
SURFICIAL DRIFT PROVENANCE CONTACT
EXISTING LAKE
INTERLOBATE MORAINIC
XUM



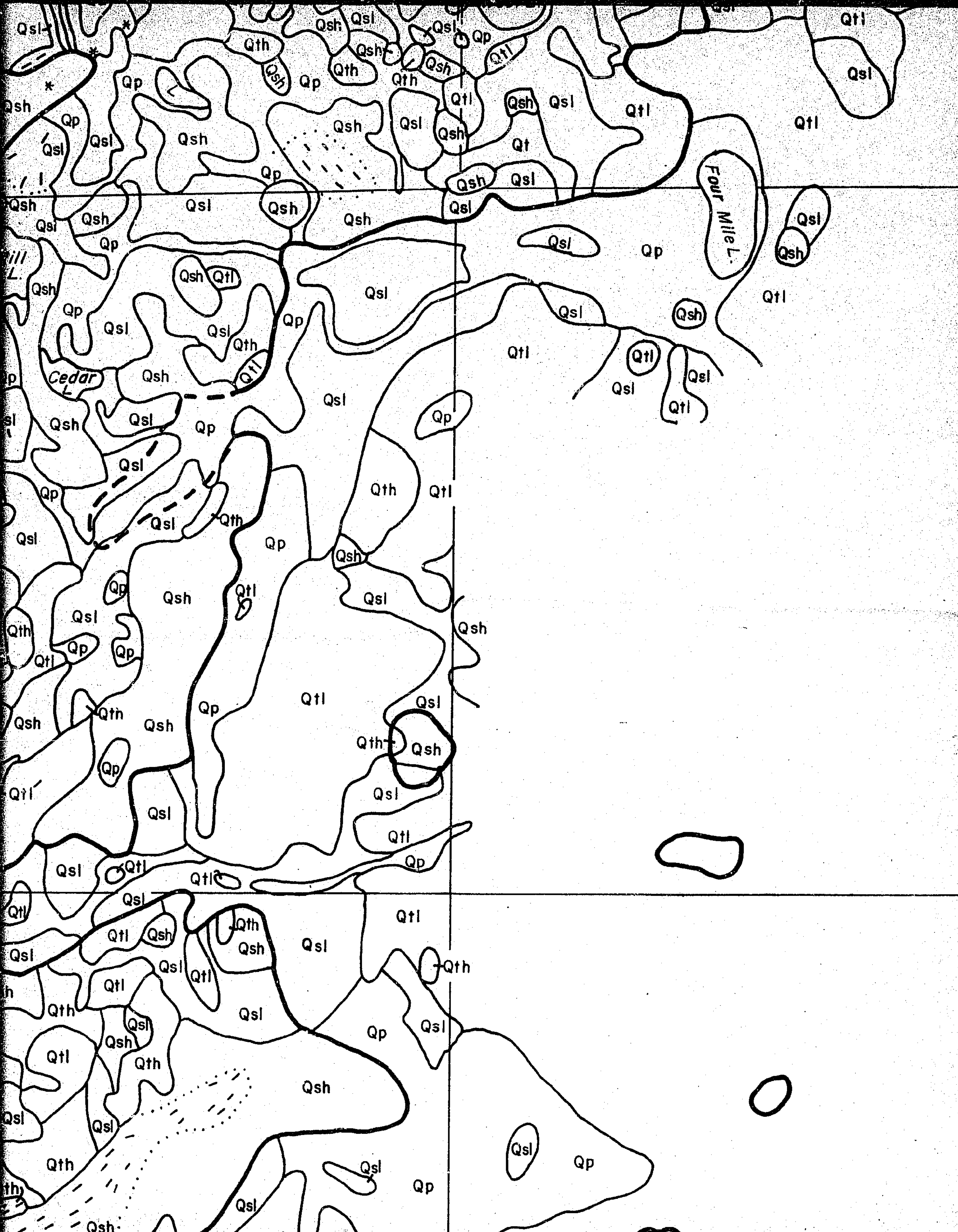
XUM



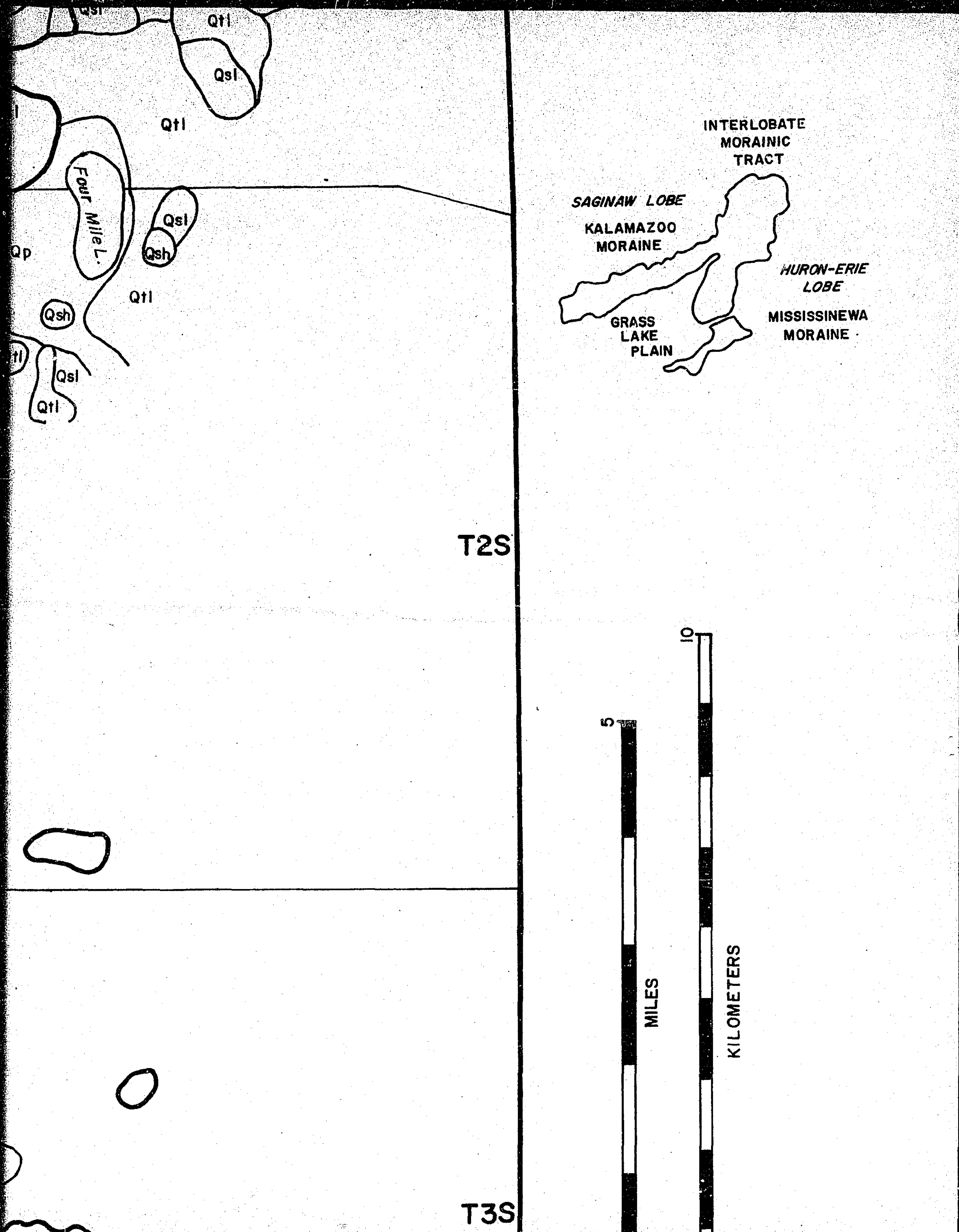
XUM

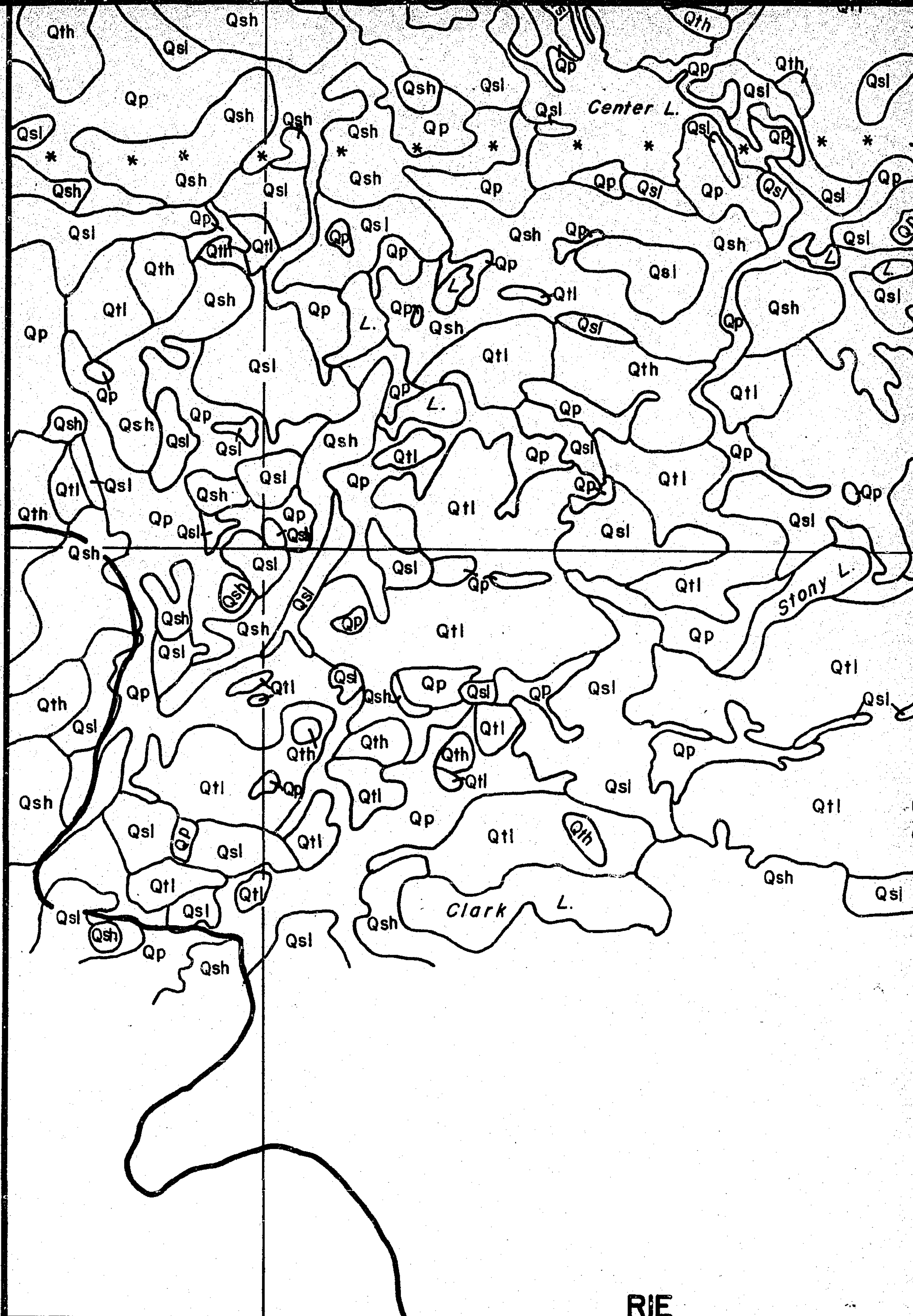


XUM



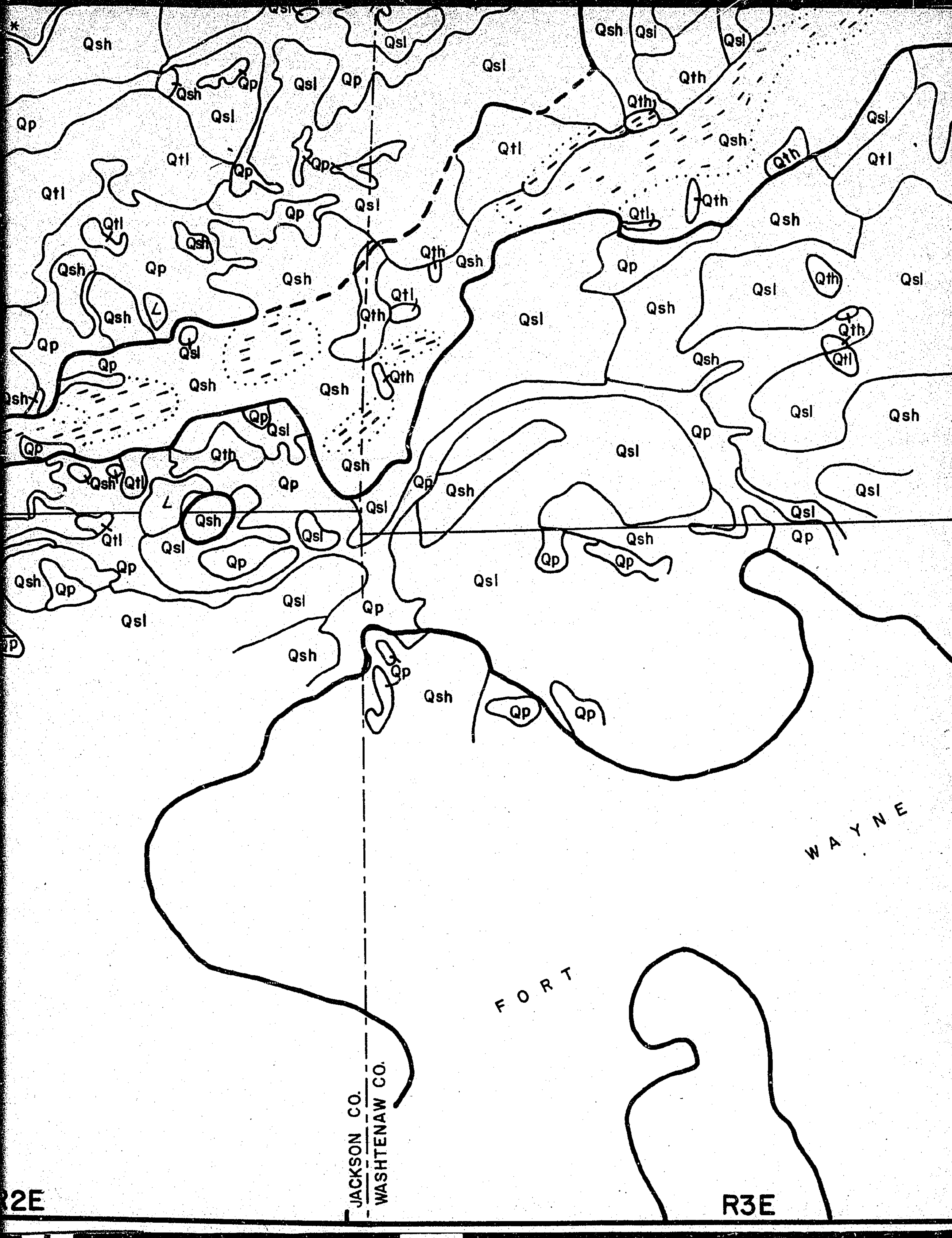
XUM

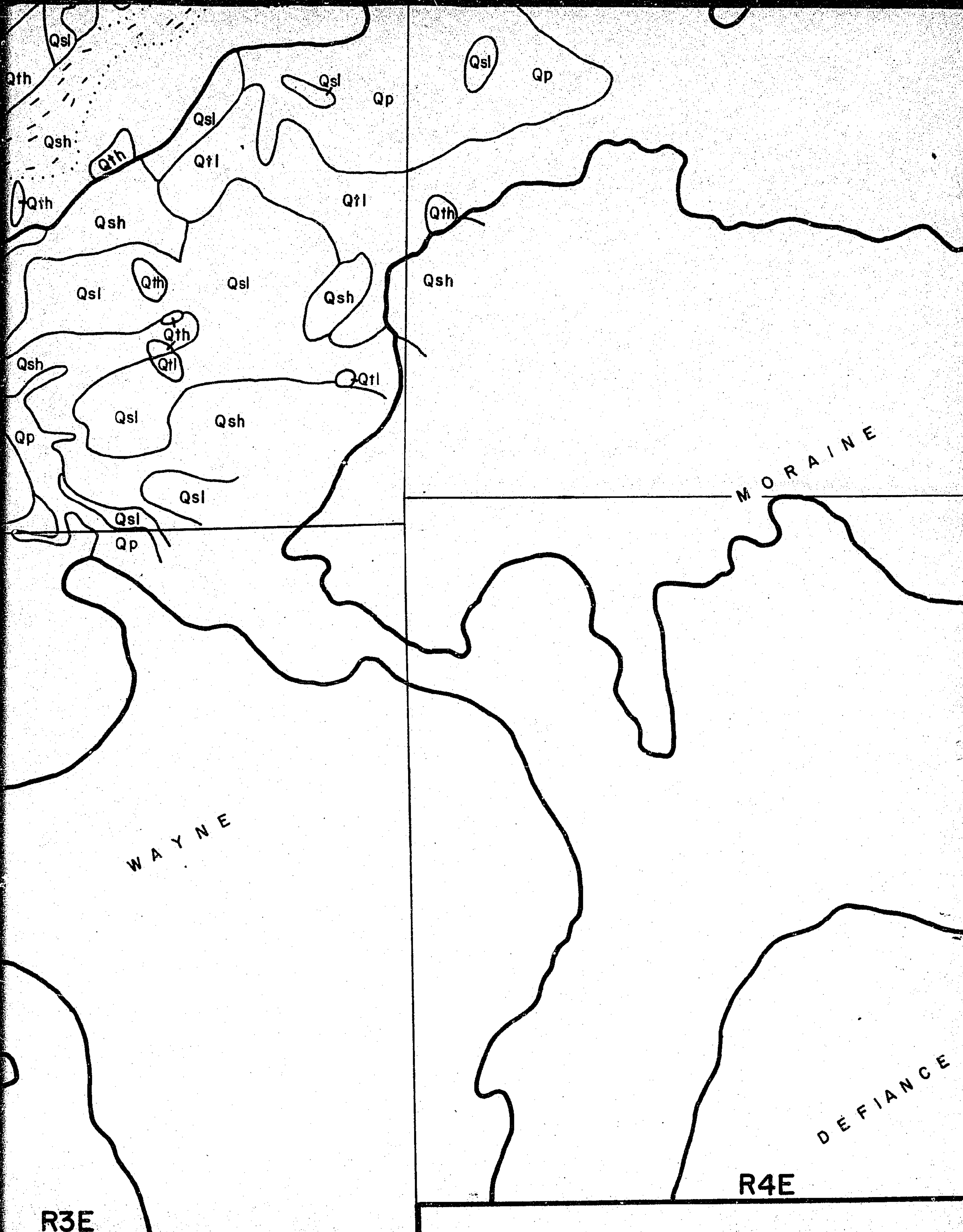

Qtl
Qsl
Qtl
Four Mile L.
Qsl
Qsh
Qp
Qtl
Qsh
Qsl
Qtl
INTERLOBATE MORAINIC TRACT
SAGINAW LOBE
KALAMAZOO MORAINE
HURON-ERIE LOBE
GRASS LAKE PLAIN
MISSISSINEWA MORAINE
T2S
T3S
5
MILES
10
KILOMETERS



XUM

XUM


Qsh
Qsl
Qp
Qtl
Qth
FORT WAYNE
JACKSON CO.
WASHTENAW CO.
R2E
R3E


Qsl
Qth
Qsh
Qth
Qth
Qsl
Qsl
Qp
Qtl
Qtl
Qsh
Qsl
Qth
Qsl
Qsh
Qth
Qtl
Qsh
Qtl
Qsl
Qsh
Qp
Qsl
Qsl
Qp
Qsl
Qp
Qth
Qsh
MORAINE
WAYNE
DEFIANCE
R3E
R4E

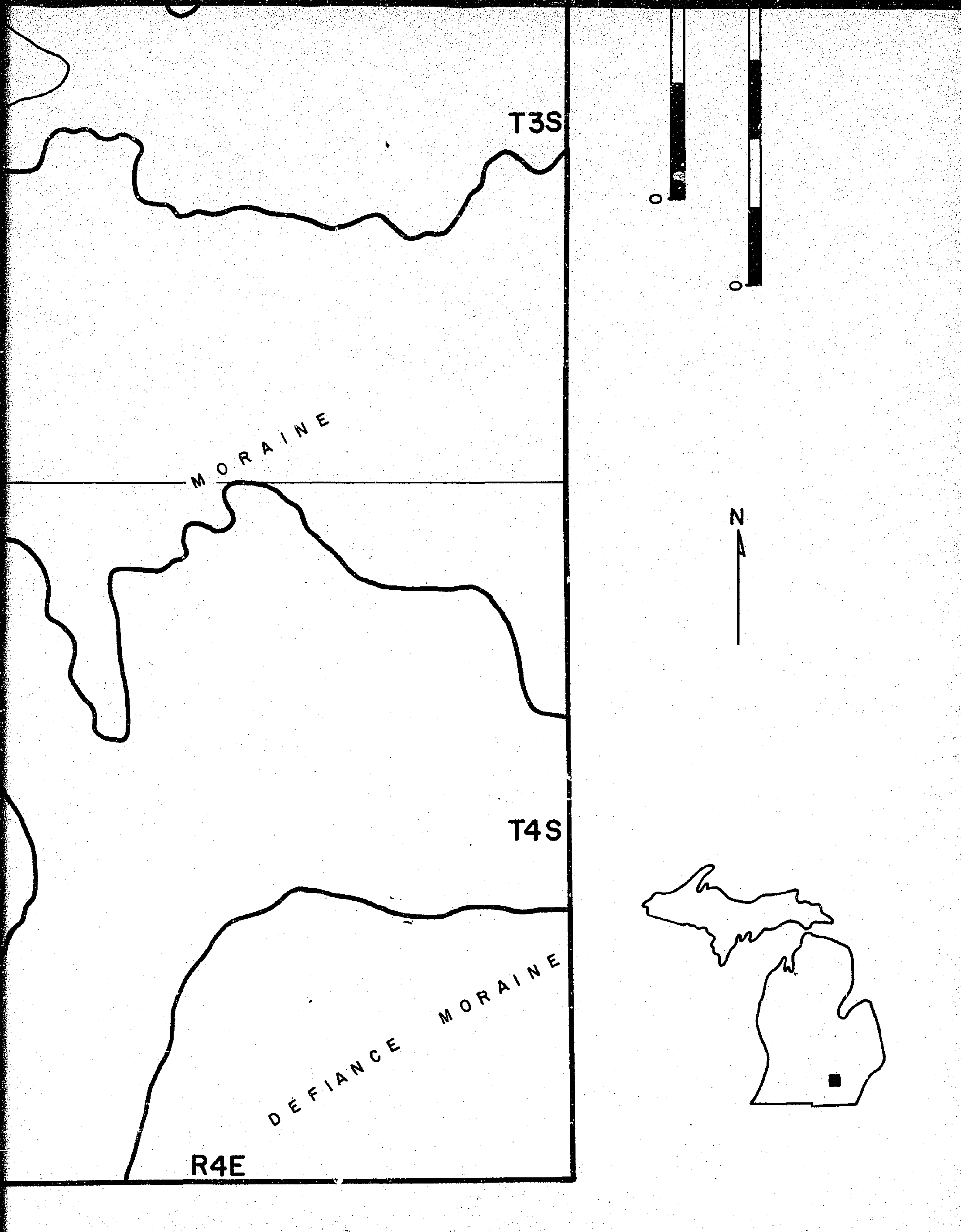
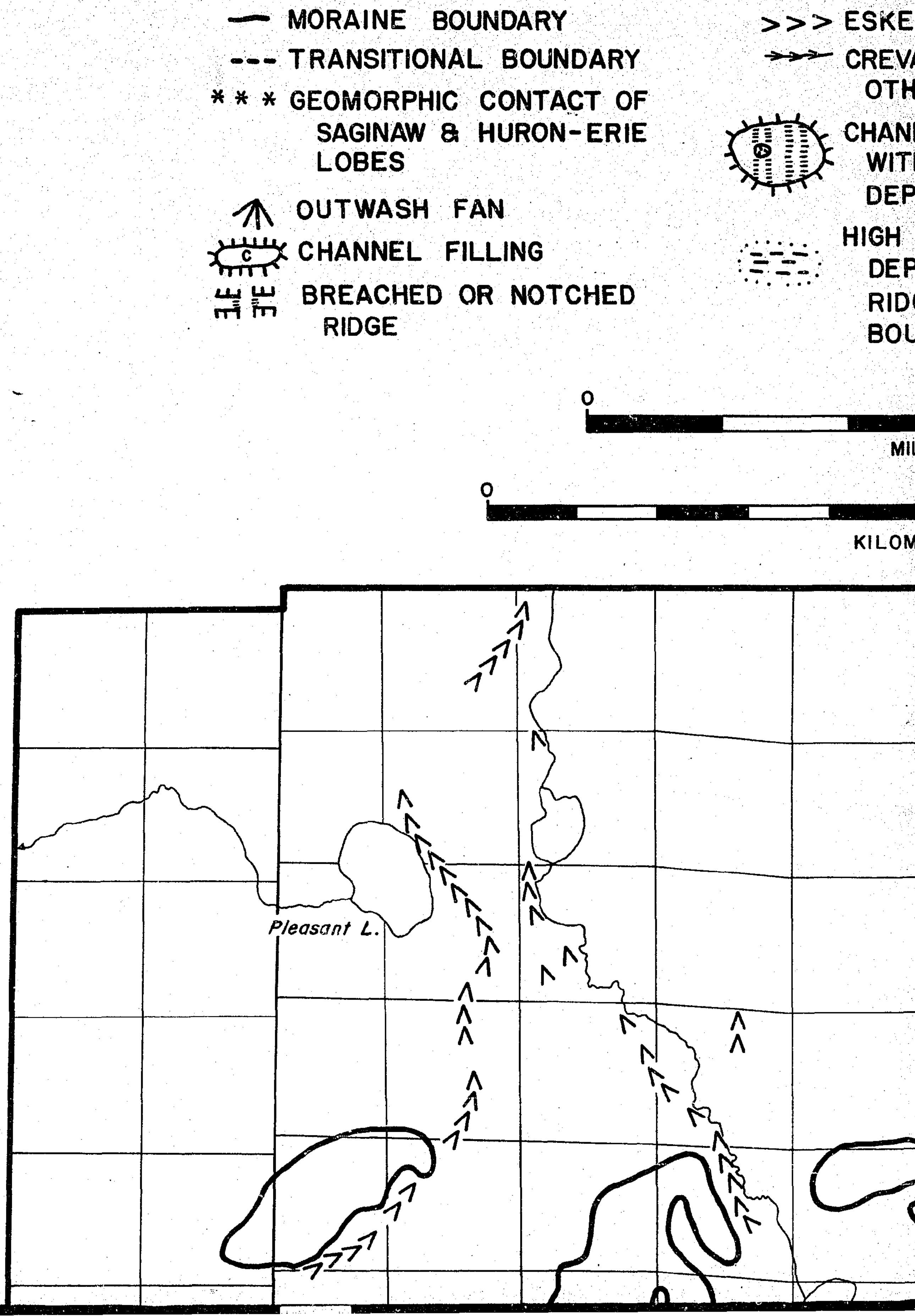

T3S
MORAINE
N
T4S
DEFIANCE MORAINE
R4E

FIGURE 32. SELEC



32. SELECTED LANDFORMS

>>> ESKER

CREVASSE FILLING OR OTHER RIDGE

CHANNELED PLATEAU- WITH & WITHOUT DEPRESSION

HIGH RELIEF LINEAR DEPRESSIONS & RIDGES-WITH BOUNDARY

SHALLOW LINEAR DEPRESSIONS

ICE-CONTACT & OTHER STEEP SLOPES 30-200 FEET (9-60M) HIGH

SUBAERIAL

SUBLACUSTRINE

DRY CHANNEL

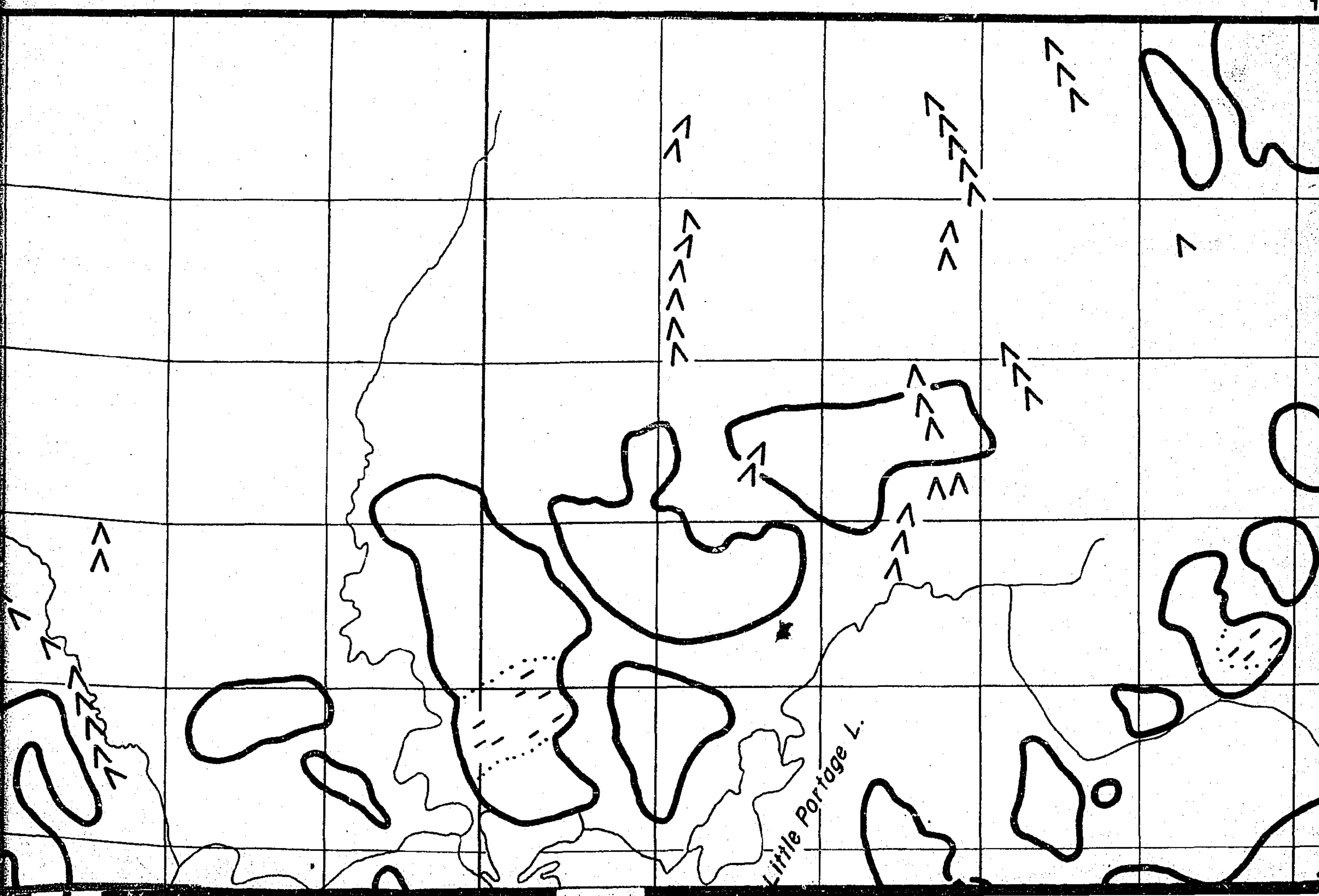
DRY PERCHED CHANNEL

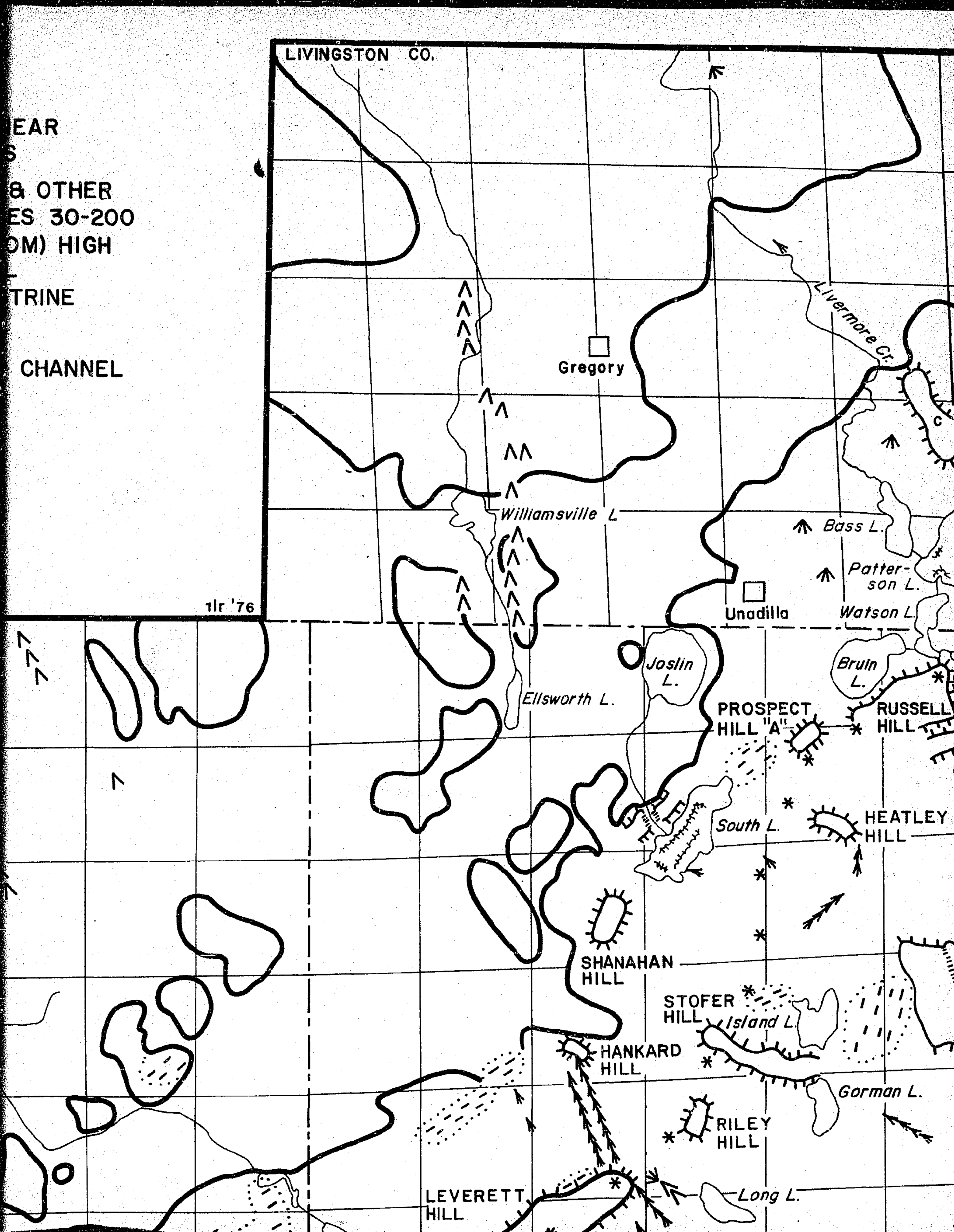
5

MILES

10

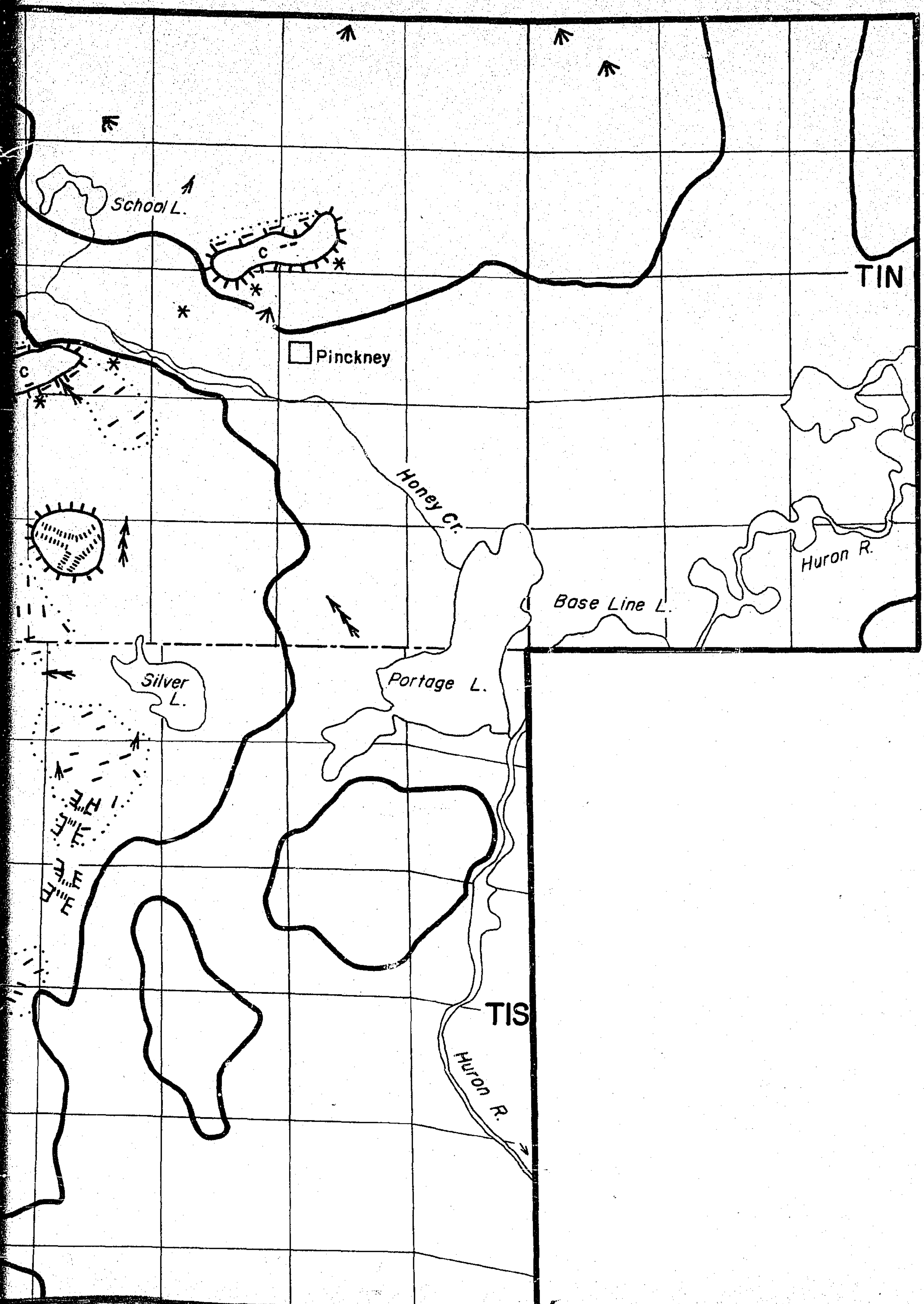
KILOMETERS



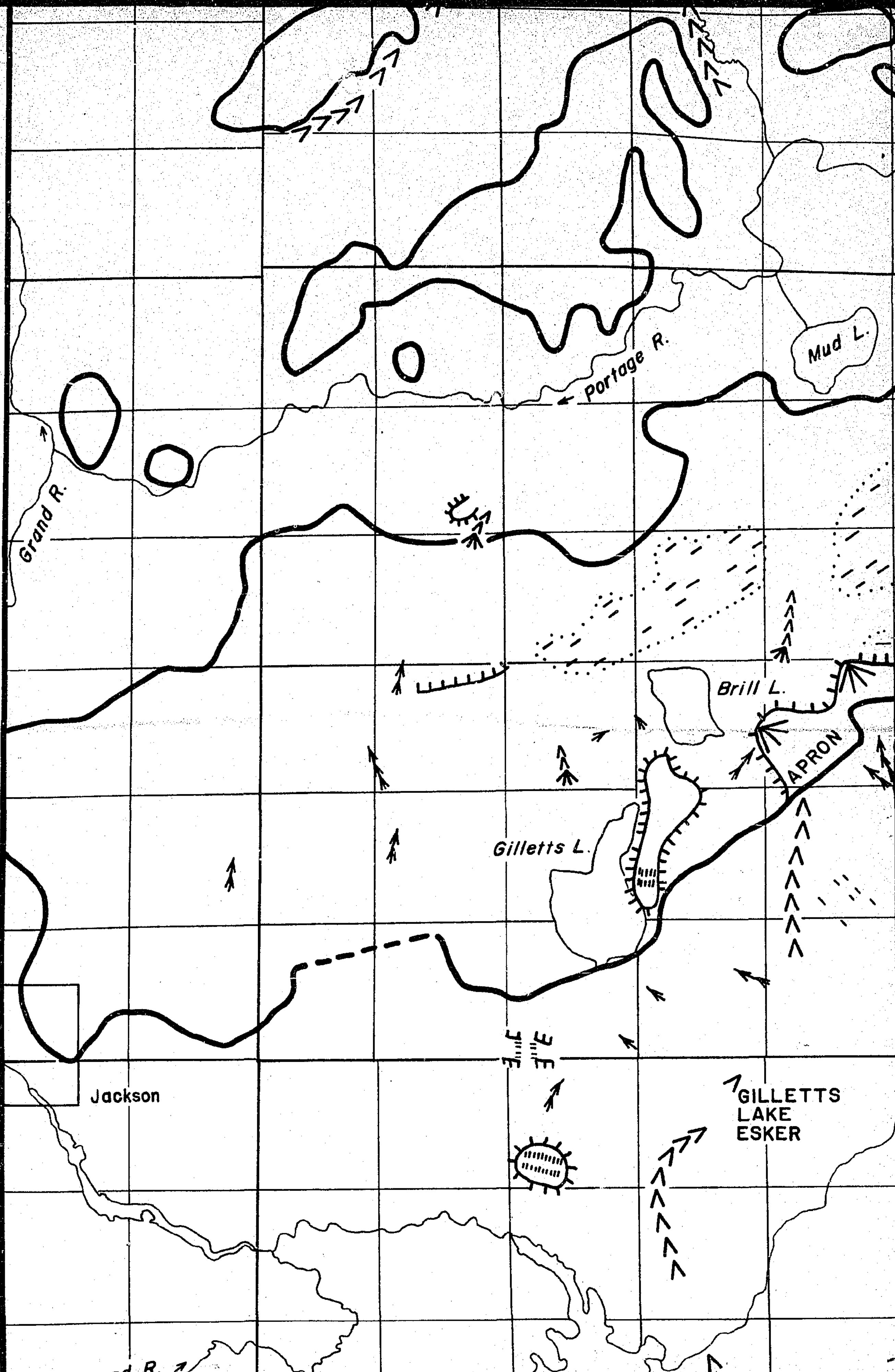


EAR
S
& OTHER
ES 30-200
OM) HIGH
TRINE
CHANNEL
LIVINGSTON CO.
Livermore Cr.
Gregory
Williamsville L.
Bass L.
Patter-son L.
Unadilla
Watson L.
Joslin L.
Bruin L.
Ellsworth L.
PROSPECT HILL "A"
RUSSELL HILL
South L.
HEATLEY HILL
SHANAHAN HILL
STOFER HILL
Island L.
HANKARD HILL
Gorman L.
RILEY HILL
LEVERETT HILL
Long L.
1lr '76

School L.
c
Livermore Cr.
Pinckney
Honey Cr.
Bass L.
Patterson L.
adilla
Watson L.
Hiland L.
Halfmoon L.
Bruin L.
Silver L.
Portage L.
Ba
OSPECT
L "A"
RUSSELL HILL
Blind L.
HEATLEY HILL
th L.
North L.
TIS
and L.
Huron R.
Gorman L.
West L.
EY
ong L.
XUM

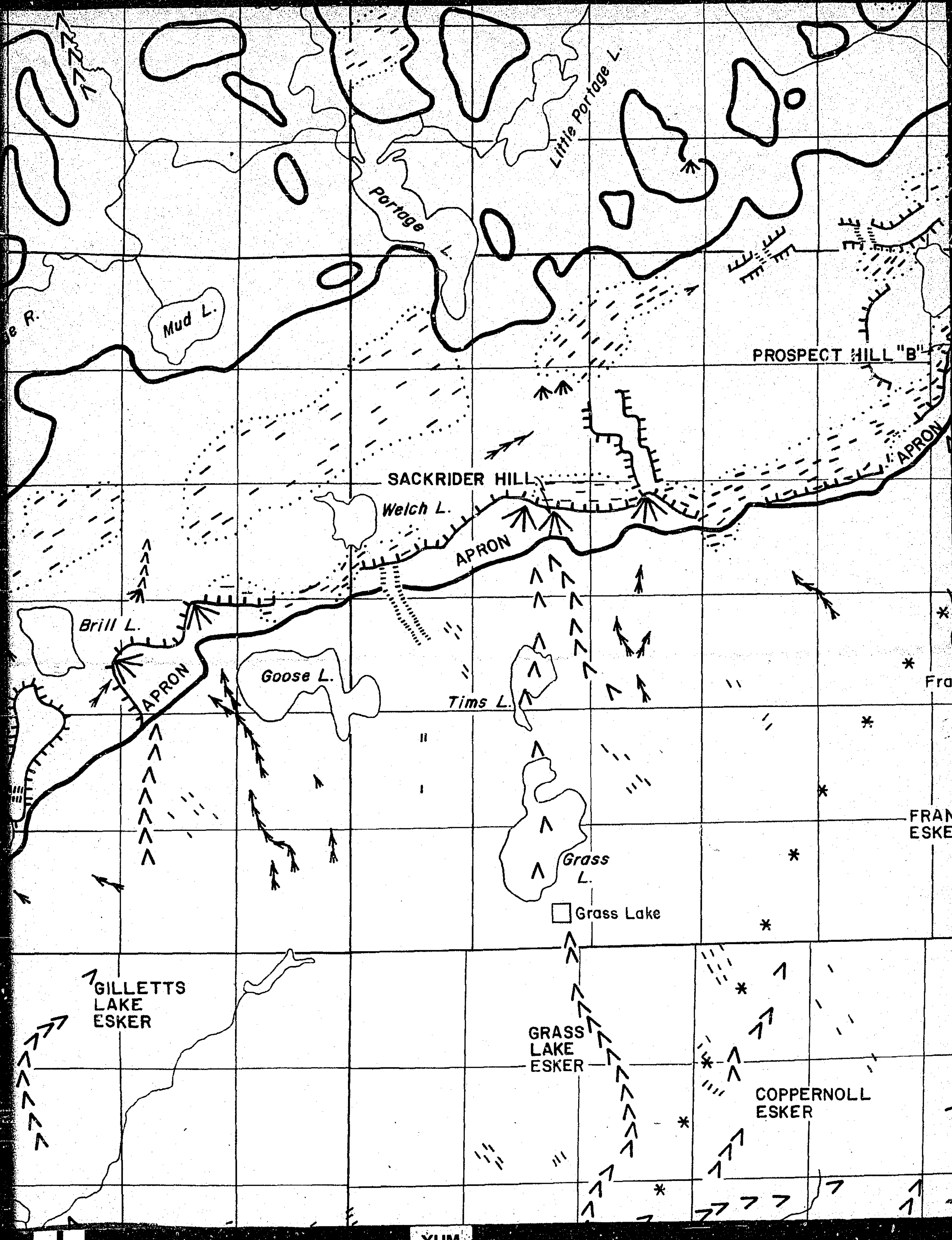

School L.
TIN
Pinckney
Honey Cr.
Huron R.
Base Line L.
Silver L.
Portage L.
TIS
Huron R.

XUM

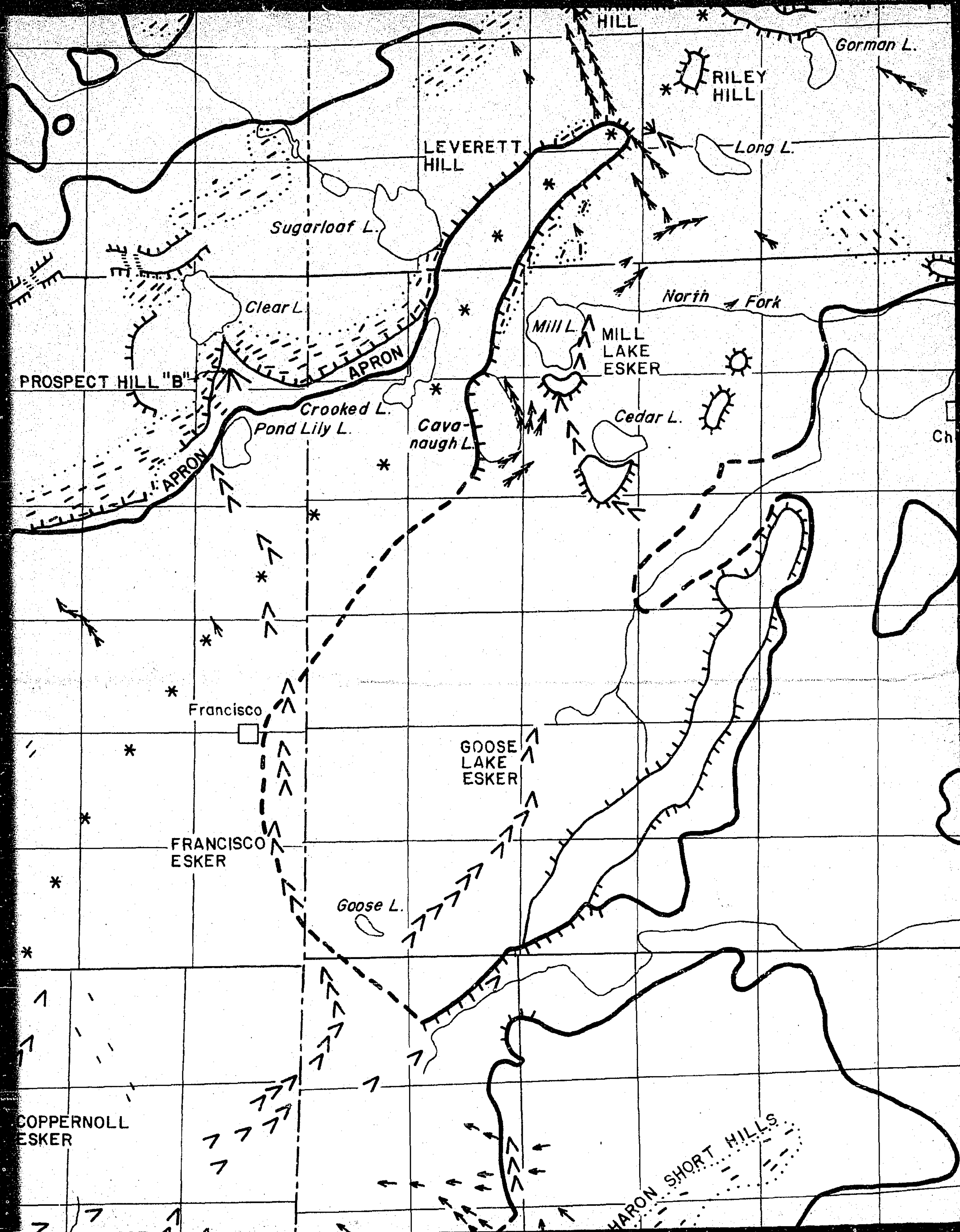


Portage R.
Mud L.
Grand R.
Brill L.
APRON
Gilletts L.
Jackson
GILLETTS
LAKE
ESKER
Grand R.

XUM

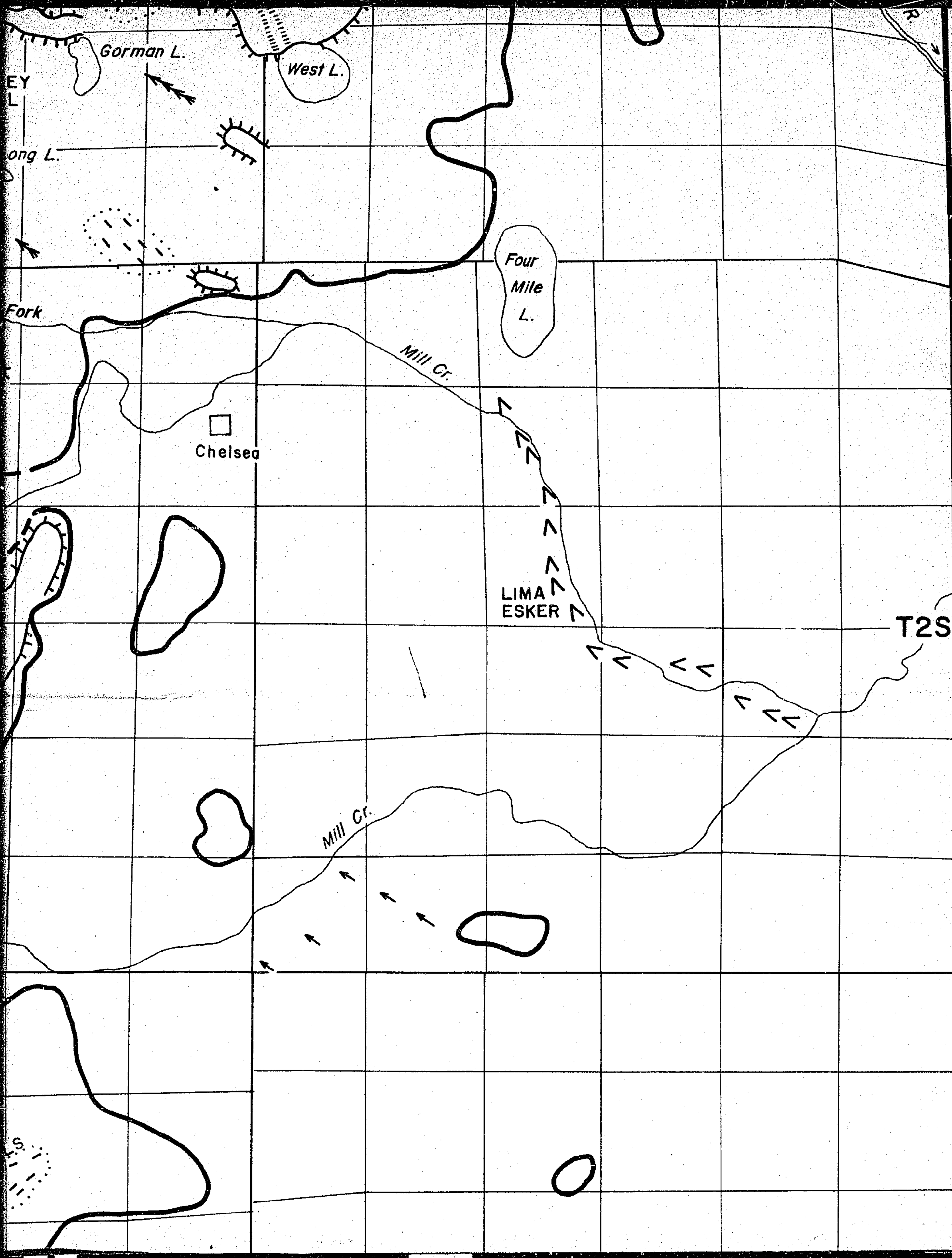


Little Portage L.
Portage L.
Mud L.
R.
PROSPECT HILL "B"
APRON
SACKRIDER HILL
Welch L.
APRON
Brill L.
Goose L.
APRON
Tims L.
Fra
FRAN
ESKE
Grass L.
Grass Lake
GILLETTS
LAKE
ESKER
GRASS
LAKE
ESKER
COPPERNOLL
ESKER
XUM



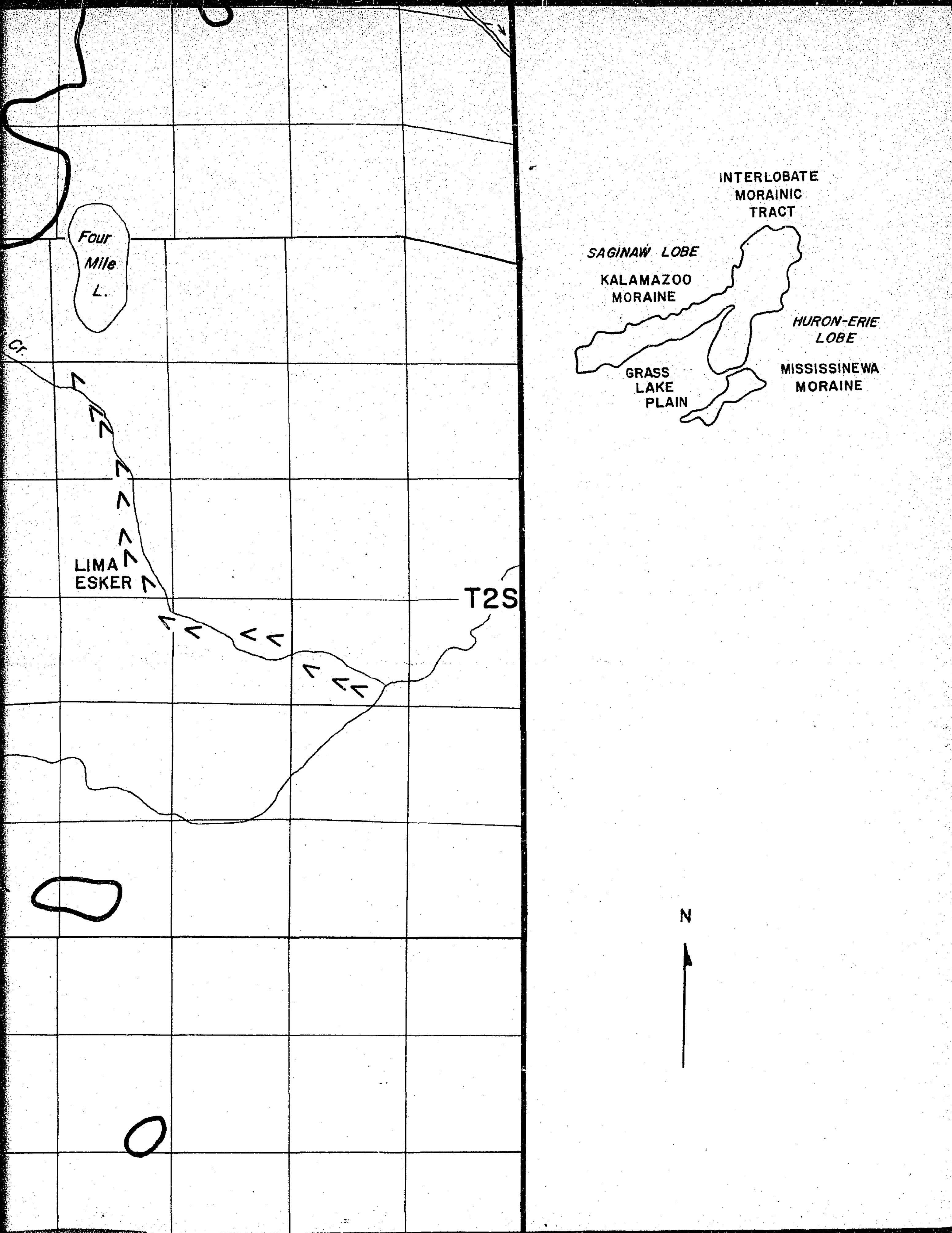
HILL
Gorman L.
RILEY
HILL
LEVERETT
HILL
Long L.
Sugarloaf L.
Clear L.
North Fork
Mill L.
MILL
LAKE
ESKER
PROSPECT HILL "B"
APRON
Crooked L.
Cava-
naugh L.
Cedar L.
Pond Lily L.
APRON
Ch
Francisco
GOOSE
LAKE
ESKER
FRANCISCO
ESKER
Goose L.
COPPERNOLL
ESKER
HARON SHORT HILLS

XUM

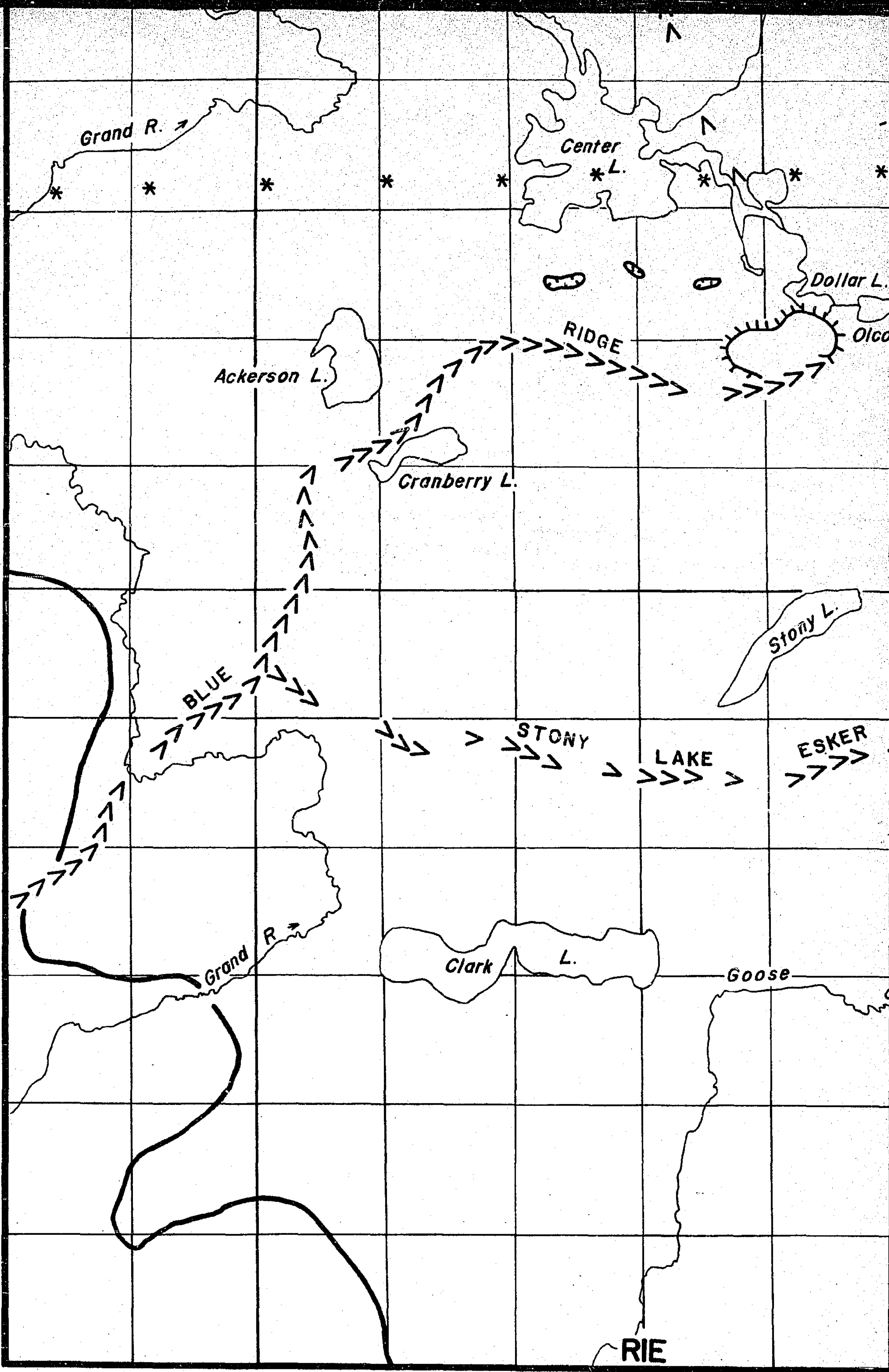


Gorman L.
West L.
EY
L
ong L.
Fork
Four
Mile
L.
Mill Cr.
Chelsea
LIMA
ESKER
T2S
Mill Cr.
S.
R.

XUM

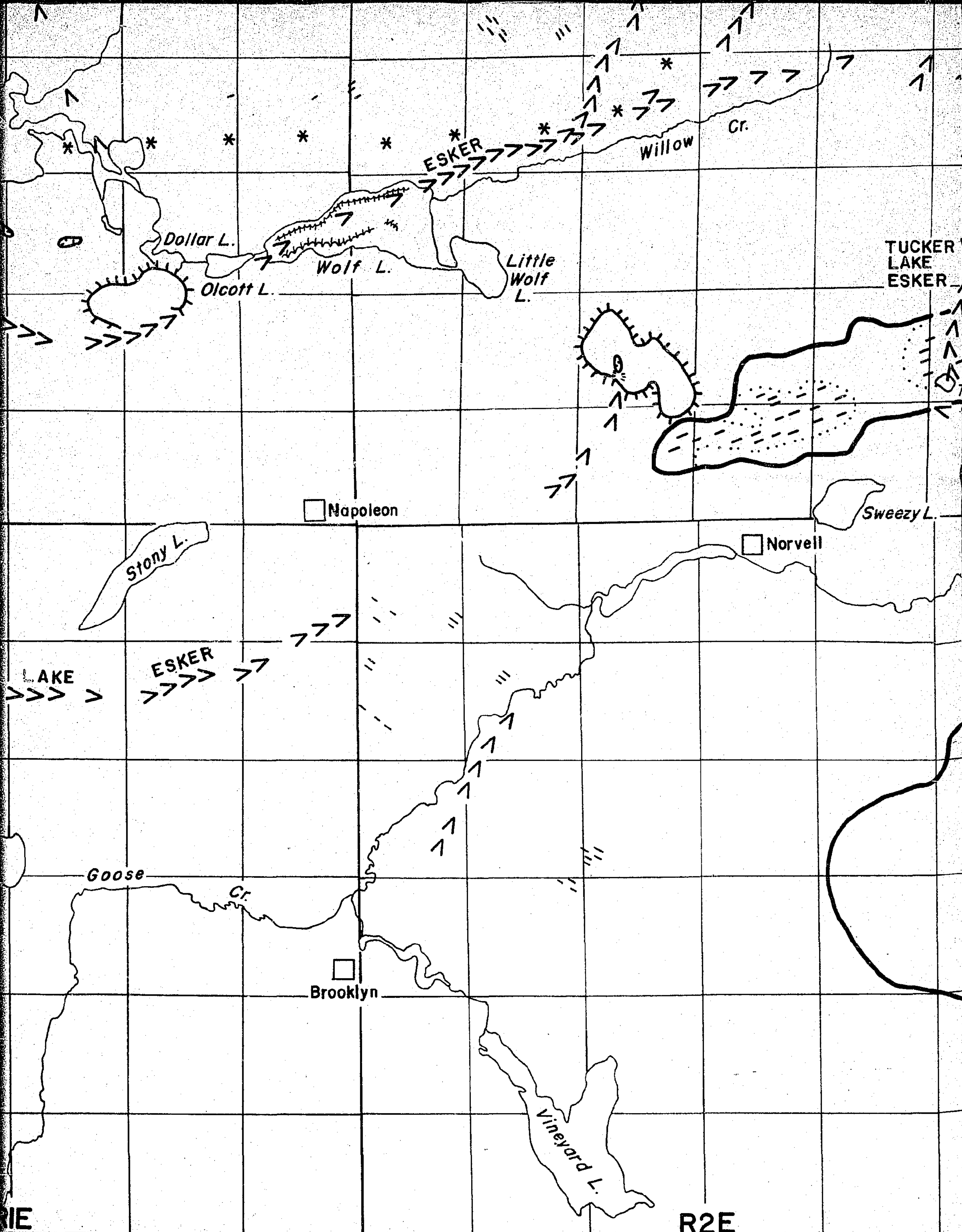

Four Mile L.
Cr.
LIMA ESKER
T2S
INTERLOBATE MORAINIC TRACT
SAGINAW LOBE
KALAMAZOO MORAINE
HURON-ERIE LOBE
GRASS LAKE PLAIN
MISSISSINEWA MORAINE
N

XUM



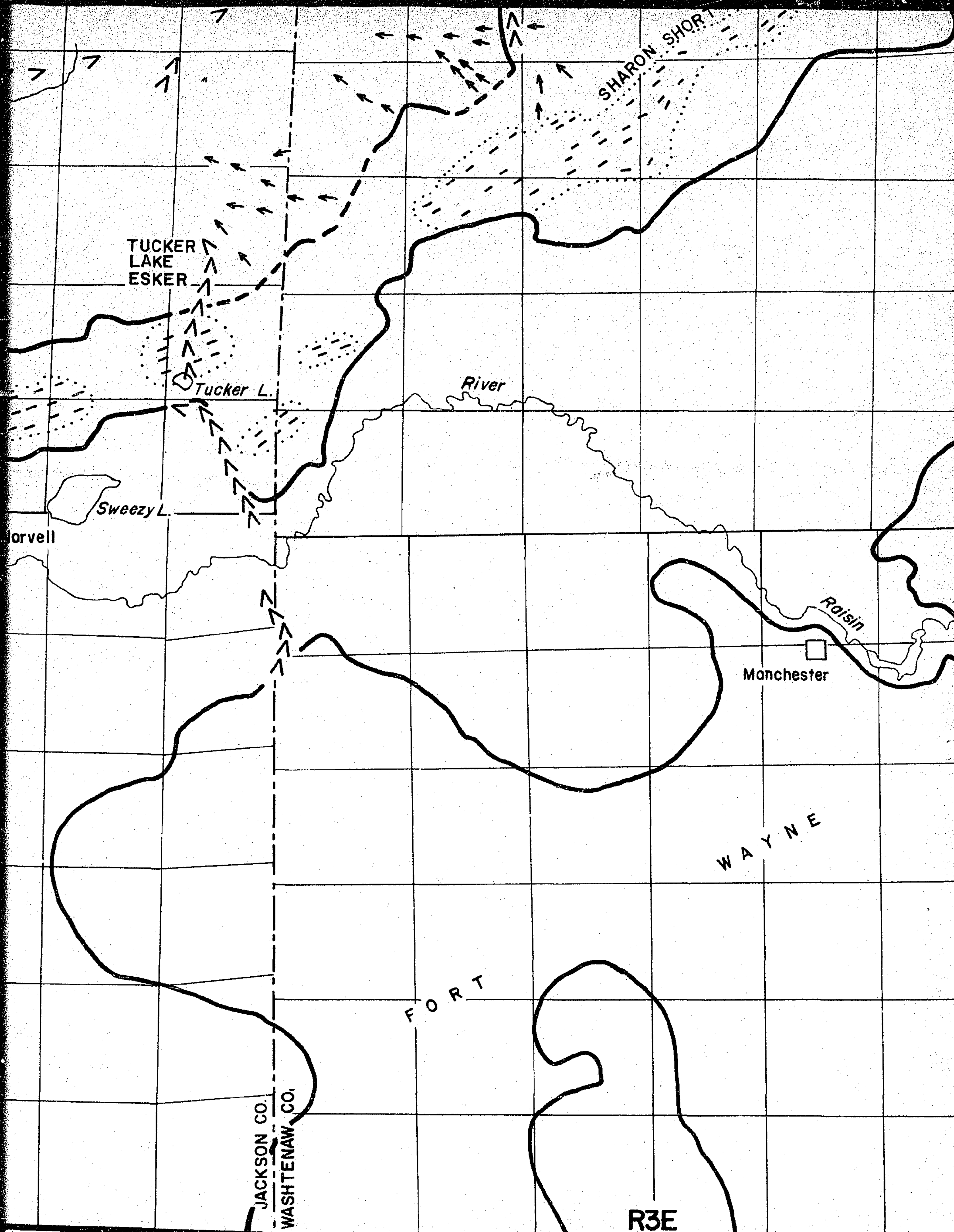
Grand R.
Center L.
Dollar L.
RIDGE
Olco
Ackerson L.
Cranberry L.
Stony L.
BLUE
STONY
LAKE
ESKER
Grand R.
Clark L.
Goose
RIE

XUM

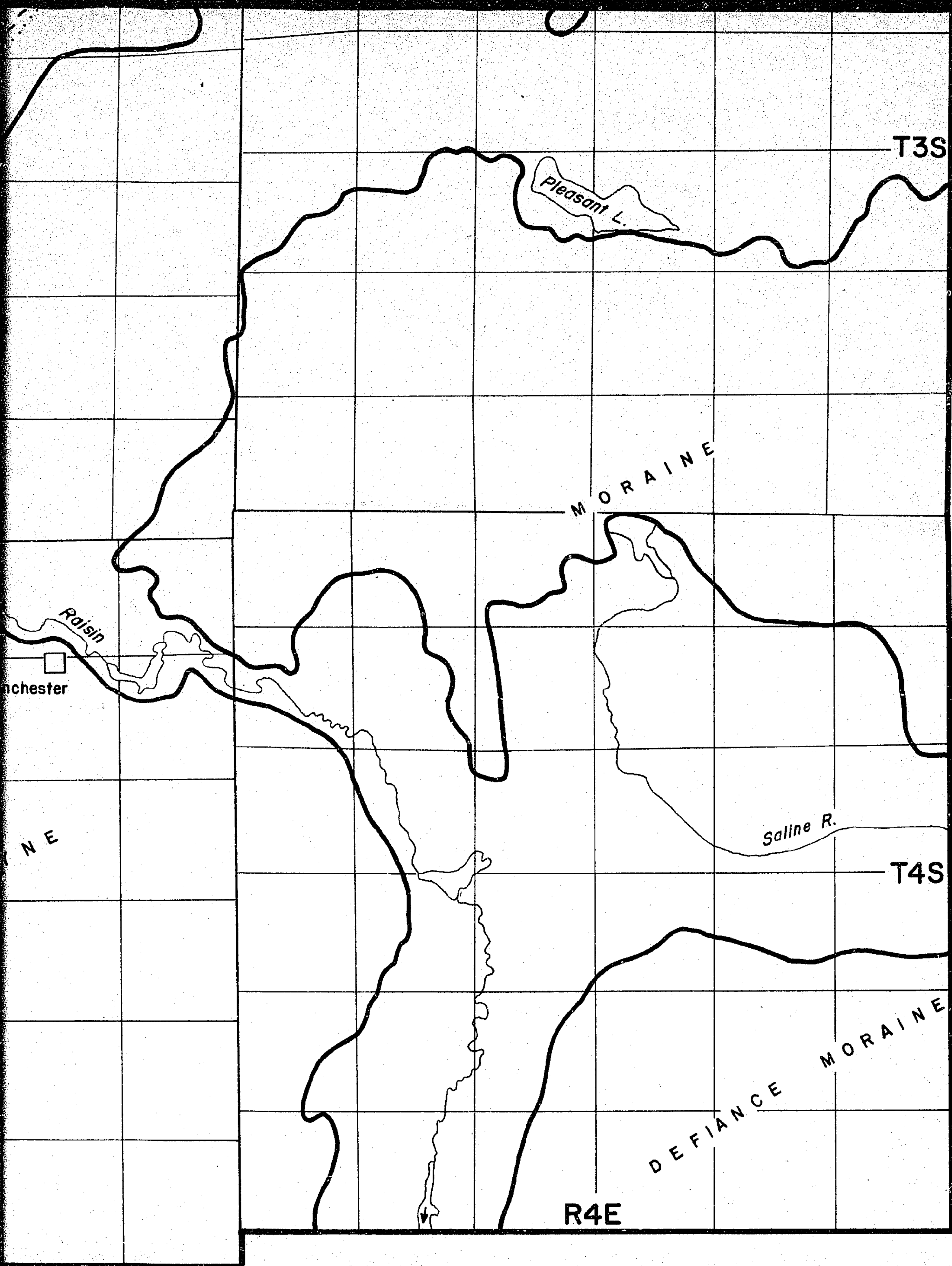


ESKER
Willow
Cr.
Dollar L.
Wolf L.
Little Wolf L.
Olcott L.
TUCKER LAKE ESKER
Napoleon
Sweezy L.
Norvell
Stony L.
LAKE
ESKER
Goose
Cr.
Brooklyn
Vineyard L.
RIE
R2E

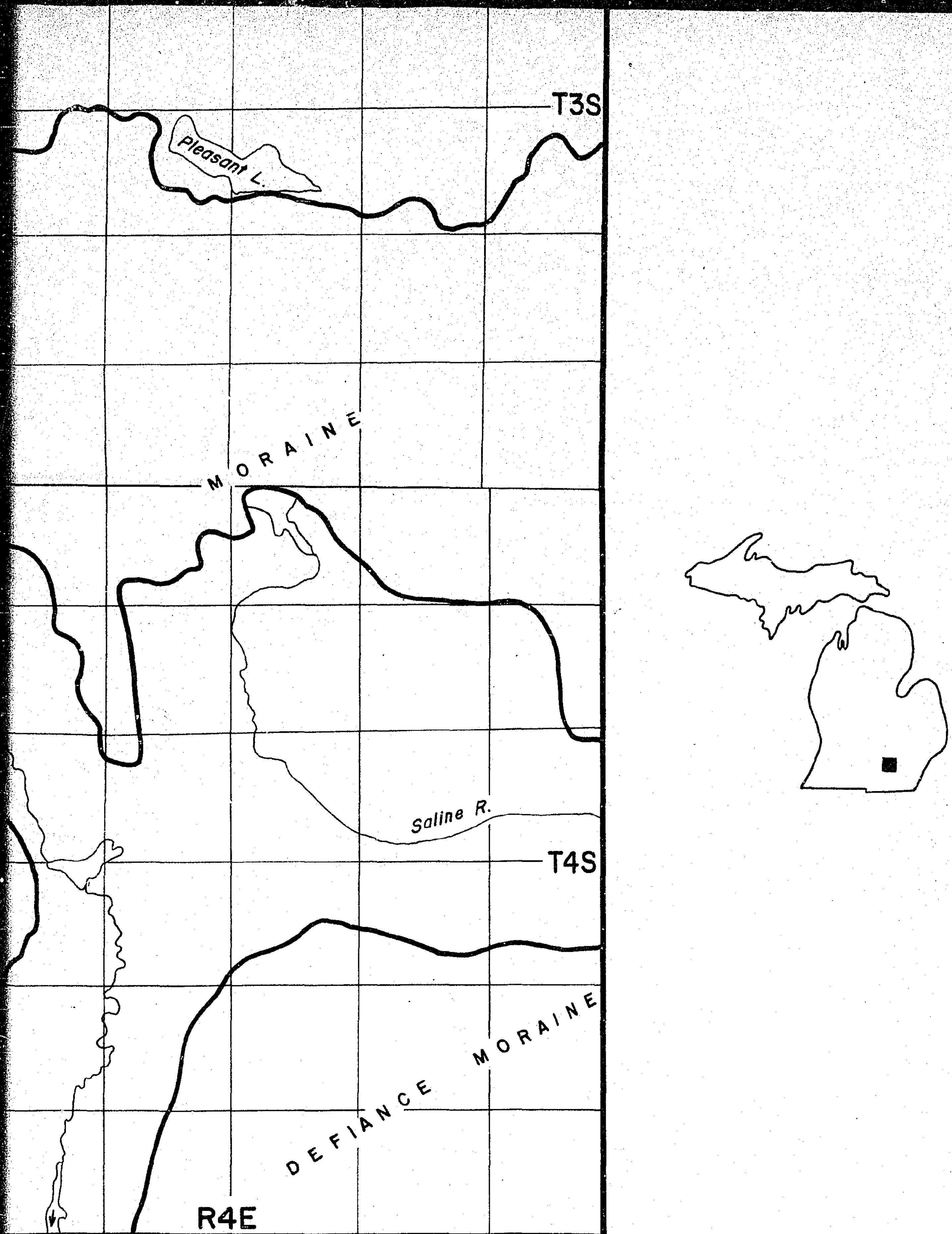
XUM


SHARON SHORT
TUCKER
LAKE
ESKER
Tucker L.
River
Sweezy L.
lorvell
Raisin
Manchester
WAYNE
FORT
JACKSON CO.
WASHTENAW CO.
R3E

XUM


T3S
Pleasant L.
MORAINE
Raisin
nchester
Saline R.
NE
T4S
DEFIANCE MORAINE
R4E

XUM



XUM