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EVALUATION OF NATURAL AGGREGATES IN KALAMAZOO COUNTY AND VICINITY MICHIGAN

By

Balkumar Prataprai Shah

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ABSTRACT

EVALUATION OF NATURAL AGGREGATES IN
KALAMAZOO COUNTY AND VICINITY
MICHIGAN

By

Balkumar Prataprai Shah

The surface geology of Kalamazoo County was remapped with the help of Frank Leverett's manuscript field maps (available at the Michigan Geological Survey) and extensive field checks. The drift samples from the county were collected using the channel and pebble volume sampling methods. The petrographic analyses of gravel samples were carried out, and the data are correlated with the similar data from the surrounding nine counties in southwestern Michigan.

Kalamazoo County lies in a reentrant district of the Lake Michigan lobe and the Saginaw lobe of the middle Wisconsinan glacial age. On the basis of provenance, observed lithologic distribution, and field evidences, a viable glacial history of the area has been pictured in seven figures. It is suggested that the Lake Michigan lobe and the Saginaw lobe were out-of-phase with each other. The Saginaw lobe sediments being laid down first

in the county and then pushed and overlain by the eastward advancing Lake Michigan lobe sediments. Characteristics of glacial, glacio-fluvial, aeolian, and other features and their associated clastics are described in detail. This information should help in future exploration of aggregate sources in Kalamazoo County.

It is desirable, however, to incorporate the information regarding the nature and structure of local bedrock, thickness of glacial drift, and soils and their relation to the parent material, to complete the total picture of the area under investigation. Using available surface and subsurface information, attempts are made to present the total picture with the help of maps, cross sections, diagrams, and tables.

The lithologic data are presented by a series of maps on which the percentages of each major lithologic group is entered, and isopleths are drawn. The resulting distribution patterns are clearly indicative of two predominant source areas in relation to sediment dispersal, and of glacial processes of two quite separate lobes. On the basis of above lithologic distribution patterns and geomorphology, the interlobate line is proposed (Plate I). The engineering properties, such as physical strength and chemical reactivity, show direct correlation with the lithologic composition of the drift in Kalamazoo County.

Balkumar Prataprai Shah

With the aid of petrographic analyses and the glacial geology, a map "Gravel Resources of Southwestern Michigan" is prepared. This map is a guide for giving preferences to the areas for prospecting future sand and gravel deposits.

DEDICATION

To My Family

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PART I

CHAPTER I

INTRODUCTION

This investigation was undertaken initially at the request of the Research Laboratory Section of the Michigan Department of State Highways, and subsequently has been developed as a dissertation for the doctoral degree. As such it forms an expanded phase of the statewide investigation of the availability and quality of sand and gravel deposits of glacial origin, and provides an opportunity for a contribution to the glacial history of southwestern Michigan. On the practical side it is hoped that the study will have value in meeting the increasing demand of suitable natural aggregates for future highway programs in this state, as well as some fresh insights into the academic view of these practical matters.

Aims and Purposes of the Study

For the purpose of this investigation, it was decided to study one area, preferably as large as a county, to be geologically and geographically representative for the systematic evaluation of sand and gravel deposits in

Michigan. The first aim is, of course, use in planning by the State Highway Department. Kalamazoo County was selected for the study because of a shortage of known aggregates for highway construction in that region. To determine the origin and quality of material in the Kalamazoo area, a systematic geological study is essential. The glacial sediments in this region have been deposited by glacial and glaciofluvial processes of two separate glacial lobes of the Wisconsinan glaciation, i.e., the Lake Michigan lobe and the Saginaw lobe affecting the area with repeated invasions of ice. This has produced what will be referred to as an interlobate "reentrant district," defined as an area in which materials from two different sources have become intermixed. Because, this situation makes field interpretations often quite difficult, the writer has mapped and sampled a large number of surficial deposits in the study area, and using field and laboratory interpretive techniques, attempts to clarify Pleistocene stratigraphy of these complex surface deposits. By applying time-stratigraphic, rock-stratigraphic, soil-stratigraphic, and morpho-stratigraphic analyses to the sequence, a glacial history of the area is evolved. Although some important questions remain unanswered, it is hoped that the new information here presented will be helpful in future exploration of such aggregates and in the interpretation of geologically significant interlobate areas elsewhere in this state and in other regions where glacial, glacio-fluvial, and glacio-lacustrine processes have been dominant.

The originally stated specific aims of this investigation, both for the Highway Department and for the dissertation were:

1. To prepare a detailed surface geologic map of the study area, and describe the geology and the glacial history of the area.
2. To point out sand and gravel deposits of the area with economic potential.
3. To determine the lithologic distribution of aggregates in the glacial drift by petrographic and other applicable methods.
4. To determine if the deposits of two different glacial lobes can be traced on the basis of their composition and engineering properties.

Previous Work

Previous work which bears on this subject, consists of some small scale areal mapping and the description of surface features in this area. Leverett and Taylor (1915, the Pleistocene of Indiana and Michigan, U.S.G.S. monograph 53) and Leverett (1924, Map of the Surface Formations of the Southern Peninsula of Michigan) are broad reconnaissance studies of the glacial geology.

These do not show the details necessary to characterize effectively the glacial aggregate sources. Helen Martin (1955) compiled a map of the Surface Formations of the Southern Peninsula of Michigan, which also depicts the general distribution of the surface features. She also reported informally on the glacial history of Kalamazoo County (1957).

Detailed glacial mapping on a one-county basis was done by Terwilliger (1954) in Van Buren County as part of a state groundwater resources survey. Kneller (1964) studied the gravel sources of Washtenaw County and prepared a gravel resources map. Ibrahim (1970) made wide use of the gravity method to delineate buried bedrock valleys in Kalamazoo County, and prepared a bedrock topographic map of the county. Folsom (1971) did his doctoral thesis on the Hastings Quadrangle area in Barry County, Michigan, and worked on the interlobate problem between the Lake Michigan lobe and the Saginaw lobe; but the area of his concentration was too restricted to give much understanding of the situation pertaining to the whole reentrant district.

Wingard (1969) carried out a study of glacial gravels in Michigan, also under the auspices of the Research Laboratory Section of the Michigan Department of State Highways. His work also concerned a broad region in a reconnaissance fashion to determine the engineering properties and lithologic compositions of glacier-related aggregates, and their provenance and dispersal throughout the southern peninsula of Michigan.

The present investigation was originated as a continuing and more detailed phase of the program introduced by Wingard, therefore, some specific references will be made to his research. Though the present study is mainly concentrated on the interlobate problem, it concerns itself as well with aspects of the bedrock geology, bedrock topography, drift thickness, and soils of the area. These aspects are covered in Part II. In Part III lithologic distribution, economic considerations, and engineering usage of aggregates are considered.

CHAPTER II

PHYSICAL SETTING

Location

Area

Kalamazoo County lies in the southwestern part of the southern peninsula of Michigan (Fig. 1). The area is nearly square in shape and has sixteen full civil townships. The total area covered by this county is approximately 562 square miles. It is surrounded by seven other counties: Allegan, Barry, Calhoun, Branch, St. Joseph, Cass, and VanBuren. Selective supplementary studies, equally significant to this investigation in southwestern Michigan (Fig. 2) have also been conducted in these surrounding seven counties and in Berrien and Eaton counties.

Geologically, Kalamazoo County is located on the western edge of an interlobate reentrant district between the Lake Michigan lobe and the Saginaw lobe of the Wisconsinan glacial age. The position of the reentrant is shown on Plate I.

Cultural Geography

Kalamazoo County was organized as a Civil Unit in July, 1829, the earliest settlers having come chiefly from

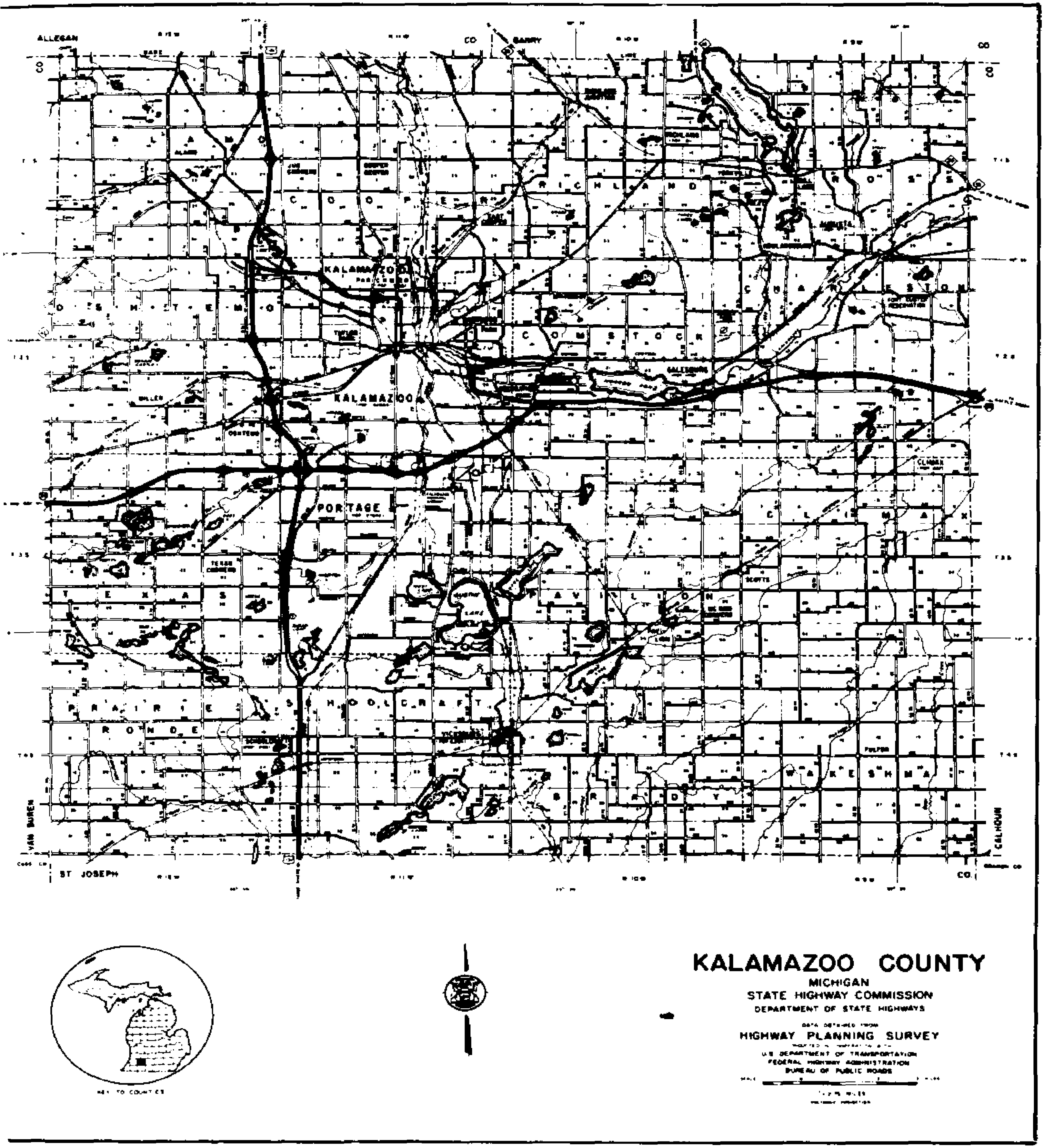


Figure 1. Primary study area.

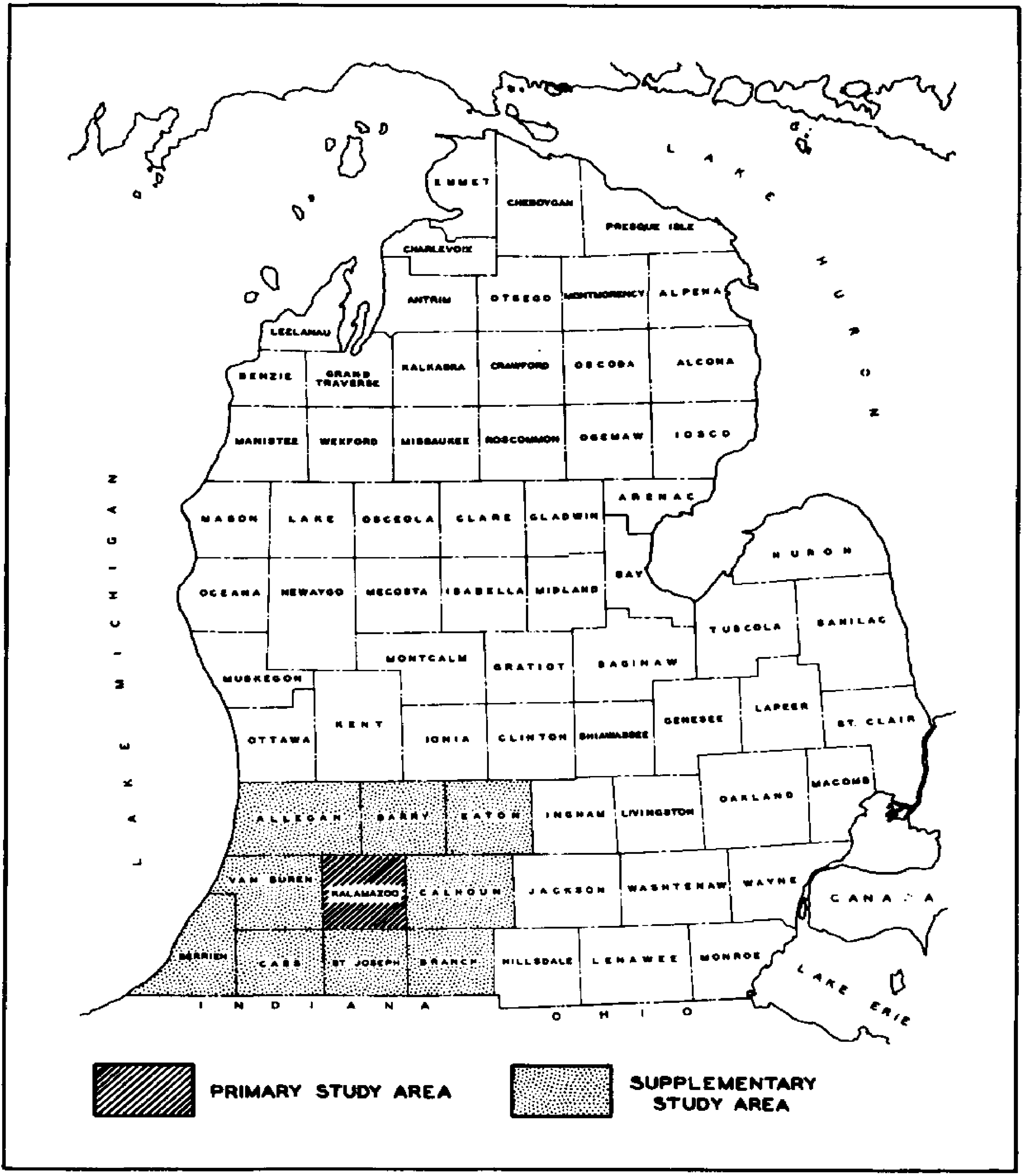


Figure 2. Location map noting Primary and Supplementary study areas.

New York State. The population by 1850 had risen to 13,179, and by 1860 it had about doubled. The 1970 census reports a population of 201,550 for the entire county, and 85,550 for the city of Kalamazoo.

The area is easily accessible by federal and state highways, county roads, and township roads. The main across-state highways serving the county are I-96, US-131, M-43, M-89, and M-96. All county and township roads, which usually parallel the section lines, are well surfaced. The county is further served by the Grand Trunk, New York Central, and Pennsylvania railroads.

The industry of the area involves manufacture of diversified products, among the most important being paper and allied products, pharmaceuticals, chemicals, transportation equipment, and various types of machinery. Mineral industries in the county produce processed sand and gravel, marl, and some peat.

The county also yields a variety of specialized and general farm products, the most important agricultural exports being celery, blueberries, cherries, and grapes.

Geomorphological Character

Relief

The present geomorphic features of Kalamazoo County area were formed during the Cary stage of the Wisconsinan glacial age, and thus are largely in a youthful stage of geomorphic development. The highest elevation in Kalamazoo County is in Oshtemo Township, the elevation being 1,040 feet above sea level. The general relief of the county is 50 to 275 feet above the bed of the Kalamazoo River. Surface relief in the northwestern and west-central parts of the county, however, is appreciably higher due to marginal features. The rest of the area below about 900-foot elevation is generally flat, and consists of glacio-fluvial sediments, with a maximum relief of 80 to 100 feet. Most of the flat area is breached by the Kalamazoo River and is dissected by several small tributaries. Some remnants of the outwash plain in the northeastern part of the county lie at elevations as much as 960 feet above sea level. The elevation is 800 feet where the Kalamazoo River enters the county, and 734 feet where it leaves the county.

Drainage

The Kalamazoo River, the principal drainage way of the county, flows in a westerly direction as far as the city of Kalamazoo, and then in a northerly direction, leaving the county in a northwesterly direction. In general, the northern half of the county is in the Kalamazoo River drainage basin, and most of the tributaries flow into the Kalamazoo River. The rest of the county lies in the drainage system of the St. Joseph River, only a few tributaries of which reach the county. The northwestern corner of the county is drained by the

Paw Paw River basin. All the drainage from Kalamazoo County eventually reaches Lake Michigan.

There are numerous lakes in the county, several of which are interconnected. Gull Lake is the largest of all, the next largest being Austin Lake. Chains of lakes abound in the upper reaches of the main streams. In general, most of these lakes were formed during deglaciation, and lie in the reentrant district between the two glacial lobes noted above.

In general, drainage in the county is marked by irregular stream courses, swamps, ponds, and lakes, and it can be described as a "deranged pattern" in geomorphic terms (Thornbury, 1962).

Climate

Weather-wise, Kalamazoo County experiences short and warm summers and long winters which are not unusually severe. In winter the temperatures may fall to 15° to 20°F or more below zero, for a week or so, but not for prolonged periods. In summer the temperatures may range from 34°F to 100°F. The mean annual temperature is around 50°F. Lake Michigan greatly affects the weather in the county, as the prevailing westerly winds are warmed in winter and cooled in the summer while passing over the lake, thus giving the region a slightly "maritime" aspect.

The annual precipitation in this area averages about 35 inches a year, with precipitation being heaviest in spring and summer. The driest month is February, in which the average precipitation is only about 2 inches.

Kalamazoo County lies on the eastern edge of the snow belt, which is induced by moisture and warmth picked up by the westerly winds crossing Lake Michigan. Consequently, the average annual snowfall in the county is 10 to 15 inches greater than in the central and eastern parts of southern lower Michigan. In the last decade, the snowfall has averaged about 55 inches annually, though the secular climatic trend, at present involves a gradual winter cooling of several degrees since the 1940's. Nevertheless, the climatic conditions are essentially temperate.

PART II

CHAPTER III

FIELD INVESTIGATIONS

Keeping the initial scope and objectives in mind, systematic and detailed field investigations were carried out. Objectives of the field investigations were divided into the following phases: (1) to prepare a detailed surface geologic map and work out the glacial history of Kalamazoo County, so that it can be used to locate and evaluate natural aggregates of glacial origin; and (2) to locate suitable exposures for sampling and collection of representative glacial drift for petrological analysis, so that evaluation can be made of its potential for use in construction projects in southwestern Michigan.

Surface Mapping

Originally the surface geology of Kalamazoo County was mapped by Frank Leverett and published by Leverett and Taylor (1915) in U.S. Geological Survey Monograph 53. Later, Leverett, who was largely responsible for the field work in this area, published (1924) a slightly revised map of the surface formations of the southern peninsula of Michigan. Helen M. Martin in 1955 published another large scale map of the surface formations of the southern peninsula of Michigan, in which very few changes were made from Leverett's maps.

The above mentioned maps cover large areas and are very general in their applicability to a small area like a county. To answer the need for more detailed studies, the writer decided to remap Kalamazoo County from field observations, using additional available surface and subsurface information which has recently come to light.

The surface mapping was carried out by observations along roads, with occasional foot traverses off the roads of course, often with the permission of property owners. The county has a very good network of section-line roads, and is covered by topographic quadrangles. The U.S. Geological Survey topographic quadrangle maps, the Michigan Department of State Highways county roads map (1 inch = 1 mile), and copies of Leverett's original manuscript maps were essentially used as field guides. All possible exposures were visited and auger holes drilled at a number of places for evaluation of the parent material of glacial origin. Additional information from highway borings has also proved useful.

Study of aerial photographs has aided the mapping in the field as well as in the laboratory. The individual photographs used are at a scale of approximately 1:20,000. The composite index photo map for the whole county has also been useful, at a smaller scale, for a detailed study of regional glacial features, and to locate any gravel and borrow pits not listed in the Michigan Department of State Highways' Gravel Pit Inventory. A soil map prepared by the Bureau of Soils (1922) has also helped in the mapping of glacial features and the assessment of parent material uncovered at given locations.

Subsurface information regarding the nature of the material and its association with glacial features was obtained from waterlogs and oil and gas well logs available at the Michigan Geological Survey. Also, information from various ground-water investigations was referred to, and at times conversations with well drillers and local people were carried out.

After gathering the above information in 1968, a detailed map of the surface geology of Kalamazoo County was prepared (Fig. 6). Later on part of the studies were extended into neighboring counties, so it has become necessary to compile from all available information a map of the surface geology of southwestern Michigan (Plate I).

Field Sampling

The sampling of glacial material was carried out simultaneously with the surface mapping. Over 90 large and small gravel pits were visited throughout Kalamazoo County to determine their suitability for sampling. Out of these, 18 pits were initially sampled, using the channel sampling method. Samples were collected for the petrographic and mechanical analysis of the glacial material. Later on, it was found necessary to gather additional petrographic data in the county, with 23 more locations being sampled by the spot sampling method. Over 100 locations (including the above) were sampled for petrographic and mechanical analysis of sand, using channel, spot, and auger sampling methods.

The locations to be sampled were based on the following characteristics: (1) freshness of exposure, though in several old gravel pits, fresh exposures were unavailable because of extensive slumping and the growth of vegetation, which made it difficult to obtain representative samples in some cases; (2) type of deposit and the nature of its glacial origin; (3) size and texture of the material; (4) the associated glacial lobe and its former direction of ice flow; and (5) sampling density. Many gravel pits were not sampled because of lack of fresh and suitable exposures.

It was desirable to take a commercial or engineering type of sample, as this study is concerned with evaluating the gravel deposits, as a whole, for their desirability as concrete aggregates. Suitable sampling methods and procedures for an engineering type of sample were decided from the outcome of earlier similar studies conducted in the Research Laboratory, Michigan Department of State Highways (Wingard, 1969).

Large Samples--Channel Sampling Method

Channel sampling method was used for the first 18 samples obtained in Kalamazoo County, and samples 19-22 obtained by Wingard (see Table 3 in the Appendix). These samples were large (weighing 600-1200 pounds) and were used for laboratory petrographic and mechanical analyses. Channel samples were always taken normal to the bedding of the deposit. First, all materials that had slumped over the face of an exposure or a pit were shovelled away in order to prepare a more or less vertical face. Usually about 20 feet of face (excluding the overlying soil profile) was cleared to obtain a wide range of the material to be analyzed. Precautions were taken to remove weathered and out-of-place material from the face. Then a channel about 9-12 inches wide and 5-6 inches deep was dug in the wall. The depth of the channel was more than the diameter of the largest pebble in the sampling zone. The entire vertical column was sampled by using a two liter laboratory scoop and a pick-mattock. Any excess of caved-in material was discarded. In order to obtain a representative and properly weighted sample, the material was sampled from each bed in proportion to its thickness. Occasionally sample transects were offset in order to obtain complete vertical sections. In each gravel pit anywhere from one to four channel samples were taken, depending on the amount of fresh exposure.

Small Samples--Spot Sampling Method

An isolated sample taken at a particular point on the exposure is termed a spot sample. But, here the concept of a spot sample is used in a slightly different way. These types of samples were taken from gravel pits, small borrow pits, and other small man-made exposures. The sample consisted of an integrated composite of a zone, or selected random samples taken in a small vertical channel in coarse sedimentary strata only. Using a laboratory scoop, only coarse material was taken and the 1/2-inch to 1-inch pebble fraction was separated by hand sieving through square mesh screens. Approximately 10 pounds of material were bagged for further pebble volume analysis (see Chapter IX).

This method of sampling and analysis has been successfully used in earlier work by the Research Laboratory Division, Michigan Department of State Highways, and has been proved by Wingard (1969) to be very economical and reasonably accurate for determining lithologic composition of drift materials. The writer, therefore, decided to use it, to compare his data with similar data acquired by previous investigations of the Research Laboratory, Michigan Department of State Highways in the vicinity of Kalamazoo County.

Analysis of the first 18 samples suggested that additional lithologic data were needed to make more precise glacial interpretations. Thus, an additional 23 locations were sampled by using the above described sampling method and related volume pebble analysis.

Auger Sampling

In Kalamazoo County, wherever surface and subsurface information was insufficient for interpreting the geology of the area, auger holes were drilled and samples collected. In all 13 holes were drilled throughout the county, the depths varying between 42 feet and 72 feet. A truck-mounted six-inch uncased power auger was used, provided by the Soils Division, District #7, Michigan Department of State Highways. Subsurface information was recorded at every five-foot vertical interval and, as noted above, samples were collected for further analyses.

Occasionally a six-foot hand auger was used in the field for mapping purposes and for collecting small samples, especially for sand analysis. Samples from a large truck-mounted auger were also used for sand analysis, but none of the auger samples could be used for petrographic analysis of coarse size (+3/16-inch) material, because of the inability of the auger to bring many large rocks to the surface.

Sampling Problems

A few problems are associated with these sampling methods. Caving or slumping was found to be the largest problem encountered in the channel sampling method. Every so often during sample collections material would cave in or slumping would occur to upset the procedure. Almost always there was at least some slight disturbance in the middle of sampling. Thus the channel sampling method proved to be quite a time consuming process--more so than the spot sampling method, but it provided more information than the other technique. Also, when the water-table was higher than the lower limit of a dug channel, serious problems of caving-in were experienced. Just as caving-in introduces complexities into the sampling picture, induration further complicates the sampling. Generally induration in sand and gravel deposits is the result of carbonate or silica cementation. Such indurated material (hardpan) is very difficult to scoop out or break loose, and can offset the sampling continuity.

CHAPTER IV

GLACIAL HISTORY AND STRATIGRAPHY

The Pleistocene Glacial Epoch in the geologic history of Kalamazoo County and vicinity is the most significant with respect to yields of commercial sand and gravel, and to important resources of ground water for the area. The rather comprehensive earlier studies of the Pleistocene geology of this area, were done by Leverett (Leverett and Taylor, 1915) and subsequently by several others including water resources investigations (Terwilliger, 1954; Travis, 1964). Earlier workers suggested several probable invasions of continental Laurentide glacial ice in southwestern Michigan, but the problem of recognizing and dating the various invasions and ice fluctuations remains inconclusive in most sectors because of insufficient surface evidence. Also, glacial sediments of earlier ice advances and retreats have either been destroyed, covered, or modified by erosive and depositional effects of younger ice. Thus the recognition of earlier ice age deposits in Kalamazoo County must be made primarily from well records, which, because of improper and incomplete recording becomes a frustrating and difficult procedure. In fact, the nature and composition of subsurface materials is too often inadequately indicated in well records, and if noted at all, usually cannot be extended areally for any particular horizon owing to the absence of records from adjacent sites, or because of inconsistencies on the part of drillers in their descriptions and use of terminology.

Pre-Wisconsinan Glaciation

It is a sufficiently established fact that all of the surficial sediments of Kalamazoo County are related to the Wisconsinan Glacial age except recent (Holocene) alluvial sediments along presently existing rivers and streams. On the basis of morainal sequences in Ohio and Indiana to the south, we know that pre-Wisconsinan ice once covered Kalamazoo County and presumably unloaded some of its material in the form of glacial and glaciofluvial deposits. The writer has observed what he believes to be oxidized early Wisconsinan or pre-Wisconsinan drift in the neighboring Parma area of Jackson County, Michigan (see the Glossary). Also, others have reported presumed pre-Wisconsinan material at the base of the Wisconsinan drift in the Devils Lake sector south of the Irish Hills in Michigan (Miller, personal communications, 1971) and in the Grand Rapids area (Zumberge, 1964). Also, one's attention can be drawn to the Glacial Map of the United States East of the Rocky Mountains (Geological Society of America, 1959), on which a clearly delineated zone of Illinoian and earlier drift is shown extending across southern Illinois, southern Indiana, and southern Ohio, well covering the region adjacent to and south of the study area.

It follows that Kalamazoo County lies on a direct path of pre-Wisconsinan Laurentide ice, the provenance of which was in the source area of the Lake Michigan and Saginaw (Huron) lobes to the north. Whether Nebraskan and Kansan glaciation actively affected Kalamazoo County is not indicated by any identifiable older drift, though a detailed study of well records also suggests that Illinoian glaciation probably left its mark in this area. It is fair to state that the uncertainty which surrounds the extent and nature of pre-Wisconsinan drift in Kalamazoo County stems simply from a lack of sufficient information. What pre-Wisconsinan drift does occur is most likely of Illinoian age, this drift or correlated erosional topography of which seem to underlie much of the Wisconsinan drift in this sector of Michigan's southern peninsula.

It should further be noted that Leverett and Taylor (1915) reported pre-Wisconsinan till farther east, especially in the southeastern and eastern parts of Michigan (U.S.G.S. Monograph 53). This till is generally unoxidized darker blue-gray material, quite distinct from the newer drift. This older material is also described as more stony, and considerably indurated. Sometimes this older till is referred to as "hardpan" by well drillers and in places is overlain by dark colored Sangamonian soil profiles or deeply weathered zones marked by brown coloration from oxidation. In the Leverett and Taylor examples the supposedly Illinoian deposits appear to be largely sand and gravel or loose (non-compacted) textured material, in which case they cannot easily be separated from Wisconsinan deposits, except on the basis of rock-stratigraphic and weathering differences.

It is suspected by the writer that Illinoian deposits do, in fact, occur in Kalamazoo County as preglacial valley fillings and in thin patchy zones over buried bedrock surfaces. Some of this postulated Illinoian drift could have been reworded and redeposited by Wisconsinan glacial ice, in which cases the evidence of earlier glacial effects would be largely destroyed. The basis for this suggestion is that several deep well records in Kalamazoo County reveal the presence of hard stoney and bouldery clay, "hardpan," blue-gray clay balls, and silt-clay just a few feet above bedrock. In several areas above layers of hard blue clay there are thin (10-15 feet) zones of brown silty clay and brown sandy and gravelly clay, a situation which somewhat fits the

Leverett and Taylor description of Illinoian till in southeastern Michigan.

In addition to the above, Abdelwahid Ibrahim (1970) reports from Kalamazoo County finding references in driller's logs to buried soil profiles containing tree logs, brush stems, and muck and peat beds. He found references to a sufficient number of places to reinforce the belief that glacial sediments in Kalamazoo County were indeed, deposited during more than one glacial age. This writer has also found two driller's logs reporting soil profiles at considerable depth near bedrock in Kalamazoo County. The presence of highly weathered boulders found in a number of gravel pits in the county may also relate to older presumably re-worked Illinoian drift fragments.

Wisconsinan Glaciation

It has been well documented in the glacial geological literature that the Wisconsinan ice spread completely over the state of Michigan and about two-thirds of Indiana and large adjoining areas of Illinois and Ohio. As the present area of study is in southwestern Michigan, it is well within these borders, and hence the surficial drift deposits throughout this area are of the Wisconsinan age. The pattern of known ice-sheet limits indicates a considerably more lobated form at the time of its different stages than that of the

Illinoian and earlier ice-sheets. Present landforms in Kalamazoo County and immediate vicinity were essentially the result of Wisconsinan ice pulsations, still-stands, and withdrawals, during downwasting being characterized by repeated small readvances producing myriads of oscillation moraines and much varied relief. The ice was believed to be enormous in thickness compared to present-day temperate icefields around the globe, with the exception of the continental to subcontinental polar ice sheets in Antarctica and Greenland which are considered at least morphologically comparable. For this reason, studies of such existing ice masses can improve one's understanding of conditions in Michigan during Wisconsinan time.

Time-Stratigraphic Relations

The stratigraphy of the Wisconsinan age has been rather descriptively treated by earlier workers because of its complex nature, and the lack of sufficient direct glacialogical experience in regions of existing glaciers. Leverett and Taylor (1915), who were well-trained Pleistocene geologists, in their U.S. Geological Survey Monograph 53 worked out in broad outline the approximate time relations of these ice lobes and morainic systems, emphasizing the Wisconsinan glaciation in Indiana and southern Michigan. Because of the large number and intricately combined nature of these moraines, Leverett and Taylor considered them in groups, rather than correlating each individual moraine across the whole region. They rightfully considered that this method simplified questionable correlations of individual moraines, and of course it served its purpose by providing a fine general framework. But they left many details untouched.

Since about 1950, the stratigraphy of Wisconsinan age deposits has been reexamined in more detail. A critical study of newly available road cuts, gravel pits, building foundations, streambank exposures, and other types of outcrops has provided a new basis for major improvements in and alterations of the earlier concepts.

Classification of the Wisconsinan age has been reviewed recently by Leighton (1958, 1959, 1960), Frye and Willman (1960), and Wright (1964); also in some recent studies by Wayne (1963) and Gooding (1963). In 1958 the Illinois State Geological Survey issued a report on its official classification policy (Willman, Swann, and Frye, 1958), and in 1961 the American Commission on Stratigraphic Nomenclature (A.C.S.N.) issued its proposed stratigraphic code for North America (A.C.S.N., 1961). From these two publications, the principles of classification are reviewed and modified in detail into a recent report, "Pleistocene Stratigraphy of Illinois," by Willman and Frye (1970).

In most of the papers, it is difficult to determine what type of classification is being used. The most common form is based on time-stratigraphy. The Illinois State Geological Survey recognizes several independent categories of stratigraphic classification, out of which the following four are formally used in the report by Willman and Frye (1970):

Time - stratigraphic
Rock - stratigraphic
Soil - stratigraphic
Morpho - stratigraphic

For the purposes of the present paper, reference is made primarily to the most recent and commonly applied time-stratigraphic classification. The evolutionary history of the Wisconsinan age is shown diagrammatically in Figure 3. According to the A.C.S.N. Code of 1961, "A time-stratigraphic unit is a subdivision of rocks considered solely as a record of a specific interval of geologic time." More detailed description of a time-stratigraphic classification need not be repeated as it is given in the A.C.S.N. Code (1961, p. 657). With respect to the sequences in Figure 3, the Leighton chronology appears to be more applicable to the present study because it is in more detail than the chronology found to apply in Illinois alone.

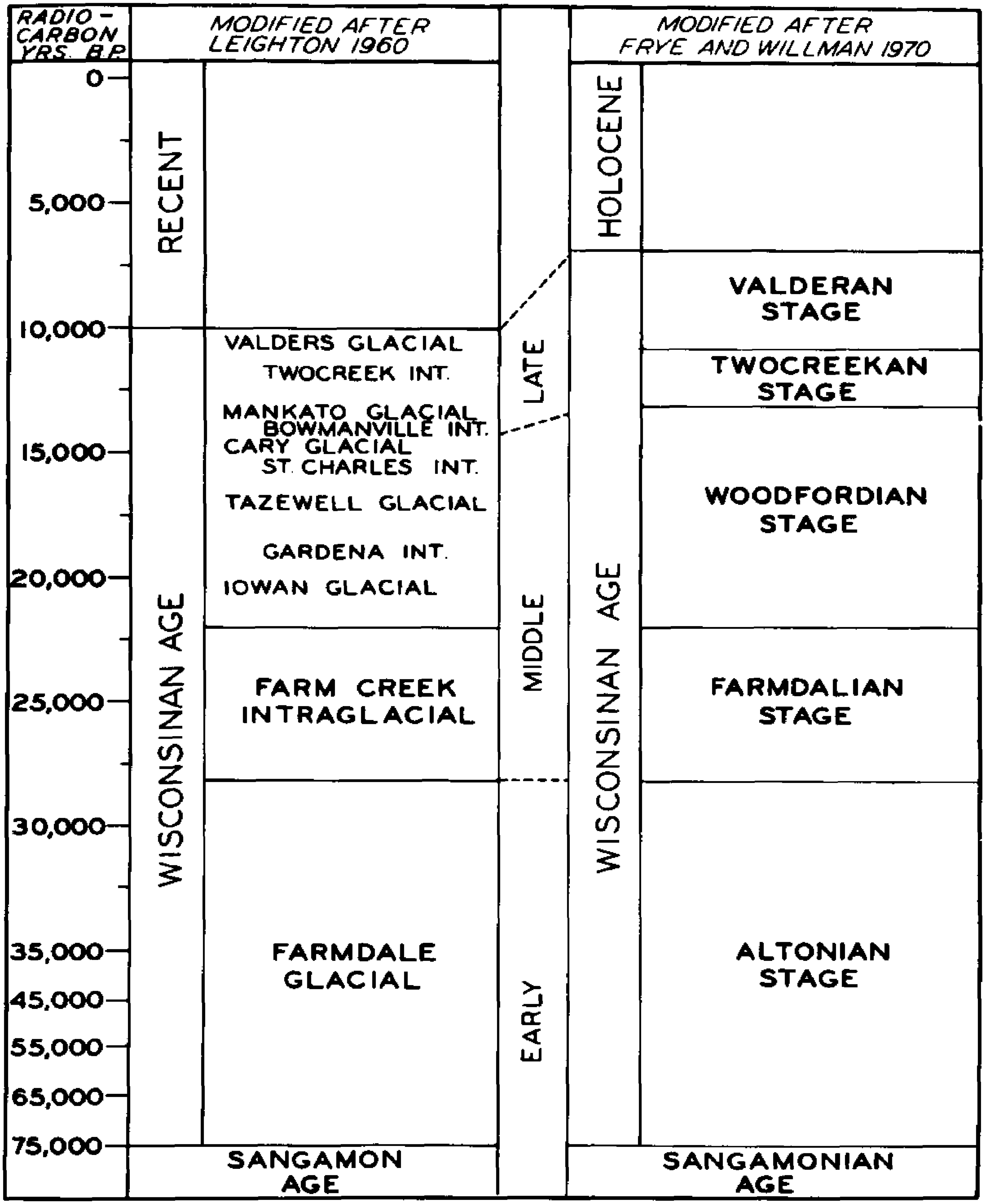


Figure 3. Modified Stratigraphic Classification of the Wisconsinan deposits in Illinois.

Distribution of Drift

The entire Kalamazoo County and vicinity was covered by two lobes of the Wisconsinan age continental glacier, the Lake Michigan lobe which advanced from the northwest, and the Saginaw lobe from the northeast. These two lobes, along with the Erie lobe to the east, extended southward into northern Illinois, northern Indiana, and northern Ohio. The maximum advance of these three lobes is considered to be the Minooka moraine of the Lake Michigan lobe, the Iroquois-Packerton Moraines of the Saginaw lobe, and the Union City moraine of the Erie lobe (Fig. 4). Zumberge (1960) considers that these moraines mark the Cary drift border in Illinois, Indiana, and Ohio. Retreat of the ice margin of all these lobes formed the present surface features in northeastern Illinois, northern Indiana, northern Ohio, and southern lower Michigan. Therefore, the present surface geology of Kalamazoo County and vicinity came into existence because of the major withdrawal of ice in middle Wisconsinan time (Fig. 3), with minor readvances of the Lake Michigan lobe and the Saginaw lobe of the Cary stage of the Wisconsinan age. It is probable that the thickness of glacier ice in these two lobes, within a few miles of its border, was more than one mile, which effected the huge bold morainic patterns found. Advances and retreats of both the Lake Michigan and the Saginaw lobes were presumably controlled by glacio-climatic

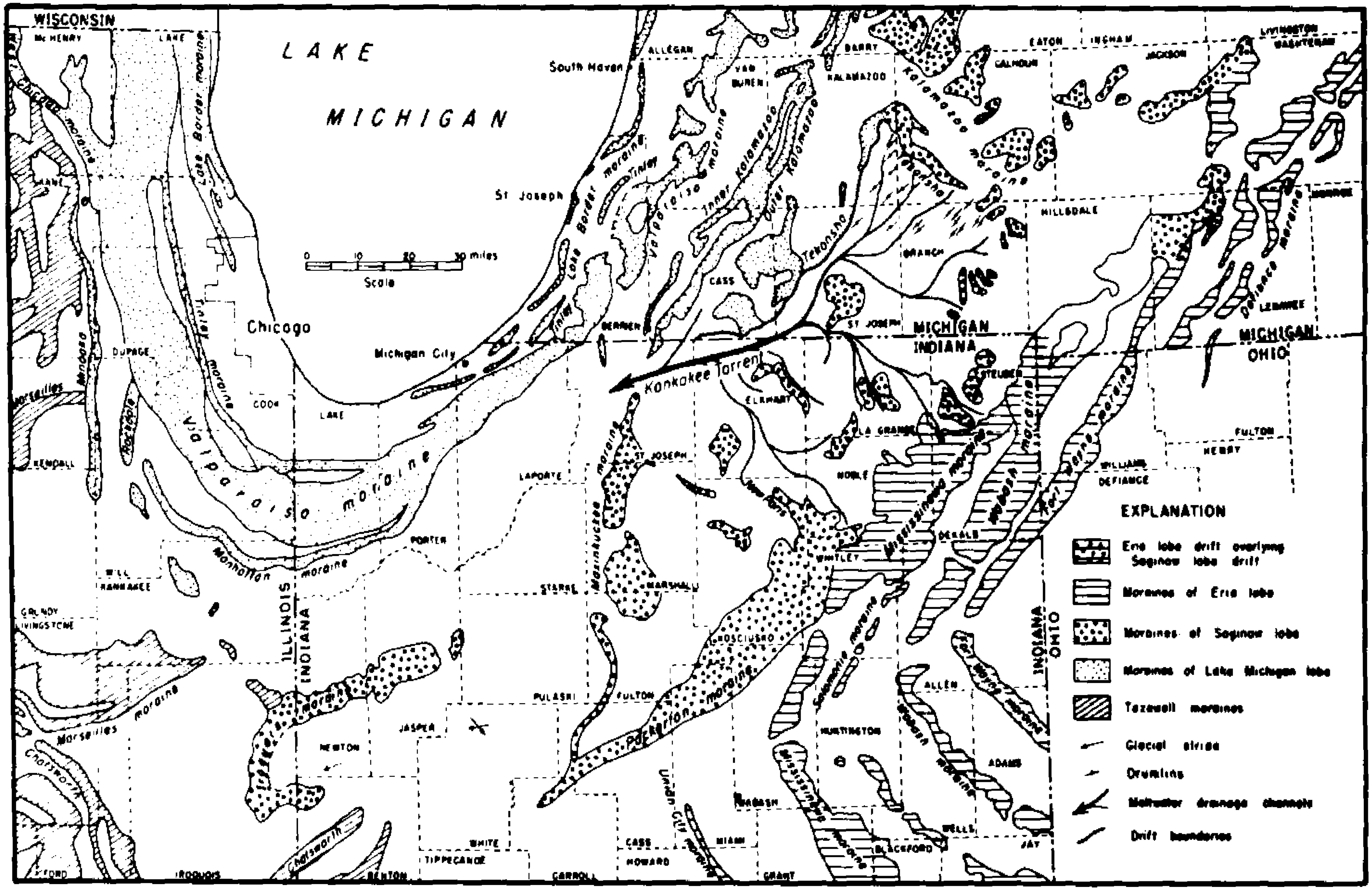


Figure 4. Map of Wisconsinan age moraines, Northeastern Illinois, Northern Indiana, Southern Michigan, and Northwestern Ohio (after J. H. Zumberge, 1960).

changes in the net accumulation in nourishment zones (Névé areas), or inner areas, i.e., the interior icesheet.

Lake Michigan Lobe.--In terms of the Wisconsinan glacial history, the Lake Michigan lobe continued to fluctuate in marginal position and volume during all of the time between the deposition of the Minooka moraine in northeastern Illinois and the readvances of Valders ice in the late Wisconsinan time. The Lake Michigan lobe fed by ice flow from one or more ice centers located around and probably somewhat southwest of the Hudson's Bay area. This lobe (along with the Green Bay lobe) flowed southward into the Lake Michigan lowland along preglacial river valleys, with glacial erosion taking place on weak rocks of Middle and Lower Paleozoic age.

The major ice limits of all stages and main Wisconsinan moraines were first worked out by Leverett (1902), using topographic and morphologic methods. According to Leverett and Taylor (1915), after the development of the Bloomington morainic system there seems to have been rapid recession along the junction (Fig. 5) of the Lake Michigan and Huron-Erie lobes across the Kankakee basin and on northeastward into southern Michigan as far as the Kalamazoo area. Late retreatal history of the Lake Michigan lobe is intimately related to the history of Lake Chicago and associated low-water stages (Bretz, 1951, 1955; Hough, 1955, 1958; Zumberge and Potzer, 1956).

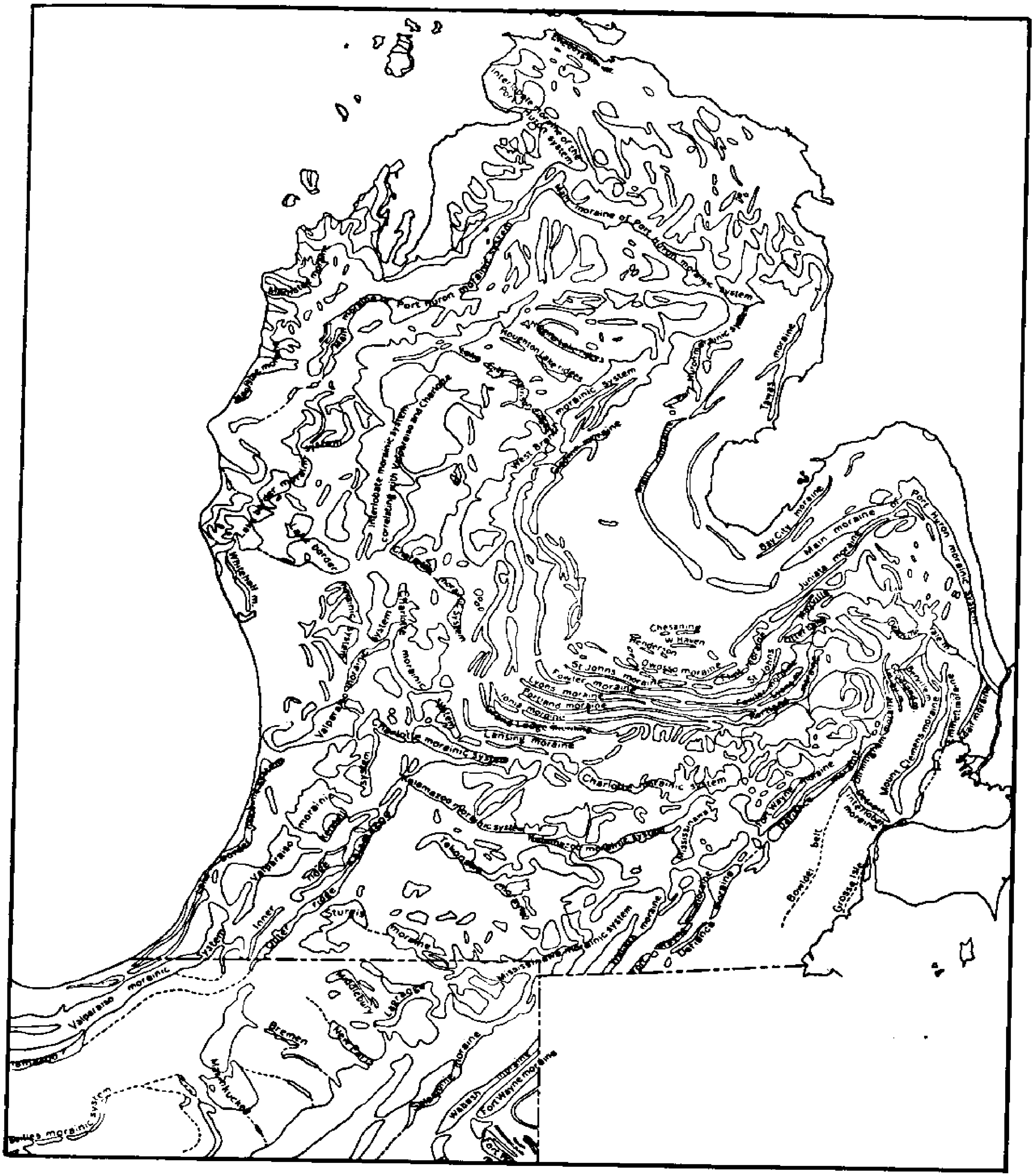


Figure 5. Designated morainic systems of Michigan and Northern Indiana (after Leverett and Taylor, 1915).

Horberg and Anderson (1956) believe that the Lake Michigan and Green Bay lobes were deflected southwestward by ice streams from the east which deposited huge piles of drift east of the interlobate area at the time of the Tazewell stage. They support this interpretation on the basis of drift lithologies (rock-stratigraphy) and moraine patterns (morpho-stratigraphy), which in effect involves a litho-morphostratigraphic interpretation. This concept of a westward shifting of the axis of the Lake Michigan lobe was described by Leverett (1915) in U.S. Geological Survey Monograph 53. The eastern side of the Lake Michigan lobe had thus less freedom for deployment than the western edge, with the ice tending to hold its position on the east while advancing on the west. The present glacial features of the Lake Michigan lobe and the Saginaw lobe in Kalamazoo County were formed during this eastern orientation of the axis, followed by the downwasting and retreatal phases of the Cary stage (Fig. 5).

Saginaw Lobe.--At the time of the Cary stage, the Saginaw lobe of Laurentide ice moved southwestward through and beyond the Lake Huron-Saginaw Bay area into Michigan and northwestern Indiana. Iroquois-Packerton moraines in northern Indiana represent the maximum advance of the Saginaw lobe at the time of Cary glaciation. Horberg and Anderson (1956) placed the boundary of the outer Cary at the Iroquois moraine. This is lithologically distinct from the Lake Michigan lobe Cary moraines, but it is similar to the Tazewell moraines found farther southwest. Leverett studied moraines and deposits of all three lobes (Leverett and Taylor, 1915, p. 123) and concluded the following:

> A study of the moraines of northern Indiana and southern Michigan has shown that the portion of the ice sheet which moved southwestward from the Saginaw basin into Indiana melted back and disappeared from northern Indiana while the Lake Michigan and Huron-Erie lobes still extended into that state. This perhaps is not surprising, for the path of the Saginaw lobe, especially the part beyond the immediate basin of Saginaw Bay, was across more elevated country than the path of the bordering lobes. Its thickness must have been correspondingly less and its movement correspondingly weaker, and these differences would become more noticeable with the waning of glaciation and decrease in the bulk of the ice sheet.

It is of interest that this description connotes strong out-of-phase fluctuations of major proportion in these two main lobes. Further evidence of this and its consequences will be considered later with respect to specific features in this study.

On the same page Leverett also explains the strong moraines in southern Michigan formed by the Saginaw lobe, in spite of its degenerative regime compared with the Michigan lobe at that time. He suggested that simultaneous convergence of the three lobes might have caused an excessive loading with drift material in the part of the ice sheet which subsequently became differentiated into the Saginaw lobe. Further, Leverett thinks that this excessive loading may have been even more influential than the comparative thinness of the ice in bringing about the reduction in flow.

With the further recession of the Saginaw lobe into southern Michigan, reentrant angles developed between it and the Lake Michigan lobe in southwestern Michigan, and between it and the Huron-Erie lobe in southeastern Michigan. This was the simplest possible explanation given by Leverett (1915). He suggested that the actual history may have been much more complicated. The border of these lobes, for instance, may have readvanced instead of merely halting at the moraines formed during recession. Due to a lack of more detailed evidence, however, Leverett did not go into a complicated interpretation. From the last quarter of a century's studies of existing glaciers around the globe, it is a well-documented fact that major ice retreats from vigorous advance positions are usually associated with minor readvances and vice-versa. These pulsations are related to many factors in the general systems nature of ice sheets as quite sensitive responders to climatic perturbations.

The Lake Michigan-Saginaw Interlobate Area.--An interlobate area is defined as an area between bold end moraine systems from different glacial lobes and also along the line of junction of two adjacent glacier lobes. In this definition southwestern Michigan is a classic interlobate area frequently referred to as a reentrant district (Leverett's term). The reentrant angle is the angle at the junction of two end morainic systems formed by two quite separate glacier lobes.

Most of Kalamazoo County and vicinity lies within such a reentrant district, situated between the bold Kalamazoo morainic system of the Lake Michigan lobe to the northwest and the bold moraines of the Saginaw lobe to the northeast (Fig. 6 and Plate I). During the formation of the Kalamazoo morainic system, the interlobate junction was in Barry County, a few miles southwest of Hastings and immediately north of Kalamazoo County (Plate I). From this location, the interlobate tract runs northward in a zigzag course toward southern Wexford and Missaukee counties, which lie in the upper middle center of the western "hand" of Michigan (Fig. 5). In this interlobate tract are the most prominent moraines developed anywhere in the southern peninsula. From the axis of this interlobate tract, there is a general westward topographic descent toward the Lake Michigan basin, and a general eastward descent toward the Saginaw basin.

At the interlobate junction southwest of Hastings in Barry County, the Kalamazoo morainic system is characterized by larger lakes than are commonly found elsewhere along the interlobate tract. Also the tract includes several small gravel plains developed as an outwash from

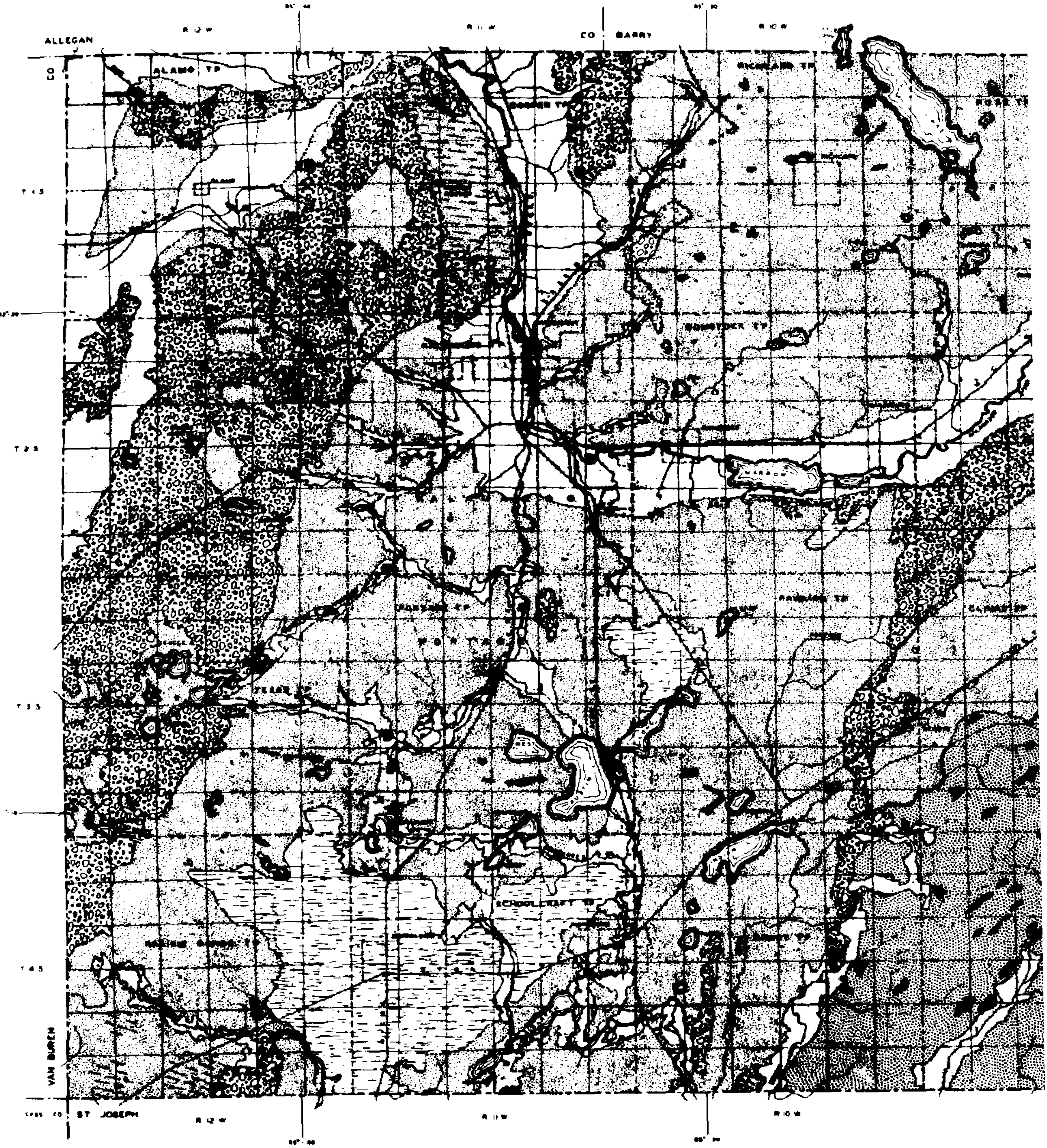
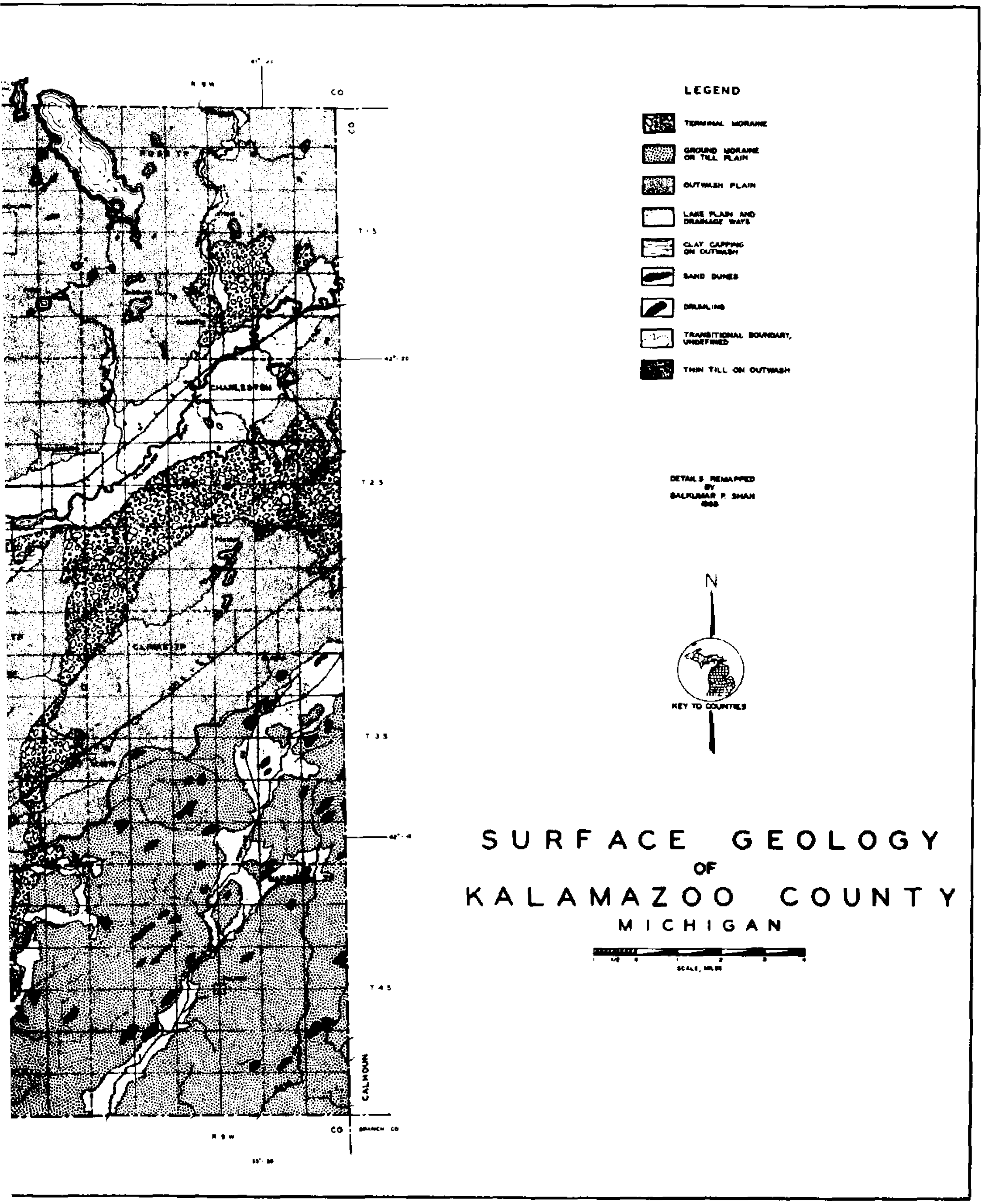


Figure 6. Surface geology of Kalamazoo



eology of Kalamazoo County, Michigan.

one or both of the ice lobes. According to Leverett (1915), these outwash plains are in places characterized by small in-filled basins of sediments at the border between the gravel plains and the associated moraines. He thought that the slopes of the outwash plains and the distribution of these basins indicated the source of the outwash, which in some places appeared to be the product either of one or both lobes.

Leverett (1915) further pointed out the relation and trends of the moraines of both lobes in the reentrant angle. Moraines of the Lake Michigan lobe lead up to the line of junction from southwest or south, and those of the Saginaw lobe lead up to the junction line from the southeast. At this junction much outwash is found.

Leverett (1915, p. 186) thought that both lobes for a while retreated from south to north along the line of junction up to the southwestern part of Mecosta County. He thought that probably both lobes thinned and shrunk away toward the Lake Michigan lowland to the west and the Saginaw lowland to the east, leaving a massive moraine system extending northward from southwestern Mecosta County to Cadillac. This interpretation may be correct, but it is quite different from Leverett's interpretation regarding the earlier disappearance of the Saginaw ice from northern Indiana while the Lake Michigan and Huron-Erie lobes still extended into that state. The present writer suggests that Leverett's second interpretation is probably more realistic in the interlobate area between the Lake Michigan lobe and the Saginaw lobe.

Broad scale correlative studies of all three, the Lake Michigan, Saginaw, and Huron-Erie lobes, have been carried out by investigators such as Leverett and Taylor (1915), Wayne and Thornbury (1951, 1955), Horberg and Anderson (1956), Anderson (1957), Zumberge (1960), Wayne and Zumberge (1965) and several others in Indiana and Michigan. Most of the studies, however, are focused on the regional relationship between terminal moraines of all three lobes in northern Illinois, northern Indiana, and northern Ohio. Very few detailed correlative studies have been done along the border between Michigan and Indiana, and particularly the present area of study. Leverett (1915) has described individual glacial features and deposits in the Kalamazoo area, but he posed problems for interpretation of the history of deposition of the complex intermingling of various kinds of tills, outwash sediments, and lake deposits, both here and in the northern part of Indiana. These problems have not yet been adequately solved.

This writer's interpretations are based on field examinations, laboratory analysis of surficial gravels and sands, and study of other literature some relating to the area of Kalamazoo County and vicinity. The interpretations given in the following pages may, of course, be subject to change in the future when additional data may become available from future road cuts and excavations. The present chapter presents a brief glacial history of the reentrant district, with detailed description of individual glacial features in Kalamazoo County covered in the succeeding chapter.

Anderson (1957) determined pebble and sand lithologies of the major Wisconsinan glacial lobes of the central lowland in this country, and he interpreted distribution of lithologic types in terms of provenance, lithologic properties, and glacial processes. It appeared difficult for him to differentiate glacial lobes on the basis of a single "indicator" lithology. Only the Saginaw lobe contained the always identifiable Precambrian (Huronian Gowganda) tillite and the well-recognized jasper conglomerate from the Lorraine formation (also of Huronian age) which are not found in the Lake Michigan and other lobes. The present writer considers that these two indicator rocks (index erratics) are ideal for differentiating deposits of the two different lobes in this study area, on the basis that the Saginaw lobe only contains these indicator rocks with a provenance in Ontario.

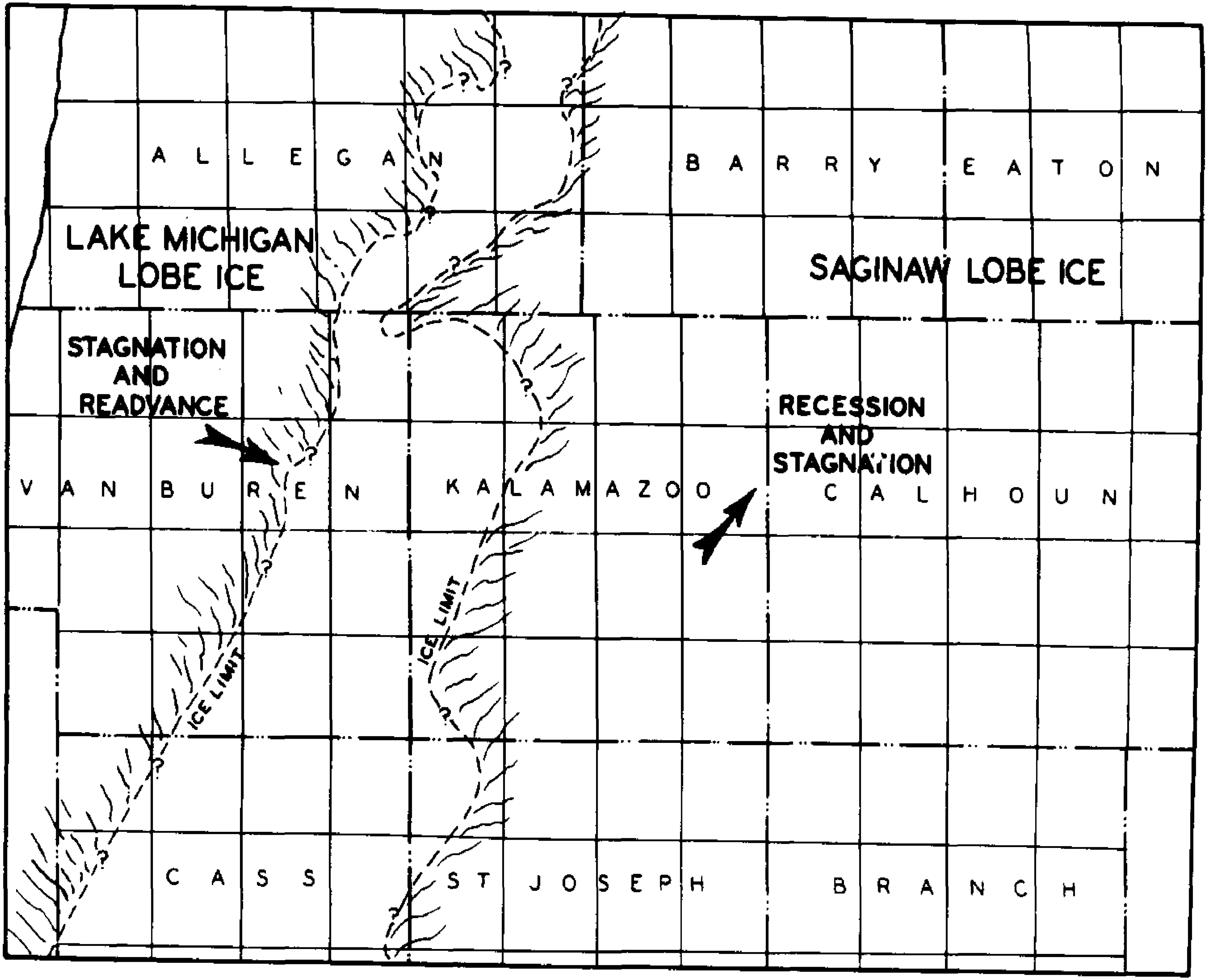
Anderson's investigation suggests that the relative proportion of lithologic types is the most fruitful method for the differentiation of glacial lobes. Lithologic composition of a particular drift must be dependent upon the sources of the ice and the composition of the bedrock floor over which it passed. Comparison of the lithologies of the drift deposited by ice lobes moving over different bedrock lithologies should, therefore, show differences intimately related to the former directions of flow.

A detailed petrographic analysis of gravels from several locations in Kalamazoo County was carried out by the writer, and the data (see Tables 3 and 5 in the Appendix) are correlated with similar types of data from surrounding counties. It is clear that pebble-sized fractions show significant differences between the Lake Michigan lobe deposits and the Saginaw lobe deposits. More detailed interpretation of various proportions of lithologies associated with each lobe is given in Chapter X, under the heading "Lithologic Distribution of Aggregates." As in Anderson's (1957) investigation, this writer finds that the correlation of the relative proportions of certain types of groups of lithologies--i.e., rock-stratigraphy--provides the most useful method for differentiating deposits of these two lobes.

Considering all available information, it is suggested what Leverett had apparently unwillingly hinted, that, the terminal behavior of the Lake Michigan lobe and the Saginaw lobe in middle Wisconsinan time were quite out-of-phase with each other. A sequence of regional trends within the glacial borders of both lobes in the Kalamazoo reentrant district are illustrated in Figures 7-13. Arrows in these figures only indicate shift in position of ice margins due to downwasting and not the direction of actual ice flows.

First, the Saginaw lobe ice (Fig. 7) was extended through most of Kalamazoo County, all the way, passing southward across the Michigan-Indiana border. At this time the Lake Michigan lobe ice margin was farther west and northwest (Figs. 3 and 4, and Plate I) and well contained in the Lake Michigan basin. When the ice margin of the Saginaw lobe started retreating with associated small ice advances, its terminus shifted towards the Saginaw basin leaving in its way a series of relatively bold maraines, till plains, outwash plains (valley trains in narrow linear areas), and recessional moraines; the Lake Michigan lobe in contrast appears to have started advancing again towards the southeast and east in the area of southwestern Michigan. Presumably this represented a difference in the dominant storm track pattern affecting the different source areas, or névés, of these ice systems, as has been well demonstrated in comprehensive studies of smaller icefield systems of present glaciation in the middle latitudes (Miller, 1963, 1972).

The retreating Saginaw lobe (Fig. 8) resulted in the Sturgis moraine (Figs. 4 and 5; Plate I) in St. Joseph County, part of the Alamo moraine in the northern part of



Note: Arrows only indicate shift in position of ice margins due to regime changes and not the direction of actual ice flows.

Figure 7. First regime trend in the Lake Michigan-Saginaw interlobate glaciation.

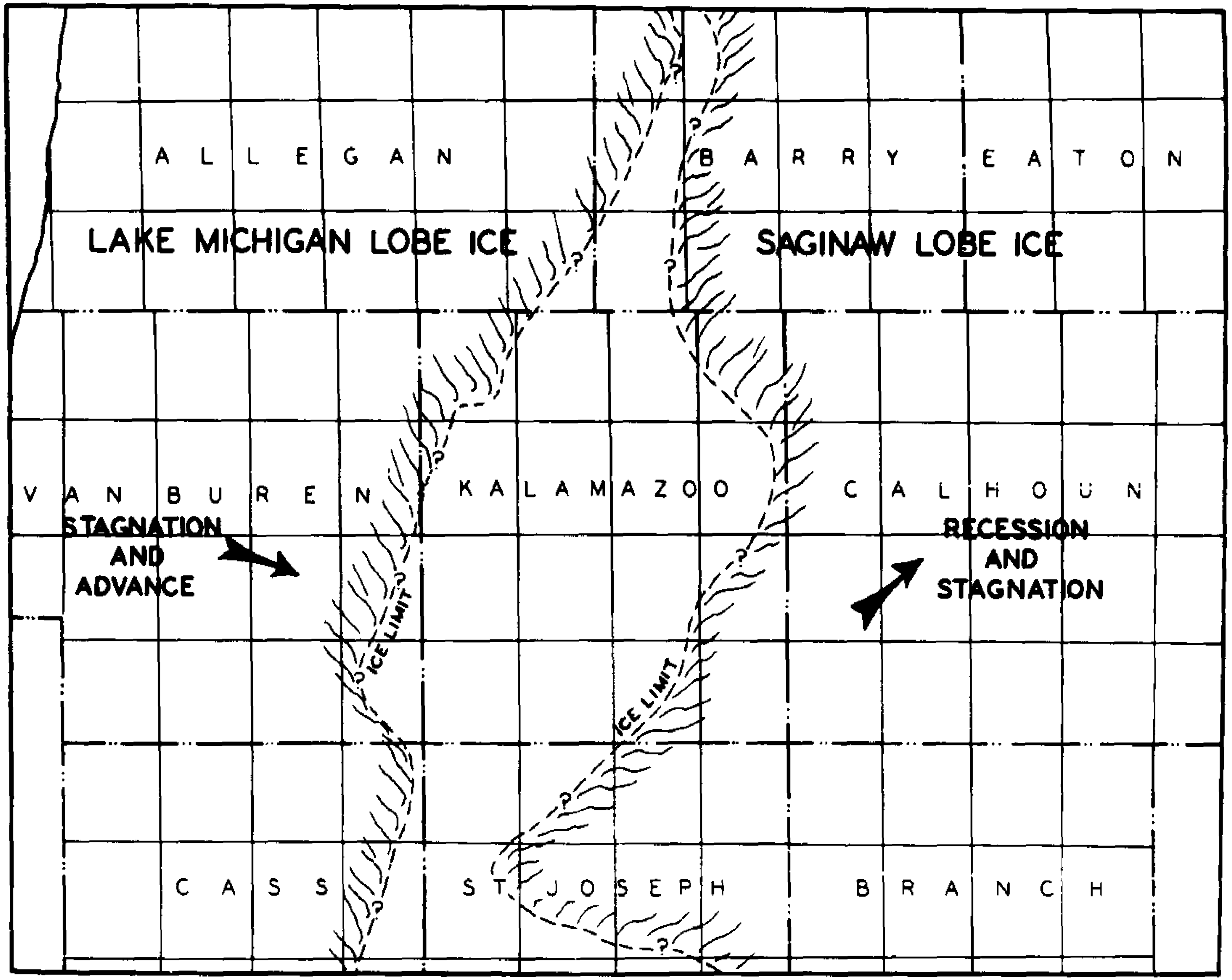


Figure 8. Second regime trend in the Lake Michigan-Saginaw interlobate glaciation.

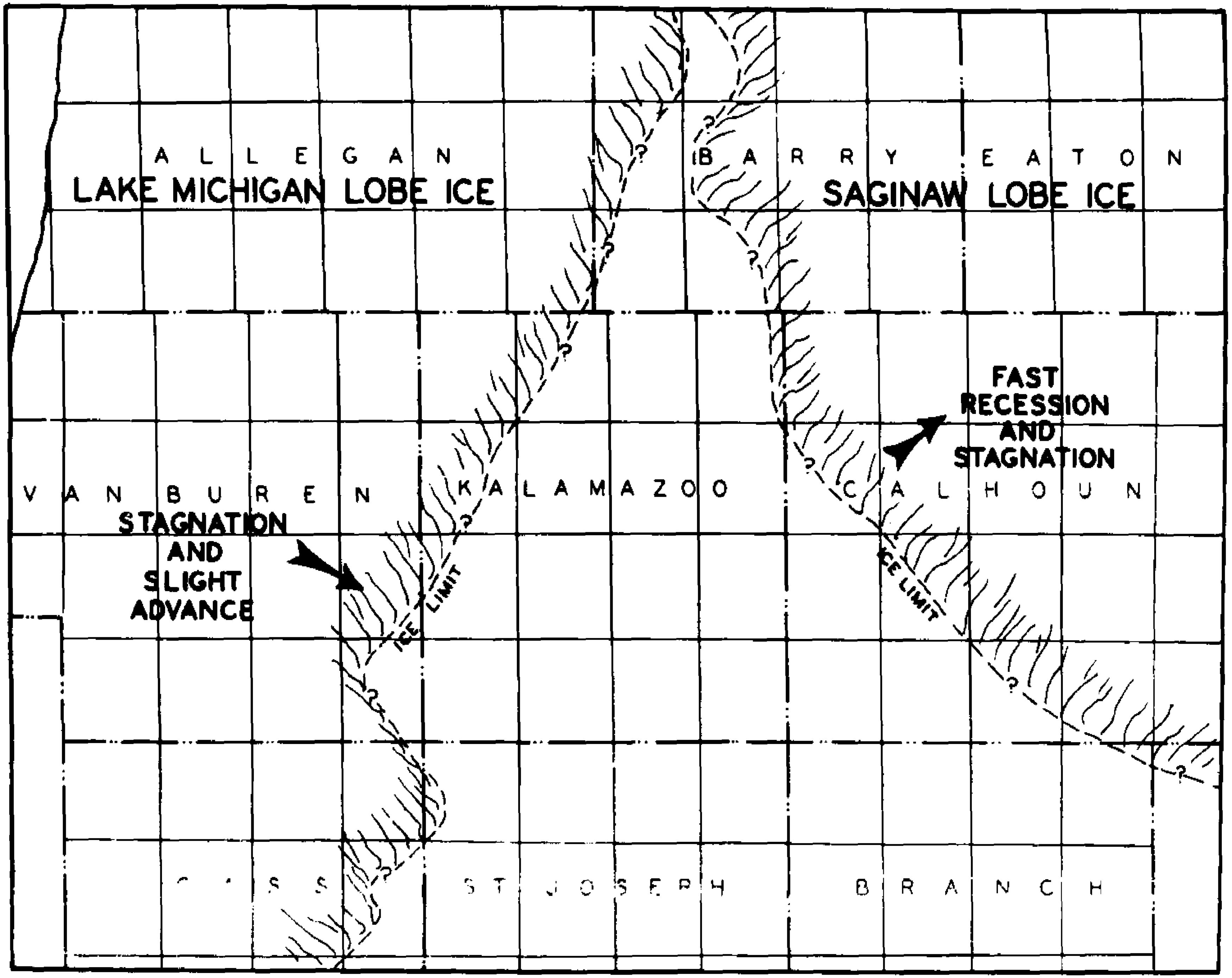


Figure 9. Third regime trend in the Lake Michigan-Saginaw interlobate glaciation.

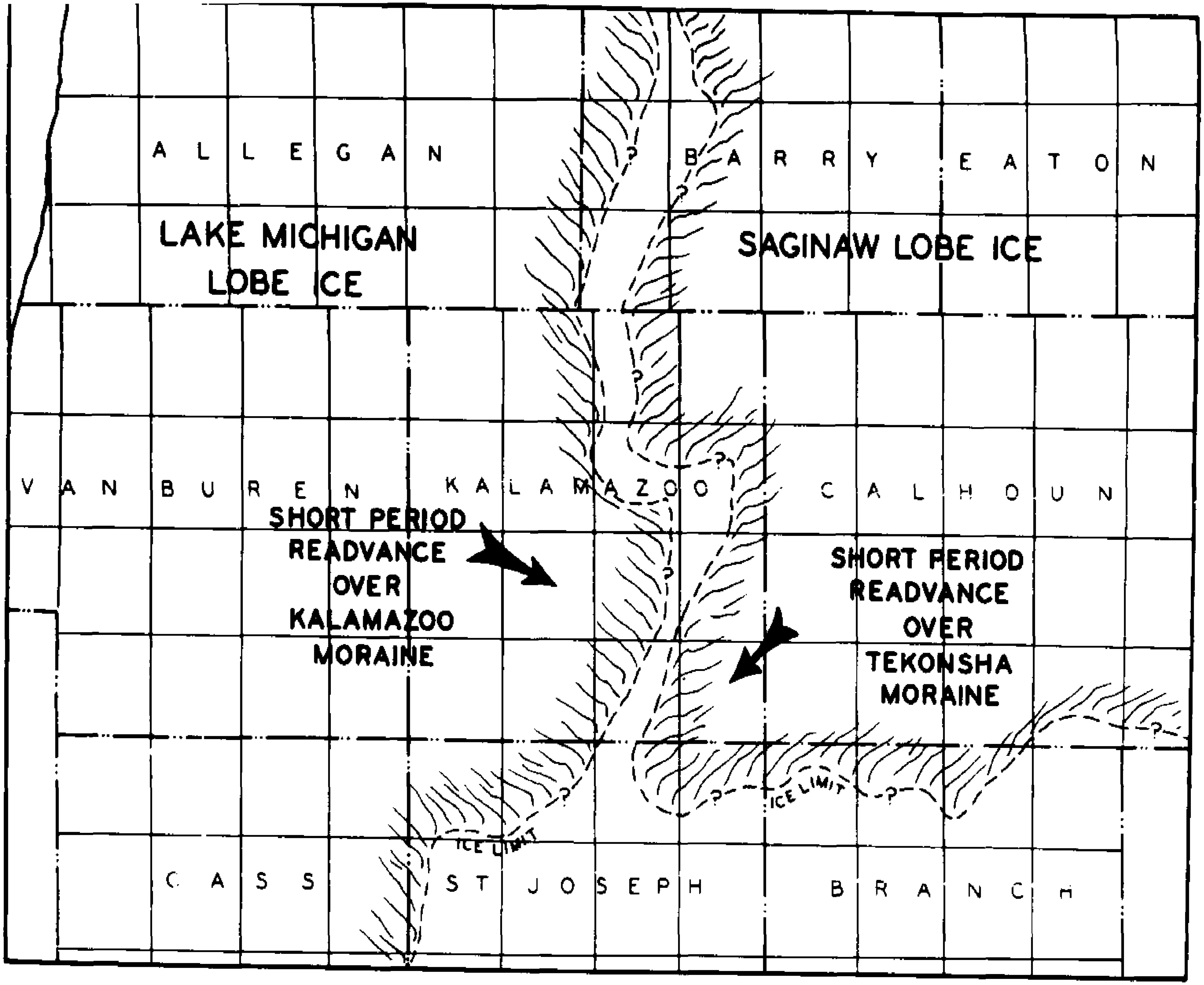


Figure 10. Fourth regime trend in the Lake Michigan-Saginaw interlobate glaciation.

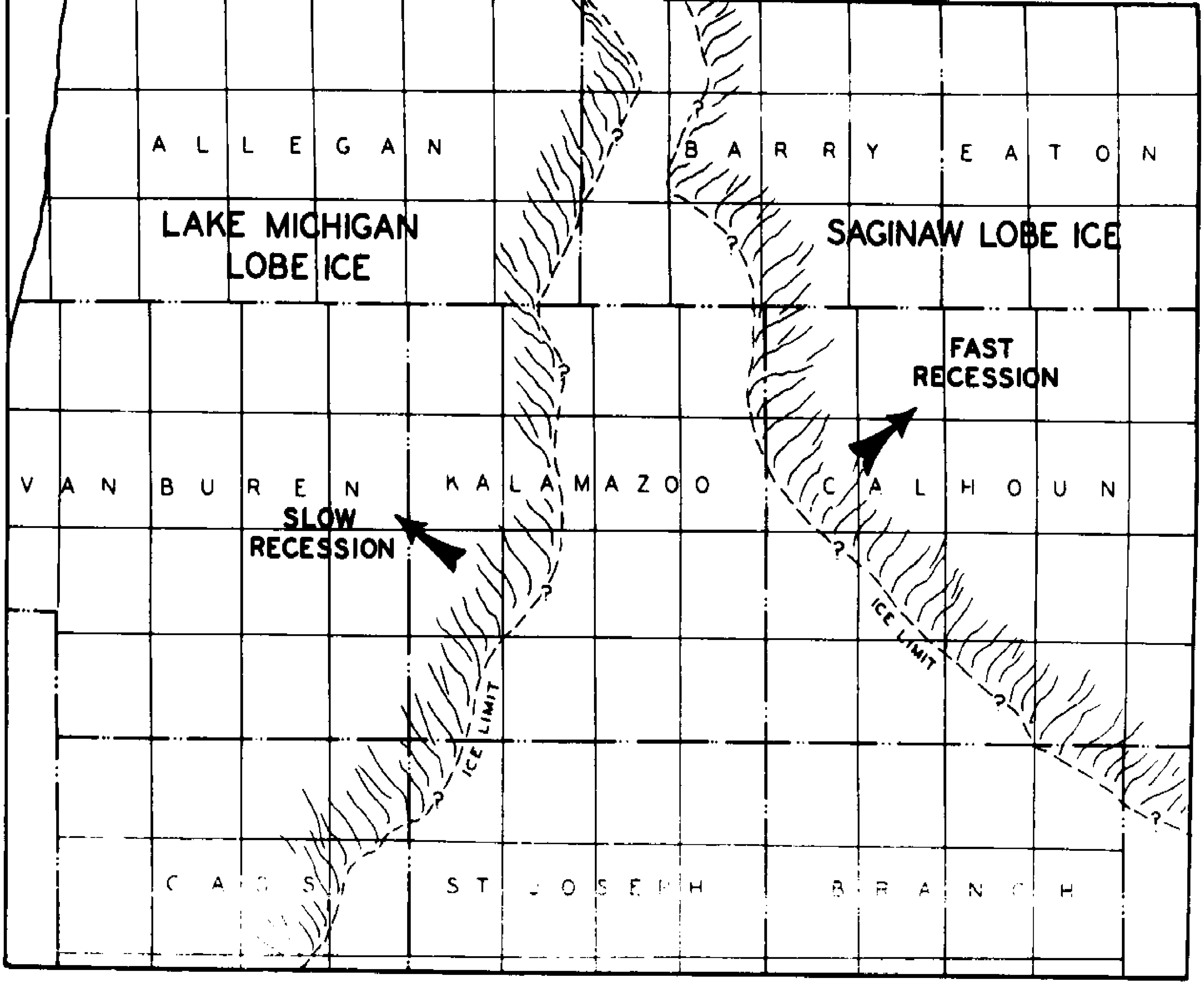


Figure 11. Fifth regime trend in the Lake Michigan-Saginaw interlobate glaciation.

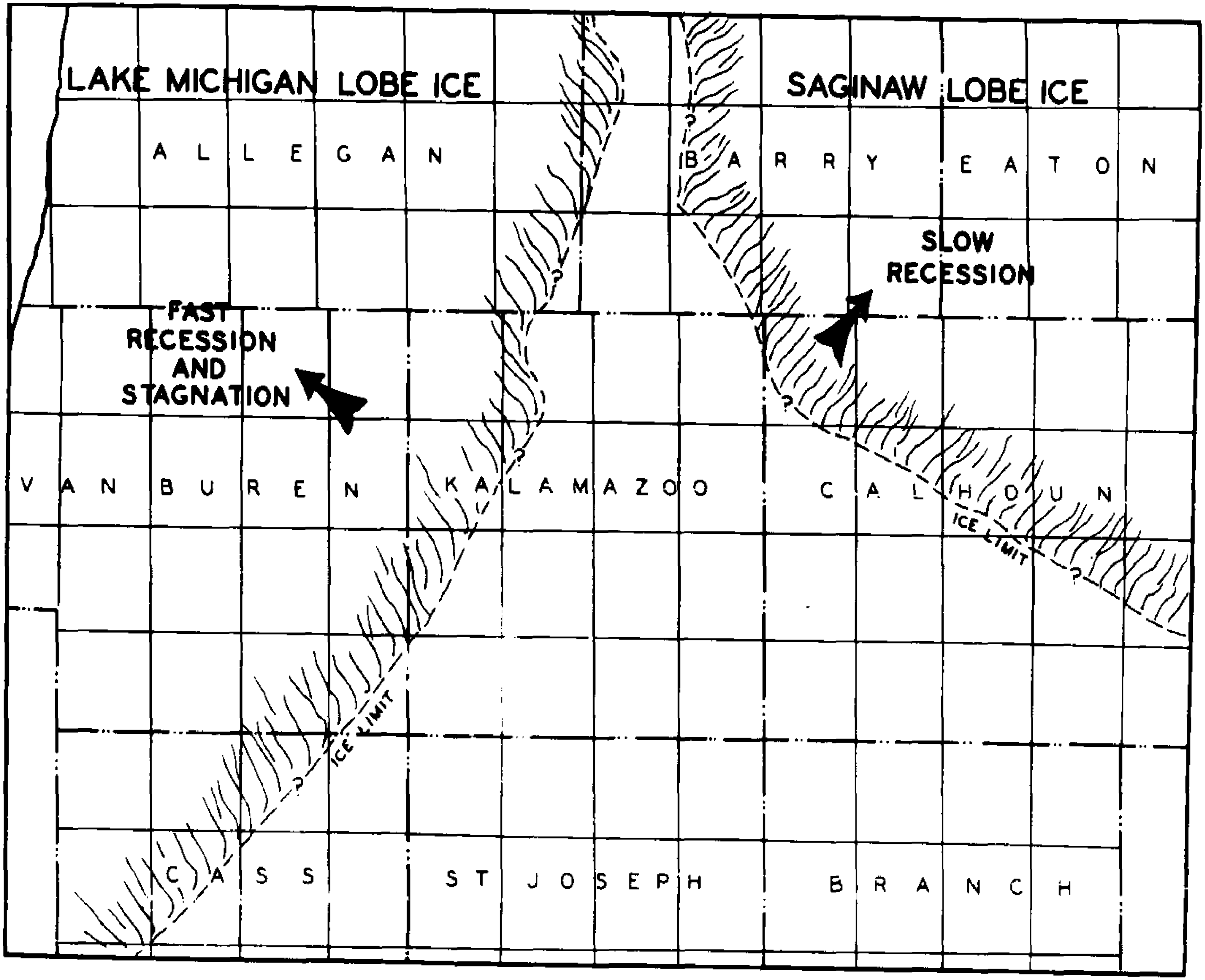


Figure 12. Sixth regime trend in the Lake Michigan-Saginaw interlobate glaciation.

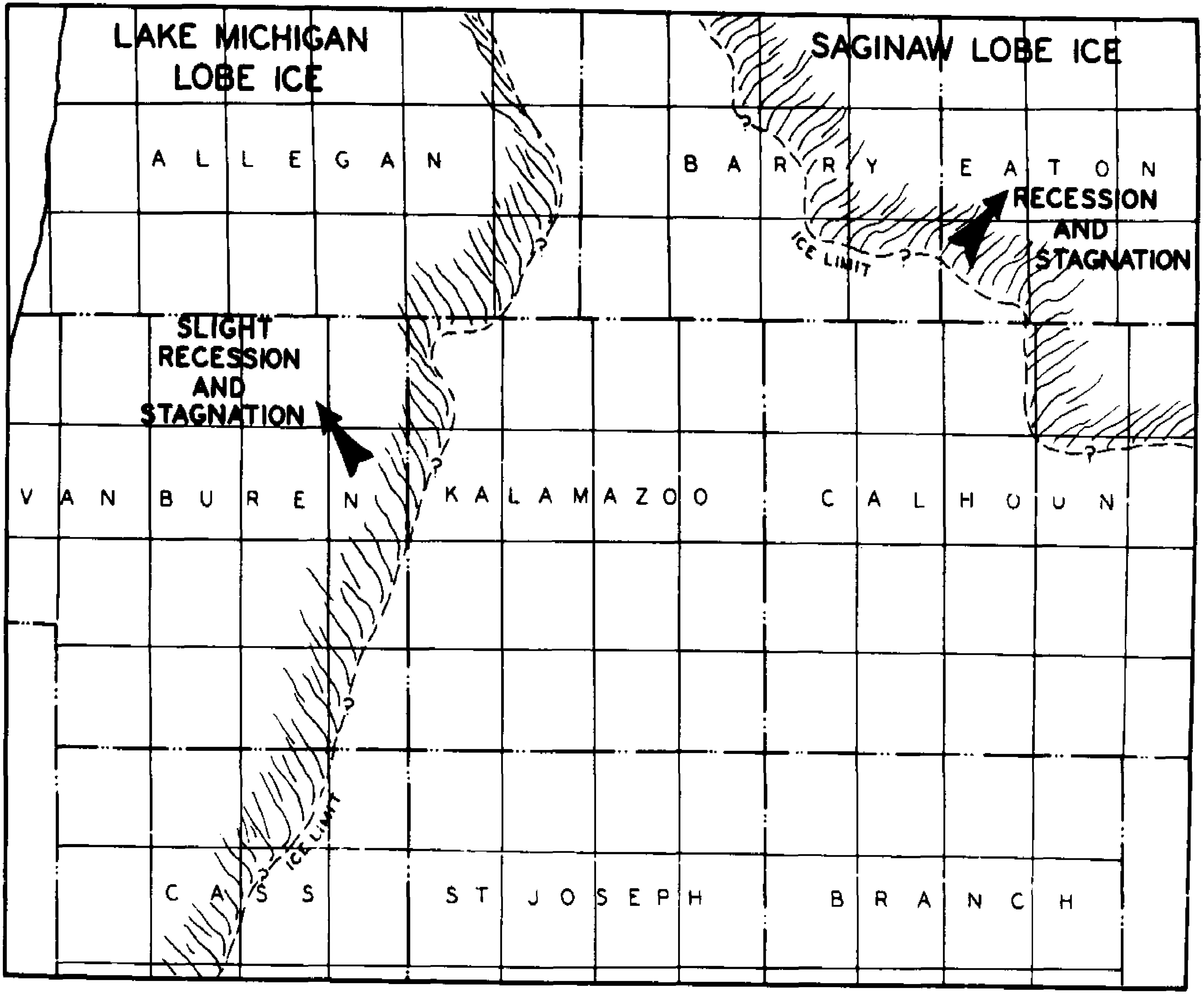


Figure 13. Seventh regime trend in the Lake Michigan-Saginaw interlobate glaciation.

Alamo Township of Kalamazoo County; and possibly the Kendall moraine (Fig. 5) in northeastern Van Buren County, which is believed (Leverett and Taylor, 1915) to be a possible westward extension of the Alamo moraine. This may also be the earlier phase of the Kalamazoo moraine in Van Buren, Kalamazoo, and Barry counties, which is considered to be the outermost bold moraine of the Lake Michigan lobe in this area. Field evidence indicates that at this time the previously stagnant and retreating Lake Michigan ice border advanced again into the western part of Kalamazoo County and overrode previously deposited Kendall and Alamo moraines of the earlier Saginaw lobe. The ice then stagnated near the present main axis of the northeasterly and southwesterly striking Kalamazoo moraine. Greater relief and boldness of this moraine indicates a vigorous ice push, followed by a rapid retreat from this moraine, and then continuing stagnation, as a still-stand phase, characterized by minor fluctuations, as shown by the existence of many lesser moraines.

Overriding of the Lake Michigan lobate front over the Alamo and Kendall moraines is suggested on the basis of two lines of evidences: Firstly, the petrographic analysis (Figs. 28-37) of samples taken from the Alamo and Kendall moraines area have lithologic composition quite similar to the rest of the known Saginaw lobe samples. Leverett (1915, p. 183) described the Kendall moraine, at least its northern half of which is very hummoky and bouldery, and he suggested the possible correlation between this moraine and the Alamo moraine in Kalamazoo County. Leverett also pointed out that in the northern half of the Kendall moraine there were many huge boulders, some up to 8 or 10 feet in diameter. Amongst these boulders he reported conglomerates of various kinds, including the red jasper conglomerate from Ontario which has been previously regarded as an indicater rock of the Saginaw lobe. He also reported a few pieces of gypsum, and numerous limestone fragments from Mississippian formations to the north. Such evidence shows strong correlation of these two morainic ridges with the Saginaw lobe moraine system. Secondly, the strike of the Alamo moraine and northern half of the Kendall moraine, north of the village of Kendall in Van Buren County (Plate I), is east-west. This strike is parallel to most of the moraines of the Saginaw lobe. Suggesting further that these two moraines were formed by ice earlier from the Saginaw lobe.

From the glaciological studies of Miller (1964, 1970) and others of the existing glaciers of today in Alaska and elsewhere in the world, we know that glaciers retreat and advance and thin and thicken due to climatological changes, and changes in other physical parameters controlling individual glaciers. Recent studies of Taku glacier and adjoining Norris Glacier (Lawrence, 1950; Eagan, 1971) of the Juneau icefield in Alaska show that Taku Glacier since the 1890's has been advancing abnormally fast, while the Norris Glacier since the 1910's has been slowly downwasting and retreating. The former advancing phase of the Norris Glacier ice once overrode but did not destroy earlier terminal moraines formed by the Taku Galcier in its previous advance and retreat 200 years ago (Miller, Egan, and Yates, 1964). This modern small scale example can be applied to large scale continental glacier lobes, where the terminal ice was probably of comparable thickness, at least sufficiently thin in its terminal zone to override moraines like the Alamo and Kendall without disturbing them.

After formation of the Sturgis moraine, the Saginaw lobe (Fig. 9) continued to retreat more rapidly, forming a series of till plains (Plate I) and outwash plains up to the Tekonsha moraines (Figs. 4, 5, and 6), where it then experienced a stillstand and allowed establishment of the Tekonsha moraine as a strong recessional feature. The Lake Michigan lobe was more or less at a standstill too, with smaller advances which built the western end of the Sturgis moraine (Plate I) in Cass County and the outer part of the Kalamazoo moraine north of Kalamazoo River in Kalamazoo and Barry counties. This part of the Kalamazoo moraine in the Hastings quadrangle in Barry

County is described by Folsom (1970) as an interlobate moraine.

The Saginaw lobe (Fig. 10) readvanced slightly for a short time as far as the outer limit of the drumlin field (Plate I) lying southeast of Kalamazoo County. This readvance is indicated by drumlins and thin ablation till (Fig. 16) on the top of the northwest-southeast trending Tekonsha moraine. At the same time the Lake Michigan ice readvanced over the Kalamazoo moraine up to the Saginaw ice border in the southeastern part of Kalamazoo County, a situation shown in Figure 10. This readvance of the Lake Michigan lobe appears to have pushed the surface material east of the Kalamazoo moraine, previously deposited by Saginaw ice. Pushed material was thus redeposited in the form of weak morainic ridges marking the outermost advance of the Lake Michigan lobe in Kalamazoo County.

North-south trending ridges (Plate I), which are also allied to the Tekonsha moraine system of the Lake Michigan lobe in eastern Kalamazoo County, are correlated by Leverett (1915) with the Takonsha moraine of the Saginaw lobe. There are a couple of other weak ridges, one in Comstock Township (Fig. 6) and another just northeast of the city of Kalamazoo. These two ridges were probably also formed as push moraines at the same time. The writer suggests that material was pushed eastward by this readvance. The evidence here is that the lithologic composition of samples taken to the east (Figs. 28-37) of the Kalamazoo moraine of the Lake Michigan lobe shows strong correlation with the samples of the Saginaw lobe towards the northeast. Yet the geomorphic character of glacial features shows stronger ties with those of the Lake Michigan lobe. In this sector, readvance of the Lake Michigan ice is also marked by sandy ablation till on the top of the Kalamazoo moraine.

On the basis of the above interpretation, an interlobate boundary line (Plate I) is drawn through these weak ridges formed by the maximum advance of the Lake Michigan ice in Kalamazoo County. This interlobate line passes farther north through the interlobate moraine described by Folsom (1970), in southwestern Barry County. Similarly, the interlobate line to the south of Kalamazoo County is considered to pass through weak moraines perpendicular to the Sturgis moraine of the Saginaw lobe in the western part of St. Joseph County. It is suspected that this line may pass through farther northwest part of St. Joseph County. A sample taken from the Sturgis moraine in St. Joseph County falls into the Saginaw lobe lithology class, and the sample taken from the Sturgis moraine in Cass County falls into the Lake Michigan lobe lithology class (Figs. 28-37).

Figure 11 indicates how the Saginaw lobe ice retreated rapidly, shifting its front back to the line of the Tekonsha moraine and forming drumlins on the top of till plains. In contrast, the Lake Michigan lobe retreated slowly to the Kalamazoo moraine position, and produced a few north-south trending weak ridges in consequence of its minor marginal fluctuations. These weak ridges are mapped (Fig. 6) as thin linear moraines in the southeast Prairie Ronde, northeast Portage, and northwest Cooper townships of Kalamazoo County.

After forming these small ridges, the Lake Michigan lobe ice retreated (Fig. 12) rather rapidly to the present Kalamazoo moraine position. Such an accelerated recession is explained by the presence of a thin till capping (Fig. 6) outwash deposits in Cooper and Prairie Ronde townships of Kalamazoo County. In contrast, at this time the Saginaw lobe experienced a slow retreat, forming series of parallel and quite subdued moraines northeast of the outermost main Tekonsha ridge. Some of these ridges of the Tekonsha morainic system show a plexal relationship, indicating again that small readvances characterized the retreat of Saginaw ice.

Figure 13 shows the last significant event or trend in the glaciological regime when ice from both lobes retreated to their respective positions of the present Kalamazoo morainic system. Here a major still-stand occurred for a long period but again with minor fluctuations resulting in the strikingly irregular scenes of superimposed small ridges on the massive structure of the main bold moraines in southern lower Michigan. The behavior of both lobes during the main retreatal phase that followed, i.e., through the rest of Wisconsinan time--have been generally described in the Leverett and Taylor monograph (1915).

The integration of all factors supporting this interpretation is given in the Conclusions, Part III, pages 170-71.

CHAPTER V

CHARACTER OF SURFACE GEOLOGY

The surface geology of Kalamazoo County is made up of unconsolidated materials, predominantly of glacial origin. The near-surface materials have been deposited directly by the Wisconsinan ice, or indirectly by melt-waters from the retreating glaciers, along with a very few aeolian deposits of post-Cary age. Surface features are classified, in four major categories: (1) glacial, (2) glacio-fluvial, (3) aeolian, and (4) others. The character of each major feature and associated clastics is described, with the idealized interrelationship and sequence of formation of these features illustrated diagrammatically in Figure 14.

Glacial Features

Glacial features in Kalamazoo County include terminal or end moraines, lateral moraines, ground moraines or till plains, and drumlins. These features are mostly comprised of tills containing local lenses of stratified sand and gravel.

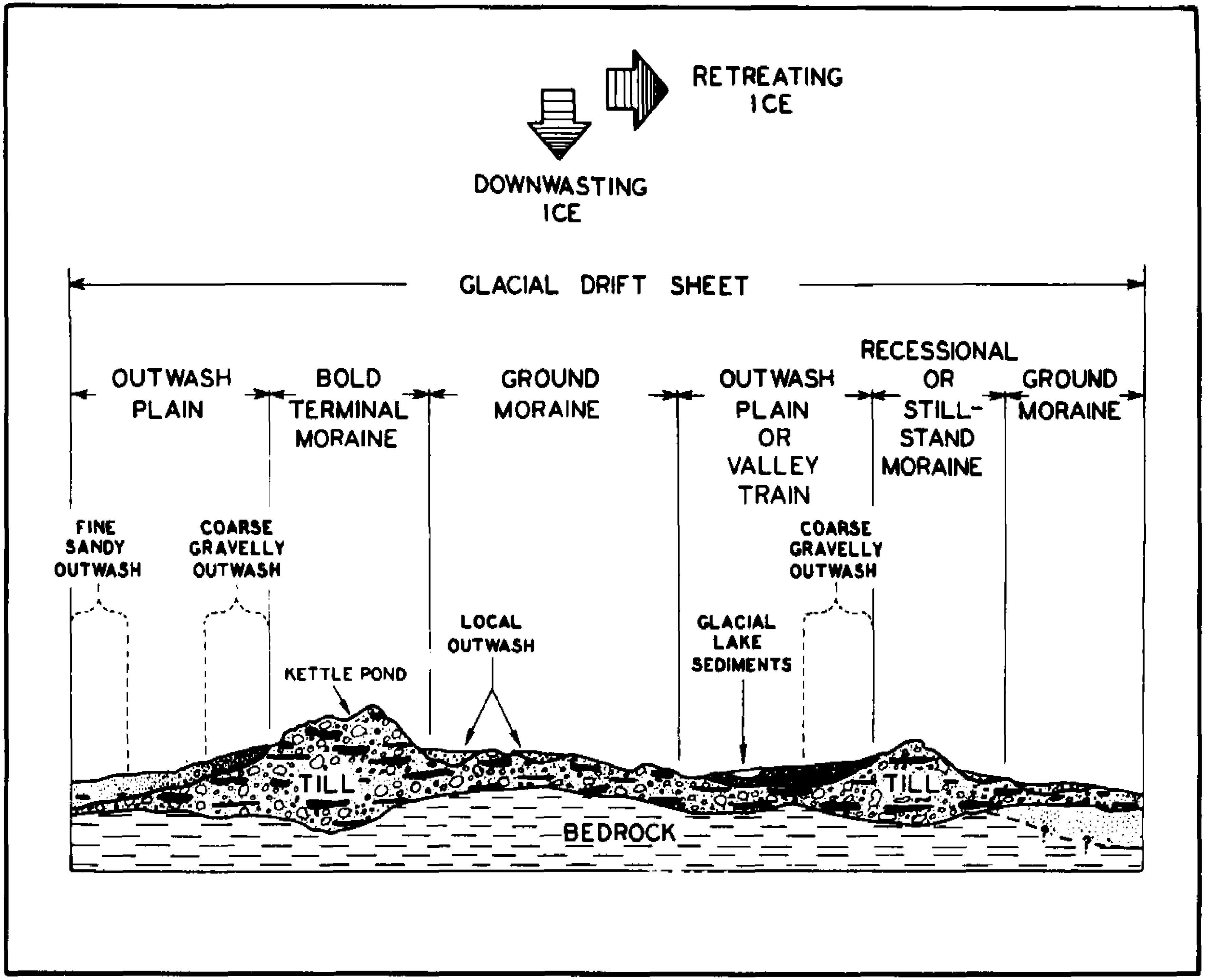


Figure 14. Hypothetical cross section showing interrelationship and sequence of formation of glacial, glacio-fluvial, and glacio-lacustrine depositional features by a retreating and downwasting ice front.

Terminal and Lateral Moraines

Moraines of Kalamazoo County are associated with the activities of the Lake Michigan lobe and Saginaw lobe of the Wisconsinan ice sheets. Evidences for assigning the following moraines to a particular lobe are also considered in the previous chapter and Chapter X.

The Kalamazoo Morainic System.--This moraine system of the Lake Michigan lobe occupies the northwestern part of Kalamazoo County (Figs. 5 and 6). It includes mostly all of Oshtemo Township and parts of Alamo, Cooper, Texas, and Prairie Ronde townships.

Leverett (1915, p. 174) described this system in southern Michigan as having two well-defined ridges (outer and inner ridges) separated by a narrow nearly continuous gravel plain. In Kalamazoo County, however, this system does not have this configuration. More often it appears with the outer and inner ridges merging to form one large, bold moraine (Fig. 6). Disconnected shallow patches of local outwash commonly occur along the moraine axis.

The highest elevation of the Kalamazoo moraine in this county is 1,040 feet in sections 9 and 10 of Oshtemo Township. The moraine's average elevation is around 950 feet, and the average width, including the patches of outwash, 4 to 5 miles. The maximum width along an east-west direction is about 7 miles, and is found in Alamo and Cooper townships.

The outer margin of the moraine shows slight relief above the onlapping outwash plain to the east which in some places extends outward from the moraine. Patchy outwash between the outer and inner margins of this moraine is found close to the average elevation of the moraine itself. The inner or western margin drops steeply to a narrow outwash plain or valley train associated with a glacial drainage channel.

The Kalamazoo moraine exhibits strong knob and kettle topography. Several knobs are developed 50 to 75 feet above the neighboring kettle holes, but only 25 to 50 feet above the bordering outwash apron (Fig. 6). Below this a number of kettle-like basins have depths of 25 feet or more. Few of the kettles are occupied by water, but where small lakes occur they are called kettle ponds (Fig. 14). Many kettle ponds have become dry and show deposits of stratified material near the bottom.

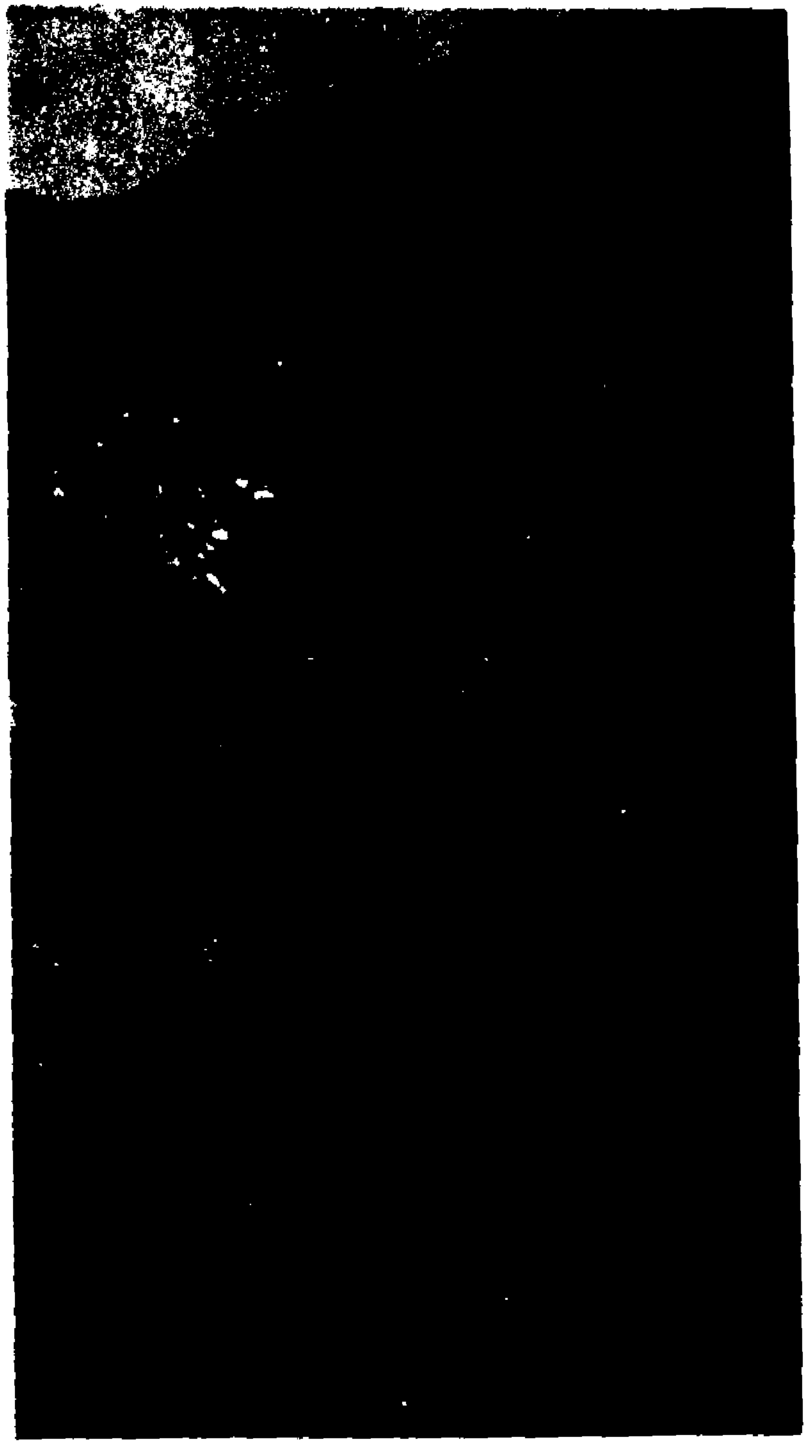
High Ridge in the northeast corner of Cooper Township and the northwest corner of Richland Township, is a north-eastward continuation of the Kalamazoo moraine beyond the Kalamazoo River valley. It is this sector which reaches in altitude of 1,040 feet above sea level, in Section 1 of Cooper and Section 6 of Richland townships. The bold topography and high relief resembles that of the interlobate moraine in southern Barry County (Folsom, 1971) which is, in fact, the northeastward continuation of this ridge in Kalamazoo County.

The Kalamazoo moraine is composed of assorted material of various grades of coarseness. Most of the drift is sandy and gravelly and in general thick beds of sand and gravel are found interbedded with clay till (Figs. 25 and 26) right down to bedrock. Layers of silt are also reported in some wells. The layers of sand and gravel are considered to be the result of deposition by large amount of meltwater associated with the final disappearance of large stagnant ice masses. More or less throughout the moraine, near-surface material is either loose-textured stony clay or sandy drift (Leverett, 1915), with entrained cobbles and boulders. Such cobbles and boulders, along with sandy or clayey material, are often seen in cultivated fields (Fig. 15). In general, near-surface sand seems to predominate over loose-textured clay. The inhomogeneous character of the unstratified sand and the loose texture of the clay, containing some gravel and cobbles, indicate that ablation till covers large surface areas in the Kalamazoo moraine. Below this sandy ablation till, thicknesses of which vary from place to place, brown discontinuous clay layers of varying thickness also are present (Figs. 25 and 26). At greater depth, in well logs, clay layers are described to be blue or gray in color, with some exceptions of brown or yellow clay.

The Kalamazoo moraine in the sector north of the Kalamazoo River, in the northeast corner of Cooper

Figure 15. Boulders and cobbles in a cultivated field on the Kalamazoo moraine, Alamo Township, Kalamazoo County.

Figure 16. Ablation till overlying stratified outwash, Tekonsha moraine, Charleston Township, Kalamazoo County.



Township, also has much sandy till at the surface with many large boulders similar to those found in both the Lake Michigan and Saginaw lobes. This relationship helps the interpretation of an interlobate moraine (Plate I).

The Tekonsha Moraine.--In Kalamazoo County this moraine was also formed by the interplay of glacial activities in the Lake Michigan and Saginaw lobes (Figs. 5 and 6, Plate I). The Tekonsha moraine of the Saginaw lobe, however, is stronger than that of the Lake Michigan lobe, and comes into Kalamazoo County from Quincy, Michigan in a northwesterly direction, passing through Calhoun County. The Tekonsha moraine of the Saginaw lobe also forms a reentrant angle with the Tekonsha of the Lake Michigan lobe, just west of the Kalamazoo-Calhoun County line and south of the Kalamazoo River valley in Charleston Township (Fig. 6). This part of the moraine trends northward from the reentrant area which forms a couple of isolated spurs in Ross Township north of the Kalamazoo valley. The reentrant area between the Tekonsha moraine segments of both lobes extends southward (Plate I) beyond the boundaries of Kalamazoo County and into neighboring counties.

The Tekonsha moraine, like the Kalamazoo, has a general width of 4 to 5 miles east of Kalamazoo County but is in places much narrower. The width reduces to 2 to 3 miles and becomes very narrow in Pavillion and

Brady townships toward the southwest (Fig. 6). The writer believes that this weaker and narrower northeast-southwest trending moraine was formed as a push moraine by the Lake Michigan ice. Leverett in his Michigan Geological Survey manuscript field maps, refers to this moraine as the eastern limit of Lake Michigan ice.

Topography of the Tekonsha moraine is characterized by small knobs and kettles and is subdued compared to the bold Kalamazoo moraine segments. The moraine also is dissected by valley-like gaps in Brady Township where glacial drainage (Leverett, 1915) seems to have been forced across it while it was in contact with stagnating and downwasting ice in Kalamazoo County. The maximum altitude reached by this moraine is about 1,000 feet above sea level, and this occurs at the moraine junction south of Fort Custer Military Reservation in Charleston Township (Fig. 6 and Plate I). The greater part of the moraine south of the Kalamazoo River, is a bit lower, reaching elevations between 925 and 975 feet. The morainal spurs north of the Kalamazoo River are slightly lower reaching an average of 900 feet elevation.

The relief towards the outer margin of the Tekonsha moraine is very gentle except for a few large knobs and groups of knobs having 100 feet or so of relief. The inner margin has slightly greater relief than the outer margin. Width, relief, and elevation decrease considerably towards the southwest, in Pavilion and Brady townships. North of Climax village this moraine is known locally as "Tobys Hill." There are very few lakes near the head of this reentrant district compared with the head of the reentrant area between the Kalamazoo moraines (Fig. 6). The Tekonsha spurs north of the Kalamazoo valley, however, have large depressions below the bordering gravel plains, and surficial stratified materials reveal much slumping, which suggests that stagnant ice conditions may have persisted here during the building of outwash from the Kalamazoo moraine.

The Tekonsha moraine in Kalamazoo County is composed of loose-textured sand and gravel and isolated areas of finer clayey material. Sand predominantes. Leverett (1915) believed that this excessive sand was derived from neighboring sandstone formations to the northeast, as well as from the removal of finer material during deposition. From a few well records (Figs. 25 and 26) it seems that there are some thick layers of clay till 50 to 80 feet below the surface, and near-surface sandy material is oxidized to yellow to brownish-red color. Diversity of structure even in small areas suggests too that ice borders of both lobes must have been very active in this interlobate area. The writer observed 6 to 8 feet of ablation till overlying stratified outwash sediments at sample site number 16 (Figs. 16 and 28 and Plate I). on the southern margin of the Michigan-Saginaw ice junction, in the southwestern part of Section 22, Charleston Township (see X on Plate I). This till connotes a significant readvance of the Saginaw lobe towards the southwest. It is of interest that similar type of till is not found on top of the outermost northeast-southwesterly trending Tekonsha moraine of the Lake Michigan lobe. Also, boulders and cobbles are numerous at the interlobate junction area south of the Kalamazoo River valley.

<u>Other Small Moraines in Kalamazoo County</u>.--There is a norrow east-west trending ridge south of Marrow Lake which connects the main Tekonsha Moraine of the Lake Michigan lobe in Sections 24 and 25 of Comstock Township (Fig. 6 and Plate I). Leverett, in his manuscript field maps (Michigan Geological Survey), named this as the Battle Creek Moraine of the Lake Michigan lobe and showed a connection with the western part of the morainal spur in Ross Township. On the basis of morphology and lithologic distribution of sediment, this writer disagrees with this interpretation, believing instead, that this narrow ridge marks the maximum advance of the Lake Michigan lobe and was formed at the same time as the northeast-southwest trending Tekonsha moraine (Figs. 5 and 6, and Plate I). Also, this narrow east-west trending moraine may have connected with the weak and disconnected almost north-south

trending moraine in northwest Comstock and southwest Richland townships (Fig. 6 and Plate I).

The east-west trending Tekonsha moraine in Comstock Township has very low relief and is mostly composed of loose-textured sandy material. According to this writer's interpretation of interlobate line (Plate I) in the last chapter, the nearly north-south trending moraine, in northwest Comstock and southwest Richland townships, also marks the latest maximum advance of the Lake Michigan lobe against the Saginaw lobe. According to Leverett's (Mich. Geol. Sur. manuscript maps) interpretation, he considered this as a pre-Kalamazoo moraine, but the writer suggests that this moraine was formed between Lake Michigan ice and Saginaw ice (Fig. 10), when the Lake Michigan lobe ice overrode the bold Kalamazoo moraine. The rationale here is that this moraine also has loose-textured sandy material mixed with clay in some areas, but at a depth of more than 50 to 60 feet thick clay till layers are present according to well log data. In other words, this moraine seems to show connection to the north with the bold interlobate moraine (Folsom, 1971) formed in the northeast part of Cooper and northwest part of Richland townships. In case the reader questions the validity of small linear moraines representing the outer limit of Lake Michigan ice, he is reminded that the regional trend of these moraines is aligned with the well-established Lake Michigan ice moraines to the west.

A narrow north-south trending morainal ridge about 3 to 4 miles long exists in Sections 17, 20, 29, 31, and 32 in Brady Township (Fig. 6). Its southern end is dissected by Portage Creek. This ridge, too, has very low relief and its width is about one-third mile. Surface material is again loose-textured and sandy looking similar to the above described two small moraines which are suggested as marking the limit of the Lake Michigan lobe in Kalamazoo County.

There are also two small, elongated, spur-like ridges present in this county (Fig. 6). One is a north-south trending ridge mostly in Sections 2 and 11 of Portage Township, southwest of the Kalamazoo Municipal Airport. Detailed characteristics of this spur are not known except in one gravel pit where sample 17 was collected. In this gravel pit materials vary from clay to boulder size. Some coarse gravel is crudely stratified and sand and clay near the surface are not laminated. Boulders and cobbles are scattered all over the pit. Thin clay till is present on top of the loose-textured sand and clay. A second northwest-southeast trending spur-like ridge is present 2 miles north of Cooper Center in Sections 4, 5, 8, and 9 of Cooper Township. Here, too, there is little information available about this narrow ridge due to lack of exposures and very few wells drilled in the area.

A small moraine (Plate I) in Sections 26, 34, and 35 of Prairie Ronde Township is believed (Leverett, 1915, p. 147) to be the northward extension of the massive Sturgis moraine lying to the south in Cass and St. Joseph counties. We should recall the Sturgis moraine which lies on the interlobate tract between the Lake Michigan and Saginaw lobes (Plate I). Topography of this moraine in Cass and St. Joseph counties is similar to that of the interlobate moraine in southwestern Barry County. The high knobs of this moraine are among the most prominent in southwestern Michigan. In this connection, Leverett (Leverett and Taylor, 1915, p. 149) suggested a possible overriding by the Lake Michigan lobe on deposits of the Saginaw lobe. Here the writer agrees with Leverett's interpretation, based on analysis of petrographic data. Further discussion of this point is given in Chapter X.

The northward extension of the Sturgis moraine in northern Flowerfield Township, St. Joseph County and Prairie Ronde Township of Kalamazoo County, was mainly formed by the retreating Lake Michigan lobe ice. Knob and kettle topography is conspicuous. The altitude reached by this moraine in Prairie Ronde Township is between 850 to 900 feet. The average width of its north-south trending ridge is 2 miles, narrowing to half a mile in Sections 26 and 36 of Prairie Ronde Township.

Here the surface material is not as sandy as that of the Kalamazoo moraine, but it differs by the presence of numerous boulders and cobbles and loose-textured clayey till near the surface. This writer has drilled a few drill holes up to the depth of 72 feet to the west of this moraine, which revealed the presence of tight clay till at depths between 40 and 60 feet. More detailed information of the deeper part of this moraine is not available because of the lack of deeper wells in the area.

Till Plains

There are three gently undulating till plains which are important in the glacial history of Kalamazoo County and vicinity (Fig. 6 and Plate I).

The major till plain of Climax, Wakeshma, Brady, and Pavillion townships in southeastern Kalamazoo County (Fig. 6) was formed during the main north-eastward retreat of Saginaw ice, accompanied by minor readvances of the Saginaw ice, accompanied by minor readvances of the Saginaw lobe. This till is traversed by a group of drumlins, and later has been dissected by meltwater channels flowing towards the southwest during retreat of the Saginaw lobe ice. This till plain was formed at the same time and in the same way that other till plains formed in neighboring Calhoun, Branch, and northeastern St. Joseph counties. In southeastern Kalamazoo County and immediate vicinity this till plain is composed of clayey till and has a gently undulating surface with numerous 10 to 40 feet high knolls. Some of these have drumlin shape. Boulders and cobbles are plentiful in the area as one may see along the sides of the roads and in fields. It is believed (Martin, 1957) that some of the sandy and gravelly outwash from the Tekonsha moraine in reentrant area covered the ground moraine or this till plain by forming an outwash capping over it (see Fig. 14 as an example). There is very little information regarding the detailed subsurface structure of this till plain.

Till plain in Cooper Township (Fig. 6) has also characteristic undulating topography resulting from the westward retreat of Lake Michigan ice. This till plain is composed of about 2 to 8 feet of boulder and cobbly clay till overlying earlier formed valley train deposits, just the opposite of the above described case in southeastern Kalamazoo County. This till plain, however, is discontinuous at some places where the underlying outwash is exposed at the surface. Good exposures can be seen in the American Aggregate Company's gravel pit northeast of Cooper Center. Such a till capping over valley train deposits reveals readvance of the Lake Michigan lobe overriding the earlier Kalamazoo moraine and outwash. A similar but smaller till plain overlying an outwash plain is present in Prairie Ronde Township (Fig. 6), west of the Sturgis moraine. This one indicates a seemingly rapid retreat of Lake Michigan ice up to the Lake Michigan Kalamazoo moraine, in that stagnant ice would produce more irregular terrain.

Drumlins

Most of the drumlins in this area are formed over till plains, except for a few surrounded by glacial drainage, in southeastern Kalamazoo County. The "ideal" streamlined drumlin usually looks like an inverted half-ellipsoidal bowl or spoon, but drumlins in Kalamazoo County vary much from this ideal shape. Some are long narrow elliptical hills; some have sharply pointed ends pointing in both upstream and downstream directions, and some are lacking systematic form. Their long axes, however, generally parallel the direction of flow of the Saginaw lobe ice. The presence of drumlins in this county (Plate I) connotes short readvance of the Saginaw lobe, also in neighboring Calhoun, Branch, and St. Joseph counties.

Due to the lack of sufficient exposures and subsurface information, the internal structure or composition of these drumlins is not known. From the study of surficial deposits and soil types and a few well logs, it seems that they are composed of clay till. These unusually streamlined features are presumed to be the result of very actively flowing ice of the Saginaw lobe just before formation of the massive Kalamazoo moraine where complex and rugged morphology was subsequently modified by stagnating and dead ice conditions.

Glacio-fluvial Features

Glacio-fluvial features in the study area consist of a group of stratified sediments and a group of ice-contact stratified sediments. In Kalamazoo County, most of the glacio-fluvial features are proglacial, indicating outwash plains, lacustrine plains, drainage ways, and clay and silt capping on fluvial plains. Major ice-contact features like kames and eskers have not been found in Kalamazoo County. The question of their presence is discussed in a later part of this chapter.

Outwash Plains

Outwash plains of Kalamazoo County and vicinity were built during the shrinkage of the Saginaw and Lake Michigan lobes respectively. Whatever outwash was built by pre-Cary ice was overridden and destroyed or buried before the two lobes reached their maxima in Kalamazoo County.

Kalamazoo County has two-thirds of its area covered by outwash plains developed (Plate I) by the melt-waters from both ice lobes. The vigorous line of fluvial discharge in the reentrant district produced an outwash plain which descends southward continuously from the reentrant angle between the two lobes to across the Kalamazoo River valley up to St. Joseph River valley. In places this outwash plain is more in the form of a tributary valley train situation. As a unit, however, it constitutes most of the outwash in Kalamazoo County. The width of the outwash (Fig. 6) is about 12 to 15 miles, and the elevation lies between 1,000 feet near the head of the reentrant and 950 feet within a few miles to the south. The elevation is nearly 950 feet along much of the outer margin of the Kalamazoo moraine in the western part of Kalamazoo County, and remains above 900 feet in the southwestern part of the county. The surface elevation drops 60 to 80 feet near the center of Kalamazoo County where meltwaters from the west and northeast joined together and flowed southward towards the Kankakee Torrent (Fig. 4).

Outwash to the north of the Kalamazoo River in the northeastern part of Kalamazoo County and all the way up to the head of the reentrant area is coarse with numerous pits. Some of these pits are very large and indicate that huge detached masses of ice remained when the Saginaw ice retreated back to form the Kalamazoo morainic system. Time was insufficient to melt these detached masses before they become surrounded by outwash, and also the climate might have been cooled a little to preserve these masses, while the filling of outwash around them from the downwasting Kalamazoo moraine system was completed. Eventually, of course, the detached ice masses melted away, leaving large pits, as inverted topographic forms. Taking into consideration the general slope, the writer interprets the lithologic composition as is similar to that found elsewhere derived from the Saginaw lobe. Thus the outwash north of the Kalamazoo River is considered as carrying meltwaters of the Saginaw lobe. Considering similar factors, the outwash to the south of the Kalamazoo River and to the west of the Tekonsha moraine of the Lake Michigan lobe was formed by earlier retreating Saginaw ice and later overridden by the Lake Michigan ice. Thus the outwash east of the Kalamazoo moraine (the Lake Michigan lobe segment) up to the line of southward flowing drainage (Fig. 6) was formed by meltwaters from the Lake Michigan lobe.

The outwash in the reentrant angle between the Tekonsha moraines of both lobes slopes from northeast to southwest. The elevation is 990 feet at the northeast edge and drops to 912 feet at Scotts station in the southeastern part of the county. It is very coarse in the northeast, but becomes sandy toward the southwest. South of Climax this outwash seems to be spread over the northern part of a till plain which was built earlier.

A long narrow body of outwash (Fig. 6) covered by a thin till plain in Cooper Township east of the Kalamazoo moraine, is a classic valley-train deposit. This valley-train form of outwash indicates that active deposition must have taken place by braided meltwater streams in a narrow valley, with water derived from the ice of both lobes. Thus it seems that the Kalamazoo River valley was blocked by advancing Lake Michigan ice. Presence of current beddings (Fig. 17), slumped outwash, channel fillings, varying dip directions indicating rapid fluctuations of streams, terracing, locally deposited lake clay interbedded with sand and gravel (Fig. 18) and so forth reveals the complexities of this depositional history. About 60 per cent of the material is sandy and quite a few cobbles are seen embedded in coarse gravel beds (Fig. 17).

There is other outwash covering small areas in the western part of the county. A small outwash plain formed south of the Alamo moraine slopes south indicating meltwater direction from north. Small areas of patchy outwash along the axis of the Kalamazoo moraine also represent shallow local deposits, underlain by till and probably filling large kettle holes in this major moraine system (Fig. 14).

In general along the border next to the moraines the outwash material is much coarser than it is at a distance (Fig. 14). Cobbles and coarse gravels are common for about half a mile from the moraine, but average grain size diminishes downstream away from moraine, whereas roundness of particles increases, as does the sorting in a classic fashion.

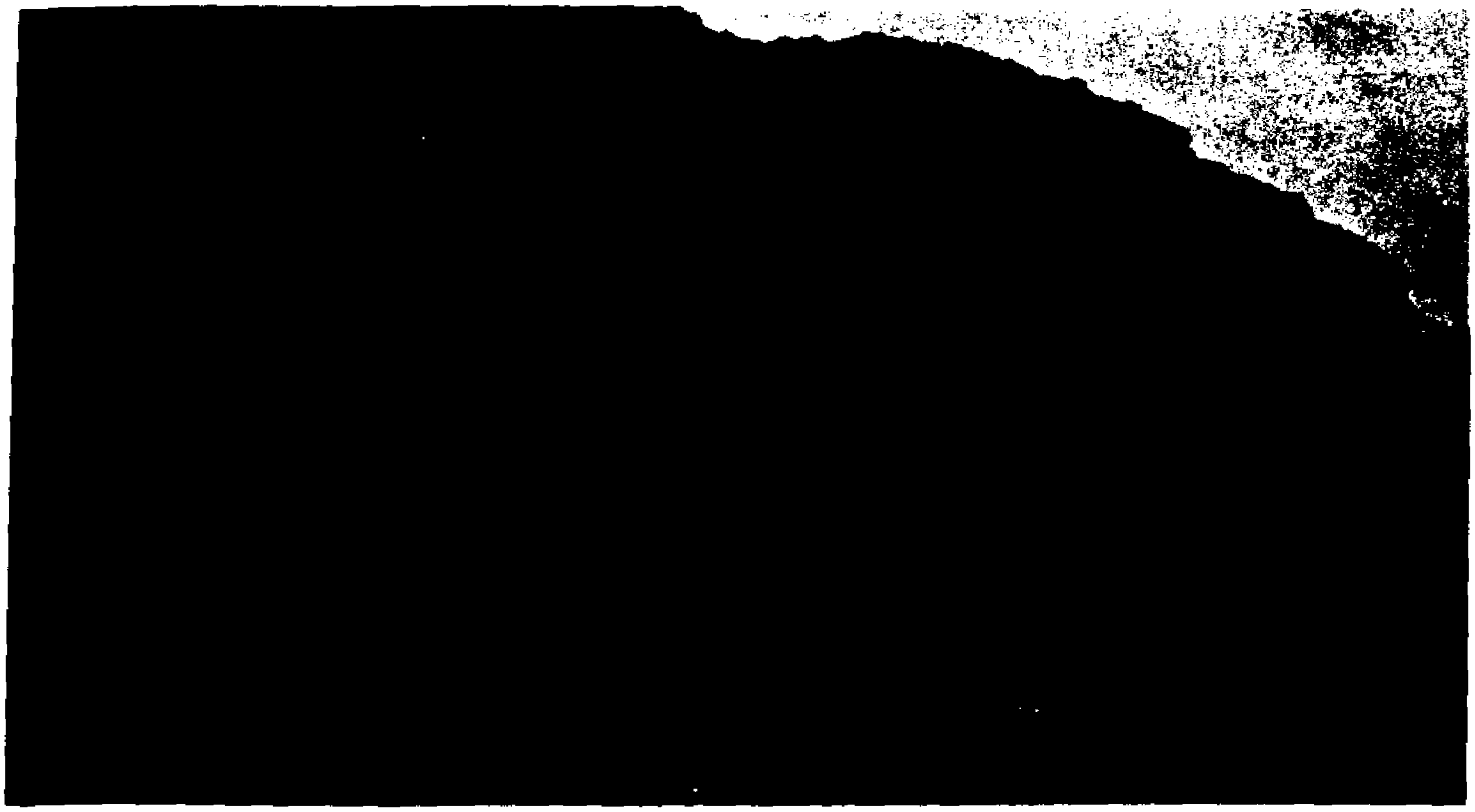


Figure 17. Current bedding in a valley train deposit, American Aggregate Co. pit, Cooper Township, Kalamazoo County.

Figure 18. Large pocket of locally deposited lake clay, American Aggregate Co. pit, Cooper Township, Kalamazoo County.

Lacustrine Plains and Drainage Ways

Retreating Lake Michigan lobe ice made a halt, at the west end of the Alamo moraine, forming proglacial Lake Dowagiac to the north and proglacial Lake Alamo to the south of the Alamo moraine (Fig. 6). When the ice retreated farther west into Van Buren County, Lake Alamo was connected to Lake Dowagiac which later drained through a southwestward outlet west of the Kalamazoo moraine system. Then Lake Michigan ice retreated after forming narrow moraine of the Kalamazoo moraine system in northwestern Oshtemo and southeastern Alamo townships.

The Alamo lacustrine plain is made up of sandy reworked outwash with very few pebbles, whereas the Dowagiac lacustrine plain consists of clayey, silty, and sandy material with boulders and cobbles in some areas. These plains are 2 to 3 miles wide with quite a flat surface and they are parallel to the Alamo moraine.

The main glacial drainage in central Kalamazoo County was southward, originating at the reentrant between the Kalamazoo moraine systems of the Lake Michigan and Saginaw lobes in southern Barry County. The drainage flowed directly across the present course of the Kalamazoo River east of Kalamazoo. When the northward trending Kalamazoo River valley was blocked by the Lake Michigan ice the Kalamazoo River flowed southward (Fig. 6) via the Austin Lake area. Then most of the meltwaters from the reentrant drained through this outlet and joined the main trunk line drainage southward to eventually join the Kankakee Torrent (Fig. 4). Earlier meltwaters from the reentrant of Tekonsha moraines drained through two south-westwardly flowing drainage channels in the southeastern part of Kalamazoo County. One channel divides the till plain in half, and another channel in Brady Township lies west of the till plain between Glacier and the Tekonsha moraine. This one cuts the terrace and cliffs along the western margin of the Tekonsha moraine. Both of these drainage channels flowed southwestward through main trunk drainage in St. Joseph County.

After the ice had withdrawn from the Kalamazoo River valley north of Kalamazoo, meltwaters from the re-entrant between the two lobes in northeastern Allegan County drained southward along the Run River valley to the Kalamazoo River valley and finally southward through the low channel west of the Kalamazoo moraine system in the vicinity of Paw Paw (Plate I).

Clay and Silt Capping on Fluvial Plains

As the meltwaters from retreating glaciers drained southward through these flat lowlands, fluvial plains of fine stratified outwash sediments were built in some areas (Fig. 6) especially south of the Kalamazoo River. Above these sandy fluvial plains can be found about 1 to 4 feet of lake clay and silt layers. It is probable that this clay and silt capping on fluvial plains was due to shallow local ponding of waters. Major sites of this type in Kalamazoo County are found in Schoolcraft and Prairie Ronde townships, along with two small areas north of Long Lake and south of Marrow Lake. Development of prairie soil made these areas fertile.

Aeolian Features

Wind-blown sediments are also present over some of the glacial sediments in Kalamazoo County. The aeolian features are few in number, however, and cover too small an area to draw any inferences as to climatic conditions or their direct relation to glacial activity in this area.

Sand Dunes and Loess Sediments

Inactive sand dunes or wind-blown sand deposits in Kalamazoo County were probably originally built by reworked glacial and glacio-fluvial drift. They have been recognized in Alamo, Texas, Portage, and Pavillion townships (Fig. 6). Sand dunes are difficult to recognize in the field, because of the sandy nature of the surface drift throughout the county. Also, some of them have become covered with vegetation. Some sand dunes plotted in Portage Township by Leverett on his manuscript field maps, have been covered by recent construction. Where found, they are very thin wind-blown deposits and vary much in shape. Longitudinal dune patterns on both sides of

Austin Lake and U-shaped dune patterns west of Pickerel Lake indicate that some dunes were formed by eastward blowing winds in a climate appearing rather dry, at least locally.

Loess deposits in Kalamazoo County are not very well recognized, but it is just a guess that silt associated with clay capping over an outwash (Fig. 6) may be wind-blown in nature.

Other Features

Besides the features described above, there are other lesser features deserving mention, as they are useful in locating sand and gravel deposits.

Undefined Transitional Zones

In the field it is often difficult to recognize an exact line separating morainal deposits from outwash deposits, due to lack of exposures and difficulty of access to the area. The dashed lines on the map (Fig. 6) represent such undefined transitional boundaries or zones between two recognized and well-mapped features. Such zones are usually about one-fourth to one-half mile wide in which materials show gradation from coarse to fine or vice-versa. For example, as noted in Figure 14, the outwash in this zone is thin and coarse and usually underlain by till at shallow depth. This transitional zone is ideal for prospecting for coarse aggregates. As one goes down slope, the outwash generally becomes finer.

<u>The Question of Kames</u>

Kames are usually known to be ice-contact features formed either by accumulation of water-worked detritus on the surface or inside stagnant ice, or else in the form of delta or outwash cones built in front of the ice by vigorous meltwater stream action. Usually a kame is a jumble of conical knolls and hollows and is formed of stratified gravel, sand, and silt which may contain local pockets of till. The possibility of kames is usually higher in interlobate areas, but due to practical difficulties in proper identification in Kalamazoo County, they were not shown on the map (Fig. 6). If kames are present at all in this county, they would be mixed with the knob and kettle topography in the complex moraines.

Folsom (1970, p. 110) reported kamic-type landscapes which cover about seven square miles of area in the central part of Hastings quadrangle, Barry County. Excepting this area, there are no other kames reported or observed in the reentrant districts. It is purely a guess of this writer, that there were very large and numerous kames built in the Saginaw-Huron-Erie interlobate area in southeastern Michigan due to smaller reentrant angles than that between the Lake Michigan and the Saginaw lobes. In addition to the reentrant angle factor, other factors like longer periods of stagnation of ice, thickness of ice, and intensity of meltwater activities may be responsible for building large kames. The subject needs further study beyond present purposes of this investigation.

Types and Associated Clastics

The most common clastic sediments of glacial origin in Kalamazoo County can be divided into three major groups: (1) boulders and cobbles, (2) gravel and sand, and (3) silt and clay.

Boulders and Cobbles

Free boulders and large cobbles in Kalamazoo County are mostly associated with terminal and lateral moraines and till plains, where they can be seen in the fields or along the road sides. Boulders and cobbles are found in moderate number on the surface of the Kalamazoo, Tekonsha, and other small subterminal moraine zones of the main Lake Michigan lateral moraine system. Also, they are found in substantial number on the till plain of the southeastern part of the county. Most of the boulders and cobbles are no longer evident in densely populated areas, having been used in foundations and building purposes. Originally most of these were of crystalline rocks of different sizes and shapes, and some show exfoliation on the surface. These boulders and cobbles do not show any particular system of patterns in Kalamazoo County, except that they are most prevalent on interlobate moraines in northeastern Cooper Township and southwestern Barry County.

The majority of boulders and cobbles associated with Saginaw ice are granite, granite gneiss, and pink and white quartzites, but many are of other rock types. Among these are index erratics such as the red jasper conglomerate derived from Huronian ledges north of Bruce Mines, Ontario, and a Precambrian tillite (quite certainly Gowganda from Ontario) containing pink granite pebbles. The writer observed large-sized cobbles and boulders of jasper conglomerate and the Pre-Cambrian tillite in four localities in Kalamazoo County. Specifically, these are: (1) in fields associated with the till plain in Wakeshma Township; (2) in a gravel pit associated with the morainal spur in Ross Township, where sample 44 was taken; (3) associated with valley train deposits in a gravel pit in Cooper Township where sample 2 was taken; and (4) in a gravel pit associated with the Kalamazoo moraine of the Lake Michigan lobe in Prairie Ronde Township, where sample 18 was taken.

Boulders and cobbles associated with Lake Michigan ice are granite, granite gneiss, some purple quartzites, and many dark crystalline rocks. But, the Lake Michigan lobe material does not contain any peculiar or exotic rock type such as the Gowganda, which can be used as an index rock for this lobe. The foregoing information was taken into consideration in interpreting the glacial history of the area.

Gravel and Sand

In Kalamazoo County and vicinity, gravel and sand are easily accessible in many parts of the area. Gravel is less widely distributed than sand, which makes up about 60 per cent of the surface material. Most of the gravel and sand deposits of the county are associated with outwash plains and small outwash deposits; and they are better sorted and stratified than in other areas. Some of the outwash is rather poorly sorted and difficult to distinguish from adjacent till. As shown in Figure 14, generally coarse gravelly material is present showing crude stratification associated with the transitional zone between moraines and outwash. In general, the grain size decreases and the quality of stratification improves with increasing distance downstream from the source. At several places gravel and sand deposits are interbedded with numerous lenses of fine sand, salt, and clay.

Gravel and sand deposits associated with other glacial, glacio-fluvial, glacio-lacustrine, and aeolian features are described under each heading in this chapter and so need not be repeated again.

Silt and Clay

Silt and clay deposits associated with tills of this county are, in most places, too full of stony and sandy material, whereas, lake bottom deposits are predominantly fine sand, silt, and clays. The most recent drainage channel deposits, however, are locally interbedded with lake-deposited silt and clay and are mantled by silt deposits of the modern rivers in this county. Clay and silt capping on the fluvial plains (Fig. 6) south of the Kalamazoo River is described previously in this chapter. The silt deposits mixed in with clay in this area may have partially been laid down by wind in locally ponded waters or it could have been brought by southward flowing meltwaters. In general, silt and clay deposits near the surface have been observed to overlie the glacio-fluvial sediments which cover such large areas in Kalamazoo County.

CHAPTER VI

BEDROCK GEOLOGY

Consolidated sediments beneath the unconsolidated glacial sediments of Kalamazoo County are all of Paleozoic age. Owing to the total absence of rock outcrops and the limited number of deep wells in the county knowledge of the subsurface geology in this region is restricted in scope. A few widely scattered oil and gas wells penetrate the bedrock formations, and some water wells reach the bedrock surface; but many of the well logs lack adequate descriptions of the rock penetrated. Hence, the following discussion pertaining to the lithology, extent, configuration, and structure of bedrock is based on rather limited data obtained from wells within the county and from available outcrops examined. In spite of this inadequacy, some knowledge of the bedrock formations, however, is essential to the interpretation of the source and presence of local lithologies in the surficial deposits of glacial origin.

The Lithologic Sequence

The bedrock geology map of southwestern Michigan (Fig. 19) and available well logs reaching bedrock in Kalamazoo County reveal that the glacial drift is underlain primarily by Colwater shales and Lower Marshall sandstones of lower Mississippian age. Below these formations, as indicated by deep borings, the stratigraphy is represented by older Paleozoic sediments of Devonian and Silurian age. These older strata in turn may be underlain by still older Paleozoics resting upon crystalline rocks of Precambrian age. The Coldwater shale forms about 95 per cent of the bedrock surface in Kalamazoo County. The remaining 5 per cent is formed by the Lower Marshall sandstone. Both of these formations in Kalamazoo County are briefly described as follows, and their stratigraphic sections are pictured in Figure 20.

Coldwater Shale

The Coldwater shale is the main bedrock lithology in Kalamazoo County, running beneath the drift as a broad belt about 25 miles wide trending northwest-southeast across the county. This shale further extends toward the northwest, southwest, and southeast well into the neighboring counties. Cohee (1965) suggested that this shale was deposited during early Mississippian time, and its source was supposedly from the western side of the

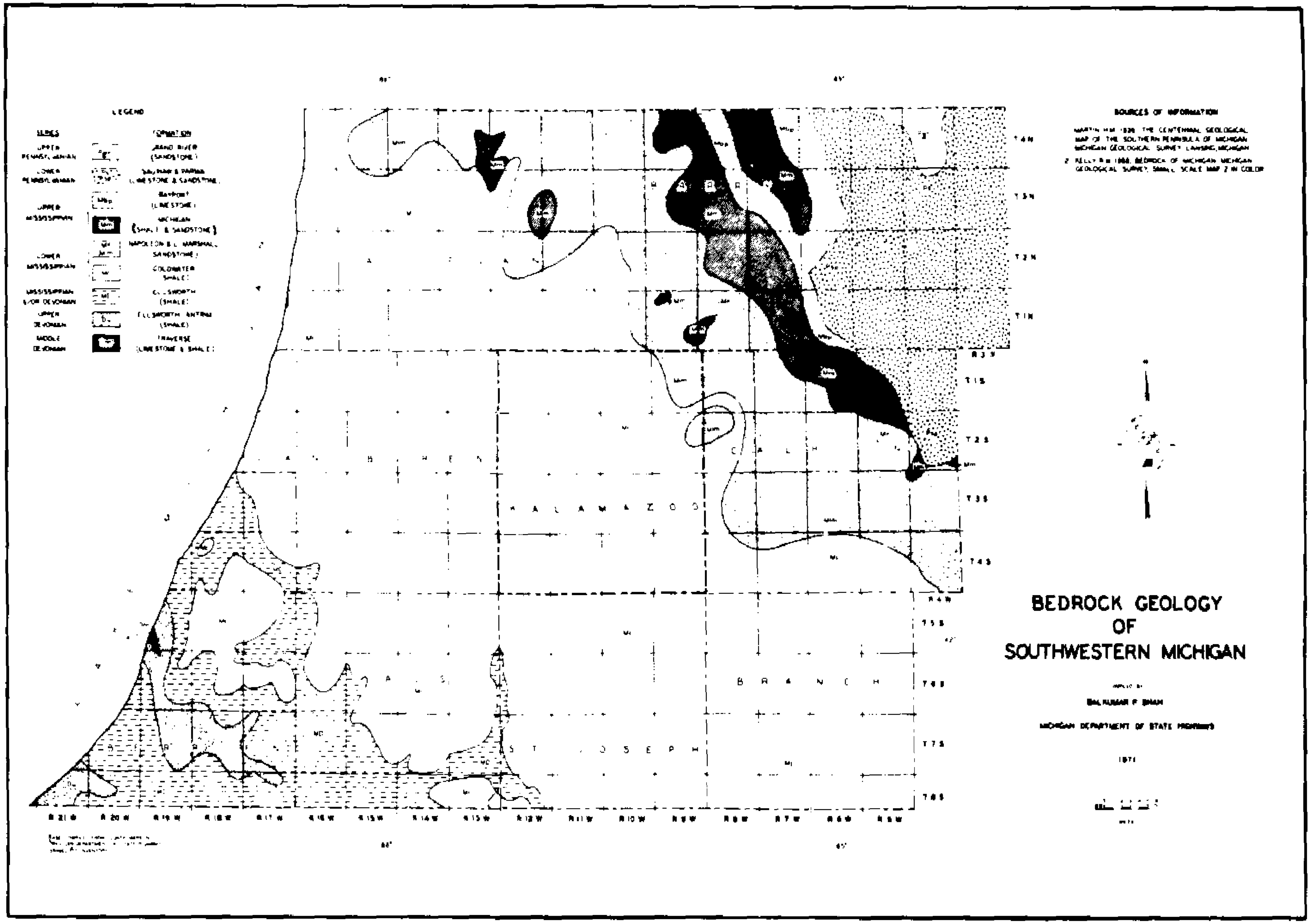


Figure 19. Bedrock geology of Southwestern Michigan.

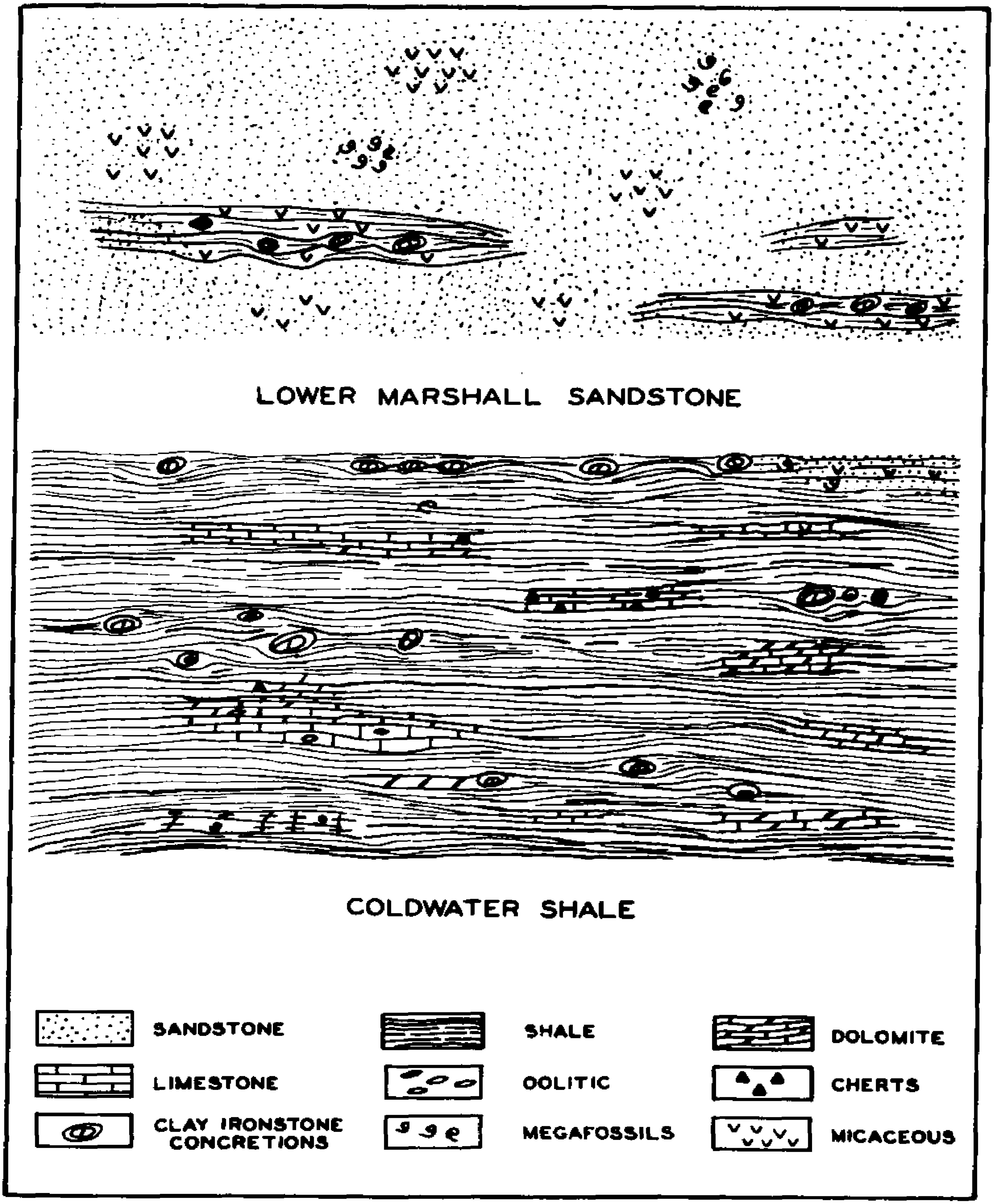


Figure 20. Generalized stratigraphic sections of the Lower Marshall sandstone and Coldwater shale in Southwestern Michigan showing unique identifiable characteristics.

Michigan Basin as a result of uplift and erosion in the Wisconsin highlands (Fig. 19).

The Coldwater formation was first described in 1895 by Lane. In the southwestern part of Michigan it is dominantly a blue to gray and occasionally greenish shale or sandy shale becoming more micaceous and arenaceous upward, and gradually passing into overlying Lower Marshall sandstone. These shales seem to be more blue than gray towards the northeastern part of Kalamazoo County. There are thin interspersed beds of limestone and dolomite (Fig. 20) which are discontinuous over large areas. These are more common in the western and southwestern parts of the county. In the northeastern part of the county, near the top, interbedded sandstones and shales are reported in oil and gas logs. Hard brownish zones of shale, also revealed by logs, are present toward the southeastern part of the county. These shales are known to contain thin zones of cherty limestone, oolitic limestone, dolomitic limestone, fossiliferous limestone, and clay ironstone concretions. The writer visited the type locality and several other outcrops of Coldwater shale in Branch and Calhoun counties, where he observed a number of zones of clay ironstone concretions and ferruginous bands in shale. Also he came across septarian-like structures with secondary mineralization of calcite. One can also see, in these outcrops, fossiliferous zones containing mainly varieties of brachiopods and other less common fossils. Near the base of several oil and gas logs, a reddish or purplish rock (called "Red Rock") has also been recorded. This is variable in composition, and may not be used as a direct horizon marker. The average thickness of the Coldwater formation in Kalamazoo County is approximately 650 feet.

Lower Marshall Sandstone

The presence of Lower Marshall sandstone in the northeastern part of Kalamazoo County is indicated by a very few well logs. Its contact line with the underlying Coldwater shales (Fig. 19) is a matter of debate. Winchell (1861) first described this sandstone as white, gray, green, and red in color, locally very micaceous and fossiliferous (Fig. 20). Again clay ironstone concretions are present in blue-gray sandy shale lenses. Streaks and pockets of coal and coaly vegetation impressions are reported. Data pertaining to the occurrence of this sandstone in Kalamazoo County are mostly lacking, and so it is not described more completely.

Bedrock Configuration and Pre-glacial Drainage

Configuration of the bedrock surface (Fig. 21) in southwestern Michigan is complex. Its character suggests that different processes were active during a series of geomorphic cycles. The present bedrock

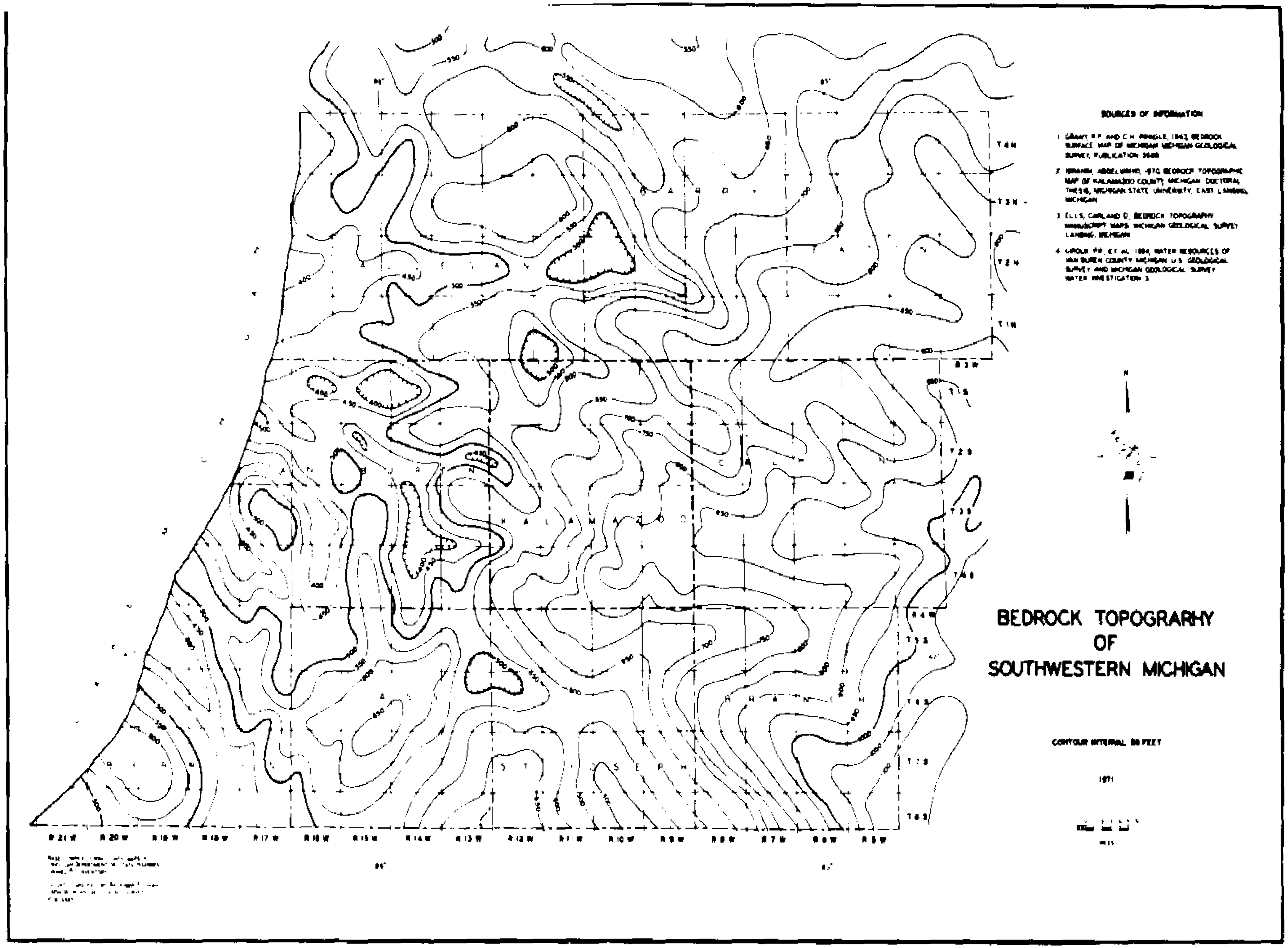


Figure 21. Bedrock topography of Southwestern Michigan.

topography in the study area was shaped by preglacial crustal deformation accompanied by fluvial erosion, then glacial and glacio-fluvial erosion, and then post-glacio-fluvial modification. Interpretation of the principal drainage lines has been attempted by several previous workers on the basis of its general topography, bedrock structure, and the differential hardness of bedrock, i.e., whether shales, sandstones, or carbonates. Horberg and Anderson (1956) and several other earlier workers believed that the pre-glacial drainage flowed toward the Lake Michigan lowland which further emptied eastward into the St. Lawrence River. Bedrock drainage patterns observed on the maps in Figures 21 and 22, suggest that bedrock channels dip toward the Lake Michigan lowland, and are generally parallel to the strike of the underlying bed-rock.

On a broad scale, bedrock topography also is known to influence the pattern of ice movement, especially when we take into consideration the dominant importance of the angle of surface slope in the flow-law of ice (Miller, 1970). Therefore, it seems possible that the general slope of the bedrock surface in southwestern Michigan toward the Lake Michigan lowland could have promoted advance of the Lake Michigan lobe toward the east and south-east, with the result being much glacial plucking and erosional modification of the pre-glacial bedrock surface.

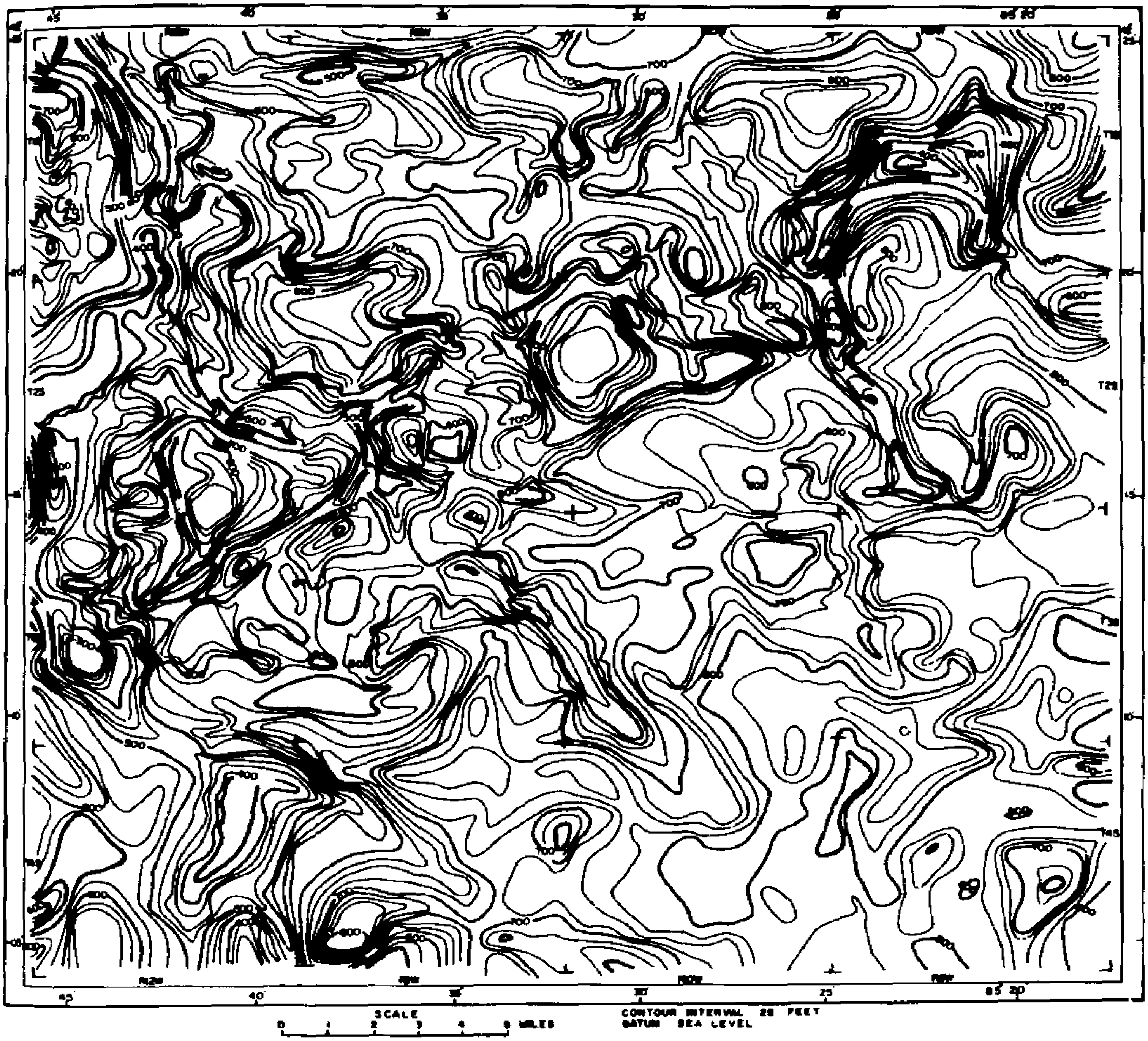


Figure 22. Bedrock topographic map of Kalamazoo County (after Ibrahim, 1970).

Similarly, the bedrock highland in the southeastern part of the area (Fig. 21) of study may have reduced the erosive effectiveness of the Saginaw ice. This bedrock high is assumed to be the result of the greater hardness of lithologies in this sector, as well as some control exercised by structure (Fig. 21).

Ibrahim (1970) mapped in detail the bedrock topography (Figs. 22 and 24) and buried pre-glacial bedrock drainage channels of Kalamazoo County, using available well log data and gravity surveys. His purpose was an analysis of the pre-glacial and glacier marginal drainage and groundwater potential of the county. In this he also attempted to reconstruct the drainage pattern before and during glaciation.

Figure 24 shows the distribution of bedrock channels and surface geology in Kalamazoo County. It is apparent that present surface drainage is westward, as is the buried bedrock drainage, but they do not exactly coincide with each other. In general, however, the surface channels of Kalamazoo County exist more or less in the same areas where underlying bedrock channels exist, except where bedrock channels are blocked by great thicknesses of drift. In fact, some of the surface channels coincide very closely with the buried bedrock channels, although in a broader sense the correlation between surface topography, drift thickness, and the bedrock configuration is inversed in Kalamazoo County. To explain this, while the pre-existing bedrock surface generally slopes downward to the west in this county, the present surface topography, as well as the average thickness of the drift is highest at the western side of the county, i.e., it slopes and thins to the east (Figs. 25 and 26). The situation appears to be just opposite in the eastern part of the county. This situation is considered in the next chapter, and is illustrated by the cross-sectional diagrams in Figures 25 and 26.

Structures

The formations of lower Mississippian age, which make up the bedrock in Kalamazoo County, are part of the bowl-shaped structure of the Michigan Basin. The predominantly Paleozoic formations of this basin outcrop in more or less concentric bands, the youngest being at the surface in the central part of the structure and the oldest at the surface around the perimeter. Kalamazoo County and vicinity lies in the southwestern part of the Michigan Basin. The Coldwater shale and Lower Marshall sandstone (Fig. 19) gently dip northeastward toward the center of the basin and strike northwestward. Here, it is noteworthy that in the Kalamazoo County area the Lake Michigan lobe ice eroded the bedrock formations along their strike, whereas the Saginaw lobe eroded some formations perpendicular to their strike.

In the southeastern part of the study area shown in Figure 21, the major upland, which strikes northeast, conforms very closely to the bedrock lithology and is possibly a residual structure of an earlier age. This lithology is predominantly the durable Lower Marshall sandstone with the exception of some hard facies of Coldwater shale. This upland is named the Marshall Upland (Horberg and Anderson, 1956), and it follows the strike line of the sandstone. Apparently this upland to some extent, impeded the advance of the Lake Michigan and Huron-Erie lobes, a fact which is borne out by the morainal pattern in southern lower Michigan. Residual bedrock structure, if present, could in part at least reflect the physiographic expression of the Marshall upland.

CHAPTER VII

DRIFT THICKNESS AND STRUCTURE

Most of the Kalamazoo County landscape is developed on unconsolidated glacial deposits, overlying bedrock of varying configuration. These galcial sediments are parent materials for Kalamazoo County soils, as well as being important sources of building aggregates, and of ground water. Thus they deeply affect land use, mining, construction, and water drilling operations in the county. Also, they must be removed or penetrated in any oil and gas drilling operations that go into the bedrock. For these reasons a description of the thickness and structural character of the unconsolidated deposits in Kalamazoo County is significant, and the more detailed the information the greater its potential in regional and local site-evaluation problems.

Isopach Map of Kalamazoo County

A generalized drift isopach map of Kalamazoo County (Fig. 23) is compiled from deep well records, the drift thickness map of 1938 (Mich. Geol. Surv., Pub.

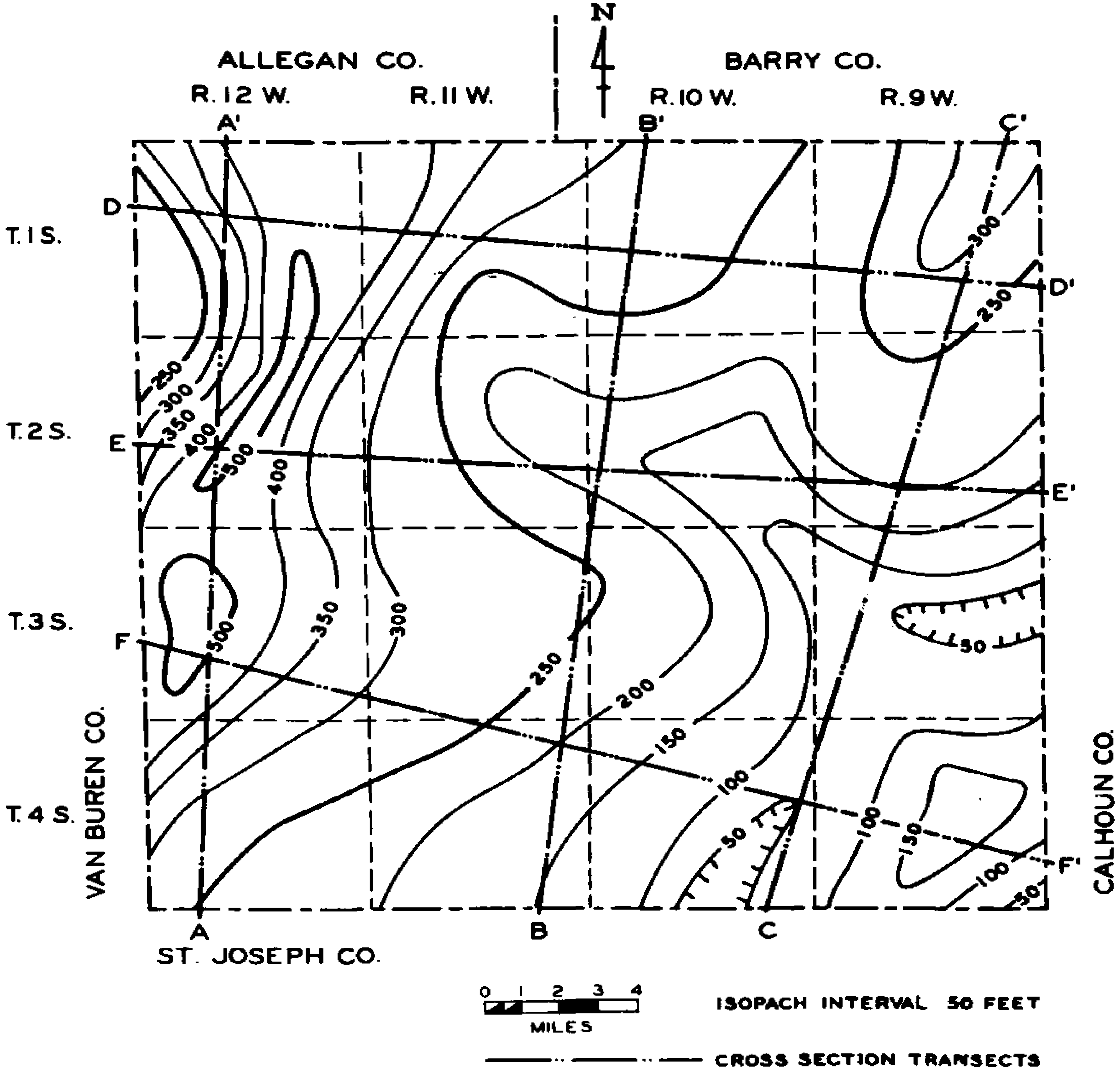


Figure 23. Generalized drift isopach map of Kalamazoo County. Dashed lines show cross section transects.

3528), and known differences in land surface elevations and the depth of bedrock (Figs. 25 and 26) in selected areas.

On this isopach map, glacial drift in Kalamazoo County is seen to range in thickness from less than 50 feet to above 500 feet. The thickest drift occurs over major valleys cut into bedrock. Regionally, it is thickest in the northwestern part of the county. The thinnest drift (less than 100 feet) occurs over a sector of southeastern Kalamazoo County. Additional regional details on the drift thickness may be obtained from deep driller's logs available in the files of Michigan Geological Survey. The isopach pattern shown in Figure 23 reflects irregularities at the base of the drift or at the top of the drift, or both. The surface irregularities were, of course, fashioned mostly by Wisconsinan glaciers and subsequent Holocene erosion. Although the drift is very thin in the southeastern part of the county, it becomes even thinner in neighboring Calhoun and Branch counties, a region where bedrock is widely exposed. These areas may be of special interest to industry, especially those which require quarried shale and sandstone, as well as to highway engineers for planning. Such isopach maps can also be useful for ground water studies and for the petroleum industry in exploration drilling.

Cross Sections

Six structural cross sections are presented here (Figs. 24, 25, and 26) representing Kalamazoo County. Of these, three trend approximately north-south, and the other three trend approximately east-west. Bedrock elevations are taken from the bedrock topographic map of Kalamazoo County (Ibrahim, 1970), and the present land surface elevations are taken from existing U.S. Geological Survey topographic maps. Subsurface stratigraphic information is generalized from available water well logs and oil and gas logs in the county.

These cross sections show the general character and thickness of drift to vary from place to place. They also indicate that unconsolidated materials are relatively young and are terrigenic, as opposed to the consolidated layered marinogenic bedrock underlying the drift. Drift material generally consists of boulders, gravel, sand, silt, and clay, most of it being sand and gravel with lenses of clay. Most of the clay can be defined as clay till, since it contains some sand and gravel and has no stratification. In general clay near the surface is brown (light) colored and near the bedrock blue-gray (dark) colored, though there are some exceptions. The source of the blue-gray clay is very well like that of the Coldwater shale. Sand and gravel deposits are also present on the buried bedrock surface and these are

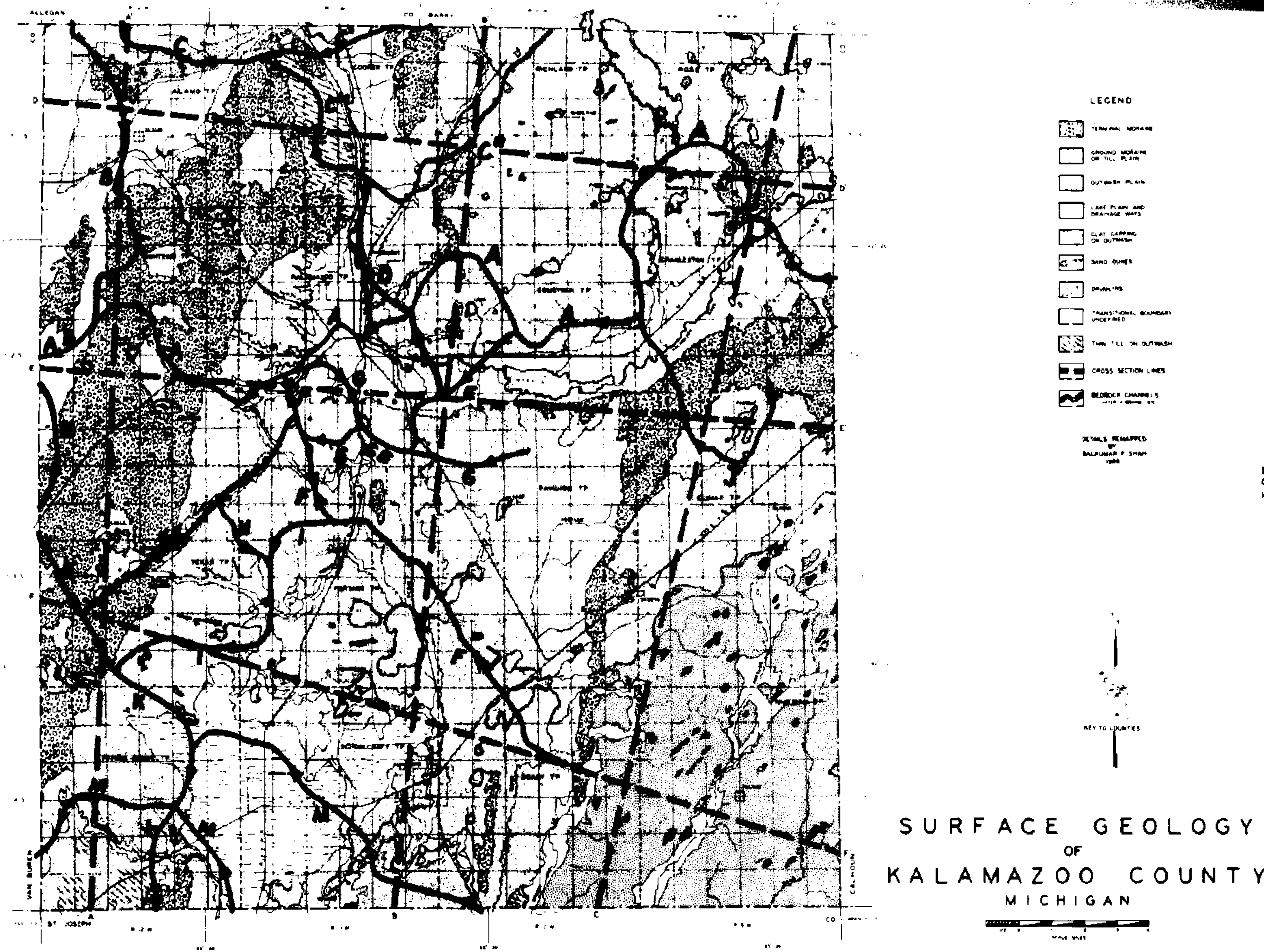


Figure 24. Map showing surface geology, cross section transects, and bedrock valleys.

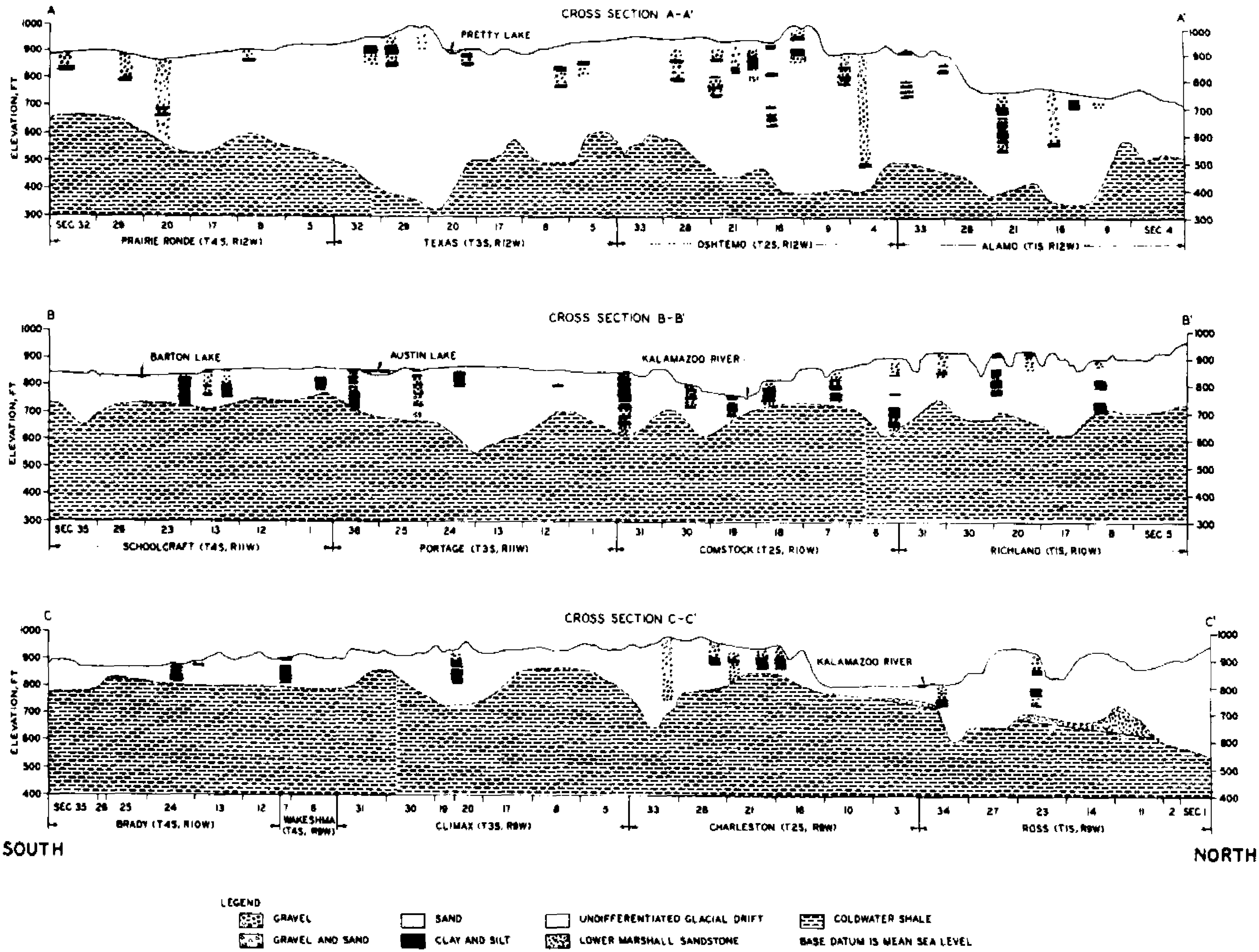


Figure 25. South-North cross sections AA', BB', and CC' in Kalamazoo County.

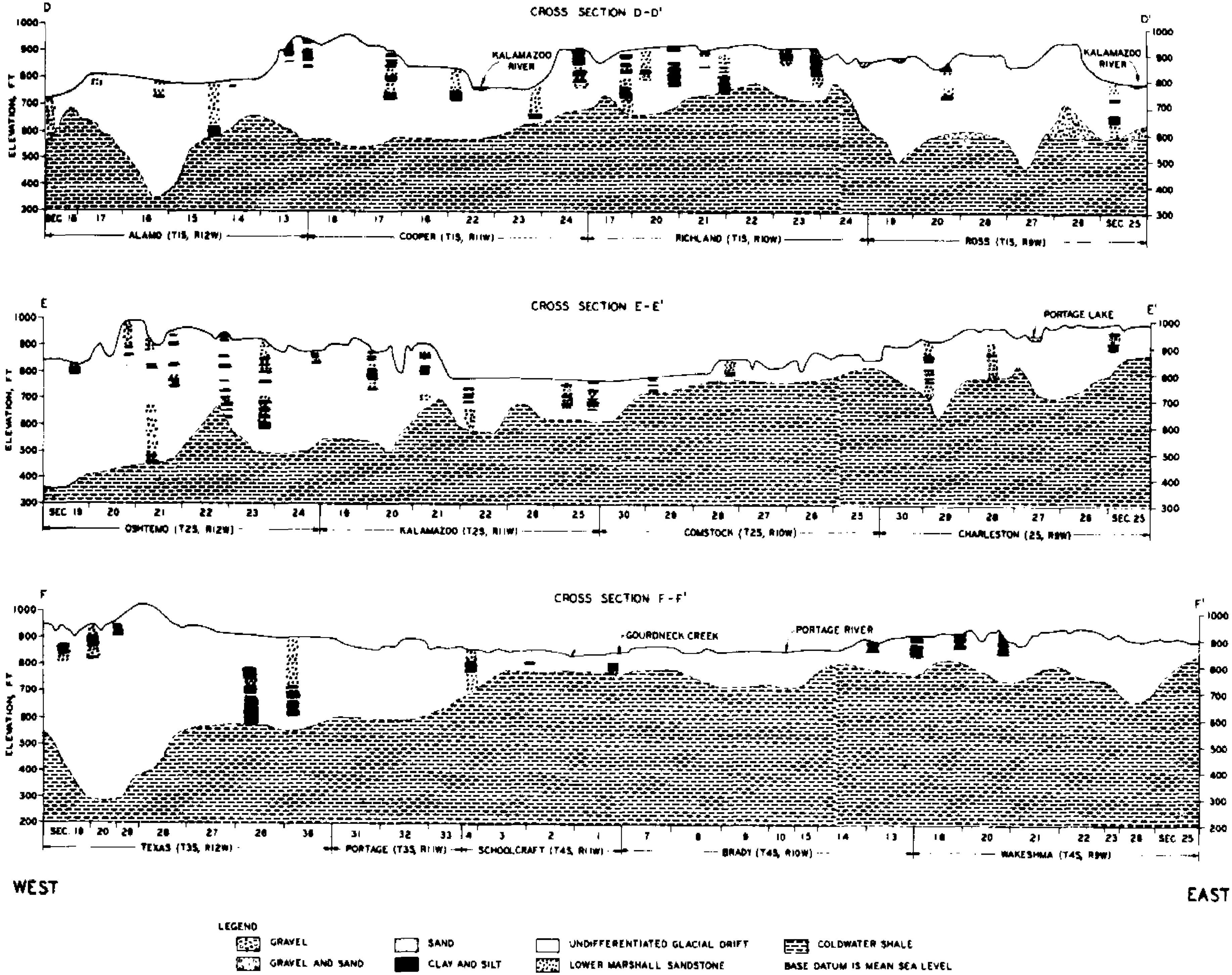


Figure 26. West-East cross sections DD', EE', and FF' in Kalamazoo County.

possibly of pre-Cary age. The cross sections show that the bedrock has great gross relief and that the drift mantle has somewhat lessened the control of the older topographic configuration, as far as the subaerial surface of today is concerned.

Correlations of Bedrock and Drift Thickness

A complicated erosion surface with valleys and uplands was developed on the uppermost Coldwater shale and Lower Marshall sandstone before and during glaciation. This resulted in deposition of unconsolidated drift on a very uneven floor. The glacial and glacio-fluvial processes, however, have been mostly responsible for fashioning the major landforms that make the upper surface of the uneven drift. Holocene fluvial erosion in some areas has produced further minor irregularities. The cross sections in this chapter (Figs. 25 and 26) and a comparison of Figure 23 and Figure 24 show the tendency for drift to be thicker in large bedrock valley areas and thinner in the bedrock upland areas. For example, where the main Kalamazoo moraine either crosses or is aligned with bedrock valleys, the drift is further thickened. Therefore, drift thickness and the alignment of isopach lines essentially reflect the bedrock configuration. The bedrock topography may, therefore, have been a major controlling factor in the thickening and thinning of terminal ice in the interlobate zone, as well as exercising a direct control on the relief and depth of the glacial drift.

CHAPTER VIII

SOILS OF THE AREA

Soil is the collection of natural bodies in the upper portion of the earth's crust that has been altered *in situ* by natural processes into layers or horizons whose physical, chemical, and biological properties differ from each other and the underlying unaltered parent rock materials from which they were formed.

In Kalamazoo County such materials are originally of glacial origin and have been altered at various times since by weathering, action of water, air, and organisms. The soil processes, of course, began after glaciers retreated, depositing unconsolidated glacial drift with diverse textures and lithologies exposed to weathering. Such soils are usually classified into more complex classifications, than merely as glacial soils, depending on the physical, chemical, and biological properties of the individual layers, or on soil profile characteristics and their interpretations. In some places several grades of soil on a single glacial feature have been described because of differences in their properties.

Interpretation of soil morphology, soil genesis and soil classification are related to the following soil formation factors, which deserve mention here:

1. Parent rock material--texture, structure, or fabric and mineralogical or chemical composition.
2. Soil climate--soil moisture, soil temperature, and soil air.
3. Topography--shape of the soil body in relation to the earth's center of gravity, water table, and sun's rays.
4. Organisms--plants or animals or man.
5. Time or age--for which land surface is exposed to above factors.

A genetic soil classification is based on the above soil formation factors, and a morphological soil classification is based on observed properties of soils. But, the best classification is a combination of both. The new soil classification system adopted by the National Cooperative Soil Survey on January 1, 1965, is more realistic as well as more comprehensive than any ever developed in the United States. Because of the aim of this investigation, the simplest approach is desired, hence hereafter terms from the classification used prior to 1965 are used.

Soil Series

The first detailed report on the soil survey of Kalamazoo County was by S. O. Perkins and James Tyson, published by the U.S. Department of Agriculture in 1928, in cooperation with the Michigan Agricultural Experiment Station. This report has a colored soil map (Plate II) of the county prepared by the Bureau of Soils in 1922. It describes all soils in detail and shows distribution of the soil series and their types in the county. After 1928 no new detailed and revised soil survey report or soil map of Kalamazoo County has been published. The Kalamazoo County Soil Conservation District has made more detailed soil maps of scattered farms for planning purposes. The writer makes primary reference to the 1922 soil map and uses soil series names which precede the new classification.

In Table 1 an attempt is made to correlate soil series names from the older classification with that of the new classification. Also in the table, the associated natural drainage, parent material, and glacial features are briefly described. In all, 13 mineral soil series, and organic soils have been reported in Kalamazoo County (Plate II). Out of these, the Bellefontaine series is now a part of the Fox series and the Griffin series is described as the Shoals series. According to Whiteside *et al.* (1963), most of the better drained local soils

TABLE 1
CLASSIFICATION OF SOIL SERIES IN KALAMAZOO COUNTY IN OLD AND NEW CLASSIFICATION SYSTEMS WITH THEIR ASSOCIATED NATURAL DRAINAGE, PARENT MATERIALS, AND GLACIAL FEATURES

Soil Series Names used in U.S.D.A. Soil Survey Report 1926	New Equivalent Series	New Classification Family Name (After 1967)	Order - New Classification (Order - Old Classification)	Associated Natural Drainage	Associated Parent Material and Texture	Associated Glacial Feature
Bellefontaine	Fox	Fine-loamy over sand or sandy-skeletal, mixed, mesic, Typic Hapludalfs	Alfisol (Zonal Soil)	Well drained	U. story: Sandy loam to silt loam. 20"-40" L. story: Gravel and Sand. (Two-storied)	Moraines and Eskers (some Drumlines and high relief Outwash)
Brady	--	Coarse-loamy, mixed, mesic, Aquollic Hapludalfs	Alfisol (Zonal Soil)	Imperfectly or somewhat poorly drained	U. story: Loamy sand to sandy loam. 20"-40" L. story: Gravel and Sand. (Two-storied)	Outwash plains
Coloma	Spinks	Sandy, mixed, mesic, Psammentic Hapludalfs	Alfisol (Zonal Soil)	Well drained	Loamy sands or sands with textural bands. (One-storied)	Moraines
Conover	--	Fine-loamy mixed, mesic, Udollic Ochraqualfs	Alfisol (Zonal Soil)	Imperfectly or somewhat poorly drained	Loam or silt loam (One-storied)	Till plains and Lake plains
Crosby	--	Fine-loamy mixed, mesic, Aeric Ochraqualfs	Alfisol (Zonal Soil)	Imperfectly or somewhat poorly drained	Loam or silt loam. (One-storied)	Till plains
Fox	--	Fine-loamy over sand or sandy-skeletal, mixed mesic, Typic Hapludalfs	Alfisol (Zonal Soil)	Well drained	U. story: Sandy loam to silt loam. 20"-40" L. story: Gravel and sand. (Two-storied)	Outwash plains and Glacial drainage underlain by sand & gravel
Griffin	Shoals	Fine-loamy, mixed mesic, Aeric Fluvaquents (non-acid)	Entisol (Azonal Soil)	Imperfectly or somewhat poorly drained	Loam to silt loam (Stratified)	Alluvial deposits
Maumee	--	Sandy, mixed, non-acid, mesic, Typic Haplaquolls (non-calcareous)	Mollisol (Intrazonal Soil)	Poorly or very poorly drained	Sand to loamy sand (One or two storied)	Outwash plains (Sandy)
Newton	--	Sandy, mixed, acid mesic, Typic Humaquepts	Inceptisol (Intrazonal Soil)	Poorly or very poorly drained	Sand (One-storied)	Outwash plains (Sandy)
Oshtemo	--	Coarse - loamy mixed, mesic, Typic Hapludalfs	Alfisol (Zonal Soil)	Well drained	U. story: Loamy sand to sandy loam. 20"-40" L. story: Gravel and sand. (Two-storied)	Outwash plains (Sandy)
Plainfield	--	Sandy, mixed, acid mesic, Typic Udipsamments	Entisol (Azonal Soil)	Well drained	Sand (One-storied)	Outwash plains (Sandy)
Rodman	--	Sandy-skeletal, carbonatic, mixed, mesic, Typic Hapludolls	Mollisol (Intrazonal Soil)	Well drained	U. story: Gravelly sandy loam to loam. L story: Gravel and sand. (Two-storied)	Cobbly, gravelly and sandy narrow Outwash, and Eskers
Warsaw	--	Fine-loamy over sandy or sandy skeletal, mixed, mesic, Typic Argiudolls	Mollisol (Zonal Soil)	Well drained	U. story: Sandy loam to silt loam. 20"-40" L. story: Gravel and sand. (Two-storied)	Prairie over Outwash and Glacial drainage.
Muck (Organic Soil)	--	--	Histisol (Intrazonal Soil)	Very poorly drained	--	--

belonged to the Gray-Brown Podzolic soil group in the former classification, or Alfisols in the new classification. Principal subgroups are classified according to the degree and type of soil profile development, texture, the nature of parent material, and natural drainage development.

In the column under new classification names the family name is given. This includes the name of each of the higher categories in the complete classification of that series in the new system. The new names connote the major properties of the kind of soils included in each class, and the names also indicate how they are related to each higher category. Each family, for example, coarse-loamy, mixed, mesic, also indicates how it differs within the higher categories. For more detailed information regarding the new classification, one may refer to "Pedological-Lectures on Soil Classification" by Guy D. Smith (1965), published by the Belgian Soil Science Society, and "Soil Taxonomy" by the U.S. Department of Agriculture (1971, in press).

Among the 13 mineral soils, five have one-storied parent material, six have two-storied parent material, the Maumee series can have either one- or two-storied parent material, and the Griffin series include Holocene stratified alluvial deposits along the banks of rivers and streams. Seven soils are well drained, four soils are imperfectly or somewhat poorly drained, and the remaining two soils and organic soils (muck) are poorly or very poorly drained.

Relation to Parent Material and Surface Geology

The texture, fabric, and mineralogical composition of glacial sediments in Kalamazoo County vary greatly, these varied sediments, of course, being the parent materials of the soils. The texture of such parent material varies from very coarse gravel (with a few boulders and cobbles) to sands to silts to clays, all of which have relict affect on the soil profile. The fabric or structure of the materials varies from relatively porous layered glacial outwash and fluvial deposits to unconsolidated sandy till to compact clay till of varied composition texturally.

The geologist is commonly more interested in the mineralogical or lithological composition of the parent materials and its relation to soils, than in textures and fabrics of glacial sediments. For this reason, in this study some petrographic analyses of surficial sediments and a study of soils have been made in Kalamazoo County. The data are shown in Figures 28 to 37. These interpretations reveal local variations in composition, but in general, coarse parent material contains about 60 per cent carbonates, and about 30 per cent crystalline rocks, with the remaining 10 per cent comprised of other lithologies.

From this it is clear that parent materials in Kalamazoo County contain much free lime, with most of the soils here being less acidic than in other areas in Michigan where there is less limey parent material or the deposits are of older age. In southeastern and the extreme northwestern part of Kalamazoo County, the percentage of carbonates is somewhat less than 60, and the proportion of crystalline rocks rises to 40 per cent. Here we find more acidic (pH less than 5.5) soils such as the Newton and Plainfield types, in association with other series. This example reveals that the composition of parent material is a most important factor in soil formation.

Because of many abrupt horizontal changes in texture, structure, and composition of parent material of glacial origin, the soils of Kalamazoo County are very complex, and their distribution essentially parallels that of the distribution of parent material and natural drainage conditions. The soils are geologically young, as the surficial drift was deposited less than 20,000 years ago. Though topography and drainage of the county were initially induced by the latest glaciation, they are in a geomorphologically youthful state. Neither weathering nor geologic erosion is extensive, and the initial undrained depressions are commonly filled with reducing environment organic soils (mostly mucks).

The depth of weathering varies from 3 to 5 feet, and in the southeastern part of the county it is little over 6 feet (indicated by the newly named Hillsdale series developed over till plain). Following the leaching of calcium carbonate the development of an argillic horizon (a horizon with illuvial clays), with downward migration of clays, is characteristic mineral soil profiles in Kalamazoo County. The majority of soils in this county show development of each of the A, B, and C horizons, with distinct argillic Bt horizons. This argillic horizon is a distinct characteristic of the humid region Alfisols (Gray-Brown Podzolic) of southern Michigan. In Kalamazoo County, the best example of illuvial migration of clays can be seen in the American Aggregate Company's gravel pit (location of sample no. 2) in Cooper Township. Here stratified sandy and gravelly materials of valley train deposits are overlain by a thin veneer of clay till. Illuvial clays from above lying till are migrating downward into sand in irregular bands which are not necessarily parallel to the bedding plains of the sand. Soil developed in this area is mapped as Fox loam (Plate II).

Use of Soils in Surface Mapping

Soil maps and soil descriptions are very useful tools in mapping surface geology, especially the glacial geology in Kalamazoo County and elsewhere in the state of Michigan. In Table 1, the first and last columns show the relationship between soil types and associated glacial features in this county. These soils are largely the direct product of weathering of the parent materials whose properties are so directly related to former glacial processes in the area. In fact in Kalamazoo County there is, in some areas, quite good agreement between the soil map and the glacial geology map.

The writer has made considerable use of the 1922 soil map to trace the surface geology of Kalamazoo County, especially in areas where drift exposures are lacking and the nature of the material is unknown. One has to be very careful, however, in using soil maps, because soil series boundaries do vary in consequence of human error. The Bellefontaine series, which is now called Fox, is usually associated with morainal deposits in Kalamazoo County, but it is also associated with drumlin crests and high level outwash plains, as well as pitted outwash. So one has to recognize and delineate the limitations of soil maps before surface mapping of formerly glaciated areas may begin.

Field recognition of soils has proved to be very useful in locating sand and gravel deposits of the area. For example, knowing two-storied soil which has two-storied parent material, can greatly aid in locating some slightly buried sands and gravels. The upper story of the Fox series, as a case in point, usually consists of two to three feet of sandy loam or silt loam, whereas the lower story is composed of sandy and gravelly material. Beneath the lower story one may find coarse sand and gravel deposits, which shows that soil is a reflection of underlying materials. A geologist should certainly use soils information wherever available, but similarly knowledge of the geology of such an area can also aid the soil scientist when preparing soil maps.

PART III

CHAPTER IX

LABORATORY ANALYSIS OF SAMPLES

Large channel samples, small spot samples, and auger samples were collected during the field work and brought into the Michigan Department of State Highways' Research Laboratory for analysis. Mechanical and petrographic analyses were made of coarse (+3/16 inch) and fine (-3/16 inch) fractions, to determine the size frequency distribution and lithologic distribution of glacial drift aggregates. Other physical and chemical characteristics such as texture, roundness, sphericity, surface coating, and so forth were not determined, since many of these have been delineated by Wingard (1969) in a study conducted to evaluate gravel resources of southern lower Michigan. In Wingard's study, he concluded that such additional properties of individual gravel particles show generally low but consistent correlations, and are only useful for local or detailed assessment of individual gravel deposits. In the present investigation, three key properties, lithologic composition, physical strength, and chemical reactivity of aggregates, were determined in detail, since they play the major role in the durability of concrete.

Mechanical Analysis

An initial 18 channel samples of bank-run sand and gravel material were split using a Jones sample splitter until final split portions weighed about 75-100 pounds. Using a Gilson sieve shaker, particle size distribution of coarse fraction (gravel) of each sample was determined. Sieving time was 10 minutes. Samples were sieved into the following sizes: +2, 2-1-1/2, 1-1/2-1, 1-3/4, 3/4-1/2, 1/2-3/8, 3/8-3/16, -3/16 inches. Material less than 3/16 inch size was considered as a fine fraction (sand). Such fine fractions were quartered to about 500 grams and sieved by using the following U.S. Standard (ASTM number) Sieves: 10 (2000μ), 18 (1000μ), 35 (500μ), 60 (250μ), 120 (125μ), 230 (62μ), and pan (-230). Fine fractions from the first 18 channel samples and other spot and auger samples were used for mechanical analysis. Complete mecnanical analysis of corase and fine aggregates is given in Tables 4 and 6 (in the Appendix).

Petrographic Analysis

The petrographic analysis consisted of basic lithologic identification of each particle of coarse and fine fractions of glacial materials, and determination of the physical strength and chemical reactivity of individual particles in the coarse fractions only. Particle counts are commonly made as a basis of discrimination between drift sheets of different glacial epochs. In this study, however, the purpose of the petrographic analysis was to determine relative percentages of specific rock types associated with the two different ice lobes laying down deposits of relatively the same age. At the same time, the information regarding their mineral composition and physical and chemical characteristics can be extremely useful for engineering applications of the materials. The petrographic examination was carried out mainly with the help of a binocular microscope. Lithologic identification of the pebble fractions was made by breaking each with a hammer. Occasionally thin-sections were made and examined for identification of a particular rock.

Lithologic Terms and Classification

Lithologic terminology and classification was standardized for this study (Table 2). The writer's earlier experience with the Highway Department in petrographic analysis of glacial gravels associated with the Lake Michigan lobe and the Saginaw lobe, helped to simplify the lithologic terminology and classification for this study. In Table 2, an initial classification I was established for a coarse fraction, which included the 18 lithologic categories expected in the gravels of this area. Later on a more simplified but yet meaningful new classification II was adopted for faster and more

TABLE 2

LITHOLOGIC TERMINOLOGY AND CLASSIFICATION

COARSE FRACTION		FINE FRACTION
Classification I (Initial)	Classification II (Simplified)	Classification III
Phaneritic Acid Igneous	Acid Igneous	Acid Igneous
Phaneritic Intermediate Igneous	Basic Igneous	Basic Igneous
Phaneritic Basic Igneous	Foliated Metamorphic	Metamorphic
Micro-Phaneritic Igneous	Non-Foliated Metamorphic	Carbonate
Aphanitic Acid Igneous	Carbonate	Chert
Aphanitic Basic Igneous	Sandstone	Clastic
Foliated Metamorphic	Siltstone and Shale	Feldspar
Non-Foliated Metamorphic	Clay Ironstone Concretions	Quartz
Dolomite	Porous Chert	Others*
Dolomitic Limestone	Dense Chert	
Limestone	Others*	
Sandstone		
Siltstone		
Shale		
Clay Ironstone Concretions		
Porous Chert		
Dense Chert		
Others*		

*This refers to any rock which was extremely difficult to identify because of extensive weathering or could not be placed in any of the above lithologic categories due to its rarity.

efficient identification of lithologies. This included only 11 lithologic categories. In this study, more specific lithologic terms, used in the earlier studies of Wingard (1969), were eliminated to avoid complicating certain glacial interpretations in the area.

Classification III was designed for petrographic analysis of the fine fractions (sand size), and in this classification only nine lithologic categories were used on the basis of expected rocks and minerals in this fraction.

Description of the standard lithologic terms is not given here, since they can be found described in any petrology or petrographic text or reference book or in any geological glossary.

Coarse Aggregates

For petrographic analysis of coarse aggregates, two types of samples, channel samples, and spot samples, were used. A detailed five-size fraction analysis was used for channel samples 1 through 18, and a pebble volume analysis was used for the rest of the spot samples.

Five-Size Fraction.--Coarse material used for the mechanical analysis was also taken for petrographic analysis. The following five-size fractions were selected for petrographic analysis:

Size 1 -	+ 1 inch
Size 2 -	1 - 3/4 inch
Size 3 -	3/4 - 1/2 inch
Size 4 -	1/2 - 3/8 inch
Size 5 -	3/8 - 3/16 inch

The above size fractions were quartered, whenever possible, to 200 pebbles each. All five-size fractions of 18 channel samples yielded 200 pebbles each, with the exception of greater than 1 inch (Size 1) fractions of 3 samples, which yielded a few less than 200 pebbles; for the sake of uniformity of the data these were still used for the analysis. A total of about 1,000 pebbles were analyzed per sample. This brings the total figure to 17,860 pebbles analyzed for 18 channel samples.

Lithologic classification I (Table 2) was used for this five-size fraction analysis of 18 gravel samples. Data were recorded in code numbers to speed up the procedure. Percentages of each lithology present in each fraction were calculated. Then these data were regrouped into the following 11 lithologic categories: igneous and others, foliated metamorphic, non-foliated metamorphic, dolomite, dolomitic limestone, limestone, sandstone, siltstone and shale, clay ironstone concretions, porous chert, and dense chert. This breakdown was made to study the lithologic distribution according to variations in size of the material. Using the whole data of 18 channel samples, mean percentages of each lithology (mean of 18 samples) in each size were claculated. These are represented graphically in Figure 27.

From a plot in Figure 27, it can be said in general that all lithologies except clay ironstone concretions, porous chert, and dense chert, show more or less similar distribution in all five sizes. Petrographic analysis of sizes 2 and 3 can give average value of lithologic distribution in a particular deposit. Clay ironstone concretions seem to decrease in number with the decrease in size of the material and this could be due to the weak physical nature of these concretions. The number of porous and dense cherts seems to increase with the decrease in the size of the material. This may be due to the deleterious nature of chert, which can expedite mechanical breakdown compared to other rocks. Limestones show slight increase in number with decreases in particle size. This could be also due to mechanical breakdown.

The petrographic data for 18 channel samples were averaged for the whole sample and again regrouped into classification II (Table 2) for correlating with spot sample data. These data are given in Table 3 (in the Appendix).

<u>Pebble Volume</u>.--A pebble volume analysis was used for 23 spot samples (No. 23 to 45) of coarse material collected in Kalamazoo County. This method has been

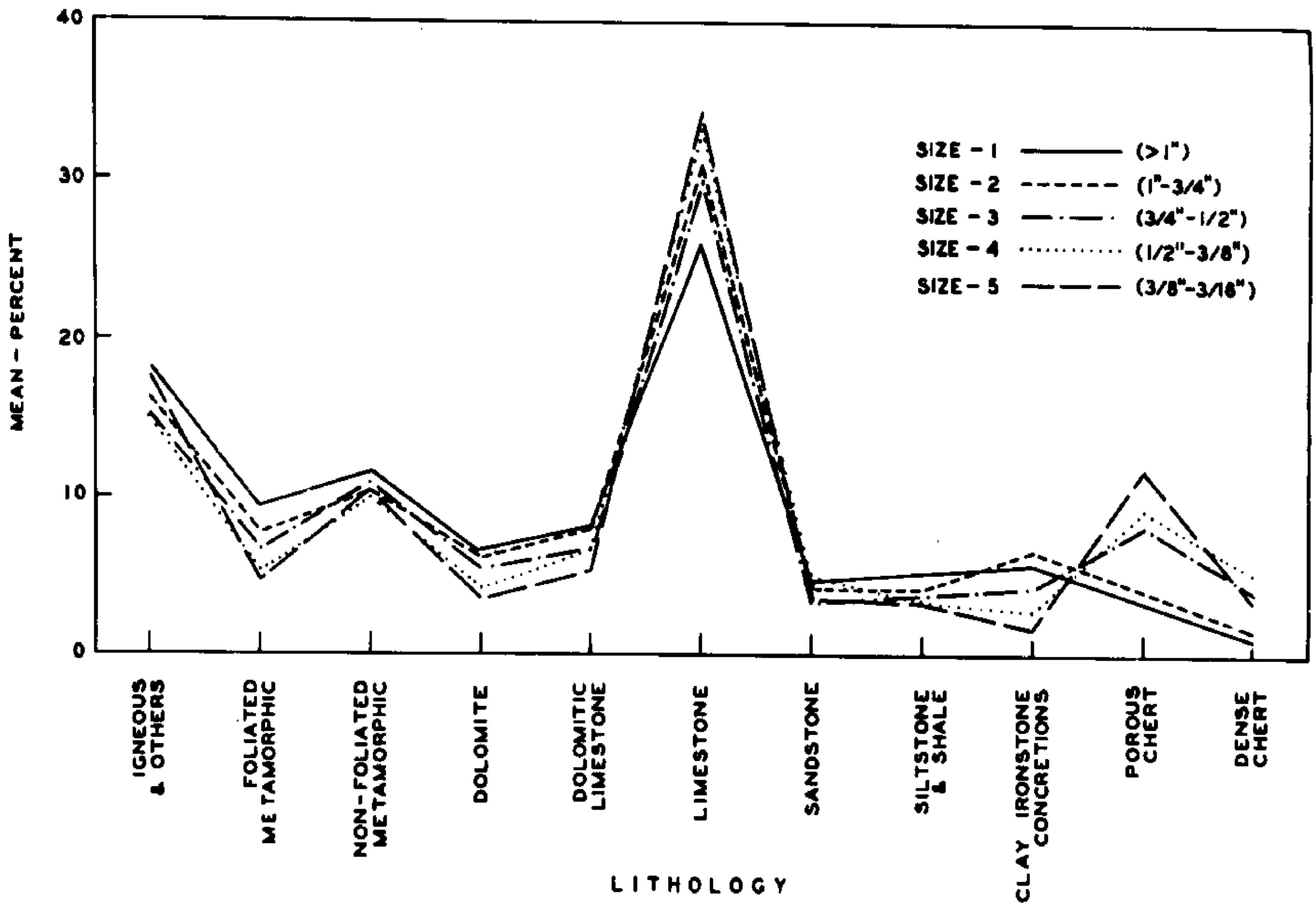


Figure 27. Relationship between material sizes and lithologic distribution.

stressed by Ehrlich and David (1968) in their study of glacio-fluvial sediments, and is also described and used by Wingard (1969) in the study of drift materials carried out in the Research Laboratory, Michigan Department of State Highways. This method gives lithologic percentage by volume rather than by number of pebbles.

The pebble volume procedure needs to be briefly described here. Gravel samples in 1/2 to 1 inch sizes were collected in the field and washed to free them from clay or fine material in the samples. Then they were quartered until approximately a 2 liter fraction remained. Pebbles were packed by agitating in a 2 liter waxed strong cardboard cylinder mold to obtain the approximate initial volume.

Pebbles from a 2 liter volume were petrographically analyzed into 11 different lithologic categories of classification II (Table 2). Then the volume of each lithologic fraction was determined by weighing, in grams, all pebbles in each category, in air and then in water. The difference between the two weights (in grams) is equal to the volume in cubic centimeters. From this volume percentage by volume for each lithology was determined. Approximately 12,000 pebbles were analyzed using this method.

Lithologic data collected using 1/2 to 1 inch sized fractions are believed to be representative of all size grades of coarse aggregate. This fact is revealed by Figure 27. This assumption is supported by Figure 27 in which volumes of sizes 2 and 3 (1/2 to 1 inch) are shown as an average of all five sizes. Anderson (1957) believed that the 1/2 to 1 inch size grade contains the greatest variety of rock types, and hence he also used this size for pebble counts.

Fine Aggregates

In Kalamazoo County, more than 100 samples were collected for the sand analysis using the channel, spot, and auger sampling methods. Of these, 88 samples were subjected to petrographic and mechanical analyses.

One-Size Fraction.--The sand fraction of 1 to 2 mm. (ASTM No. 18-10) size from each sample was petrographically investigated. This size grade was chosen because of the large variety of lithologies, which with the aid of tweezers can be rather accurately identified under a binocular microscope. The fractions were coned and quartered until reduced to about 350 grains. Only 300 grains were examined. Sand grains were classified into nine different lithologic and mineralogic categories. These are listed in Table 2 under Classification III. A total of about 27,000 sand grains were analyzed and the data are tabulated in Table 6 (in the Appendix).

The sand analysis was carried out to abet the interpretations of glacial history, but because of heterogeneity this did not provide as much information as did the coarse fraction.

Heavy Minerals

The heavy mineral analysis can be used as an additional tool for differentiating various drift sheets. It is well established that the heavy minerals in sand fractions are mostly concentrated in its finer grades, and that they can be separated from the lighter minerals by using heavy liquids of different density, and then identified under a petrographic microscope. A pilot study of heavy minerals was therefore made from a -270 mesh fraction of channel samples numbered 1 to 18. These were separated using acetylene tetrabromide (specific gravity 2.96 at 20°C). The results show that 1 to 5 per cent heavy minerals by weights are present in -270 mesh fractions of all samples.

Comparison of Channel and Pebble Volume Techniques

Both channel and pebble volume methods were used, the channel technique for engineering types of samples and pebble volumes for lithologic samples. Each technique has its advantages and disadvantages, as noted below.

The channel sample subjected to mechanical analysis gives more detailed engineering type of information, especially regarding the particle size distribution in the deposit. The pebble volume sample cannot provide this valuable information because of its small volume and single size grade. The petrographic data on channel samples give a more detailed lithologic distribution within each size grade, whereas the pebble volume sample data are derived from one size grade only, and so does not represent an average of the whole deposit. Similarly, other engineering information such as physical strength and chemical reactivity can be obtained for the whole deposit from a channel sample, whereas these characteristics can be defined only for the 1/2 to 1 inch size fraction of the whole deposit from a pebble volume sample. The channel sample technique is more lengthy and more expensive, and most of the time it requires new or fresh exposure to cut the cost of operation. In contrast the pebble volume technique is quick and less expensive, and it does not require many efforts to obtain a fresh sample. Lastly, the channel sample method gives more detailed information and the pebble volume technique gives more general information.

Determination of Engineering Quality

The two most important properties affecting the engineering quality of glacial materials are physical strength and chemical reactivity. Glacial aggregates are usually used in concrete for construction purposes, so determination of these two properties, along with petrographic analysis of coarse aggregates, is most desirable. Economic effects of these properties are discussed in Chapter XII.

The physical strength was determined by estimating how strong the blow of a hammer was required to break a rock particle. Two categories of physical strength were used: i.e., simply either strong or weak. Extensive weathering affects the physical strength of some rocks; also, these rocks may have lower density and rough surface texture or smooth clayey texture. Some of the weathered or altered mineral products may be chemically reactive with cement, causing a premature failure of concrete.

The chemical reactivity of each particle was determined after its lithological composition was defined, the latter, of course, being directly related to the chemistry of each mineral present. Rocks with free silica react (alkali-silica reaction) with hydrating alkali cement. Also some dolomitic limestones or calcareous dolomites are known to create alkali-carbonate reactions, causing failures in concrete. Therefore, the reactive and non-reactive rocks were identified and recorded for further analysis.

These two key properties were determined in samples number 1 to 18 in Kalamazoo County. The resulting data are discussed in Chapter XII.

CHAPTER X

LITHOLOGIC DISTRIBUTION OF AGGREGATES

What started as an apparently simple study to evaluate gravel deposits in Kalamazoo County with respect to their suitability for concrete aggregates soon became revealed as a very complex problem. This complexity has been revealed by the recognition of out-of-phase fluctuational relationships between the Lake Michigan lobe and the Saginaw lobe (see Chapter IV), and by the detailed picture of the distribution of gravel lithologies in southwestern Michigan shown by isopleth maps (Figs. 29-37).

Initial data gathered just from Kalamazoo County are insufficient to draw any firm conclusions from regarding provenance and lithologic distribution of glacial materials in the county. The main reason for this inadequacy is that sample locations in the county are not properly distributed throughout the county. This is directly related to the lack of good exposures (see Chapter III), some of which, of course, are more dense in certain areas (Fig. 28). After several inconclusive attempts, the writer decided to compare petrographic data from Kalamazoo County with similar types of data from surrounding counties in southwestern Michigan. The data from surrounding counties are cited in the earlier pilot study by Wingard (1971), of aggregate sources in Michigan. Usable parts of these data are rearranged (see Tables 3 and 5 in the Appendix) to match the writer's data from Kalamazoo County.

Lithologic Map Interpretation and Provenance

Petrographic data from 130 sample locations (45 in Kalamazoo County and 85 in surrounding counties) are utilized for this interpretation. Each sample location is indicated by a symbol depicting associated glacial feature. The majority of locations lie on moraines, outwash plains, and moraine-outwash contacts. Bedrock outcrop locations and their lithologies are also shown on the map. The map in Figure 28 shows only gravel sample locations and their numbers, as given in Tables 3 and 5 (in the Appendix).

All petrographic data are regrouped into the following nine broad lithologic categories, each considering common occurrence, source area, local bedrock lithology, bedrock configuration, and glacial lobe movements. Minor amounts of rare lithologies as a group are eliminated. For more details one may refer to Tables 3 and 5 (in the Appendix).

Igneous (Acid + Basic) Metamorphics (Foliated + Non-foliated) Crystallines (Igneous + Metamorphics)	<u>Precambrian Fraction (Possible Source:</u> Canadian Shield Area)
Cherts Carbonates and Cherts Sandstones Siltstones and Shales Clay Ironstone Concretions Clastics (Sandstone + Siltstone + Shale + C.I. Concretions)	<u>Paleozoic Fraction (Possible Source:</u> Michigan Basin Area)

Igneous and metamorphics are grouped together into broader and more general categories of crystallines, for the purpose of observing the reflection of gross lithology from the same source areas. Carbonates and cherts are grouped together, since cherts are usually associated with carbonates, which means that they have the same source. Siltstones and shales are grouped together, as they are present in minor amounts and seem to have the same source. Sandstones, siltstones, shales, and clay ironstone concretions are grouped into the general category of clastics, because in certain areas, they represent local bedrock lithologies and seem to show increased amounts of mixing and dilution of other lithologies due to increased erosion and the glacial plucking of bedrock.

For a simple and clearer interpretation, percent lithologies for each lithologic group are plotted on nine different maps (Figs. 29-37), and isopleths are drawn to develop a pattern. These patterns show glacial and

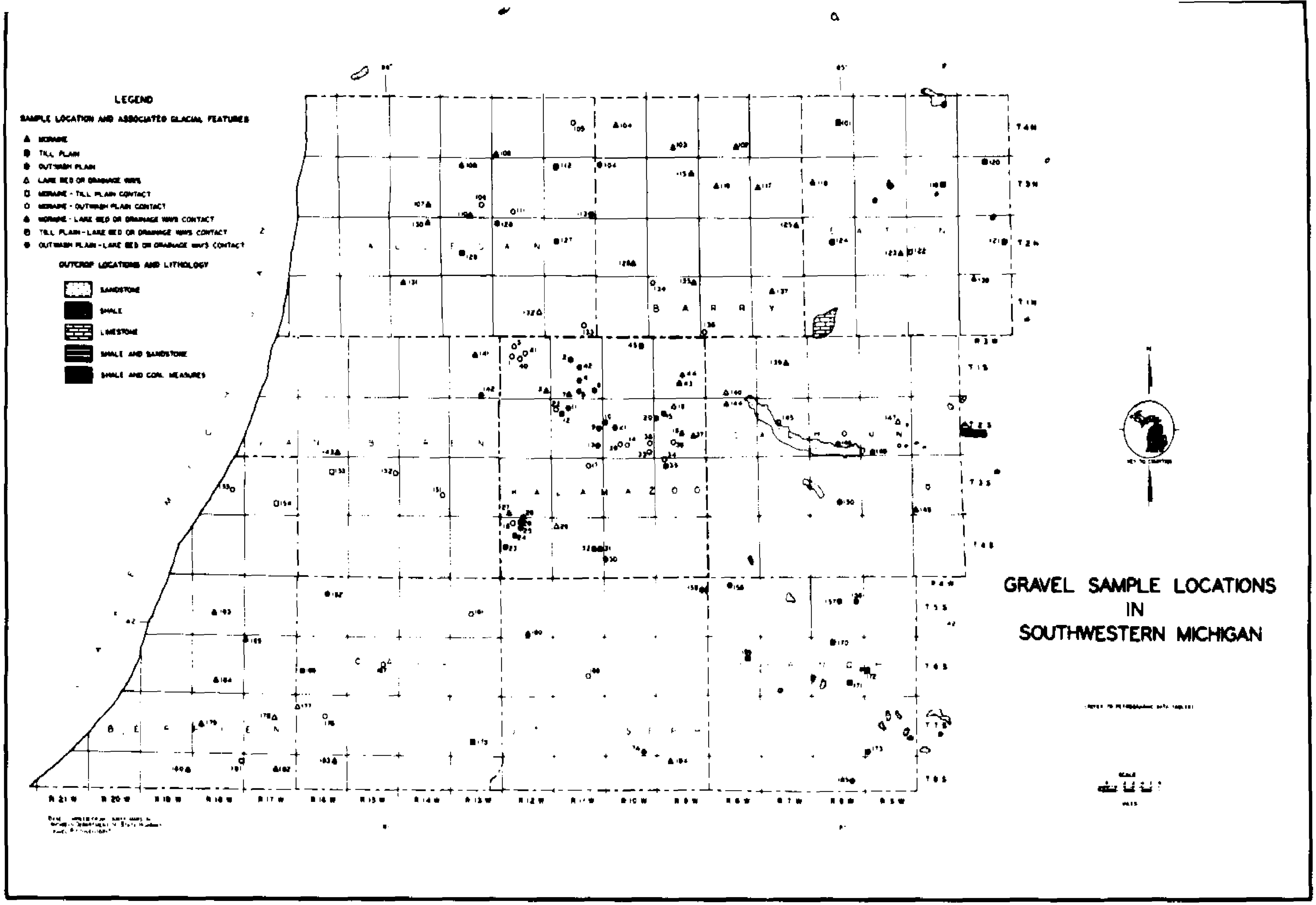


Figure 28. Sample locations in Southwestern Michigan.

proglacial dispersal of materials in relation to their source. Therefore, they are helpful in interpreting the glacial history of the area.

Strikingly enough, the isopleth patterns on these maps indicate the difference in gross lithologies related to two separate lobes. There are some exceptions where an increased influx of local lithologies has taken place, due to glacial reworking of earlier deposits and glacial erosion of bedrock. This influx is very obvious where the source is very near.

The maps in Figures 29 through 37 are sufficiently descriptive of the lithologic distribution of materials and permit ready interpretation. Each gravel lithology map is briefly described. While reading the following interpretations the reader should refer to Figures 19, 20, and 21 (see Chapter VI).

Igneous Rock Content

In general the igneous rock content (Fig. 29) is higher in the eastern part of the study area, which is indicative of Saginaw lobe deposits. The 20 per cent isopleth passing through Kalamazoo County seems to be an arbitrary line for separating deposits of the two lobes. Remarkably, two samples from the Kendall moraine in northeastern Van Buren County shows an isopleth high, thus seeming to correlate with the Saginaw lobe deposits. This supports the overriding hypothesis disucssed in

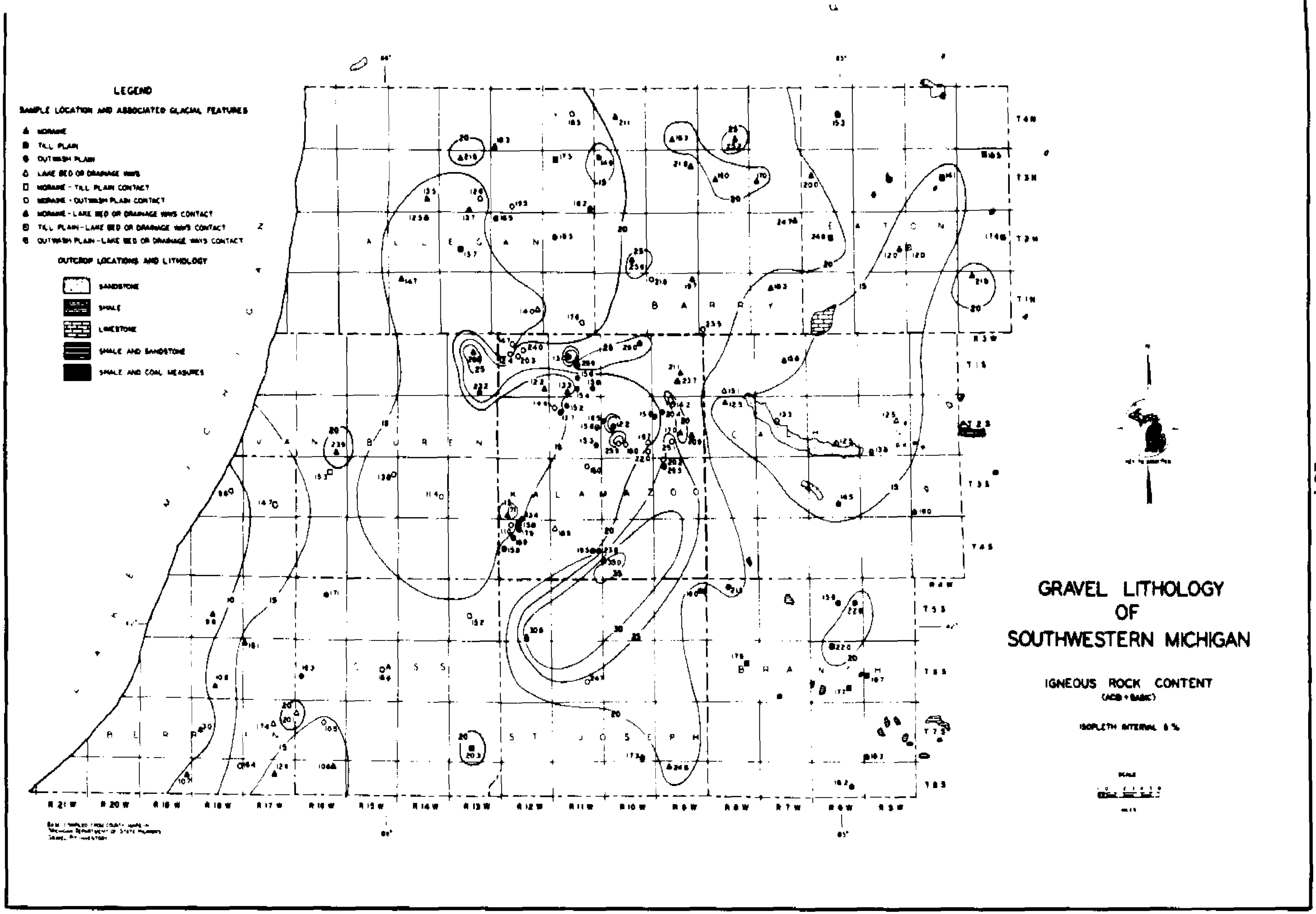


Figure 29. Igneous rock content in Southwestern Michigan.

Chapter IV. The Lake Michigan lobe deposits in general show less than 20 per cent igneous rock content, with some exceptions. An isopleth of 15 per cent in Calhoun and Eaton counties can be explained by the increased influx of local bedrock lithologies.

Metamorphic Rock Content

The metamorphic rock content pattern (Fig. 30) also, in general shows higher percentages in the eastern part of the study area. The 10 per cent isopleth passing through the western part of Kalamazoo County seems to be the arbitrary line separating deposits of the two lobes. The Lake Michigan lobe deposits in general contains less than 10 per cent metamorphic rocks, except at a very few locations where they are higher than 10 per cent but less than 15 per cent. According to Anderson (1957), the metamorphic rock content of the Saginaw lobe is higher than the Lake Michigan lobe due to an influx of quartzite pebbles. This fact was also corroborated by the writer in his petrographic analysis.

Crystalline Rock Content

In the study area (Fig. 31), the Saginaw lobe deposits generally contain more than 30 per cent crystalline rocks, and in certain areas it is higher than 40 per cent. The Lake Michigan lobe deposits, on the other hand, show crystalline rock content to be less than 30

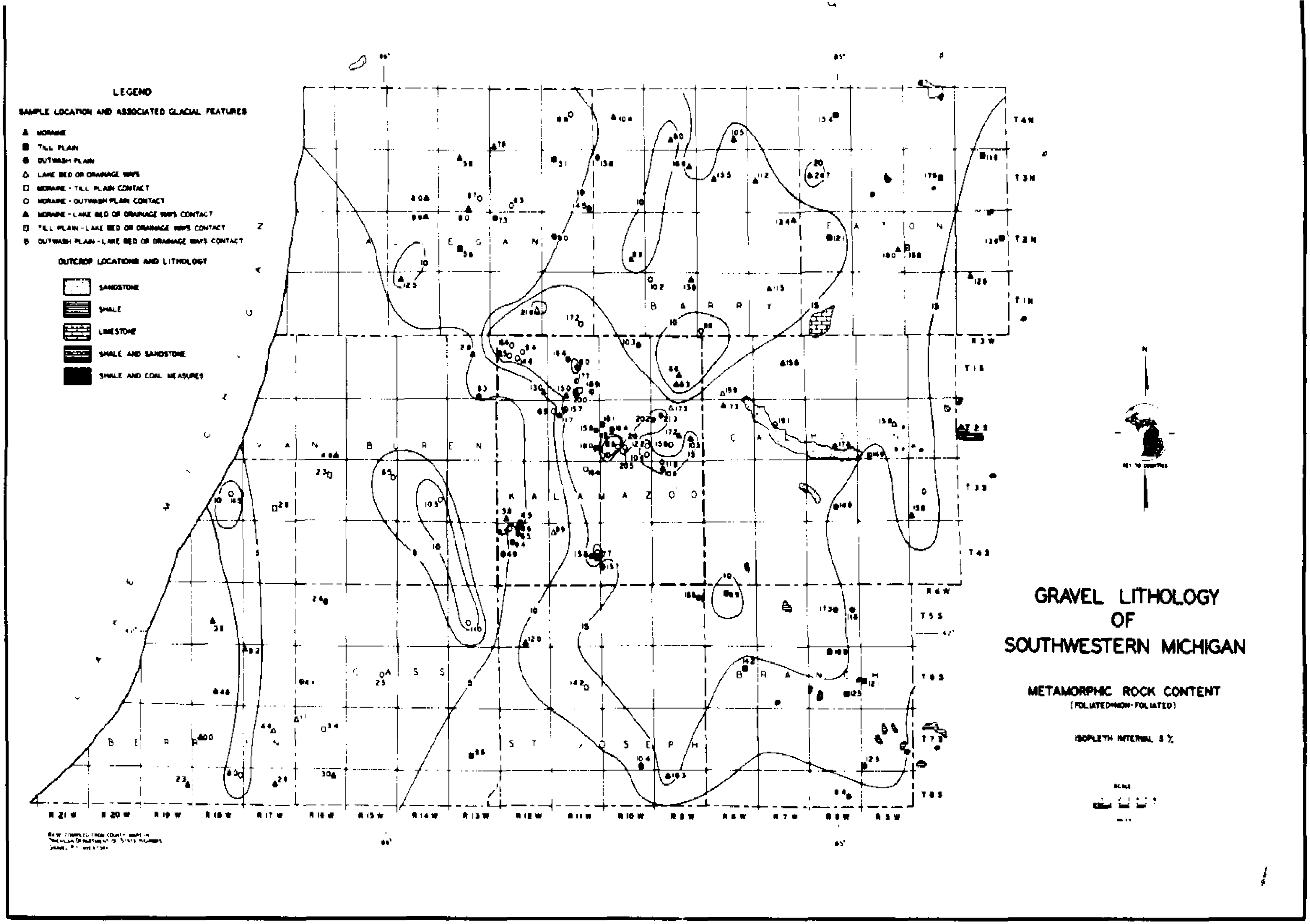


Figure 30. Metamorphic rock content in Southwestern Michigan.

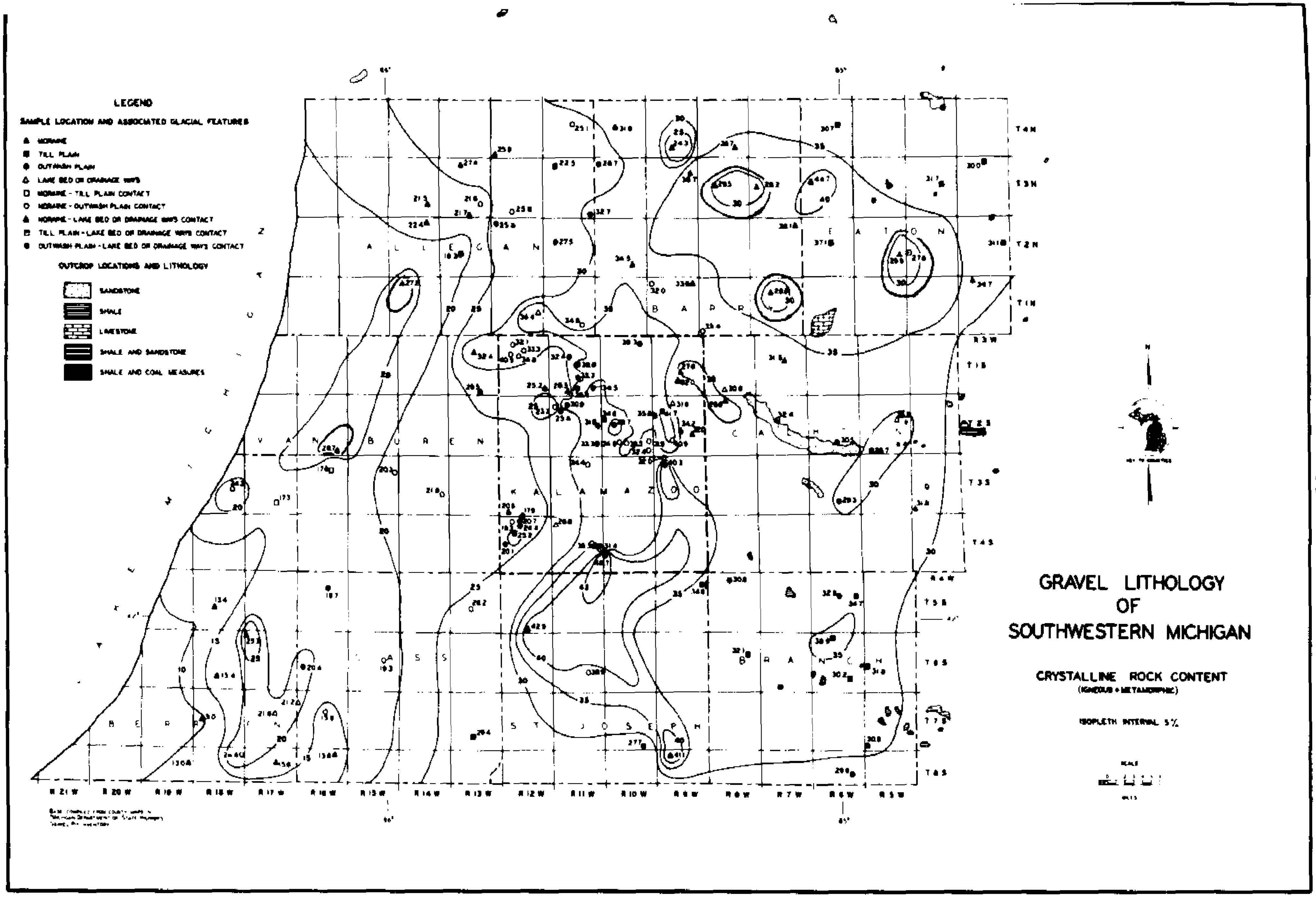


Figure 31. Crystalline rock content in Southwestern Michigan.

per cent. Therefore, the 30 per cent isopleth passing through the western part of Kalamazoo County seems to be an arbitrary lithologic interlobate line. Patterns on this map show the net result of combined igneous and metamorphic rocks, which demonstrates the best separation of deposits of both lobes.

Isolated lows can be best explained by the increased influx of the Paleozoic fraction due to glacial and glacio-fluvial processes. The high crystalline content of the Saginaw lobe and low crystalline content of the Lake Michigan lobe can be explained by two factors: (1) distance from the source area and the degree of erosion and mixing of the Paleozoic sediments; (2) the amount of reworking of the older drift by the glacial ice. Highly weathered Precambrian cobbles and pebbles have been observed in the field along with less weathered or almost fresh Precambrian rocks.

Here, the high crystalline content in the extreme northeast corner of Van Buren County and the northwest corner of Kalamazoo County supports the overriding hypothesis previously discussed. Another interesting observation is that the high crystalline content in the study area is generally associated with till plains (Plate I). The slow decrease in the amount of crystalline content in the southeastern Branch County may be because of an influx of sediments via the Erie lobe.

Due to insufficient data in that area, this suggestion is not overstressed.

Chert Content

The map in Figure 32 shows high values of chert content associated with both lobes, with the high chert content of the Saginaw lobe sediments seeming to cover larger areas than the high chert content of the Lake Michigan lobe sediments. Widespread high chert content of the Saginaw lobe sediments is attributed to the glacial erosion of large areas of cherty Mississippian Bayport limestone and subsequent Pennsylvanian carbonates (Fig. 19). The source of cherts in the Lake Michigan lobe sediments very well could be the cherty carbonates of Devonian age derived from the Lake Michigan basin floor. A high concentration of chert in Berrien County is probably due to the erosion of the Traverse formation, a subcrop of which is located in the northwestern part of the county (Fig. 19). The isopleth pattern in Berrien County suggests the direction of glacial ice. The 8 per cent isopleth passing through western Kalamazoo County and the city of Kalamazoo seems to be the arbitrary lithologic interlobate line.

Carbonate and Chert Content

In this map (Fig. 33) total carbonates and cherts are added together. The pattern here shows that in general

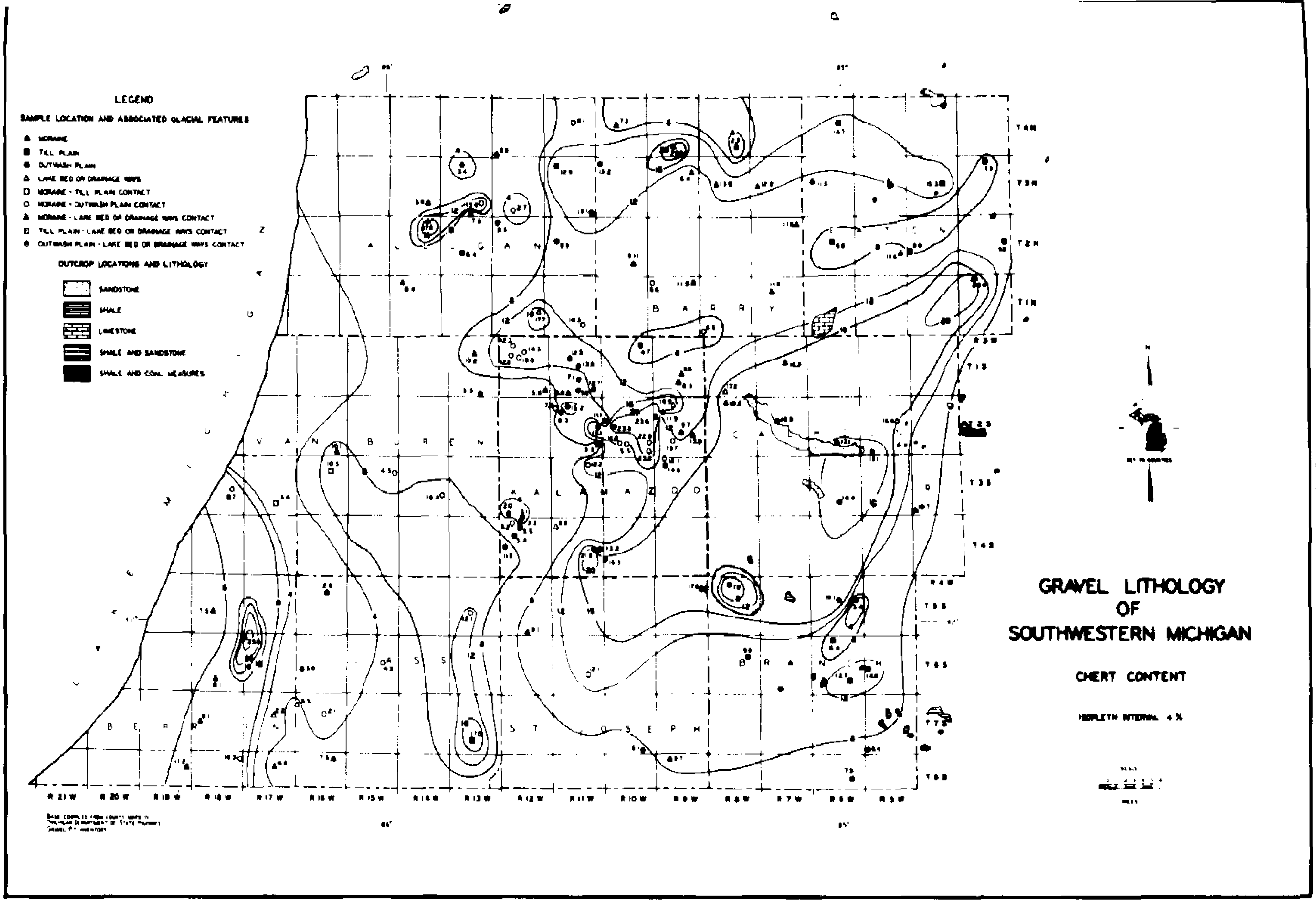


Figure 32. Chert content in Southwestern Michigan.

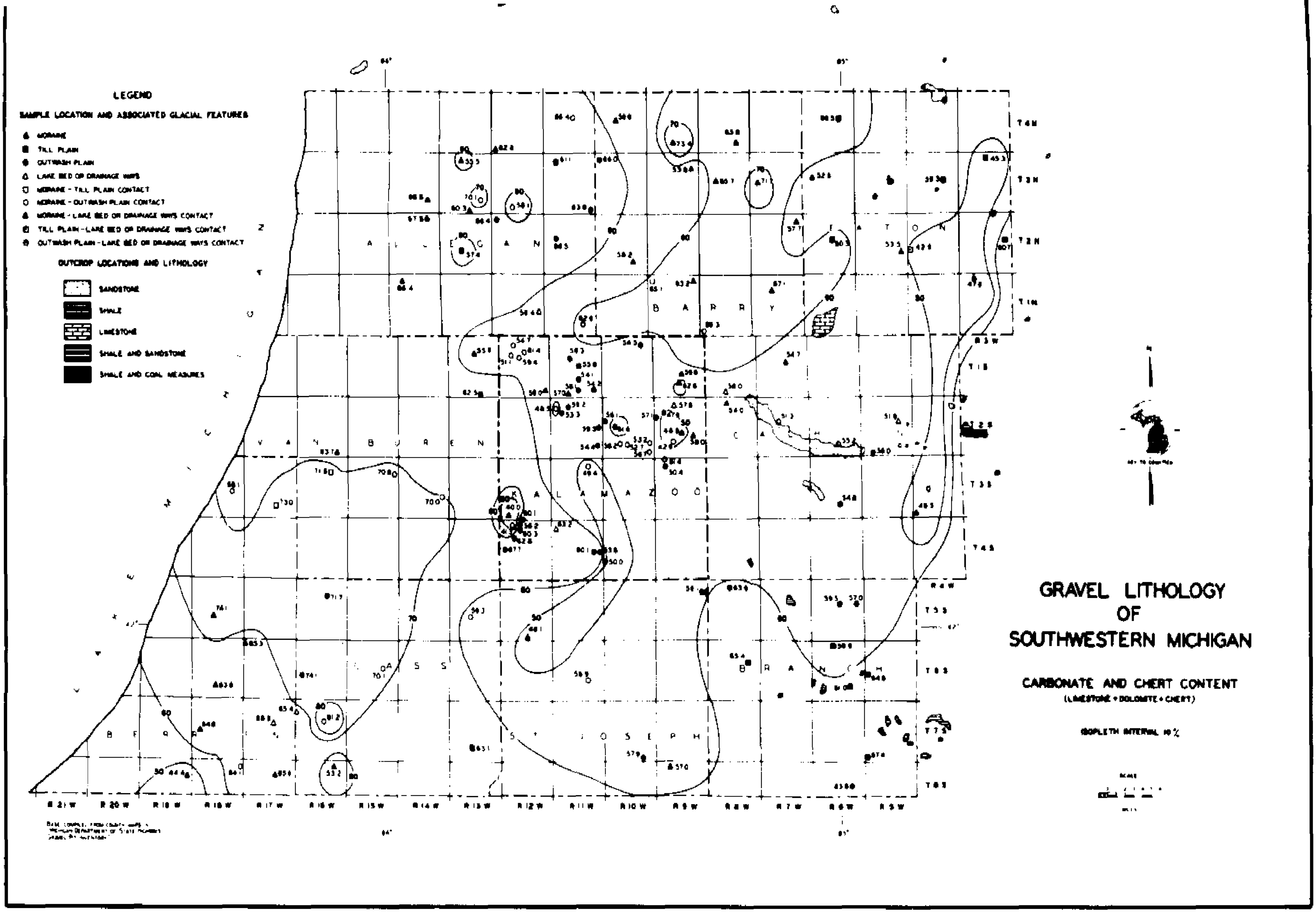


Figure 33. Carbonate and Chert content in Southwestern Michigan.

the carbonate and chert content of the Lake Michigan lobe sediments is above 60 per cent, and in some areas, presumably near the Devonian carbonate source (Fig. 19), is above 70 per cent. Values below 60 per cent could be because of the dilution from the increased amount of clastics (Fig. 37). The carbonate and chert content of the Saginaw lobe sediments is in general less than 60 per cent, and in some areas it is below 50 per cent for the same reason given in the case of the Lake Michigan lobe (Plate I). Values above 60 per cent, northeast of Kalamazoo County are probably due to bedrock erosion of cherty Bayport limestone of upper Mississippian age, and some carbonates of Pennsylvanian age. The writer has observed slightly higher dolomite content in the Lake Michigan lobe sediments than the Saginaw lobe sediments. Dolomite may have come from cherty dolomitic lenses in the Coldwater shale; or from any other source in the Lake Michigan basin. The 60 per cent isopleth passing through western Kalamazoo County seems to be the arbitrary lithologic interlobate line. Increased values in the southeastern part of Branch County may again be due to the contamination from the Erie lobe sediments.

Sandstone Content

The sandstone content map (Fig. 34) does not show any clear pattern distinguishing the Lake Michigan lobe sediments from the Saginaw lobe sediments. In general a

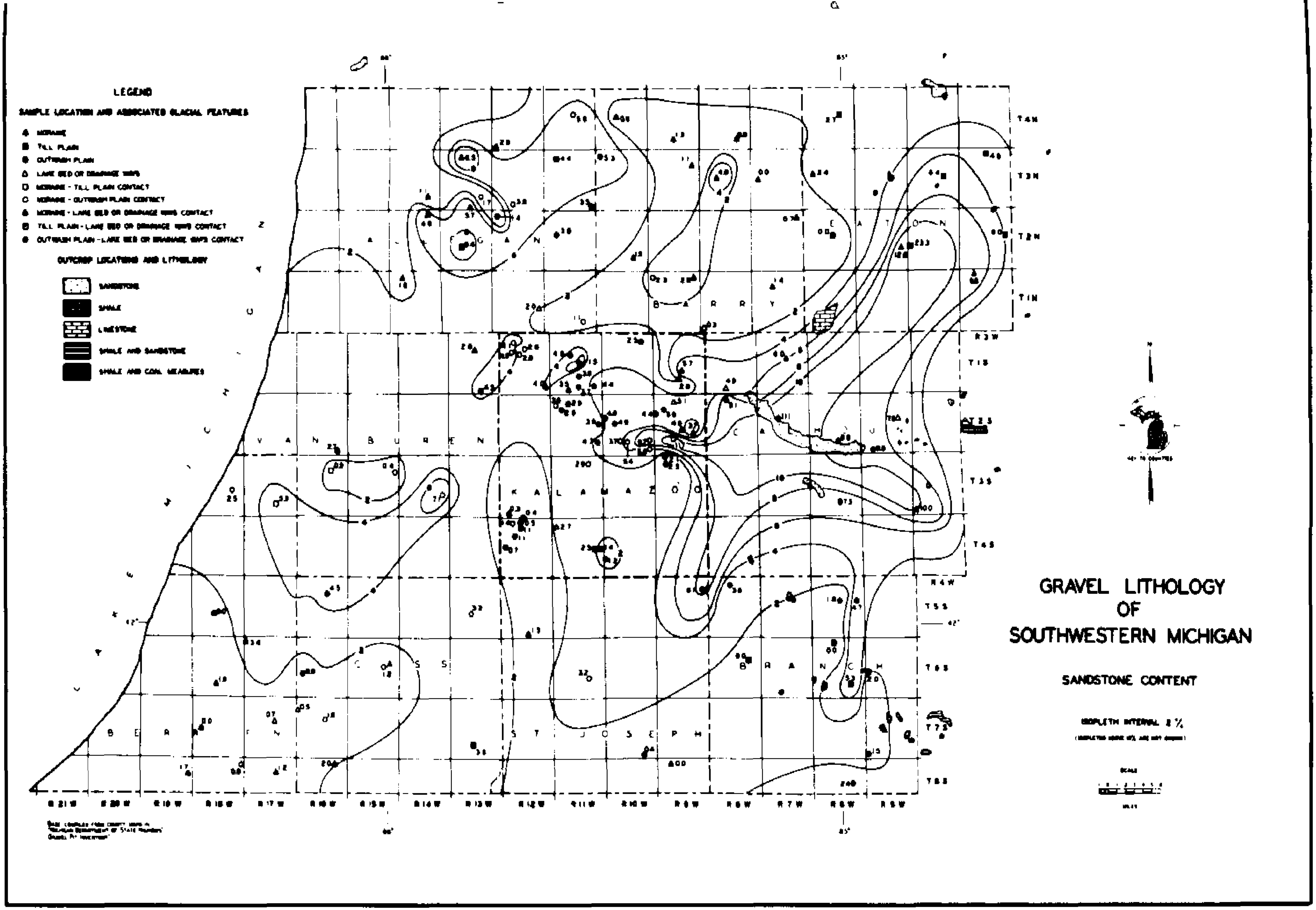


Figure 34. Sandstone content in Southwestern Michigan.

high concentration of sandstone is clearly observed near sandstone outcrops and thin drift areas. Lower Mississippian and Pennsylvanian sandstone formations are mainly responsible for the sandstone content of this area. The pattern in Eaton and Calhoun counties shows a clear relationship between the source area and dispersal by the glacial flow.

Siltstone and Shale Content

Siltstones and shales (Fig. 35) are more uniformly distributed in the Saginaw lobe sediments. These show spotty distribution in the Lake Michigan lobe sediments, with very high values in isolated areas. The pattern showing high values in the Calhoun County area more or less matches with that of the chert content (Fig. 32) in the same area indicating local provenance and similar dispersal by glacial flow from the northeast. Most siltstones and shales of the Saginaw lobe are presumably derived from the underlying Coldwater formation.

Extremely high values in southwestern Kalamazoo County can be explained by local influx of siltstone and shale derived from the Coldwater formation, by glacial plucking of pre-glacial valley floors in Van Buren County, i.e., by Lake Michigan ice. Glacial plucking can be suspected because of the isolated and disconnected bedrock lows in this area (Fig. 21). High siltstone and shale content in Berrien and Cass counties may be due to the

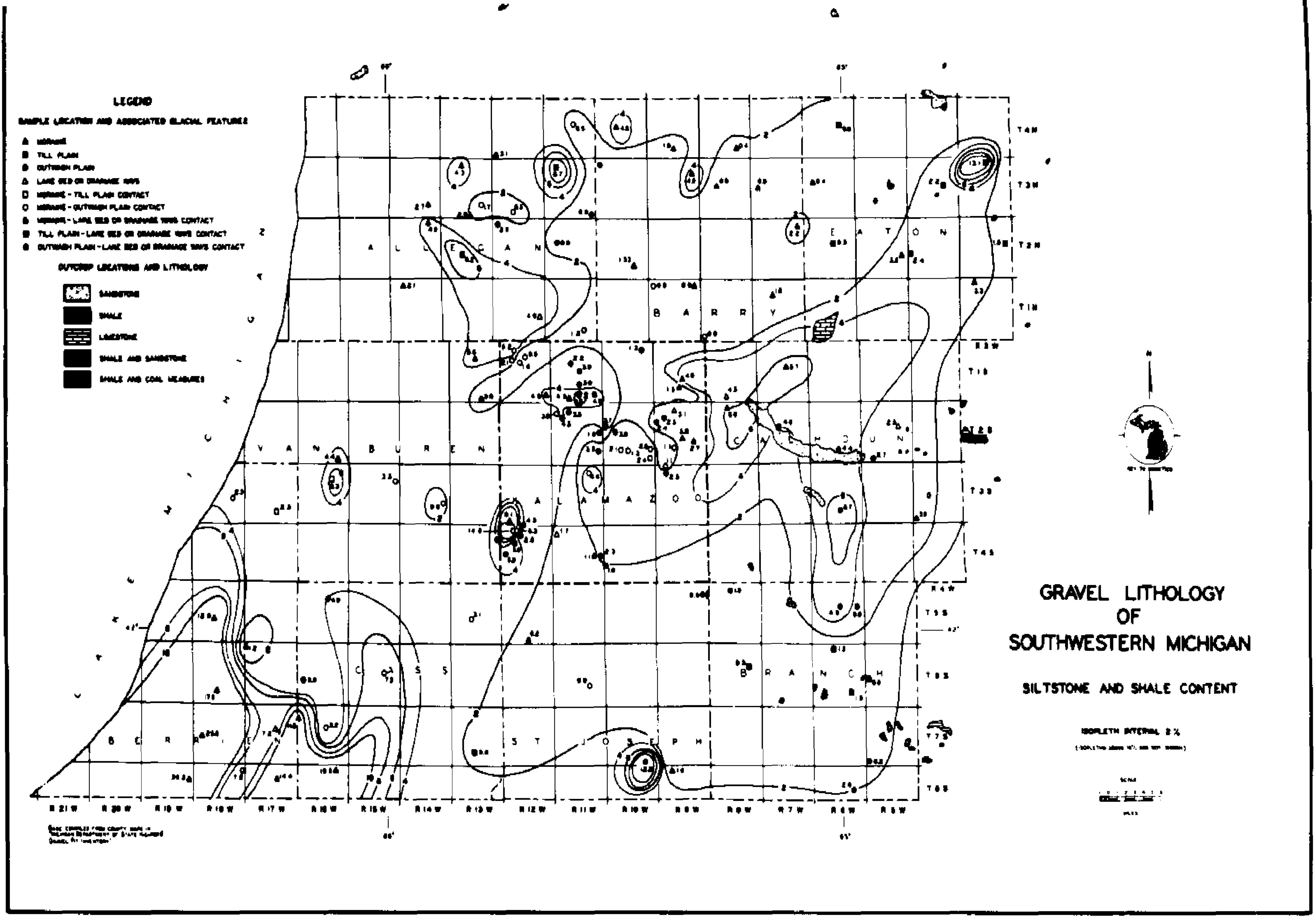


Figure 35. Siltstone and Shale content in Southwestern Michigan.

erosion and glacial plucking of the Ellsworth-Antrim shales by Lake Michigan ice. A 2 per cent isopleth in western Kalamazoo County seems to indicate the arbitrary lithologic interlobate line.

Clay Ironstone Concretion Content

The map in Figure 36 shows mostly less than a 2 per cent clay ironstone concretion content in the Saginaw lobe sediments, while values of clay ironstone concretions in the Lake Michigan lobe sediments show extremely high concentrations in isolated areas such as southwestern Kalamazoo County. This again can be explained by glacial plucking and abrasion of the source rock. It is suggested that most of these concretions are derived from the Coldwater formation, with some from the Lower Marshall formation, and a few from other formations. Antrim shales are known to contain these concretions, but low values in Berrien County do not seem to correlate with the high values of siltstone and shale content (Fig. 35) in the same county. The 2 per cent isopleth passing through Kalamazoo County seems to indicate, once more, the arbitrary lithologic interlobate line. Once again it is brought to the attention of the reader that, the 1.8 per cent clay ironstone content of a sample, from the northern part of the Kendall moraine in the extreme northeastern corner of Van Buren County, correlates with the Saginaw lobe sediments.

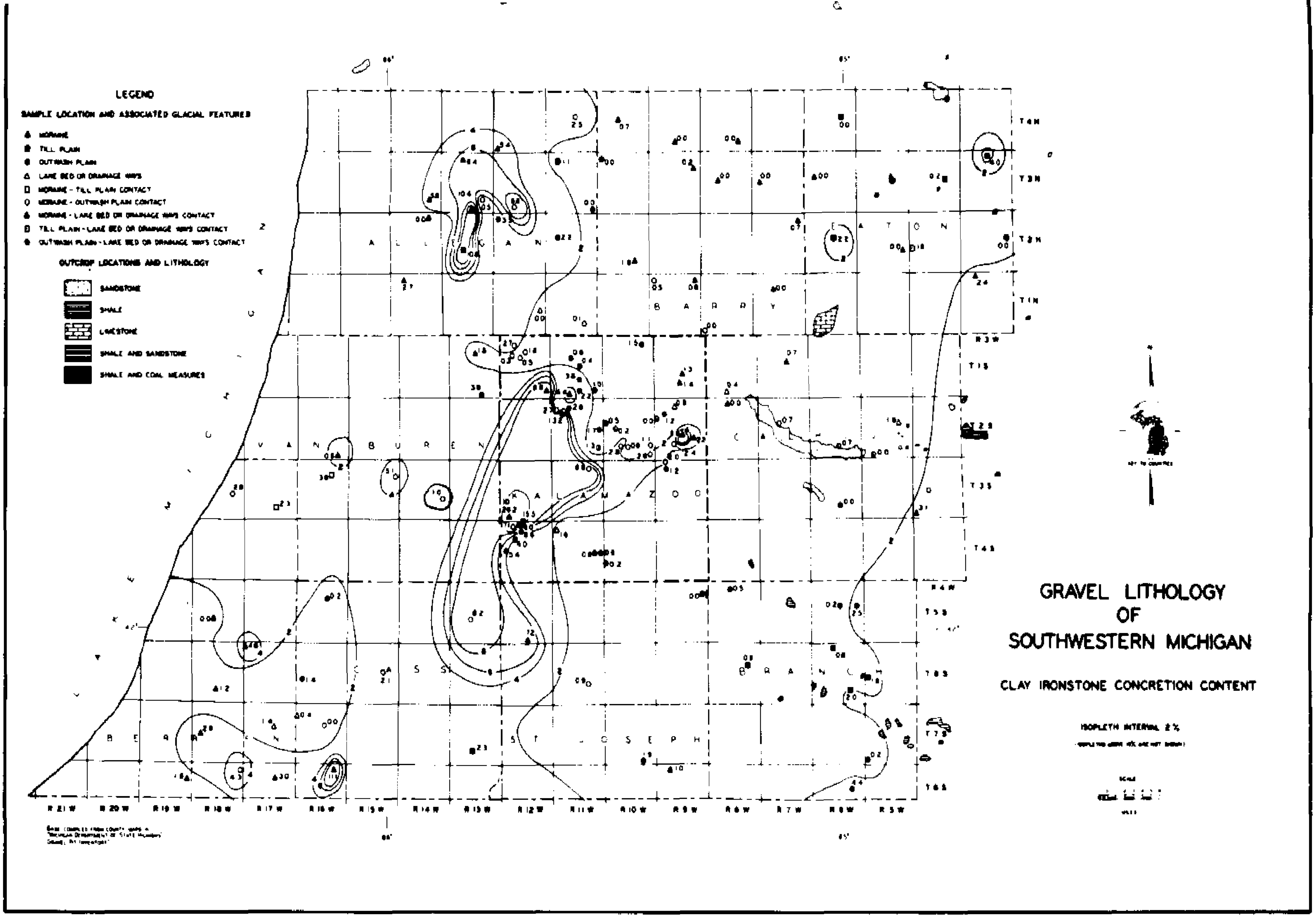


Figure 36. Clay Ironstone Concretion content in Southwestern Michigan.

Clastic Rock Content

The total of clastic lithologies plotted on the map (Fig. 37) do not seem to form a clear pattern indicative of the both lobes. Patterns in this figure do not exactly correlate with patterns in Figures 34, 35, and 36, but they show the net effect of all three lithologies together. For example, in some areas, the effect of the high values of one lithology is neutralized by the low values of another lithology, and wherever the high values of two lithologies fall together in one place, they tend to intensify the effect. This is due to the random distribution of local lithologies in the drift, though this is not indicated in Figures 29, 30, and 31 where the distribution is more uniform.

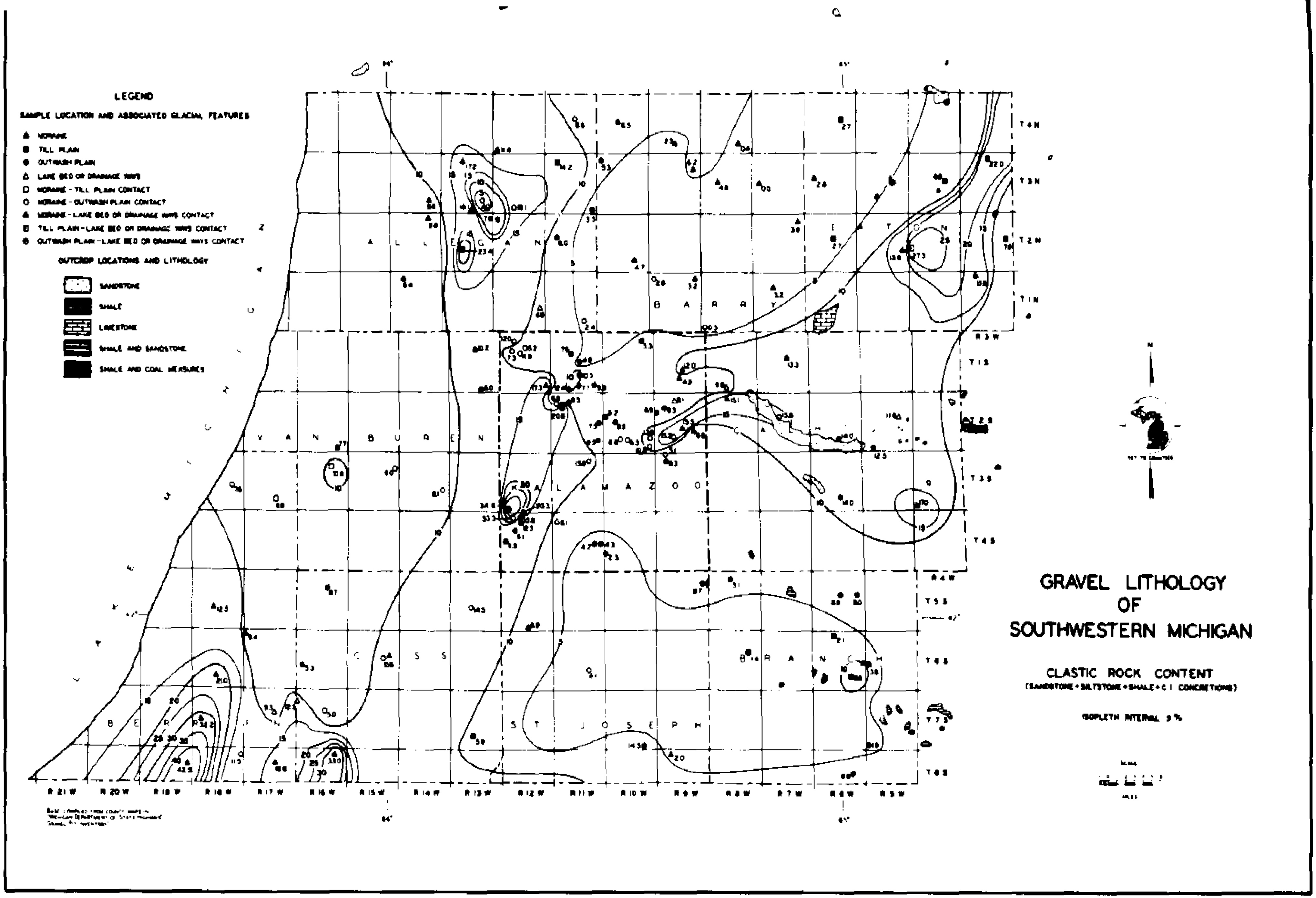


Figure 37. Clastic rock content in Southwestern Michigan.

CHAPTER XI

ECONOMIC CONSIDERATIONS

The role of the geologist is a very essential one in the sand and gravel industry, which is considered the largest (tonnage-wise) mining industry in the world. The sand and gravel industry is expanding as a new highway program and other construction projects are increased. In 1969, Michigan alone produced 58,092,000 short tons of sand and gravel valued at $58,968,000, thus ranking second nationally in production. Most of this tonnage was mined in areas adjacent to the larger metropolitan areas of the state. About 1.6 per cent of the total sand and gravel output was processed in Kalamazoo County. In 1969 this county produced 941,000 short tons worth about $1,163,000.

As sand and gravel production in Michigan increases every year, it is a fact that presently known gravel sources are depleting rapidly. There is a need for locating additional sand and gravel resources for servicing future highway construction and planning future building construction.

Sand and Gravel Economics

In recent years, depletion of material and the new zoning laws which have been involved because of increasing environmental concerns, has made the industry ask the geologist for help in locating suitable new sand and gravel resources. The average layman thinks that sand and gravel deposits of glacial origin are everywhere in Michigan and that the supply is unlimited. But he is not aware of the fact that these deposits have to meet certain specifications in terms of gradation and composition. In fact, an economically feasible sand and gravel deposit must meet specific physical and chemical characteristics. If the deposit does not meet these requirements, the quality of that deposit can be upgraded to the required standard by using different beneficiation methods. Note is made of all these concerns in this chapter.

Industry and Cost

In 1969 there were eight sand and gravel producers operating in Kalamazoo County. Among these, the American Aggregate Corporation was the principal producer. American Aggregate Corporation's sand and gravel pit is the largest in the county. It is located in Cooper Township along the west bank of the Kalamazoo River, about one mile east of Cooper Center. Although sand and gravel can be produced throughout the county, the low value and high transportation cost have demanded that the production be concentrated near the city of Kalamazoo and major highways (Fig. 38). Presently, processed gravel in Kalamazoo County costs slightly more than a dollar per short ton on the average. This cost may increase in the near future when all useable sand and gravel sources near the metropolitan area and major highways are depleted. Then it will become necessary to transport aggregates from the rural and suburban areas into metropolitan centers.

Beneficiation

In recent years, the demand for premium aggregates has rapidly increased, because of the rigid standards of quality control and increasing technology in the field of concrete mixing. Deposits of inferior material can be upgraded by several beneficiation methods. Detailed discussion of specific beneficiation methods is, of course, beyond the scope of the present study. The reader is directed, however, to Lenhart (1962), Kneller (1964), and Wingard (1969) for a more comprehensive discussion of the sand and gravel beneficiation methods, problems of processing specific rock types, and specification standards set by different agencies for concrete aggregates.

Lenhart discussed the Heavy Media Separation (HMS) method in detail along with general discussion of the sand and gravel industry. Kneller describes the following six commonly used beneficiation methods: (1) screening, washing, and crushing; (2) jigging; (3) elastic

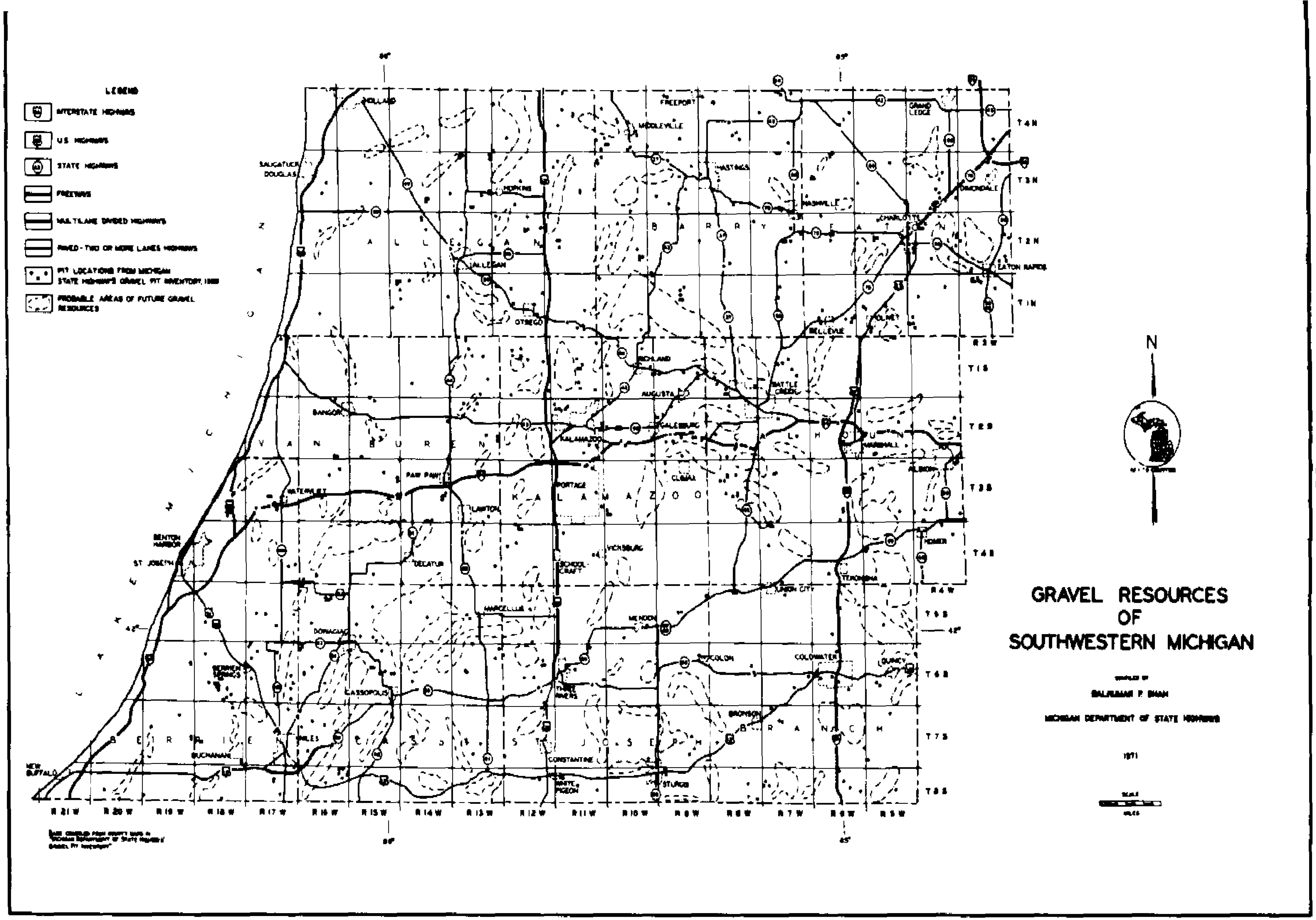


Figure 38. Gravel resources of Southwestern Michigan.

fractionation (bounce modulus); (4) cage mill disintegrators; (5) heavy media separation (HMS); and (6) the one-two-punch system which combines the elastic fractionation and the heavy media separation methods. Wingard has very briefly discussed the HMS process and problems of upgrading some deleterious gravels in some areas specifically in southern lower Michigan.

The Heavy Media Separation (HMS) or the so-called "Sink-Float" process, using heavy media of specific gravity between 2.50 and 2.60, usually produces the premium aggregates required by the Michigan Department of State Highways. The disadvantage of the HMS method is that it will not eliminate high-gravity deleterious (undesirable) material such as clay ironstone concretions. It is an expensive method but certainly the most suitable process for production of superior quality material.

Potential Building Aggregates

With increasing needs of the large sand and gravel industry, it has become necessary for a geologist to outline areas of potential building aggregates. To do this, it is necessary to study the locations of abandoned and presently operating sand and gravel pits. This is the approach used in the present study area. Attempts are made on the map (Fig. 38), "Gravel Resources of Southwestern Michigan," to outline the probable areas of future gravel resources. These areas are outlined, taking into consideration the gravel pit location pattern and assuming that coarse gravel (required for the highway construction) can most likely be found near the transitional boundary between moraine and outwash deposits. This map is just a guide for prospecting for future sand and gravel deposits. It should be used with great caution and, of course, also with a detailed geologic study of the location. It may prove to be unsatisfactory in some areas.

Gravel Pit Locations

Gravel pit locations which are shown on the gravel resources map are taken from the Michigan Department of State Highways'gravel pit inventory (1966). These include all abandoned and operating pits from which the MDSH purchased aggregates through the end of 1966. In Kalamazoo County, some additional pits are shown which were discovered and sampled at the time of field work for this study.

Highways, Population, and Gravel Pit Density Relations

The gravel resources map shows in general that the density of gravel pit locations is higher near the population centers (cities and towns) and highways, and decreases away from them. This relationship exists because of one or both of the following factors: (1) low values and high hauling costs demanded that production be concentrated near the major population centers and highways;

and (2) unfavorable and unidentifiable glacio-morphological conditions (e.g., transitional zones) which usually produce gravel reserves but not easily found to date. With rapid depletion of sand and gravel reserves and stockpiles near cities, towns, and present highway systems, it will become necessary to explore these potential areas more fully for sand and gravel, even though the costs will become higher.

Ground Water in Kalamazoo County

The major supplies of ground water in Kalamazoo County comes from aquifers in the glacial drift. Minor supplies come from wells penetrating the Marshall sandstone (Fig. 19) in the northeastern part of the county. The Coldwater shale which underlies the glacial sediments throughout the county, and other Paleozoic rocks that underlie the Coldwater formation, have little or no potential for future ground water development. Glacial sediments are the source of water in most of the wells in the county, and these have considerable potential for future development.

Ibrahim (1970) pointed out that the water-saturated glacial sediment thickness is small where the drift thickness is low and hence in such situations the possibility of developing suitable aquifers is minimal. He also noted that areas of large thickness in glacial sediments are more favorable for locating aquifers of appreciable thickness and suitable yield. Further, Ibrahim points out that bedrock channels are especially favorable for locating ground water aquifers, also discussing more specific areas, including bedrock channels, possible quite suitable for high yields of ground water.

It has also been noted by Deutsch, Vanlier, and Grioux (1960) that permeable outwash and channel deposits are good sources of water for wells of large capacity. Higher permeability sand and gravel beds between lower permeability till in moraines locally yield larger supplies of fresh water. This situation sometimes develops more than one aquifer. In general, two aquifers (upper and lower) are reported (Deutsch et al., 1960; Reed et al., 1956; Ibrahim, 1970; Allen, 1972) in some areas of the county, especially in the city of Kalamazoo and vicinity. The thickness of these two aquifers varies from place to place, and they are separated by about 30 to 40 feet of less permeable material. In this area, several water wells are located along or near the Kalamazoo River and other streams, so that pumping of wells in such an area will induce the migration of water (Travis, 1966, and Allen, 1972) from the stream toward the wells. In this case, polluted rivers and streams can pollute the ground water in this area. The waters of the Kalamazoo River, which is the largest surface drainage in Kalamazoo County, and the Portage Creek are already polluted, so there is urgent need to clean up these rivers and creeks and stop discharging industrial and other wastes into them.

Subsurface and ground water information must be considered before excavating for future sand and gravel deposits to be used in planning for future highways. It is already clear that much care must be taken not to disturb natural aquifer conditions existing in the glacial sediments.

Environmental Application

A map (Fig. 39) of the geologic environment for solid waste disposal in Kalamazoo County was prepared by using the surface and subsurface information gathered for this study. Most of the subsurface information comes from water well logs and oil and gas logs. About 230 well logs were used, and their locations are plotted on the map.

Three types of areas are outlined: satisfactory, less satisfactory, and unsatisfactory for solid waste disposal and for planning other land uses. An explanation for the delineated areas is given on the map, which should be consulted before locating sanitary landfill sites. The present guidelines developed by the Illinois State Geological Survey, and followed by the Michigan Geological Survey in cooperation with the Department of Public Health, require a minimum of 25 to 30 feet of clay or relatively impermeable material between the base of a landfill and the shallowest underlying water-yielding aquifer. With

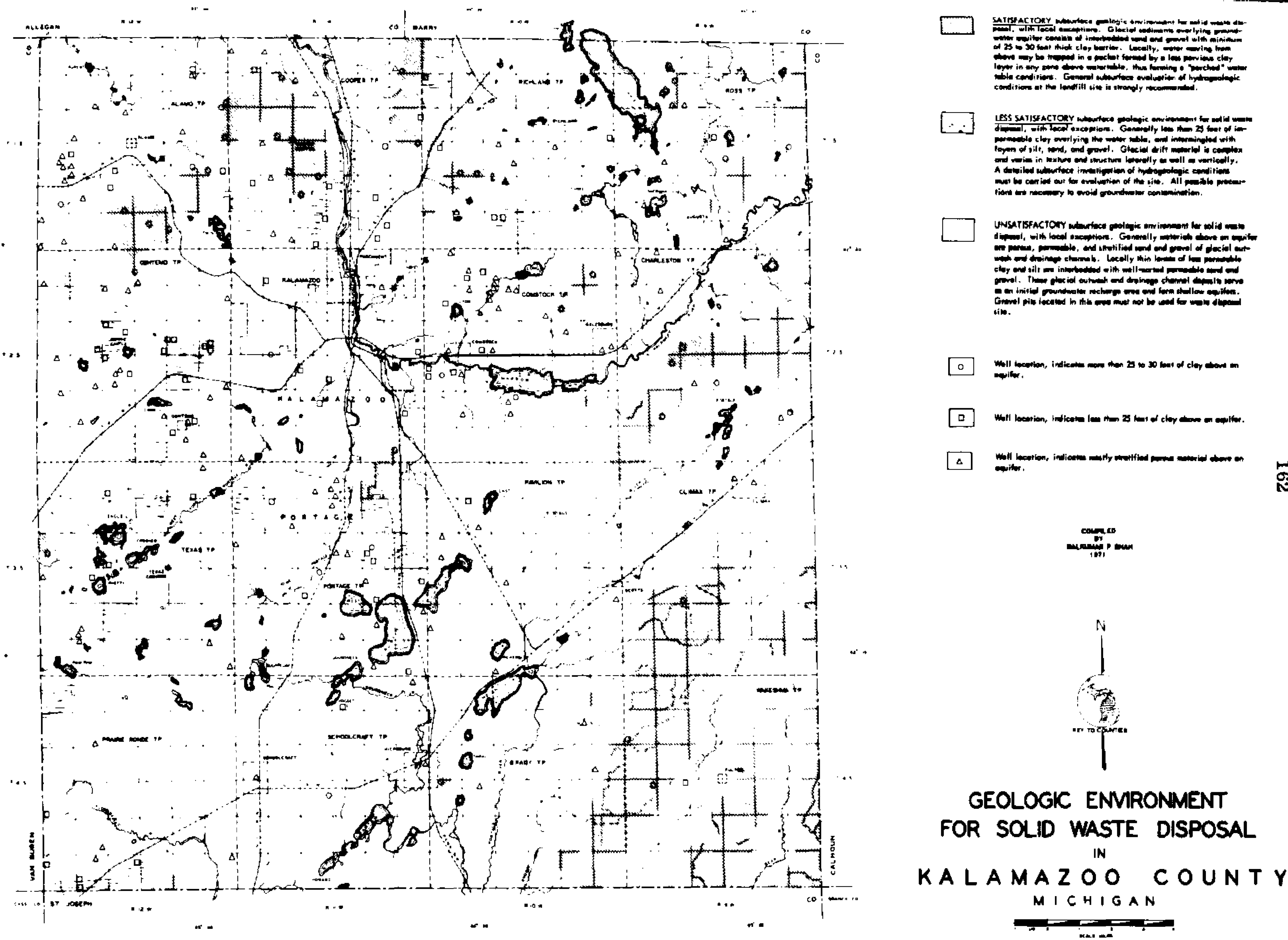


Figure 39. Geologic environment for solid waste disposal in Kalamazoo County, Michigan.

this criterion kept in mind, the map in Figure 39 was prepared. This map also is but a guide for giving preferences to different areas for quick location of a proper landfill site.

CHAPTER XII

AGGREGATE SUITABILITY FOR ENGINEERING USAGE

Variations in lithologic composition and distribution of glacial materials, which are direct products of the geologic history of the area, are discussed in Chapter X. Their economic considerations are noted in Chapter XI. Discussion in the present chapter is brief, and relevant to the few important properties of aggregates determined in this study affecting their performance in concrete.

Several other factors relating to aggregate suitability and the engineering test results are discussed by Wingard (1969) in his work, carried out in the Research Laboratory Division of the Michigan Department of State Highways prior to the present study. The reader is directed to Wingard's work for more details. There are several other good sources of information regarding the application of petrography and other geologic information in the evaluation, selection, processing, and use of aggregates in concrete and elsewhere. A few of these are listed, along with other related references, in the reference section at the end of this paper.

Properties and Performance of Aggregates

In the world of today, Portland cement concrete is still a construction material of fundamental importance and unique versatility. The design and control of concrete many times depends on the physical, chemical, and lithological properties of the materials used. Aggregates generally occupy 60 to 80 per cent of the volume of concrete, and also influence mix proportions and economy. They must conform to certain requirements for certain types of jobs. There are many causes of inferior quality or failure of concrete, of which two are given special attention in this study and discussed briefly as follows.

Physical Strength and Chemical Reactivity

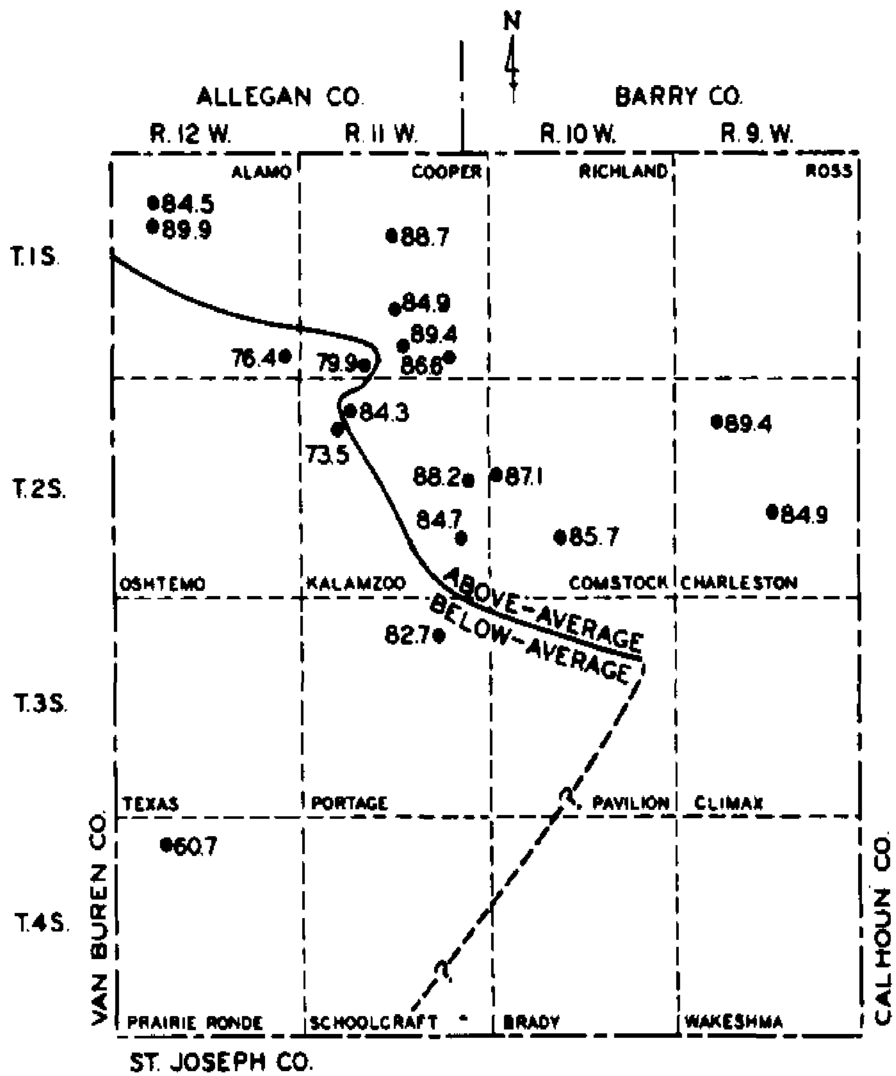
Physically weak and chemically reactive particles can lead to the deterioration or failure of concrete, whereas an increased number of physically sound and chemically nonreactive rocks can strengthen the concrete. The effects of these properties are also discussed by Wingard. Methods for determining these two properties are outlined in Chapter IX of the present report.

Total percentages of the physically strong and chemically nonreactive particles for each channel sample (1 through 18) in Kalamazoo County were determined.

Values for each sample location are shown in Figures 40 and 41. The average mean value for all 18 samples was determined as shown in these figures and an arbitrary line separating the above-average from the below-average values has been drawn. It is obvious from these figures that the arbitrary lines coincide in general with arbitrary lithologic interlobate lines on the lithologic maps discussed in Chapter X, i.e., note the maps in Figures 29 to 37. In both of the Figures 40 and 41, the values which are above-average appear to correlate with the Saginaw lobe sediments, presumably because of the comparatively high crystalline rock content in that lobe. Values which are below-average appear to correlate with the Michigan lobe sediments, presumably because of the comparatively high clastic rock content in that lobe. This observation reveals that even engineering properties of aggregates are directly related to the lithologic distribution (because of different provenance) of drift materials and of course, also their provenance. For planning and exploration purposes, attention is, of course, drawn to the solid lines in these figures and their positions with respect to the township borders for the purpose of explicit location.

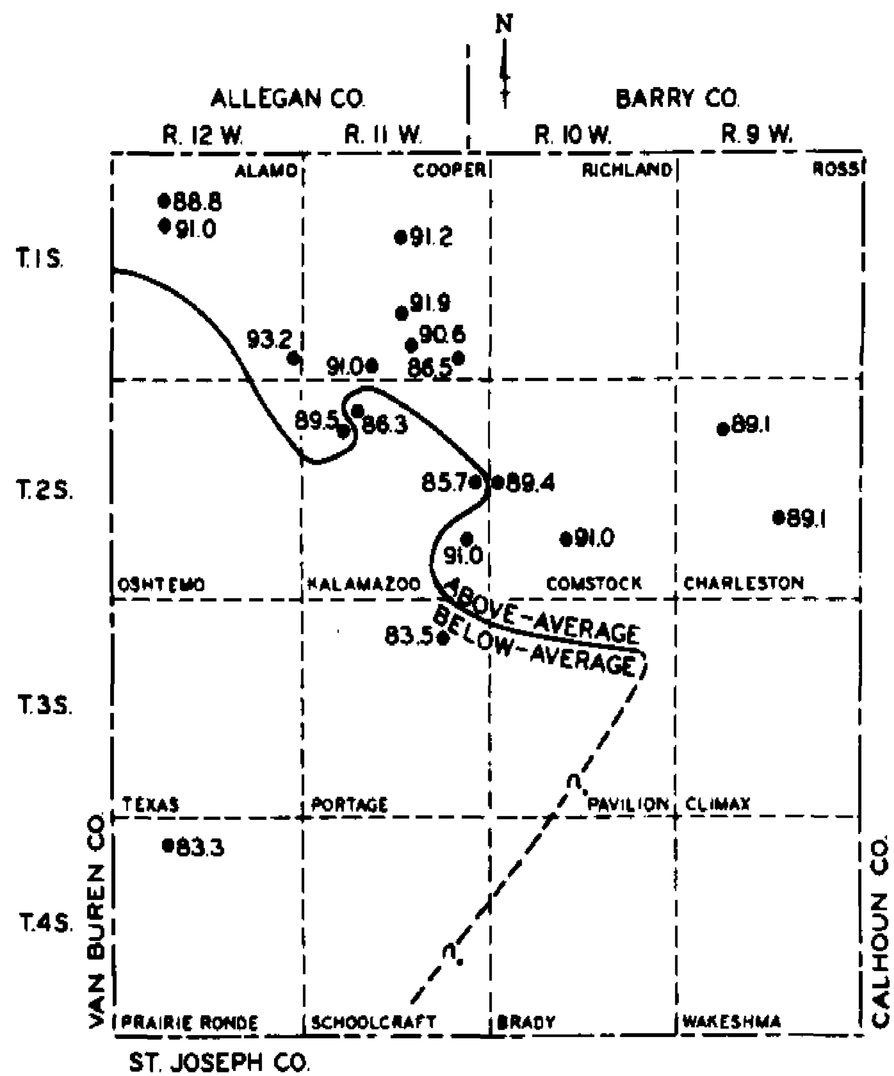
Deleterious Aggregates and Their Desirability in Concrete

Physically unsound and/or chemically reactive particles are considered deleterious (undesirable) in



(Above-average values relate to the Saginaw lobe sediments and below-average values relate to the Lake Michigan lobe sediments. Average value: 83.4).

Figure 40. Percent distribution of Physically Strong particles in near surface drift of Kalamazoo County, Michigan.



(Above-average values relate to the Saginaw lobe sediments and below-average values relate to the Lake Michigan lobe sediments. Average value: 89.0).

Figure 41. Percent distribution of Chemically Non-reactive particles in near surface drift of Kalamazoo County, Michigan.

concrete. Usually weak, friable, or weathered and laminated aggregate particles are physically unsound, and hence not desirable. Especially friable sandstone, siltstones, shales, clay ironstone concretions, weathered cherts, leached limestones, and highly weathered crystallines are physically unsound; rocks with free amorphous silica and iron oxide, like porous cherts, cherty or siliceous limestones, siliceous shales, phyllites, and other minor rock varieties are chemically reactive. All above listed rocks should be avoided as much as possible if one is to assure the best quality of concrete.

CONCLUSIONS, ACADEMIC AND ECONOMIC

1. Detailed glacial mapping of an area, preferably as large as a county, is essential for the systematic evaluation of sand and gravel deposits and for future highway planning. Also, it helps a great deal in the groundwater studies.

2. The channel sampling method, even though more lengthy and tedious, gives a representative sample of glacial sediments and reveals more valuable information. The pebble volume is quick and more economical, but its applications are limited, and it can be only used for a broad scale reconnaissance study of the large areas.

3. On the basis of rock-stratigraphy, morpho-stratigraphy, time-stratigraphy, and soil-stratigraphy a viable glacial history of the area is worked out. It is suggested that at the Cary time, the terminal behaviors of the Lake Michigan lobe and the Saginaw lobe were out-of-phase with each other.

4. Field evidences and gravel lithologies indicate that the Saginaw lobe ice covered Kalamazoo County first, and after it started retreating, the Lake Michigan lobe ice advanced, pushing the material eastward and overriding its own bold Kalamazoo moraine along with the Kendall and the Alamo moraines built earlier by the Saginaw ice. This eastward pushing produced several weak and parallel moraines including the Tekonsha in eastern Kalamazoo County.

On the basis of morpho-stratigraphy and rock-stratigraphy a somewhat arbitrary interlobate line is suggested (Plate I).

Following weak line of evidences put together strongly supports the interpretation of overriding and the placement of an interlobate line. These evidences are briefly reiterated:

A. Presence of what appears to be an example of ablation till over the Kalamazoo moraine of the Lake Michigan lobe.

B. Lithology of the Alamo and Kendall moraines is similar to that of the Saginaw lobe sediments.

C. Presence of the Precambrian jasper conglomerate and tillite (index erratics of the Saginaw lobe) in the Kalamazoo and Kendall moraines.

D. Presence of thin till plains over outwash plains in Cooper and Prairie Ronde townships of Kalamazoo County.

E. Fluctuation of lithologic interlobate line within 4 to 6 mile zone east of the Kalamazoo moraine (see Figs. 29-37).

F. Presence of weak push moraines east of the Kalamazoo moraine, and they are parallel to the moraines of the Lake Michigan lobe. They may indicate glacial surges or usually strong pulsations in the Lake Michigan lobe in consequence of differing of flow-lags.

G. Axes of elongated lakes in Kalamazoo County are parallel to the moraines of both lobes.

H. The heads of glacial drainage, the originating point in the Tekonsha reentrant district mark the related ice margin and provide the clue as to the direction of the former ice flow.

5. In a broader sense, the correlation between surface topography, drift thickness, and bedrock configuration is inversed in Kalamazoo County. This observation is illustrated by the geologic cross sections of the county.

6. In Kalamazoo County, there is a general agreement between the lithologic composition of parent materials, and properties of some soil types.

7. Significant lithologic differences exist among the Lake Michigan lobe and the Saginaw lobe sediments; and an investigation of the relative proportion of lithologic types appears to be the most fruitful method for exploration and evaluation of gravel resources of these two lobes.

8. The Precambrian lithologies play a valuable role in differentiating the Lake Michigan lobe sediments from the Saginaw lobe sediments. In general, the Precambrian lithologic content of the Saginaw lobe is higher than the Lake Michigan lobe in southwestern Michigan.

9. Local Paleozoic clastic lithologies display greater variations between the two lobes. Therefore, sometimes local clastics content alone can not be used very successfully in differentiating between two lobes in southwestern Michigan. A relatively high amount of clastics in isolated areas indicates extensive bedrock erosion and plucking by the glacier ice. It also indicates a relatively close source area.

10. Regional knowledge of the glacial geology and petrographic analyses provides the basis for predicting regional trends of aggregate quality and potential areas of their sources.

11. Variations in gross lithology within each lobe in Kalamazoo County are also reflected by the regional variations in the engineering properties, such as physical strength and chemical reactivity.

12. The gross deleterious rock content of sand and gravel deposits of the Saginaw lobe is slightly less than that of the Lake Michigan lobe in southwestern Michigan. It is strongly recommended that all the deposits investigated must be beneficiated in varying degrees to meet the specifications set by the Michigan Department of State Highways and other agencies for use in concrete. The isopleth maps in Figures 28 through 37 help an investigator to recommend what beneficiation process is needed to upgrade a given deposit.

SUGGESTIONS FOR FURTHER RESEARCH

The writer believes that there is a place and a need for future studies of this type in the fields of highway planning and research, sand and gravel industry, ready-mixed concrete industry, asphaltic concrete industry, soil surveys, ground-water surveys, and economic resource surveys for the state and federal agencies. It is hoped that the geological approach in this research, will serve as a basic model for future detailed studies of this kind. Further information in the following areas will be helpful for future evaluation of natural aggregate sources in the state of Michigan and elsewhere.

1. This type of study is more essential in glaciated interlobate areas in Michigan or elsewhere for determining the distribution of natural aggregates.
2. Studies of the performance of deleterious aggregates in concrete subjected to severe weather conditions should be carried out with varying size and composition of natural aggregates.
3. An updated and a detailed bedrock configuration map of Michigan is essential for a glacial, a

subsurface, and a petroleum geologist, and for an engineer. This type of map can be useful in various phases of their work.

4. Detailed petrographic physical and chemical properties of various rocks outcropping in the state should be determined to know about their possible use for highways and other construction.

5. Closer relationships should be established between the composition of surface aggregates and engineering properties of soils.

6. Clay content and minerology of shales and tills in the drift may be helpful to determine possible sources of clays.

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GLOSSARY

GLOSSARY

The following terms, as used in this dissertation are explained for purposes of consistency in the text. These definitions are also deemed adviseable for readers not fully familiar with the language of glacial geology, and as well to insure clarity because of some ambiguity in the use of these and alternative nomenclature in the literature.

Ablation till: Till deposited during downwasting (ablation) and recession of a glacier. Such till is frequently more sandy than basal or linear moraine tills, and is found directly at the surface of the ground and often overlies more clayey lodgement till.

Age: Any major period of time in the history of the earth or the material universe marked by special phases of physical conditions or organic development. In this dissertation this term is specifically applied to the Wisconsinan glaciation, because in the literature age is commonly used for reference to the deposits of earlier glaciations of the Pleistocene, e.g., Illinoian age deposits.

Flow-lag: The lag in years whereby the effect of significant changes in the névé are expressed by advances, stillstands, or retreats in the terminal area of a glacier.

Holocene: The term which is generally used for reference to the time interval since retreat of the last major ice advance of the Wisconsinan age, i.e., usually this represents the last 10,000 years.

Interlobate line: An interpretive line drawn between deposits and geomorphic features from two adjacent glacial lobes. Such an interlobate line in this dissertation (see Plate I) is drawn from evidences given by the lithologic distribution (see Figs. 29-37) and the geomorphology of an area. It is not always a sharp line, but rather a zone, in some cases 4 to 6 miles wide, in which weak and parallel moraines are found.

Isopleth: A line of equal abundance or magnitude, in this dissertation used to show changes in average lithological composition of glacial gravels.

Névé area: Accumulation area or nourishment zone in the upper part of glaciers (in the broadest sense, the ice centers of continental glaciation). A névé is composed of consolidated granular snow "not yet changed to glacier ice," called firn.

Parma till: An early Wisconsinan or Illinoian (?) basal till, which is characterized by considerable induration, hence actually a tillite. This tillite was exposed in May, 1971 by sewer treatment excavations and subsequently buried. The writer observed the outcrop southeast of the Parma, Jackson County, Michigan near a series of turf farms. The till is composed of angular fragments of Bayport-type (?) limestone and what appear to be rounded pre-Cambrian pebbles. It overlies Parma sandstone and lies at shallow depth below muck (turf) and bogs in this region. The tillite has been weathered substantially, with a surface gossan which separates easily into a limonite-stained powder.

Pleistocene: The Pleistocene is the latest epoch of the Tertiary Period (Cenozoic Era). This epoch is subdivided into four major glacial ages, the Nebraskan, Kansan, Illinoian, and Wisconsinan, taken in order from oldest to youngest.

Plexal zone: An area in which a differential forward movement of ice has created contrasting relations between older and newer geomorphic features of the same lobe and provenance. Thus making the chronological interpretation difficult. This single lobate sequence equates to the complexities of an interlobate sequence.

Provenance: Origin or source.

Stage: A time-stratigraphic unit, used as a time term for major glaciations of the Pleistocene epoch. In this dissertation it refers to subdivisions of the Wisconsinan age, because the term age is applied to subdivisions of the Pleistocene epoch.

Till: An unsorted mixture of boulders, cobbles, pebbles, sand, silt, and clay--deposited by the advance and retreat of glaciers.

Valley train: A long narrow body of outwash confined within a valley.

Wisconsinan: Latest major glacial age of the Pleistocene epoch.

APPENDIX

TABLE 3
GRAVEL LITHOLOGY OF KALAMAZOO COUNTY, MICHIGAN

SAMPLE NUMBER	LOCATION: 1/4	LOCATION: 1/4	LOCATION: SECTION	LOCATION: TOWNSHIP S.	LOCATION: RANGE W.	LOCATION: TOWNSHIP NAME	TYPE OF SAMPLE	PERCENT LITHOLOGY: ACID IGNEOUS	BASIC IGNEOUS	FOLIATED METAMORPHIC	NON-FOLIATED METAMORPHIC	CARBONATE	SANDSTONE	SILTSTONE AND SHALE	CLAY IRONSTONE CONCRETION	POROUS CHERT	DENSE CHERT	OTHERS	TOTAL	TOTAL PEBBLE COUNTS OR VOLUME	PERCENT GROUP LITHOLOGY: CRYSTALLINE	CARBONATE AND CHERT	CLASTIC	*PERCENT DELETERIOUS (SILTSTONE + SHALE + C. I. CONC. + POROUS CHERT + DENSE CHERT)	ASSOCIATED GLACIAL LOBE(S)
1	SW	SE	8	1	12	Alamo	Channel	7.60	4.80	9.20	19.30	38.30	4.90	2.10	0.30	6.60	6.20	0.70	100.00	1000	40.90	51.10	7.30	15.20	Lake Mich.-Sag. Interlobate
2	NE	SE	16	1	11	Cooper	Channel	6.40	6.60	6.60	12.80	45.80	4.80	2.20	0.60	6.00	6.50	1.70	100.00	1000	32.40	58.30	7.60	15.30	Lake Mich.-Sag. Interlobate
3	SE	NE	36	1	12	Alamo	Channel	6.30	5.90	5.50	7.50	50.40	4.00	4.50	8.60	3.30	2.30	1.50	100.00	1000	25.20	56.00	17.30	18.90	Lake Michigan
4	NW	NW	27	1	11	Cooper	Channel	8.00	7.58	6.55	11.12	47.09	3.64	3.01	3.65	4.05	3.01	2.06	100.01	962	33.25	54.15	10.50	13.92	Lake Mich.-Sag. Interlobate
5	NW	NE	6	1	12	Alamo	Channel	8.40	6.30	5.50	11.90	42.40	4.10	5.20	2.70	7.60	4.70	1.20	100.00	1000	32.10	54.70	12.00	20.20	Lake Mich.-Sag. Interlobate
6	SW	NW	36	1	11	Cooper	Channel	8.82	6.76	7.51	11.43	41.46	4.35	4.57	0.98	9.79	2.94	1.31	99.92	919	34.51	54.19	9.90	18.28	Lake Mich.-Sag. Interlobate
7	SW	SW	33	1	11	Cooper	Channel	8.30	5.00	7.50	7.50	48.20	3.50	4.50	4.40	4.80	4.00	2.30	100.00	1000	28.30	57.00	12.40	17.70	Lake Michigan
8	NE	NW	34	1	11	Cooper	Channel	9.00	6.40	9.40	10.60	46.50	3.70	1.80	2.20	6.80	2.80	0.80	100.00	1000	35.40	56.10	7.70	13.60	Lake Mich.-Sag. Interlobate
9	SE	SE	13	2	11	Kalamazoo	Channel	9.40	6.23	6.33	9.60	43.51	3.88	1.84	1.74	11.75	4.29	1.43	100.00	979	31.56	59.55	7.46	19.62	Lake Mich.-Sag. Interlobate
10	SW	NW	18	2	10	Comstock	Channel	9.30	7.20	6.80	11.30	45.00	4.00	3.70	0.50	7.50	3.60	1.10	100.00	1000	34.60	56.10	8.20	15.30	Lake Mich.-Sag. Interlobate
11	SE	SE	5	2	11	Kalamazoo	Channel	9.60	5.60	5.60	10.10	46.00	2.90	3.80	2.80	9.60	3.60	0.40	100.00	1000	30.90	59.20	9.50	19.80	Lake Mich.-Sag. Interlobate
12	W1/2	NW	8	2	11	Kalamazoo	Channel	7.40	6.30	5.50	6.20	45.00	2.90	4.50	13.20	6.90	1.40	0.70	100.00	1000	25.40	53.30	20.60	26.00	Lake Mich.-Sag. Interlobate
13	NW	SE	25	2	11	Kalamazoo	Channel	8.40	6.90	6.40	11.60	49.10	4.30	3.90	1.30	5.40	1.90	0.40	100.00	1000	33.30	56.40	9.50	12.50	Lake Mich.-Sag. Interlobate
14	NW	SE	28	2	10	Comstock	Channel	10.10	7.90	6.50	14.00	43.20	6.40	1.30	0.60	7.10	2.40	0.50	100.00	1000	38.50	52.70	8.30	11.40	Lake Mich.-Sag. Interlobate
15	NW	SW	8	2	9	Charleston	Channel	12.10	8.30	8.20	13.10	35.70	5.60	2.50	1.20	8.40	3.50	1.40	100.00	1000	41.70	47.60	9.30	15.60	Saginaw
16	SW	SW	22	2	9	Charleston	Channel	8.60	8.40	7.00	10.20	39.20	4.90	3.80	6.80	7.80	1.90	1.40	100.00	1000	34.20	48.90	15.50	20.30	Saginaw
17	SE	SW	2	3	11	Portage	Channel	9.90	8.10	6.30	10.10	37.20	2.90	4.40	8.30	11.30	0.90	0.60	100.00	1000	34.40	49.40	15.60	24.90	Lake Mich.-Sag. Interlobate
18	NE	SE	5	4	12	Prairie Ronde	Channel	4.50	6.50	3.70	4.60	36.10	1.40	14.80	17.10	4.60	0.60	6.10	100.00	1000	19.30	41.30	33.30	37.10	Lake Michigan
19	SW	SW	4	2	9	Charleston	Channel	6.00	8.23	3.33	14.00	40.00	5.11	3.11	0.89	17.78		2.44	100.89	450	31.56	57.78	9.11	21.78	Saginaw
20	SE	SW	7	2	9	Charleston	Channel	10.23	5.34	1.56	18.67	33.56	4.44	2.44	0.00	23.56		0.22	100.02	450	35.80	57.12	6.88	26.00	Saginaw
21	SW	SE	17	2	10	Comstock	Channel	7.56	4.67	1.33	15.11	37.78	4.89	3.78	0.22	23.78		1.33	100.45	450	28.67	61.56	8.89	27.78	Lake Mich.-Sag. Interlobate
22	NE	NE	7	2	11	Kalamazoo	Channel	8.66	5.78	2.89	6.00	40.89	3.56	3.56	2.67	7.56		20.01	101.58	450	23.33	48.45	9.79	13.79	Lake Michigan
23	SW	SE	18	4	12	Prairie Ronde	Spot	3.67	11.51	1.39	3.51	55.75	0.73	5.79	5.39	8.82	3.10	0.33	99.99	2 liters	20.08	67.67	11.91	23.10	Lake Michigan
24	SE	SE	8	4	12	Prairie Ronde	Spot	9.99	8.86	2.58	3.79	57.37	1.13	5.88	4.03	4.75	0.64	0.97	100.00	2 liters	25.22	62.76	11.04	15.30	Lake Michigan
25	SW	SW	4	4	12	Prairie Ronde	Spot	4.39	13.50	3.37	3.12	54.77	1.09	2.78	8.61	3.63	1.88	3.54	99.98	2 liters	24.38	60.28	12.48	16.90	Lake Michigan
26	NW	NW	4	4	12	Prairie Ronde	Spot	4.56	11.24	3.80	1.10	52.75	0.51	6.34	8.96	2.45	1.01	7.27	99.99	2 liters	20.70	56.21	15.81	18.76	Lake Michigan
27	SW	SW	32	3	12	Texas	Spot	1.92	15.13	2.42	1.42	37.96	0.33	8.03	26.25	0.59	1.42	4.52	99.99	2 liters	20.89	39.97	34.61	36.29	Lake Michigan
28	NE	NW	4	4	12	Prairie Ronde	Spot	3.97	9.43	2.65	1.82	56.91	0.41	4.30	15.55	1.24	1.90	1.82	100.00	2 liters	17.87	60.05	20.26	22.99	Lake Michigan
29	SW	SE	6	4	11	Schoolcraft	Spot	8.18	10.73	5.62	4.29	56.56	2.73	1.73	1.65	3.14	3.47	1.90	100.00	2 liters	28.82	63.17	6.11	9.99	Lake Mich.-Sag. Interlobate
30	NW	NW	30	4	10	Brady	Spot	17.46	17.53	1.81	11.87	32.43	1.21	0.98	0.15	10.81	5.74	0.00	99.99	2 liters	48.67	48.98	2.34	17.68	Lake Mich.-Sag. Interlobate
31	NE	NW	24	4	11	Schoolcraft	Spot	10.56	13.20	2.08	5.60	50.40	1.36	2.32	0.64	8.64	4.56	0.64	100.00	2 liters	31.44	63.60	4.32	16.16	Lake Mich.-Sag. Interlobate
32	NW	NW	24	4	11	Schoolcraft	Spot	9.32	10.22	6.46	9.32	38.10	2.45	1.14	0.57	17.25	4.66	0.49	99.98	2 liters	35.32	60.01	4.16	23.62	Lake Mich.-Sag. Interlobate
33	NE	SE	36	2	10	Comstock	Spot	8.58	13.40	2.21	8.17	33.50	5.80	2.37	2.61	20.26	2.94	0.16	100.00	2 liters	32.36	56.70	10.78	28.16	Lake Mich.-Sag. Interlobate
34	NW	NW	5	3	9	Climax	Spot	7.63	12.55	3.61	8.20	49.22	2.05	1.07	1.97	9.68	2.46	1.56	100.00	2 liters	31.99	61.36	5.09	15.18	Lake Mich.-Sag. Interlobate
35	SW	SW	5	3	9	Climax	Spot	10.14	19.31	4.42	6.44	35.80	5.47	2.49	1.29	12.07	2.57	0.00	100.00	2 liters	40.31	50.44	9.25	18.42	Lake Mich.-Sag. Interlobate
36	NW	NW	28	2	9	Charleston	Spot	7.50	17.60	3.50	12.31	29.26	11.74	1.06	2.36	12.22	1.47	0.98	100.00	2 liters	40.91	42.95	15.16	17.11	Saginaw
37	SE	SW	23	2	9	Charleston	Spot	8.68	12.26	3.34	7.72	44.19	3.66	2.71	2.23	11.78	2.07	1.35	99.99	2 liters	32.00	58.04	6.60	18.79	Saginaw
38	SW	NE	25	2	10	Comstock	Spot	7.28	12.38	2.43	9.79	31.21	9.71	2.76	1.09	18.74	3.26	1.34	99.99	2 liters	31.88	53.21	13.56	25.85	Lake Mich.-Sag. Interlobate
39	SW	NW	28	2	10	Comstock	Spot	10.24	15.68	2.35	6.50	40.05	3.74	2.11	2.76	15.52	0.65	0.40	100.00	2 liters	34.77	56.22	8.61	21.04	Lake Mich.-Sag. Interlobate
40	SW	SE	9	1	12	Alamo	Spot	10.44	9.79	1.63	12.97	40.37	2.85	1.55	0.49	17.46	1.55	0.90	100.00	2 liters	34.83	59.38	4.89	21.05	Lake Mich.-Sag. Interlobate
41	NE	SE	9	1	12	Alamo	Spot	10.34	13.62	2.48	6.89	47.04	2.80	0.56	1.84	12.42	1.92	0.08	99.99	2 liters	33.33	61.38	5.20	16.74	Lake Mich.-Sag. Interlobate
42	SW	SE	15	1	11	Cooper	Spot	11.78	18.08	3.63	5.33	41.97	1.53	2.99	0.40	12.51	1.29	0.48	99.99	2 liters	38.82	55.77	4.92	17.19	Lake Mich.-Sag. Interlobate
43	NW	SW	27	1	9	Ross	Spot	6.25	17.48	1.68	6.57	54.25	2.00	1.52	1.36	7.29	1.04	0.56	100.00	2 liters	31.98	62.58	4.88	11.21	Saginaw
44	SW	NE	22	1	9	Ross	Spot	4.24	16.81	2.33	4.24	49.92	5.74	4.91	1.33	7.49	2.16	0.63	100.00	2 liters	27.62	59.57	11.98	15.89	Saginaw
45	SE	SE	2	1	10	Richland	Spot	10.12	18.88	4.06	6.21	49.8	2.55	1.27	1.51	4.78	0.64	0.16	99.98	2 liters	39.27	54.50	5.33	8.20	Saginaw

* This value may be higher after addition of other physically weak and chemically reactive rocks, which can not be separated individually in this table.

TABLE 4
MECHANICAL ANALYSIS

Grade Size	Diameter mm.	Sample Number																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Weight Percent Frequency																	
2-in.	50.80	4.15	--	8.96	1.26	0.97	2.41	1.43	0.70	--	3.51	1.74	3.17	1.63	2.66	1.85	6.15	--	5.12
1-1/2-in.	38.10	1.61	3.22	3.16	2.63	3.26	0.97	2.49	2.11	1.60	2.47	1.04	4.37	1.88	2.46	2.09	4.38	2.59	9.72
1-in.	25.40	2.54	3.98	6.21	5.06	5.10	2.02	3.26	4.10	2.01	3.37	0.56	4.79	5.58	4.06	3.17	5.55	5.83	11.83
3/4-in.	19.00	3.28	3.35	5.53	4.72	4.96	1.97	5.61	4.86	2.74	4.03	1.11	5.98	5.14	3.45	4.48	4.66	5.51	9.85
1/2-in.	12.70	10.12	6.99	6.43	6.96	5.99	3.73	5.77	4.07	5.43	7.03	2.31	6.70	7.52	7.39	7.43	5.74	6.22	11.74
3/8-in.	9.51	7.97	4.75	4.29	6.21	5.10	2.94	3.90	3.40	4.10	5.72	1.92	4.67	6.08	5.91	5.27	4.00	4.86	7.16
3/16-in.	4.76	24.45	13.00	10.73	16.46	17.02	9.73	9.31	20.35	12.58	17.05	6.80	12.56	18.67	18.86	15.93	10.51	12.12	12.73
ASTM No. 10	2.00	16.80	17.22	9.73	12.41	24.07	13.38	9.00	26.33	16.59	13.57	10.65	13.04	20.33	19.65	27.97	12.04	12.89	8.78
ASTM No. 18	1.00	11.80	14.64	9.30	9.12	13.48	12.24	8.05	12.92	18.02	10.85	13.01	10.44	16.53	11.54	19.54	10.32	9.74	5.47
ASTM No. 35	0.50	8.00	15.74	15.31	11.45	7.48	18.85	15.14	9.36	14.87	15.28	24.67	14.08	8.93	11.09	7.23	14.87	13.39	6.40
ASTM No. 60	0.25	5.75	12.38	15.86	11.10	6.39	25.91	27.14	6.46	14.87	12.15	26.78	15.58	4.55	8.50	3.76	15.81	17.92	7.29
ASTM No. 120	0.125	1.80	3.61	3.23	10.03	5.24	4.64	8.05	2.41	5.65	3.58	8.36	3.69	2.19	2.54	0.72	4.36	5.72	2.23
ASTM No. 230	0.062	0.83	0.52	0.82	1.87	0.50	0.53	0.61	1.27	1.00	0.62	0.76	0.46	0.48	0.88	0.24	0.94	1.51	0.73
ASTM No. -230	-0.062	0.83	0.45	0.42	0.57	0.45	0.45	0.27	1.63	0.43	0.68	0.33	0.40	0.48	0.99	0.29	0.59	1.63	0.92
Total Percent		99.90	99.85	99.99	99.85	100.01	99.77	100.03	99.97	99.90	99.91	100.04	99.93	99.99	99.98	99.97	99.92	99.93	99.97

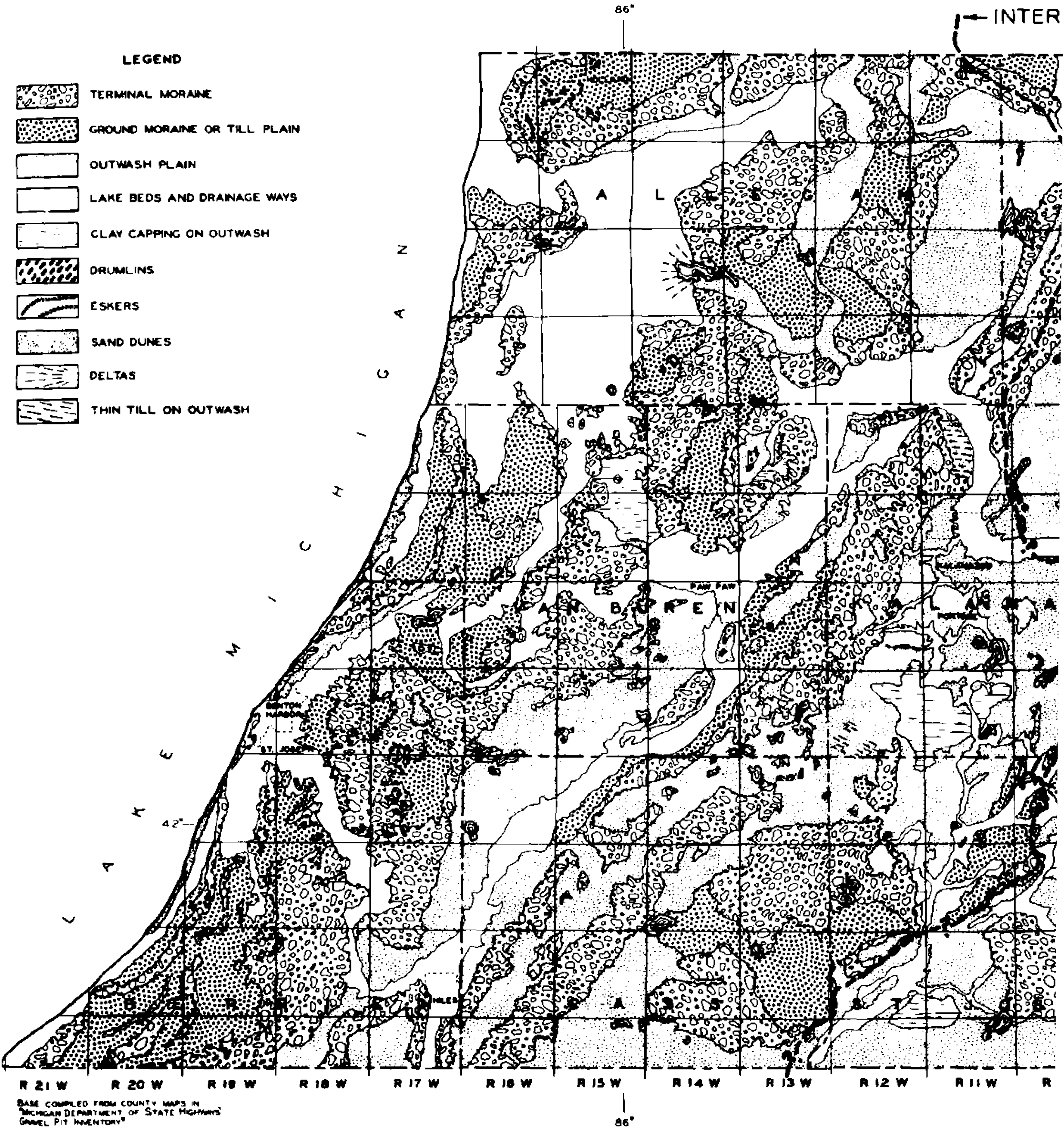
TABLE 5
GRAVEL LITHOLOGY OF SUPPLEMENTARY STUDY AREA, SOUTHWESTERN MICHIGAN

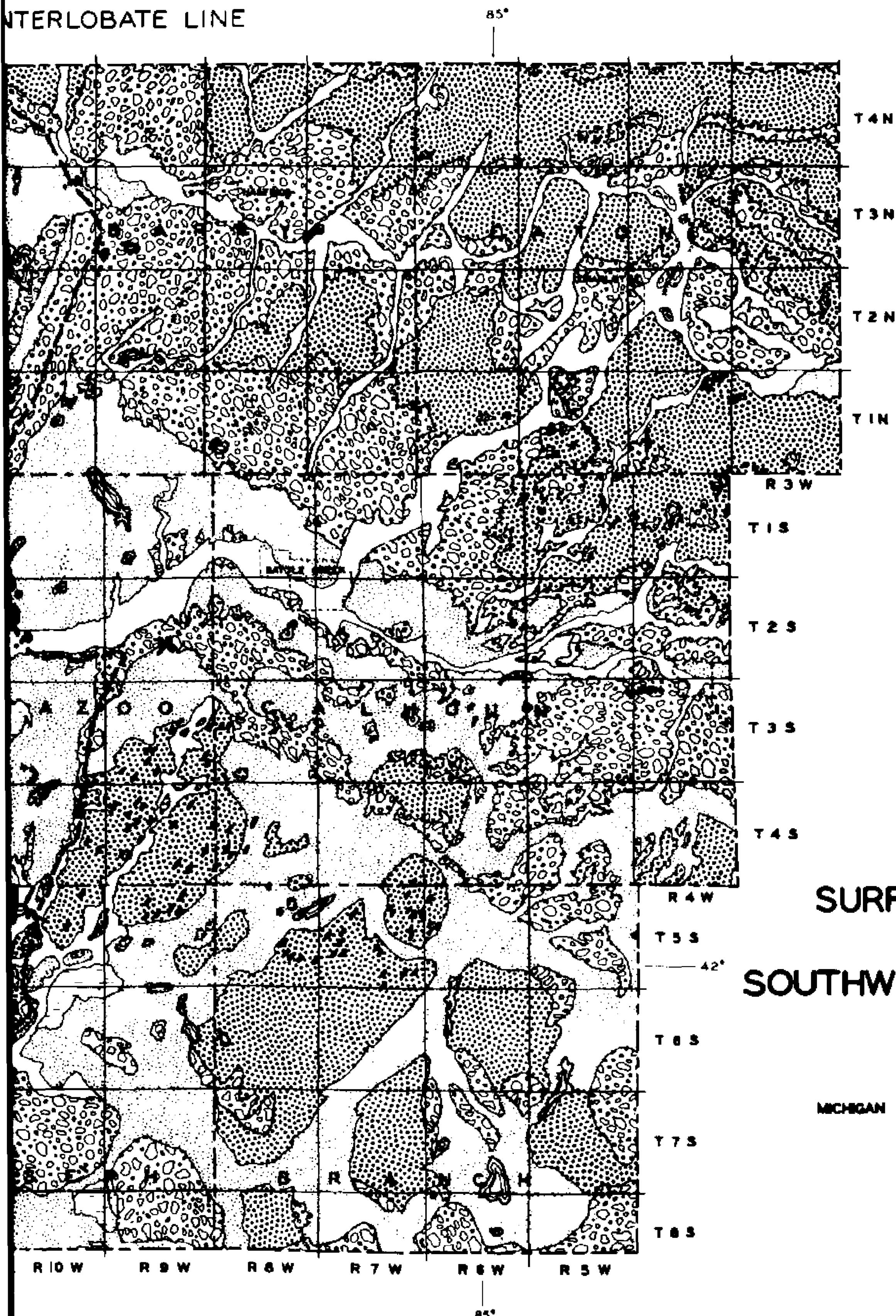
SAMPLE NUMBER	LOCATION			TYPE OF SAMPLE	PERCENT LITHOLOGY										TOTAL PEBBLE COUNTS OR VOLUME	PERCENT GROUP LITHOLOGY			*PERCENT DELETERIOUS (CHERT+SILTSTONE+SHALE+C.I. CONCRETION)	ASSOCIATED GLACIAL LOBE(S)
	SECTION	TOWNSHIP AND RANGE	COUNTY		IGNEOUS (ACID+BASIC)	FOLIATED METAMORPHIC	NON-FOLIATED METAMORPHIC	CARBONATE	CHERT	SANDSTONE	SILTSTONE AND SHALE	CLAY IRONSTONE CONCRETION	OTHERS	TOTAL		CRYSTALLINE	CARBONATE AND CHERT	CLASTIC		
101	14	T.4N., R.8W.	Eaton	Spot	15.30	3.50	9.90	51.90	14.70	2.70	--	--	--	100.00	2 liters	30.70	66.50	2.70	14.70	Saginaw
102	26	T.4N., R.8W.	Barry	Spot	25.20	1.80	8.00	50.90	2.90	--	0.40	--	--	99.90	2 liters	35.70	63.80	0.40	3.30	Saginaw
103	27	T.4N., R.9W.	Barry	Spot	16.30	1.30	6.70	53.10	20.30	1.30	1.00	--	--	100.00	2 liters	24.30	73.40	2.30	21.30	Saginaw
104	16	T.4N., R.10W.	Barry	Channel	21.11	2.44	8.00	52.23	7.33	0.89	4.89	0.67	2.87	100.43	450	31.55	59.56	6.45	12.89	Saginaw
105	15	T.4N., R.11W.	Allegan	Spot	16.30	1.90	6.90	57.30	9.10	5.60	0.50	2.50	--	100.10	2 liters	25.10	66.40	8.60	12.10	Lake Michigan
106	31	T.4N., R.12W.	Allegan	Spot	18.30	2.20	5.40	57.80	5.00	2.90	3.10	5.40	--	100.10	2 liters	25.90	62.80	11.40	13.50	Lake Michigan
107	28	T.3N., R.14W.	Allegan	Spot	13.50	0.30	7.70	63.20	5.60	1.10	2.70	5.80	--	99.90	2 liters	21.50	68.80	9.60	14.10	Lake Michigan
108	4	T.3N., R.13W.	Allegan	Spot	21.80	1.70	3.90	52.10	3.40	4.50	4.30	8.40	--	100.10	2 liters	27.40	55.50	17.20	14.10	Lake Michigan
109	26	T.3N., R.13W.	Allegan	Channel	12.84	0.99	8.17	54.95	15.10	1.73	1.74	0.60	4.89	100.51	450	21.90	70.05	3.97	17.34	Lake Michigan
110	34	T.3N., R.13W.	Allegan	Spot	13.70	1.10	6.90	52.50	3.40	6.50	4.30	8.40	--	100.10	2 liters	21.70	60.30	18.10	20.20	Lake Michigan
111	33	T.3N., R.13W.	Allegan	Spot	19.50	2.10	4.20	55.40	2.70	5.80	0.50	9.80	--	100.00	2 liters	25.80	58.10	16.10	13.00	Lake Michigan
112	5	T.3N., R.11W	Allegan	Channel	14.34	1.11	4.00	46.22	12.89	4.44	6.67	1.11	4.54	99.32	450	22.45	61.11	14.22	22.67	Lake Michigan
113	36	T.3N., R.11W.	Allegan	Spot	16.20	3.20	11.30	50.70	13.10	3.50	--	--	--	100.00	2 liters	32.70	63.80	3.50	13.10	Lake Mich.-Sag. Interlobate
114	6	T.3N., R.10W.	Barry	Spot	14.90	5.70	8.10	52.80	13.20	5.30	--	--	--	100.00	2 liters	28.70	66.00	5.30	13.20	Lake Michigan
115	12	T.3N., R.9W.	Barry	Channel	21.79	2.67	14.22	45.33	8.44	1.11	4.89	0.22	1.33	100.00	450	38.68	53.77	6.22	13.55	Saginaw
116	16	T.3N., R.8W.	Barry	Spot	16.00	1.40	12.10	49.80	15.90	4.80	--	--	--	100.00	2 liters	29.50	65.70	4.80	15.90	Saginaw
117	18	T.3N., R.7W.	Barry	Spot	17.00	2.70	8.50	59.50	12.20	--	--	--	--	99.90	2 liters	28.20	71.70	--	12.20	Saginaw
118	17	T.3N., R.6W.	Eaton	Spot	20.00	1.40	23.30	41.10	11.50	2.40	0.40	--	--	100.10	2 liters	44.70	52.60	2.80	11.90	Saginaw
119	14	T.3N., R.4W.	Eaton	Channel	14.10	2.00	15.56	44.01	15.33	4.44	2.22	0.22	0.98	100.86	450	31.66	59.34	6.88	17.77	Saginaw
120	3	T.3N., R.3W.	Eaton	Channel	18.45	1.56	10.00	38.00	7.33	4.89	13.11	4.00	3.23	100.57	450	30.01	45.33	22.00	24.44	Saginaw
121	13	T.3N., R.3W.	Eaton	Channel	17.56	1.78	11.78	50.68	9.78	6.00	1.77	--	1.23	100.78	450	31.12	60.66	7.77	11.55	Saginaw
122	19	T.2N., R.4W.	Eaton	Channel	12.00	2.44	13.33	34.66	8.00	23.33	2.44	1.56	2.44	100.43	450	27.77	42.89	27.33	12.00	Saginaw
123	34	T.2N., R.5W.	Eaton	Channel	11.99	2.00	16.00	37.11	16.44	12.00	3.56	--	1.45	100.55	450	29.99	53.55	15.56	20.00	Saginaw
124	15	T.2N., R.6W.	Eaton	Spot	24.90	1.30	10.90	54.30	6.00	--	0.50	2.20	--	100.10	2 liters	37.10	60.30	2.70	8.70	Saginaw
125	1	T.2N., R.7W.	Barry	Channel	24.73	1.34	12.03	46.10	11.58	0.87	2.23	0.67	1.45	100.80	450	38.10	57.68	3.57	14.48	Saginaw
126	26	T.2N., R.10W.	Barry	Channel	25.54	2.00	6.89	49.11	9.11	1.56	1.33	1.78	3.23	100.57	450	34.45	58.22	4.67	12.22	Saginaw
127	17	T.2N., R.11W.	Allegan	Spot	18.50	5.50	3.50	54.90	9.40	3.80	--	2.20	--	100.00	2 liters	27.50	66.50	6.00	11.60	Lake Michigan
128	6	T.2N., R.12W.	Allegan	Spot	18.50	1.90	5.40	59.90	6.50	1.40	2.90	3.50	--	100.00	2 liters	25.80	66.40	7.80	12.90	Lake Michigan
129	21	T.2N., R.13W.	Allegan	Spot	13.70	0.80	4.80	51.00	6.40	6.40	6.20	10.80	--	100.10	2 liters	19.30	57.40	23.40	23.40	Lake Michigan
130	2	T.2N., R.14W.	Allegan	Spot	12.50	3.20	6.70	50.20	17.40	4.90	4.90	--	--	100.00	2 liters	22.40	67.80	9.80	22.50	Lake Michigan
131	5	T.1N., R.14W.	Allegan	Spot	14.70	4.20	8.30	60.00	6.40	1.60	2.10	2.70	--	100.00	2 liters	27.20	66.40	6.40	11.20	Lake Michigan
132	24	T.1N., R.12W.	Allegan	Channel	14.00	2.89	18.87	38.66	17.78	2.00	4.89	--	1.33	100.22	450	35.56	56.44	6.89	22.67	Lake Michigan
133	28	T.1N., R.11W.	Allegan	Spot	17.40	6.70	8.50	52.40	10.50	1.10	1.20	0.10	--	100.10	2 liters	34.80	62.90	2.40	11.80	Lake Mich.-Sag. Interlobate
134	6	T.1N., R.9W.	Barry	Spot	21.80	2.60	7.60	54.50	6.60	2.30	--	0.50	--	99.90	2 liters	32.00	65.10	2.80	9.10	Saginaw
135	1	T.1N., R.9W.	Barry	Spot	19.70	5.90	8.00	51.70	11.50	2.80	--	0.60	--	100.00	2 liters	33.60	63.20	3.20	12.10	Saginaw
136	31	T.1N., R.6W.	Barry	Spot	23.50	2.70	7.20	59.80	6.50	0.30	--	--	--	100.00	2 liters	33.40	66.30	0.30	4.50	Saginaw
137	8	T.1N., R.7W.	Barry	Spot	18.30	5.10	6.40	55.30	11.80	1.40	1.80	--	--	100.10	2 liters	29.80	67.10	3.20	13.60	Saginaw
138	5	T.1N., R.3W.	Eaton	Channel	21.76	1.33	11.56	27.33	20.44	9.78	3.33	2.44	2.77	100.74	450	34.65	47.77	15.55	26.31	Saginaw
139	15	T.1S., R.7W.	Calhoun	Channel	15.77	2.22	13.56	38.45	16.22	6.00	6.67	0.67	0.66	100.22	450	31.55	54.67	13.34	23.56	Saginaw
140	33	T.1S., R.8W.	Calhoun	Channel	15.07	1.34	14.51	40.85	17.19	4.91	4.47	0.45	1.78	100.57	450	30.92	58.04	9.83	22.11	Saginaw
141	9	T.1S., R.13W.	Van Buren	Spot	29.63	0.93	1.85	45.37	10.18	2.78	5.56	1.85	1.85	100.00	2 liters	32.41	55.55	10.19	17.59	Lake Mich.-Sag. Interlobate
142	34	T.1S., R.13W.	Van Buren	Spot	23.21	0.89	5.36	57.14	5.36	4.46	--	3.57	--	99.98	2 liters	29.46	62.49	8.03	8.92	Lake Michigan
143	35	T.2S., R.16W.	Van Buren	Spot	23.90	1.20	3.60	53.40	10.30	2.70	4.40	0.60	--	100.10	2 liters	28.70	63.70	7.70	15.10	Lake Michigan
144	4	T.2S., R.8W.	Calhoun	Channel	12.45	1.33	16.00	35.78	18.22	9.11	6.00	--	1.22	100.11	450	29.78	54.00	15.11	24.22	Saginaw
145	16	T.2S., R.7W.	Calhoun	Channel	13.33	1.78	17.33	32.44	18.89	11.11	4.00	0.47	0.58	100.10	450	32.44	51.33	15.76	23.56	Saginaw
146	27	T.2S., R.6W.	Calhoun	Channel	12.47	1.56	16.26	42.09	13.14	8.91	4.44	0.67	0.89	100.43	450	30.29	55.23	14.02	18.25	Saginaw
147	14	T.2S., R.5W.	Calhoun	Channel	12.45	1.11	14.67	43.56	16.00	7.66	2.45	1.56	0.88	100.24	450	28.23	59.56	11.57	20.01	Saginaw
148	32	T.2S., R.5W	Calhoun	Channel	13.77	0.69	14.00	42.89	13.11	9.78	2.67	--	3.00	100.11	450	28.86	56.00	12.45	15.78	Saginaw
149	31	T.3S., R.4W.	Calhoun	Channel	15.99	1.56	14.22	38.60	10.67	10.00	3.67	3.11	1.89	100.11	450	31.77	49.47	16.98	17.45	Saginaw
150	27	T.3S., R.6W.	Calhoun	Channel	14.45	2.22	12.67	40.39	14.44	7.33	6.67	--	2.56	100.73	450	29.34	54.83	14.00	21.11	Saginaw
151	23	T.3S., R.14W.	Van Buren	Spot	11.40	5.70	4.60	59.60	10.40	7.10	--	1.00	--	100.00	2 liters	21.90	70.00	8.10	11.40	Lake Michigan
152	12	T.3S., R.15W.	Van Buren	Spot	13.80	3.60	2.90	66.30	4.50	0.40	3.50	5.10	--	100.10	2 liters	20.30	70.80	9.00	13.11	Lake Michigan
153	11	T.3S., R.16W.	Van Buren	Spot	15.30	1.20	1.10	61.10	10.50	0.90	6.30	3.40	--	100.00	2 liters	17.60	71.60	10.60	20.40	Lake Michigan
154	27	T.3S., R.17W.	Berrien	Spot	14.70	1.30	1.30	69.60	3.40	5.30	2.30	2.30	--	100.20	2 liters	17.30	73.00	9.90	8.00	Lake Michigan
155	23	T.3S., R.18W.	Berrien	Spot	9.80	8.40	6.10	59.40	8.70	2.50	2.30	2.60	--	100.00	2 liters	24.30	68.10	7.40	13.60	Lake Michigan
156	13	T.5S., R.6W.	Branch	Spot	22.90	3.00	8.80	53.80	3.40	4.70	0.80	2.50	--	99.90	2 liters	34.70	57.20	8.00	6.70	Saginaw
157	15	T.5S., R.6W.	Branch	Channel	16.55	1.78	15.56	40.44	19.11	1.78	4.69	0.22	0.77	100.10	450	32.89	59.55	6.69	24.22	Saginaw
158	4	T.5S., R.8W.	Branch	Spot	21.90	2.74	6.20	56.12	7.81	3.62	0.97	0.48	0.16	100.00	2 liters	30.84	63.93	5.07	9.26	Saginaw
159	12	T.5S., R.9W.	St. Joseph	Spot	16.00	6.30	12.30	41.40	17.60	8.10	0.60	--	--	102.30	2 liters	34.60	63.00	8.70	18.20	Saginaw
160	34	T.5S., R.12W.	St. Joseph	Spot	30.90	4.30	7.70	39.00	9.10	1.50	0.20	7.20	--	99.90	2 liters	42.90	48.10	8.90	16.50	Lake Mich.-Sag. Interlobate
161	21	T.5S., R.13W.	Cass	Spot	15.20	4.00	7.00	47.20	12.10	3.20	3.10	8.20	--	100.00	2 liters	26.20	59.30	14.50	23.40	Lake Michigan
162	10	T.5S., R.16W.	Cass	Spot	17.10	1.80	0.80	69.10	2.60	4.50	4.00	0.20	--	100.10	2 liters	19.70	71.70	8.70	6.80	Lake Michigan
163	21	T.5S., R.18W.	Berrien	Spot	9.80	3.00	0.60	66.60	7.50	--	12.50	--	--	100.00	2 liters	13.40	74.10	12.50	20.00	Lake Michigan
164	28	T.6S., R.18W.	Berrien	Spot	10.60	1.50	3.30	55.50	8.10	1.90	17.90	1.20	--	100.00	2 liters	15.40	63.60	21.00	27.20	Lake Michigan
165	6	T.6S., R.17W.	Berrien	Spot	16.10	6.40	2.80	39.70	25.60	3.40	1.20	4.80	--	100.00	2 liters	25.30	65.30	9.40	31.60	Lake Michigan
166	19	T.6S., R.14W.	Cass	Spot	16.30	2.20	1.90	71.10	3.00	0.90	3.00	1.40	--	99.80	2 liters	20.40	74.10	5.30	7.40	Lake Michigan
167	14	T.6S., R.15W.	Cass	Spot	16.60	1.90	0.80	65.80	4.30	1.20	7.30	2.10	--	100.00	2 liters	19.30	70.10	10.60	13.70	Lake Michigan
168	26	T.6S., R.11W.	St. Joseph	Spot	24.70	3.30	10.90	44.60	12.10	3.20	--	0.90	--	99.90	2 liters	38.90	56.90	4.10	13.00	Lake Mich.-Sag. Interlobate
169	14	T.6S., R.8W.	Branch	Spot	17.90	2.70	11.50	55.80	9.60	--	0.50	0.90	--	98.90	2 liters	32.10	65.40	1.40	11.00	Saginaw
170	4	T.6S., R.6W.	Branch	Spot	22.00	8.60	8.30	52.50	6.40	--	1.30	0.80	--	99.90	2 liters	38.90	58.90	2.10	8.50	Saginaw
171	24	T.6S., R.6W.	Branch	Spot	17.70	4.70	7.80	48.30	12.70	5.30	1.60	2.00	--	100.00	2 liters	30.20	61.00	8.80	16.20	Saginaw
172	19	T.6S., R.7W.	Branch	Spot	19.70	2.60	9.50	49.60	14.80	2.00	--	1.60	--	100.00	2 liters	31.80	64.40	3.60	16.40	Saginaw
173	31	T.7S., R.5W.	Branch	Spot	18.30	4.50	8.00	61.00	6.40	1.50	0.20	0.20	--	100.10	2 liters	30.80	67.40	1.90	6.80	Saginaw
174	36	T.7S., R.10W.	St. Joseph	Spot	17.30	3.70	6.70	51.60	6.10	0.40	12.20	1.90	--	100.10	2 liters	27.70	57.90	14.50	20.20	Lake Mich.-Sag. Interlobate
175	29	T.7S., R.13W.	Cass	Spot	20.30	6.00	3.60	46.10	17.00	3.60	--	2.30	--	98.90	2 liters	29.38	63.10	5.90	19.30	Lake Mich.-Sag. Interlobate
176	15	T.7S., R.16W.	Cass	Spot	10.50	1.00	2.40	79.10	2.10	1.80	3.20	--	--	100.10	2 liters	13.90	81.20	5.00	5.30	Lake Michigan
177	12	T.7S., R.17W.	Berrien	Spot	20.10	0.20	0.90	59.90	6.60	0.50	11.60	0.40	--	99.10	2 liters	21.20	66.40	12.60	17.50	Lake Michigan
178	16	T.7S., R.11W.	Berrien	Spot	17.40	2.70	1.70	66.70	2.20	0.70	7.20	1.40	--	100.00	2 liters	21.80	68.90	9.30	10.80	Lake Michigan
179	19	T.7S., R.18W.	Berrien	Spot	3.00	--	--	55.70	9.10	--	28.60	2.60	--	100.00	2 liters	3.00	64.60	32.20	41.30	Lake Michigan
180	12	T.8S., R.19W.	Berrien	Spot	10.70	1.30	1.00	33.20	11.20	1.70	38.20	1.60	--	99.80	2 liters	13.00	44.40	42.50	52.00	Lake Michigan
181	1	T.8S., R.18W.	Berrien	Spot	16.40	5.40	2.60	53.80	10.30	--	7.20	4.30	--	100.00	2 liters	24.40	64.10	11.50	21.80	Lake Michigan
182	10	T.8S., R.17W.	Berrien	Spot	12.90	1.40	1.50	61.20	4.40	1.20	14.40	3.00	--	100.00	2 liters	15.80	66.60	18.60	21.80	Lake Michigan
183	2	T.8S., R.16W.	Cass	Spot	10.60	1.00	2.20	46.60	7.60	2.00	18.90	11.10	--	100.00	2 liters	13.80	53.20	33.00	38.60	Lake Michigan
184	5	T.8S., R.9W.	St. Joseph	Spot	24.60	5.60	10.60	47.30	9.70	--	1.00	1.00	--	100.00	2 liters	41.00	57.00	2.00	11.70	Saginaw
185	14	T.8S., R.6W.	Branch	Spot	18.20	2.90	5.50	58.10	7.50	2.40	2.00	4.40	--	99.00	2 liters	26.60	65.60	8.80	13.90	Saginaw-Erie Interlobate ?

* This value may be higher after addition of other physically weak and chemically reactive rocks, which can not be separated individually in this table.

TABLE 6
SAND ANALYSIS FROM KALAMAZOO COUNTY, MICHIGAN

SAMPLE LOCATION	LOCATION						TYPE OF SAMPLE	PERCENT LITHOLOGY										MECHANICAL ANALYSIS SCREEN SIZES							
	1/4	1/4	SECTION	TOWNSHIP S.	RANGE W.	TOWNSHIP NAME		ACID IGNEOUS	BASIC IGNEOUS	METAMORPHIC	CARBONATE	CHERT	CLASTIC	FELDSPAR	QUARTZ	OTHERS	TOTAL	ASTM NO. 10	ASTM NO. 18	ASTM NO. 35	ASTM NO. 60	ASTM NO. 120	ASTM NO. 230	PAN (-NO. 230)	TOTAL PERCENT
1	NW	NW	15	1	11	Cooper	Channel	4.33	11.00	3.33	37.00	7.33	3.33	12.33	21.00	0.33	99.98	26.70	21.70	24.40	19.20	5.60	0.80	0.70	100.10
2	SE	NE	36	1	12	Alamo	Channel	4.67	8.00	1.67	43.67	12.33	4.33	7.33	17.67	0.33	100.00	17.80	17.00	28.00	29.00	5.90	1.50	0.89	100.00
3	NW	NW	27	1	11	Cooper	Channel	7.67	7.33	6.00	28.33	10.33	6.00	14.00	21.00	0.33	99.99	21.90	14.10	20.20	19.80	17.70	3.30	1.00	99.80
4	NW	NE	8	1	12	Alamo	Channel	7.00	9.33	4.33	37.67	8.00	4.00	12.67	17.00	--	100.00	41.80	23.40	13.00	11.10	9.10	0.90	0.80	100.10
5	SW	NW	36	1	11	Cooper	Channel	4.00	11.33	3.00	30.00	16.67	2.33	10.67	22.00	--	100.00	17.60	16.10	24.80	34.10	6.10	0.70	0.60	100.00
6	SW	SW	33	1	11	Cooper	Channel	3.00	8.00	3.67	29.33	12.67	8.33	11.00	23.67	0.33	100.00	13.30	11.60	22.20	38.80	11.80	0.90	0.40	100.10
7	NE	NW	34	1	11	Cooper	Channel	7.33	11.00	6.00	37.67	9.33	3.00	8.33	17.33	--	99.99	43.60	21.40	15.50	10.70	4.00	2.10	2.70	100.00
8	SW	??	16	2	10	Comstock	Channel	5.33	9.00	8.33	33.33	9.00	4.67	12.33	17.67	0.33	99.99	23.90	19.10	28.90	21.40	6.30	1.10	1.20	99.90
9	SE	SE	5	2	11	Kalamazoo	Channel	7.00	10.00	4.33	33.67	10.67	6.33	9.67	19.33	--	100.00	12.60	15.40	28.20	31.70	9.90	0.90	0.40	100.10
10	W1/2	NW	8	2	11	Kalamazoo	Channel	5.33	11.00	4.33	39.67	7.67	6.67	10.00	15.33	--	100.00	22.60	18.10	24.40	27.00	6.40	0.80	0.70	100.00
11	NW	SE	25	2	11	Kalamazoo	Channel	6.67	12.33	3.33	38.33	6.33	3.00	8.00	22.00	--	99.99	38.00	30.90	16.70	6.50	4.10	0.80	0.90	100.00
12	NW	SE	28	2	10	Comstock	Channel	8.67	9.33	5.33	36.33	9.00	3.67	11.33	19.33	--	99.99	35.60	20.90	20.10	15.40	4.60	1.60	1.90	100.00
13	NW	SW	5	2	9	Charleston	Channel	9.00	11.67	3.00	32.00	8.00	3.33	11.33	21.33	0.33	99.99	44.80	32.70	12.10	8.30	1.20	0.40	0.50	100.00
14	SW	SW	32	2	9	Charleston	Channel	6.33	8.67	4.00	36.00	7.00	7.33	6.33	24.33	--	99.99	20.40	17.50	25.20	26.80	7.40	1.60	1.00	99.90
15	SE	SW	2	3	11	Portage	Channel	7.67	11.67	6.00	32.00	5.33	9.67	7.33	17.33	--	100.00	20.50	15.50	21.30	26.50	9.10	2.40	2.40	99.80
16	?E	SE	5	4	12	Prairie Ronde	Channel	5.00	8.33	6.00	39.00	3.33	10.00	7.33	22.67	0.33	99.99	27.40	17.20	20.10	22.80	7.00	2.30	2.90	100.00
17	?W	NW	17	1	12	Alamo	Auger	11.67	10.67	5.67	15.33	5.00	5.33	20.33	25.67	0.33	100.00	26.23	30.52	16.19	13.08	5.23	4.74	--	99.99
18	NW	SW	5	1	12	Alamo	Auger	1.00	1.00	1.00	--	1.00	88.33	6.67	4.00	--	100.00	0.99	2.33	8.14	38.04	36.87	9.59	6.62	99.98
19	S?	SE	10	1	12	Alamo	Auger	6.33	10.67	1.00	--	4.67	48.33	7.67	23.33	--	100.00	18.67	14.39	8.29	21.92	27.06	9.67	--	99.99
20	NW	N?	20	1	12	Alamo	Auger	12.67	9.33	3.67	--	20.33	9.67	15.00	28.67	0.67	100.01	1.57	5.98	17.72	49.58	21.67	2.83	0.65	99.99
21	NW	NW	32	1	12	Alamo	Auger	11.00	7.33	3.00	43.00	6.67	3.67	3.67	7.33	--	100.00	6.27	7.22	14.44	50.36	18.26	2.39	1.06	99.99
22	?W	SW	32	1	12	Alamo	Auger	12.00	6.00	4.33	4.67	23.67	8.67	10.67	29.33	0.67	100.01	9.04	15.63	44.70	25.33	3.16	0.81	1.33	100.00
23	??	SW	32	1	12	Alamo	Spot	5.67	11.00	4.00	31.00	11.67	5.00	9.00	22.33	0.33	100.00	59.32	13.64	8.32	13.14	4.28	1.09	--	99.99
24	N?	SW	32	1	12	Alamo	Spot	8.00	10.00	4.33	31.00	7.33	4.67	15.00	19.33	0.33	99.99	20.28	9.21	15.58	48.41	7.59	0.75	--	99.99
25	??	NE	32	1	12	Alamo	Spot	7.00	12.33	4.67	10.33	7.00	34.67	7.33	16.33	0.33	99.99	15.41	10.80	15.30	36.77	17.13	3.16	2.33	100.00
26	?E	NW	26	1	12	Alamo	Auger	13.33	10.33	5.00	3.33	8.33	13.00	16.33	30.33	--	99.98	1.75	1.38	7.43	48.75	36.08	5.03	1.61	100.01
27	C	NW	25	1	12	Alamo	Spot	5.33	8.67	2.67	43.00	5.67	5.00	11.33	17.67	0.67	100.01	10.48	10.91	18.38	33.37	24.08	2.14	0.69	99.99
28	SW	SW	30	1	12	Cooper	Auger	5.67	11.00	5.00	0.33	8.33	39.67	10.00	19.67	0.33	100.00	13.87	11.08	21.35	31.98	13.29	4.40	4.03	100.00
29	NW	NE	36	1	12	Alamo	Spot	6.67	4.67	3.67	37.00	8.00	9.00	12.00	18.67	0.33	100.01	2.85	4.18	13.52	51.83	23.66	3.19	0.77	100.00
30	NE	SW	36	1	12	Alamo	Spot	7.67	5.67	9.00	40.33	5.00	8.67	6.00	16.67	--	100.01	9.16	8.34	13.59	40.11	22.81	4.32	1.68	100.00
31	??	NE	2	2	12	Oshtemo	Auger	6.67	10.67	3.00	37.33	9.61	6.33	7.67	18.67	--	100.01	13.47	14.85	27.09	32.21	9.66	2.63	--	100.01
32	NW	SE	36	1	12	Alamo	Auger	4.00	18.33	2.67	37.67	18.33	10.33	5.33	5.33	--	99.99	3.23	14.38	30.36	28.50	13.76	6.40	3.49	100.00
33	C	N?	13	1	12	Alamo	Auger	6.67	7.67	4.33	34.00	9.33	3.00	18.00	16.67	0.33	100.00	14.36	14.40	24.40	34.17	11.11	0.90	0.66	100.00
34	NW	N?	9	1	11	Cooper	Auger	6.67	14.00	6.33	23.33	8.33	5.33	13.00	22.00	--	99.99	30.37	26.87	24.17	10.57	2.62	1.80	3.80	100.00
35	NW	SW	4	1	11	Cooper	Spot	2.33	4.00	2.00	1.00	2.00	77.33	3.33	7.33	0.67	99.99	17.51	5.32	8.92	26.43	26.47	15.35	--	100.00
36	SE	NE	4	1	11	Cooper	Auger	11.67	14.00	10.33	--	18.33	10.67	11.00	23.00	1.00	100.00	49.62	7.18	13.4	22.31	5.85	2.09	--	99.87
37	SW	??	17	1	11	Cooper	Spot	9.67	12.33	4.67	10.33	18.00	8.00	10.33	27.33	0.33	99.99	0.57	1.41	21.62	68.78	7.00	0.72	--	100.00
38	SW	NW	7	1	10	Richland	Auger	19.33	8.33	7.47	0.33	17.47	10.00	12.00	25.33	1.33	99.99	3.64	5.07	17.79	50.60	17.94	2.65	2.24	100.01
39	SW	NW	18	1	10	Richland	Auger	14.33	8.67	7.33	0.33	28.00	8.00	6.67	26.67	--	100.00	4.46	7.24	19.73	48.27	17.73	1.68	0.88	100.01
40	NE	??	31	1	11	Cooper	Spot	6.33	9.33	6.00	24.00	10.47	14.00	6.33	23.00	0.33	99.99	68.22	8.60	7.88	11.68	3.94	1.68	--	99.98
41	SE	NE	30	1	11	Cooper	Auger	1.00	1.67	1.33	--	1.67	92.33	0.67	1.33	--	100.00	2.15	1.43	4.69	29.43	36.38	25.92	--	100.00
42	NE	NE	31	1	11	Cooper	Auger	5.33	4.67	1.33	--	3.00	70.00	4.33	11.33	--	99.99	14.93	15.57	16.98	29.74	14.29	4.23	4.28	100.00
43	C	NW	25	1	11	Cooper	Spot	11.67	11.00	4.33	23.00	14.00	8.67	3.33	22.67	1.33	100.00	0.57	2.24	10.40	41.77	30.30	10.35	4.38	100.01
44	SW	NW	10	2	12	Oshtemo	Spot	10.67	7.33	9.00	18.33	13.00	8.67	7.33	24.67	--	100.00	4.77	3.28	10.52	50.78	27.73	2.98	--	99.99
45	NE	SW	3	2	12	Oshtemo	Spot	13.33	8.00	5.67	--	16.67	15.67	15.00	25.67	--	100.01	6.73	3.28	10.65	50.59	16.58	3.19	--	100.00
46	SE	NE	15	2	12	Oshtemo	Spot	13.00	8.00	7.33	--	18.00	9.33	15.33	26.00	1.00	99.99	3.11	3.45	11.42	54.61	23.18	4.22	--	99.99
47	NE	NE	22	2	12	Oshtemo	Spot	3.67	3.00	4.67	--	6.00	73.33	2.33	7.00	--	100.00	6.06	1.87	7.76	46.47	23.38	14.48	--	100.01
48	SW	NE	6	3	9	Climax	Spot	12.67	9.00	6.67	0.33	18.67	7.33	10.33	32.33	0.67	100.00	21.11	9.34	23.18	37.37	5.20	3.81	--	100.01
49	SW	SE	8	4	9	Wakeshma	Spot	4.67	4.33	2.67	--	6.67	70.33	3.00	8.00	0.33	100.00	13.08	6.48	12.42	31.68	19.87	8.57	7.82	100.00
50	SW	NW	28	4	12	Prairie Ronde	Spot	11.67	9.67	9.00	1.00	22.33	15.00	8.00	23.00	0.33	100.00	3.78	3.44	14.83	61.55	14.90	1.17	0.36	99.99
51	SE	SE	18	4	12	Prairie Ronde	Spot	12.00	7.00	5.33	31.00	12.33	6.33	5.67	19.67	0.67	100.00	29.08	11.60	27.31	26.39	4.52	0.49	0.61	100.00
52	SE	SE	9	4	12	Prairie Ronde	Spot	7.33	6.00	5.33	36.33	6.67	9.67	11.33	16.00	0.38	99.99	28.93	12.76	17.55	29.32	10.40	0.69	0.34	99.99
53	SW	SW	4	4	12	Prairie Ronde	Spot	6.67	5.33	5.00	38.33	10.33	5.67	2.00	19.33	1.67	99.99	48.58	15.47	17.15	15.24	2.24	0.58	0.74	100.00
54	NW	NW	4	4	12	Prairie Ronde	Spot	5.67	10.00	7.33	31.67	7.33	17.00	5.00	16.00	1.00	100.00	42.68	13.94	16.94	21.28	3.98	0.60	0.59	100.00
55	SW	SW	33	3	12	Texas	Spot	6.67	8.67	6.00	38.67	10.00	10.33	8.67	14.67	1.33	100.03	50.02	17.50	15.98	11.48	3.48	0.61	0.98	100.00
56	NE	NW	4	4	12	Prairie Ronde	Spot	5.67	10.00	6.00	32.33	10.67	10.67	6.33	17.33	1.00	100.00	67.04	16.72	6.54	6.33	2.08	0.12	1.18	100.01
57	SW	SE	6	4	11	Schoolcraft	Spot	7.33	9.33	5.00	33.67	12.00	4.33	8.00	20.00	0.33	99.99	33.13	12.46	16.72	34.20	2.06	0.19	0.24	99.99
58	NW	NW	30	4	10	Brady	Spot	13.67	7.67	7.67	0.33	23.33	10.00	11.33	26.00	--	100.00	7.78	7.28	37.88	38.54	10.01	1.02	0.50	100.01
59	NE	NW	24	4	11	Schoolcraft	Spot	7.67	9.00	7.33	31.67	6.67	5.33	9.00	21.00	0.33	100.00	15.12	17.42	28.92	18.81	18.28	2.10	0.34	99.99
60	SW	NW	24	4	11	Schoolcraft	Spot	10.33	6.67	8.67	2.00	19.33	21.33	11.00	17.67	1.00	100.00	24.62	11.06	25.48	24.53	5.34	5.43	3.46	100.00
61	NW	NE	31	3	10	Pavilion	Spot	9.00	8.33	3.33	27.00	12.33	16.67	6.00	17.33	--	99.99	5.06	4.43	21.10	61.78	6.42	0.51	0.73	100.00
62	NW	NW	24	3	11	Portage	Spot	2.33	1.33	0.67	--	4.00	82.33	4.67	4.33	0.33	99.99	8.21	10.96	21.47	38.31	14.49	3.17	2.39	100.00
63	NE	SE	36	2	10	Comstock	Spot	7.33	9.33	6.00	21.67	13.33	16.33	3.67	23.33	--	99.99	57.19	15.22	13.14	10.89	1.15	1.20	1.11	100.00
64	NW	NW	6	3	9	Climax	Spot	8.67	4.67	6.67	33.33	6.33	2.33	8.33	27.67	--	100.00	53.27	13.79	13.58	14.14	4.37	0.54	0.29	100.00
65	SW	SW	5	3	9	Climax	Spot	12.00	10.00	4.33	26.67	8.67	4.00	7.67	25.00	0.67	100.01	26.87	14.82	21.50	27.94	8.33	0.88	0.90	100.01
66	NW	NW	28	2	9	Charleston	Spot	6.33	8.33	8.00	36.67	8.67	3.33	6.67	28.67	0.33	100.00	22.36	18.09	13.11	36.51	3.34	0.21	0.38	99.99
67	SE	SW	23	2	9	Charleston	Spot	9.00	11.67	7.33	15.67	11.67	18.33	5.00	20.67	0.67	100.01	43.73	10.16	14.68	19.68	7.59	2.26	1.90	100.00
68	NE	NW	26	2	9	Charleston	Spot	14.00	10.00	4.67	--	21.00	10.00	6.33	34.67	0.33	100.00	4.12	3.79	26.76	44.28	15.96	2.41	0.69	100.00
69	SW	NE	26	2	10	Comstock	Spot	10.00	8.00	7.00	28.33	7.67	3.33	10.00	24.00	0.67	100.00	36.74	28.64	21.43	10.03	1.98	0.43	1.77	100.00
70	SW	SW	29	2	10	Comstock	Spot	9.67	13.33	5.00	33.33	5.33	5.67	10.33	26.00	1.33	99.99	40.63	11.36	16.52	20.11	6.40	1.96	2.85	100.00
71	NE	SW	9	3	12	Texas	Spot	8.00	9.33	8.33	0.33	33.00	9.00	13.00	26.67	0.33	99.99	33.64	17.40	26.00	17.33	4.54	0.45	0.48	100.00
72	SW	SW	36	1	12	Alamo	Spot	0.33	0.33	0.33	1.00	0.33	96.67	0.67	0.33	--	99.99	43.30	15.26	11.26	10.51	6.51	4.86	8.30	100.00
73	SW	SE	9	1	12	Alamo	Spot	6.00	7.33	8.33	27.33	13.00	3.00	9.33	26.67	1.00	99.99	67.73	8.83	9.69	9.36	2.71	0.86	0.97	99.99
74	NE	SE	9	1	12	Alamo	Spot	7.67	8.00	11.00	30.67	5.67	2.33	7.33	21.00	0.33	100.00	69.99	11.46	7.46	6.77	2.87	0.68	0.93	100.00
75	SW	SE	16	1	11	Cooper	Spot	8.33	12.00	6.67	24.33	13.33	6.33	5.33	22.67	1.00	100.00	62.99	10.33	9.11	5.73	3.27	0.56	1.81	99.90
76	NW	SW	19	1	10	Richland	Spot	10.67	8.00	9.33	0.33	14.33	3.00	13.67	38.00	0.67	100.00	4.76	3.60	12.00	66.12	10.74	3.59	3.81	100.00
77	SW	NE	16	1	9	Ross	Spot	8.33	7.33	7.00	24.00	16.67	5.00	9.67	22.00	1.00	100.00	18.27	22.36	43.86	14.70	3.31	0.41	1.32	100.01
78	NW	SW	27	1	9	Ross	Spot	7.67	12.33	6.67	40.67	3.00	7.67	3.33	16.67	1.00	100.00	61.99	11.93	9.01	11.70	3.38	0.89	0.81	100.01
79	SW	NE	22	1	9	Ross	Spot	9.00	8.00	8.00	13.67	9.33	10.00	8.67	19.00	0.33	100.00	41.86	10.69	11.66	17.46	11.46	4.80	1.80	100.00
80	SE	SE	3	1	10	Richland	Spot	10.67	14.67	6.67	10.33	7.33	14.00	5.33	30.67	0.33	100.00	27.40	12.78	25.54	19.74	2.63	0.71	1.23	100.00
81	NE	NW	24	1	9	Ross	Spot	1.00	4.33	1.67	--	4.33	74.00	4.00	10.00	0.67	100.00	9.25	0.73	30.80	33.07	16.39	3.36	1.38	99.98
82	NW	NW	35	3	10	Pavilion	Spot	6.67	6.33	3.00	0.33	30.33	16.67	11.33	9.33	3.33	99.99	13.36	10.14	30.69	33.66	10.60	3.16	0.68	100.01
83	SW	NW	6	1	11	Cooper	Auger	3.67	12.00	4.33	11.33	13.33	16.67	10.33	21.67	--	99.99	29.06	10.36	19.03	33.36	6.03	0.77	1.13	100.01
84	SE	SE	3	1	12	Alamo	Auger	6.00	10.00	7.33	26.67	11.00	4.67	15.00	17.33	--	100.00	18.56	13.00	31.96	29.44	6.00	0.74	0.70	100.00
85	NE	NE	11	1	12	Alamo	Auger	3.67	4.67	1.33	0.33	6.67	64.67	6.00	16.67	--	100.01	20.00	11.01	13.96	33.96	10.30	6.00	3.61	100.00
86	NE	NE	33	4	12	Prairie Ronde	Auger	1.00	3.33	--	--	4.33	74.67	7.67	8.67	0.33	100.00	3.00	0.80	10.36	46.30	18.64	3.10	1.48	100.00
87	SE	SE	29	4	12	Prairie Ronde	Auger	5.67	4.00	8.00	10.67	11.00	28.67	16.67	34.33	--	100.01	18.20	14.41	30.63	31.60	4.16	0.66	0.60	100.00
88	SW	SW	32	4	12	Prairie Ronde	Auger	5.33	10.33	3.67	0.33	7.33	44.67	16.00	13.00	0.33	99.99	16.56	8.30	17.77	44.00	11.10	1.06	0.67	99.99


LEGEND
TERMINAL MORAINE
GROUND MORAINE OR TILL PLAIN
OUTWASH PLAIN
LAKE BEDS AND DRAINAGE WAYS
CLAY CAPPING ON OUTWASH
DRUMLINS
ESKERS
SAND DUNES
DELTAS
THIN TILL ON OUTWASH
INTER
86°
LAKE MICHIGAN
42°
PAW PAW
BENTON HARBOR
ST. JOSEPH
NILES
R 21 W
R 20 W
R 19 W
R 18 W
R 17 W
R 16 W
R 15 W
R 14 W
R 13 W
R 12 W
R 11 W
R
BASE COMPILED FROM COUNTY MAPS IN "MICHIGAN DEPARTMENT OF STATE HIGHWAYS' GRAVEL PIT INVENTORY"
86°



SOURCES OF INFORMATION

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3. Martin, Helen M., 1955, Map of the surface for of the Southern Peninsula of Michigan and manus maps, Geol. Sur. Div., Michigan Dept. of Cons tion, publication 49.
4. Shah, Balkumar P., 1968, Map of the Surface G of Kalamazoo County, Michigan, Research Labor Mich. Dept. of State Highways.

SURFACE GEOLOGY OF SOUTHWESTERN MICHIGAN

COMPILED BY

BALKUMAR P. SHAH

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

1970

SCALE

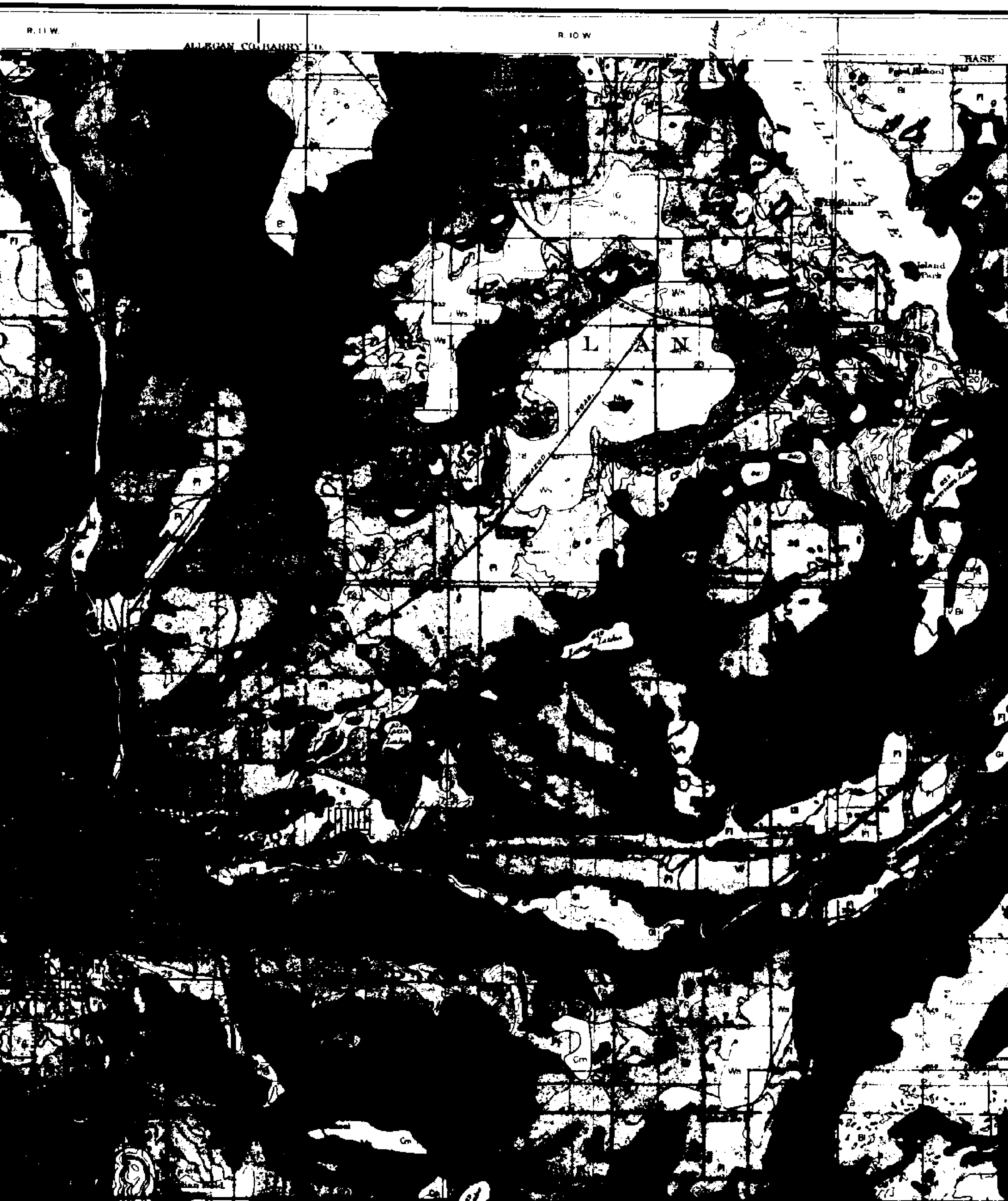
1 0 1 2 3 4 5 6

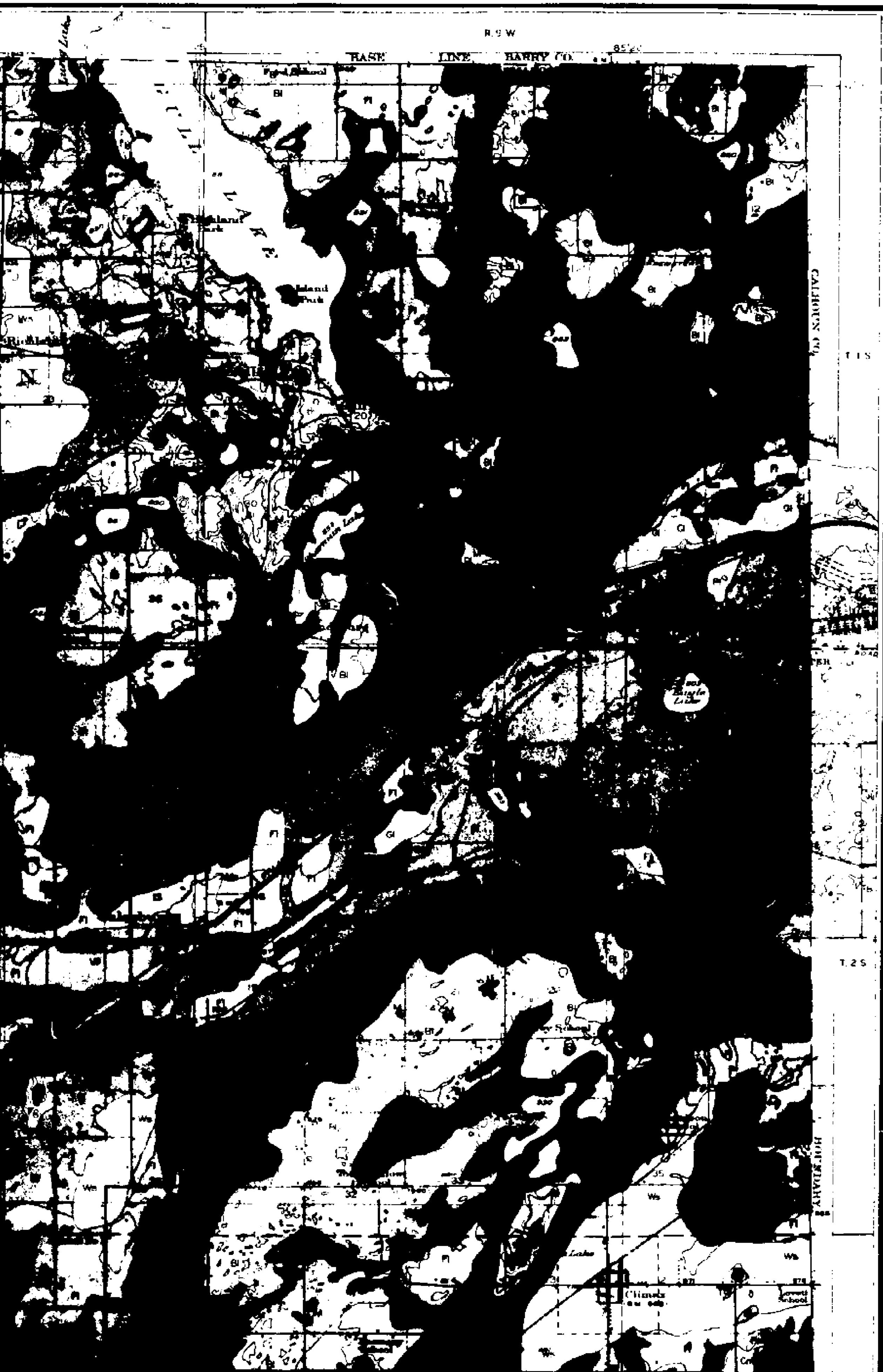
MILES

PLATE I

U. S. DEPARTMENT OF AGRICULTURE
BUREAU OF SOILS
IN COOPERATION WITH THE
MICHIGAN AGRICULTURAL EXPERIMENT STATION

SOIL MAP

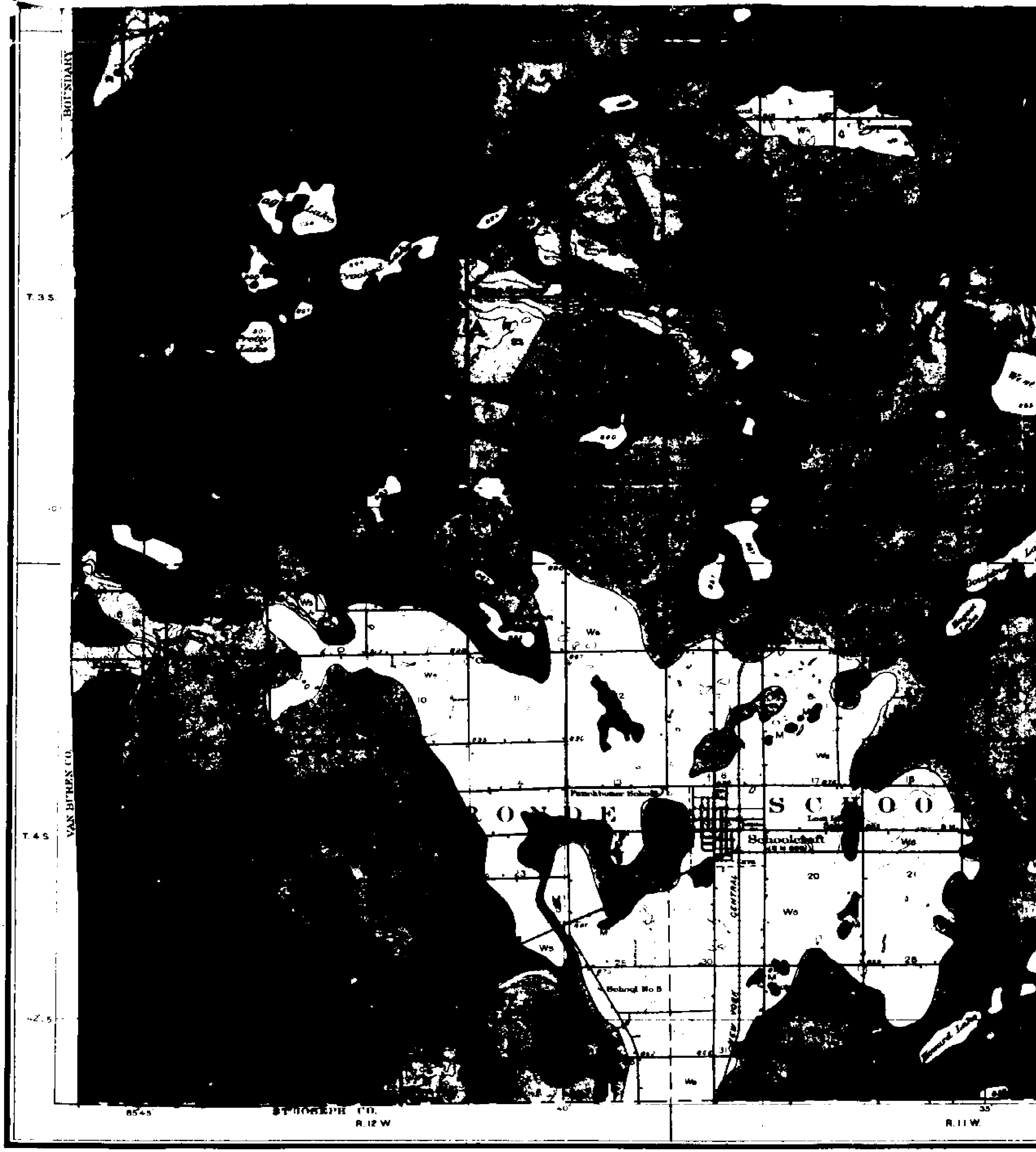




LEGEND

Bellefontaine sandy loam	Newton sandy loam
Bellefontaine loam (Bl)	Newton loam
Brady loam	Newton silt loam (Nt)
Coloma loamy sand	Newton silty clay loam
Coloma fine sand	Oshtemo sandy loam
Coloma sandy loam	Oshtemo loam
Conover loam (Cl)	Plainfield sand
Crosby loam (Cm)	Plainfield sandy loam (Pl)
Fox gravelly loam	Rodman gravelly sandy loam
Fox sandy loam	Warsaw loam (W)
Gravelly phase	Warsaw silt loam (Ws)
Fox loam	Muck
Fox silt loam	Shallow phase over sand
Griffin loam (Gl)	Shallow phase over marl or marly clay
Maumee silty clay loam	

CONVENTIONAL SIGNS



Soils surveyed by S. O. Perkins of the U. S. Department of Agriculture, in charge, and James Tyson, of the Michigan Agricultural Experiment Station.

BASE MAP FROM
U. S. GEOLOGICAL SURVEY SHEETS


Long Lake
AUSTIN LAKE
Indian Lake
LINE
R 11 W
R 10 W
Scale
Miles
Kilometers
Contour interval 10 and 20 feet

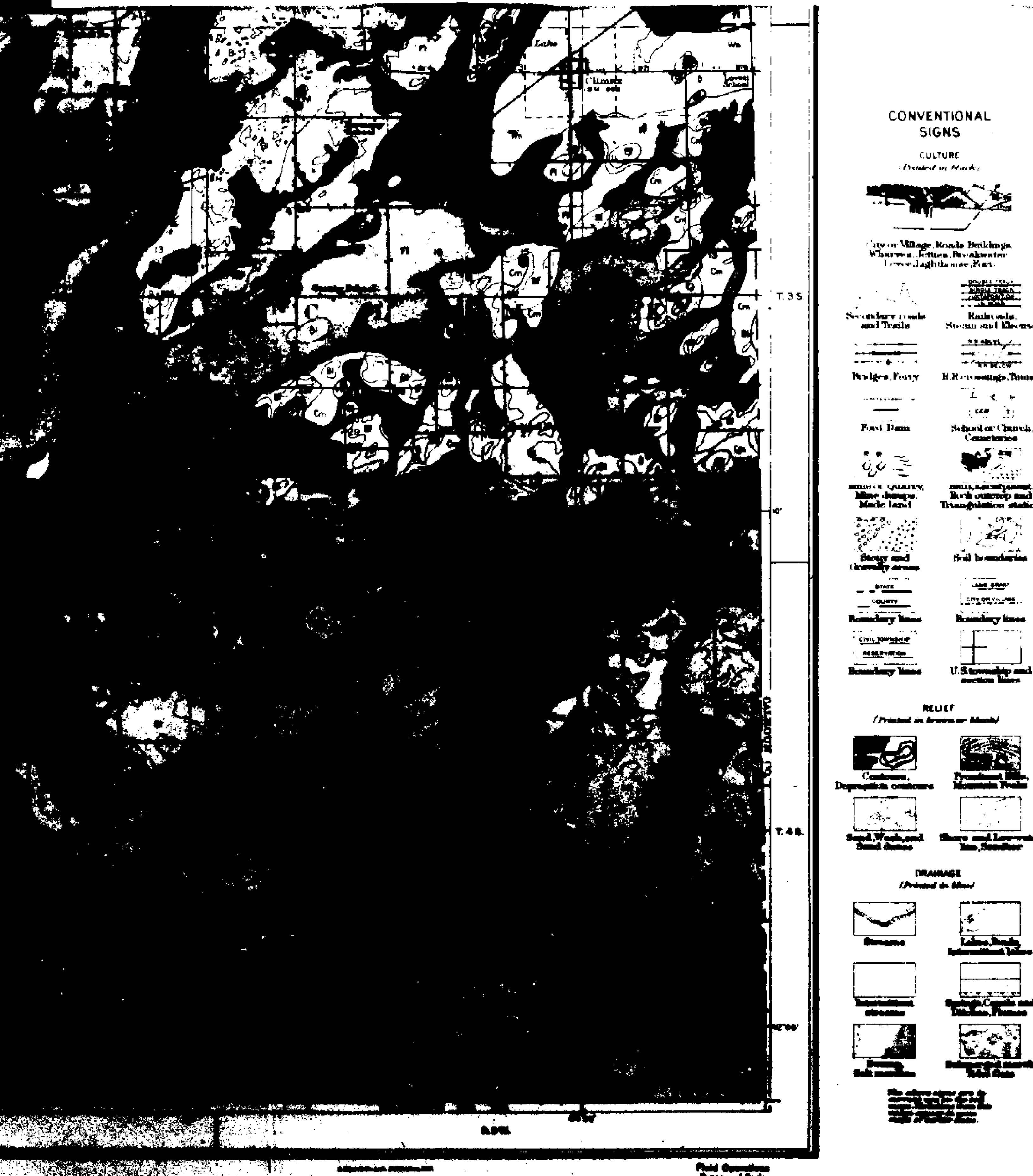

Climax
Lake
T.3 S.
T.4 S.
CONVENTIONAL SIGNS
CULTURE
(Printed in black)
City or Village, Roads, Buildings, Wharves, Jetties, Breakwater, Levee, Lighthouse, Fort.
Secondary roads and Trails
Railroads, Steam and Electric
Bridges, Ferry
R.R. crossings, Tunnel
Ford, Dam
School or Church, Cemeteries
Mine or Quarry, Mine dumps, Made land
Rock outcrop and Triangulation station
Stony and Gravelly areas
Soil boundaries
Boundary lines
U.S. township and section lines
RELIEF
(Printed in brown or black)
Contours, Depression contours
Prominent Hills, Mountain Peaks
Sand, Wash, and Sand Dunes
Shore and Low-water line, Sandbar
DRAINAGE
(Printed in blue)
Streams
Lakes, Ponds, Intermittent lakes
Intermittent streams
Springs, Canals and Ditches, Flumes
Swamp, Salt marsh
Submerged marsh, Tidal flats
Field Operations
Bureau of Soils

PLATE II