GLACIAL AGGREGATE EVALUATION IN KALAMAZOO COUNTY AND VICINITY MICHIGAN

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GLACIAL AGGREGATE EVALUATION IN KALAMAZOO COUNTY AND VICINITY MICHIGAN

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INTRODUCTION

This investigation was undertaken as a departmental research project and a specialized area study of a Highway Planning and Research project, 'Evaluation of Aggregate Sources of Glacial Origin.' As such, it is an expanded phase of the statewide investigation of the availability and quality of sand and gravel deposits of glacial origin. It is hoped that the study will have value in meeting the increasing demand for suitable natural aggregates for future highway programs in this State.

Aims and Purposes of the Study

The purpose of this investigation was to study one area, preferably as large as a county, which would be geologically and geographically representative for the systematic evaluation of sand and gravel deposits in Michigan. The primary aim of this study is to facilitate the usage of glacial aggregates in future construction 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 was essential. The writer has remapped and sampled a large number of surficial deposits in the study area and, using field and laboratory interpretive techniques, attempts to clarify the Pleistocene geology of these complex surface deposits. Although some important questions remain unanswered, it is hoped that this new information 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 were:

1) To prepare a detailed surface geologic map of the study area, and describe the geology and brief 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

Figure 1. Location map noting Primary and Supplementary study areas.

4) To determine if the deposits of two different glacial lobes can be traced on the basis of their composition and engineering properties.

Wingard (1) carried out a study of glacial gravels in Michigan, and his work surveyed a broad region in a reconnaissance manner to determine the engineering properties and lithologic compositions of glacier-related aggregates, and their source and dispersal throughout the southern peninsula of Michigan.

The present research project 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.

AREA LOCATION AND EXTENT

Kalamazoo County lies in the southwestern part of the southern peninsula of Michigan (Fig. 1). This area is nearly square in shape and has 16 townships. The total area covered by this county is approximately 580 square miles. It is surrounded by seven other counties: Allegan, Barry, Calhoun, Branch, St. Joseph, Cass, and VanBuren. Selective supplementary studies in southwestern Michigan, equally significant to this investigation, have also been conducted in these surrounding seven counties and in Berrien and Eaton Counties.

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 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 collecting representative glacial drift for petrological analysis, so that evaluation could be made of its potential for use in construction projects in southwestern Michigan.

Surface Mapping

Surface geologic maps of the study area were published by Leverett and Taylor (2), Leverett (3), and Martin (4). These maps cover large areas and are very general in their applicability to a small county size area. To answer the need for more detailed studies, it was decided to remap Kalamazoo County from field observations, using additional available surface and subsurface information which has recently come to light (Fig. 2).

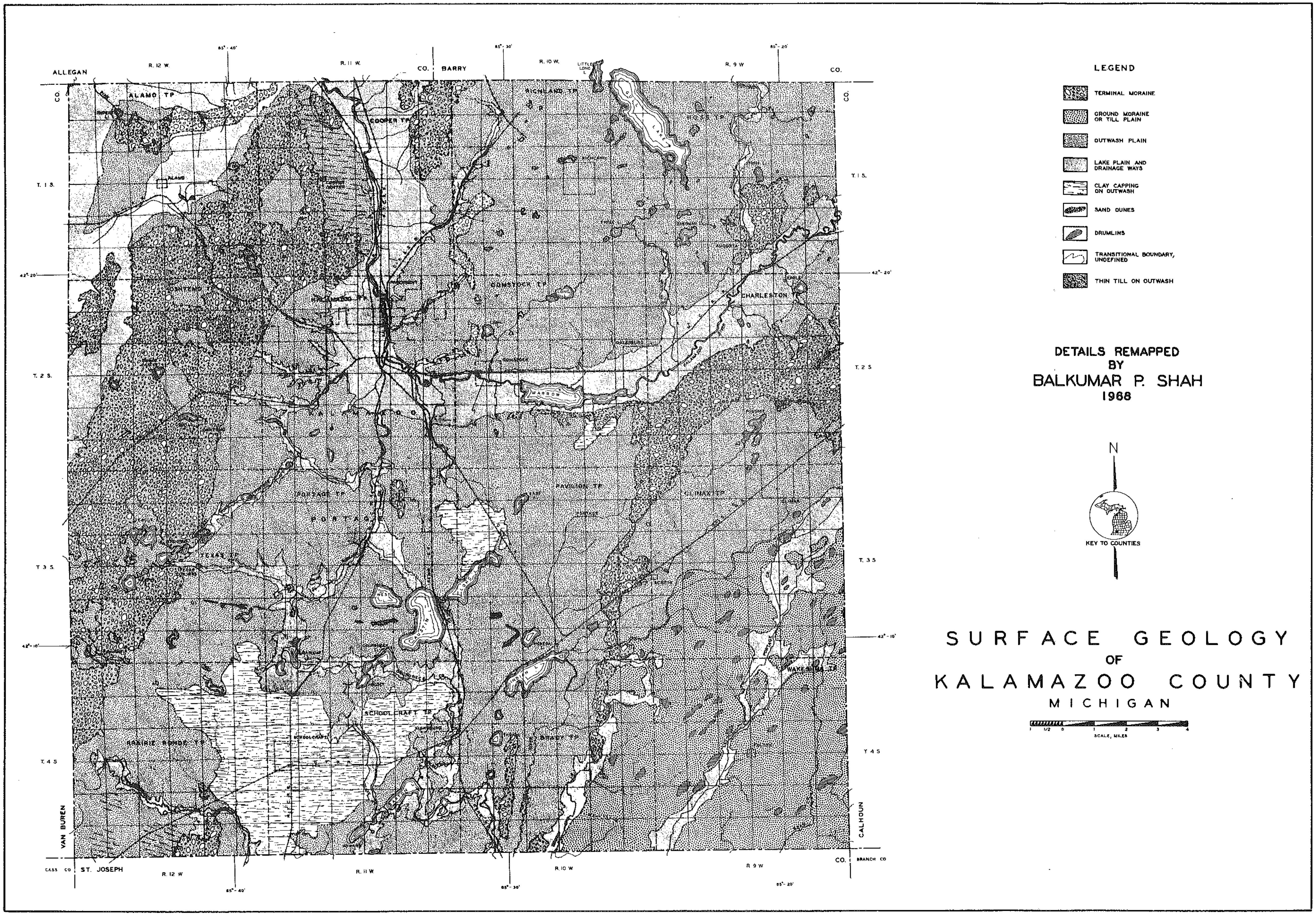


Figure 2. Surface geology of Kalamazoo County, Michigan.

The surface mapping was carried out by observations along roads, with occasional foot traverses off the roads. 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 road 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.

Aerial photographs were studied as an aid to field mapping and laboratory interpretation. 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 MDSH 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. 2). Later on, part of the studies were extended into neighboring counties, making it necessary to compile, from all available information, a map of the surface geology of southwestern Michigan (Fig. 3).

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 vertical 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.

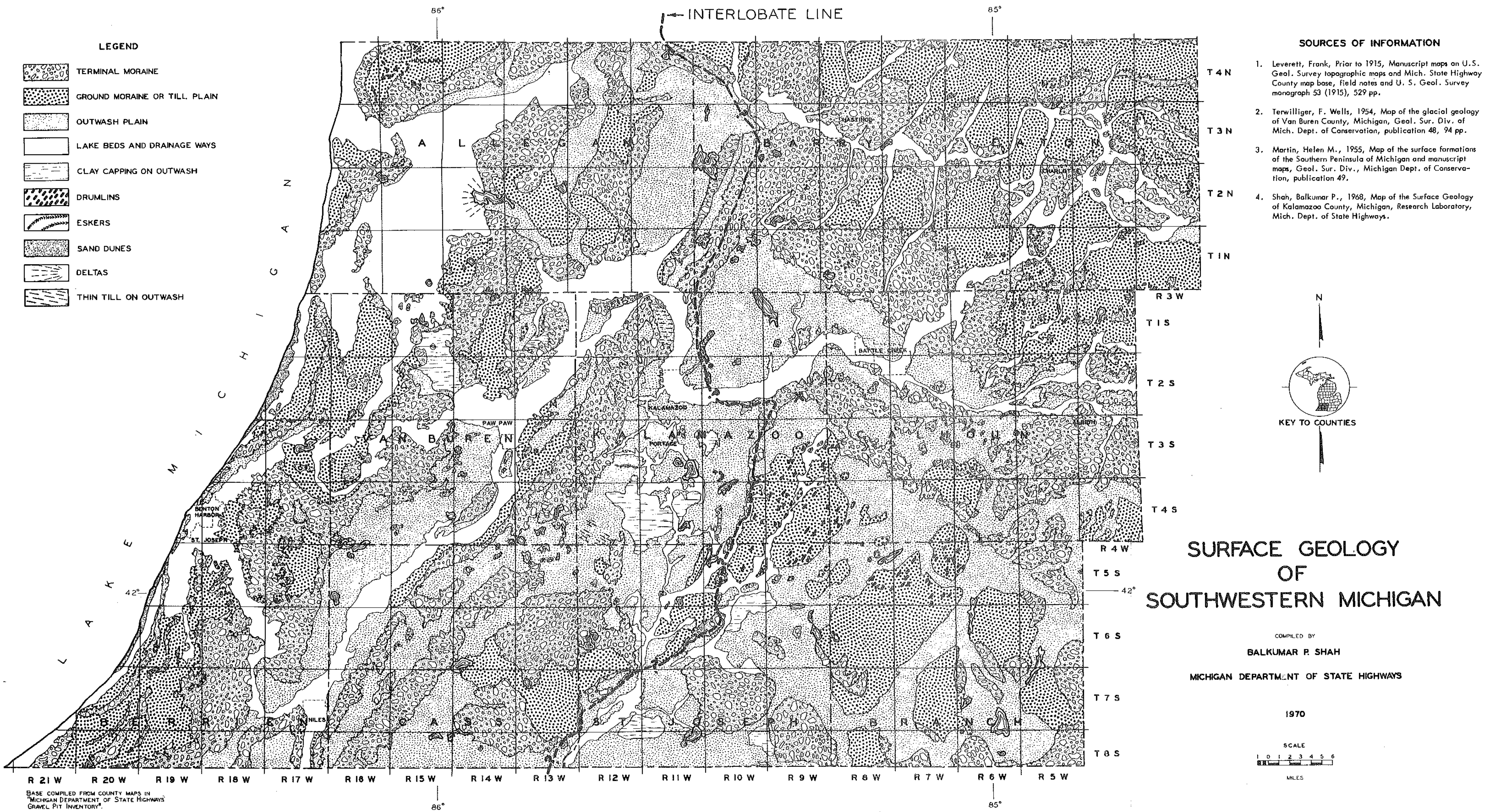


Figure 3. Surface geology of southwestern Michigan.

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 selected, based upon the outcome of earlier similar studies conducted in the Research Laboratory (1).

Large Samples--Channel Sampling Method

Channel sampling method was used for the first 18 samples obtained in Kalamazoo County, and samples 19 through 22 obtained by Wingard (see Table 3 in the Appendix). These samples were large (weighing 600 to 1,200 lb) 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 shoveled away in order to prepare a more or less vertical face. Usually about 20 ft 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 to 12 in. wide and 5 to 6 in. deep was dug in the wall; the depth of the channel being more than the diameter of the largest pebble in the sampling zone. The entire vertical column was sampled by using a 2-l 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 to 1-in. pebble fraction was separated by hand sieving through square mesh screens. Approximately 10 lb of material were bagged for further pebble volume analysis (see p. 23).

This method of sampling and analysis has been successfully used in earlier work by the Research Laboratory, and has been proved by Wingard to be very economical and reasonably accurate for determining lithologic composition of drift materials. Thus, it was used here to compare current data with similar data acquired by previous investigations of the Research Laboratory in the vicinity of Kalamazoo County.

Analyses of the first 18 samples suggested that additional lithologic data were needed to make more precise glacial interpretations. Therefore, an additional 23 locations were sampled using the above described spot sampling method.

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 and 72 ft. A truck-mounted 6-in. uncased power auger was used for this sampling. Subsurface information was recorded at every 5-ft vertical interval and, as noted above, samples were collected for further analyses.

Occasionally a 6-ft 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-in.) 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 cave-in problems were experienced. Just as cave-ins introduce 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.

GEOLOGY

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 resources of the area. The surficial sediments in this region have been deposited by glacial and glacio-fluvial 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 is referred as an interlobe area or "reentrant district," defined as an area in which materials from two different sources have become intermixed. Thus, the recognition of these deposits is a difficult problem in the field.

Presence of Pre-Wisconsinan or early Wisconsinan age glacial sediments underneath the surficial deposits is questionable in this area. From a few indications in well logs and observations in surrounding areas, it is believed that there is a good possibility of the presence of Pre-Wisconsinan or early Wisconsinan sediments near the bedrock in the form of scattered indurated till deposits.

The Lake Michigan - Saginaw Interlobate Area

At the time of the middle Wisconsinan age, a portion of the Lake Michigan lobe ice moved southeastward through and beyond the Lake Michigan basin towards Kalamazoo County and passed the Michigan-Indiana state border. Similarly about the same time or slightly earlier, a portion of the Saginaw lobe ice advanced southwestward through and beyond the Lake Huron and Saginaw Bay area, towards Kalamazoo County, passing the Michigan-Indiana state border. The extension of these two lobes into southwestern Michigan developed an interlobate area between the terminals of both lobes. Later, the Saginaw lobe and then the Lake Michigan lobe started retreating with minor readvances in their terminal areas. These terminal fluxuations

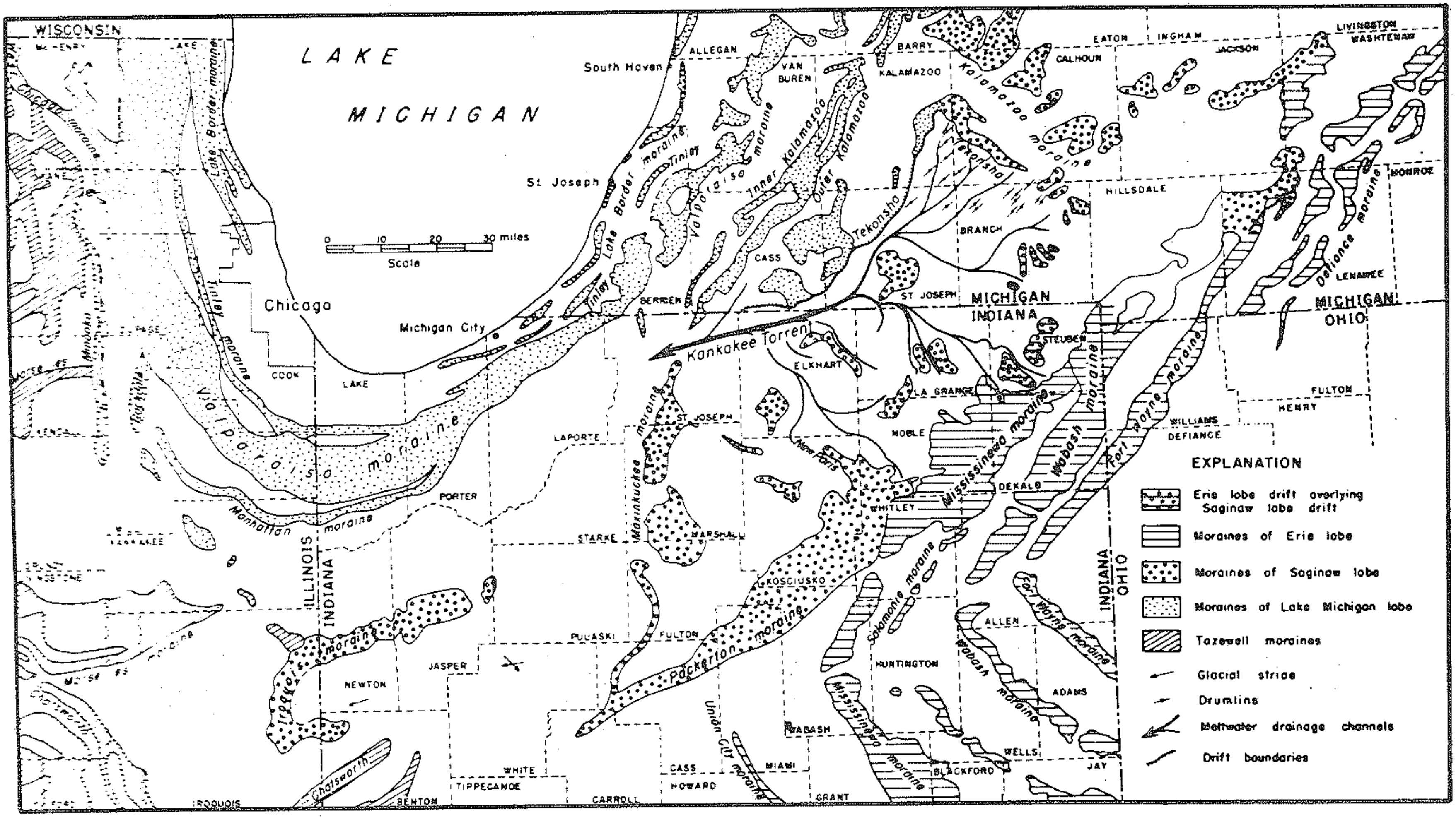


Figure 4. Designated morainic systems of Michigan and Northern Indiana (after Leverett and Taylor, 1915).

have created complexities in the distribution of sediments and glacial landforms in Kalamazoo County and vicinity.

By evaluating literature on the area, field evidences, geomorphology (Figs. 2 and 3) and isopleth patterns (Figs. 10 to 18) of the area, it is believed that the terminal behavior of the Lake Michigan lobe and the Saginaw lobe in the middle Wisconsinan time were out-of-phase with each other. Terminal ice of the Saginaw lobe first covered most of Kalamazoo County and then retreated northeastward laying the sediments of its own provenance. Soon after, the terminal ice of the Lake Michigan lobe advanced southeastward by pushing and overlapping the previously laid down Saginaw lobe sediments, and then retreated back towards the northwest. With the aid of the glacial history of the area, an interlobate line is suggested and is shown in Figure 3. Reference (5) provides a further detailed description of the glacial history between the two lobes in the study area and an interlobate line. Eventually both glacial lobes, along with the Erie lobe, melted away from Michigan leaving many prominent glacial features. The pattern of the designated morainic systems is shown in Figure 4.

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 meltwaters from the retreating glaciers, along with a very few aeolian and alluvial deposits of post-Wisconsinan age. Surface features in Kalamazoo County are classified into four general categories: 1) glacial, 2) glaciofluvial, 3) aeolian, and, 4) others. The idealized interrelationship and sequence of formation of these features is illustrated diagrammatically in Figure 5.

Glacial Features - Glacial features in Kalamazoo County include terminal moraines, ground moraines or till plains, and drumlins. These features are mostly composed of tills containing local lenses of stratified sand and gravel, and are shown on the map in Figure 2.

The above mentioned features are associated with the activities of the Lake Michigan lobe and Saginaw lobe of the Wisconsinan ice sheets. The major terminal moraines are the Kalamazoo and Tekonsha. The Kalamazoo moraine is located in the western part of the county and is built by the Lake Michigan lobe (Fig. 2). Whereas the Tekonsha moraine is located in the eastern part of the county, and mostly built by advancing Lake Michigan ice, except the part in eastern Charleston Township (T 25, R9W). The

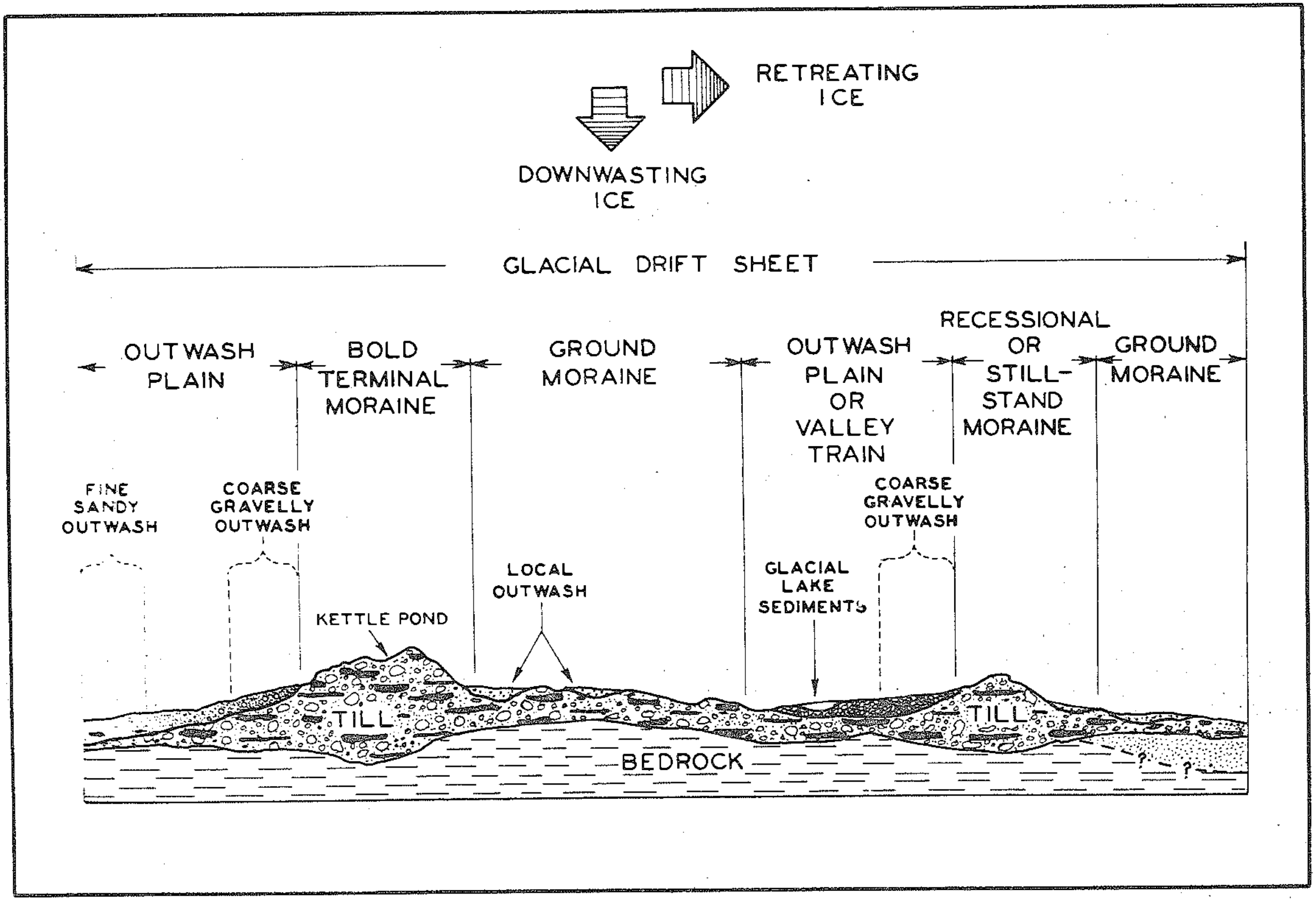


Figure 5. Hypothetical cross section showing interrelationship and sequence of formation of glacial, glacio-fluvial, and glacio-lacustrine depositional features by a retreating and downwasting ice front.

major till plain in the southeastern part of the County is built by the retreating Saginaw lobe ice. Drumlins associated with this plain are also built by the activities of the Saginaw lobe.

Glacio-fluvial Features - Glacio-fluvial features in Kalamazoo County consist of a group of stratified sediments. In this county most of the glacio-fluvial features are proglacial; indicating outwash plains, lacustrine plains, drainageways, and clay and silt capping on outwash plains. Major ice-contact features like kames and eskers have not been located clearly in Kalamazoo County, and their presence is questionable.

Kalamazoo County has two-thirds of its area covered by outwash plains developed by the metlwaters from both retreating ice lobes (Fig. 3). The vigorous line of fluvial discharge in the reentrant district produced wide and thick outwash plains. In general they descend away from the bold terminal moraines. Along the border next to the moraines the outwash material is much coarser than it is at a distance (Fig. 5). Cobbles and coarse gravel are common for about half a mile from the moraine, but average grain size diminishes downstream away from the moraine, whereas roundness of particles increases as does the sorting in a classic fashion.

Large lacustrine plains are present west of the Kalamazoo moraine in Alamo Township (TIS, R 12 W). They are made up of sandy reworked outwash with very few pebbles, and in some places clayey, silty, and sandy material with a few boulders and cobbles. Drainageways are seen in many parts of the county, and they are very narrow and elongated areas consisting of mainly well sorted sandy material with pockets of gravel (Fig. 2).

Clay and silt capping on very flat and fine stratified outwash was probably built by shallow local ponding of southward traveling meltwaters from both ice lobes. This capping varies in thickness from 1 to 4 ft and major sites of this type are found in the southern half of Kalamazoo County.

Aeolian Features - Inactive sand dunes or wind-blown sand deposits in Kalamazoo County have been recognized in Alamo, Texas, Portage, and Pavillion townships (Fig. 2). In general, these deposits are difficult to recognize in the field because of the sandy nature of the surface drift throughout the county. Moreover, some of them have become covered with vegetation.

Other Features - There are a couple of other features, like undefined transitional zones and kames, that deserve brief explanation since they are useful in locating sand and gravel deposits.

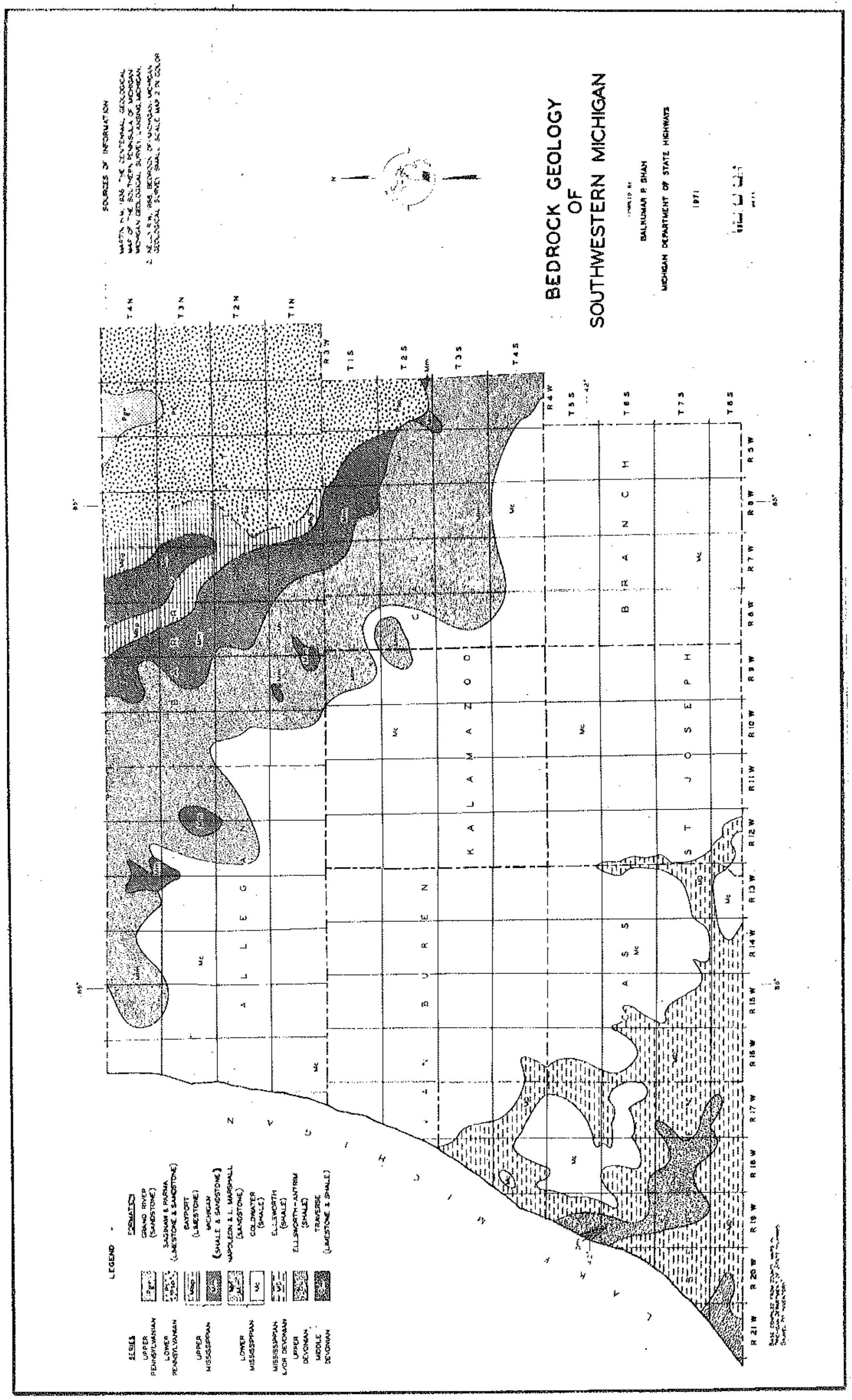


Figure 6. Bedrock geology of Southwestern Michigan.

In the field it is often difficult to recognize an exact line separating morainal deposits from outwash deposits. The dashed lines on the map in Figure 2 represent undefined transitional boundaries or zones between two well recognized features. For example, such a zone between moraines and outwash is usually about one-quarter mile wide, in which materials show gradation from coarse to fine or vice-versa (Fig. 5). This transitional zone is ideal for prospecting for coarse aggregates.

Kames and eskers are usually known to be ice-contact features and their presence in Kalamazoo County is highly questionable. These ice-contact features are known to contain good gravel sources and they are described briefly by Wingard (1). 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. 2). If kames are present at all in this county, they would be mixed-in with the knob and kettle topography in the complex moraines.

Bedrock Formations

Consolidated sediments beneath the unconsolidated glacial sediments of Kalamazoo County are all of the Paleozoic age. The Coldwater shale and the Lower Marshall sandstone make up the bedrock surface of this county. The age, name, lithology, and extent of each formation in southwestern Michigan are shown in Figure 6. The great deal of materials that make up gravels and other glacial deposits in Kalamazoo County and vicinity are derived from the underlying local bedrock by erosion and plucking action of the Michigan lobe and Saginaw lobe ice. Interpretations of the source and presence of local lithologies in surficial deposits are given elsewhere in this report.

Drift Thickness

Glacial drift above bedrock surface in Kalamazoo County is seen to range in thickness from about 50 to over 500 ft (Fig. 7). The thickest drift occurs over major valleys cut into bedrock. Regionally, it is thickest in the northwestern and western part of the county. The thinnest drift (less than 100 ft) occurs over a sector of southeastern Kalamazoo County. Although the drift is very thin in the southeastern part of the county, it becomes even thinner in neighboring Calhoun and Branch Counties. These areas may be of special interest to highway engineers for planning. Additional regional details on the drift thickness can be obtained from deep drillers logs available in the files of Michigan Geological Survey.

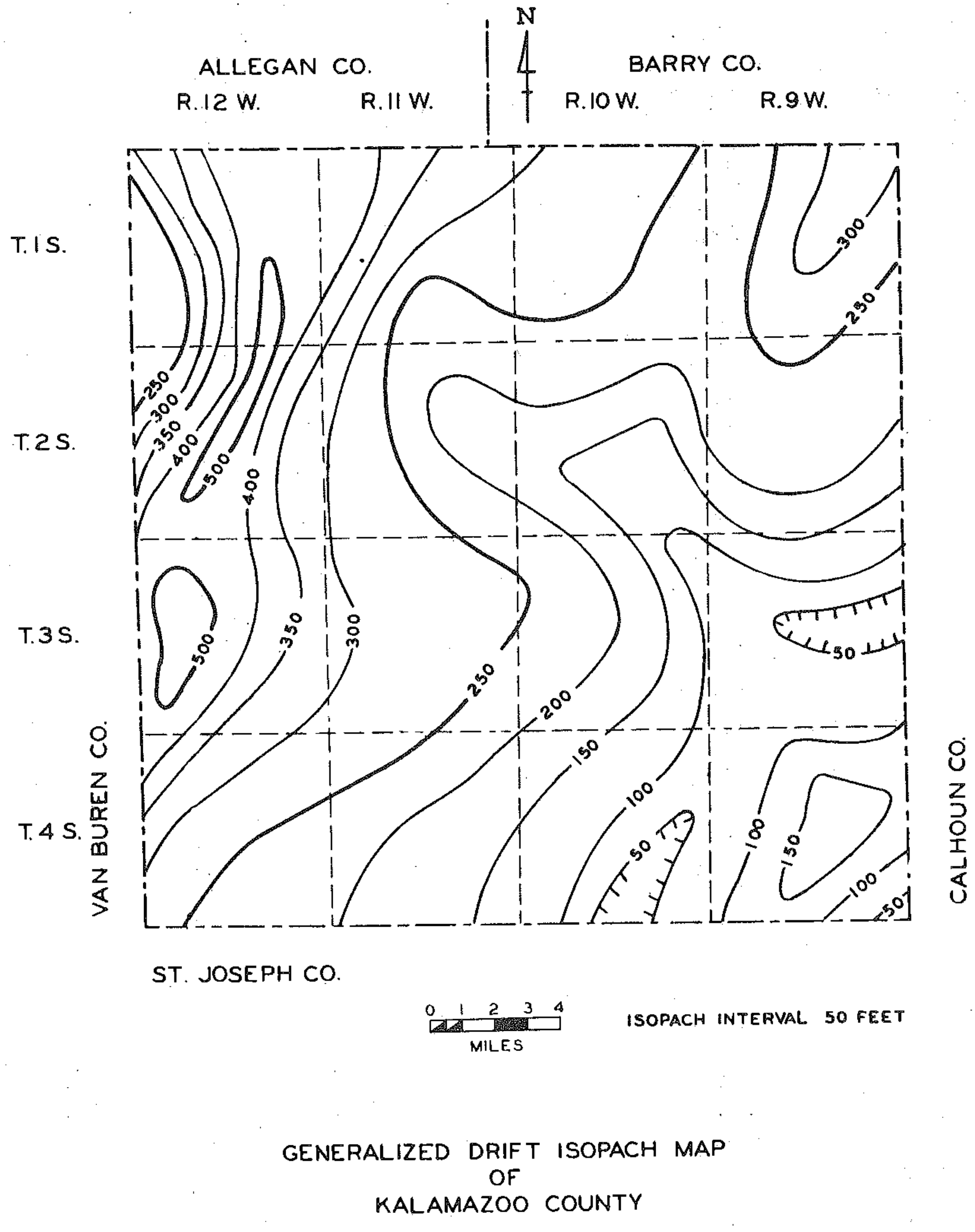


Figure 7. Generalized drift thickness map of Kalamazoo County.

SOILS OF KALAMAZOO COUNTY

The first detailed report on the soil survey of Kalamazoo County was by S. O. Perkins and James Tyson, published in 1928 (6). This report contains a colored soils map 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. In this report primary reference is made to the 1922 soil map and soil series names which precede the new classification.

Table 1 is an attempt to correlate soil series names from the older classification with those of the new classification (adopted by the National Cooperative Soil Survey on January 1, 1965). Also in the table, the associated natural drainage, parent material, and glacial features are briefly described. In all, 13 mineral soil series and one organic soil have been reported in Kalamazoo County. Out of these, the Bellefontaine series is now a part of the Fox series, the Coloma series is the same as the Spinks series, and the Griffin series is described as the Shoals series.

Most of the better drained local soils 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, 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 see references (7) and (8).

LABORATORY ANALYSIS

Large channel samples, small spot samples, and auger samples were collected in the field and brought into the Research Laboratory for analysis. Mechanical and petrographic analyses were made of coarse (+3/16 in.) and fine (-3/16 in.) fractions, to determine the size frequency distribution and

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 1928	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, Pasmmentic 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	--	--

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 in a study conducted to evaluate gravel resources of southern lower Michigan (1). In the present investigation, three key properties--lithologic composition, physical strength, and chemical reactivity of aggregates--were determined in detail, since it is thought they play a dominant 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 to 100 lb. 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 to 1-1/2, 1-1/2 to 1, 1 to 3/4, 3/4 to 1/2, 1/2 to 3/8, 3/8 to 3/16, and -3/16 in. Material less than 3/16-in. size was considered as a fine fraction (sand). Such fine fractions were quartered to about 500 g and sieved using the following U.S. Standard (ASTM number) Sieves: 10, 18, 35, 60, 120, 230, and pan. Fine fractions from the first 18 channel samples and other spot and auger samples were used for mechanical analysis. Complete mechanical analysis data of coarse 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 ages. 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 mainly carried out with 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.

TABLE 2
LITHOLOGIC TERMINOLOGY AND CLASSIFICATION

COARSE FRACTION		FINE FRACTION
Classification I (Initial) (No. 4 to 1-1/2 in.)	Classification II (Simplified) (1/2 to 1 in. Fraction)	Classification III (ASTM No. 10 to 18)
Phaneritic Acid Igneous Phaneritic Intermediate Igneous Phaneritic Basic Igneous Micro-Phaneritic Igneous Aphanitic Acid Igneous Aphanitic Basic Igneous	Acid Igneous Basic Igneous	Acid Igneous Basic Igneous
Foliated Metamorphic Non-Foliated Metamorphic	Foliated Metamorphic Non-Foliated Metamorphic	Metamorphic
Dolomite Dolomitic Limestone Limestone Sandstone Siltstone Shale	Carbonate Sandstone Siltstone and Shale	Carbonate Clastic
Clay Ironstone Concretions Porous Chert Dense Chert Others*	Clay Ironstone Concretions Porous Chert Dense Chert Others*	Chert Feldspar Quartz 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.

Lithologic Terms and Classification

Lithologic terminology and classification were standardized for this study (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 still meaningful new classification, II, was adopted for faster and more efficient identification of lithologies. This included only 11 lithologic categories. In this study, more specific lithologic terms, used in the earlier studies of Wingard (1), 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 9 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 petrography text or reference book or in any geological glossary (13, 14, 15, 16, 17, 18).

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 in.
Size 2	-	1 to 3/4 in.
Size 3	-	3/4 to 1/2 in.
Size 4	-	1/2 to 3/8 in.
Size 5	-	3/8 to 3/16 in.

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 in. (Size 1) fractions of three 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.

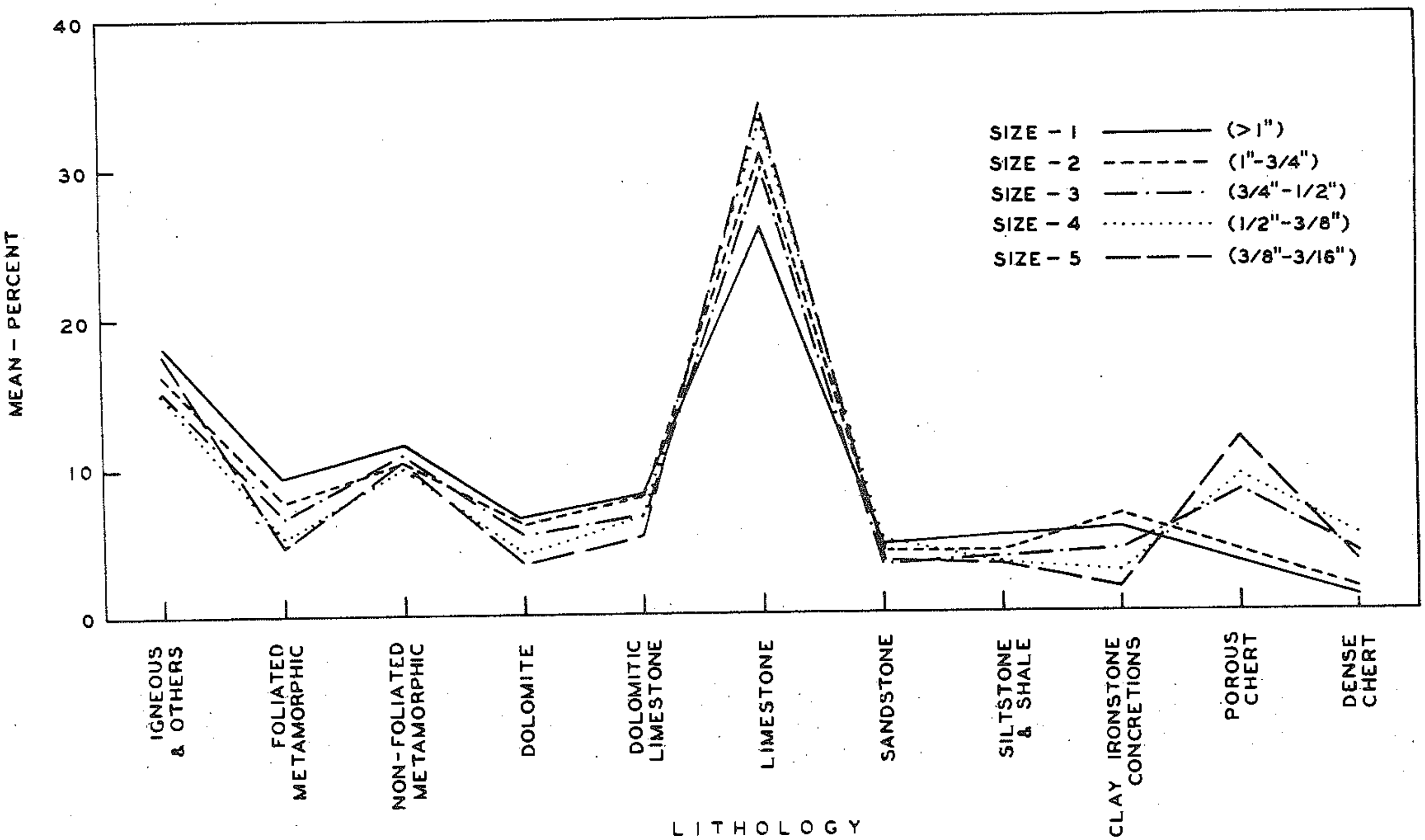


Figure 8. Relationship between material sizes and lithologic distribution.

Percentages of each lithology present in each fraction were calculated. These data were then regrouped into 11 lithologic categories listed under classification II. 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 calculated. These are represented graphically in Figure 8.

From a plot in Figure 8, it can be generally said 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 an 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 also be 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.

Pebble Volume - A pebble volume analysis was used for 23 spot samples (Nos. 23 to 45) of coarse material collected in Kalamazoo County. This method has been stressed by Ehrlich and Davies (9) in their study of glacio-fluvial sediments, and is also described and used by Wingard in the study of drift materials carried out in the Research Laboratory. This method gives lithologic percentage by volume rather than by number of pebbles.

The pebble volume procedure is, briefly, as follows. Gravel samples in 1/2 to 1 in. sizes were collected in the field and washed to free them from clay or fine material in the samples. They were then quartered until approximately a 2-l fraction remained. Pebbles were packed by agitating in a 2-l waxed strong cardboard cylinder mold to obtain the approximate initial volume.

Pebbles from a 2-l 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 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-in. sized fractions are believed to be representative of all size grades of coarse aggregate. This assumption is supported by Figure 8 in which volumes of sizes 2 and 3 (1/2 to 1 in.) are shown as an average of all five sizes. Anderson (10) believed that the 1/2 to 1-in. 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 the heterogeneity this did not provide as much information as did the coarse fraction.

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 give the detailed picture 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-in. 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.

Determination of Engineering Quality

Two important properties thought to affect the engineering quality of glaçial materials are physical strength and chemical reactivity. Glacial aggregates are often used in concrete, so determination of these two properties, along with petrographic analysis of coarse aggregates, is most desirable.

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 lowering of concrete strength or durability.

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 amorphous silica react with alkali or hydrating cement (alkali-silica reaction). Further, some dolomitic limestones or calcareous dolomites are known to create alkali-carbonate reactions, causing failures in concrete. Therefore, the potentially reactive and non-reactive rocks were identified and recorded for further analysis.

These two key properties were determined in sample Nos. 1 through 18 in Kalamazoo County. The resulting data are discussed on pages 43, 45.

LITHOLOGIC DISTRIBUTION OF AGGREGATES

Evaluation of gravel deposits of two separate glacial lobes in Kalamazoo County with respect to their suitability for concrete is a very complex

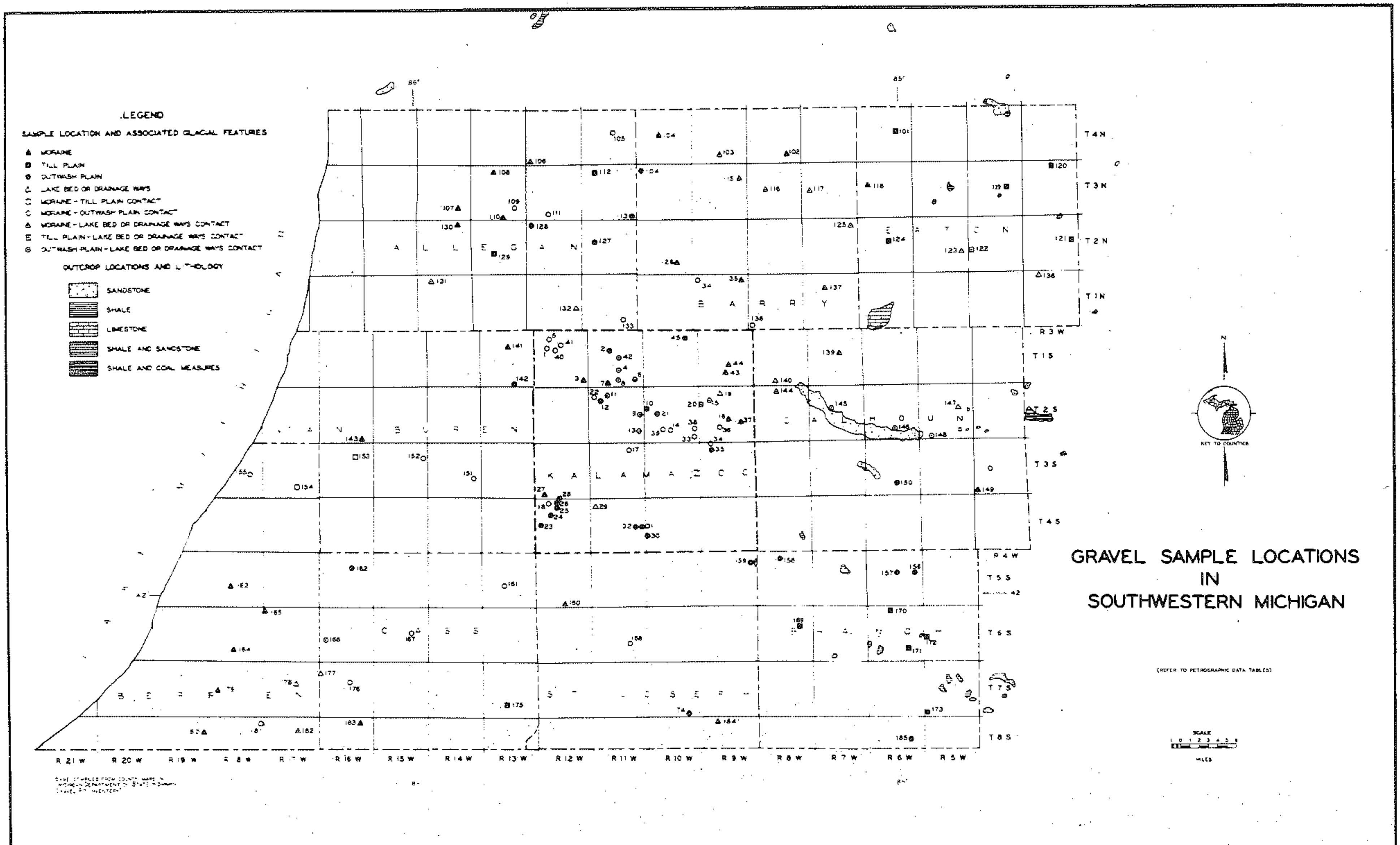


Figure 9. Sample locations in Southwestern Michigan.

problem. This complexity has been revealed by the recognition of out-of-phase fluctuational relationships between the Lake Michigan lobe and the Saginaw lobe, and by the detailed picture of the distribution of gravel lithologies in southwestern Michigan shown by isopleth maps (Figs. 10 through 18).

Lithologic Map Interpretation and Provenance

Petrographic data from 130 sample locations (45 in Kalamazoo County and 85 in surrounding counties) were utilized for this interpretation. Each sample location is indicated by a symbol depicting an 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 9 shows only gravel sample locations and their numbers, as given in Tables 3 and 5 in the Appendix.

All petrographic data are regrouped into 9 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. The 9 categories are:

Igneous (acid + basic) Metamorphics (foliated + non-foliated) Crystallines (igneous + metamorphics)	Precambrian Fraction (Possible Source: Canadian Shield Area)
Cherts Carbonates and cherts Sandstones Siltstones and shales Clay Ironstone Concretions Clastics (sandstone + siltstone + shale + C. I. concretions)	Paleozoic Fraction (Possible Source: Michigan Basin Area)

For a simple and clearer interpretation, percent lithologies for each lithologic group are plotted on nine different maps (Figs. 10 through 18) and isopleths are drawn to develop a pattern. These patterns show glacial and 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

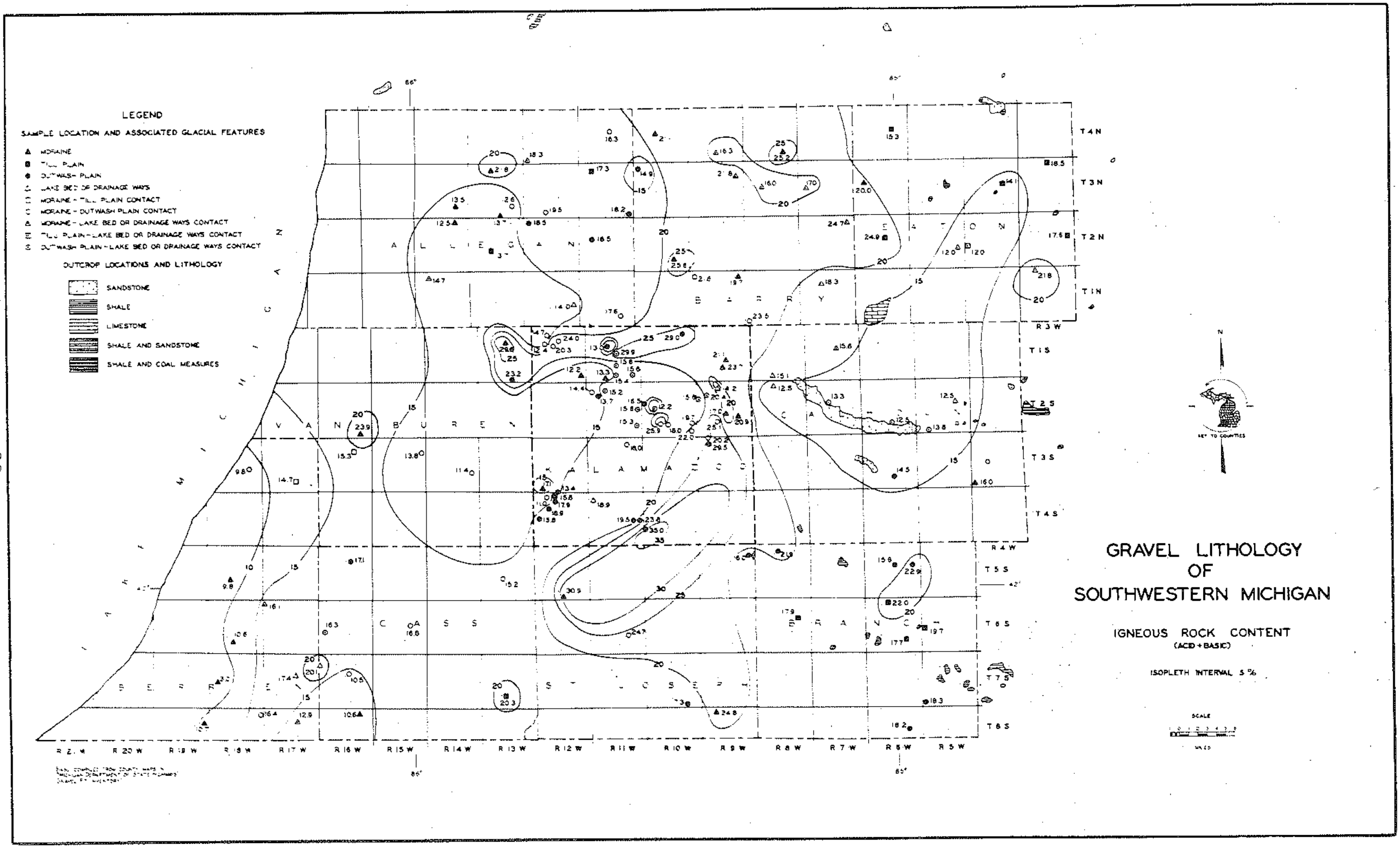


Figure 10. Igneous rock content in Southwestern Michigan.

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 10 through 18 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 Figure 6.

Igneous, Metamorphic, and Crystalline Rock Content - In general, the igneous rock content is higher in the eastern part of the study area, which is indicative of Saginaw lobe deposits (Fig. 10). The 20 percent isopleth passing through Kalamazoo County seems to be an arbitrary line for separating deposits of the two lobes. An isopleth of 15 percent in Calhoun and Eaton Counties can be explained by the increased influx of local bedrock lithologies.

The metamorphic rock content pattern also, in general, shows higher percentages in the eastern part of the study area (Fig. 11). The 10 percent isopleth passing through the western part of Kalamazoo County seems to be the arbitrary line separating deposits of the two lobes. According to Anderson (10), the metamorphic rock content of the Saginaw lobe is higher than the Lake Michigan lobe sediments due to an influx of quartzite pebbles. This fact was also corroborated by the writer in his petrographic analysis.

To demonstrate the best separation of deposits of two different sources, igneous rock and metamorphic rock categories were combined under a single category of crystalline (Precambrian) rocks. In the study area the Saginaw lobe deposits generally contain more than 30 percent crystalline rocks, and in certain areas it is higher than 40 percent (Fig. 12). The Lake Michigan lobe deposits, on the other hand, show crystalline rock content to be less than 30 percent. Therefore, the 30 percent isopleth passing through the western part of Kalamazoo County seems to be the arbitrary lithologic interlobate line.

Isolated lows can be 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.

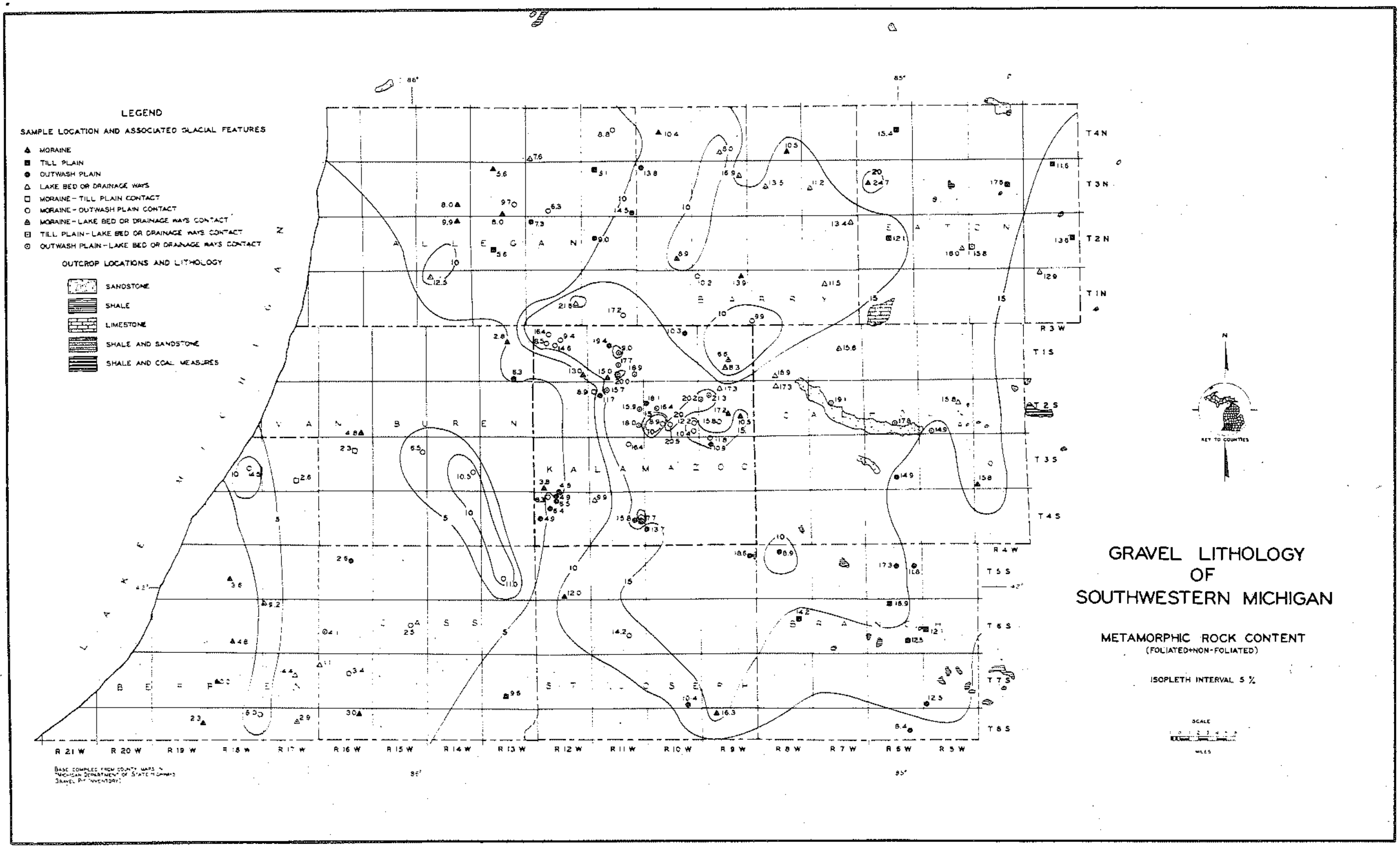


Figure 11. Metamorphic rock content in Southwestern Michigan.

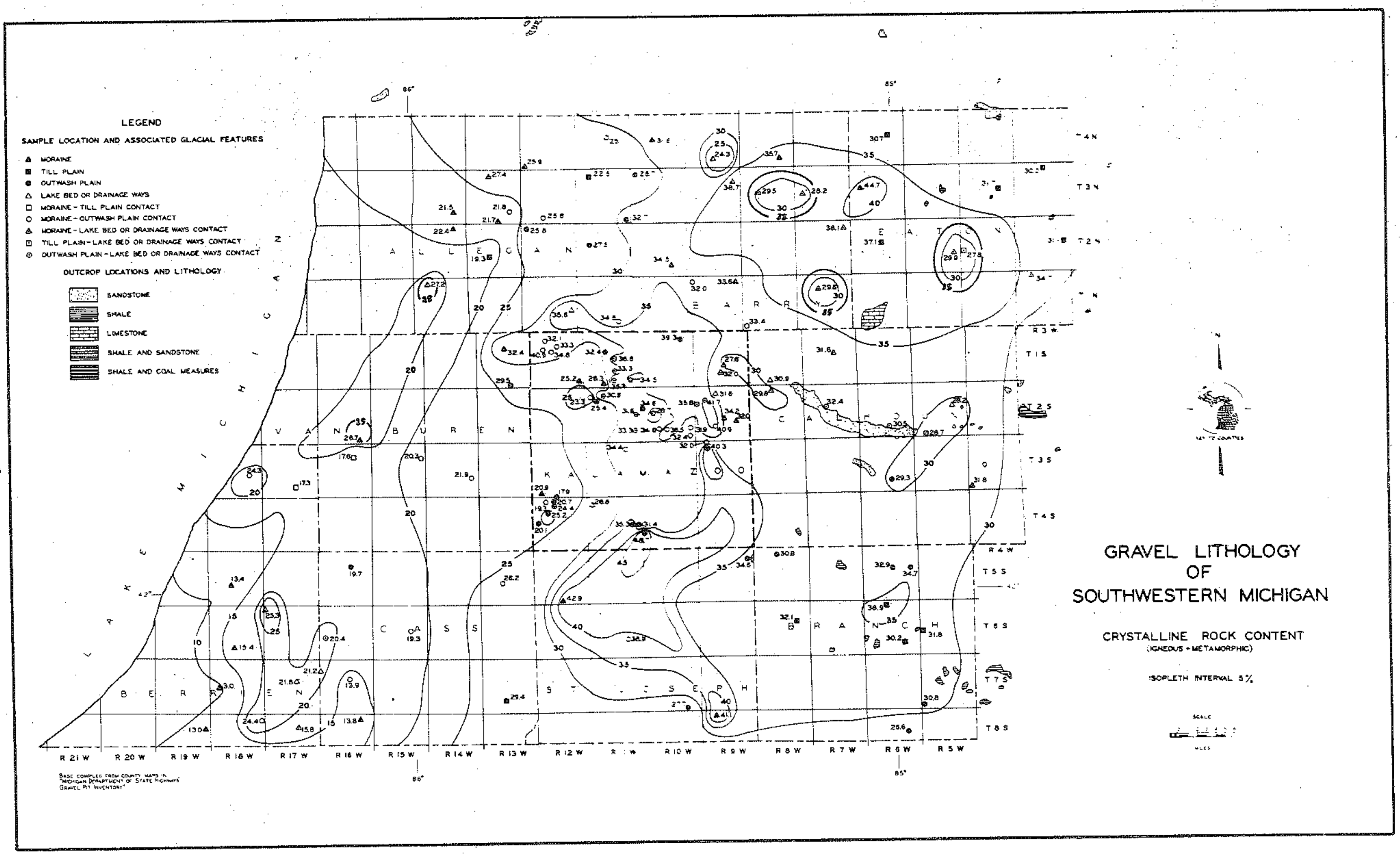


Figure 12. Crystalline rock content in Southwestern Michigan.

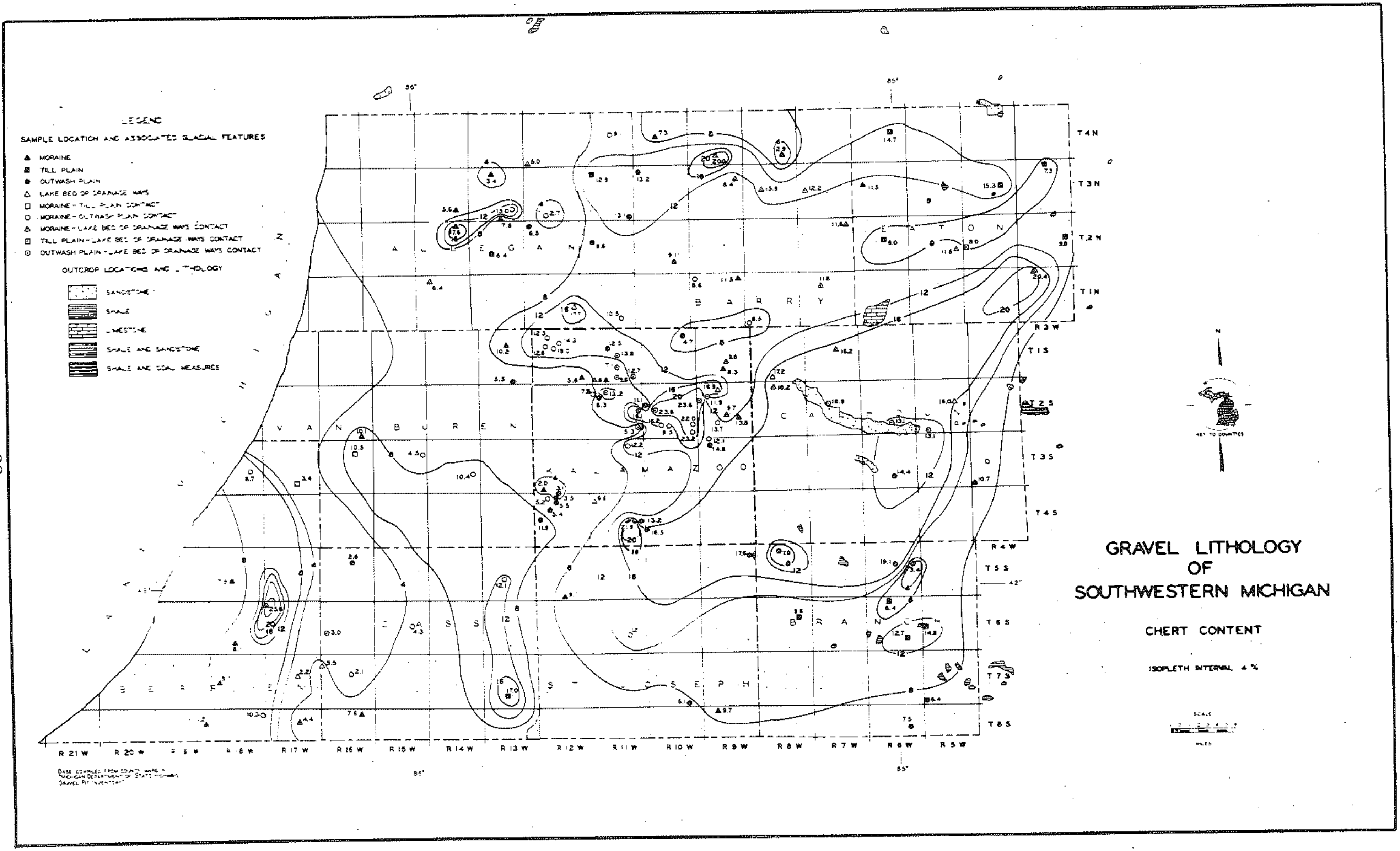


Figure 13. Chert content in Southwestern Michigan.

Chert Content - The map in Figure 13 shows high chert content values 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. 6). The source of cherts in the Lake Michigan lobe sediments could very well 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. The isopleth pattern in Berrien County suggests the direction of glacial ice.

Carbonate and Chert Content - Figure 14 is a map in which the total carbonates and cherts are added together. The pattern here shows that in general the carbonate and chert content of the Lake Michigan lobe sediments is above 60 percent and in some areas, presumably near the Devonian carbonate source (Fig. 6), is above 70 percent. Values below 60 percent could be caused by dilution from the increased amount of clastics. The carbonate and chert content of the Saginaw lobe sediments is in general less than 60 percent, and in some areas it is below 50 percent for the same reason given in the case of the Lake Michigan lobe. Values above 60 percent, northeast of Kalamazoo County, are probably due to bedrock erosion of cherty Bayport limestone of the upper Mississippian age, and some carbonates of the Pennsylvanian age. Slightly higher dolomite content has been observed 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 percent isopleth passing through western Kalamazoo County seems to be the arbitrary lithologic interlobate line.

Sandstone Content - The sandstone content map does not show any clear pattern distinguishing the Lake Michigan lobe sediments from the Saginaw lobe sediments (Fig. 15). In general, a 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 are more uniformly distributed in the Saginaw lobe sediments (Fig. 16). 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

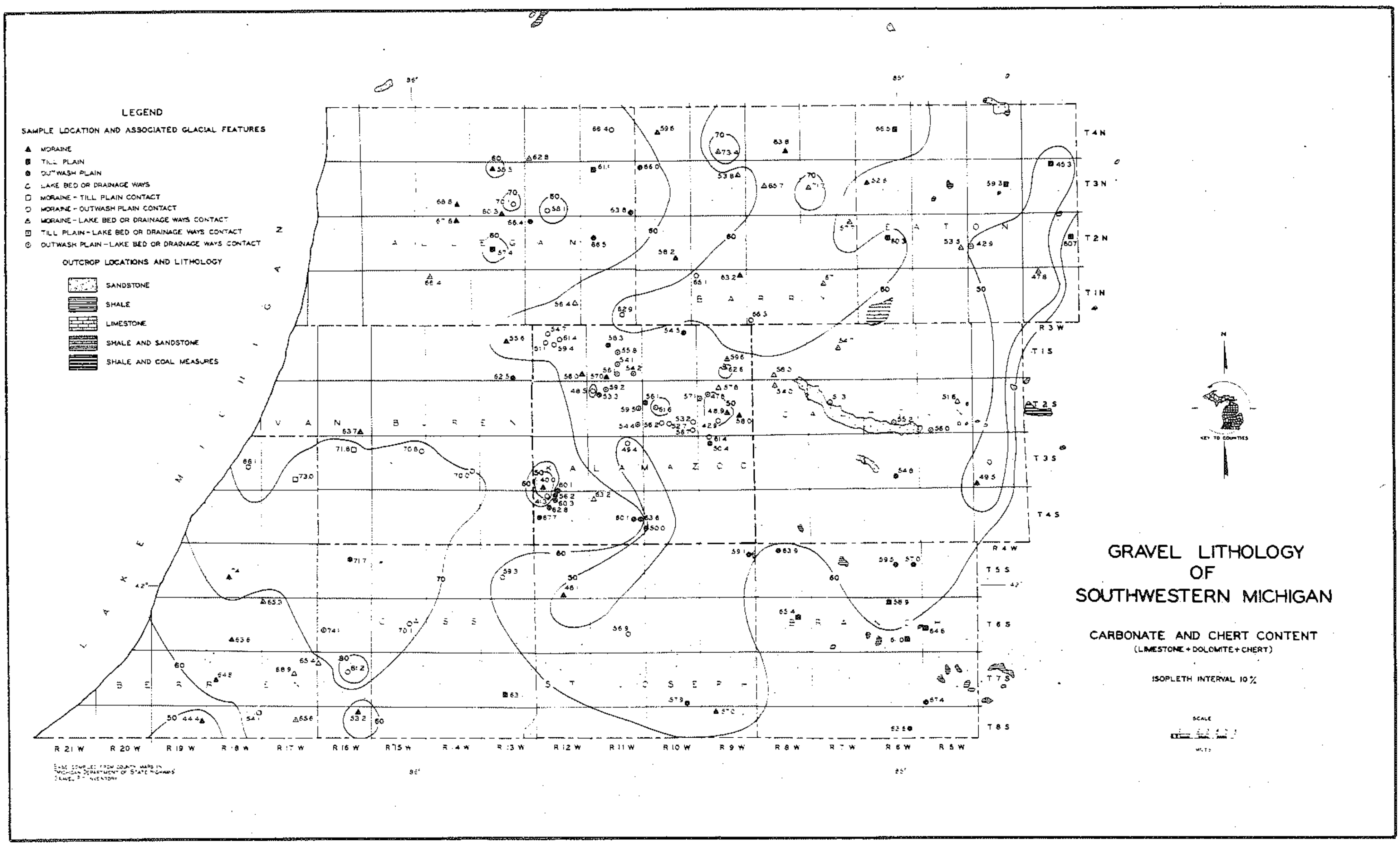


Figure 14. Carbonate and Chert content in Southwestern Michigan.

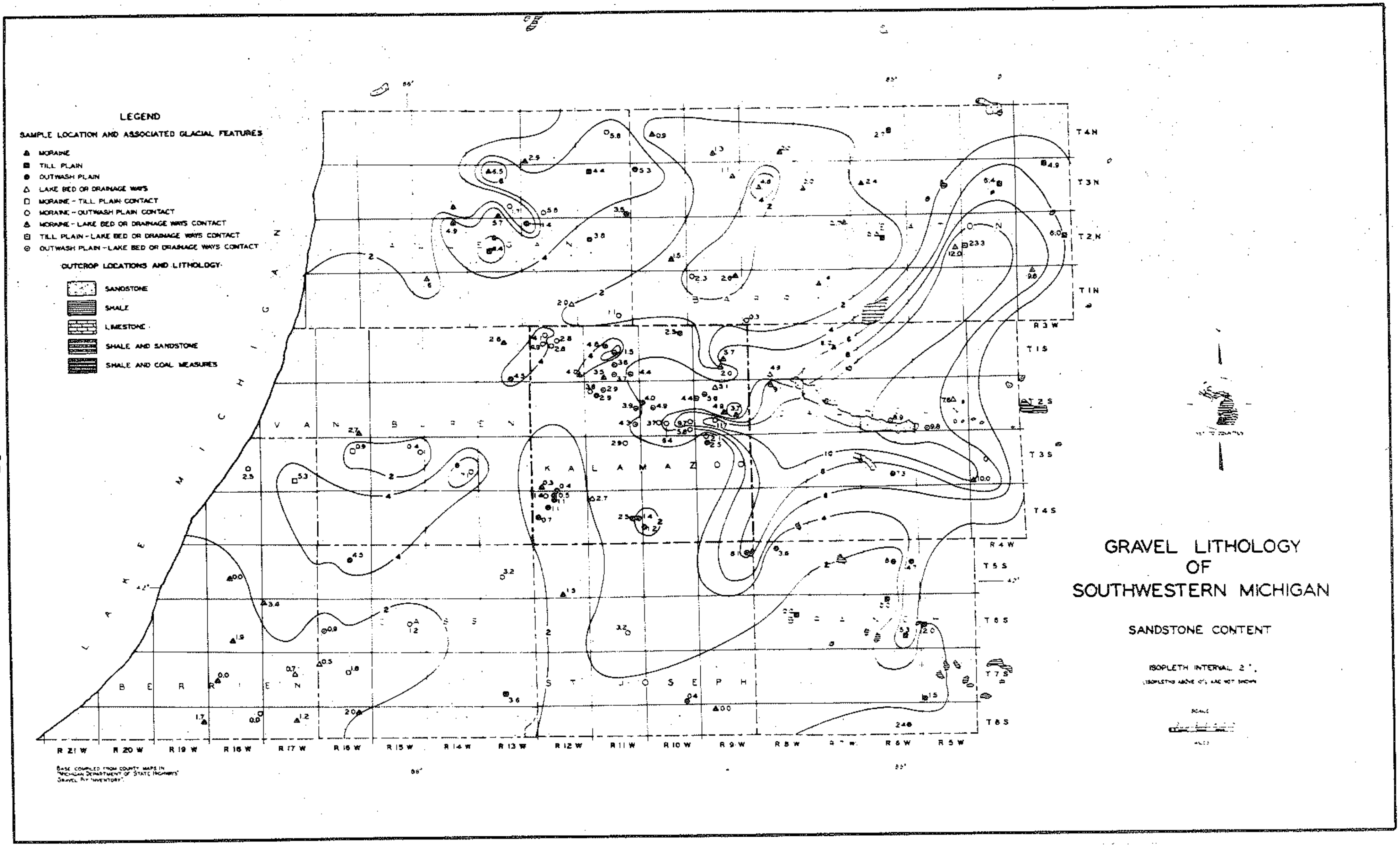


Figure 15. Sandstone content in Southwestern Michigan.

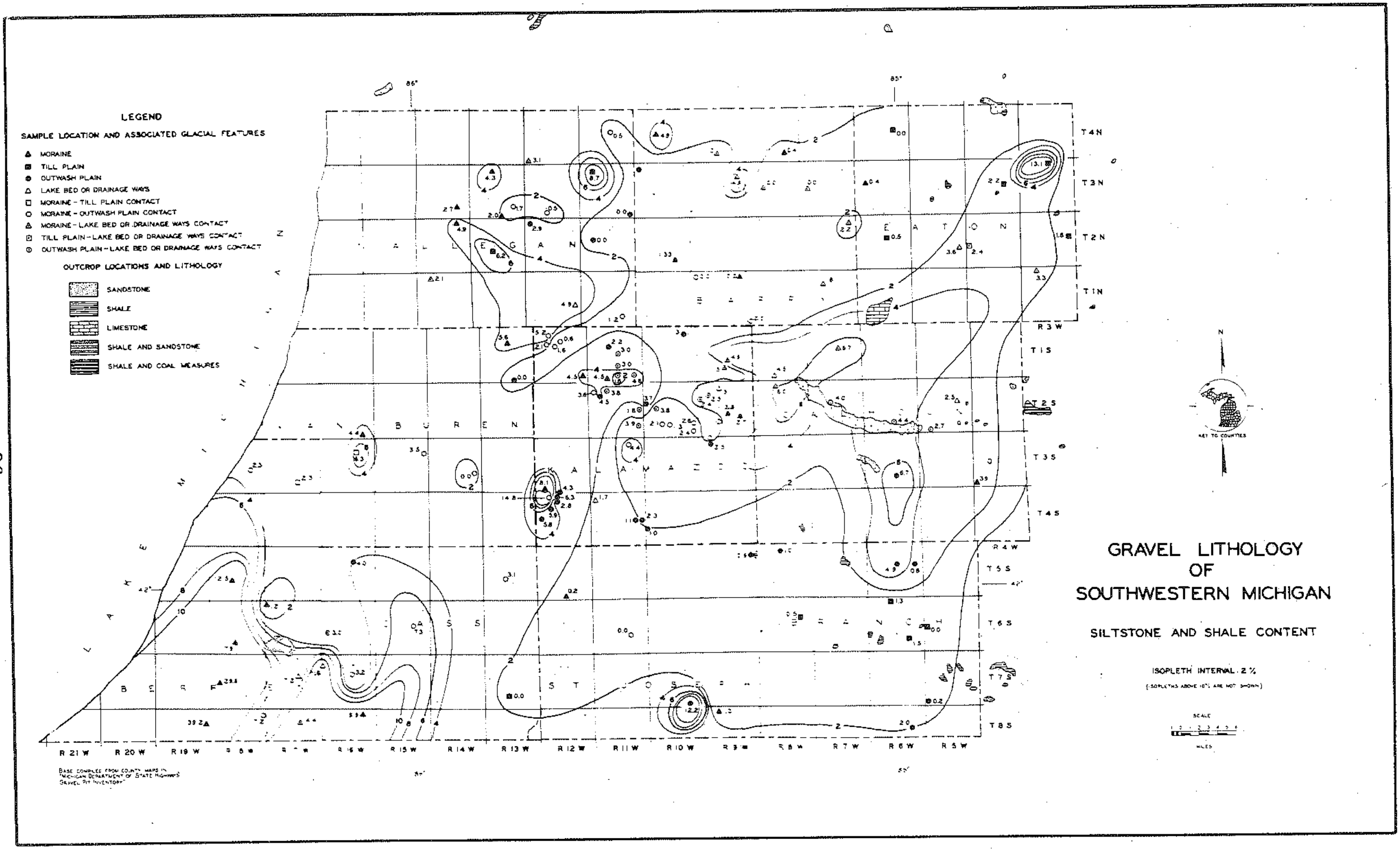


Figure 16. Siltstone and Shale content in Southwestern Michigan.

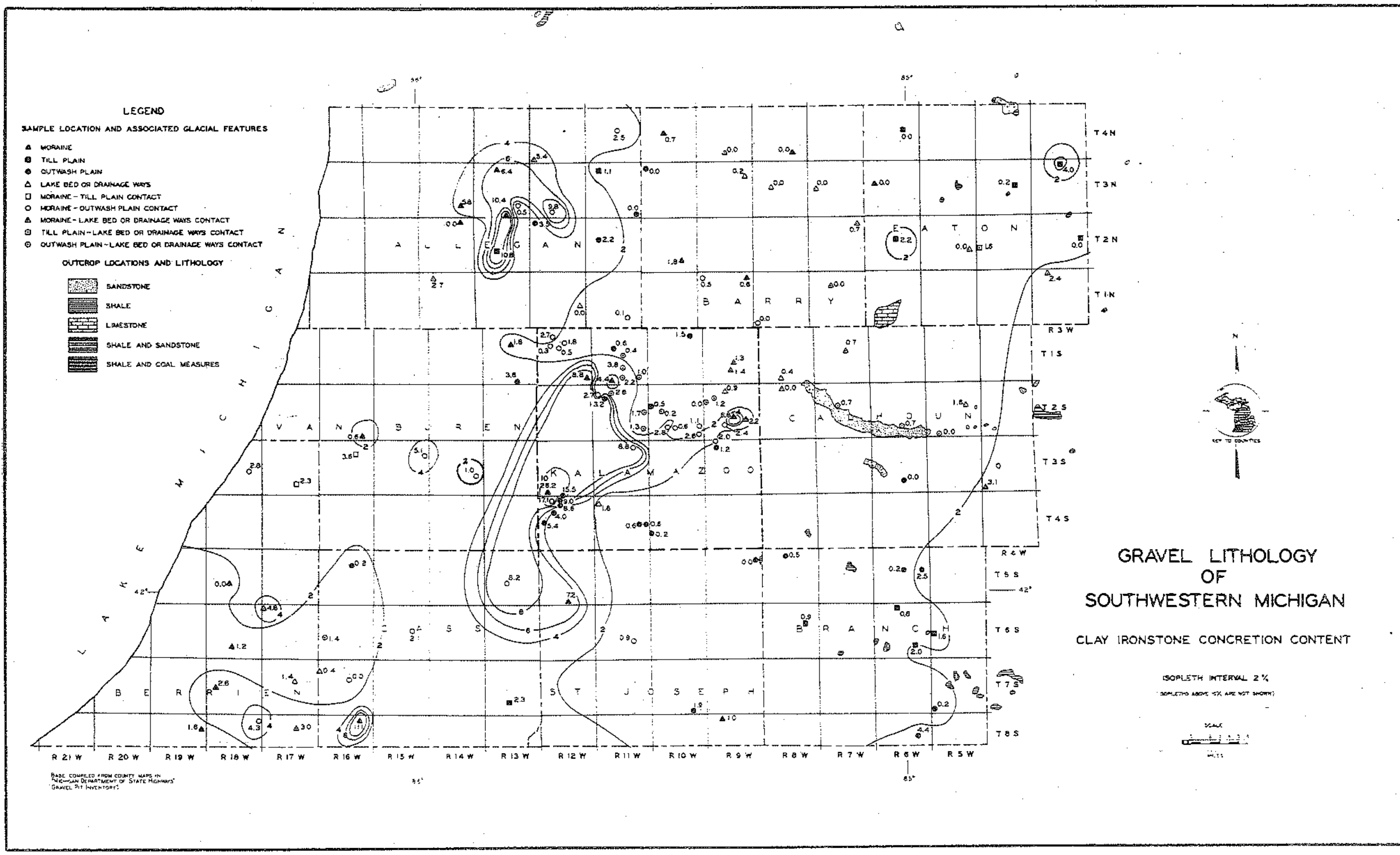


Figure 17. Clay Ironstone Concretion content in Southwestern Michigan.

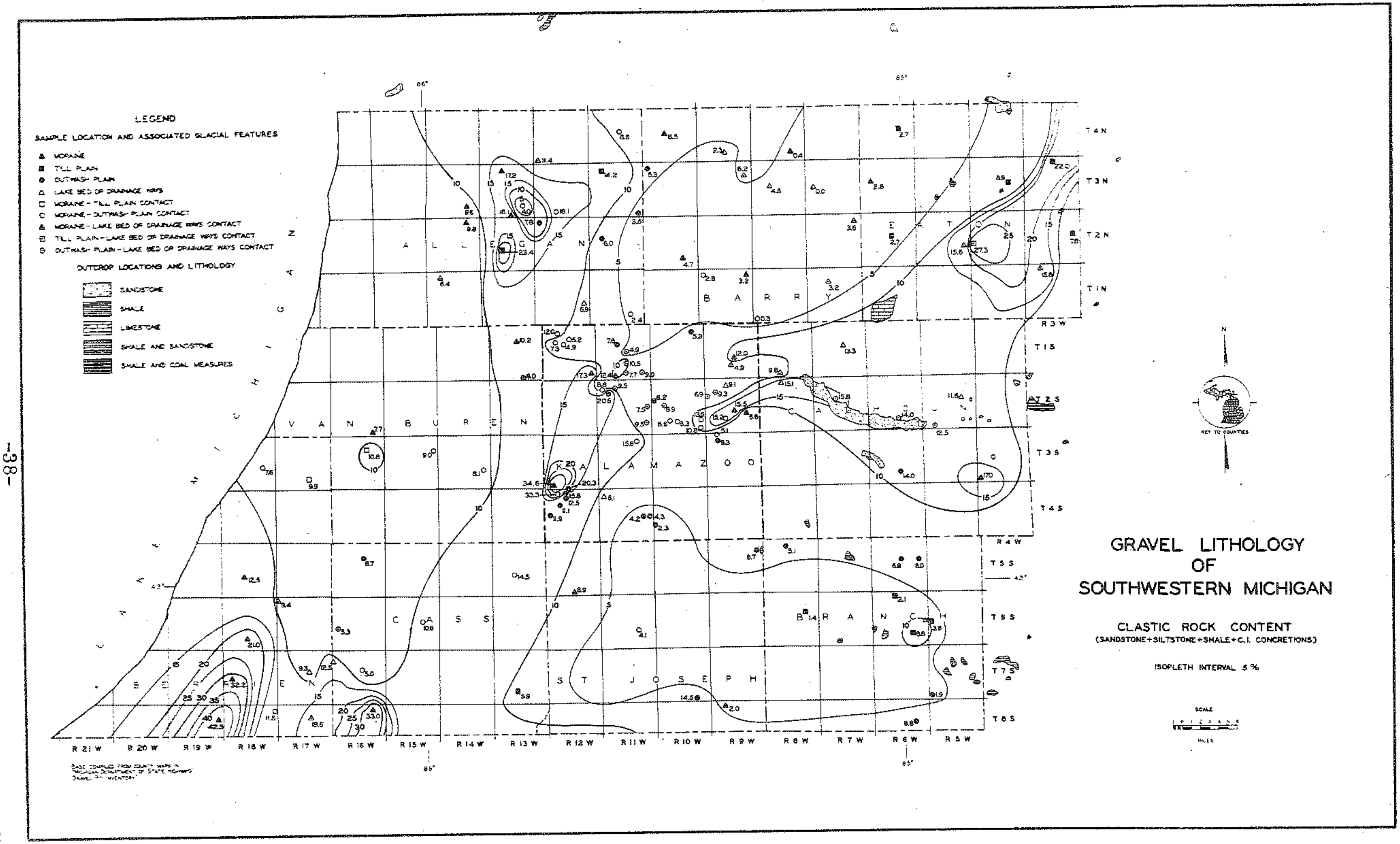


Figure 18. Clastic rock content in Southwestern Michigan.

more or less matches with that of the chert content (Fig. 13) 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. High siltstone and shale content in Berrien and Cass Counties may be due to the glacial erosion of the Ellsworth-Antrim shales by Lake Michigan ice.

Clay Ironstone Concretion Content

The map in Figure 17 shows that clay ironstone concretion content in the Saginaw lobe sediments are mostly less than 2 percent, 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 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. The 2 percent isopleth passing through Kalamazoo County seems to indicate, once more, the arbitrary lithologic interlobate line.

Clastic Rock Content

The total of clastic lithologies plotted on the map (Fig. 18) do not seem to form a clear pattern indicative of both the lobes. Patterns in this figure do not exactly correlate with patterns in Figures 15, 16, and 17, 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 10, 11, and 12 where the distribution is more uniform.

ECONOMIC CONSIDERATIONS

The sand and gravel industry in Michigan is expanding as new highway programs and other construction projects increase. In 1971, Michigan alone produced 56,613,000 tons of sand and gravel valued at $62,898,000, thus ranking second nationally in production. Most of this tonnage was mined in areas adjacent to the larger metropolitan areas of the state. About 1.8 percent of the total sand and gravel output was processed in Kalamazoo County. In 1971 this county produced 1,003,000 tons worth about $1,459,000.

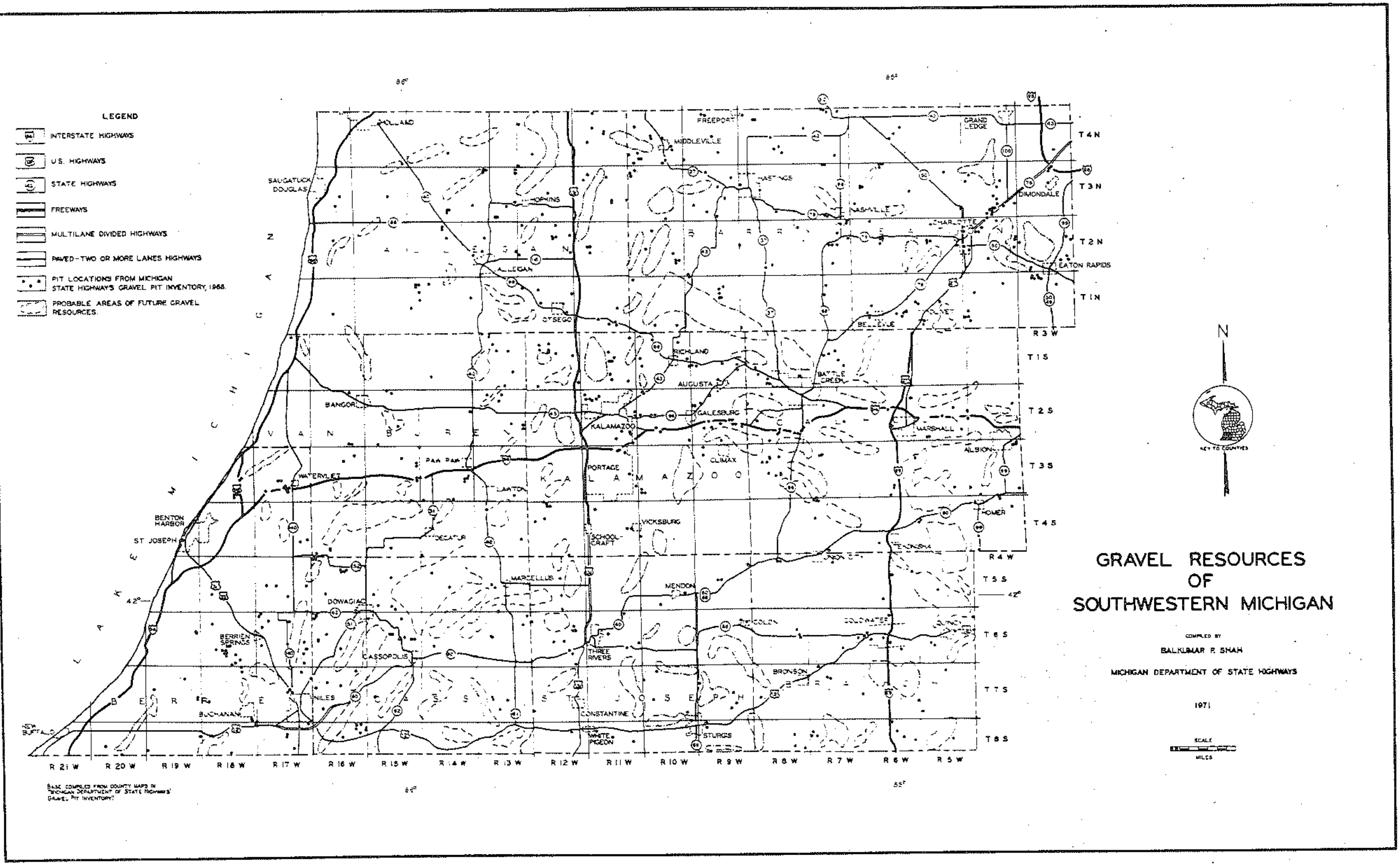


Figure 19. Gravel resources of Southwestern Michigan.

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

Sand and Gravel Economics

In recent years, depletion of material and new zoning laws enacted because of increasing environmental concerns, have caused the industry to ask the geologist for help in locating suitable new sand and gravel resources. In general, it is believed that sand and gravel deposits of glacial origin are everywhere in Michigan and that the supply is unlimited. This is not always true, because of the fact that these deposits have to meet certain specifications in terms of gradation and composition. An economically feasible sand and gravel deposit must also 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 1971 there were 11 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. 19). Presently, processed gravel in Kalamazoo County costs slightly more than a \$1.10 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 materials 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 (11), Kneller (12), and Wingard (1) 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 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, 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 materials.

Potential Building Aggregates

With the increasing demands placed upon the large sand and gravel industry, it has become necessary for the 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, "Gravel Resources of Southwestern Michigan" (Fig. 19), 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 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; and should be used with great caution and supplemented with a detailed geologic study of the location. It may prove to be unsatisfactory in some areas.

Gravel Pit Locations - Gravel pit locations that 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 that in general the density of gravel pit locations is higher near the population centers 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 are not easily found. 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.

AGGREGATE SUITABILITY FOR ENGINEERING USAGE

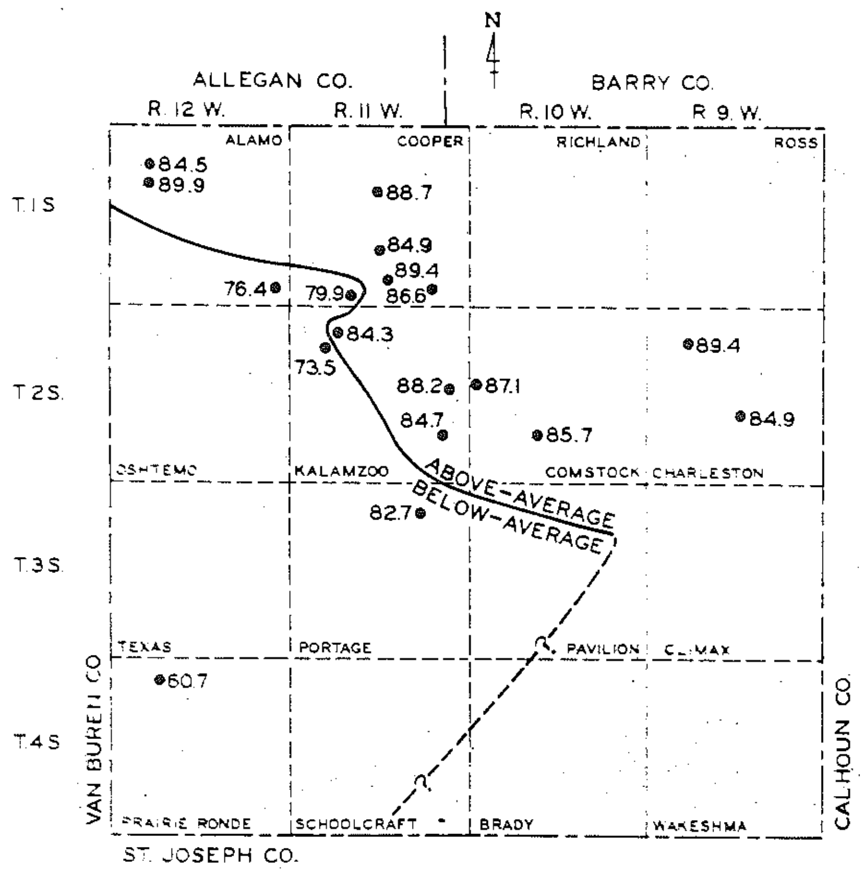
Variations in lithologic composition and distribution of glacial materials are discussed earlier and also their economic considerations are noted. Discussion here is brief, and relevant to the few important properties of aggregates determined in this study affecting their performance in concrete.

Several other factors relating to aggregate suitability and the engineering test results are discussed by Wingard (1) in his work, carried out in the Research Laboratory Section of the Michigan Department of State Highways prior to the present study. The reader is directed to Wingard's work for more details.

Properties and Performance of Aggregates

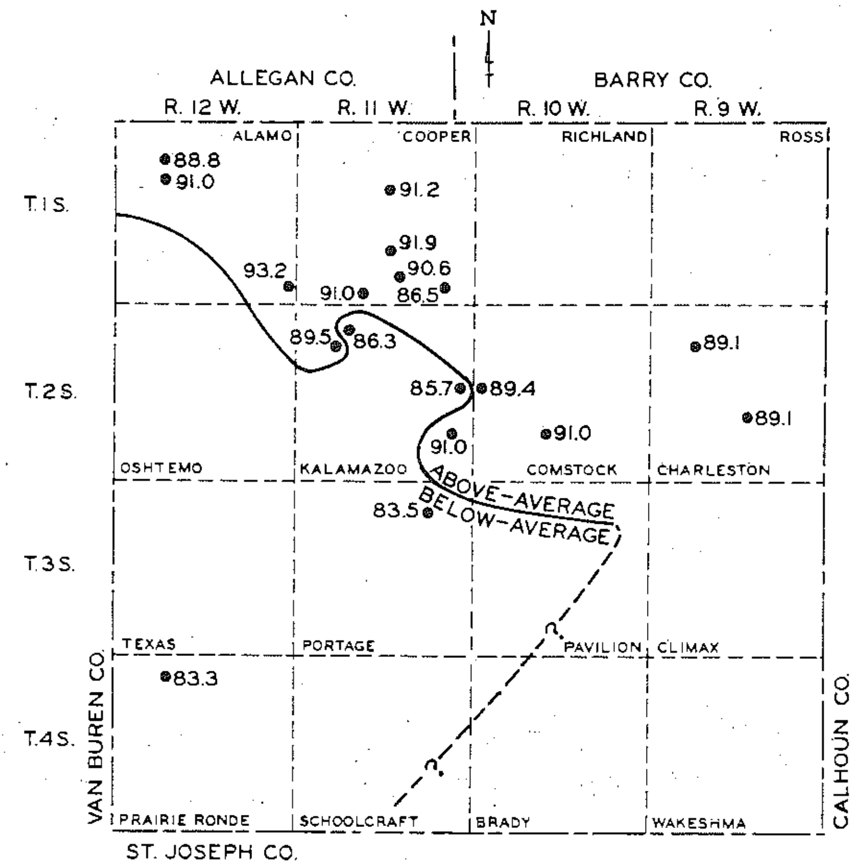
The design and control of concrete frequently depends on the physical, chemical, and lithological properties of the materials used. Aggregates generally occupy 70 to 80 percent of the volume of concrete, and also influence mix proportions and economy. They must conform to certain requirements for certain 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 on page 25 of the present report.



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 20. 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 21. Percent distribution of chemically non-reactive particles in near surface drift of Kalamazoo County, Michigan.

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 20 and 21. The average mean value for all 18 samples were 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 the arbitrary lithologic interlobate lines on the lithologic maps discussed in Figures 10 through 18. In both Figures 20 and 21, 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, their provenance. For planning and exploration purposes, attention is 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 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 phyllites, and other minor rock varieties are chemically reactive. It is also known that some siltstones, shale, iron-clay concretions, and certain type cherts will dilate under moist freeze-thaw conditions causing surface pop-outs or internal distress. All above listed rocks should be avoided as much as possible if one is to assure the best quality concrete for strength and durability.

CONCLUSIONS

1. Detailed glacial mapping of an area, preferably as large as a county, is essential for the systematic economic evaluation of aggregate deposits for utilization in a highway construction program.

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

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

4. 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.

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

6. Local Paleozoic clastic lithologies display greater variations between the two lobes. Therefore, sometimes local clastic content alone cannot be used very successfully in differentiating between the deposits of 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 closer source area.

7. 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.

8. The gross deleterious rock content of 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 to 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 10 through 18 can 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 geological research of this type in the fields of highway planning, sand and gravel industry, ready-mixed concrete industry, asphaltic concrete industry, soil surveys, groundwater surveys, and economic resource surveys for the state and federal agencies. It is hoped that the approach used in this research will serve as a basic model for future detailed studies in specific areas for aggregate evaluation in geologically critical areas. Following are a few areas in which future research is necessary.

1. This type of study could be undertaken in other areas of the state, especially in glaciated interlobate areas 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. Detailed petrographic, physical and chemical properties of various rocks outcropping in the state should be determined in order to know about their possible use for highways and other construction.

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

REFERENCES

1. Wingard, N. E., "Evaluation of Aggregate Sources of Glacial Origin," Michigan Department of State Highways, Research Report No. R-746, 1971.

2. Leverett, Frank, and Taylor, F. B., "The Pleistocene of Indiana and Michigan and the History of the Great Lakes," U.S. Geol. Surv., Monograph 53, p. 529, 1915.

3. Leverett, Frank, "Map of the Surface Formations of the Southern Peninsula of Michigan," Mich. Geol. Surv. Div., 1924.

4. Martin, H. M., "Map of the Surface Formations of the Southern Peninsula of Michigan," Mich. Geol. Surv., Publ. 49, 1955.

5. Shah, B. P., "Evaluation of Natural Aggregates in Kalamazoo County and Vicinity, Michigan," Ph.D. thesis, Dept. of Geology, Michigan State University, 1971.

6. Perkins, S. O., and Tyson, J., "Soil Survey of Kalamazoo County, Michigan," U.S. Dept. of Agriculture Soil Survey, Report, 1928.

7. Smith, G. D., "Pedological Lectures on Soil Classification," Belgian Soil Science Society, 1965.

8. "Soil Taxonomy," U.S. Department of Agriculture, 1972.

9. Ehrlich, R., and Davies, D. K., "Sedimentological Indices of Transport Direction, Distance, and Process Intensity in Glacio-Fluvial Sediments," Jour. Sed. Petrology, V. 38, No. 4, pp. 1166-1170, 1968.

10. Anderson, R. C., "Pebble and Sand Lithology of the Major Wisconsinan Glacial Lobes of the Central Lowland," Geol. Soc. America Bull., V. 68, No. 11, pp. 1415-1450, 1957.

11. Lenhart, W. B., "Sand and Gravel," Reviews of Engineering Geology, V. I., Fluhr, T. and Legget, R. F., editors: Geol. Soc. America, pp. 187-95, 1962.

12. Kneller, W. A., "A Geological and Economic Study of Gravel Deposits of Washtenaw County and Vicinity, Michigan," Ph.D. thesis, Dept. of Geology, University of Michigan, 1964.

REFERENCES (Cont.)

13. Huang, Walter, Petrology, McGraw-Hill, New York, 1962.

14. Moorehouse, W. W., The Study of Rocks in Thin Section, Harpers, New York, 1959.

15. Krumbein, W. C., and Pettijohn, F., Manual of Sedimentary Petrography, Appleton-Century, New York, 1938.

16. Milner, H. B., Sedimentary Petrography, Arrowsmith, Bristol, Eng., 1962.

17. Spock, L. E., Guide to the Study of Rocks, Harpers, New York, 1953.

18. Pettijohn, F. J., Sedimentary Rocks, Harpers, New York, 1957.

FURTHER REFERENCES

Allen, W. B., et al., "Availability of Water in Kalamazoo County, Southwestern Michigan: U.S. Geol. Surv.," Water Supply paper, No. 1973 (in press), 1972.

American Society for Testing Materials, Concrete and Mineral Aggregates: ASTM Standards, Part 10; Philadelphia, p. 620, 1970.

Anderson, R. C., "Pebble lithology of the Marselles till sheet in Northeastern Illinois," Jour. Geology, V. 63, pp. 228-243, 1955.

Blanks, R. F., "Good concrete Depends on Good Aggregate," Civil Engineering, V. 122, No. 9, pp. 651-55, 1952.

Deutsch, M., Vanlier, K. E., and Giroux, P. R., "Ground-Water Hydrology and Glacial Geology of the Kalamazoo area, Michigan," Mich. Geol. Surv., Progress Report 23, p. 122, 1960.

Flint, R. F., "Glacial and Quaternary Geology," John Wiley and Sons, Inc., New York, London, p. 892, 1971.

Folk, R. L., and Weaver, C. E., "A Study of the Texture and Composition of Chert," Amer. Jour. Sci., V. 250, pp. 498-510, 1952.

Highway Geology Symposium, "Geology as Applied to Highway Engineering," Sponsored by the Department of Highways, Richmond, Virginia, 1950.

Highway Research Board, "Aggregate Characteristics and Examination," Publication 1361, 1966.

Hough, J. L., "Geology of the Great Lakes," Univ. of Illinois Press, Urbana, p. 313, 1958.

Ibrahim, Abdelwahid, "The Application of the Gravity Method to Mapping Bedrock Topography in Kalamazoo County, Michigan," Ph.D. thesis, Dept. of Geology, Michigan State University, 1970.

Krumbein, W. C., and Pettijohn, F. J., "Manual of Sedimentary Petrography," Appleton-Century-Crofts, Inc., New York, p. 549, 1938.

Krynine, P. D., and Judd, W. R., "Principles of Engineering Geology and Geotechnics," McGraw-Hill Book Co., Inc., p. 730, 1957.

Legg, F. F., Jr., and Vogler, R. H., "Alkalicarbonate Rock Reactions in Michigan," Highway Research Records, No. 45, HRB, NAS-NRC, publ. 1167, 1964.

Lenhart, W. B., "Sand and Gravel, in Industrial Minerals and Rocks;" Amer. Inst. Min. Met. Eng., pp. 733-58, 1961.

Leverett, Frank, Specific reference is made to chapters written by Leverett alone in the US Geol. Survey Monograph 53 (Leverett and Taylor), 1915.

Martin, H. M., "The Centennial Geological Map of the Southern Peninsula of Michigan," Mich. Geol. Surv., Publ. 39, 1936.

Mielenz, R. C., "Petrography Applied to Portland Cement Concrete," Reviews in Engineering Geology, V. I., Fluhr, T. and Legget, R. F., editors: Geol. Soc. America, pp. 1-38, 1962.

Miller, M. M., "Taku Glacier Evaluation Study," State of Alaska, Dept. of Highways and U.S. Dept. of Commerce, Bureau of Public Roads, p. 200 with figures, 1963.

Riggs, C. H., "Geology of Allegan County, Michigan," Mich. Geol. Surv. Prog. Report 4, 1938.

Slawson, C. B., "The Jasper Conglomerate, An Index of Drift Dispersion," Jour. Geology, V. 41, pp. 546-552, 1933.

Swenson, E. G., and Chaly, V., "Basis for Classifying Deleterious Characteristics of Concrete Aggregate Materials," The Crushed Stone Jour., June-Sept., pp. 17-26; Jour. Amer. Concrete Inst., V. 27, No. 9, May, Proceedings, V. 52, 1956.

Terwilliger, F. W., "The Glacial Geology and Ground-Water Resources of Van Buren County, Michigan," Mich. Geol. Surv. Publ. 48, Part I, p. 95, 1954.

Thornbury, W. D., "Principles of Geomorphology," John Wiley and Sons, Inc., New York, p. 618, 1962.

Wayne, W. J., and Zumberge, J. H., "Pleistocene Geology of Indiana and Michigan," in The Quaternary of the United States, Princeton Univ. Press, Princeton, New Jersey, pp. 63-83, 1965.

Wilson, L. M., "Surficial Glacial Deposits of the Michigan-Saginaw Lobes in Grand Rapids Area, Michigan," A study of relationship: M. S thesis, Dept. of Geology, Michigan State University, 1955.

Zumberge, J. H., "Correlation of Wisconsin Drifts in Illinois, Indiana, Michigan, and Ohio," Geol. Soc. Amer. Bull., V. 71, pp. 1177-1188, 1960.

APPENDIX

TABLE 3

GRAVEL LITHOLOGY OF KALAMAZOO COUNTY, MICHIGAN

SAMPLE NUMBER	LOCATION						TYPE OF SAMPLE	PERCENT LITHOLOGY												TOTAL PEBBLE COUNTS OR VOLUME	PERCENT GROUP LITHOLOGY			*PERCENT DELETERIOUS (SILTSTONE + SHALE + C.I.CONC. + POROUS CHERT + DENSE CHERT)	ASSOCIATED GLACIAL LOBE(S)
	1/4	1/4	SECTION	TOWNSHIP S.	RANGE W.	TOWNSHIP NAME		ACID IGNEOUS	BASIC IGNEOUS	FOLIATED METAMORPHIC	NON-FOLIATED METAMORPHIC	CARBONATE	SANDSTONE	SILTSTONE AND SHALE	CLAY IRONSTONE CONCRETION	POROUS CHERT	DENSE CHERT	OTHERS	TOTAL		CRYSTALLINE	CARBONATE AND CHERT	CLASTIC		
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	40.00	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	8.80	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	7.56	6.55	11.12	47.09	3.64	3.01	3.85	4.05	3.01	2.08	100.01	962	33.25	54.15	10.50	13.92	Lake Mich.-Sag. Interlobate
5	NW	NE	8	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	8.32	6.76	7.51	11.43	41.48	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	48.50	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	6.60	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	19.50	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	0.80	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	5.20	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	8.00	6.23	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	2.69	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	8.56	2.55	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	2.76	8.61	3.63	1.18	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	3.50	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	1.51	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	2.09	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	28.18	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	8.69	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	16.74	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	2.45	6.89	47.04	2.80	0.56	1.84	12.42	1.92	0.08	99.99	2 liters	33.33	61.38	[illegible]	[illegible]	Lake Mich.-Sag. Interlobate
42	SW	SE	5		11	Cooper	Spot	11.78	14.09	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	17.45	1.65	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	16.51	2.33	4.24	49.92	5.74	4.91	1.33	7.49	2.16	0.83	100.00	2 liters	27.62	59.57	11.98	15.59	Saginaw
45	SE	SE	2	1	10	Richland	Spot	10.12	15.55	4.06	6.21	49.8	2.55	1.27	1.51	4.79	0.64	0.16	99.98	2 liters	39.27	54.50	5.33	5.29	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: SECTION	LOCATION: TOWNSHIP AND RANGE	LOCATION: COUNTY	TYPE OF SAMPLE	PERCENT LITHOLOGY: IGNEOUS (ACID+BASIC)	FOLIATED METAMORPHIC	NON-FOLIATED METAMORPHIC	CARBONATE	CHERT	SANDSTONE	SILTSTONE AND SHALE	CLAY (IRONSTONE CONCRETION)	OTHERS	TOTAL	TOTAL PEBBLE COUNTS OR VOLUME	PERCENT GROUP LITHOLOGY: CRYSTALLINE	CARBONATE AND CHERT	CLASTIC	PERCENT DELETERIOUS* (CHERT+SILTSTONE+SHALE+CL. CONCRETION)	ASSOCIATED GLACIAL LOBE(S)
101	14	T.4N., R.6W.	Eaton	Spot	15.30	5.50	9.90	51.90	14.70	2.70	--	--	--	100.00	2 liters	30.70	66.60	2.70	14.70	Saginaw
102	26	T.4N., R.8W.	Barry	Spot	28.20	1.60	9.00	60.90	2.90	--	0.40	--	--	99.90	2 liters	38.70	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	6.60	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	5.60	--	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	6.50	4.30	6.40	--	100.10	2 liters	27.40	55.50	17.20	14.10	Lake Michigan
109	26	T.3N., R.13W.	Allegan	Channel	12.64	0.99	8.17	54.95	15.10	1.73	1.74	0.50	4.69	100.51	450	21.80	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	0.50	4.30	6.40	--	100.10	2 liters	21.70	60.30	18.10	20.20	Lake Michigan
111	33	T.3N., R.12W.	Allegan	Spot	19.60	2.10	4.20	55.40	2.70	5.60	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	8.67	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	18.20	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	6.44	2.22	0.22	0.98	100.86	450	31.66	59.34	8.88	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	50.88	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	34.89	8.00	23.33	2.44	1.56	2.44	100.43	450	27.77	42.89	27.33	12.00	Saginaw
123	24	T.2N., R.6W.	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	0.67	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	25.56	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	16.50	5.60	3.50	56.90	9.60	3.80	--	2.20	--	100.00	2 liters	27.50	66.50	6.00	11.80	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	17.60	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	18.67	38.66	17.78	2.00	4.89	--	1.33	100.22	450	35.56	56.44	6.89	22.67	Lake Michigan
133	26	T.1N., R.11W.	Allegan	Spot	17.60	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	56.50	8.60	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	2.60	--	0.60	--	100.00	2 liters	33.60	63.20	3.20	12.10	Saginaw
136	31	T.1N., R.8W.	Barry	Spot	23.50	2.70	7.20	59.80	6.50	0.30	--	--	--	100.00	2 liters	33.40	66.30	0.30	6.50	Saginaw
137	9	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	26.21	Saginaw
139	15	T.1S., R.7W.	Calhoun	Channel	16.77	2.22	13.56	38.46	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.6W.	Calhoun	Channel	15.07	1.34	14.51	40.85	17.19	4.91	4.47	0.46	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	55.56	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	53.60	10.10	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	18.69	11.11	4.00	0.67	0.66	100.10	450	32.44	51.33	16.78	23.56	Saginaw
146	27	T.2S., R.6W.	Calhoun	Channel	12.47	1.56	16.26	42.09	13.14	6.91	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	12.46	1.11	14.67	43.56	16.00	7.56	2.46	1.50	0.88	100.24	450	28.23	59.56	11.57	20.01	Saginaw
148	32	T.2S., R.5W.	Calhoun	Channel	13.77	0.89	14.00	42.80	13.11	9.78	2.67	--	3.00	100.11	450	28.66	56.00	12.45	15.78	Saginaw
149	31	T.3S., R.4W.	Calhoun	Channel	15.99	1.58	14.22	38.80	10.67	10.00	3.67	3.11	1.89	100.11	450	31.77	49.47	16.98	17.65	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	4.80	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	3.60	--	100.00	2 liters	17.60	71.60	10.80	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	2.60	2.30	2.60	--	100.00	2 liters	24.30	68.10	7.60	13.60	Lake Michigan
156	13	T.5S., R.6W.	Branch	Spot	22.90	3.00	8.80	53.80	3.40	4.70	0.60	2.50	--	99.90	2 liters	34.70	57.20	8.00	6.70	Saginaw
157	15	T.5S., R.6W.	Branch	Channel	15.55	1.78	15.56	40.44	19.11	1.78	4.89	0.22	0.77	100.10	450	32.89	59.55	6.89	24.22	Saginaw
158	4	T.5S., R.6W.	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	6.10	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	1.60	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.16W.	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	0.60	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	44.80	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	0.60	--	99.90	2 liters	38.90	58.90	2.10	8.30	Saginaw
171	26	T.6S., R.6W.	Branch	Spot	17.70	4.70	7.80	48.30	12.70	5.30	1.50	2.00	--	100.00	2 liters	30.20	61.00	8.80	16.20	Saginaw
172	19	T.6S., R.5W.	Branch	Spot	19.70	2.60	9.50	49.80	14.80	2.00	--	1.60	--	100.00	2 liters	31.80	64.60	3.60	16.40	Saginaw
173	31	T.7S., R.5W.	Branch	Spot	18.30	4.50	8.00	61.00	6.40	1.60	0.20	0.20	--	100.10	2 liters	30.80	67.40	1.90	6.80	Saginaw
174	35	T.7S., R.10W.	St. Joseph	Spot	17.30	3.70	6.70	51.80	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	28	T.7S., R.13W.	Cass	Spot	20.30	6.00	3.80	46.10	17.00	3.60	--	2.30	--	99.90	2 liters	29.30	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	5.50	0.50	11.60	0.40	--	99.10	2 liters	21.20	65.40	12.50	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	21.60	68.90	9.30	10.80	Lake Michigan
179	19	T.7S., R.18W.	Berrien	Spot	3.00	--	--	55.70	9.10	--	29.60	2.60	--	100.00	2 liters	3.00	64.80	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	39.20	1.60	--	99.90	2 liters	13.00	44.40	42.50	52.00	Lake Michigan
181	1	T.6S., 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.6S., 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	65.60	18.60	21.80	Lake Michigan
183	2	T.8S., R.16W.	Cass	Spot	10.60	1.00	2.20	45.60	7.60	2.00	19.90	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	24.80	5.50	10.80	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	56.10	7.50	2.40	2.00	4.40	--	99.00	2 liters	26.60	63.60	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 1/4	1/4	SECTION	TOWNSHIP S.	RANGE W.	TOWNSHIP NAME	TYPE OF SAMPLE	PERCENT LITHOLOGY ACID IGNEOUS	BASIC IGNEOUS	METAMORPHIC	CARBONATE	CHERT	CLASTIC	FELDSPAR	QUARTZ	OTHERS	TOTAL	MECHANICAL ANALYSIS SCREEN SIZES 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	22.70	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	17.60	17.00	28.00	29.00	5.90	1.50	0.80	100.00
3	NW	NW	27	1	11	Cooper	Channel	7.67	7.33	5.00	26.33	10.33	6.00	14.00	21.00	0.33	99.99	21.90	16.10	20.20	19.60	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	41.60	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	13.20	11.60	22.20	39.80	11.60	0.90	0.40	100.10
7	NE	NW	34	1	11	Cooper	Channel	7.33	11.00	5.00	37.67	9.33	3.00	9.33	17.33	--	99.99	43.60	21.40	15.50	10.70	4.00	2.10	2.70	100.00
8	SW	NW	18	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	26.90	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	5.33	9.67	19.33	--	100.00	12.60	15.40	29.20	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	22.00	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	5.33	3.00	8.00	23.00	--	99.99	38.00	30.80	16.70	8.50	4.10	0.00	0.90	100.00
12	NW	SE	28	2	10	Comstock	Channel	6.67	9.33	5.33	35.33	9.00	3.67	11.33	19.33	--	99.99	35.60	20.90	20.10	15.40	4.60	1.60	1.80	100.00
13	NW	SW	8	2	9	Charleston	Channel	9.00	11.67	3.00	32.00	8.00	3.33	11.33	21.33	0.33	99.99	46.80	32.70	12.10	6.30	1.20	0.40	0.50	100.00
14	SW	SW	22	2	9	Charleston	Channel	6.33	8.67	4.00	38.00	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	8.33	9.67	7.33	17.33	--	100.00	20.50	15.50	21.30	28.50	9.10	2.40	2.60	99.90
16	NE	SE	5	4	12	Prairie Ronde	Channel	5.00	6.33	6.00	39.00	3.33	10.00	7.33	22.67	0.33	99.99	27.60	17.20	20.10	22.90	7.00	2.30	2.90	100.00
17	NW	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	28.23	30.52	18.19	13.08	6.23	4.74	--	99.99
18	NW	SW	5	1	12	Alamo	Auger	1.00	1.00	1.00	--	1.00	85.33	6.67	4.00	--	100.00	0.99	2.33	8.14	35.04	36.87	8.99	6.62	99.98
19	SE	SE	10	1	12	Alamo	Auger	6.33	10.67	1.00	--	4.67	46.33	7.67	23.33	--	100.00	18.67	14.39	8.29	21.92	27.05	9.67	--	99.99
20	NW	NW	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	5.96	17.72	40.59	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	18.25	2.39	1.06	99.99
22	SW	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	NE	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	NE	SW	32	1	12	Alamo	Spot	9.00	10.00	4.33	31.00	7.33	4.67	15.00	18.33	0.33	99.99	20.25	9.21	15.68	46.61	7.59	0.75	--	99.99
25	NE	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	10.90	15.30	35.77	17.13	3.16	2.33	100.00
26	SE	NW	28	1	12	Alamo	Auger	13.33	10.33	5.00	3.33	8.33	13.00	16.33	30.33	--	99.98	1.75	1.36	7.43	46.75	38.08	5.03	1.61	100.01
27	C	SW	25	1	12	Alamo	Spot	6.33	8.67	2.67	43.00	5.67	5.00	11.33	17.67	0.67	100.01	10.49	10.91	18.38	33.27	24.09	2.16	0.69	99.99
28	SW	SW	30	1	13	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	2.86	4.18	13.52	61.63	23.06	3.19	0.77	100.00
30	SW	SW	30	1	12	Alamo	Spot	7.67	5.67	9.00	40.33	5.00	8.67	8.00	15.67	--	100.01	9.16	6.34	13.59	40.11	22.61	4.32	1.68	100.00
31	NE	NE	2	2	12	Oshtemo	Auger	6.67	10.67	3.00	37.33	9.01	6.33	7.67	18.67	--	100.01	13.47	14.95	27.09	32.21	9.60	2.63	--	100.01
32	SW	SE	35	1	12	Alamo	Auger	4.00	16.33	2.67	37.67	16.33	10.33	5.33	5.33	--	99.99	3.23	14.26	30.36	28.50	13.76	6.40	3.49	100.00
33	C	NE	13	1	12	Alamo	Auger	0.67	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	NW	9	1	11	Cooper	Auger	6.67	14.00	6.33	23.33	9.33	6.33	13.00	22.00	--	99.99	30.37	26.87	24.17	10.57	2.62	1.60	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	49.02	7.18	13.4	22.31	6.65	2.00	--	99.87
37	SW	SE	17	1	11	Cooper	Spot	9.67	12.33	4.67	10.33	16.00	9.00	10.33	27.33	0.33	99.99	0.67	1.41	21.52	68.78	7.00	0.72	--	100.00
38	SW	NW	7	1	10	Richland	Auger	19.33	6.33	7.67	0.33	17.67	10.00	12.00	25.33	1.33	99.99	3.64	5.07	17.79	50.68	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	4.48	7.24	19.73	46.27	17.73	1.68	0.88	100.01
40	NE	NW	31	1	11	Cooper	Spot	6.33	9.33	6.00	24.00	10.67	14.00	6.33	23.00	0.33	99.99	68.22	6.60	7.88	11.66	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	36.36	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	16.57	16.98	29.74	14.29	4.23	4.26	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	19.33	13.00	8.67	7.33	24.67	--	100.00	4.77	3.26	10.52	50.76	27.73	2.95	--	99.99
45	NE	SW	2	2	12	Oshtemo	Spot	13.33	8.00	5.67	--	16.67	15.67	15.00	25.67	--	100.01	6.73	3.26	10.65	59.59	16.56	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	54.01	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	6.05	1.87	7.76	46.47	23.38	14.48	--	100.01
48	SW	NE	6	3	9	Climax	Spot	12.67	9.00	8.67	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	19.97	8.57	7.62	100.00
50	SW	NW	26	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	3.76	3.44	14.83	61.55	14.90	1.17	0.30	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	11.00	27.31	26.39	4.52	0.49	0.61	100.00
52	SE	SE	8	4	12	Prairie Ronde	Spot	7.33	6.00	5.33	36.33	8.67	9.67	11.33	15.00	0.33	99.99	25.93	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	6.67	2.00	19.33	1.67	99.99	48.58	15.47	17.16	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	42.08	13.94	16.94	21.28	3.98	0.60	0.59	100.00
55	SW	SW	32	3	12	Texas	Spot	6.67	8.67	6.00	36.67	10.00	10.33	5.67	14.67	1.33	100.01	50.02	17.50	15.98	11.46	3.46	0.61	0.95	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	32.13	12.46	18.72	34.20	2.05	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	35.54	10.01	1.02	0.50	100.01
59	NE	NW	24	4	11	Schoolcraft	Spot	7.67	9.00	7.33	31.67	8.67	5.33	9.00	21.00	0.33	100.00	15.12	17.42	29.92	18.81	16.28	2.10	0.34	99.99
60	NW	NW	24	4	11	Schoolcraft	Spot	10.33	8.67	8.67	2.00	19.33	21.33	11.00	17.67	1.00	100.00	24.62	11.05	25.48	24.53	5.24	5.43	3.65	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	5.05	4.43	21.10	61.76	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	9.21	10.96	21.47	38.31	14.49	3.17	2.39	100.00
63	NE	SE	36	2	10	Comstock	Spot	7.33	8.33	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	1.21	100.00
64	NW	NW	5	3	9	Climax	Spot	6.67	6.67	6.67	33.33	8.33	2.33	6.33	27.67	--	100.00	53.27	13.79	13.58	14.14	4.37	0.56	0.29	100.00
65	SW	SW	5	3	9	Climax	Spot	12.00	10.00	4.33	26.67	9.67	6.00	7.67	23.00	0.67	100.01	25.67	14.82	21.50	27.94	8.33	0.85	0.90	100.01
66	NW	NW	28	2	9	Charleston	Spot	6.33	8.33	5.00	36.67	8.67	3.33	5.67	26.67	0.33	100.00	22.36	15.09	23.11	35.51	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	43.72	10.16	14.08	19.60	7.50	2.26	1.90	100.00
68	NE	NW	26	2	9	Charleston	Spot	14.00	10.00	4.67	--	21.00	10.00	5.33	34.67	0.33	100.00	4.12	3.79	26.70	46.28	15.95	2.41	0.69	100.00
69	SW	NE	25	2	10	Comstock	Spot	10.00	9.00	7.00	28.33	7.67	3.33	10.00	24.00	0.67	100.00	35.74	28.64	21.43	10.03	1.96	0.43	1.77	100.00
70	SW	SW	28	2	10	Comstock	Spot	9.67	13.33	5.00	23.33	5.33	5.67	10.33	26.00	1.33	99.99	40.83	11.35	16.52	20.11	6.48	1.66	2.86	100.00
71	NE	SW	9	3	12	Texas	Spot	8.00	9.33	6.33	0.33	23.00	0.00	13.00	28.67	0.33	99.99	33.84	17.49	26.00	17.22	4.54	0.45	0.46	100.00
72	SW	SW	26	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	11.25	10.51	6.51	4.88	8.20	100.00
73	SW	SE	9	1	12	Alamo	Spot	6.00	7.33	8.33	27.33	13.00	2.00	9.33	25.67	1.00	99.99	67.72	8.49	9.69	9.36	2.71	0.85	0.87	99.99
74	NE	SE	9	1	12	Alamo	Spot	7.67	8.00	11.00	36.67	5.67	2.33	7.33	21.00	0.33	100.00	69.99	11.46	7.49	6.77	2.67	0.60	0.93	100.00
75	SW	SE	15	1	11	Cooper	Spot	8.33	12.00	6.67	24.33	13.33	6.33	5.33	23.67	1.00	100.00	62.99	18.33	9.11	5.78	2.27	0.55	1.01	99.99
76	NW	SW	18	1	10	Richland	Spot	10.67	8.00	8.33	0.33	14.83	3.00	12.67	32.00	0.67	100.00	4.74	2.60	12.00	55.12	19.74	2.59	3.21	100.00
77	SW	NE	16	1	9	Ross	Spot	8.33	7.33	7.00	24.00	15.67	5.00	9.67	22.00	1.00	100.00	12.27	22.25	43.65	16.70	3.31	0.41	1.22	100.01
78	NW	NW	27	1	9	Ross	Spot	7.67	12.33	5.67	42.67	3.00	7.67	3.33	16.67	1.00	100.00	61.09	11.33	9.01	11.70	3.30	0.88	0.91	100.01
79	SW	NE	22	1	9	Ross	Spot	6.00	6.00	6.00	13.67	5.33	10.00	8.67	19.00	0.33	100.00	41.84	10.60	11.84	17.48	11.46	4.80	1.80	100.00
80	SE	SE	2	1	10	Richland	Spot	10.67	14.67	8.67	18.33	7.33	14.00	5.33	20.67	0.33	100.00	37.40	12.75	26.54	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	8.73	30.99	33.07	14.20	2.38	1.39	99.99
82	NW	NW	25	3	10	Pavilion	Spot	5.67	6.33	3.00	0.33	26.33	10.67	11.33	0.33	2.33	99.99	13.35	10.14	20.62	32.60	20.60	2.18	0.52	100.01
83	SW	NW	6	1	11	Cooper	Auger	3.67	12.00	4.33	11.33	12.33	24.33	10.33	21.67	--	99.99	29.86	19.35	19.03	23.26	6.62	0.77	1.12	100.01
84	SE	SE	2	1	12	Alamo	Auger	6.00	12.00	7.33	29.67	11.00	4.67	12.00	17.33	--	100.00	18.56	13.00	31.96	29.44	5.60	0.74	0.70	100.00
85	NE	NE	11	1	12	Alamo	Auger	2.67	4.67	1.33	0.33	5.67	64.67	5.00	15.67	--	100.01	25.00	11.81	12.96	22.26	18.28	5.86	3.81	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	3.69	6.69	18.95	46.28	19.64	3.10	1.45	100.00
87	SE	SE	29	4	12	Prairie Ronde	Auger	5.67	4.00	6.00	10.67	11.00	22.67	15.67	24.33	--	100.01	18.20	14.41	30.69	31.40	4.16	0.55	0.60	100.00
88	SW	SW	32	4	12	Prairie Ronde	Auger	5.33	10.33	2.67	0.33	7.33	44.67	16.00	13.00	0.33	99.99	16.55	8.36	17.77	44.40	11.19	1.05	0.67	99.99