BOTTOM SEDIMENTS OF SAGINAW BAY, MICHIGAN

Thesis for the Degree of Ph. D.

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Leonard Eugene Wood

1958

This is to certify that the

thesis entitled

BOTTOM SEDIMENTS OF SAGINAW BAY, MICHIGAN

presented by

LEONARD EUGENE WOOD

has been accepted towards fulfillment of the requirements for

PhD degree in GEOLOGY

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Date December 9, 1958

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BOTTOM SEDIMENTS

OF

SAGINAW BAY, MICHIGAN

by

LEONARD EUGENE WOOD

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Geology

1958

ABSTRACT

Sixty-one bottom samples were taken from Saginaw Bay with a Petersen dredge and an orange-peel sampler. Samples were taken in six predetermined northwest-southeast traverses. Standard mechanical, chemical, and statistical analyses were performed on all samples.

Sediments of the bay are predominantly sand. Locally, coarse sand, granules, and pebbles are found close to the shore; fine silt and sand are in the glacial Saginaw River trench and in areas protected from waves and currents.

Since the amount of sediment entering the shallow bay is not great, the distribution is directly related to the attributes within the individual grain and the physical environment of the bay.

Median diameter isopleth patterns indicate belts of major currents which enter the bay from the north, flow around Au Sable Point, continue to the west end of the bay, and leave around Pt. aux Barques. Prevailing currents appear to be deflected toward Charity Island in the vicinity of Sand Point, then turn shoreward again near Hat Point. Current patterns are not clear in the center of the west half of the bay.

Poor sorting is common in, although not confined to the fine sediments. Extremely poor sorting in the coarse sediments in the southeast corner of the bay is related to

ABSTRACT, continued

discharge from the Saginaw River. Sorting in Saginaw Bay in general is more a function of currents than depth.

The concentration of heavy minerals is closely related to areas of prevailing currents. Heavy mineral percentage is generally 3.0 per cent throughout the bay; in a few localities amounts up to 11.0 per cent are noted.

Since the heavy minerals are derived from heterogenous glacial drift surrounding the bay, there is little distribution according to species. Physical characteristics cause an individual grain to respond to a given hydraulic condition as shown in the distribution of the metallic opaques, amphiboles, and pyroxenes. Where the opaques are abundant the amphiboles and pyroxenes are noticeably lacking.

Roundness and sphericity values of grains are only remotely related to the current patterns. If such a relation does exist it is a result of selective sorting due to the ability of the current to move a grain according to shape, and not to the degree of abrasion by current action.

The amount of acid solubles in the sediments averages less than 1.0 per cent. Sediments with more than 3.0 per cent acid solubles may be composed of detrital limestone or shell fragments. Acid soluble content of the Saginaw Bay sediment is related to the source of acid soluble materials rather than the selective distribution of these materials by currents.

ABSTRACT, continued

Organic carbon in the sediments averages less than 1.0 per cent, but amounts up to 7.0 per cent are found locally. Organic carbon, prevelant in the fine sediments, is derived from planktonic material in the bay and humus from the surrounding farm land. Total amount of organic carbon in the sediments is more nearly related to depth than any other factor. The distribution and rate of deposition of both organic and inorganic sediments is largely a function of currents.

The sediments in Saginaw Bay conform to the current patterns with local exceptions, and they vary with a degree of complexity proportional to the complexity of the surrounding controlling agents.

From the study of recent Saginaw Bay sediments one may establish, with qualification, the rules of sedimentary deposition applicable to ancient sediments.

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INTRODUCTION

Saginaw Bay is an extension of Lake Huron, reaching approximately fifty miles southwestward into Michigan midway on the western shore of Lake Huron. This shallow body of water is bordered by the agricultural counties of Iosco and Arenac on the northwest, Bay on the west, and Tuscola and Huron on the southeast (Fig. 1).

Bay City, at the mouth of the Saginaw River, is the only major city on the bay. Smaller fishing and farming communities are scattered along the 160 miles of shoreline.

<u>HYDROGEOGRAPHY</u> -- The bay is approximately 50 miles long and 20 to 25 miles wide, narrowing to 13 miles near its mid-line between Sand Point and Point Lookout. Charity and Little Charity Islands are in this narrows. A shoal extends from Sand Point nearly 10 miles northeast to these islands.

Several islands are in the bay; the most prominent of which is Charity Island. It is approximately one mile wide. A group of islands lie to the southwest of Sand Point, of which North, Stony, and Katechay are the largest. Three islands of lesser size are between Katechay Island and the mouth of the Sebewaing River.

Although there are 1,125 square miles of surface area, shallow water limits navigation on the bay. Data compiled by the Bureau of Commercial Fisheries, Ann Arbor, show that

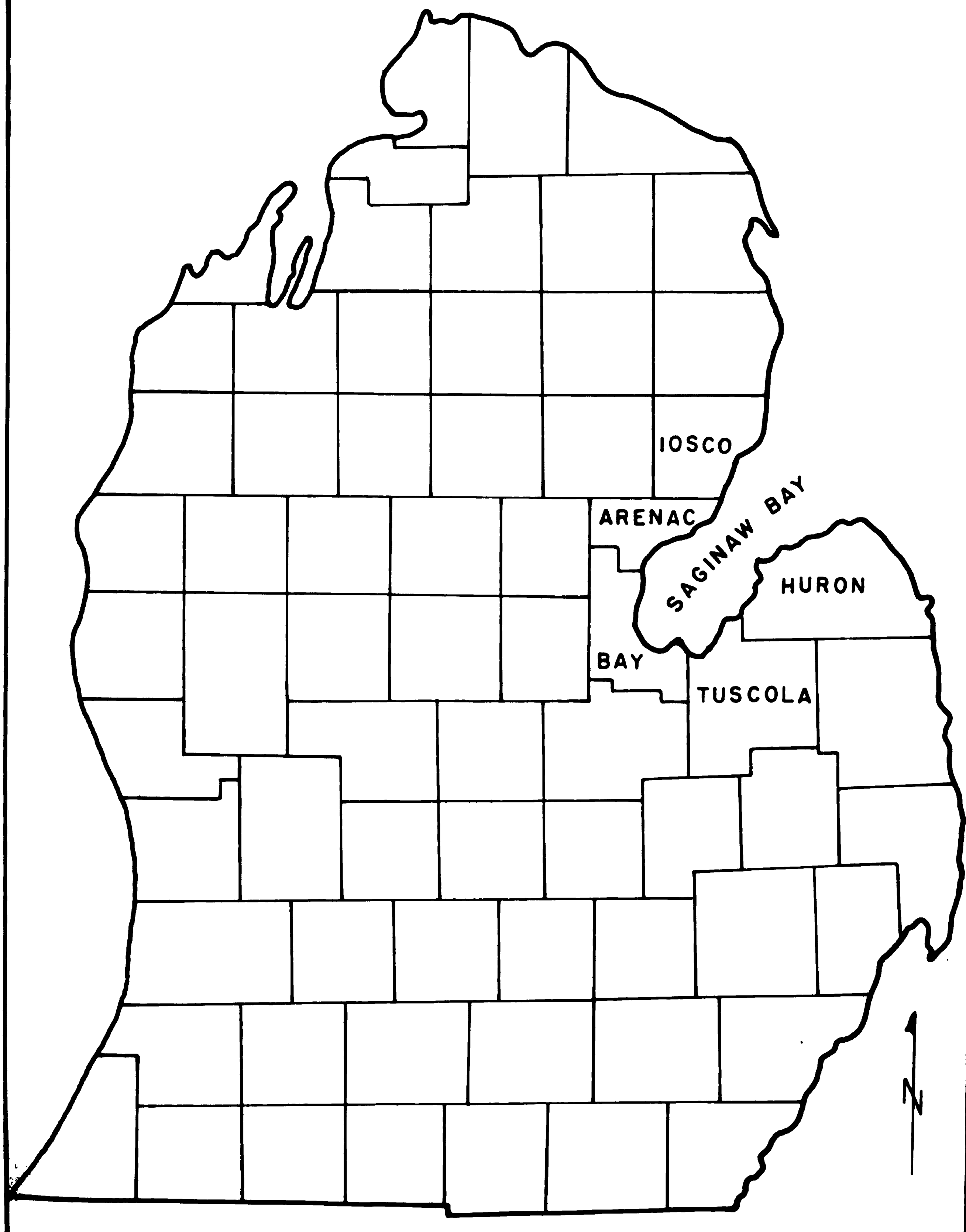


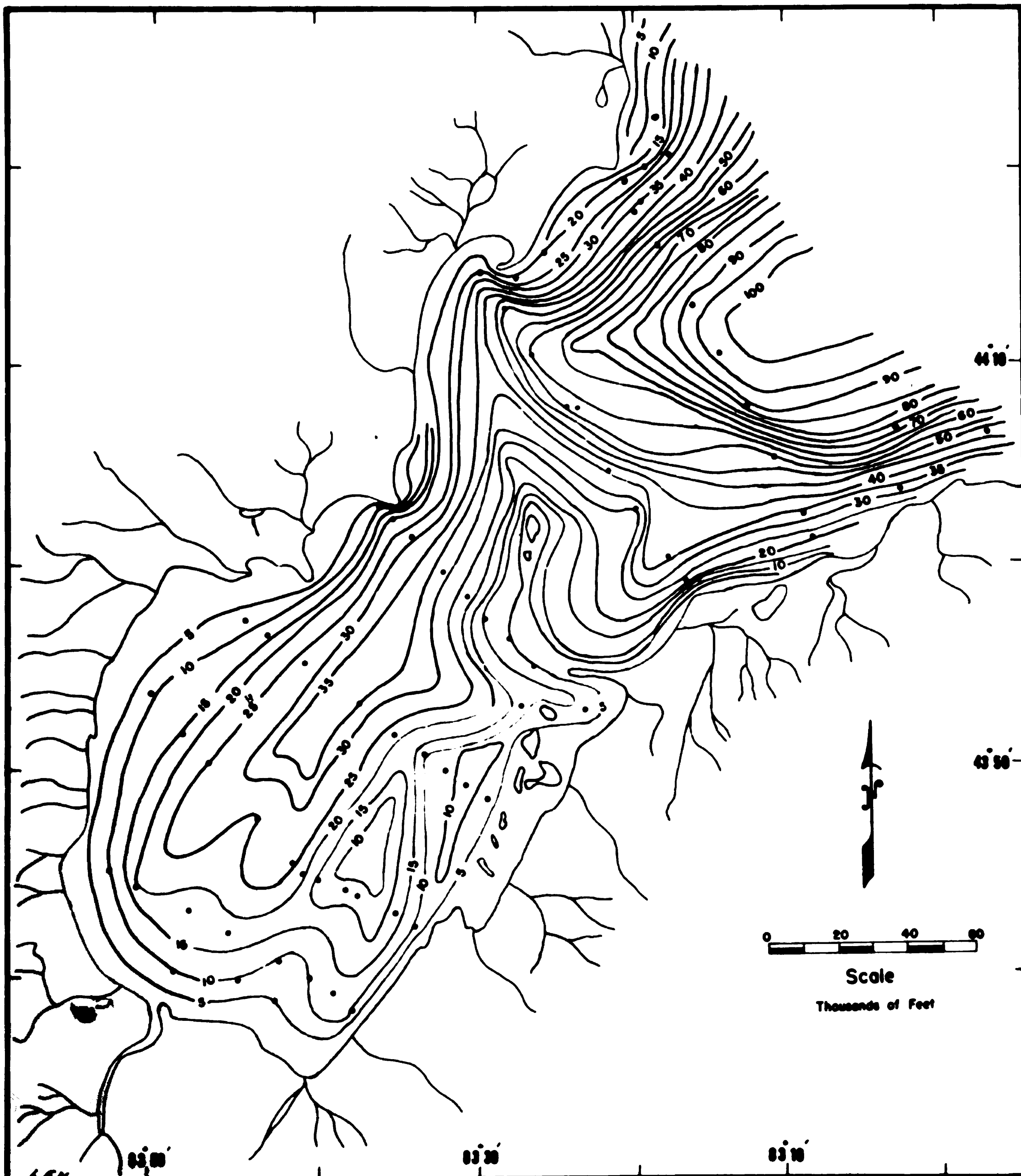
Figure 1. Saginaw Bay and surrounding counties.

57.1 per cent of the bay by volume is 24 feet or less in depth and 34.3 per cent is 12 feet or less. Maximum depth in the western half of the bay is approximately 46 feet. East of Charity Island the water deepens to approximately 126 feet at the bay entrance (Pl. 1). Lake Huron Hydrographic Chart No. 52 (1955) was used as a base for sample locations and to determine the depth of water.

Marsh areas are extensive along the western shores. Rocky bottom lies beneath a few feet of water on the south-east side of the bay northeast of the Pigeon River near Oak Point. Much the same type of shore that forms the southeast side of the bay east of Sand Point extends eastward from Point Lookout on the north shore.

The irregularity of the shoreline is largely a result of deltas and littoral current depositional features built into the bay. Fish Point, Sand Point, and Oak Point on the southeast shore; Point Au Gres, Point Lookout, Tawas Point, and Au Sable Point on the northwest shore are the most prominent features (Pl. 2). Numerous depositional features of lesser importance add to the irregular shoreline. The Tawas Point hook nearly encloses a portion of the larger bay area and forms Tawas Bay at Tawas City. The irregularity of the coast plays a prominent role in the course of prevailing current patterns in the bay.

Very little change occurs between shore and lake bottom from Bay City eastward to Bay Port. The shore area

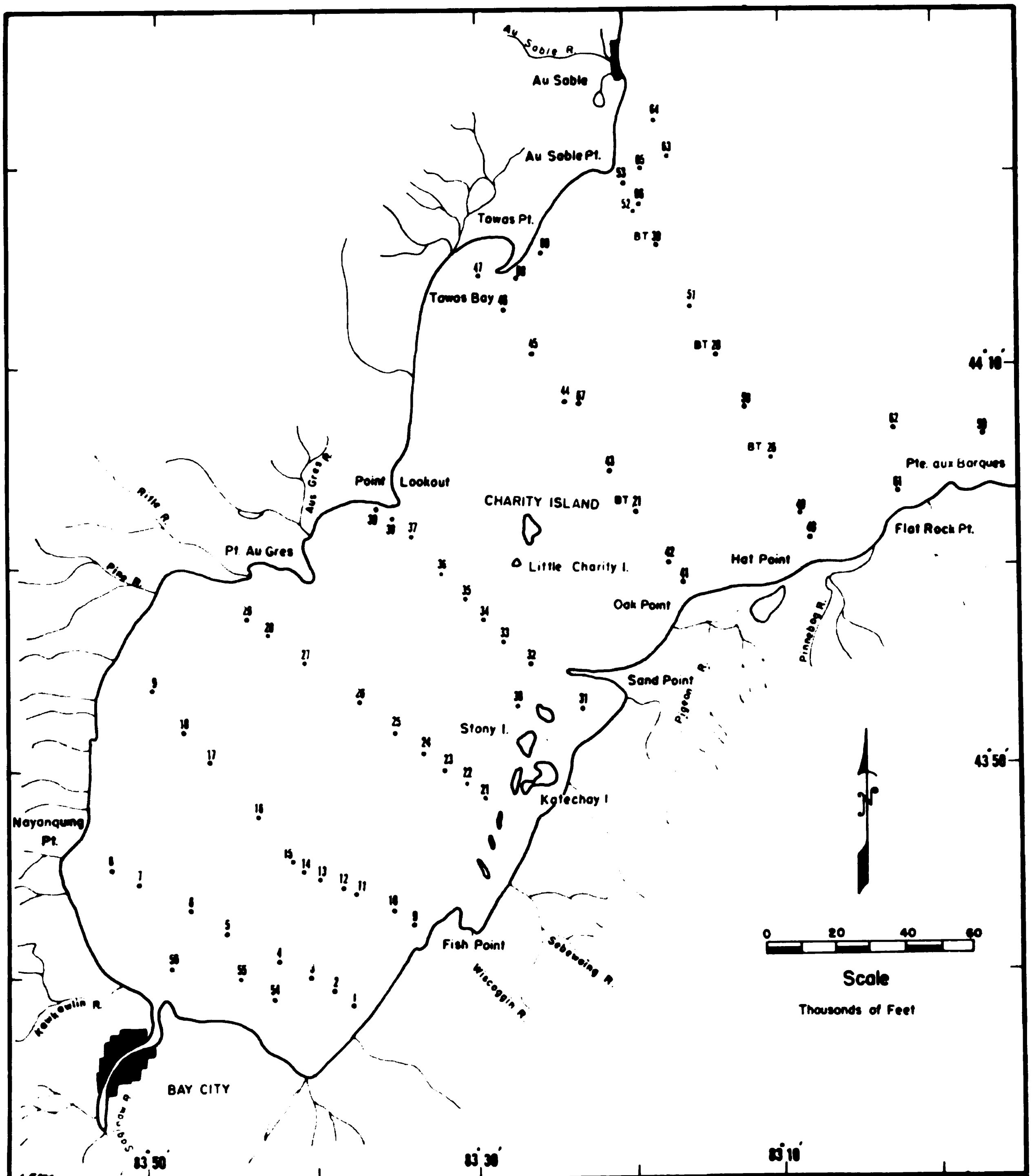


SAGINAW BAY

DEPTH OF WATER

ISOPLETH INTERVAL: 5 Feet

PLATE I



SAGINAW BAY

SAMPLE LOCATIONS

And

LANDMARKS

PLATE 2

consists of flat, low-lying sand ridges which rise inland from the shore; and the beaches, such as they are, range from pebbly to sandy. Marsh areas are extensive. Davis (1908) noted that mud from sluggish streams is trapped in the marshes by vegetation and shoreward wave action.

The shoreline on the northwest side of the bay is similar to that southeast of Bay City. As far northeast as the Rifle River the coast features range from very low marsh areas to low-lying sand accumulations. Houghton, in his report of 1893, described this area as low with, "...large portions of the immediate shores composed of marsh." Similar observations were made by Cooper (1905).

The coast from Sand Point to Point aux Barques is marked by strong relief between shore and bay bottom. The shore from Sand Point to Port Austin is generally sandy, whereas from Port Austin to Point aux Barques it is rocky.

The shoreline from Point Au Gres to Au Sable Point consists of sandy beaches with a few rocky promontories jutting out into the bay. These promontories probably aid in the accumulation of sand along much of the shoreline.

The northwest-southeast bay bottom profiles (Figs. 2A, B and 3B) show two distinct channels extending eastward in the bay. The deeper channel approximately parallels the north shore. In the west end of the bay the channel is wider, shallower, and less well defined (Fig. 2B). The east-west profile (Fig. 3A) shows two distinct depressions

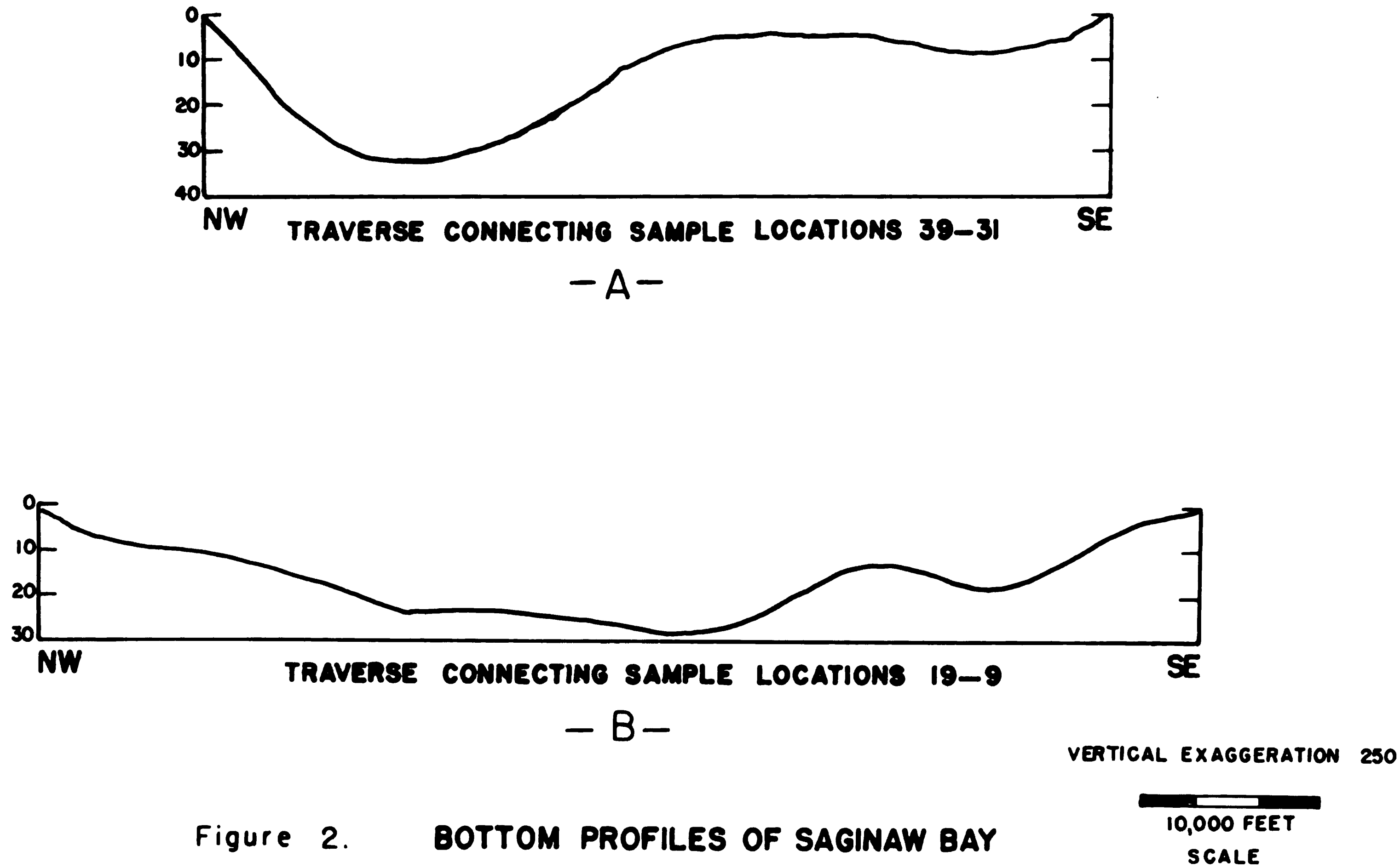


Figure 2. **BOTTOM PROFILES OF SAGINAW BAY**

separated by a ridge or shoal across the bay in the vicinity of Charity Island. East of Charity Island the bottom slopes off gradually toward the open end of the bay. At no place is there an abrupt change in the bottom topography, and the gentle slopes should not be a great factor in the distribution of sediments.

The narrow channel formed by the glacial Saginaw (Huronian) River extends from Bay City along the north shore to Lake Huron, thus providing a somewhat deeper navigable route in the western half of the bay.

Wind prevails from the southwest. During high winds the water has on occasions blown a considerable distance away from the western shore.

Data refering to the physical properties of the bay water with regard to temperature, density and seasonal movement may be found in the Saginaw Valley Report (1937) and also in a Report of Currents and Water Masses of Lake Huron (1954).

PHYSIOGRAPHY -- The land immediately surrounding the bay was recently covered by glacial lake Saginaw. It is topographically low with the exception of a few low hills which are remnants of recessional moraines of the Saginaw Lobe and ancient beaches cut by Lake Saginaw. This area, called the Saginaw Lowland, was discussed by Sherzer (1917).

The area adjacent to the bay and in the Saginaw Lowland shows little relief above the 580 foot level of Lake

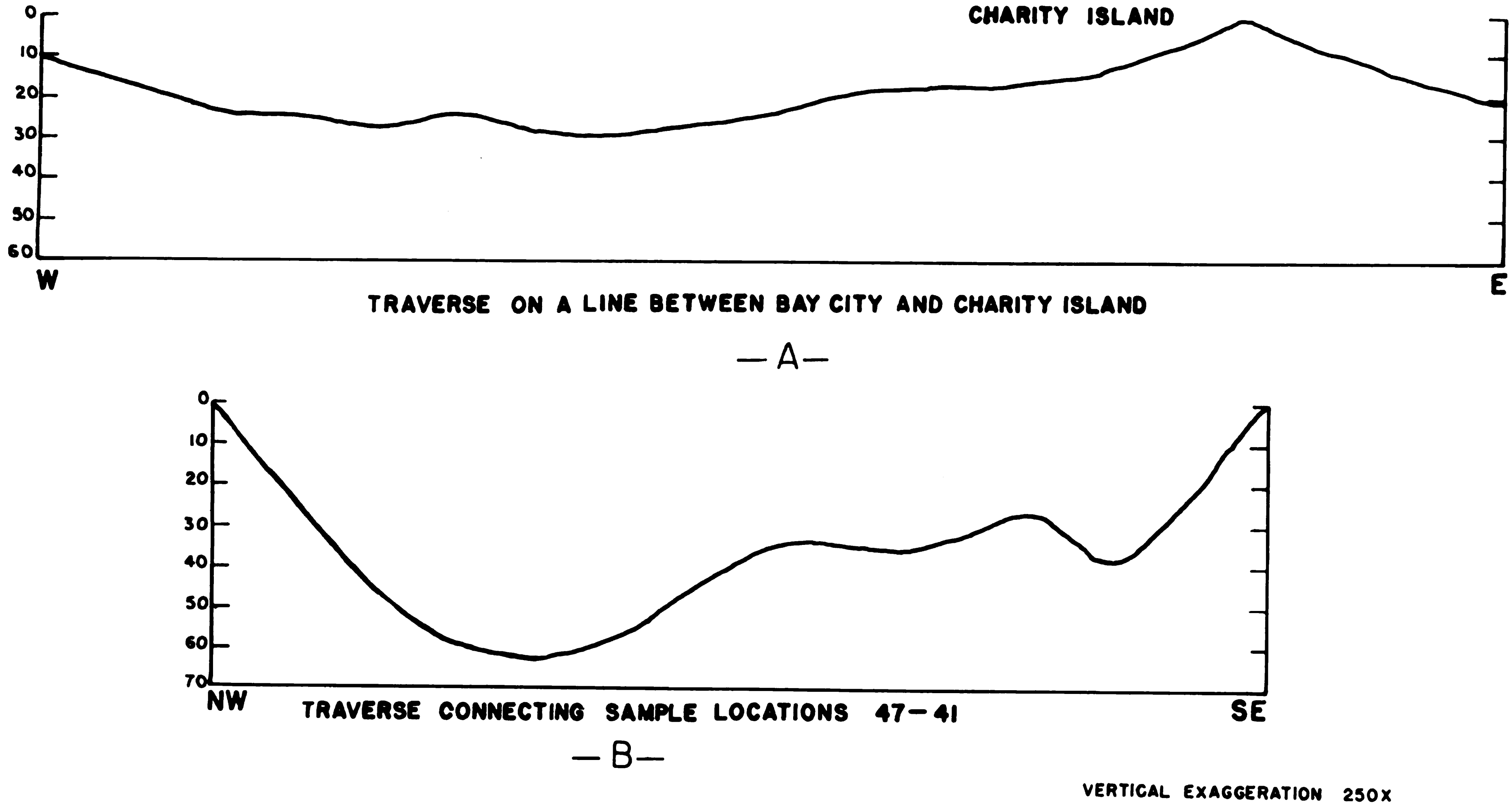


Figure 3. **BOTTOM PROFILES OF SAGINAW BAY**

Huron. The Port Huron Moraine rims the west end of Saginaw Bay, reaching altitudes of 860 feet in Tuscola County, and 820 feet near Bentley in Bay County. The Mayville Moraine reaches an altitude of 900 feet in Tuscola County.

The underlying bedrock is reflected in these larger physiographic features of the region. Newcombe (1932) noted that areas of thick drift often conform with pre-Pleistocene surface highs; however, extremely thick deposits of drift are known to fill the old drainage channels. Generally there is very little relief in the area surrounding the bay, but a gradual rise in elevation away from the lowlands indicates ancient shorelines and typical near-shore features of the glacial lake which once covered this now fertile, sandy farmland.

REGIONAL GEOLOGY -- There is no evidence of post-Paleozoic deposition in Michigan or the surrounding regions. It is generally accepted that after the Pennsylvania (or Permian) sediments were deposited, uplift exposed the beds and erosion began and continued to glacial time.

If the glacial drift were removed, the Mississippian Marshall sandstone and Coldwater shale would be exposed across the bay at its open end. Progressively younger beds including the Napolean sandstone, Michigan formation, Bayport limestone, the Pennsylvanian Parma sandstone and the Saginaw sandstone would outcrop in concentric bands inland (Fig. 4). The dip of the beds, amounting to a few degrees, is generally

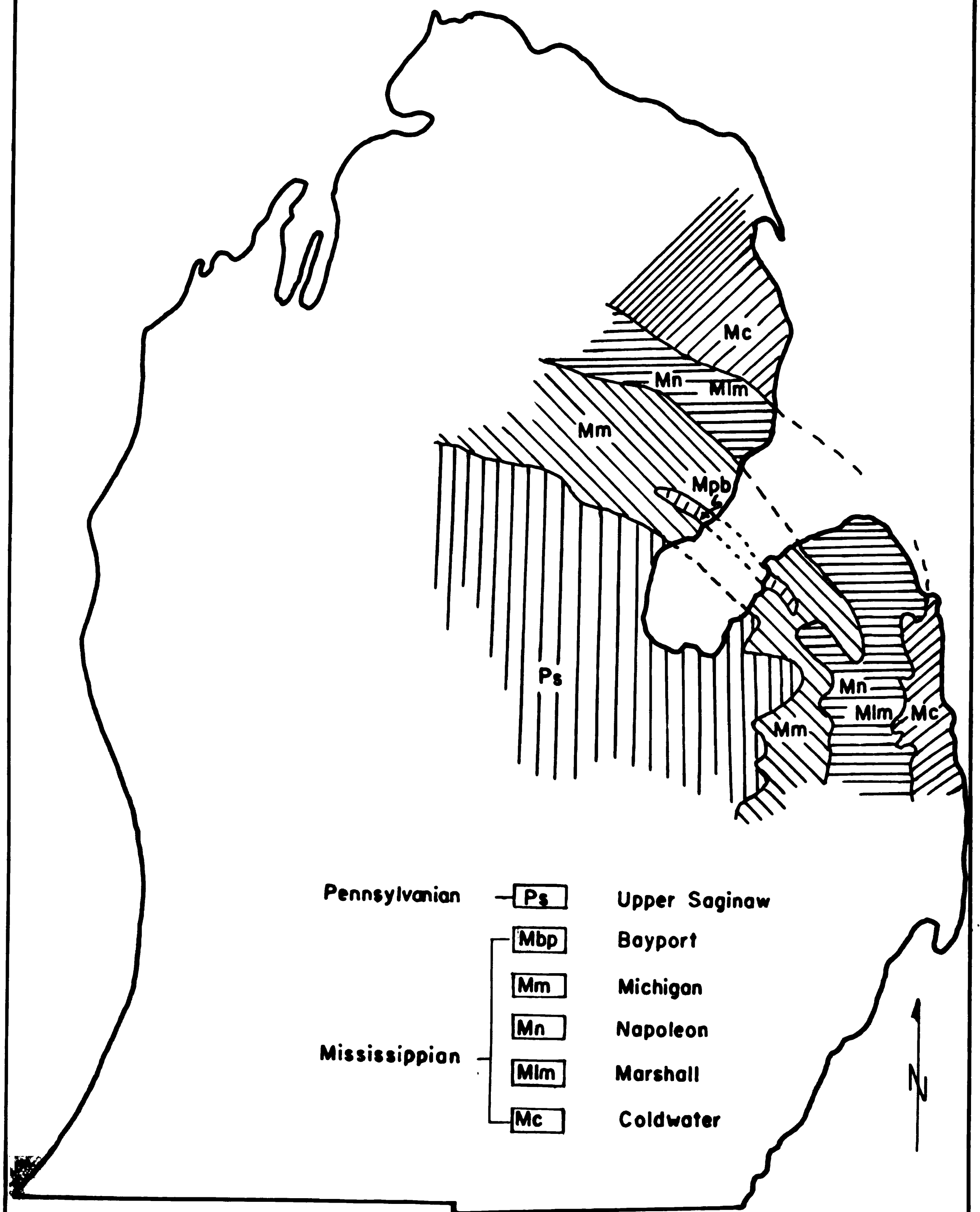


Figure 4. Distribution of Mississippian and Pennsylvanian beds in the vicinity of Saginaw Bay.

toward the center of the state; however, local structures may possess steep dips basinward. As far as one can determine none of these formations are strongly reflected in the bottom topography of the bay.

Sediments have been removed by currents locally, and the bare bedrock is subject to wave action. It is not likely that the sediments in the bay were derived in any quantity from the Mississippian and Pennsylvanian beds which are covered by the drift except for a few outcrops along the shoreline, such as Point aux Barques and Point Lookout.

The formations found on or below the surface in the general area surrounding the bay are listed below with a brief description of their lithology. They are described on the Geologic Map of the Southern Peninsula of Michigan (Martin, 1936).

PENNSYLVANIAN SYSTEM

Upper Saginaw formation Verne limestone Lower Saginaw formation	Lenticular beds of shale, sandstone, and limestone; coal beds, seams, and riders.
Parma sandstone	White, yellow, and gray glistening quartzose sandstone and conglomerate with small pebbles of white quartz.

MISSISSIPPIAN SYSTEM

Bayport limestone	White, bluish and gray fossiliferous limestone and dolomite, locally cherty and sandy.
Michigan formation	Greenish gray to black shales, dark micaceous limestone, and beds of gypsum and anhydrite.

Upper Marshall (Napoleon sandstone)	White and gray sandstone.
Lower Marshall sandstone	White, gray, green and red sandstone locally very micaceous and fossiliferous. "Peanut" conglomerate in the eastern part of the state.
Coldwater shale	Blue, gray, and occasionally red plastic shales, locally apple green. Sandstone and sandy shales in the eastern part of the state.

GLACIAL HISTORY -- The glacial history of Central Michigan and the "Thumb" area has been studied extensively for well over 50 years. Thorough work by Mudge (1897), Taylor (1912), Leverette (1939), Bretz (1951, 1952), and others has unravelled many of the details of the Wisconsin glacial stage of which the Saginaw Lobe was a part. This lobe of ice gouged out the basin for Saginaw Bay, influenced the present drainage pattern, and provided the water for the early Lake Saginaw and ultimately for Saginaw Bay.

Spencer (1894) described a large pre-glacial river in the Saginaw Lowland which he called the Huronian River. This river flowed eastward until it joined the Laurentian River northeast of the open end of Saginaw Bay. The Laurentian River originated somewhere to the north and flowed through the Lake Huron depression. Mudge (1897) added two smaller tributaries to the pre-glacial drainage in the vicinity of Grand Rapids. The northern tributary was called the Gypsum River and the river draining the area to the south was named the Hastings (Fig. 5).

Flint (1957) discussed a pronounced lowering of the water level in the Great Lakes following the Nippissing sub-stage of the Wisconsin ice sheet. It is thought that this lowering of the water level again allowed drainage to the east through the Saginaw Bay depression, and that the Saginaw River originated at this time.

The Pleistocene glacial drift, ranging in thickness from a few feet to about 500 feet, lies unconformably on the Paleozoic bed rock. The drift is thickest in Lakeview Township of Saginaw County.

Lane (1899, 1902, 1905) noted from drill hole data that the drift thickened toward the west in the direction of Grand Rapids instead of to the east as suggested by Spencer and Mudge in their earlier studies. Several other investi-gators in later years named and described many pre-glacial channels cut in the bedrock which suggested drainage away from Saginaw Bay rather than eastward through the pre-glacial depression.

The surface distribution of the moraines denotes that the edges of the Saginaw ice sheet of the Wisconsin glacier were markedly lobate, and it is generally thought that the pre-glacial drainage roughly parallels the south-westerly ice movement from Saginaw Bay. Much of the bed rock and pre-Wisconsin drift in the bay area was eroded by the Saginaw Lobe.

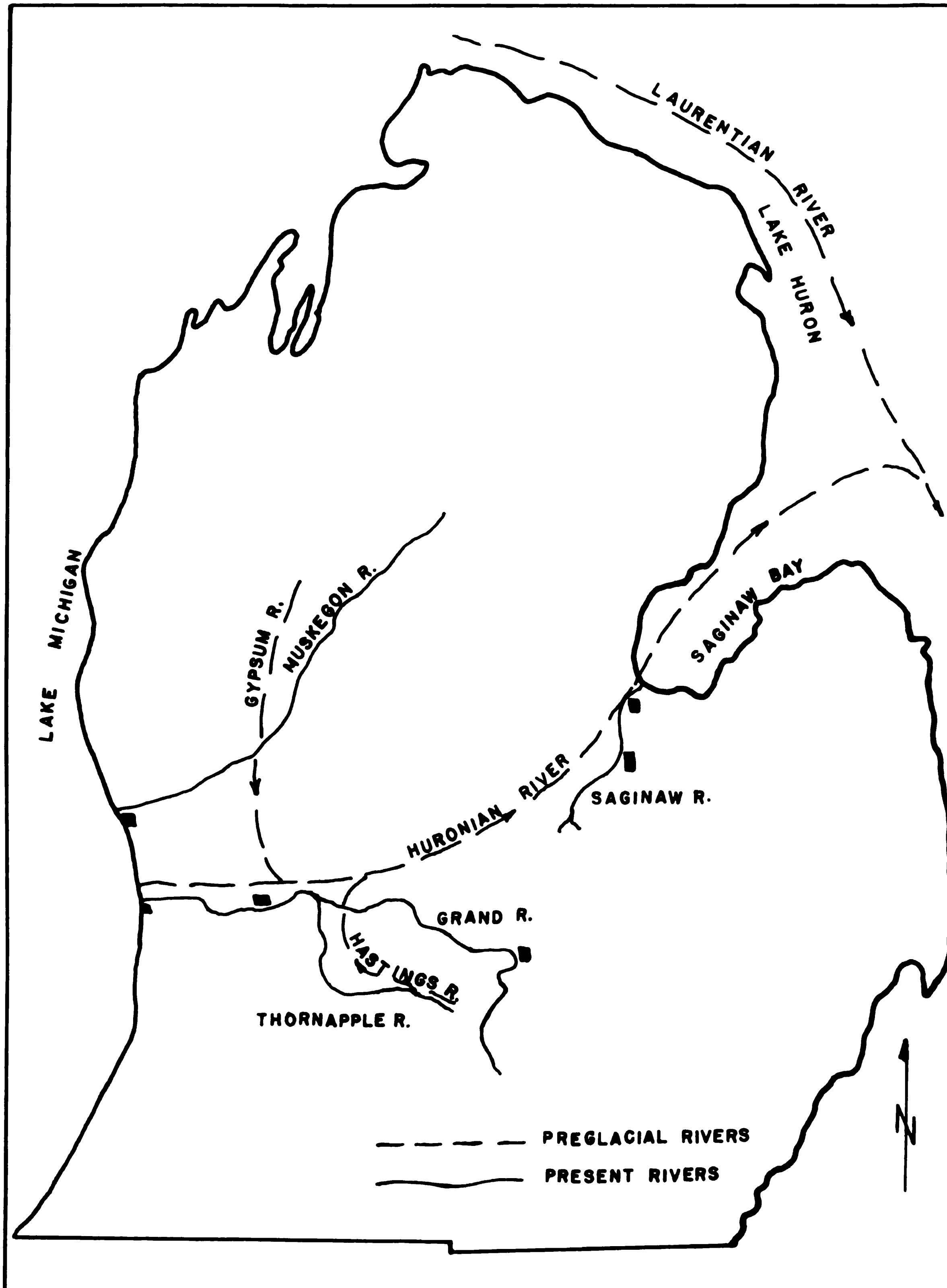


Figure 5. Present drainage correlative to supposed pre-glacial drainage (after Mudge, 1897).

Several authors support the theory that the underlying bedrock played a great part in directing the Saginaw ice movement. von Engeln (1942) observed that the portion of the Saginaw Lobe which occupied topographically low areas moved farther than those portions moving on higher bedrock areas. Leverette and Taylor (1915) noted a distinct relation between the Marshall sandstone and the orientation of the Saginaw Lobe. The ice movement adjusted to the resistant, topographically high sandstone. Kelly (1930) also mentioned the irregularity of the bedrock in the Saginaw Lowland. He pointed out that the country is low and flat, surrounded by a rim of higher land that conforms to the buried escarpment of sandstone and limestone of the Mississippian system. The surface map of Michigan (1956) supports these concepts.

<u>DRAINAGE</u> -- Cooper (1905) described the Saginaw Lowland as an area of numerous large swamps and marshes. Although today (inland from the shore) the land is generally free of marshes and swamps, the slow moving streams and numerous drainage ditches imply that the drainage in this low country is still poor.

The Saginaw Lowland is drained by sluggish streams forming somewhat of a dendritic drainage pattern. The Saginaw is the largest river discharging into the bay. Its tributaries include such major streams as the Cass River, which drains the central "Thumb" area, and the Cheboyganing Shiawassee, Flint, and Tittabawassee Rivers which drain the area toward the center of the state. The Kawkawlin, Pinconning, Pine, Rifle, Au Gres, and Au Sable Rivers drain the counties bordering the bay on the northwest. Although the Au Sable River empties into Lake Huron several miles north of the open end of the bay, currents entering the bay undoubtedly transport sediment for ultimate deposition in Saginaw Bay.

Figure 6 shows the major drainage areas contributing to Saginaw Bay as compiled by the Water Resources Commission (1956). Five of the areas shown do not have important rivers draining them, and during the summer many of the streams are reduced to practically no flow. The entire area surrounding Saginaw Bay is very low and it is not likely that much sediment is contributed to the Bay. An exception to this may take place when the rivers are in flood stage. Approximately 8,375 square miles of land is drained into the 1,125 square miles of Saginaw Bay.

Since the gradients of the rivers entering the bay are generally low, many of the streams have built deltas and bars across their mouths. These features stem largely from a lack of power to carry the sediments out into the currents Rhodehamel (1951) reports that the gradient of the Saginaw River is so low that often water from the bay backs several miles upstream when the wind blows from the northeast. It is for this reason that stream-flow data is difficult to obtain when streams are flowing under normal conditions.

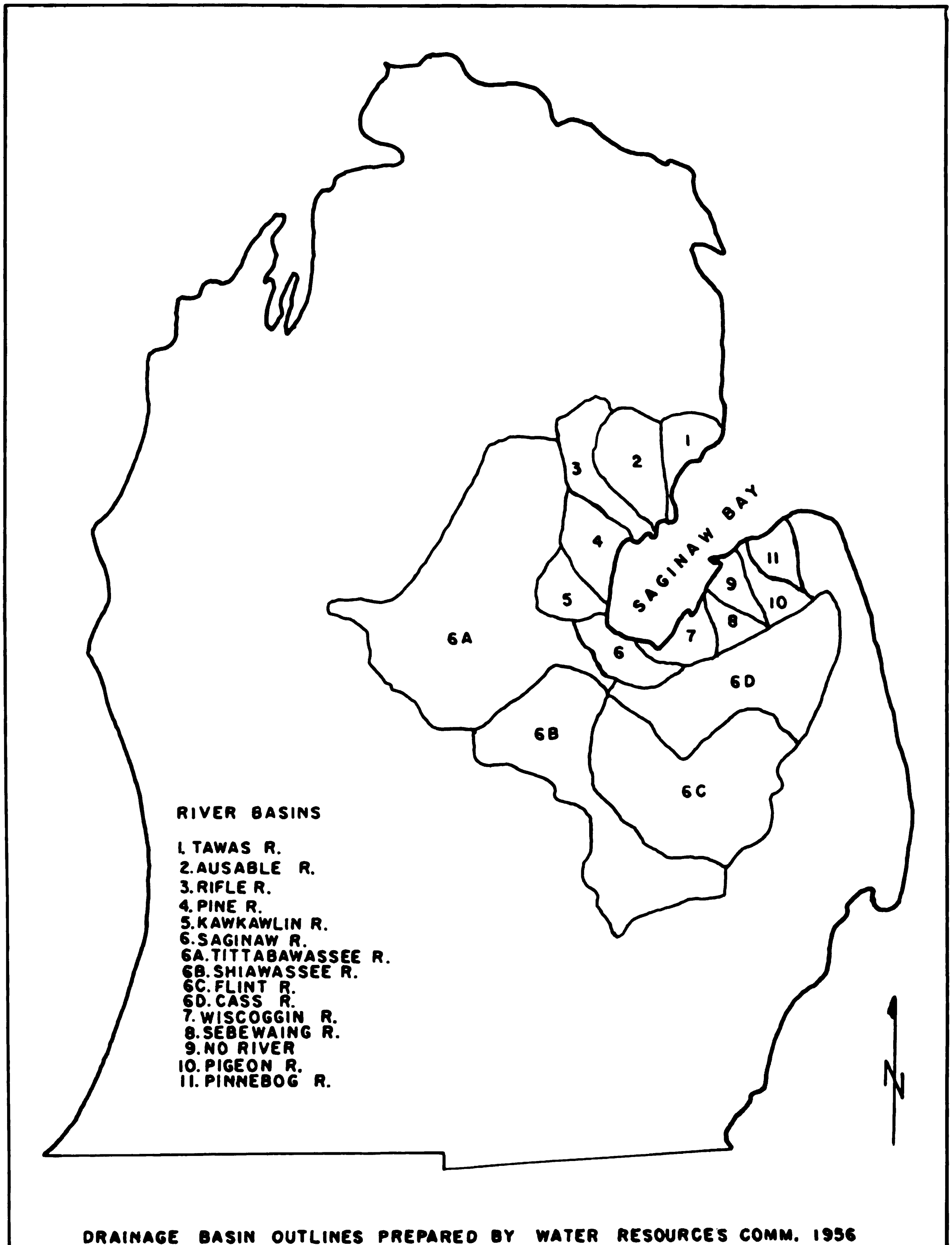


Figure 6. Drainage basins contributing to Saginaw Bay.

<u>SAMPLING</u> -- The 61 samples used in this investigation were collected by the U. S. Department of Conservation during two summer cruises in 1956, followed by supplementary cruises, one in October 1957, in the vicinity of Bay City, and one in November 1957, off the shores of Au Sable Point and Point aux Barques. The vessels used for sampling included Michigan Department of Conservation Patrol boats and the Fish and Wildlife Research Vessel <u>Cisco</u>. Sample locations are shown on plate 1.

Samples were taken along six northwest traverses which trend perpendicular to the long axis of the bay. The locations of Samples 1 to 53 were chosen to provide synoptic data on the physical and chemical conditions in Saginaw Bay and not with a sedimentary analysis in mind. Distance between the samples along the northwest traverses range from three-quarters of a mile to one mile in the western half of the bay to as much as five and one-half miles near the open end. Distance between the traverses range from five to nine miles.

Three samples off Point aux Barques on the southeast shore and three samples off Au Sable Point on the northwest shore were taken in an effort to trace current patterns and sediment movement entering and leaving the bay.

No samples were recovered from locations 4, 44, 48, 57, 58, and 60. It is assumed that at these locations either there was no sediment on the bottom or that the material was too coarse to be picked up by the sampler.

<u>SAMPLING APPARATUS</u> -- The Petersen dredge was used almost exclusively in the sampling with consistent results. However, during the later cruises in 1957, the orange-peel dredge with a canvas apron was most effective, particularly in the coarse materials.

Samples were put in pint jars in their original state. A small amount of formadal in each jar preserved organisms in the sediments in the event that a study of such bottom life might be desired.

Six cores were taken, the longest of which was six inches. The study of these cores is not included in this report.

<u>SCOPE OF PROBLEM</u> -- The purpose of the problem is to analyze the bottom sediments mechanically, statistically, and in part chemically to correlate such data obtained with the physical environments present in the bay at the time of sampling.

MEGASCOPIC DESCRIPTION OF SEDIMENTS

The sediments range from coarse materials consisting of large pebbles or cobbles, fossil corals, and shell fragments from the areas of strong current and wave action; to medium to fine, clear quartz sand found throughout the bay; to fine, gray silt or clay from deep and quiet water.

Coarse, medium, and fine size relationships are based on Wentworth's scale. Coarse: greater than 0.500 mm, medium to fine: between 0.500 and 0.062 mm, and fine: less than 0.062 mm.

Since color properties vary greatly in a sediment when it is wet, the following megascopic descriptions of the 61 bottom samples were made after drying.

SAMPLE NUMBER	DESCRIPTION
1.	Medium, predominantly quartz, buff sand containing large amounts of rock granules, fossil corals, and shell fragments.
2.	Medium, buff sand and a variety of coarse to small granules, fossil corals, and shell chips.
3.	Coarse, buff sand, large pebbles, small rock fragments, fossil corals, and shells.
4.	No Sample
5.	Fine, light buff quartz sand including a small quantity of rock fragments and fine shell chips.

SAMPLE NUMBER	DESCRIPTION
6.	Very fine, buff to nearly white quartz sand.
7.	Very fine, buff to gray silt containing shell chips and bits of organic material.
8.	Medium, light buff quartz sand and small shell and rock fragments.
9.	Medium, buff quartz sand including some small rock fragments and small pieces of shells.
10.	Medium, buff sand, small rock granules, and numerous shell fragments.
11.	Medium, light buff sand including a few rock fragments, granules, and shell chips.
12.	Fine, buff sand and a few small rock and shell fragments.
13.	Fine to medium, buff quartz sand including rock fragments, granules, and shell fragments.
14.	Very fine, buff silt including some sand, rock granules, and fossil corals.
15.	Fine, buff quartz sand containing only a few shell chips.
16.	Very fine, buff to gray silt containing small flakes of mica and shell fragments.
17.	Fine, buff to gray sand and silt, small rock fragments and shell chips.
18.	Medium, buff sand and a variety of granules, rock fragments and shell chips.
19.	Fine to medium, light buff quartz sand containing numerous granules and broken shell fragments.

SAMPLE NUMBER	DESCRIPTION
21.	Medium, buff sand, numerous rock granules and small rock fragments.
22.	Medium, buff sand and small rock fragments.
23.	Fine, light buff quartz sand, small rock fragments, and pebbles.
24.	Fine to medium, light buff quartz sand and small rock fragments.
25.	Medium, light buff to nearly white quartz sand and small rock fragments.
26.	Medium sand, some silt, and small rock fragments.
27.	Fine, gray to buff silt and a small quantity of sand.
28.	Fine to medium, light buff sand, a great variety of granules and pebbles, and a few shell flakes.
29.	Medium, buff quartz sand and a quantity of rock fragments, fossil corals, and shell fragments.
30.	Medium, buff sand and a quantity of rock fragments and granules.
31.	Fine, buff sand to silt and a few shell fragments.
32.	Fine, light buff quartz sand and a few small rock fragments.
33.	Fine, buff sand, small rock and shell fragments.
34.	Fine, light buff quartz sand containing numerous shell fragments.
35.	Fine, light buff quartz sand containing numerous shell and rock fragments.

SAMPLE NUMBER	DESCRIPTION
36.	Medium, buff quartz sand, small shells, rock fragments, and granules.
37.	Fine, light buff quartz sand, rock fragments and granules.
38.	Fine to medium, buff to gray sand and silt, rock fragments and granules.
39.	Fine to medium, buff to gray sand and small rock fragments.
41.	Very fine, buff sand to silt.
42.	Fine, buff sand to silt, some small rock fragments and shell chips.
43.	Fine, light buff quartz sand, small rock fragments and shell chips.
44.	No Sample.
45.	Fine, reddish buff quartz sand and a few small rocks and shell fragments.
46.	Fine, light buff sand and a few small rock fragments.
47.	Fine, buff sand, small rock granules, shells, and shell fragments.
48.	No Sample.
49.	Coarse, reddish to buff sand and gravel. The sand is predominantly quartz. The coarse material is a variety of rock fragments.
50.	Very fine, buff to gray sand and silt and a few small rock fragments.
51.	Fine, buff sand to gray silt and a few small rock fragments.
52.	Fine, light buff to nearly white quartz sand.

SAMPLE NUMBER	DESCRIPTION
53.	Fine to medium, light buff to nearly white quartz sand and fine shell fragments.
54.	Medium, buff sand, large grabules, shells, and shell fragments.
55.	Medium, buff sand, large granules, shells, and shell fragments.
56.	Fine to medium, buff sand to silt and small rock and shell fragments.
57.	No Sample.
58.	No Sample.
59.	Fine, light buff quartz sand and very fine shell fragments.
60.	No Sample.
61.	Fine to medium, light buff quartz sand, small rock and shell fragments.
62.	Very fine, gray to buff sand and silt.
63.	Fine to medium, light buff sand, shell fragments and organic material.
64.	Fine to medium, buff quartz sand.
65.	Fine, light buff quartz sand, small shell fragments, and bits of organic material.
66.	Fine, light buff quartz sand and small shell fragments.
67.	Fine to medium, light buff sand, bits of shell fragments, and organic matter.
68.	Fine to medium, light buff sand, bits of shell fragments, and organic matter.

SAMPLE NUMBER	DESCRIPTION
69.	Very fine, light buff quartz sand and bits of organic material.

LABORATORY PROCEDURES

Figure 7 is a flow sheet of laboratory procedures followed in the analysis of the Saginaw Bay sediments. The procedures describing each analysis will be outlined in the discussion of that analysis.

DRYING -- Each sample was washed into a pan and allowed to dry in a hood at room temperature. The clayey sediments dried into hard layers and additional treatment to disaggregate was necessary before sieving.

PREPARATION FOR SIEVE ANALYSIS -- After drying, each sample was split with the aid of a Jones sample splitter and a micro-splitter. Half of the original sample was saved for dry sieve analysis and the remainder for acid soluble, organic carbon, and heavy mineral analysis. In some instances the original sample was too small for the amount pre-determined for sieve analysis, so only the smallest amount necessary for the other determinations was removed. The remaining sediment was then sieved.

Depending on their source, sediments may often contain a great variety of organic and inorganic materials ranging from all forms of vegetation to glass, metallic fragments, and shells. Care was taken during sampling not to choose sites too near designated dumping grounds (Lake Huron Chart No. 52). Saginaw Bay, for the most part, is free of weeds

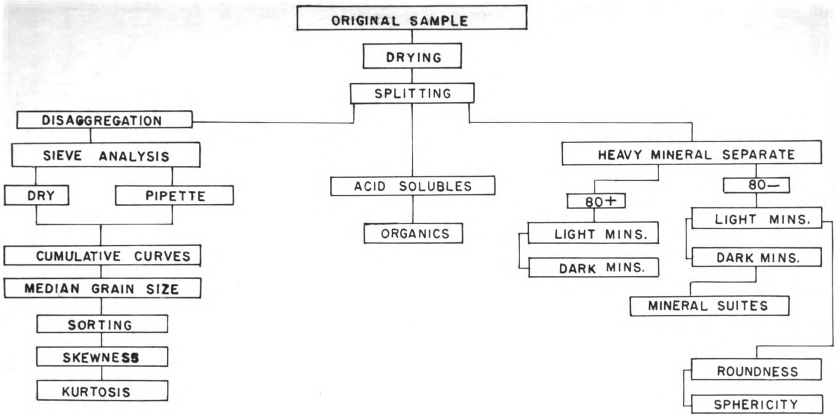


Figure 7.
LABORATORY FLOW SHEET OF SAGINAW BAY
BOTTOM SEDIMENTS ANALYSIS

and plant life, so organic content of this order is at a minimum. However, extraneous pebbles or cobbles and shell fragments cause some question as to the type of material which should be included in a mechanical analysis of sediments.

Several samples contained whole shells or large shell fragments, which because of their flat shape and size, were caught in the coarse sieves. These particles distorted the natural curve of the sediment distribution. It is the belief of the writer that such large shells or shell fragments should be removed from the sand before sieving on the basis that they do not truly represent the physical environment of the sediments. No attempt was made to remove the finely ground shell fragments, inasmuch as it is felt that their size alone lends them susceptible to all current activities and they enter into the normal curve of sediment distribution.

Krumbein and Aberdeen (1937) in their work on the sediments of Barataria Bay, Louisiana, removed shells, leaving those depending on, "...whether the shells were predominatly fragments and whether they displayed a fairly regular size distribution."

Inasmuch as fresh water shell animals are a source of food for both and fish and the waterfowl, many of the shells could be foreign to their final resting place as a result of animal rather than current transportation. Extraneous large pebbles or cobbles that might have been derived from sources by means other than currents also should be considered.

Several ways by which large pebbles may be carried into deep water have been discussed by Kuenen (1950). One, which well applies to Saginaw Bay, is rafting of materials, particularly by ice. In many localities in the bay it is difficult to say with certainty whether large materials are foreign because of rafting or by means of transportation other than water, or due to currents which have caused great variability in the sediment distribution throughout the bay. The fact that the bay is of glacial origin and that most of the sediments may have moved little from their initial deposition should be considered.

The rivers flowing into Saginaw Bay have generally a low gradient, and the sediment particles carried by these rivers under normal conditions are probably small. One can only speculate on the degree of coarseness of the sediments carried from the glacial drift during present-day floods since a large portion of the land surrounding the bay is low and comprised of the glacial Lake Saginaw lacustrine sands and clays deposited during the Cary substage of the Wisconsin glacier (Antevs, 1934).

Most of the sands show extensive wear by water which suggests that they have been in the bay a long time and that there is no great addition of new sediments coming from the surrounding drift. Although this may be a true statement, it must be kept in mind that the glacial drift contains materials produced from several cycles of erosion, and particles may be rounded or worn before entering the bay.

<u>SIEVE ANALYSIS</u> -- Standard laboratory procedures according to Krumbein and Pettijohn (1938) and Twenhofel and Tyler (1941) were used in the sieve analysis.

The coarse, sandy sediments which showed little or no aggregation were spread over a clean paper and rolled gently with a glass jar, or disaggregated by crushing between the fingers. Whenever available, 300 grams were split from the original sample and passed through 18 Tyler sieves. A nest of six sieves at a time were placed in an automatic Ro-Tap machine for 15 minutes, or as long as necessary for complete sieving, following which the individual fractions from each sieve were weighed. Care was taken to insure complete disaggregation. Figure 8 lists the screens used according to the $\sqrt[4]{2}$ ratio, in which the 200 mesh screen with an opening of 0.074 mm is used as a base (Twenhofel and Tyler, 1941).

<u>PIPETTE ANALYSIS</u> -- The fractions high in silt and clay required additional treatment beyond disaggregation by pressure. When available, a 50 gram sample was partially disaggregated by hand before being placed on a 0.062 mm screen representing the division between silt and sand.

The grains less than 0.062 mm in diameter were washed through the sieve. Care was taken to use less than 1000 ml of water which contained in solution 0.067 grams of sodium oxalate dispersing agent. The sand on the sieve was thoroughly washed to insure that all material smaller than 0.062 mm passed through the screen. The material left on the screen was carefully dried and then sieved by standard methods through the 18 Tyler sieves.

WENTWORTH GRADE SCALE, $\sqrt[4]{2}$
SCALE, AND CORRESPONDING
TYLER SIEVE OPENINGS AND MESH

Wentworth Grade Scale in mm	Openings in ratio of increase $\sqrt[4]{2}$ or 1.189 mm	Tyler Screens mm	Tyler Screens Mesh
GRANULE (4.0)	3.360	3.330	6
	2.380	2.360	8
VERY COARSE SAND (2.0)	1.680	1.650	10
	1.190	1.170	14
COARSE SAND (1.0)	0.840	0.833	20
	0.595	0.589	28
MEDIUM SAND (0.50)	0.500	0.495	32
	0.420	0.417	35
	0.354	0.351	42
	0.297	0.295	48
FINE SAND (0.25)	0.250	0.246	60
	0.210	0.208	65
	0.177	0.175	80
	0.149	0.147	100
VERY FINE SAND (0.125)	0.125	0.124	115
	0.105	0.104	150
	0.088	0.088	170
	0.074	0.074	200
SILT (0.062)	0.062	0.061	230

Figure 8. After Twenhofel and Tyler (1941).

The fluid containing particles less than 0.062 mm was poured into a graduate cylinder, and water was added to fill it to the 1000 ml line. The sediment was stirred for two minutes by extending an air hose to the bottom of the graduate and then allowed to settle according to the time scale shown in figure 9 (after Krumbein, 1935).

TIME SCALE FOR PIPETTE ANALYSIS

Diam. mm	Velocity cm/sec	Depth (h) in cm	Hr	Min	Sec
1/16	0.347	20	0	0	58
1/32	0.0869	10	0	1	56
1/64	0.0217	10	0	7	44
1/128	0.00543	10	0	31	00
1/256	0.00136	10	2	3	00
1/512	0.00034	10	8	10	00
1/1024	0.000085	5	16	21	00
1/2048	0.000021	5	65	25	00

Figure 9. After Krumbein (1935).

At the end of each time unit a pipette was inserted into the mixture to a depth indicated in the column marked (h, in cm). The solution obtained was evaporated and the sediment weighed. The stirring, pipetting, and evaporating was repeated for each time unit. Sediment percentage was calculated according to Stoke's Law (Krumbein and Pettijohn, 1938).

SIEVE ANALYSIS DATA

The results of the sieve analysis are shown in Tables 1 to 61. Data recorded includes the weight in grams of each fraction retained on each sieve, its percentage of the whole, and cumulated percentage. Loss of material during sieving, shown at the bottom of each data page, was subtracted from the original weight before the percentage calculations were made, inasmuch as there is no way to determine from which sieve fraction the loss occurred. It must, therefore, be assumed that the loss is evenly distributed throughout the size grades in a proportion relative to the amount of sand in each size. By using this method, each sample was calculated to 100 per cent and each cumulative curve completed.

Table 1

DATA FROM SIEVE ANALYSIS

Sample Number 1

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	17.496	6.447	6.447
	6600	9.292	3.424	9.871
6-	3360	19.325	7.120	16.991
6-8	2380	10.264	3.782	20.773
8-10	1651	8.380	3.088	23.861
10-14	1168	6.246	2.301	26.162
14-20	833	9.194	3.388	29.550
20-28	590	22.490	8.287	37.837
28-32	500	20.330	7.491	45.328
32-35	417	22.473	8.280	53.608
35-42	350	29.153	10.742	64.350
42-48	297	30.762	11.334	75.684
48-60	250	16.892	6.224	81.908
60-65	208	16.625	6.125	88.033
65-80	177	11.407	4.203	92.236
80-100	149	7.723	2.845	95.081
100-120	125	3.633	1.338	96.419
120-150	105	5.310	9.956	98.375
150-170	88	3.047	1.123	99.498
170-200	74	1.088	0.401	99.899
200-230	62	0.273	0.101	100.000

Sieve Loss - 1.597 grams

Table 2

DATA FROM SIEVE ANALYSIS

Sample Number 2

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	62.416	22.513	22.513
	6600	6.724	2.425	24.938
6-	3360	11.707	4.222	29.160
6-8	2380	4.991	1.800	30.960
8-10	1651	4.088	1.474	32.434
10-14	1168	4.246	1.531	33.965
14-20	833	7.071	2.550	36.515
20-28	590	18.747	6.762	43.277
28-32	500	12.559	4.530	47.807
32-35	417	20.317	7.328	55.135
35-42	350	28.021	10.107	65.242
42-48	297	36.527	13.174	78.416
48-60	250	21.575	7.782	86.198
60-65	208	19.029	6.863	93.061
65-80	177	6.735	2.429	95.490
80-100	149	5.641	2.035	97.525
100-120	125	2.502	0.902	98.427
120-150	105	2.136	0.770	99.197
150-170	88	0.778	0.281	99.478
170-200	74	0.597	0.215	99.693
200-230	62	0.849	0.307	100.000

Sieve Loss - 1.744 grams

Table 3

DATA FROM SIEVE ANALYSIS

Sample Number 3

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	188.461	62.971	62.971
	6600	23.484	7.818	70.559
6-	3360	12.475	4.153	74.712
6-8	2380	3.722	1.239	75.951
8-10	1651	2.638	0.878	76.829
10-14	1168	1.830	0.609	77.438
14-20	833	2.506	0.834	78.272
20-28	590	4.611	1.535	79.807
28-32	500	4.326	1.440	81.247
32-35	417	5.513	1.835	83.082
35-42	350	7.427	2.473	85.555
42-48	297	11.668	3.884	89.439
48-60	250	8.104	2.698	92.137
60-65	208	7.402	2.464	94.601
65-80	177	4.133	1.376	95.977
80-100	149	5.497	1.830	97.807
100-120	125	3.534	1.177	98.984
120-150	105	1.823	0.607	99.591
150-170	88	0.374	0.125	99.716
170-200	74	0.341	0.113	99.829
200-230	62	0.510	0.171	100.000

Sieve Loss - 0.621 grams

Table 4

DATA FROM SIEVE ANALYSIS

Sample Number 5

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.174	0.073	0.073
6-8	2380	0.318	0.134	0.207
8-10	1651	0.396	0.167	0.374
10-14	1168	0.688	0.290	0.664
14-20	833	1.937	0.816	1.480
20-28	590	5.863	2.470	3.950
28-32	500	6.402	2.697	6.647
32-35	417	11.126	4.688	11.335
35-42	350	19.852	8.364	19.699
42-48	297	28.849	12.155	31.854
48-60	250	18.188	7.663	39.517
60-65	208	32.152	13.546	53.063
65-80	177	12.885	5.429	58.492
80-100	149	34.957	14.729	73.221
100-120	125	25.800	10.871	84.092
120-150	105	27.008	11.379	95.471
150-170	88	6.777	2.855	98.326
170-200	74	3.289	1.387	99.713
200-230	62	0.678	0.287	100.000

Sieve Loss - 1.661 grams

Table 5

DATA FROM SIEVE ANALYSIS

Sample Number 6

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	--	--	--
6-8	2380	--	--	--
8-10	1651	--	--	--
10-14	1168	0.020	0.006	0.006
14-20	833	0.129	0.041	0.047
20-28	590	0.615	0.195	0.242
28-32	500	0.795	0.253	0.495
32-35	417	1.688	0.537	1.032
35-42	350	3.502	1.114	2.146
42-48	297	14.870	4.729	6.875
48-60	250	39.049	12.417	19.292
60-65	208	46.793	14.880	34.172
65-80	177	68.692	21.844	56.016
80-100	149	79.938	25.420	81.436
100-120	125	23.691	7.534	88.970
120-150	105	20.788	6.610	95.580
150-170	88	7.898	2.512	98.092
170-200	74	4.996	1.589	99.681
200-230	62	1.003	0.319	100.000

Sieve Loss - 1.532 grams

Table 6

DATA FROM SIEVE ANALYSIS

Sample Number 7

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.058	0.116	0.116
10-14	1168	0.078	0.156	0.272
14-20	833	0.147	0.294	0.566
20-28	590	0.258	0.516	1.083
28-32	500	0.271	0.542	1.625
32-35	417	0.280	0.560	2.185
35-42	350	0.378	0.756	2.942
42-48	297	0.686	1.373	4.315
48-60	250	0.543	1.087	5.401
60-65	208	0.534	1.071	6.472
65-80	177	0.341	0.682	7.154
80-100	149	0.280	0.560	7.714
100-120	125	0.196	0.392	8.107
120-150	105	1.397	2.796	10.902
150-170	88	4.918	9.842	20.744
170-200	74	18.974	37.970	58.714
200-230	62	2.489	4.981	63.695
230-325	31	2.247	4.497	68.191
325-	15	4.540	9.085	77.277
	7	3.725	7.454	84.731
	3	3.110	6.224	90.955
	2	1.675	3.352	94.307
	1	1.620	3.242	97.548
	0.5	0.655	1.311	98.859
	0.5-	0.570	1.141	100.000

Sieve Loss 0.029 grams

Table 7

DATA FROM SIEVE ANALYSIS

Sample Number 8

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.303	0.101	0.101
6-8	2380	0.407	0.136	0.237
8-10	1651	0.187	0.062	0.299
10-14	1168	0.275	0.092	0.391
14-20	833	0.765	0.256	0.647
20-28	590	4.037	1.349	1.996
28-32	500	7.755	2.592	4.588
32-35	417	18.620	6.223	10.811
35-42	350	36.632	12.244	23.055
42-48	297	80.322	26.847	49.902
48-60	250	69.485	23.225	73.127
60-65	208	53.239	17.795	90.922
65-80	177	46.991	5.679	96.601
80-100	149	7.555	2.525	99.126
100-120	125	1.547	0.517	99.643
120-150	105	0.803	0.268	99.911
150-170	88	0.126	0.042	99.453
170-200	74	0.095	0.032	99.985
200-230	62	0.042	0.015	100.000

Sieve Loss - 0.814 grams

Tyler
Si

6

6

8

10

14

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3

3

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Table 8

DATA FROM SIEVE ANALYSIS

Sample Number 9

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	1.069	0.846	0.846
6-8	2380	0.815	0.644	1.490
8-10	1651	1.816	1.437	2.927
10-14	1168	5.323	4.211	7.138
14-20	833	12.312	9.740	16.878
20-28	590	18.721	14.811	31.689
28-32	500	10.280	8.133	39.822
32-35	417	11.086	8.770	48.592
35-42	350	12.462	9.859	58.451
42-48	297	17.443	13.800	72.251
48-60	250	10.188	8.060	80.311
60-65	208	12.765	10.099	90.410
65-80	177	5.908	4.674	95.084
80-100	149	4.845	3.833	98.917
100-120	125	0.731	0.578	99.495
120-150	105	0.392	0.310	99.805
150-170	88	0.157	0.124	99.929
170-200	74	0.070	0.056	99.985
200-230	62	0.018	0.015	100.000

Sieve Loss - 0.599 grams

Table 9

DATA FROM SIEVE ANALYSIS

Sample Number 10

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	6600	24.067	8.016	8.016
6	3360	10.291	3.428	11.444
6-8	2380	3.807	1.268	12.712
8-10	1651	3.602	1.200	13.912
10-14	1168	4.303	1.433	15.345
14-20	833	7.710	2.568	17.913
20-28	590	15.474	5.154	23.067
28-32	500	14.126	4.705	27.772
32-35	417	22.021	7.334	35.106
35-42	350	33.159	11.044	46.150
42-48	297	47.350	15.771	61.921
48-60	250	27.059	9.013	70.934
60-65	208	29.010	9.662	80.596
65-80	177	13.527	4.505	85.101
80-100	149	22.746	7.576	92.677
100-120	125	8.575	2.856	95.533
120-150	105	7.190	2.395	97.928
150-170	88	2.846	0.948	98.876
170-200	74	2.011	0.670	99.546
200-230	62	1.361	0.454	100.000

Sieve Loss - 0.765 grams

Table 10

DATA FROM SIEVE ANALYSIS

Sample Number 11

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	6600	27.568	9.270	9.270
6	3360	14.365	4.830	14.100
6-8	2380	5.393	1.813	15.913
8-10	1651	4.936	1.660	17.573
10-14	1168	4.037	1.357	18.930
14-20	833	5.930	1.994	20.924
20-28	590	15.902	5.347	26.271
28-32	500	14.511	4.879	31.150
32-35	417	19.470	6.547	37.697
35-42	350	28.243	9.497	47.194
42-48	297	54.738	18.406	65.600
48-60	250	31.721	10.666	76.266
60-65	208	33.407	11.233	87.499
65-80	177	12.972	4.362	91.861
80-100	149	13.708	4.609	96.470
100-120	125	5.116	1.720	98.190
120-150	105	3.850	1.295	99.485
150-170	88	0.829	0.279	99.764
170-200	74	0.470	0.158	99.922
200-230	62	0.230	0.078	100.000

Sieve Loss - 1.604 grams

Table 11

DATA FROM SIEVE ANALYSIS

Sample Number 12

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.180	0.060	0.060
6-8	2380	0.132	0.044	0.104
8-10	1651	0.288	0.096	0.200
10-14	1168	0.462	0.154	0.354
14-20	833	1.035	0.346	0.700
20-28	590	4.556	1.522	2.222
28-32	500	5.184	1.732	3.954
32-35	417	9.958	3.327	7.281
35-42	350	15.648	5.227	12.508
42-48	497	46.146	15.415	27.923
48-60	250	51.563	17.225	45.148
60-65	208	62.727	20.954	66.102
65-80	177	48.750	16.285	82.387
80-100	149	40.566	13.551	95.938
100-120	125	7.657	2.558	98.496
120-150	105	3.184	1.064	99.560
150-170	88	0.824	0.275	99.835
170-200	74	0.382	0.128	99.963
200-230	62	0.109	0.037	100.000

Sieve Loss - 0.649 grams

Table 12

DATA FROM SIEVE ANALYSIS

Sample Number 13

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	40.062	13.378	13.378
	6600	3.612	1.206	14.584
6	3360	1.648	0.550	15.134
6-8	2380	0.979	0.327	15.461
8-10	1651	0.584	0.195	15.656
10-14	1168	0.989	0.330	15.986
14-20	833	2.323	0.776	16.762
20-28	590	4.482	1.497	18.259
28-32	500	4.548	1.519	19.778
32-35	417	14.150	7.725	24.503
35-42	350	37.953	12.673	37.176
42-48	297	65.060	21.725	58.901
48-60	250	37.603	12.556	71.457
60-65	208	40.959	13.677	85.134
65-80	177	21.210	7.082	92.216
80-100	149	19.235	6.423	98.639
100-120	125	2.102	0.702	99.341
120-150	105	0.681	0.227	99.568
150-170	88	0.203	0.068	99.636
170-200	74	0.201	0.067	99.703
200-230	62	0.889	0.297	100.000

Sieve Loss - 0.526 grams

Table 13

DATA FROM SIEVE ANALYSIS

Sample Number 14

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.509	0.236	0.236
6-8	2380	0.268	0.124	0.360
8-10	1651	0.520	0.241	0.601
10-14	1168	0.711	0.330	0.931
14-20	833	2.231	1.034	1.965
20-28	590	5.620	2.606	4.571
28-32	500	6.239	2.893	7.464
32-35	417	9.093	4.216	11.680
35-42	350	11.064	5.130	16.810
42-48	297	12.574	5.830	22.640
48-60	250	8.100	3.756	26.396
60-65	208	11.935	5.534	31.930
65-80	177	14.337	6.647	38.577
80-100	149	23.366	10.834	49.411
100-120	125	30.095	13.954	63.365
120-150	105	36.942	17.128	80.493
150-170	88	14.182	6.576	87.069
170-200	74	13.722	6.362	93.431
200-230	62	14.169	6.569	100.000

Sieve Loss - 1.323 grams

Table 14

DATA FROM SIEVE ANALYSIS

Sample Number 15

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
10-14	1168	0.070	0.023	0.023
14-20	833	0.147	0.049	0.072
20-28	590	0.595	0.199	0.271
28-32	500	0.774	0.259	0.530
32-35	417	1.258	0.421	0.951
35-42	350	2.526	0.845	1.796
42-48	297	13.804	4.618	6.414
48-60	250	50.952	17.046	23.460
60-65	208	97.033	32.463	55.923
65-80	177	50.106	16.763	72.686
80-100	149	54.412	18.204	90.890
100-120	125	11.409	3.817	94.707
120-150	105	7.199	2.408	97.115
150-170	88	4.292	1.436	98.551
170-200	74	2.703	0.904	99.455
200-230	62	1.626	0.545	100.000

Sieve Loss - 1.094 grams

Table 15

DATA FROM SIEVE ANALYSIS

Sample Number 16

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.107	0.214	0.214
10-14	1168	0.082	0.164	0.378
14-20	833	0.083	0.166	0.544
20-28	590	0.077	0.154	0.698
28-32	500	0.048	0.096	0.794
32-35	417	0.064	0.128	0.922
35-42	350	0.069	0.138	1.060
42-48	297	0.135	0.270	1.330
48-60	250	0.084	0.168	1.498
60-65	208	0.124	0.248	1.746
65-80	177	0.103	0.206	1.952
80-100	149	0.073	0.146	2.098
100-120	125	0.052	0.104	2.202
120-150	105	0.171	0.342	2.544
150-170	88	0.081	0.162	2.706
170-200	74	2.584	5.169	7.875
200-230	62	3.933	7.867	15.741
230-325	31	9.820	19.642	35.383
325-	15	14.840	29.683	65.066
	7	8.685	17.372	82.438
	3	2.295	4.591	87.029
	2	2.570	5.141	92.169
	1	1.895	3.790	95.959
	0.5	1.140	2.280	98.240
	0.5-	.880	1.760	100.000

Sieve Loss - 0.005 grams

Table 16

DATA FROM SIEVE ANALYSIS

Sample Number 17

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.096	0.046	0.046
6-8	2380	0.122	0.058	0.104
8-10	1651	0.291	0.138	0.242
10-14	1168	0.852	0.405	0.647
14-20	833	2.814	1.339	1.986
20-28	590	7.377	3.511	5.497
28-32	500	5.004	2.381	7.878
32-35	417	7.413	3.528	11.406
35-42	350	11.070	5.268	16.674
42-48	297	18.454	8.782	25.456
48-60	250	16.762	7.977	33.433
60-65	208	22.666	10.786	44.219
65-80	177	9.781	4.655	48.874
80-100	149	4.170	1.984	50.858
100-120	125	0.945	0.450	52.054
150-170	88	1.380	0.657	52.711
170-200	74	28.752	13.683	66.394
200-230	62	70.617	33.606	100.000

Sieve Loss - 0.134 grams

Table 17

DATA FROM SIEVE ANALYSIS

Sample Number 18

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	17.293	11.382	11.382
	6600	6.850	4.508	15.890
6	3360	11.633	7.656	23.546
6-8	2380	3.735	2.458	26.004
8-10	1651	2.358	1.552	27.556
10-14	1168	2.248	1.479	29.035
14-20	833	3.093	2.036	31.071
20-28	590	6.103	4.017	35.088
28-32	500	6.717	4.421	39.509
32-35	417	13.118	8.633	48.142
35-42	350	19.319	12.715	60.857
42-48	297	28.608	18.828	79.685
48-60	250	13.047	8.587	88.272
60-65	208	8.861	5.832	94.104
65-80	177	3.229	2.125	96.229
80-100	149	3.517	2.315	98.544
100-120	125	1.133	0.746	99.290
120-150	105	0.546	0.359	99.649
150-170	88	0.134	0.088	99.737
170-200	74	0.118	0.078	99.815
200-230	62	0.282	0.185	100.000

Sieve Loss - 0.057 grams

Table 18

DATA FROM SIEVE ANALYSIS

Sample Number 19

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	28.593	9.530	9.530
	6600	4.765	1.588	11.118
6	3360	6.289	2.096	13.214
6-8	2380	2.635	0.878	14.092
8-10	1651	2.547	0.849	14.941
10-14	1168	2.364	0.788	15.729
14-20	833	2.837	0.946	16.675
20-28	590	9.415	3.138	19.813
28-32	500	15.971	5.323	25.136
32-35	417	31.608	10.535	36.671
35-42	350	41.680	13.892	49.563
42-48	297	57.847	19.281	68.844
48-60	250	31.925	10.641	79.485
60-65	208	31.049	10.349	89.834
65-80	177	11.384	3.794	93.628
80-100	149	12.489	4.163	97.791
100-120	125	3.519	1.173	98.964
120-150	105	2.031	0.677	99.641
150-170	88	0.520	0.173	99.814
170-200	74	0.300	0.100	99.914
200-230	62	0.260	0.086	100.000

Sieve Loss - 0.972 grams

Table 19

DATA FROM SIEVE ANALYSIS

Sample Number 21

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	139.553	46.647	46.647
6-8	2380	3.534	1.181	47.828
8-10	1651	7.101	2.373	50.201
10-14	1168	14.922	4.988	55.189
14-20	833	17.059	5.702	60.891
20-28	590	14.552	4.864	65.755
28-32	500	9.504	3.177	68.932
32-35	417	12.337	4.124	73.056
35-42	350	16.234	5.426	78.482
42-48	297	24.212	8.093	86.575
48-60	250	14.345	4.795	91.370
60-65	208	11.343	3.792	95.162
65-80	177	4.398	1.470	96.632
80-100	149	3.431	1.147	97.779
100-120	125	1.093	0.365	98.144
120-150	105	1.110	0.371	98.515
150-170	88	0.687	0.230	98.745
170-200	74	1.087	0.363	99.108
200-230	62	2.667	0.892	100.000

Sieve Loss - 0.930 grams

Table 20

DATA FROM SIEVE ANALYSIS

Sample Number 22

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.573	0.191	0.191
6-8	2380	0.361	0.120	0.311
8-10	1651	0.487	0.162	0.473
10-14	1168	1.384	0.461	0.934
14-20	833	3.836	1.277	2.211
20-28	590	12.181	4.056	6.267
28-32	500	16.790	5.590	11.857
32-35	417	23.302	7.759	19.616
35-42	350	33.655	11.206	30.822
42-48	297	47.291	15.746	46.568
48-60	250	30.366	10.111	56.679
60-65	208	41.733	13.896	70.565
65-80	177	22.516	7.497	78.072
80-100	149	39.257	13.071	91.143
100-120	125	13.372	4.452	95.595
120-150	105	7.485	2.492	98.087
150-170	88	2.248	0.748	98.835
170-200	74	1.972	0.657	99.492
200-230	62	1.524	0.508	100.000

Sieve Loss - 0.667 grams

Table 21

DATA FROM SIEVE ANALYSIS

Sample Number 23

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	1.775	0.593	0.593
6-8	2380	0.532	0.178	0.771
8-10	1651	0.492	0.164	0.935
10-14	1168	0.678	0.227	1.162
14-20	833	1.729	0.578	1.740
20-28	590	6.015	2.011	3.751
28-32	500	8.722	2.916	6.667
32-35	417	22.503	7.523	14.190
35-42	350	60.897	20.359	34.549
42-48	297	89.543	29.935	64.484
48-60	250	49.707	16.618	81.102
60-65	208	34.008	11.369	92.471
65-80	177	11.352	3.795	96.266
80-100	149	8.482	2.836	99.102
100-120	125	1.349	0.451	99.553
120-150	105	0.717	0.240	99.793
150-170	88	0.289	0.097	99.890
170-200	74	0.201	0.067	99.957
200-230	62	0.131	0.043	100.000

Sieve Loss - 0.878 grams

Table 22

DATA FROM SIEVE ANALYSIS

Sample Number 24

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	1.236	0.415	0.415
6-8	2380	0.238	0.080	0.495
8-10	1651	0.390	0.131	0.626
10-14	1168	1.188	0.399	1.025
14-20	833	3.351	1.126	2.151
20-28	590	6.961	2.338	4.489
28-32	500	5.261	1.767	6.256
32-35	417	10.210	3.429	9.685
35-42	350	25.458	8.550	18.235
42-48	297	81.189	27.269	45.504
48-60	250	63.840	21.442	66.946
60-65	208	49.066	16.480	83.426
65-80	177	27.244	9.150	92.476
80-100	149	19.230	6.459	99.035
100-120	125	1.863	0.626	99.661
120-150	105	0.678	0.228	99.889
150-170	88	0.179	0.060	99.949
170-200	74	0.091	0.031	99.980
200-230	62	0.061	0.020	100.000

Sieve Loss - 1.266 grams

Table 23

DATA FROM SIEVE ANALYSIS

Sample Number 25

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	4.396	1.464	1.464
6-8	2380	2.586	0.861	2.325
8-10	1651	4.669	1.555	3.880
10-14	1168	5.624	1.873	5.753
14-20	833	7.995	2.663	8.416
20-28	590	17.494	5.826	14.242
28-32	500	20.080	6.687	20.929
32-35	417	34.602	11.524	32.453
35-42	350	50.638	16.865	49.318
42-48	297	56.490	18.814	68.132
48-60	250	29.587	9.854	77.986
60-65	208	27.820	9.265	87.251
65-80	177	13.875	4.621	91.872
80-100	149	16.693	5.559	97.431
100-120	125	3.480	1.159	98.590
120-150	105	1.524	0.508	99.098
150-170	88	0.455	0.152	99.250
170-200	74	0.510	0.170	99.420
200-230	62	1.745	0.580	100.000

Sieve Loss - 0.737 grams

Table 24

DATA FROM SIEVE ANALYSIS

Sample Number 26

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	20.715	7.030	7.030
6-8	2380	3.276	1.112	8.142
8-10	1651	2.315	0.786	8.928
10-14	1168	2.405	0.816	9.744
14-20	833	4.883	1.657	11.401
20-28	590	14.706	4.991	16.392
28-32	500	12.850	4.361	20.753
32-35	417	20.008	6.790	27.543
35-42	350	31.910	10.829	38.372
42-48	297	43.089	14.623	52.995
48-60	250	33.774	11.462	64.457
60-65	208	35.888	12.179	76.636
65-80	177	18.613	6.317	82.953
80-100	149	16.432	5.577	88.530
100-120	125	7.968	2.704	91.234
120-150	105	9.132	3.099	94.333
150-170	88	3.731	1.266	95.599
170-200	74	4.030	1.368	96.967
200-230	62	8.938	3.033	100.000

Sieve Loss - 0.337 grams

Table 25

DATA FROM SIEVE ANALYSIS

Sample Number 27

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
10-14	1168	0.048	0.096	0.096
14-20	833	0.200	0.400	0.496
20-28	590	0.270	0.540	1.036
28-32	500	0.286	0.572	1.608
32-35	417	0.539	1.078	2.687
35-42	350	0.719	1.438	4.125
42-48	297	1.248	2.497	6.621
48-60	250	0.995	1.990	8.612
60-65	208	0.943	1.886	10.498
65-80	177	0.631	1.262	11.760
80-100	149	0.293	0.586	12.347
100-120	125	0.230	0.460	12.807
120-150	105	0.290	0.580	13.387
150-170	88	0.544	1.088	14.475
170-200	74	1.288	2.577	17.051
200-230	62	0.481	0.962	18.014
230-325	31	1.890	3.781	21.794
325-	15	14.640	29.286	51.080
	7	12.100	24.205	75.285
	3	5.925	11.852	87.137
	2	2.680	5.361	92.498
	1	1.770	3.541	96.039
	0.5	1.105	2.210	98.250
	0.5-	.875	1.750	100.000

Sieve Loss - 0.010 grams

Table 26

DATA FROM SIEVE ANALYSIS

Sample Number 28

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	18.049	5.987	5.987
6-8	2380	2.294	0.761	6.748
8-10	1651	2.365	0.785	7.533
10-14	1168	3.283	1.089	8.622
14-20	833	6.082	2.018	10.640
20-28	590	12.394	4.111	14.751
28-32	500	10.367	3.439	18.190
32-35	417	17.664	5.860	24.050
35-42	350	33.386	11.075	35.125
42-48	297	67.629	22.435	57.560
48-60	250	53.927	17.889	75.449
60-65	208	43.008	14.267	89.716
65-80	177	17.128	5.682	95.398
80-100	149	9.631	3.195	98.593
100-120	125	1.541	0.511	99.104
120-150	105	1.054	0.350	99.454
150-170	88	0.303	0.000	99.554
170-200	74	0.210	0.070	99.626
200-230	62	1.132	0.376	100.000

Sieve Loss - 1.553 grams

Table 27

DATA FROM SIEVE ANALYSIS

Sample Number 29

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	44.594	14.800	14.800
	6600	7.339	2.435	17.235
6	3360	9.180	3.046	20.281
6-8	2380	2.107	0.699	20.980
8-10	1651	1.186	0.394	21.374
10-14	1168	0.980	0.325	21.699
14-20	833	1.624	0.539	22.238
20-28	590	6.366	2.113	24.351
28-32	500	7.626	2.531	26.882
32-35	417	17.329	5.751	32.633
35-42	350	36.009	11.950	44.583
42-48	297	56.645	18.798	63.381
48-60	250	39.761	13.195	76.576
60-65	208	42.741	14.184	90.760
65-80	177	16.297	5.408	96.168
80-100	149	8.438	2.800	98.968
100-120	125	1.925	0.639	99.607
120-150	105	0.818	0.271	99.878
150-170	88	0.147	0.049	99.927
170-200	74	0.080	0.027	99.954
200-230	62	0.143	0.046	100.000

Sieve Loss - 1.665 grams

Table 28

DATA FROM SIEVE ANALYSIS

Sample Number 30

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	11.347	3.755	3.755
6-8	2380	4.370	1.446	5.201
8-10	1651	3.894	1.289	6.490
10-14	1168	3.867	1.280	7.770
14-20	833	5.419	1.793	9.563
20-28	590	12.404	4.105	13.668
28-32	500	14.825	4.906	18.574
32-35	417	20.417	6.757	25.331
35-42	350	33.135	10.966	36.297
42-48	297	57.582	19.056	55.353
48-60	250	48.678	16.110	71.463
60-65	208	51.785	17.138	88.601
65-80	177	20.591	6.814	95.415
80-100	149	8.031	2.658	98.073
100-120	125	1.584	0.524	98.597
120-150	105	1.871	0.619	99.216
150-170	88	0.725	0.240	99.456
170-200	74	0.694	0.230	99.686
200-230	62	0.949	0.314	100.000

Sieve Loss - 1.832 grams

Table 29

DATA FROM SIEVE ANALYSIS

Sample Number 31

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.013	0.004	0.004
10-14	1168	0.052	0.017	0.021
14-20	833	0.128	0.043	0.064
20-28	590	0.263	0.088	0.152
28-32	500	0.247	0.083	0.235
32-35	417	0.481	0.162	0.397
35-42	350	0.857	0.288	0.685
42-48	297	2.317	0.779	1.464
48-60	250	2.821	0.949	2.413
60-65	208	4.420	1.486	3.899
65-80	177	3.834	1.289	5.188
80-100	149	5.047	1.698	6.886
100-120	125	3.608	1.213	8.099
120-150	105	24.173	8.129	16.228
150-170	88	77.608	26.097	42.325
170-200	74	114.784	38.598	80.923
200-230	62	56.727	19.077	100.000

Sieve Loss - 1.620 grams

Table 30

DATA FROM SIEVE ANALYSIS

Sample Number 32

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.228	0.076	0.076
6-8	2380	0.234	0.078	0.154
8-10	1651	0.243	0.081	0.235
10-14	1168	0.308	0.103	0.338
14-20	833	0.488	0.163	0.501
20-28	590	1.056	0.353	0.854
28-32	500	0.651	0.217	1.071
32-35	417	1.170	0.391	1.462
35-42	350	3.095	1.034	2.496
42-48	297	17.247	5.761	8.257
48-60	250	42.742	14.276	22.533
60-65	208	116.759	38.999	61.532
65-80	177	55.867	18.660	80.192
80-100	149	38.246	12.775	92.967
100-120	125	10.172	3.398	96.365
120-150	105	7.755	2.590	98.955
150-170	88	1.767	0.590	99.545
170-200	74	1.066	0.356	99.901
200-230	62	0.295	0.099	100.000

Sieve Loss - 0.611 grams

Table 31

DATA FROM SIEVE ANALYSIS

Sample Number 33

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.821	0.273	0.273
6-8	2380	0.178	0.059	0.332
8-10	1651	0.168	0.056	0.388
10-14	1168	0.358	0.119	0.507
14-20	833	0.462	0.154	0.661
20-28	590	0.813	0.270	0.931
28-32	500	0.478	0.159	1.090
32-35	417	0.987	0.328	1.418
35-42	350	2.289	0.761	2.179
42-48	297	10.262	3.414	5.593
48-60	250	32.095	10.676	16.269
60-65	208	100.822	33.537	49.806
65-80	177	94.181	31.329	81.135
80-100	149	46.333	15.412	96.547
100-120	125	5.863	1.950	98.497
120-150	105	3.097	1.030	99.527
150-170	88	0.680	0.226	99.753
170-200	74	0.576	0.192	99.945
200-230	62	0.164	0.055	100.000

Sieve Loss - 0.373 grams

Table 32

DATA FROM SIEVE ANALYSIS

Sample Number 34

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6-8	2380	0.167	0.056	0.056
8-10	1651	0.257	0.086	0.142
10-14	1168	0.521	0.174	0.316
14-20	833	0.793	0.265	0.581
20-28	590	1.722	0.576	1.157
28-32	500	2.135	0.714	1.871
32-35	417	5.084	1.699	3.570
35-42	350	16.849	5.632	9.202
42-48	297	52.488	17.544	26.746
48-60	250	76.319	25.509	52.225
60-65	208	104.337	34.874	87.129
65-80	177	23.334	7.799	94.928
80-100	149	11.318	3.783	98.711
100-120	125	1.780	0.595	99.306
120-150	105	1.423	0.476	99.782
150-170	88	0.335	0.112	99.894
170-200	74	0.218	0.072	99.966
200-230	62	0.106	0.034	100.000

Sieve Loss - 0.814 grams

Table 33

DATA FROM SIEVE ANALYSIS

Sample Number 35

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6-8	2380	0.078	0.026	0.026
8-10	1651	0.450	0.150	0.176
10-14	1168	1.375	0.459	0.635
14-20	833	4.578	1.528	2.163
20-28	590	10.900	3.638	5.801
28-32	500	11.490	3.835	9.636
32-35	417	21.580	7.203	16.839
35-42	350	38.512	12.855	29.694
42-48	297	71.033	23.711	53.405
48-60	250	46.132	15.399	68.804
60-65	208	49.215	16.428	85.232
65-80	177	21.481	7.170	92.402
80-100	149	16.487	5.503	97.905
100-120	125	3.570	1.192	99.097
120-150	105	1.836	0.613	99.710
150-170	88	0.405	0.136	99.846
170-200	74	0.313	0.105	99.951
200-230	62	0.144	0.049	100.000

Sieve Loss - 0.421 grams

Table 34

DATA FROM SIEVE ANALYSIS

Sample Number 36

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200	46.642	15.534	15.534
	6600	9.787	3.260	18.794
6	3360	19.479	6.488	25.282
6-8	2380	6.584	2.193	27.475
8-10	1651	5.688	1.894	29.369
10-14	1168	5.840	1.945	31.314
14-20	833	6.606	2.200	33.514
20-28	590	13.846	4.612	38.126
28-32	500	13.319	4.436	42.562
32-35	417	17.182	5.723	48.285
35-42	350	20.950	6.978	55.263
42-48	297	49.666	16.542	71.805
48-60	250	50.788	16.916	88.721
60-65	208	27.075	9.018	97.739
65-80	177	4.164	1.387	99.126
80-100	149	1.661	0.553	99.679
100-120	125	0.398	0.133	99.812
120-150	105	0.263	0.088	99.900
150-170	88	0.097	0.032	99.932
170-200	74	0.069	0.023	99.955
200-230	62	0.134	0.045	100.000

Sieve Loss - 0.762 grams

Table 35

DATA FROM SIEVE ANALYSIS

Sample Number 37

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6-8	2380	0.161	0.053	0.053
8-10	1651	0.114	0.038	0.091
10-14	1168	0.161	0.053	0.144
14-20	833	0.494	0.164	0.308
20-28	590	1.725	0.573	0.881
28-32	500	2.359	0.783	1.664
32-35	417	3.810	1.265	2.929
35-42	350	7.079	2.351	5.280
42-48	297	13.321	4.423	9.703
48-60	250	11.565	3.840	13.543
60-65	208	14.045	4.664	18.207
65-80	177	17.153	5.696	23.903
80-100	149	100.771	33.462	57.365
100-120	125	69.988	23.240	80.605
120-150	105	43.855	14.563	95.168
150-170	88	8.450	2.806	97.974
170-200	74	4.950	1.644	99.618
200-230	62	1.149	0.382	100.000

Sieve Loss - 1.850 grams

Table 36

DATA FROM SIEVE ANALYSIS

Sample Number 38

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	89.852	30.069	30.069
6-8	2380	0.641	0.215	30.284
8-10	1651	0.551	0.184	30.468
10-14	1168	0.543	0.182	30.650
14-20	833	1.560	0.522	31.172
20-28	590	5.134	1.718	32.890
28-32	500	6.943	2.324	35.214
32-35	417	10.447	3.496	38.710
35-42	350	17.579	5.883	44.593
42-48	297	26.173	8.759	53.352
48-60	250	17.608	5.893	59.245
60-65	208	15.910	5.324	64.569
65-80	177	10.629	3.557	68.126
80-100	149	15.749	5.270	73.396
100-120	125	23.093	7.728	81.124
120-150	105	25.093	8.397	89.521
150-170	88	9.769	3.269	92.790
170-200	74	8.065	2.699	95.489
200-230	62	13.477	4.511	100.000

Sieve Loss - 1.184 grams

Table 37

DATA FROM SIEVE ANALYSIS

Sample Number 39

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.062	0.021	0.021
6-8	2380	0.234	0.078	0.099
8-10	1651	0.467	0.155	0.254
10-14	1168	0.916	0.304	0.558
14-20	833	2.049	0.680	1.238
20-28	590	9.805	3.255	4.493
28-32	500	17.423	5.783	10.276
32-35	417	33.998	11.285	21.561
35-42	350	68.727	22.814	44.375
42-48	297	116.948	38.820	83.195
48-60	250	38.058	12.633	95.828
60-65	208	10.061	3.340	99.168
65-80	177	1.180	0.392	99.560
80-100	149	0.511	0.170	99.730
100-120	125	0.297	0.099	99.829
120-150	105	0.201	0.067	99.896
150-170	88	0.111	0.037	99.933
170-200	74	0.078	0.026	99.959
200-230	62	0.128	0.041	100.000

Sieve Loss - 1.756 grams

Table 38

DATA FROM SIEVE ANALYSIS

Sample Number 41

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
14-20	833	0.019	0.038	0.038
20-28	590	0.020	0.040	0.078
28-32	500	0.027	0.054	0.132
32-35	417	0.051	0.102	0.234
35-42	350	0.076	0.152	0.386
42-48	297	0.223	0.466	0.852
48-60	250	0.296	0.592	1.444
60-65	208	0.502	1.004	2.448
65-80	177	0.485	0.970	3.419
80-100	149	1.976	3.953	7.371
100-120	125	5.672	11.346	18.718
120-150	105	7.494	14.991	33.709
150-170	88	7.860	15.723	49.432
170-200	74	3.489	6.979	56.411
200-230	62	1.938	3.877	60.288
230-325	31	7.912	15.827	76.115
	15	1.880	3.761	79.876
	7	2.120	4.241	84.117
	3	2.130	4.261	88.378
	2	1.953	3.907	92.285
	1	2.415	4.831	97.116
	0.5	.568	1.136	98.252
	0.5-	.830	1.660	100.000

Sieve Loss - 0.010 grams

Table 39

DATA FROM SIEVE ANALYSIS

Sample Number 42

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.058	0.019	0.019
6-8	2380	0.178	0.060	0.079
8-10	1651	0.537	0.180	0.259
10-14	1168	1.344	0.450	0.709
14-20	833	3.534	1.182	1.891
20-28	590	11.918	3.986	5.877
28-32	500	13.758	4.602	10.479
32-35	417	33.233	11.115	21.594
35-42	350	25.592	8.560	30.154
42-48	297	78.940	26.402	56.556
48-60	250	53.544	17.908	74.464
60-65	208	39.808	13.314	87.778
65-80	177	11.772	3.937	91.715
80-100	149	7.712	2.579	94.294
100-120	125	5.715	1.911	96.205
120-150	105	7.571	2.532	98.737
150-170	88	2.008	0.672	99.409
170-200	74	1.197	0.400	99.809
200-230	62	0.570	0.191	100.000

Sieve Loss - 1.011 grams

Table 40

DATA FROM SIEVE ANALYSIS

Sample Number 43

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	3.128	1.039	1.039
6-8	2380	0.655	0.217	1.256
8-10	1651	0.884	0.294	1.550
10-14	1168	1.476	0.490	2.040
14-20	833	3.867	1.284	3.324
20-28	590	12.061	4.005	7.329
28-32	500	13.596	4.514	11.843
32-35	417	23.298	7.736	19.579
35-42	350	42.446	14.093	33.672
42-48	297	72.691	24.135	57.807
48-60	250	51.579	17.126	74.933
60-65	208	44.101	14.643	89.576
65-80	177	15.406	5.115	94.691
80-100	149	10.991	3.649	98.340
100-120	125	2.646	0.879	99.219
120-150	105	1.587	0.527	99.746
150-170	88	0.398	0.132	99.878
170-200	74	0.217	0.072	99.950
200-230	62	0.155	0.050	100.000

Sieve Loss - 1.818 grams

Table 41

DATA FROM SIEVE ANALYSIS

Sample Number 45

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6-8	2380	0.044	0.015	0.015
8-10	1651	0.034	0.011	0.026
10-14	1168	0.081	0.027	0.053
14-20	833	0.216	0.072	0.125
20-28	590	0.770	0.257	0.382
28-32	500	1.247	0.415	0.797
32-35	417	3.391	1.130	1.927
35-42	350	9.502	3.166	5.093
42-48	297	36.835	12.274	17.367
48-60	250	48.264	16.082	33.449
60-65	208	62.036	20.671	54.120
65-80	177	37.944	12.643	66.763
80-100	149	65.618	21.864	88.627
100-120	125	20.637	6.876	95.503
120-150	105	9.507	3.168	98.671
150-170	88	1.768	0.589	99.260
170-200	74	1.121	0.374	99.634
200-230	62	1.098	0.366	100.000

Sieve Loss - 0.887 grams

Table 42

DATA FROM SIEVE ANALYSIS

Sample Number 46

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6–8	2380	0.098	0.032	0.032
8–10	1651	0.050	0.017	0.049
10–14	1168	0.143	0.047	0.096
14–20	833	0.448	0.148	0.244
20–28	590	2.345	0.776	1.020
28–32	500	4.022	1.331	2.351
32–35	417	8.627	2.854	5.205
35–42	350	17.371	5.747	10.952
42–48	297	37.939	12.553	23.505
48–60	250	34.444	11.396	34.901
60–65	208	41.617	13.769	48.670
65–80	177	23.883	7.902	56.572
80–100	149	19.957	6.603	63.175
100–120	125	7.338	2.428	65.603
120–150	105	9.664	3.197	68.800
150–170	88	12.624	4.177	72.977
170–200	74	37.674	12.465	85.442
200–230	62	43.997	14.558	100.000

Sieve Loss - 1.759 grams

Table 43

DATA FROM SIEVE ANALYSIS

Sample Number 47

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.070	0.023	0.023
6-8	2380	0.138	0.046	0.069
8-10	1651	0.152	0.051	0.120
10-14	1168	0.263	0.088	0.208
14-20	833	0.795	0.266	0.474
20-28	590	3.458	1.157	1.631
28-32	500	6.702	2.242	3.873
32-35	417	14.905	4.986	8.859
35-42	350	30.846	10.318	19.177
42-48	297	55.157	18.450	37.627
48-60	250	46.435	15.532	53.159
60-65	208	55.557	18.583	71.742
65-80	177	30.171	10.092	81.834
80-100	149	30.771	10.293	92.127
100-120	125	10.950	3.663	95.790
120-150	105	8.244	2.758	98.548
150-170	88	1.854	0.620	99.168
170-200	74	1.344	0.449	99.617
200-230	62	1.148	0.383	100.000

Sieve Loss - 1.040 grams

Table 44

DATA FROM SIEVE ANALYSIS

Sample Number 49

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	6600	12.647	4.222	4.222
6	3360	22.058	7.364	11.586
6-8	2380	16.883	5.636	17.222
8-10	1651	16.103	5.376	22.598
10-14	1168	15.152	5.059	27.657
14-20	833	20.120	6.717	34.374
20-28	590	36.566	12.208	46.582
28-32	500	22.699	7.578	54.160
32-35	417	23.472	7.836	61.996
35-42	350	26.881	8.974	70.970
42-48	297	28.493	9.513	80.483
48-60	250	15.603	5.209	85.692
60-65	208	14.430	4.818	90.510
65-80	177	7.025	2.345	92.855
80-100	149	10.199	3.405	96.260
100-120	125	4.347	1.451	97.711
120-150	105	3.511	1.172	98.883
150-170	88	1.183	0.395	99.278
170-200	74	1.403	0.468	99.746
200-230	62	0.757	0.254	100.000

Sieve Loss - 0.568 grams

Table 45

DATA FROM SIEVE ANALYSIS

Sample Number 50

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.567	0.191	0.191
6-8	2380	0.068	0.023	0.214
8-10	1651	0.064	0.022	0.236
10-14	1168	0.143	0.048	0.284
14-20	833	0.403	0.136	0.420
20-28	590	2.581	0.869	1.289
28-32	500	4.585	1.543	2.832
32-35	417	8.133	2.738	5.570
35-42	350	13.900	4.679	10.249
42-48	297	22.211	7.476	17.725
48-60	250	16.947	5.704	23.429
60-65	208	18.772	6.319	29.748
65-80	177	9.785	3.294	33.042
80-100	149	8.512	2.865	35.907
100-120	125	4.766	1.604	37.511
120-150	105	19.422	6.537	44.048
150-170	88	30.433	10.244	54.292
170-200	74	75.585	25.442	79.734
200-230	62	60.209	20.266	100.000

Sieve Loss - 1.914 grams

Table 46

DATA FROM SIEVE ANALYSIS

Sample Number 51

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.112	0.037	0.037
6-8	2380	0.120	0.040	0.077
8-10	1651	0.178	0.060	0.137
10-14	1168	0.338	0.113	0.250
14-20	833	1.161	0.388	0.638
20-28	590	5.249	1.754	2.392
28-32	500	8.857	2.960	5.352
32-35	417	16.467	5.504	10.856
35-42	350	29.806	9.963	20.819
42-48	297	52.853	17.666	38.485
48-60	250	43.750	14.623	53.108
60-65	208	54.587	18.246	71.354
65-80	177	32.869	10.986	82.340
80-100	149	33.894	11.329	93.669
100-120	125	9.293	3.106	96.775
120-150	105	4.332	1.448	98.223
150-170	88	1.494	0.499	98.772
170-200	74	1.598	0.534	99.256
200-230	62	2.222	0.744	100.000

Sieve Loss - 0.820 grams

Table 47

DATA FROM SIEVE ANALYSIS

Sample Number 52

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.024	0.008	0.008
10-14	1168	0.176	0.059	0.067
14-20	833	0.557	0.186	0.253
20-28	590	5.049	1.686	1.939
28-32	500	11.667	3.897	5.836
32-35	417	30.548	10.203	16.039
35-42	350	65.781	21.971	38.010
42-48	297	96.825	32.340	70.350
48-60	250	43.104	14.397	84.747
60-65	208	25.720	8.590	93.337
65-80	177	7.672	2.562	95.899
80-100	149	6.195	2.069	97.968
100-120	125	2.079	0.694	98.662
120-150	105	1.683	0.562	99.224
150-170	88	0.662	0.221	99.445
170-200	74	0.546	0.182	99.627
200-230	62	1.113	0.373	100.000

Sieve Loss - 0.599 grams

Table 48

DATA FROM SIEVE ANALYSIS

Sample Number 53

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
10-14	1168	0.104	0.035	0.035
14-20	833	0.777	0.259	0.294
20-28	590	6.559	2.189	2.483
28-32	500	14.189	4.736	7.219
32-35	417	33.445	11.164	18.383
35-42	350	63.067	21.051	39.434
42-48	297	100.936	33.691	73.125
48-60	250	48.346	16.137	89.262
60-65	208	23.796	7.943	97.205
65-80	177	5.671	1.893	99.098
80-100	149	1.917	0.670	99.738
100-120	125	0.343	0.114	99.852
120-150	105	0.226	0.075	99.927
150-170	88	0.090	0.030	99.957
170-200	74	0.058	0.020	99.977
200-230	62	0.065	0.023	100.000

Sieve Loss - 0.411 grams

Table 49

DATA FROM SIEVE ANALYSIS

Sample Number 54

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.014	0.014	0.014
10-14	1168	0.036	0.036	0.050
14-20	833	0.077	0.077	0.127
20-28	596	0.269	0.269	0.396
28-32	500	0.716	0.717	1.113
32-35	417	4.009	4.014	5.127
35-42	350	22.089	22.115	27.242
42-48	297	36.095	36.137	63.379
48-60	250	13.693	13.709	77.087
60-65	208	9.857	9.868	86.956
65-80	177	4.275	4.280	91.236
80-100	149	3.472	3.476	94.712
100-120	125	1.476	1.478	96.190
120-150	105	2.184	2.187	98.376
150-170	88	0.809	0.810	99.186
170-200	74	0.208	0.208	99.394
200-230	62	0.605	0.606	100.000

Sieve Loss - 0.116 grams

Table 50

DATA FROM SIEVE ANALYSIS

Sample Number 55

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
	9200+	9.933	9.933	9.933
	9200	12.832	12.832	22.766
	6600	6.546	6.546	29.312
6	3360	3.039	3.039	32.351
6-8	2380	1.119	1.119	33.470
8-10	1651	0.969	0.969	34.439
10-14	1168	0.828	0.828	35.267
14-20	833	1.487	1.487	36.754
20-28	590	2.766	2.766	39.520
28-32	500	3.657	3.657	43.177
32-35	417	4.432	4.432	47.609
35-42	350	8.066	8.066	55.675
42-48	297	12.483	12.483	68.159
48-60	250	11.227	11.227	79.386
60-65	208	12.015	12.015	91.402
65-80	177	5.302	5.302	96.704
80-100	149	2.222	2.222	98.926
100-120	125	0.322	0.322	99.248
120-150	105	0.292	0.292	99.540
150-170	88	0.204	0.204	99.744
170-200	74	0.138	0.138	99.882
200-230	62	0.118	0.118	100.000

Sieve Loss - 0.003 grams

Table 51

DATA FROM SIEVE ANALYSIS

Sample Number 56

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	3.592	3.593	3.593
6-8	2380	1.438	1.438	5.032
8-10	1651	1.907	1.908	6.939
10-14	1168	2.112	2.113	9.052
14-20	833	2.086	2.087	11.139
20-28	590	3.234	3.235	14.374
28-32	500	3.089	3.090	17.464
32-35	417	3.462	3.463	20.927
35-42	350	5.147	5.149	26.075
42-48	297	7.029	7.023	33.098
48-60	250	7.097	7.099	40.198
60-65	208	10.021	10.024	50.222
65-80	177	11.009	11.001	61.223
80-100	149	14.155	14.159	75.382
100-120	125	8.027	8.030	83.412
120-150	105	8.131	8.134	91.545
150-170	88	2.442	2.442	93.988
170-200	74	2.543	2.544	96.531
200-230	62	1.817	1.818	98.349
230-		1.632	1.633	100.000

Sieve Loss - 0.131 grams

Table 52

DATA FROM SIEVE ANALYSIS

Sample Number 59

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.173	0.173	0.173
6-8	2380	0.229	0.229	0.402
8-10	1651	0.283	0.283	0.685
10-14	1168	0.368	0.368	1.054
14-20	833	0.400	0.400	1.454
20-28	590	1.286	1.287	2.741
28-32	500	2.361	2.362	5.103
32-35	417	2.901	2.903	8.006
35-42	350	4.533	4.536	12.542
42-48	297	6.846	6.850	19.392
48-60	250	6.005	6.009	25.401
60-65	208	6.625	6.629	32.030
65-80	177	11.736	11.743	43.773
80-100	149	44.082	44.109	87.882
100-120	125	7.782	7.787	95.668
120-150	105	3.163	3.165	98.833
150-170	88	0.654	0.654	99.488
170-200	74	0.082	0.082	99.570
200-230	62	0.430	0.430	100.000

Sieve Loss - 0.161 grams

Table 53

DATA FROM SIEVE ANALYSIS

Sample Number 61

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6-8	2380	0.025	0.025	0.025
8-10	1651	0.190	0.190	0.215
10-14	1168	0.722	0.722	0.937
14-20	833	3.485	3.486	4.423
20-28	590	7.810	7.812	12.235
28-32	500	6.127	6.128	18.363
32-35	417	7.430	7.432	25.794
35-42	350	12.941	12.944	38.738
42-48	297	21.923	21.928	60.666
48-60	250	14.747	14.750	75.416
60-65	208	12.191	12.194	87.609
65-80	177	6.841	6.842	94.452
80-100	149	4.200	4.201	98.653
100-120	125	0.483	0.483	99.136
120-150	105	0.471	0.471	99.607
150-170	88	0.217	0.217	99.824
170-200	74	0.140	0.140	99.964
200-230	62	0.036	0.036	100.000

Sieve Loss - 0.121 grams

Table 54

DATA FROM SIEVE ANALYSIS

Sample Number 62

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	1.155	1.154	1.156
6-8	2380	0.060	0.060	1.216
8-10	1651	0.156	0.156	1.372
10-14	1168	0.148	0.148	1.520
14-20	833	0.211	0.211	1.731
20-28	590	0.250	0.250	1.981
28-32	500	0.284	0.284	2.266
32-35	417	0.620	0.620	2.886
35-42	350	1.694	1.695	4.581
42-48	297	4.866	4.869	9.450
48-60	250	4.934	4.937	14.388
60-65	208	7.720	7.725	22.113
65-80	177	10.946	10.953	33.067
80-100	149	17.516	17.528	50.594
100-120	125	6.738	6.743	57.337
120-150	105	17.724	17.736	75.073
150-170	88	9.479	9.486	84.559
170-200	74	5.334	5.338	89.896
200-230	62	10.097	10.104	100.000

Sieve Loss - 0.869

Table 55

DATA FROM SIEVE ANALYSIS

Sample Number 63

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
10-14	1168	0.042	0.042	0.042
14-20	833	0.228	0.228	0.270
20-28	590	0.587	0.587	0.857
28-32	500	3.928	3.930	4.787
32-35	417	7.516	7.519	12.306
35-42	350	17.806	17.813	30.119
42-48	297	29.796	29.808	59.926
48-60	250	16.666	16.673	76.599
60-65	208	10.847	10.851	87.450
65-80	177	5.026	5.028	92.478
80-100	149	3.427	3.428	95.906
100-120	125	0.976	0.976	96.883
120-150	105	0.996	0.996	97.879
150-170	88	0.744	0.744	98.623
170-200	74	0.535	0.535	99.159
200-230	62	0.841	0.841	100.000

Sieve Loss - 0.039 grams

Table 56

DATA FROM SIEVE ANALYSIS

Sample Number 64

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
10-14	1168	0.063	0.063	0.063
14-20	833	0.148	0.148	0.211
20-28	590	1.713	1.713	1.914
28-32	500	5.034	5.035	6.949
32-35	417	11.233	11.234	18.183
35-42	350	22.571	22.574	40.757
42-48	297	28.550	28.553	69.310
48-60	250	14.513	14.515	83.824
60-65	208	9.247	9.248	93.072
65-80	177	2.977	2.977	96.050
80-100	149	0.970	0.970	97.020
100-120	125	0.648	0.648	97.668
120-150	105	0.647	0.647	98.315
150-170	88	0.581	0.581	98.896
170-200	74	0.459	0.459	99.355
200-230	62	0.635	0.635	100.000

Sieve Loss - 0.011 grams

Table 57

DATA FROM SIEVE ANALYSIS

Sample Number 65

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
10-14	1168	0.092	0.092	0.092
14-20	833	0.257	0.257	0.349
20-28	590	1.744	1.744	2.094
28-32	500	4.303	4.304	6.398
32-35	417	8.991	8.993	15.391
35-42	350	21.394	21.297	36.790
42-48	297	30.759	30.766	67.556
48-60	250	15.747	15.751	83.306
60-65	208	7.134	7.136	90.442
65-80	177	2.153	2.154	92.595
80-100	149	1.737	1.737	94.333
100-120	125	1.478	1.478	95.811
120-150	105	1.449	1.449	97.260
150-170	88	0.755	0.755	98.016
170-200	74	0.866	0.866	98.882
200-230	62	1.118	1.118	100.000

Sieve Loss - 0.023 grams

Table 58

DATA FROM SIEVE ANALYSIS

Sample Number 66

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6-8	2380	0.032	0.032	0.032
8-10	1651	0.019	0.019	0.051
10-14	1168	0.123	0.123	0.174
14-20	833	0.391	0.391	0.565
20-28	590	3.269	3.269	3.834
28-32	500	6.382	6.383	10.217
32-35	417	11.554	11.555	21.772
35-42	350	21.834	21.836	43.609
42-48	297	26.443	26.446	70.055
48-60	250	11.339	11.340	81.395
60-65	208	6.898	6.899	88.294
65-80	177	2.791	2.791	91.085
80-100	149	3.005	3.005	94.090
100-120	125	1.878	1.878	95.969
120-150	105	2.172	2.172	98.141
150-170	88	0.903	0.903	99.044
170-200	74	0.471	0.471	99.515
200-230	62	0.485	0.485	100.000

Sieve Loss - 0.011 grams

Table 59

DATA FROM SIEVE ANALYSIS

Sample Number 67

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.008	0.008	0.008
10-14	1168	0.022	0.022	0.030
14-20	833	0.019	0.019	0.049
20-28	590	0.061	0.061	0.110
28-32	500	0.327	0.327	0.437
32-35	417	0.704	0.704	1.141
35-42	350	1.282	1.282	2.424
42-48	297	3.432	3.433	5.856
48-60	250	8.086	8.088	13.944
60-65	208	31.045	31.053	44.997
65-80	177	14.336	14.340	59.337
80-100	149	24.270	24.276	83.613
100-120	125	7.560	7.562	91.175
120-150	105	5.018	5.019	96.194
150-170	88	2.616	2.617	98.811
170-200	74	0.828	0.828	99.639
200-230	62	0.361	0.361	100.000

Sieve Loss - 0.025 grams

Table 60

DATA FROM SIEVE ANALYSIS

Sample Number 68

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
8-10	1651	0.069	0.069	0.069
10-14	1168	0.099	0.099	0.168
14-20	833	0.126	0.126	0.294
20-28	590	0.171	0.171	0.465
28-32	500	0.281	0.281	0.746
32-35	417	0.797	0.797	1.543
35-42	350	2.757	2.758	4.301
42-48	297	10.533	10.535	14.836
48-60	250	17.158	17.161	31.997
60-65	208	30.162	30.168	62.165
65-80	177	17.426	17.430	79.595
80-100	149	13.359	13.362	92.957
100-120	125	3.354	3.355	96.311
120-150	105	1.949	1.949	98.261
150-170	88	0.705	0.705	98.966
170-200	74	0.550	0.550	99.516
200-230	62	0.484	0.484	100.000

Sieve Loss - 0.020 grams

Table 61

DATA FROM SIEVE ANALYSIS

Sample Number 69

Tyler Sieve Sizes	Opening Microns	Weight Grams	Weight Percent	Cumulative Percent
6	3360	0.124	0.124	0.124
6-8	2380	0.135	0.135	0.259
8-10	1651	0.059	0.059	0.318
10-14	1168	0.060	0.060	0.378
14-20	833	0.073	0.073	0.451
20-28	590	0.147	0.147	0.598
28-32	500	0.156	0.156	0.754
32-35	417	0.247	0.247	1.001
35-42	350	0.719	0.719	1.720
42-48	297	1.439	1.439	3.160
48-60	250	1.033	1.033	4.193
60-65	208	0.878	0.878	5.071
65-80	177	0.906	0.906	5.978
80-100	149	10.914	10.917	16.894
100-120	125	37.149	37.160	54.055
120-150	105	32.613	32.623	86.678
150-170	88	8.983	8.986	95.664
170-200	74	1.686	1.637	97.300
200-230	62	2.456	2.457	100.000

Sieve Loss - 0.030 grams

STATISTICAL AND GRAPHICAL PRESENTATION

Two methods of presenting a statistical sedimentary analysis are discussed by Krumbein (1939). One of the earlier methods used is the practice of presenting data in terms of the original grade sizes used in the analysis. Histograms in this case are commonly used to illustrate the modal class, various grade sizes, and any irregularities in the distribution of sand from coarse to fine. A disadvantage to this method is that it is difficult to compare any two units mathematically.

A more recent method which is successfully used is that of considering the data in terms of continuous frequency distribution. The cumulative curve is usually employed, although frequency curves are equally applicable. By using the method of continuous frequency distribution, the mathematical results can be represented on isopleth maps and all data are suited to comparison.

<u>CUMULATIVE CURVE ANALYSIS</u> -- The cumulative curves, shown in Tables 63 to 123, represent the data obtained from the sieve analysis, and were constructed on semi-logarithmic paper to obtain direct geometric ratios. The diameter of the grains in millimeters are plotted logarithmetically on the horizontal axis and the cumulative weights of the grade sizes are plotted on the vertical axis in terms of arithmetic percentage. This method of graphic presentation is discussed by Krumbein (1938).

One who is familiar with cumulative curves may view them in the same descriptive light as histograms; however, they may also provide certain statistical values not available from histograms. The values most commonly used are the median, Md; the first and third quartiles, Q_1 and Q_3; and the 10th and 90th percentiles, P_{10} and P_{90}.

Percentile calculations obtained from the sieve analysis data are shown in Table 62.

<u>MEDIAN DIAMETER</u> -- The median diameter is that value obtained at the intersection of the 50 per cent line with the cumulative curve. This number may be defined as that value which represents a diameter larger than 50 per cent of the material and smaller than 50 per cent of the material. The first quartile is represented by the intersection of the 75 per cent line and the cumulative curve; the third quartile is determined by the intersection of the cumulative curve and the 25 per cent line. The ten percentile is found by the intersection of the curve and the 10 per cent line and the 90 percentile by the intersection of the curve and the 90 per cent line.

<u>SORTING</u> -- Trask (1930 discusses the relationship of quartile deviation, quartile skewness, and quartile kurtosis. Trask's quartile deviation of "sorting" is actually the measure of spread of the cumulative curve and may be expressed mathematically in three forms.

The arithmetic quartile deviation is expressed:

$$QDa = (Q_3 - Q_1)/2$$

Trask (1932 introduced a geometric sorting coefficient:

$$QDg = So = \sqrt{Q_1/Q_3}$$

This form is the most commonly used, although many students of statistics prefer not to use the 1st and 3rd quartiles on the basis that only 50 per cent of the curve is analyzed. In the analysis of the Saginaw Bay sands, the 16th and 84th percentiles were used, thus representing 68 per cent of the curve or approximately one standard deviation from the mean. Some investigators have used the 5th and 95th percentiles. Although this may represent more of the curve, often the curves tend to flatten in this range and inaccuracies occur.

It should be noted that the quartiles are reversed in the coefficient of sorting so that positive values are obtained. By using this method, "So" becomes a "factor" independent of size and units of measurement.

A third formula used for sorting is logarithmic, and may be expressed:

$$\log QDg = \log So = (\log Q_3 - \log Q_1)/2$$

Inasmuch as geometric values cannot be compared arithmetically, the logarithmic values of sorting are determined. Thus, as sorting increases geometrically, log sorting increases arithmetically.

SKEWNESS -- Skewness is a measure of the asymmetry of the curve or the departure of the quartile from the median.

Skewness may be expressed in three forms:

$$Ska = (Q_1 + Q_3 - 2Md)/2$$

$$Skg = \sqrt{Q_1 Q_3 / Md^2}$$

$$\log Skg = (\log Q_1 + \log Q_3 - 2 \log Md)/2$$

The size factor and the units of measurement are eliminated in the coefficient of geometric skewness. Twenhofel and Tyler (1941) noted that, "If the skewness is unity the mode coincides with the median diameter. If the skewness is greater than unity, the maximum sorting of the sediment lies on the fine side of the median diameter, if it is less than unity, on the coarse side, The further the value from unity, the further is the position of maximum sorting (mode) from the median diameter."

Values will necessarily range from less than one to greater than one. When expressing these values in terms of log Skg it is necessary to introduce log 10 Sk which is positive when skewness is greater than unity, and negative when skewness is less than unity.

KURTOSIS -- Kurtosis is a mathematical indicator of the spread of the central portion of the frequency curve with relation to the entire curve. It is commonly called a measure of the degree of peakedness of a curve. This relationship is similar to sorting in that a well sorted sediment

would be expected to form a more peaked curve than a poorly sorted one. It should be kept in mind that kurtosis values decrease with increasing peakedness. Kurtosis, derived by Kelley (1924), is generally expressed arithmetically only.

$$K_{qa} = (Q_3 - Q_1)/2(P_{10} - P_{90})$$

PHI SCALE -- The "phi" scale method developed by Krumbein (1936) consists of cumulated weight percentages plotted against the logarithmic values of the grain diameter to the -log base 2. By plotting grain diameters to the -log base 2 instead of to the base 10, each Wentworth class limit is an integer. Then by plotting the phi scale along the horizontal axis, increasing the values to the right, it is possible to show directly how many Wentworth grade scales are present between the different quartiles. A factor of zero phi is equal to 1.0 mm grain diameter in the Wentworth scale; the larger diameters are negative phi, and the smaller diameters positive.

Phi scales may be plotted on any type of graph paper which offers many advantages when illustrating sedimentary data. The conversion of phi to geometric values on the logarithmic scale to the base 10, and vice versa, is troublesome. Conversion charts by Krumbein (1936) and others facilitate this process somewhat.

Table 62

PERCENTILE CALCULATIONS FROM SIEVE ANALYSIS DATA

No.	P_{10}	P_{16}	Md	P_{84}	P_{90}	So_g	Log So	Sk_g	Log Sk	Kq_a
1	6.000	3.600	0.447	0.238	0.195	3.886	0.590	2.069	0.316	0.289
2	10.000	10.000	0.468	0.267	0.226	6.116	0.786	-	-	-
3	-	-	10.000	-	-	-	-	-	-	-
5	0.432	0.377	0.224	0.131	0.118	1.694	0.229	0.990	-0.004	0.392
6	0.279	0.253	0.180	0.137	0.121	1.356	0.122	1.030	0.013	0.367
7	0.110	0.092	0.076	0.010	0.010	3.033	0.482	0.391	-0.408	0.410
8	0.415	0.380	0.297	0.226	0.210	1.296	0.113	0.988	-0.005	0.376
9	1.050	0.830	0.405	0.224	0.208	1.844	0.266	1.063	6.027	0.360
10	4.270	1.050	0.335	0.195	0.164	2.319	0.365	1.352	0.131	0.104
11	6.000	2.320	0.340	0.224	0.190	3.209	0.506	2.117	0.326	0.180
12	0.379	0.324	0.245	0.176	0.168	1.356	0.132	0.975	-0.011	0.351
13	10.000	1.100	0.325	0.206	0.180	2.311	0.364	1.463	0.165	0.046
14	0.420	0.345	0.142	0.097	0.082	1.884	0.275	1.285	0.109	0.367
15	0.265	0.249	0.219	0.157	0.148	1.257	0.099	0.902	-0.045	0.393
16	0.083	0.092	0.046	0.013	0.010	2.659	0.425	0.775	-0.111	0.541
17	0.440	0.356	0.165	0.066	0.064	2.322	0.366	0.933	-0.030	0.386

Table 62, continued

PERCENTILE CALCULATIONS FROM SIEVE ANALYSIS DATA

No.	P_{10}	P_{16}	Md	P_{84}	P_{90}	So_g	Log So	Sk_g	Log Sk	Kq_a
18	9.800	6.400	0.400	0.270	0.230	4.868	0.687	2.828	0.451	0.320
19	8.400	0.940	0.350	0.235	0.200	2.000	0.301	1.342	0.128	0.043
21	10.000	-	1.690	0.315	0.263	-	-	-	-	-
22	0.510	0.440	0.280	0.173	0.150	1.594	0.202	0.987	-0.006	0.371
23	0.440	0.400	0.330	0.231	0.215	1.315	0.119	0.799	-0.097	0.376
24	0.412	0.360	0.285	0.203	0.185	1.330	0.124	0.949	-0.043	0.346
25	0.740	0.570	0.346	0.218	0.187	1.616	0.208	1.015	0.006	0.318
26	1.050	0.600	0.308	0.373	0.135	1.483	0.171	1.311	0.118	0.179
27	0.215	0.074	0.015	-	0.010	-	-	-	-	-
28	0.930	0.540	0.320	0.228	0.205	1.536	0.186	1.100	0.041	0.215
29	10.000	8.000	0.335	0.229	0.209	5.908	0.771	2.522	0.402	0.397
30	0.800	0.540	0.306	0.220	0.201	1.565	0.195	1.127	0.052	0.267
31	0.130	0.106	0.086	0.073	0.069	1.204	0.080	1.068	0.029	0.270
32	0.235	0.265	0,215	0.170	0.155	1.249	0.097	0.989	-0.005	0.594
33	0.266	0.245	0.205	0.172	0.160	1.192	0.076	1.000	0.000	0.344
34	0.350	0.320	0.250	0.208	0.197	1.241	0.094	1.030	0.013	0.366

Table 62, continued

PERCENTILE CALCULATIONS FROM SIEVE ANALYSIS DATA

No.	P_{10}	P_{16}	Md	P_{84}	P_{90}	So_g	Log So	Sk_g	Log Sk	Kq_a
35	0.485	0.422	0.302	0.212	0.190	1.411	0.150	0.989	-0.005	0.356
36	10.000	8.600	0.390	0.260	0.240	5.745	0.759	2.170	0.336	0.427
37	0.275	0.220	0.144	0.122	0.116	1.342	0.128	1.131	0.053	0.308
38	-	-	0.320	0.120	0.101	-	-	-	-	-
39	0.500	0.440	0.350	0.395	0.278	1.221	0.087	1.030	0.013	0.327
41	0.138	0.129	0.086	0.016	0.010	2.839	0.453	0.535	-0.272	0.441
42	0.500	0.440	0.305	0.215	0.184	1.428	0.155	1.010	0.004	0.356
43	0.538	0.440	0.316	0.224	0.200	1.400	0.146	0.995	-0.002	0.320
45	0.340	0.295	0.215	0.155	0.140	1.378	0.139	1.000	0.000	0.350
46	0.360	0.319	0.200	0.075	0.070	2.062	0.314	0.773	-0.112	0.421
47	0.410	0.368	0.255	0.174	0.150	1.456	0.163	0.992	-0.003	0.373
49	3.600	2.550	0.548	0.263	0.210	3.114	0.493	1.497	0.175	0.343
50	0.345	0.300	0.092	0.072	0.068	2.042	0.310	1.643	0.216	0.412
51	0.430	0.360	0.256	0.176	0.158	1.432	0.156	0.977	-0.010	0.338
52	0.442	0.410	0.340	0.248	0.219	1.285	0.109	0.938	-0.028	0.363
53	0.460	0.419	0.340	0.265	0.243	1.257	0.099	0.978	-0.010	0.438

Table 62, continued

PERCENTILE CALCULATIONS FROM SIEVE ANALYSIS

No.	P_{10}	P_{16}	Md	P_{84}	P_{90}	So_g	Log So	Sk_g	Log Sk	Kq_a
54	0.380	0.365	0.337	0.217	0.180	1.296	0.113	0.832	-0.080	0.370
55	9.200	7.900	0.400	0.228	0.210	5.967	0.776	3.536	0.549	0.427
56	1.000	0.540	0.206	0.124	0.109	2.086	0.319	1.261	0.101	0.233
59	0.391	0.320	0.166	0.148	0.137	1.470	0.164	1.292	0.111	0.339
61	0.640	0.524	0.331	0.220	0.196	1.543	0.188	0.025	0.011	0.342
62	0.289	0.237	0.145	0.090	0.073	1.622	0.210	1.000	0.000	0.340
63	0.438	0.400	0.310	0.220	0.190	1.349	0.130	0.958	-0.019	0.363
64	0.470	0.430	0.334	0.246	0.220	1.323	0.122	0.972	-0.012	0.368
65	0.450	0.410	0.328	0.240	0.205	1.308	0.117	0.952	-0.021	0.347
66	0.500	0.450	0.343	0.235	0.190	1.386	0.142	0.948	-0.023	0.347
67	0.264	0.241	0.202	0.144	0.124	1.292	0.111	0.910	-0.041	0.346
68	0.320	0.290	0.219	0.166	0.151	1.319	0.120	1.000	0.000	0.367
69	0.205	0.176	0.148	0.126	0.117	1.179	0.072	1.000	0.000	0.284

Table 63

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 1

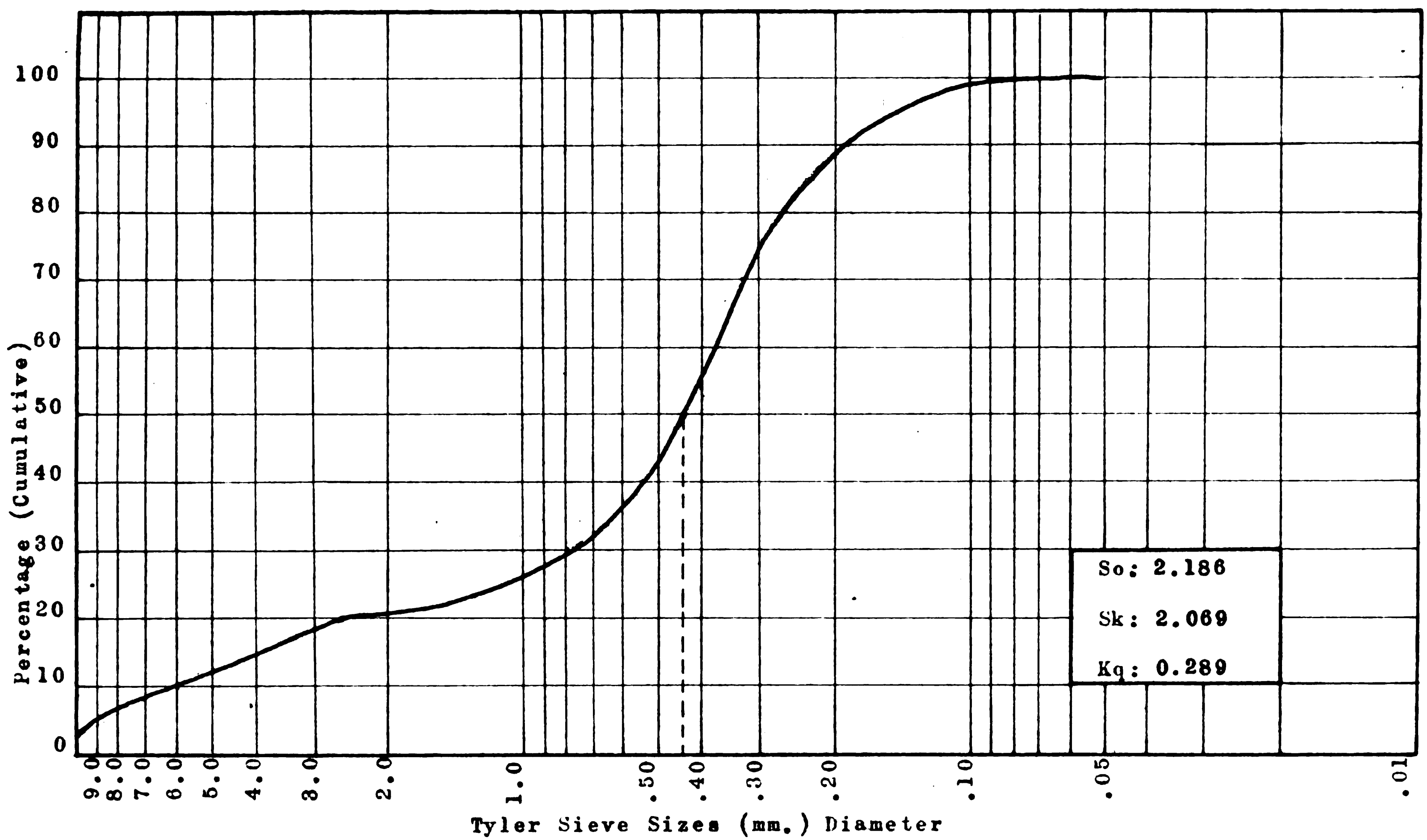


Table 64

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 2

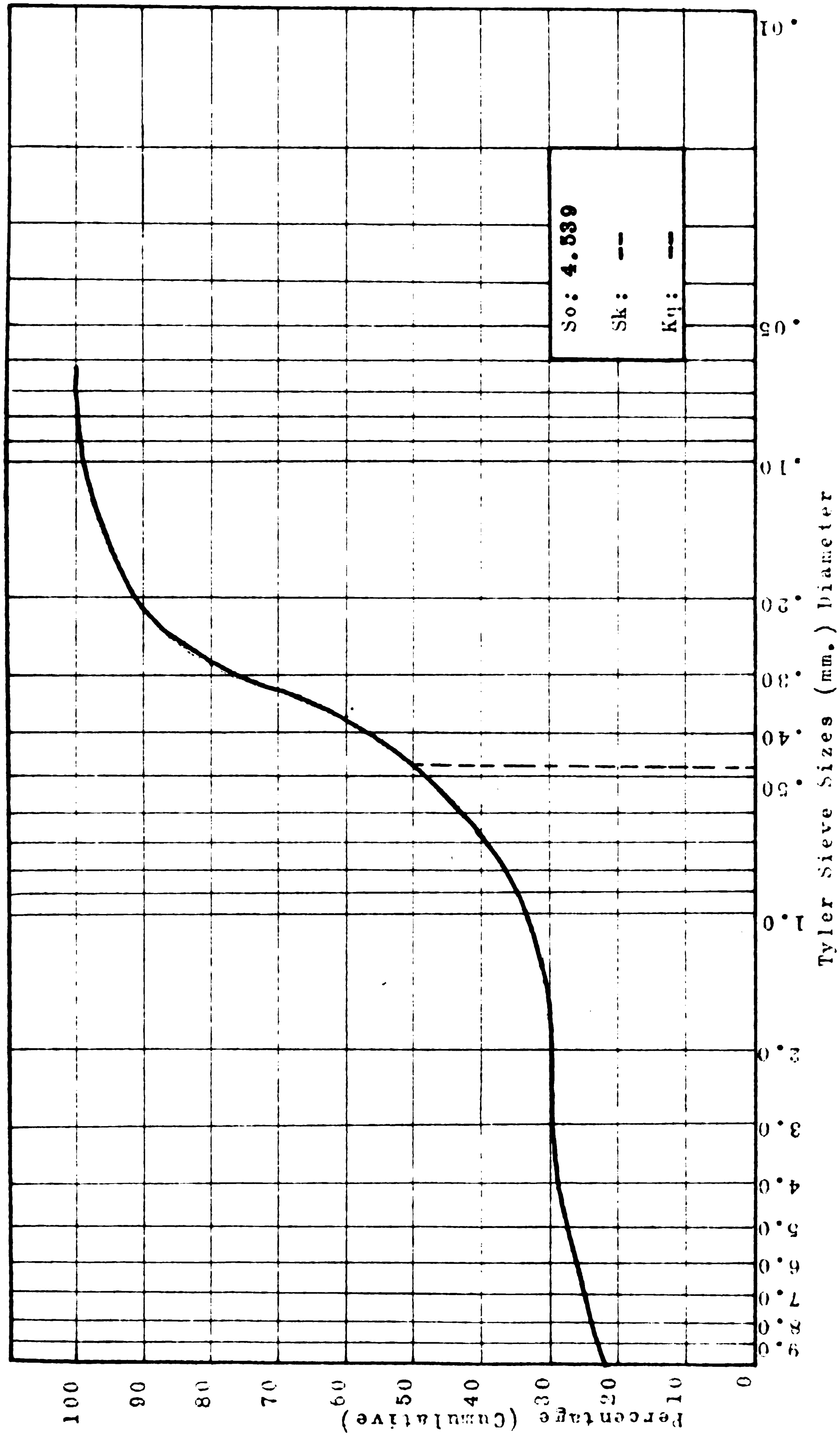


Table 65

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 3

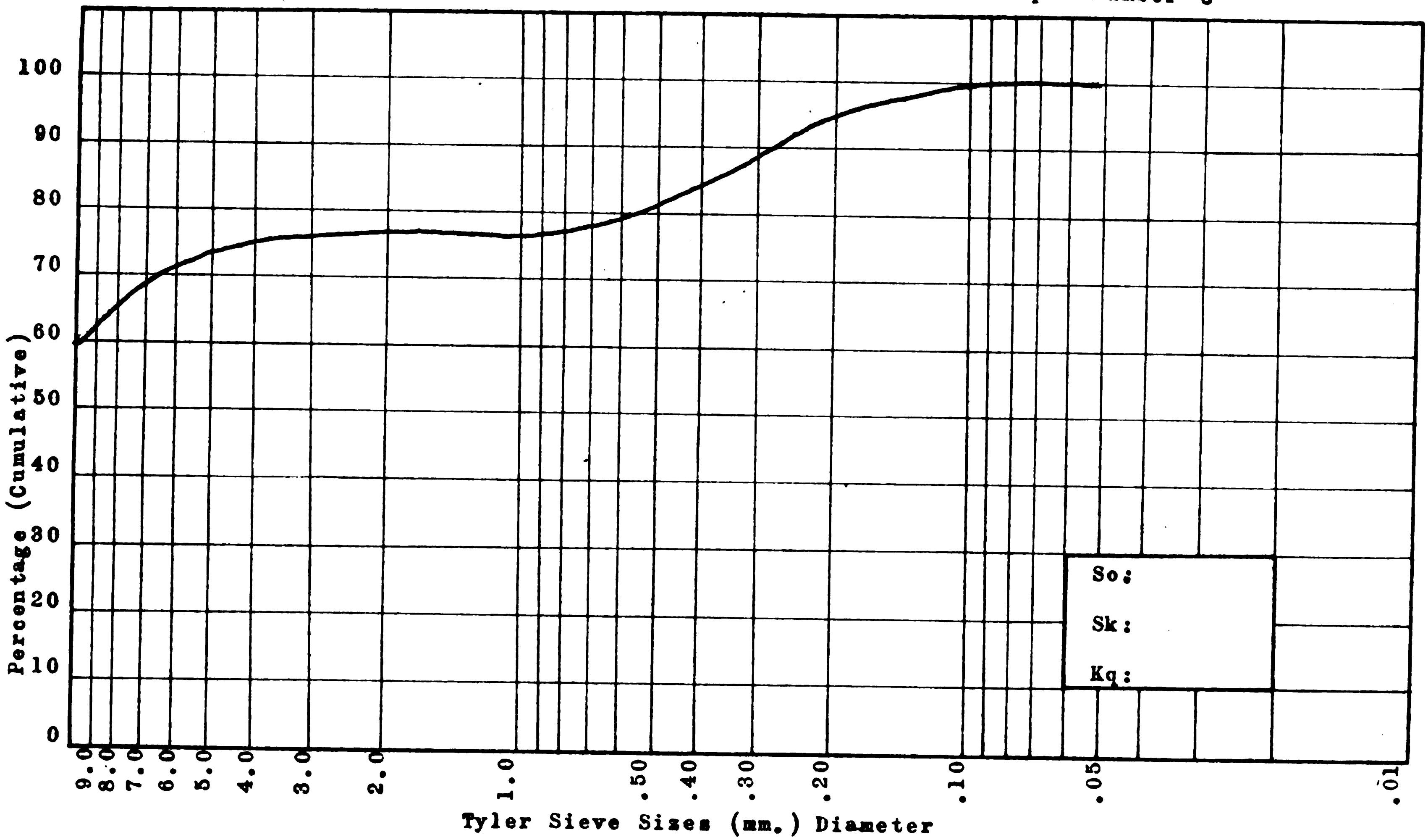


Table 66

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 5

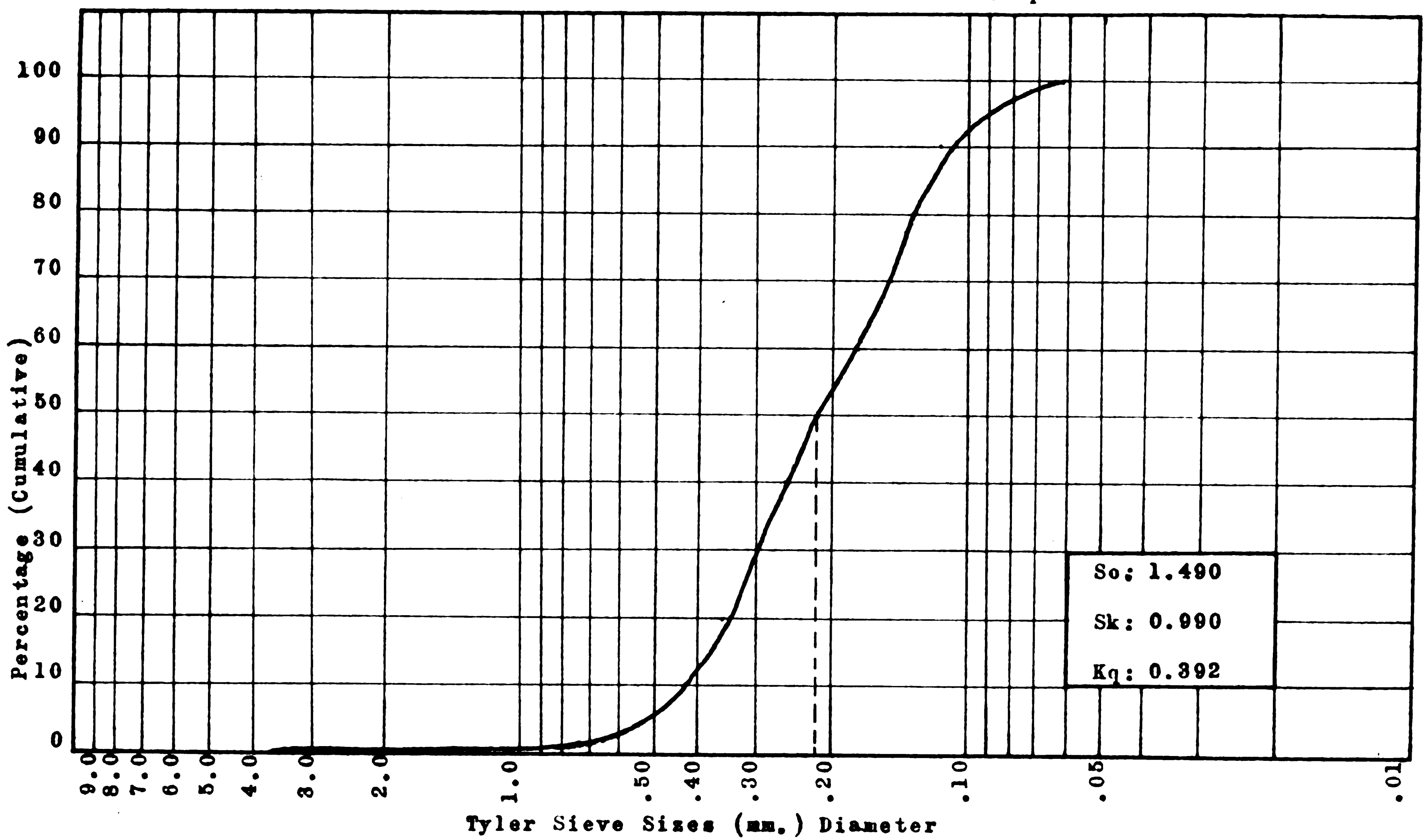


Table 67

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 6

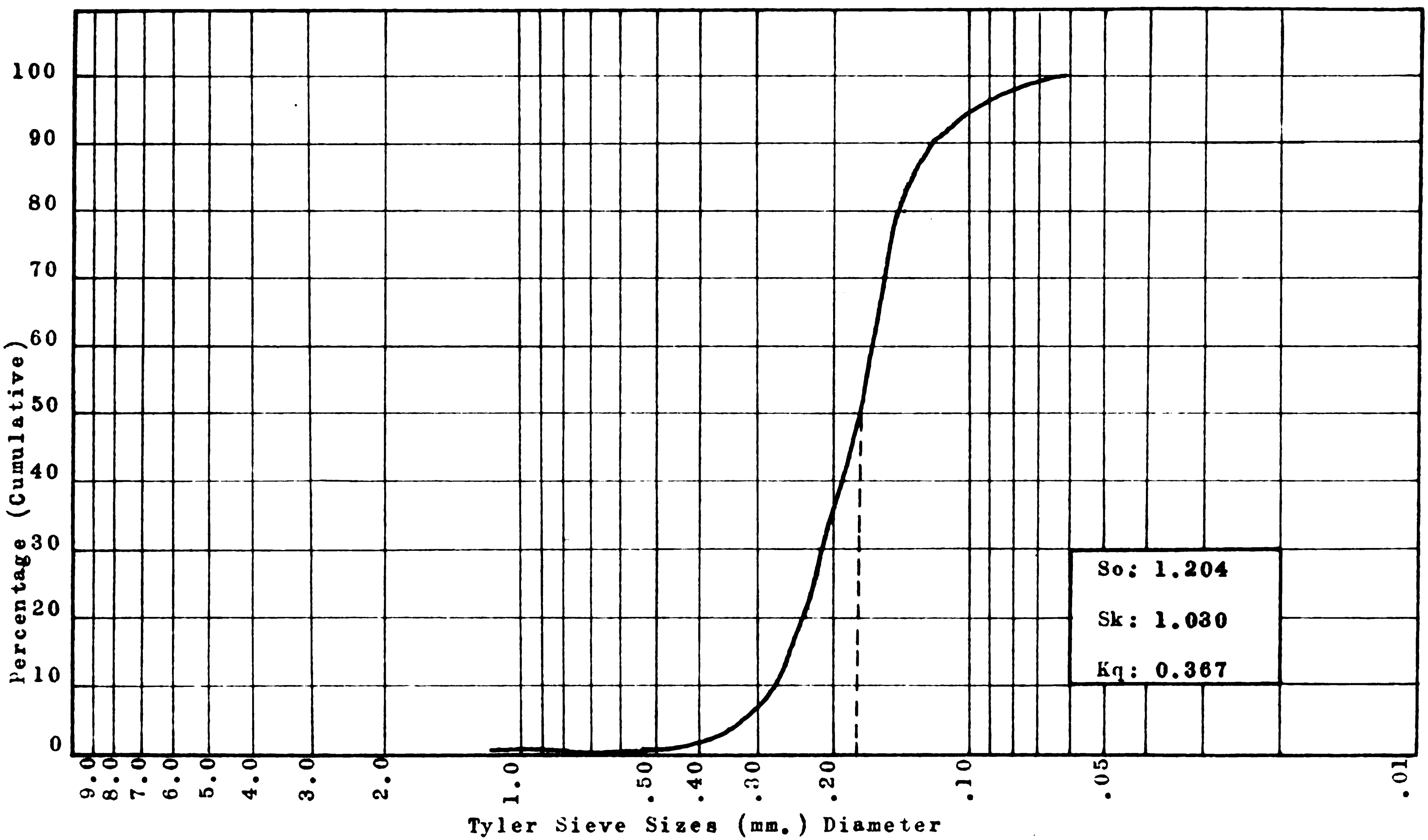


Table 68

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 7

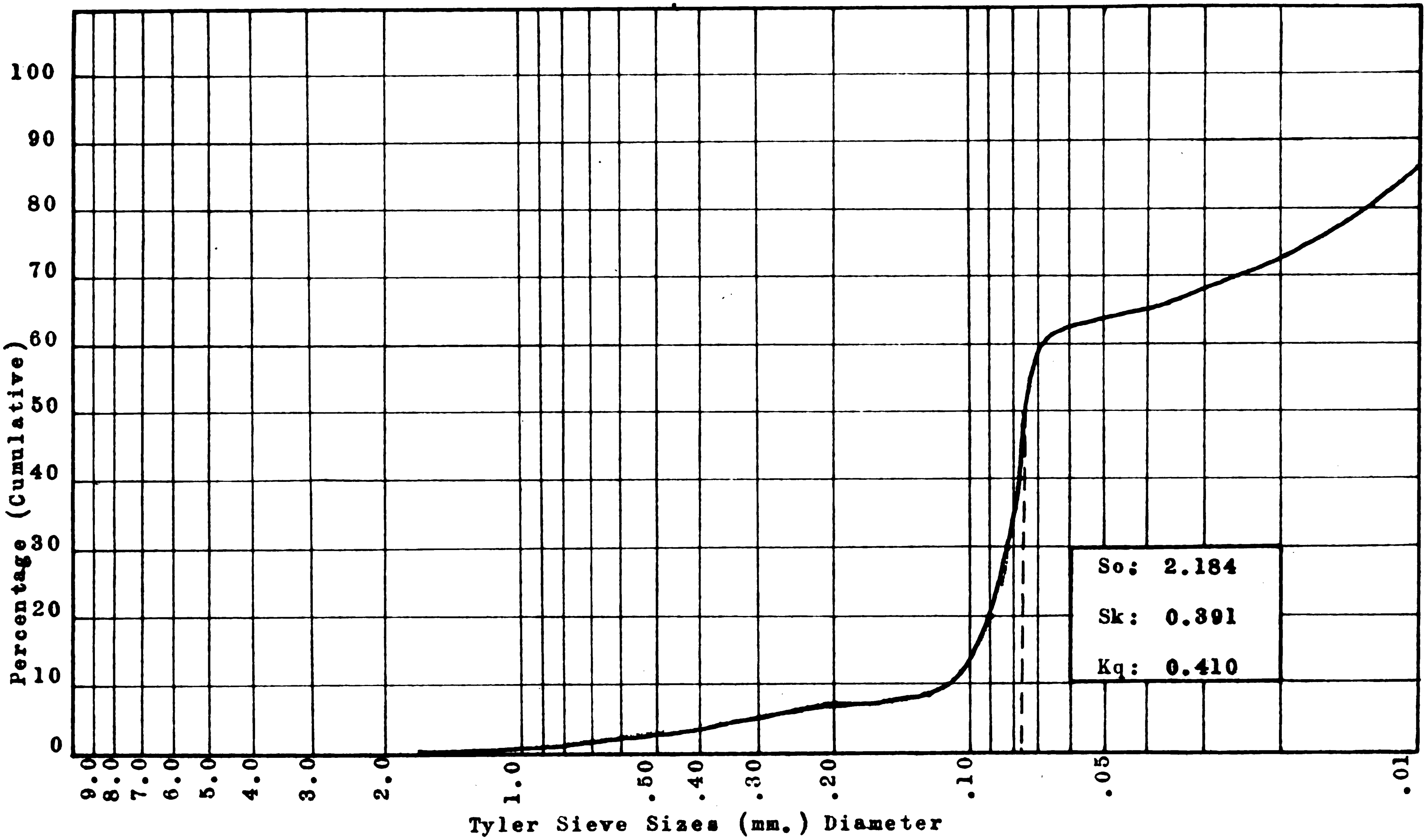


Table 69

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 8

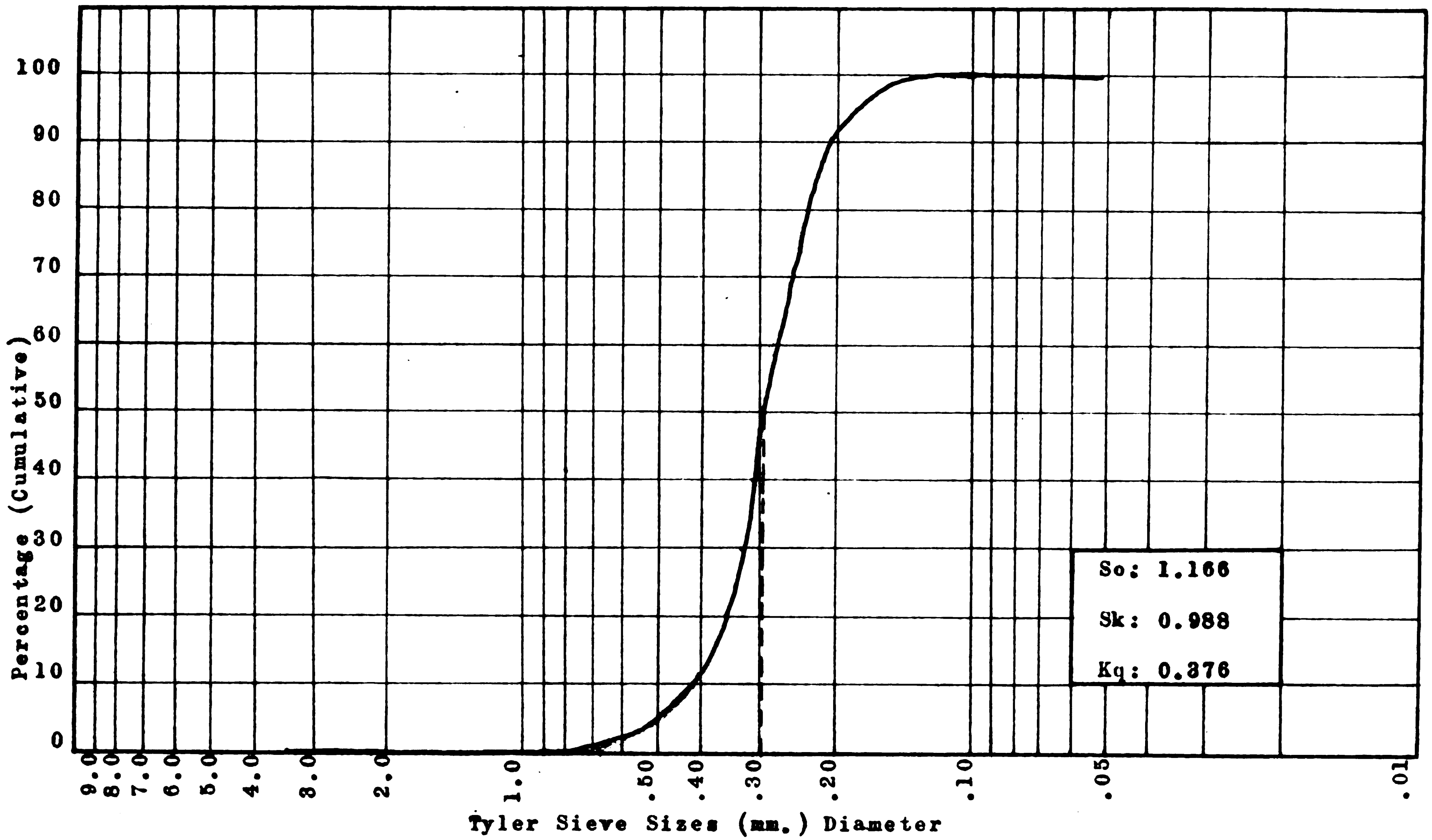


Table 70

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 9

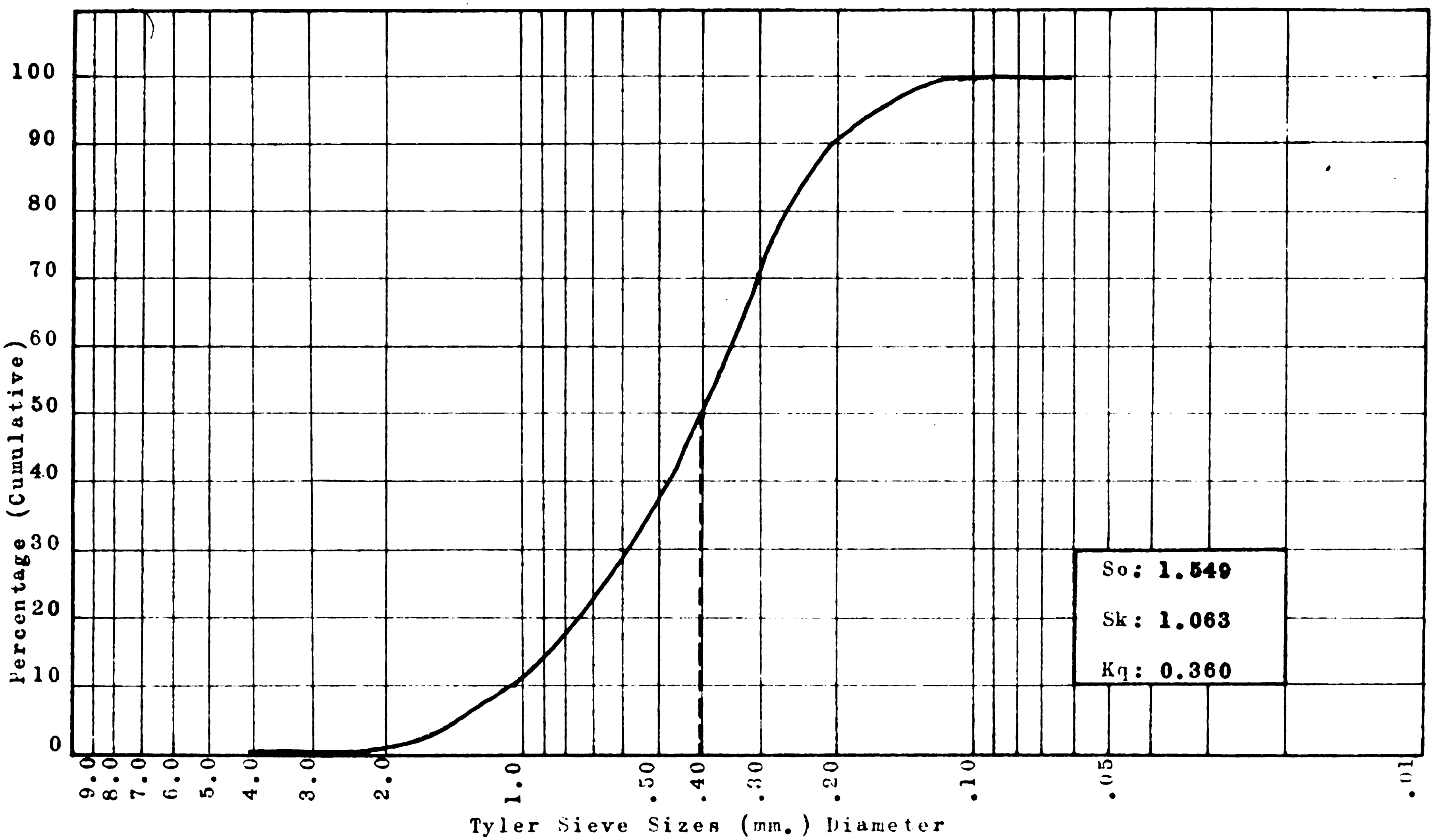


Table 71

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 10

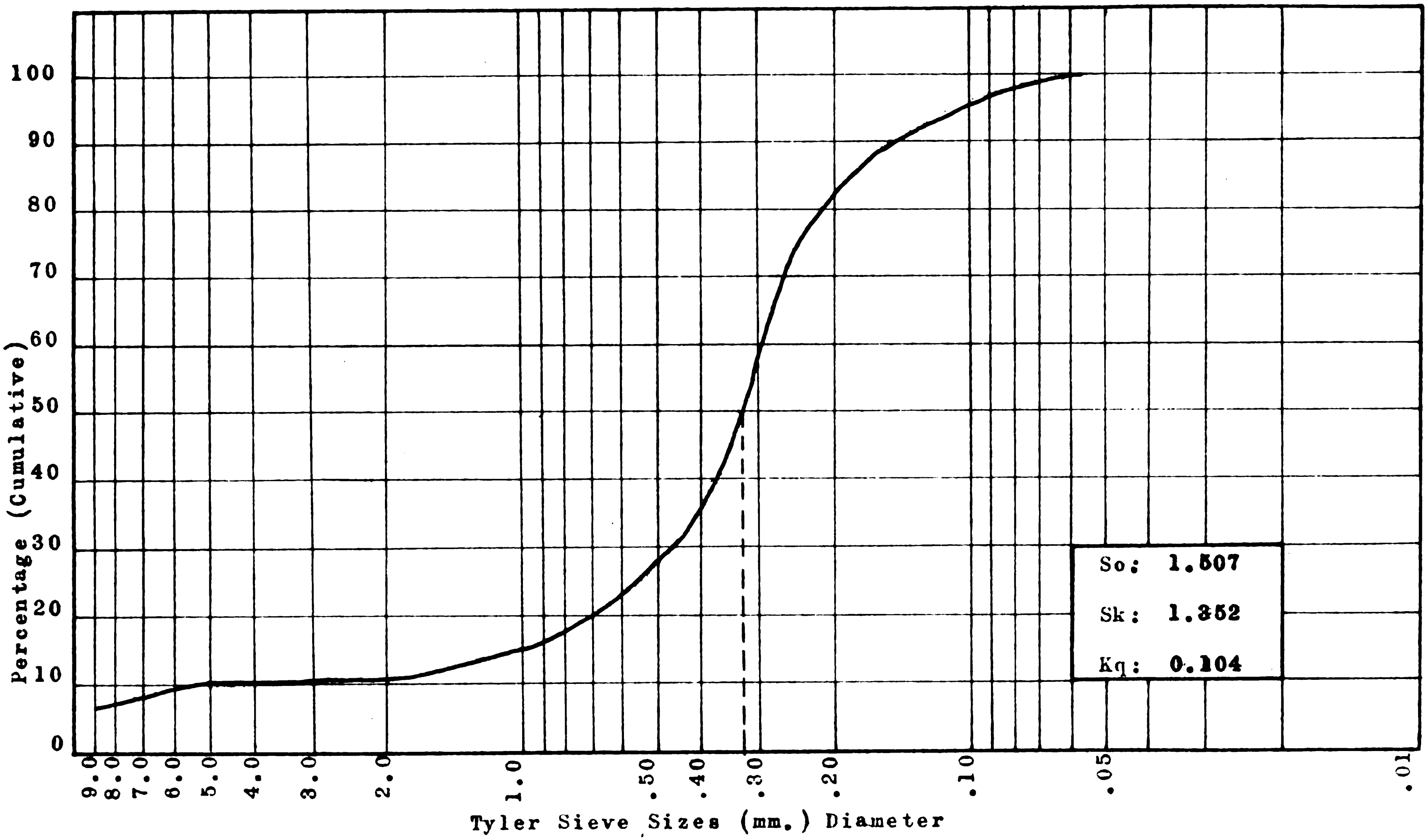


Table 72

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 11

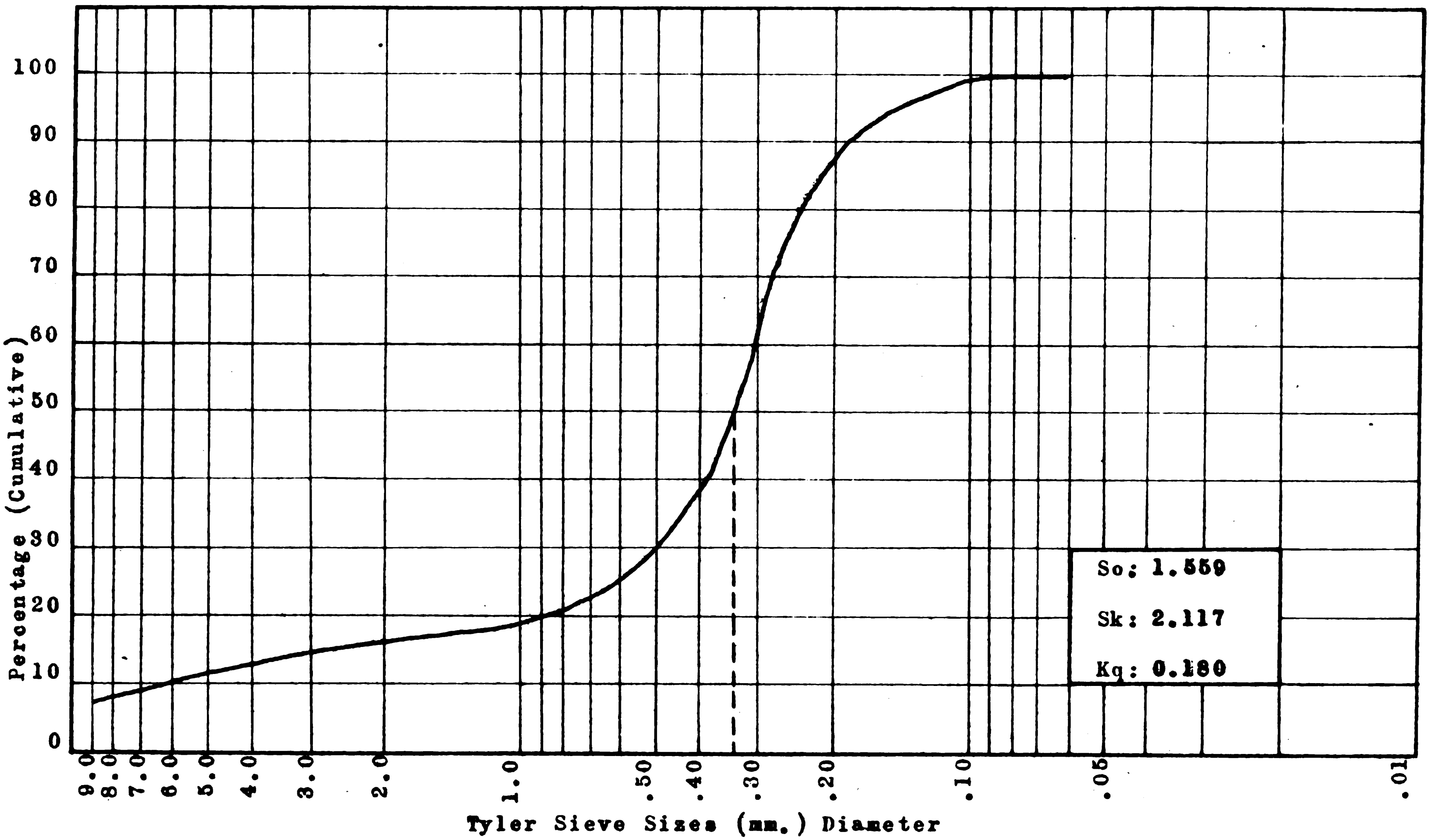


Table 73

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 12

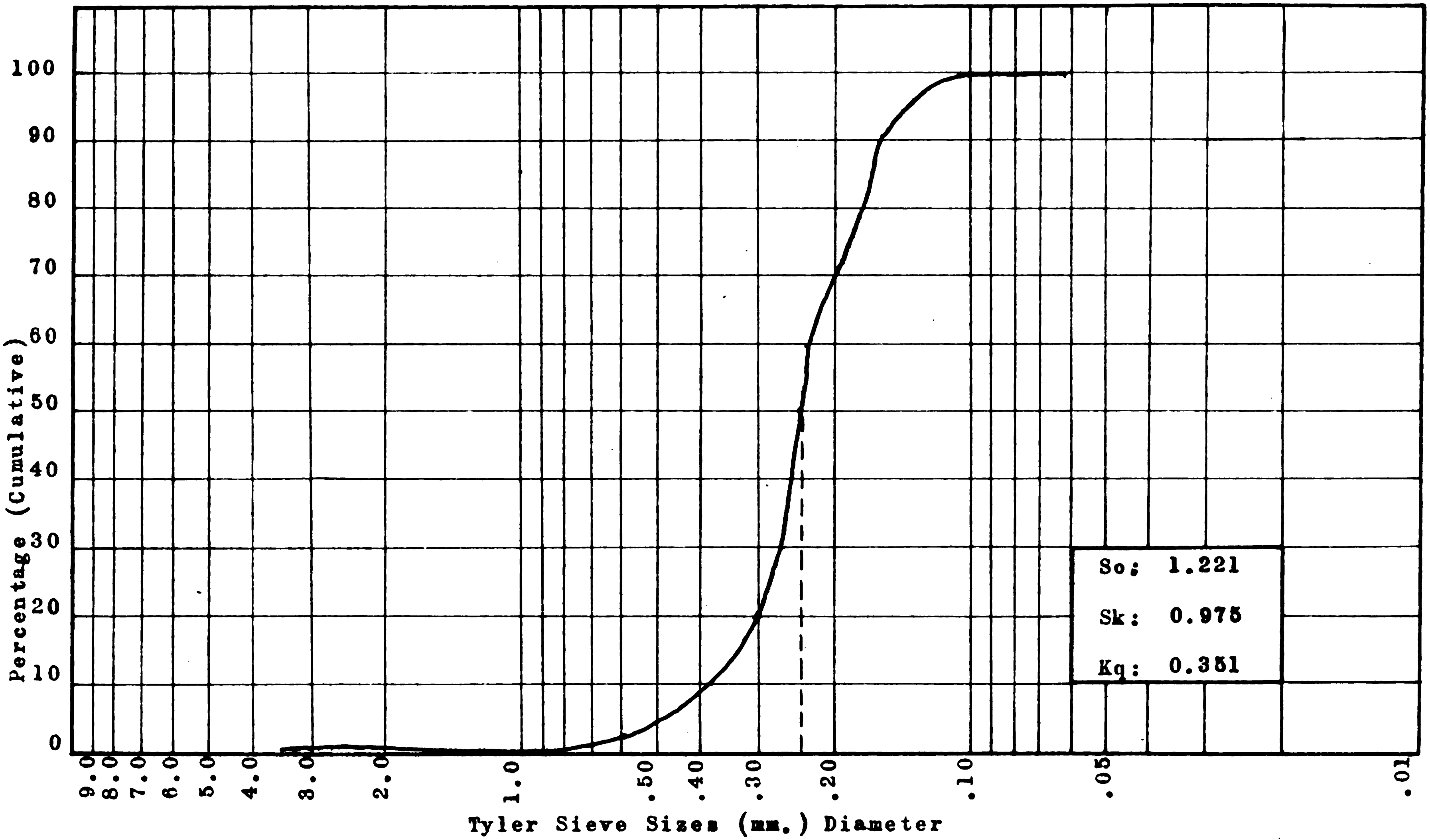


Table 74

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 13

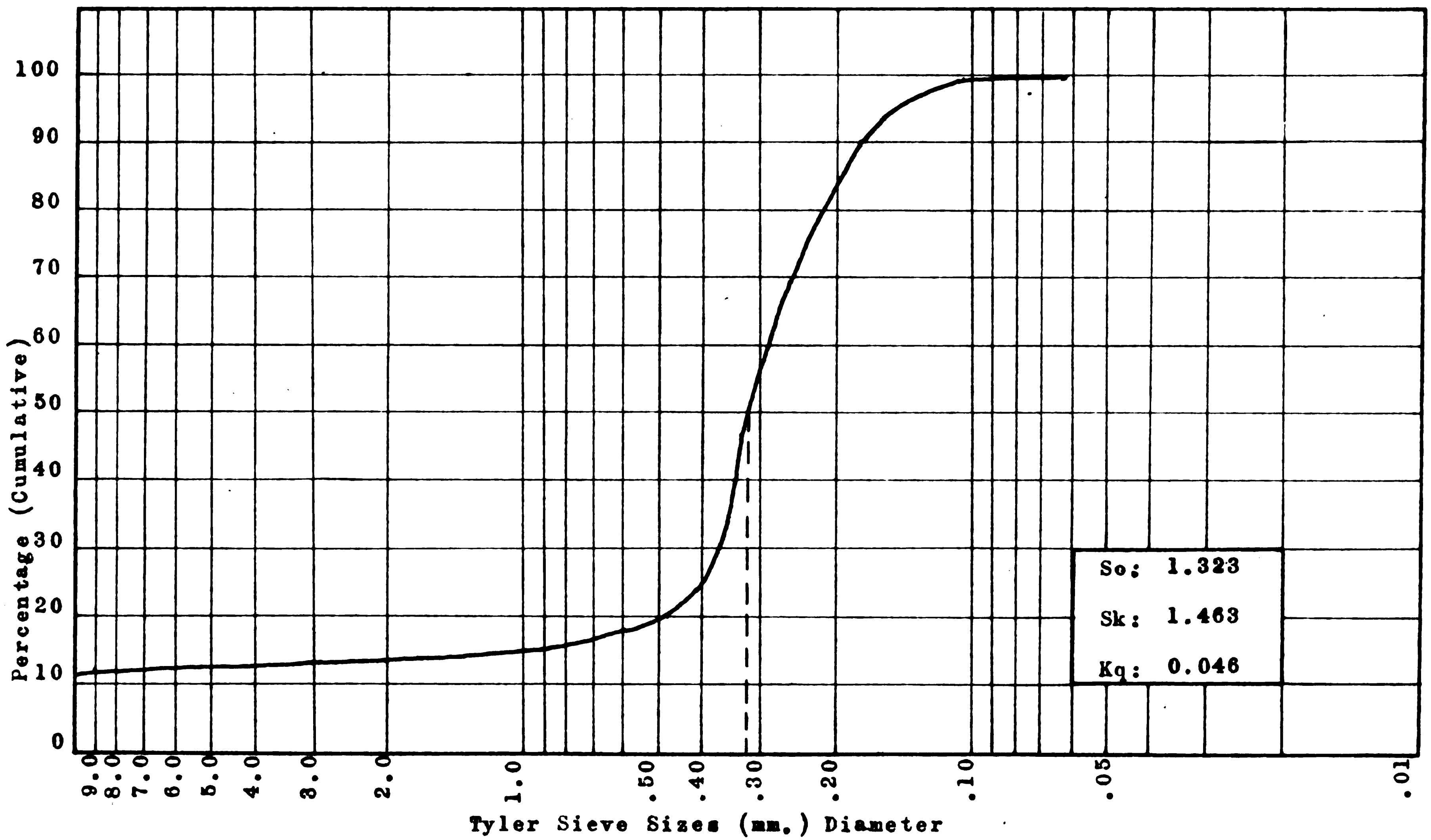


Table 75

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 14

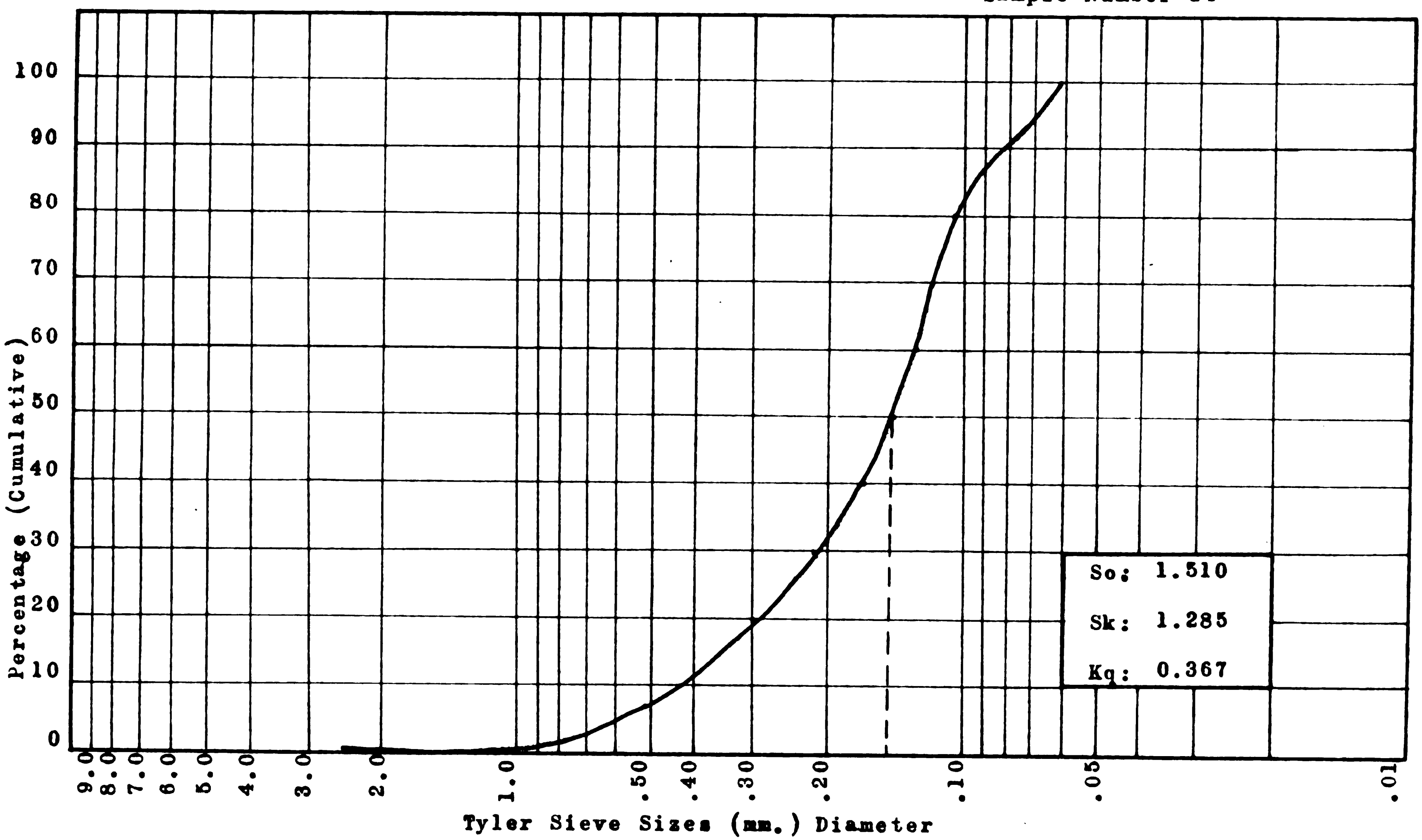


Table 76

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 15

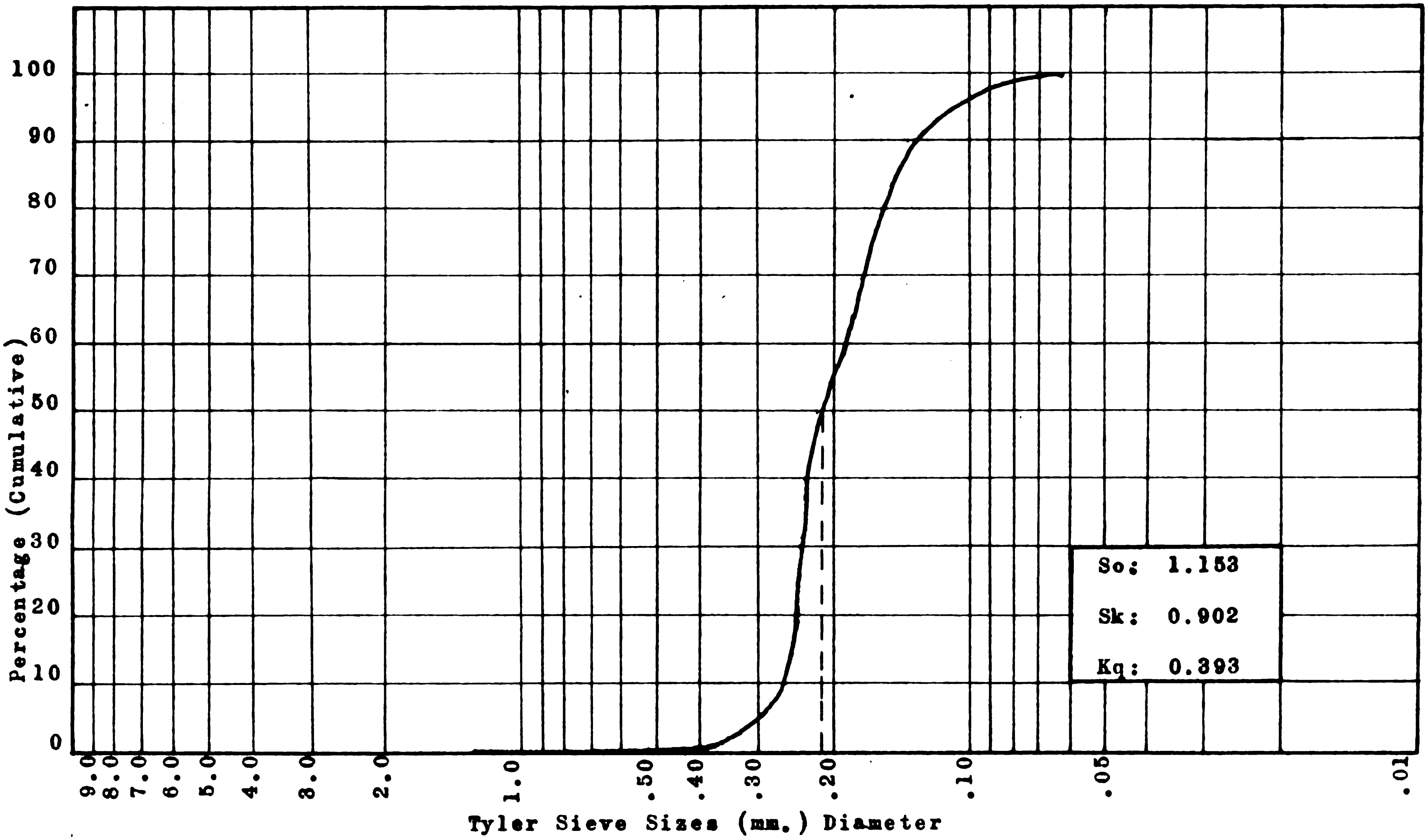


Table 77

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 16

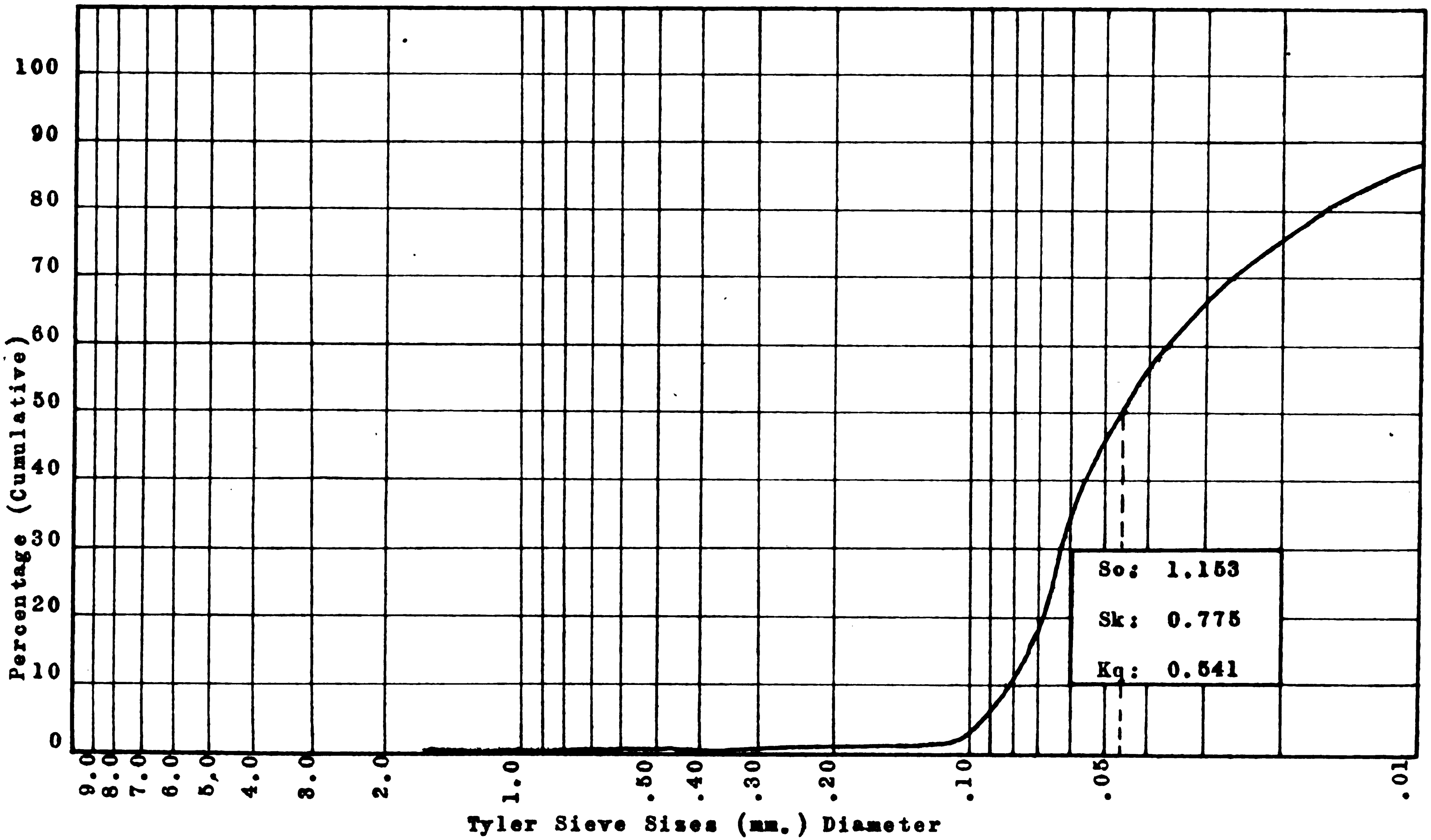


Table 78

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 17

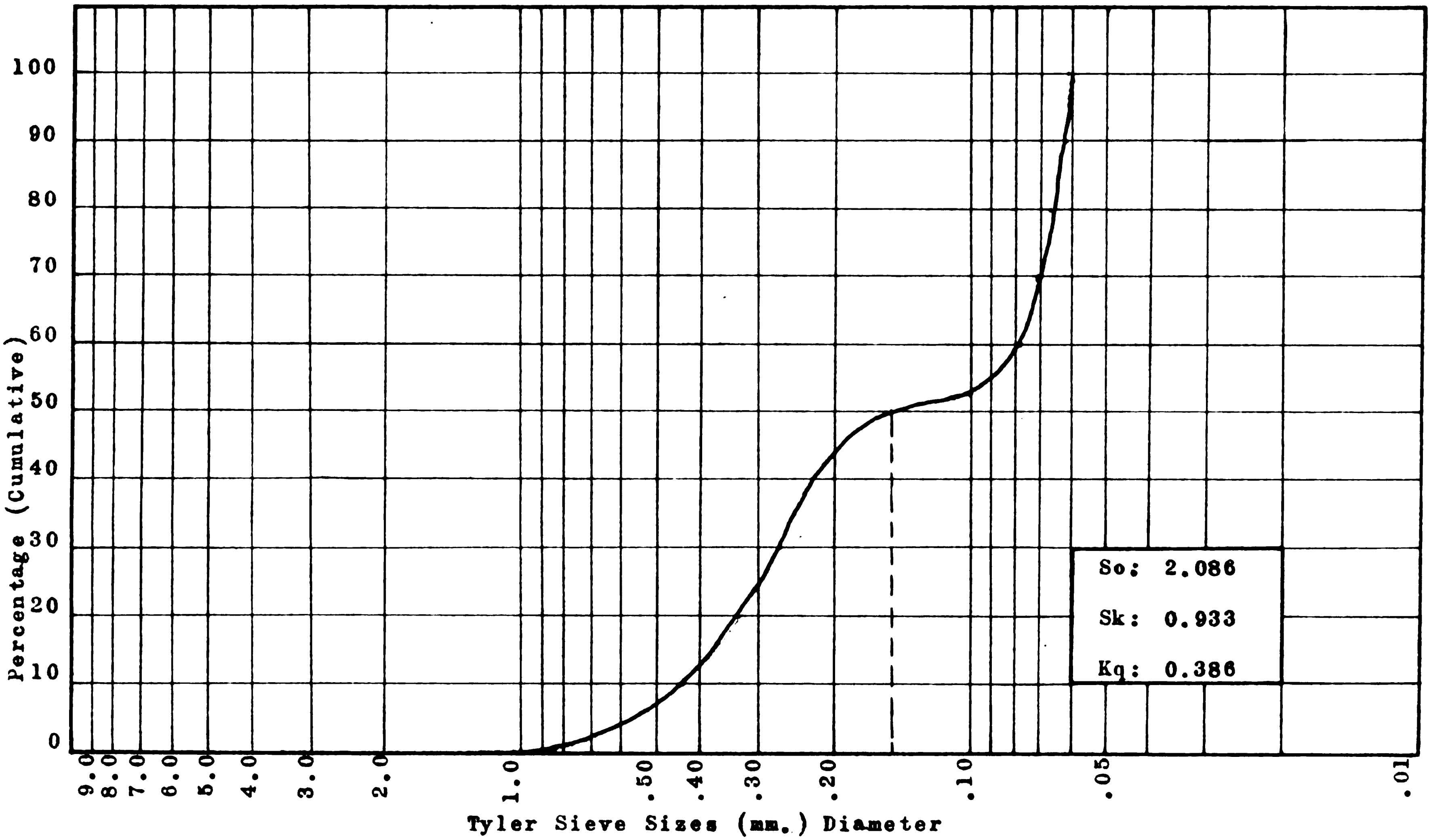


Table 79

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 18

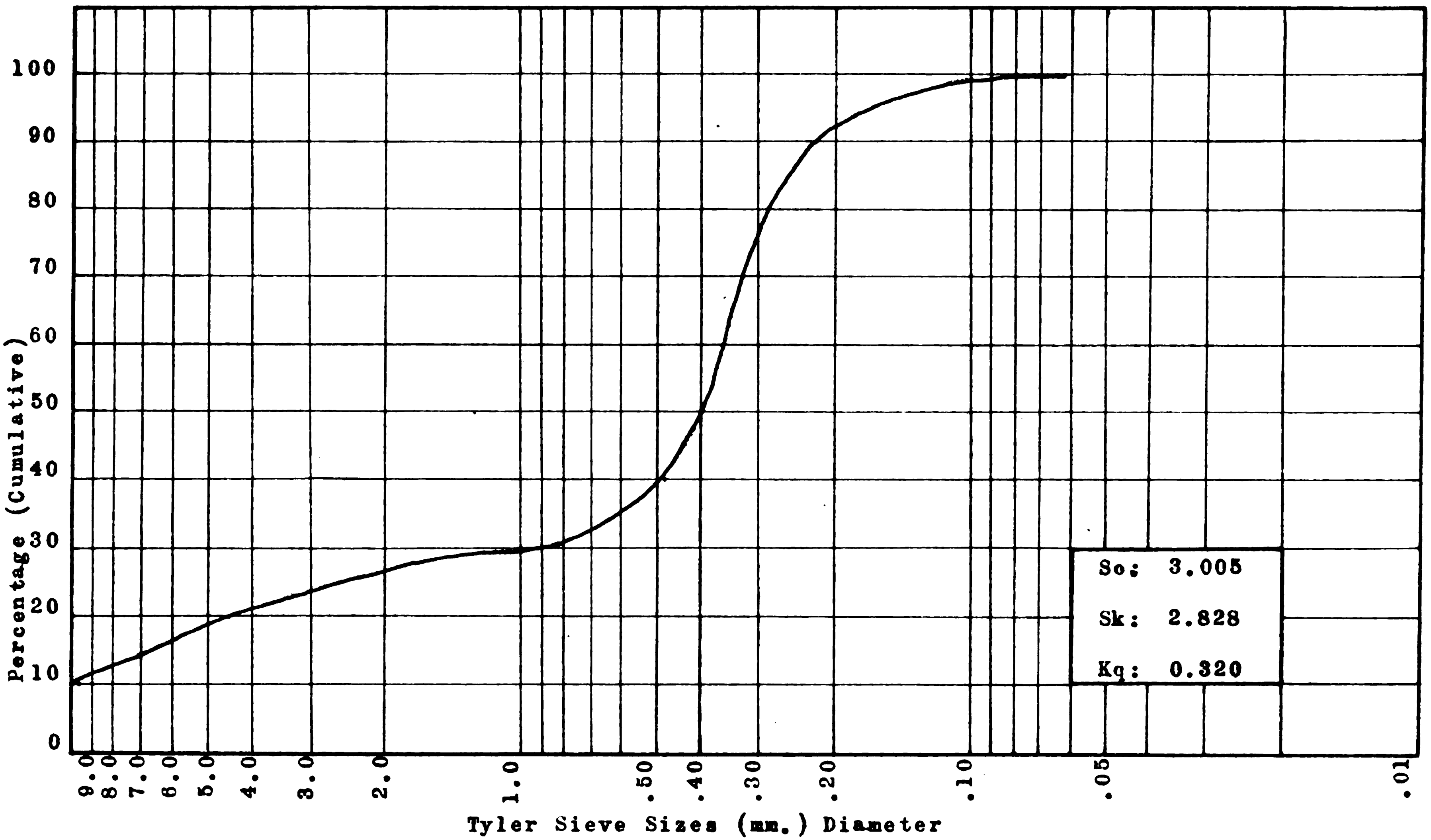


Table 80

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 19

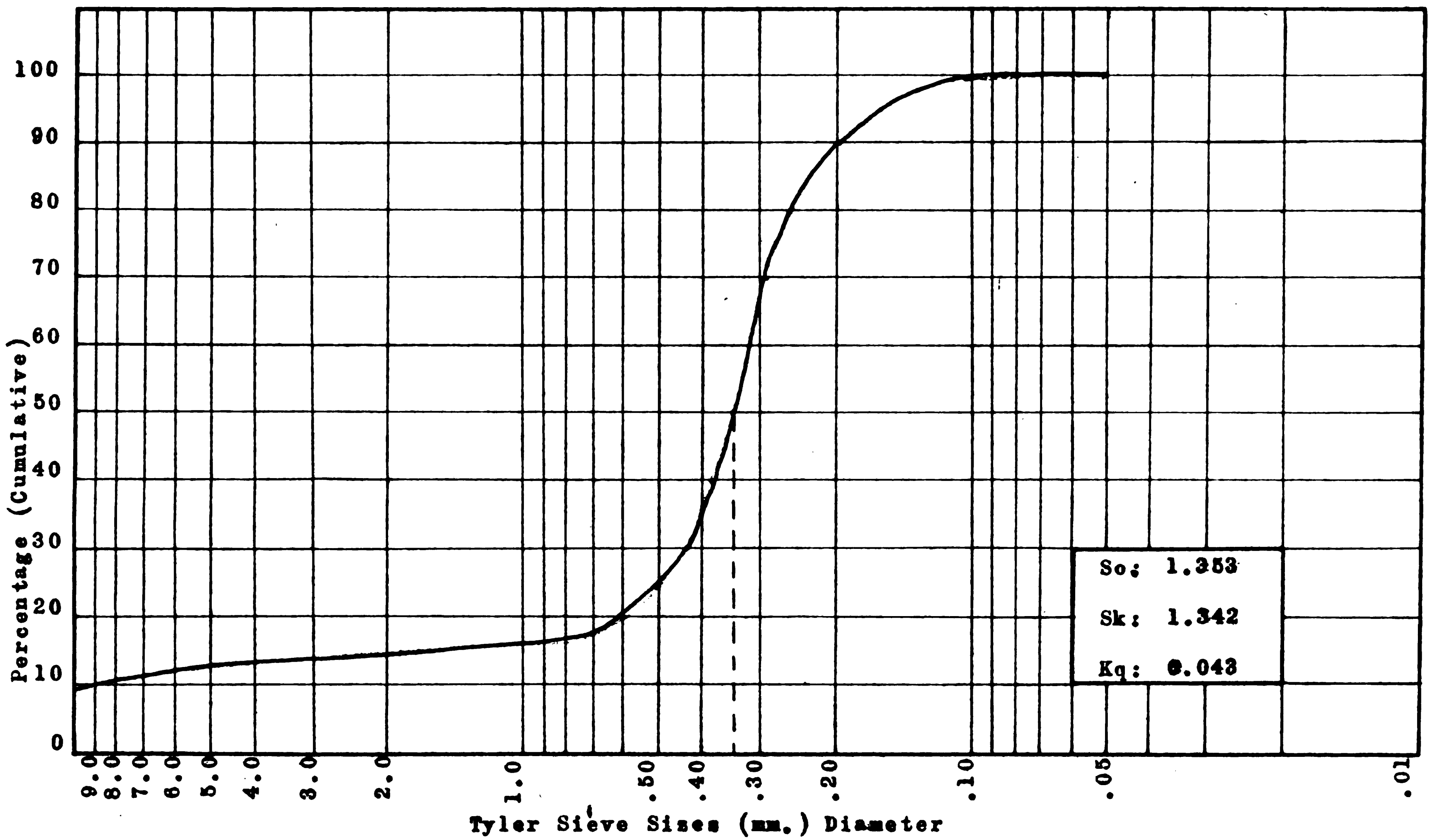
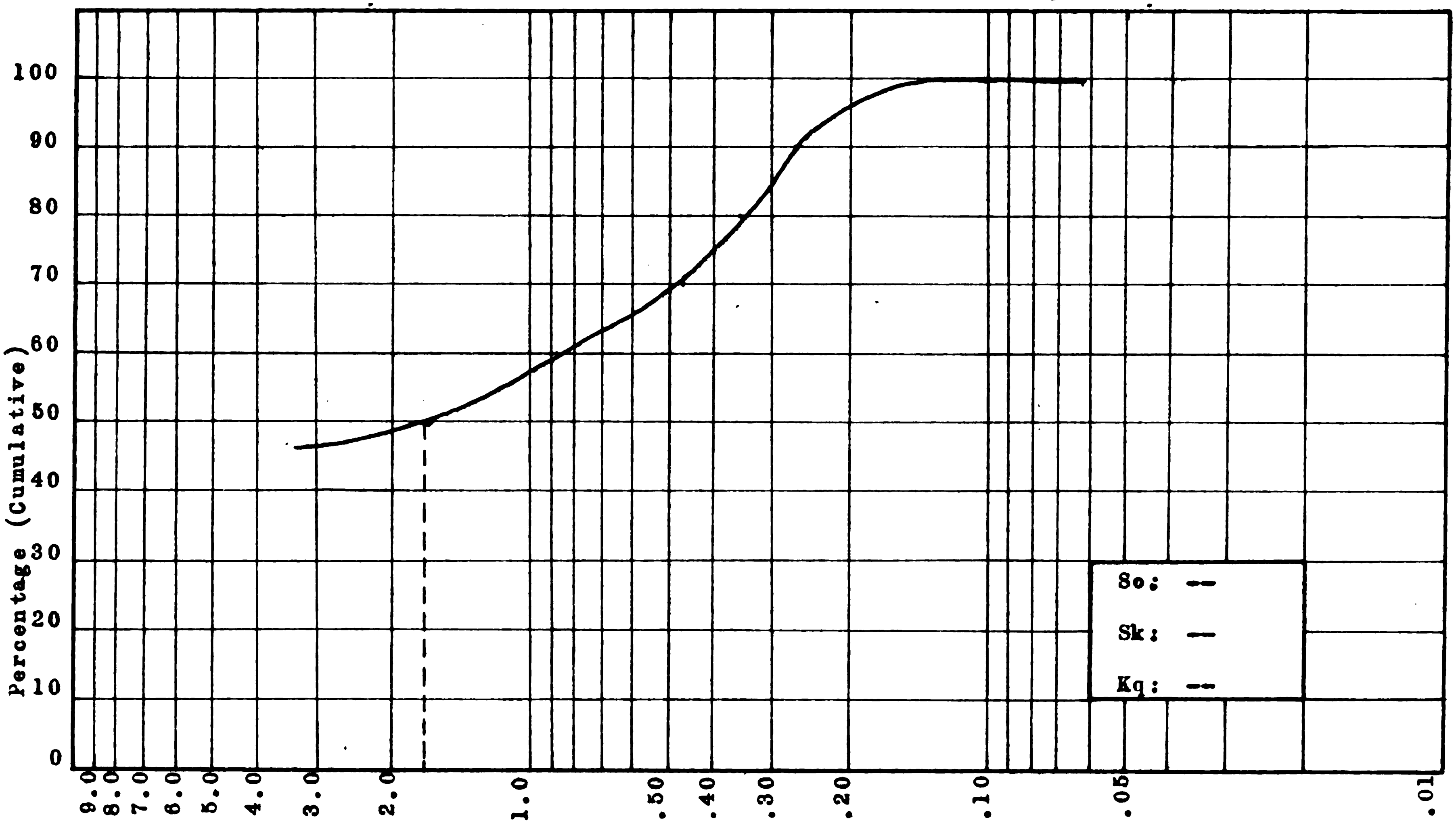


Table 81

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 21



Tyler Sieve Sizes (mm.) Diameter

Table 82

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 22

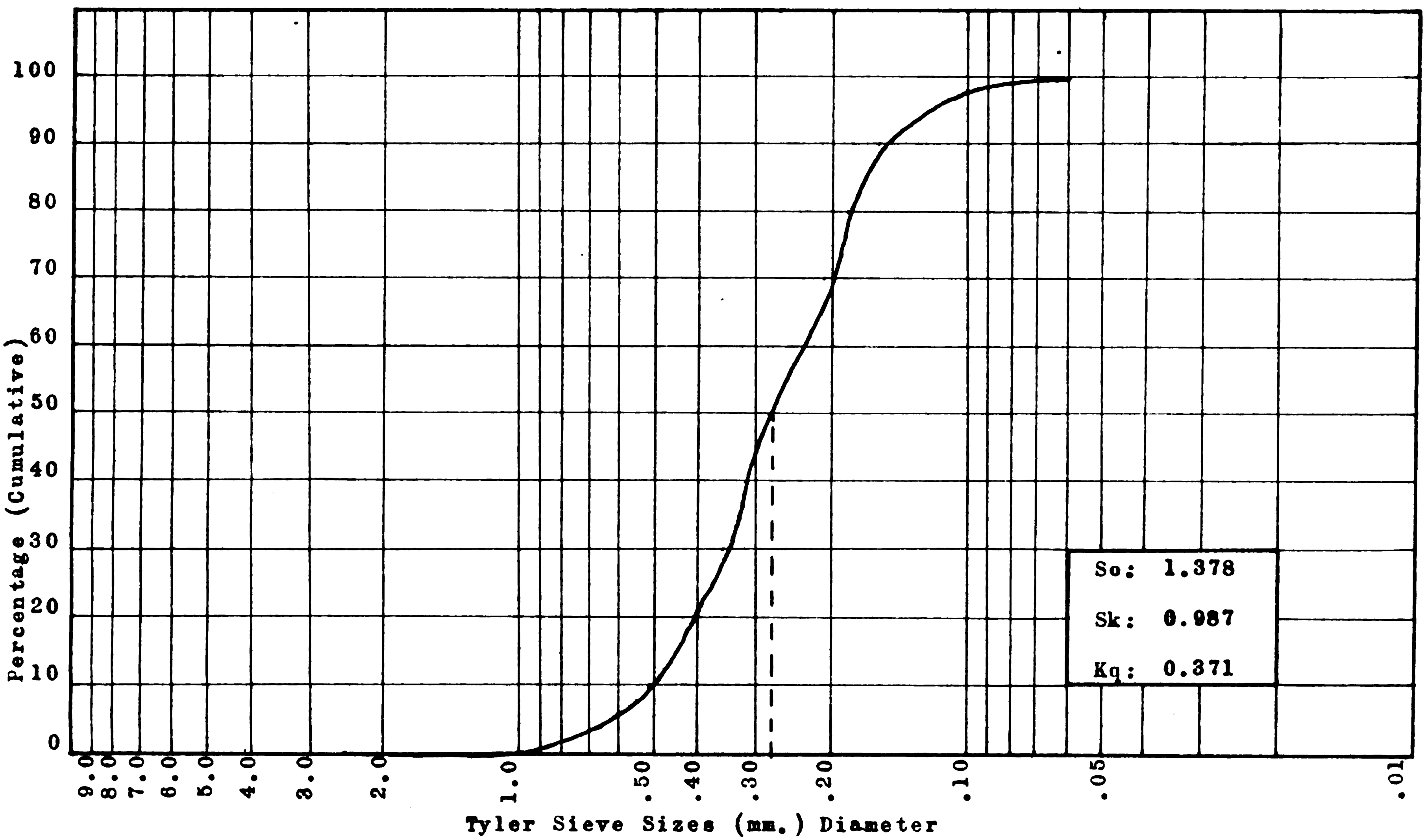


Table 83

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 23

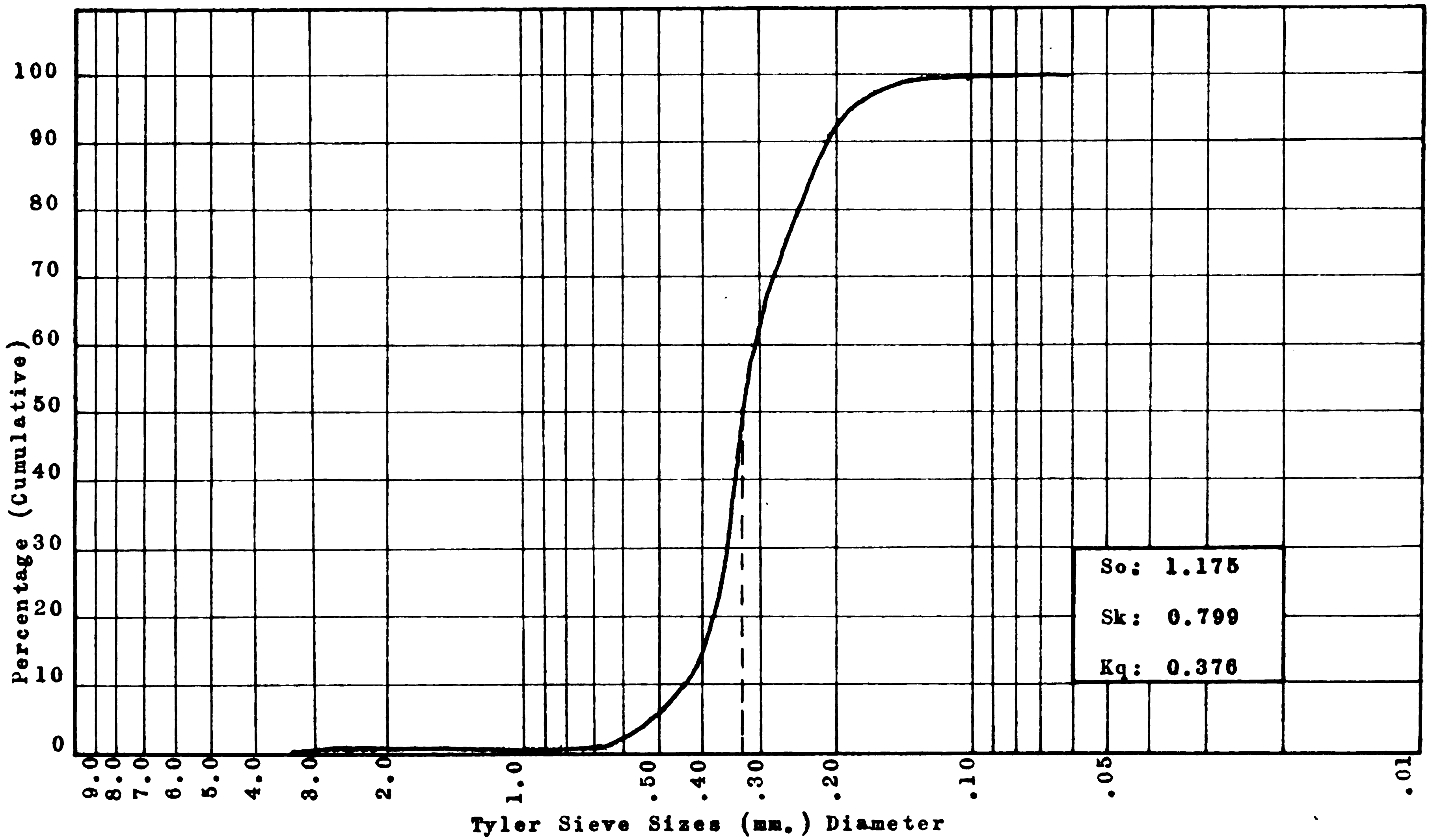


Table 84

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 24

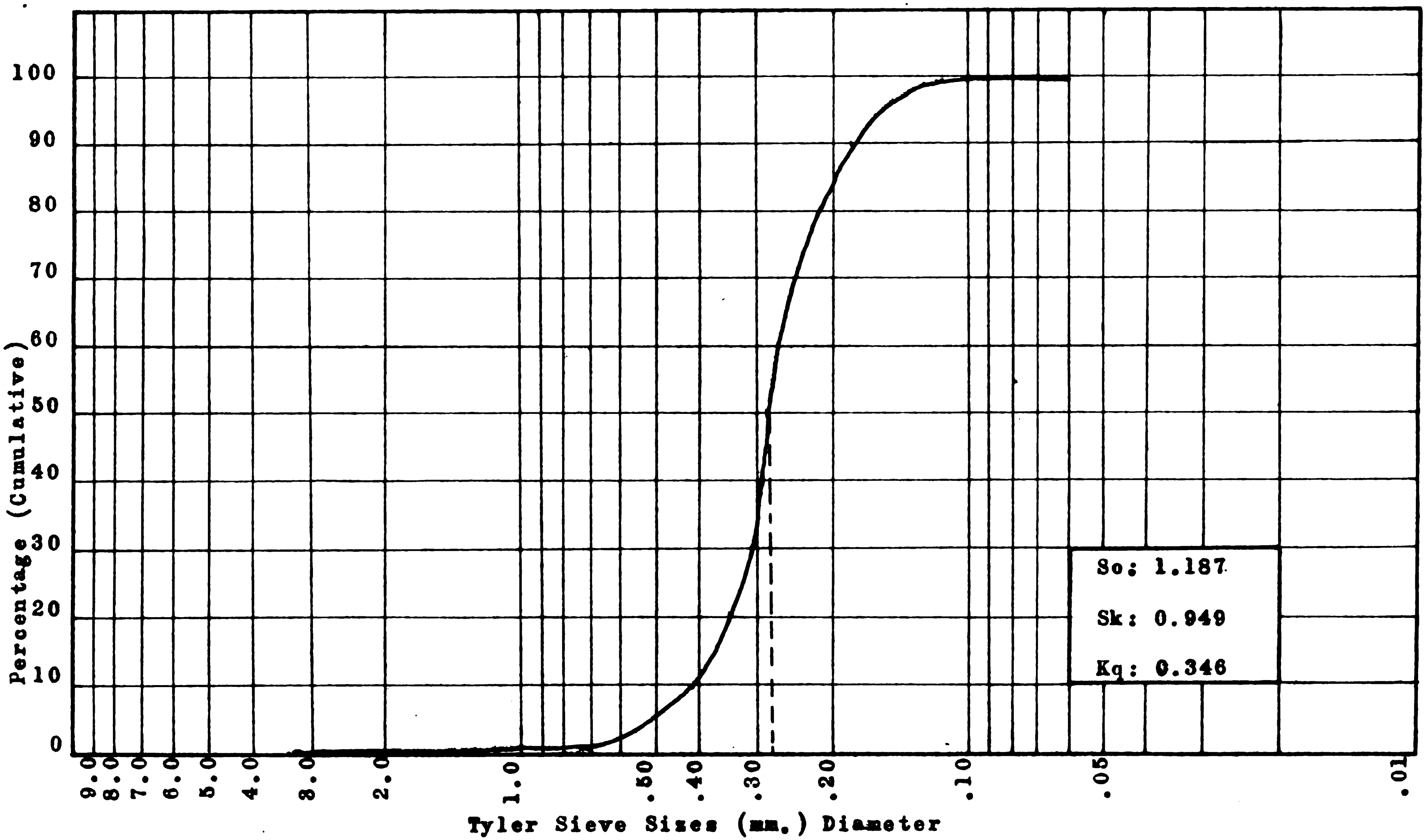


Table 85

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 25

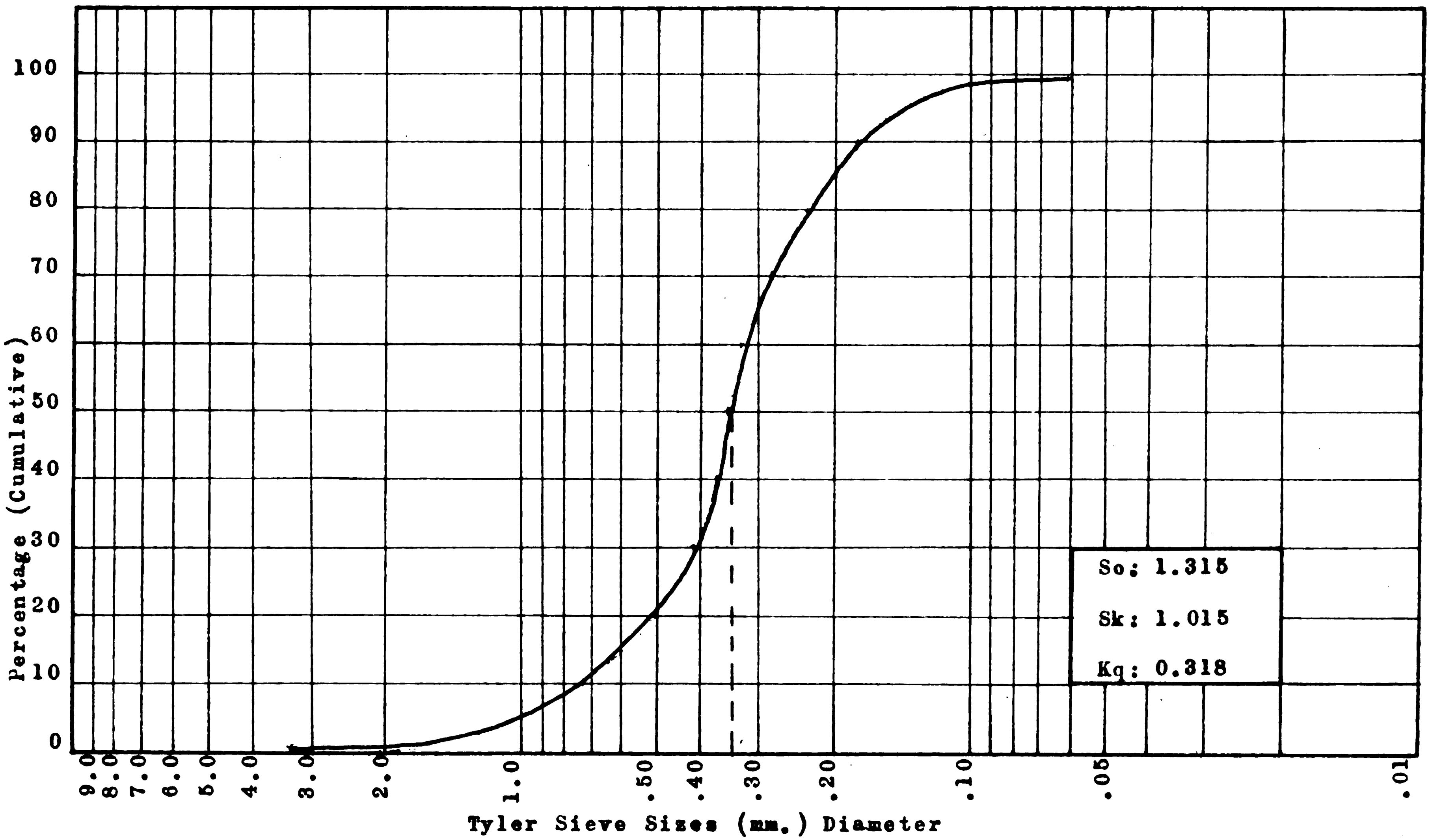


Table 86

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 26

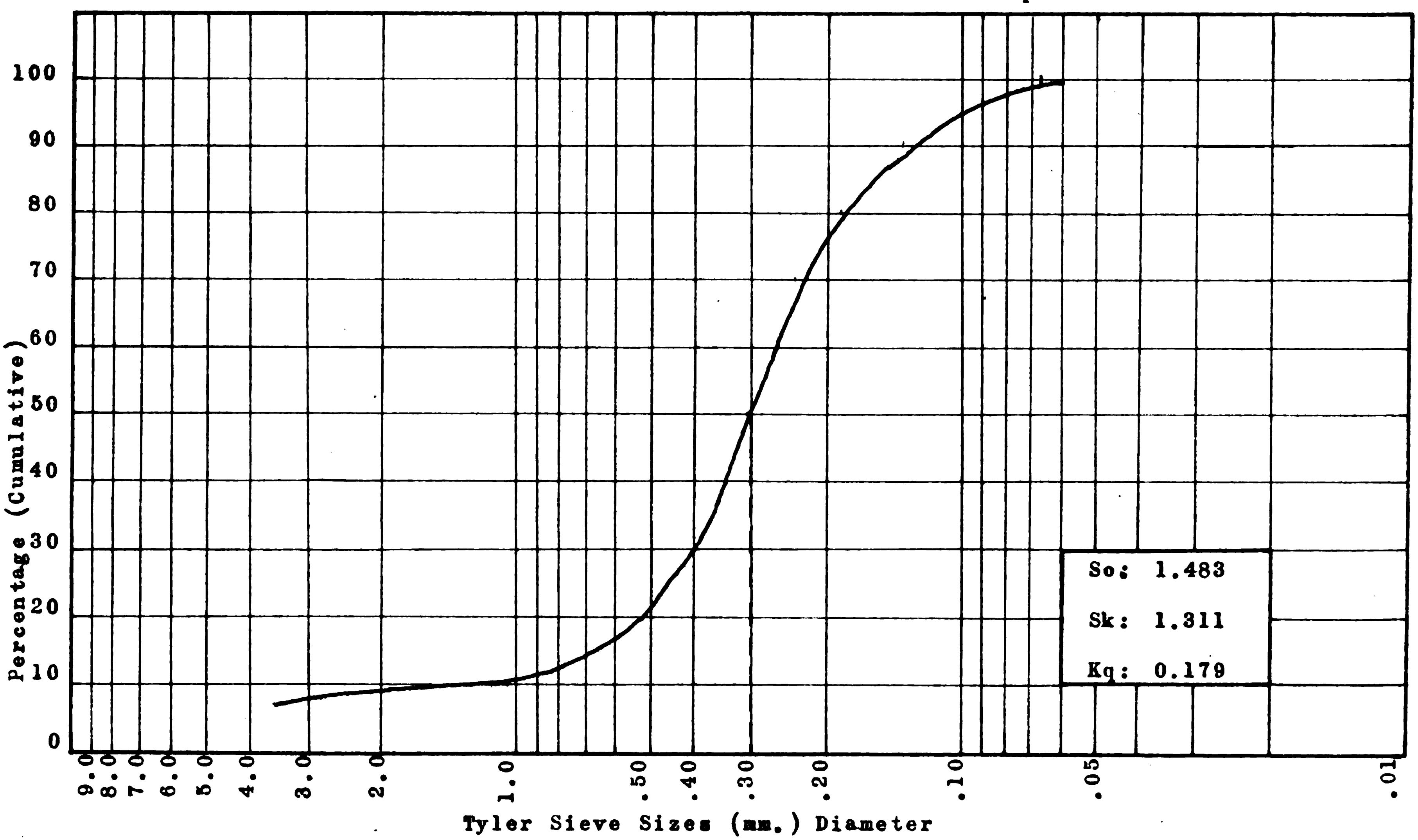


Table 87

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 27

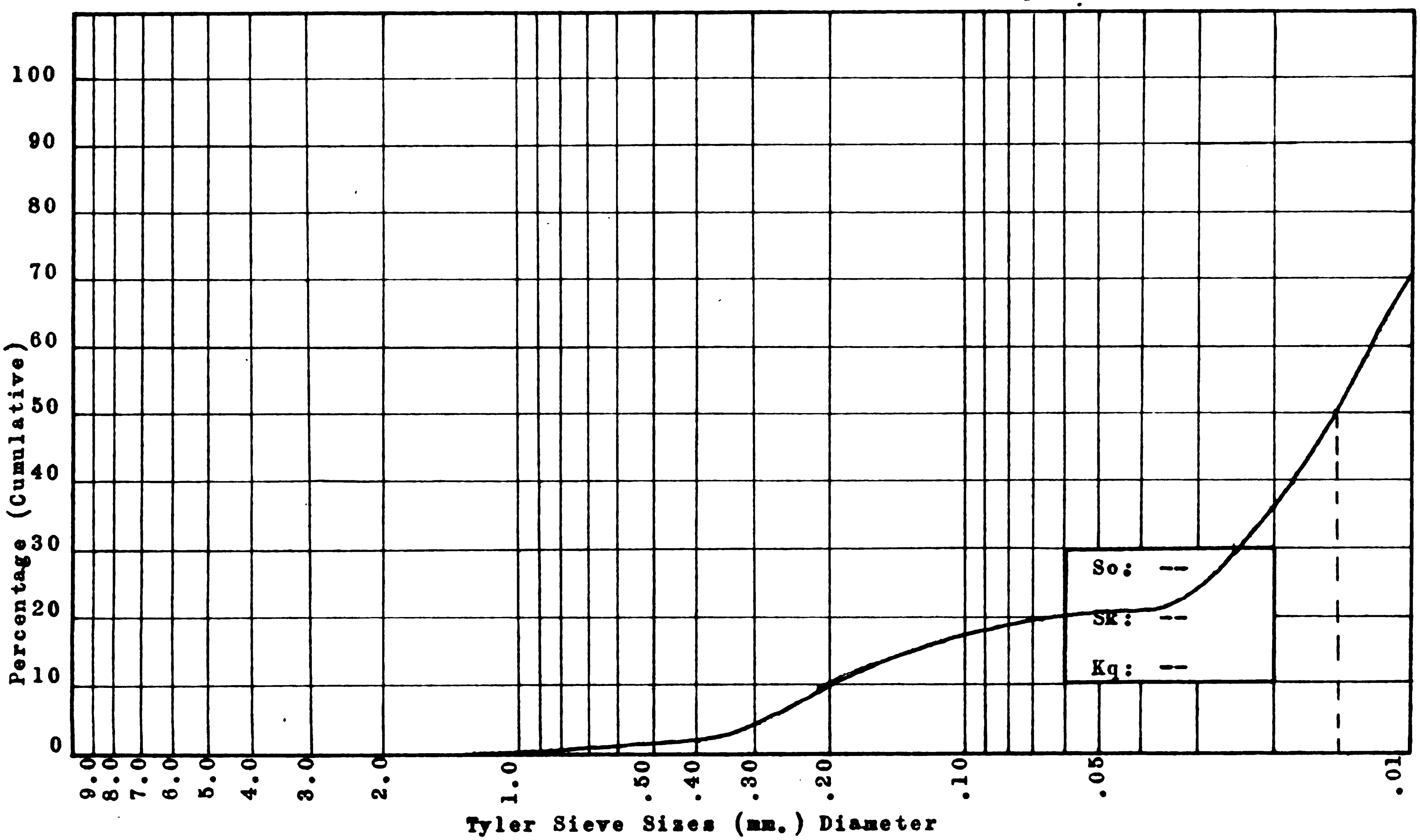


Table 88

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 28

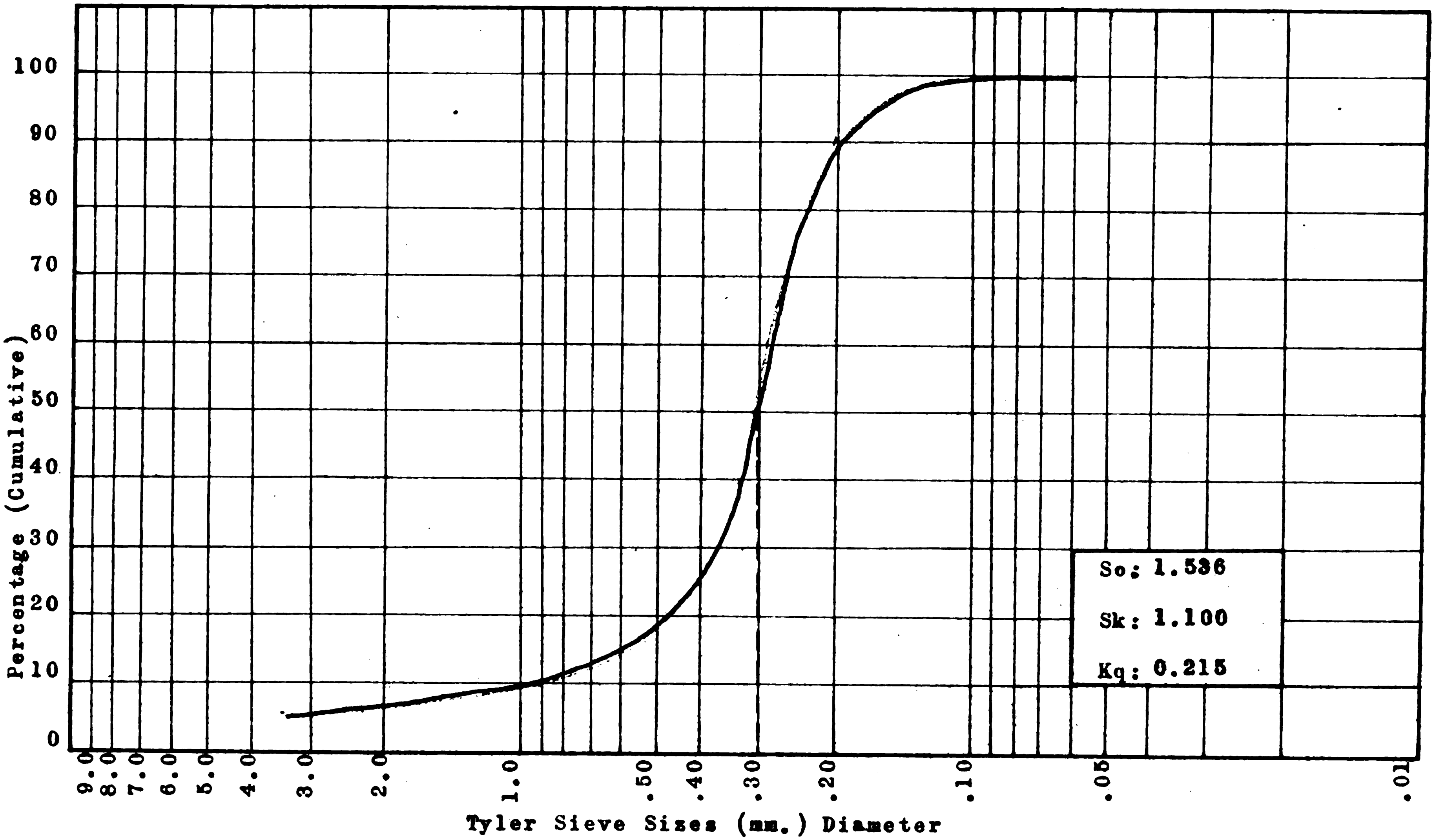


Table 89

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 29

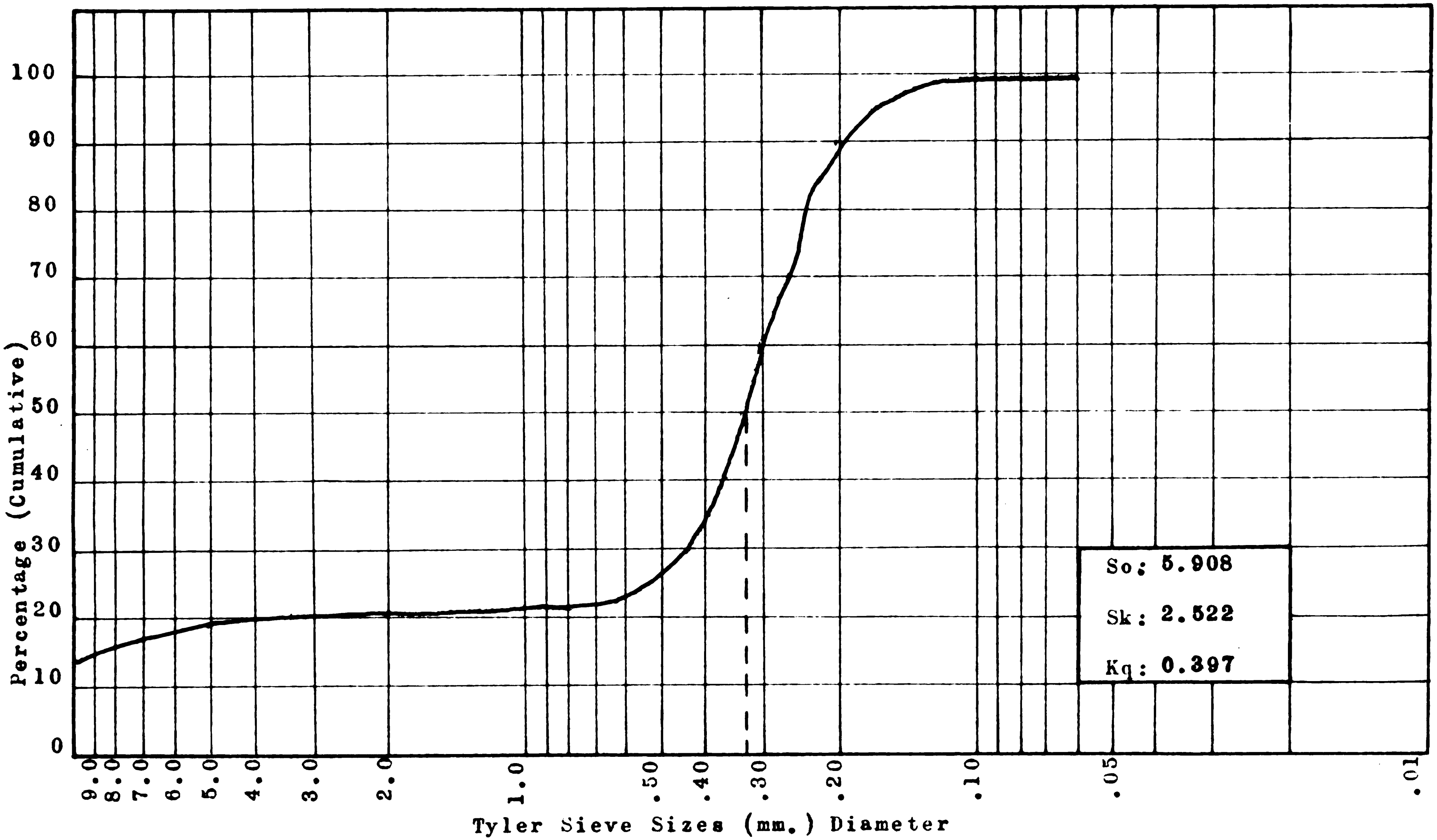


Table 90

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 30

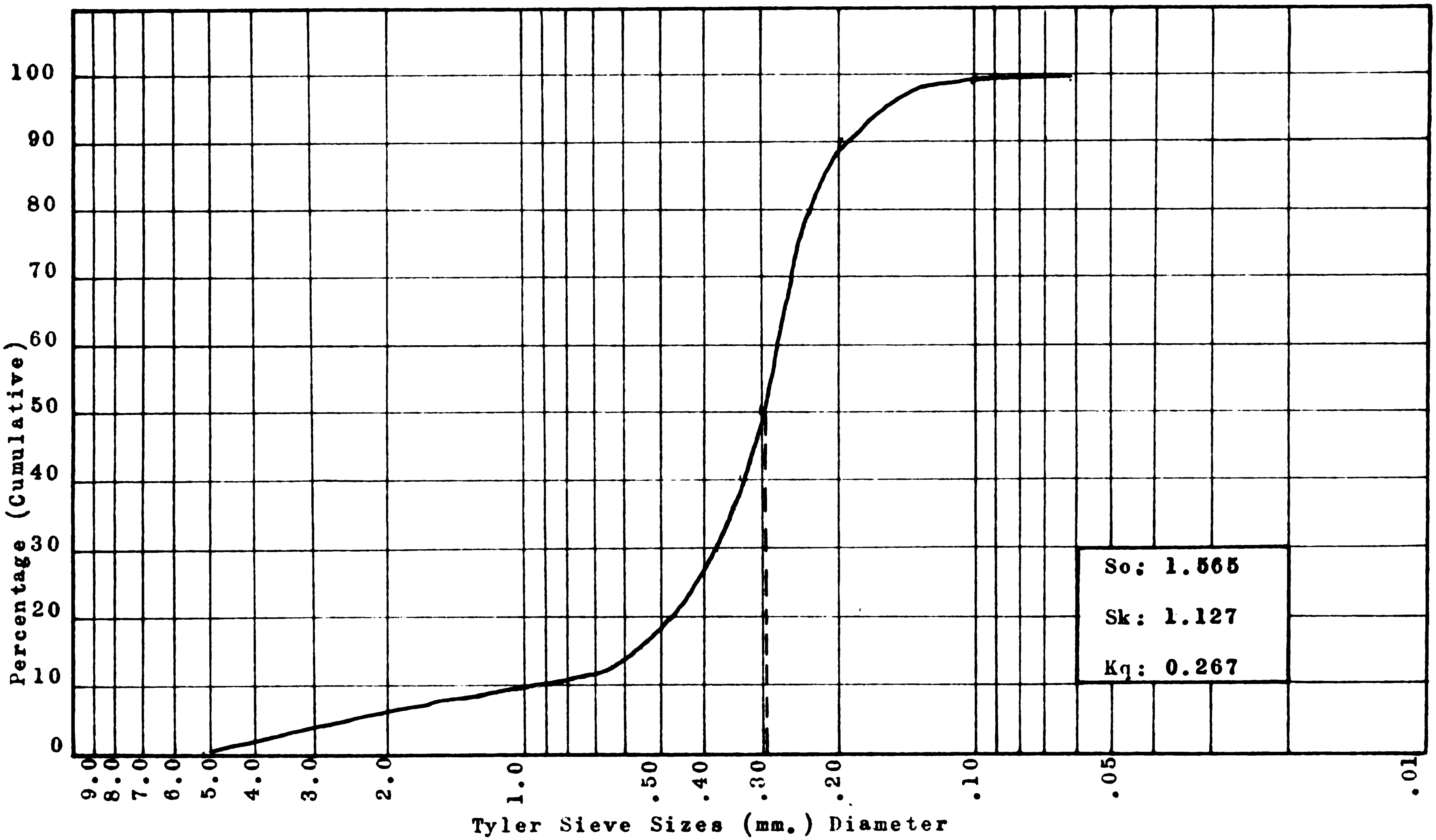


Table 91

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 91

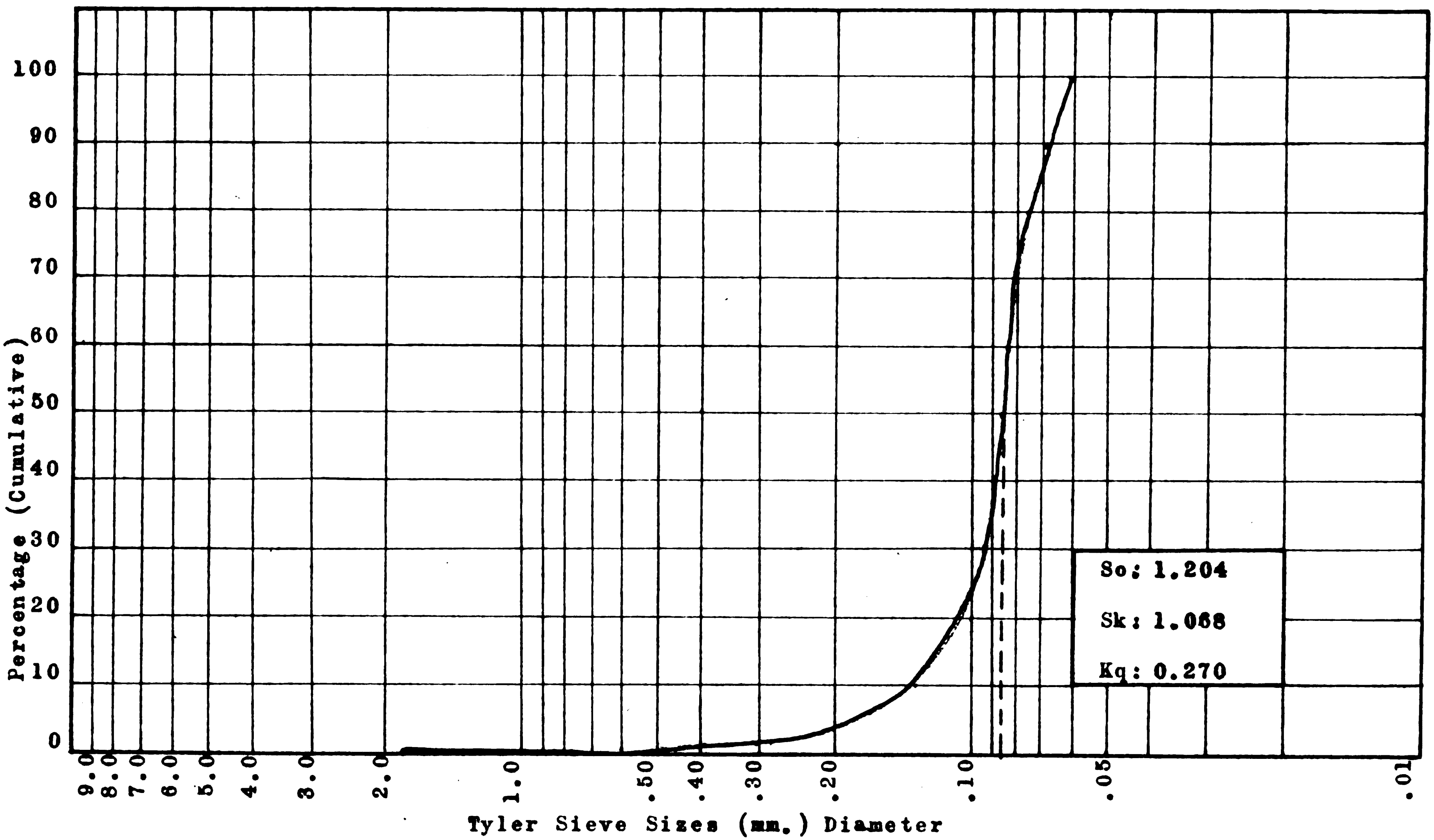


Table 92

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 32

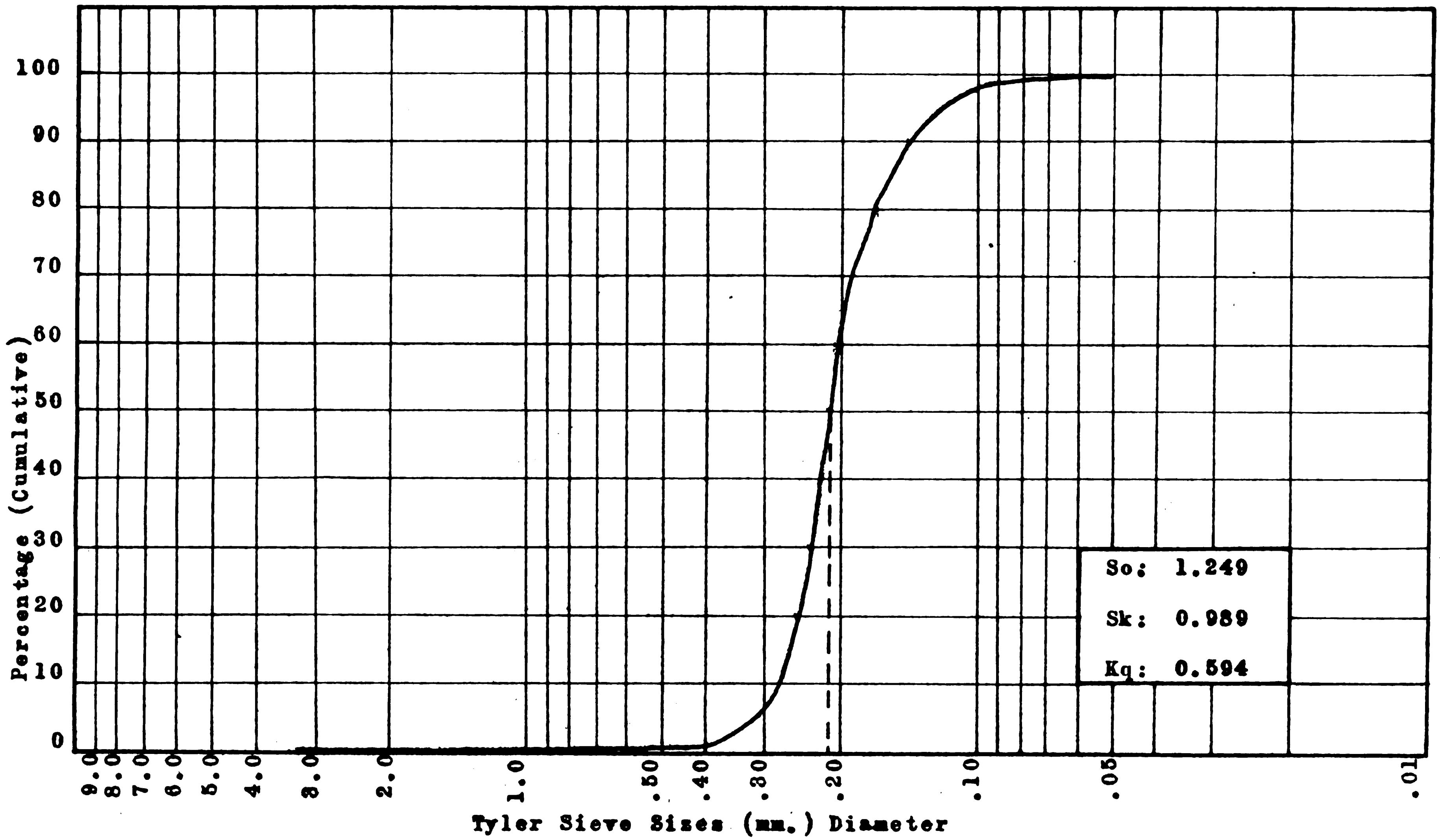


Table 93

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 33

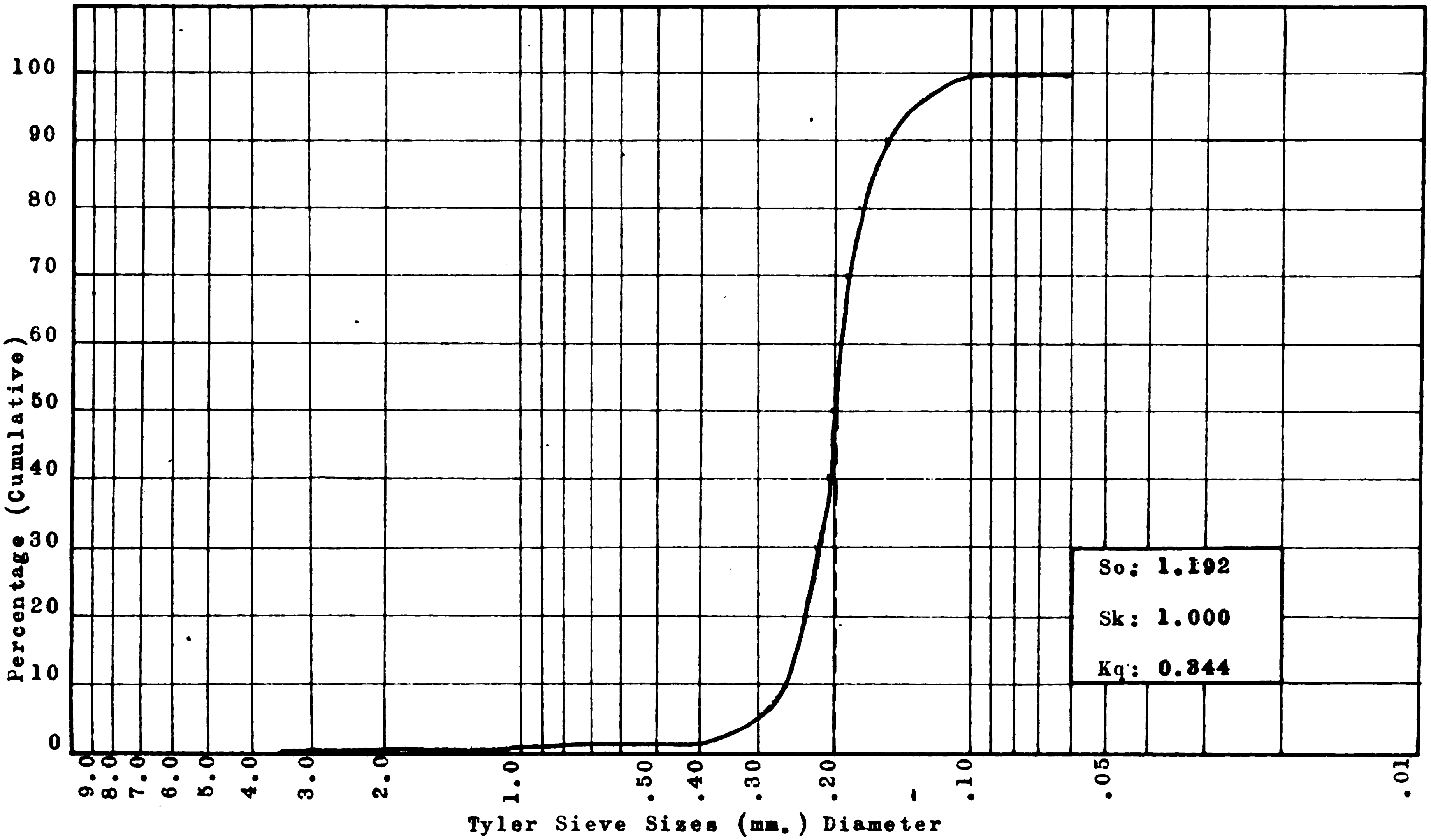


Table 94

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 34

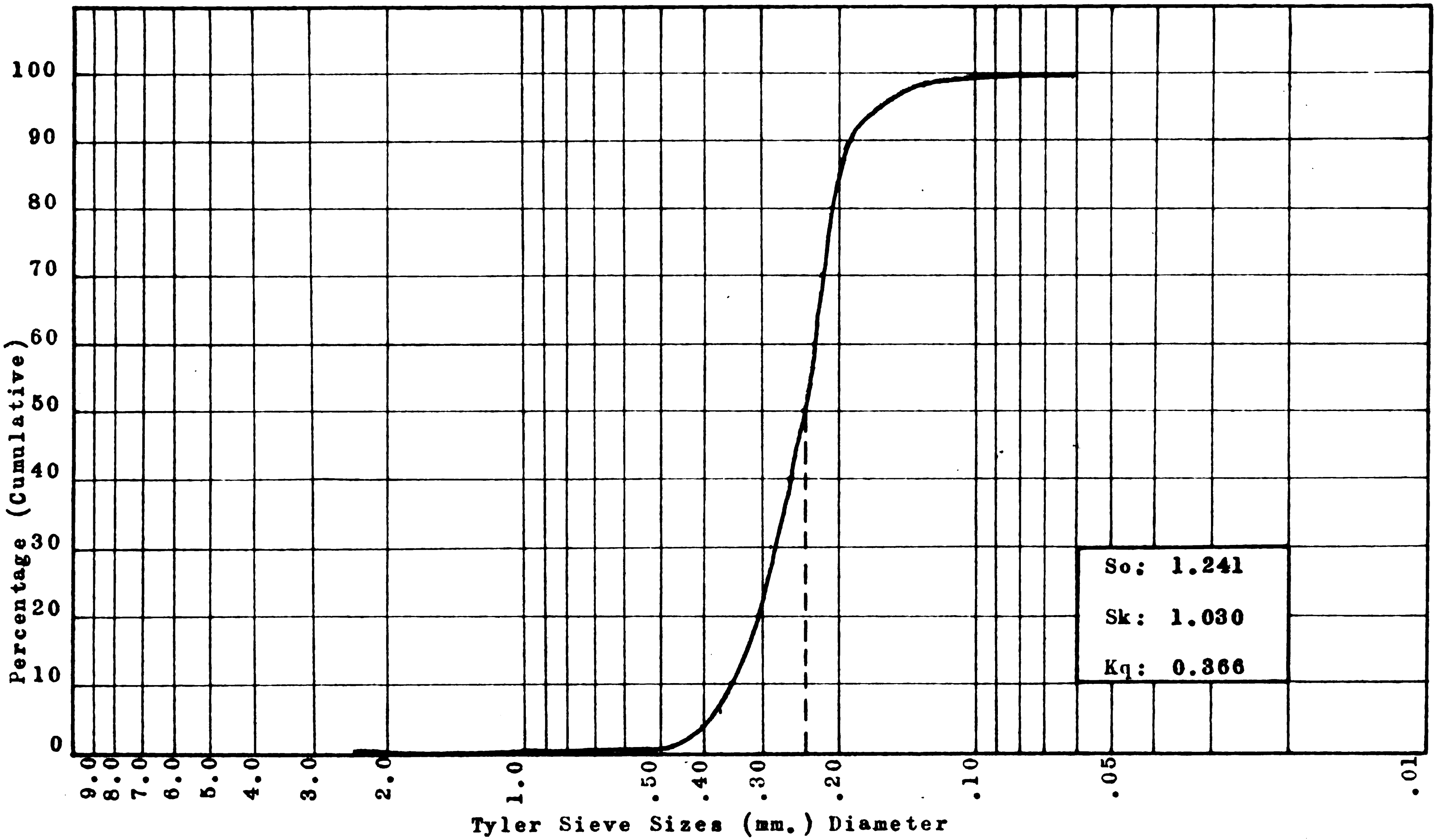


Table 95

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 85

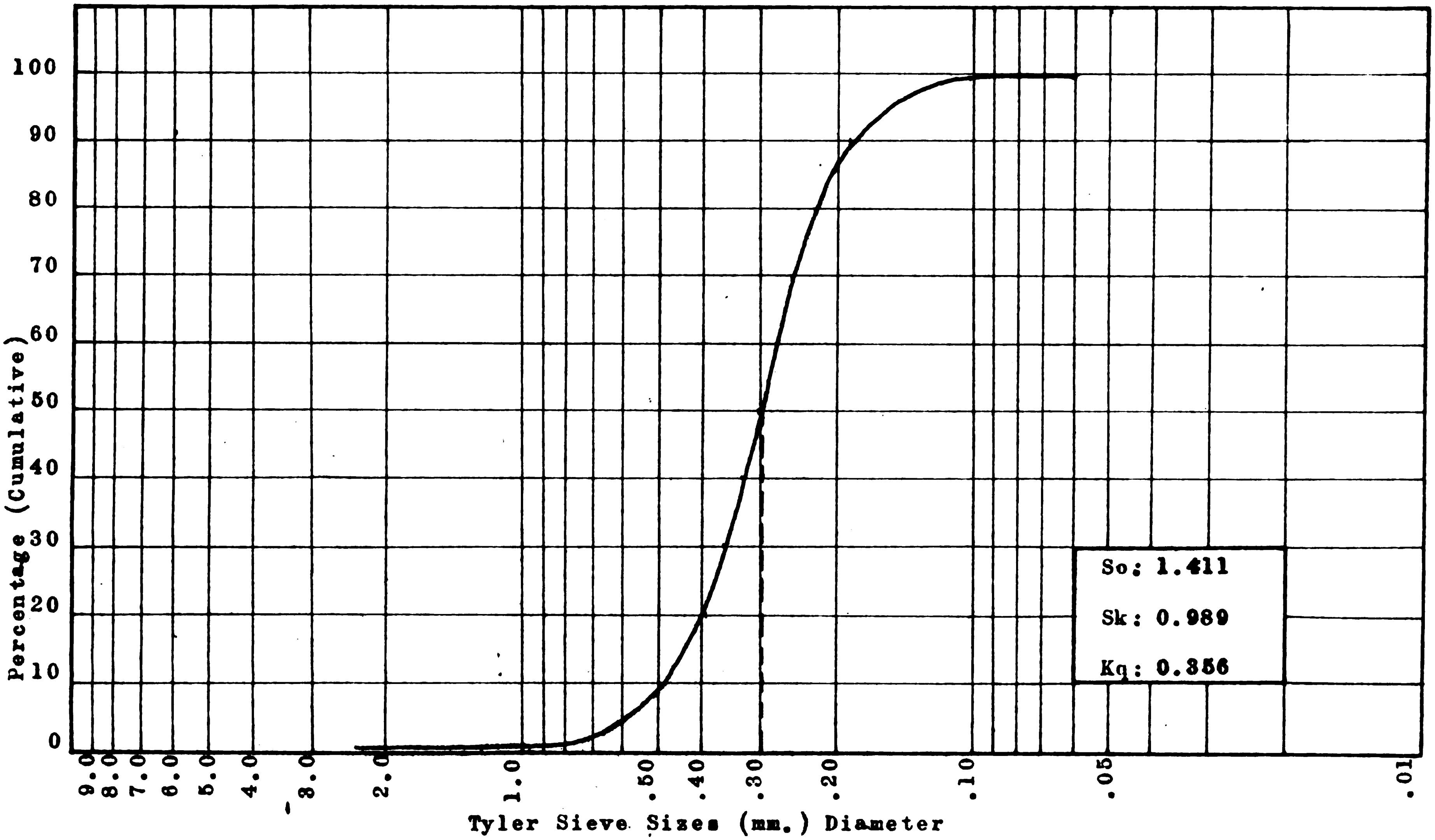


Table 96

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 36

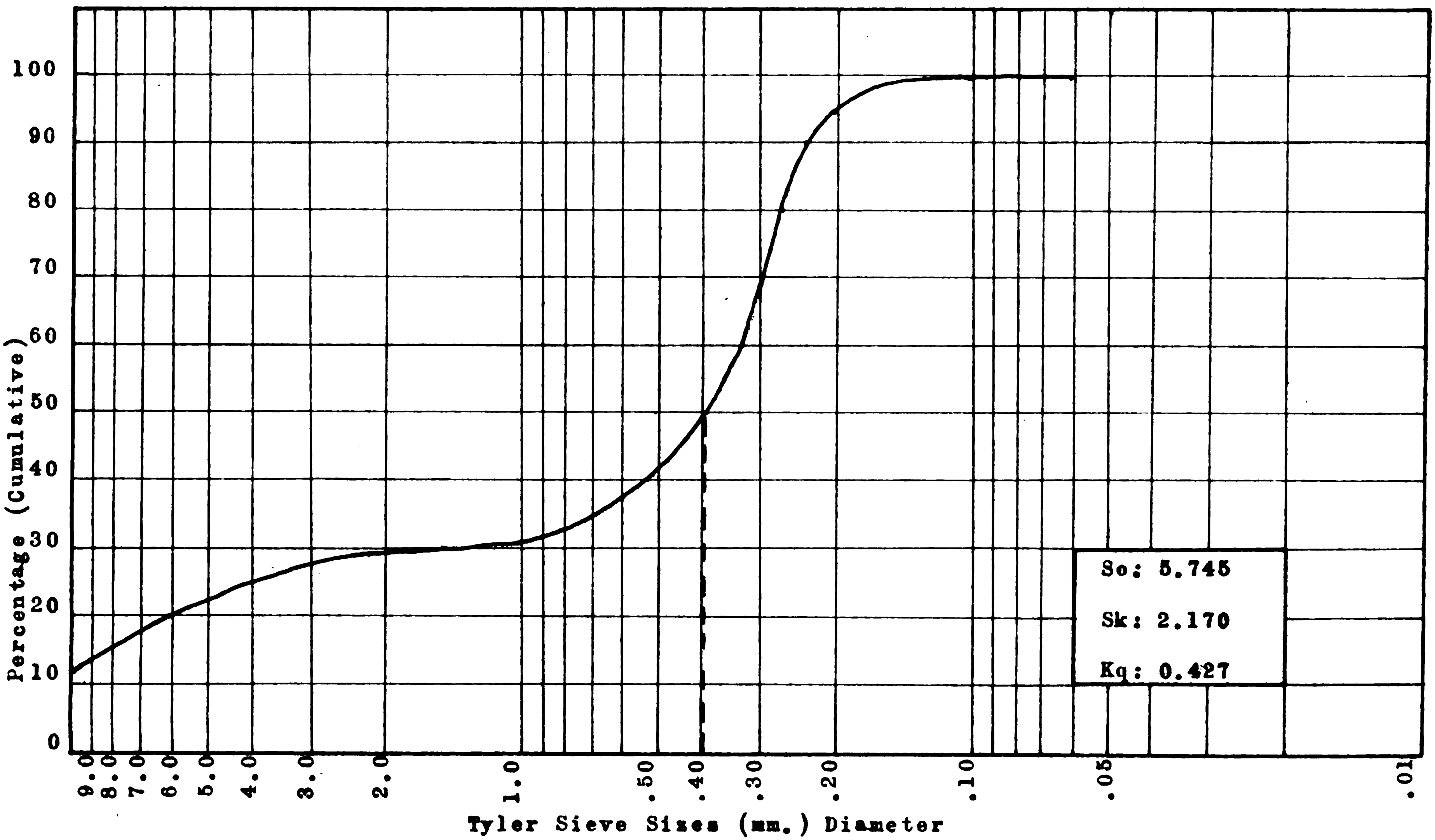


Table 97

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 37

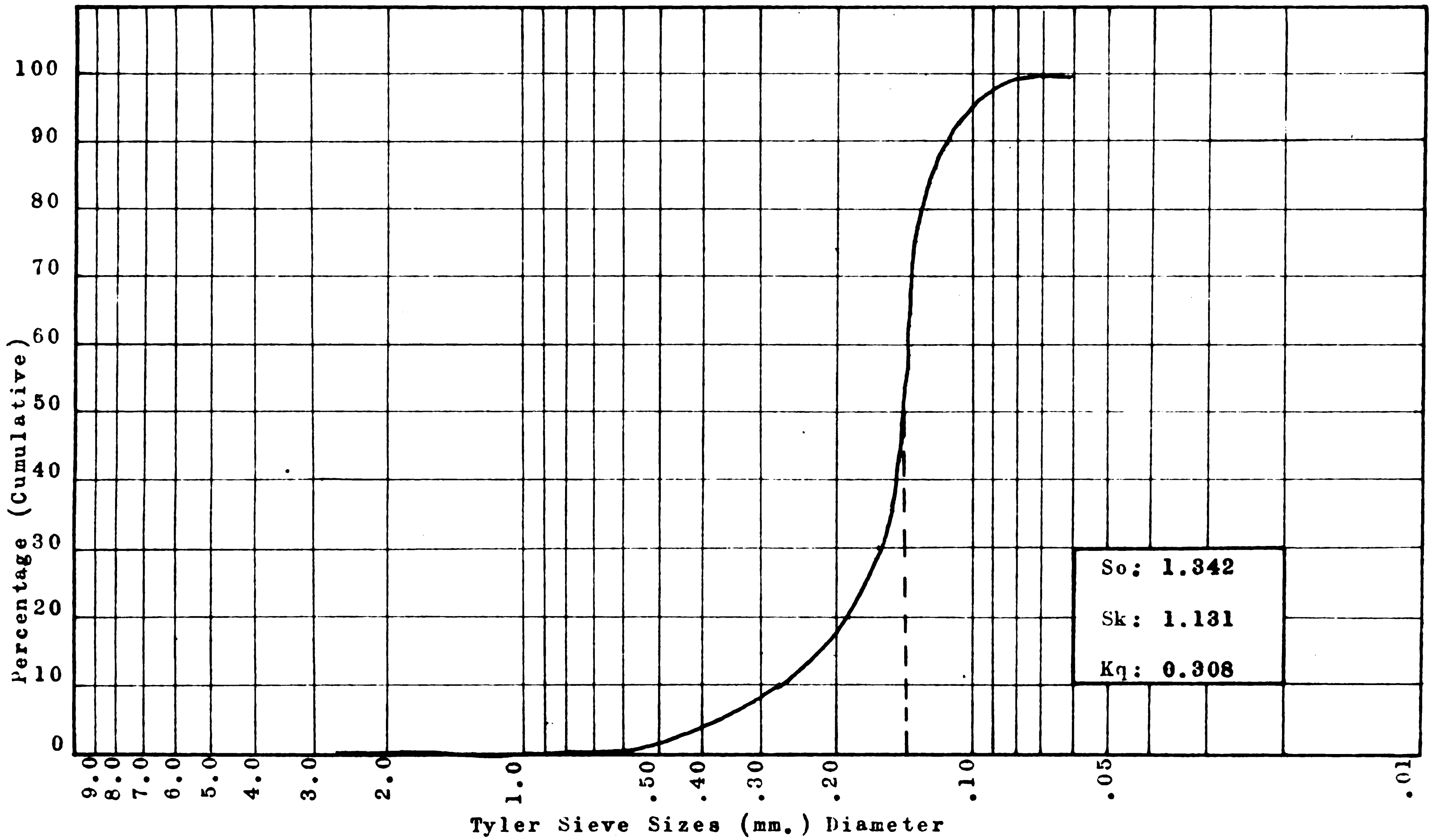


Table 98

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 38

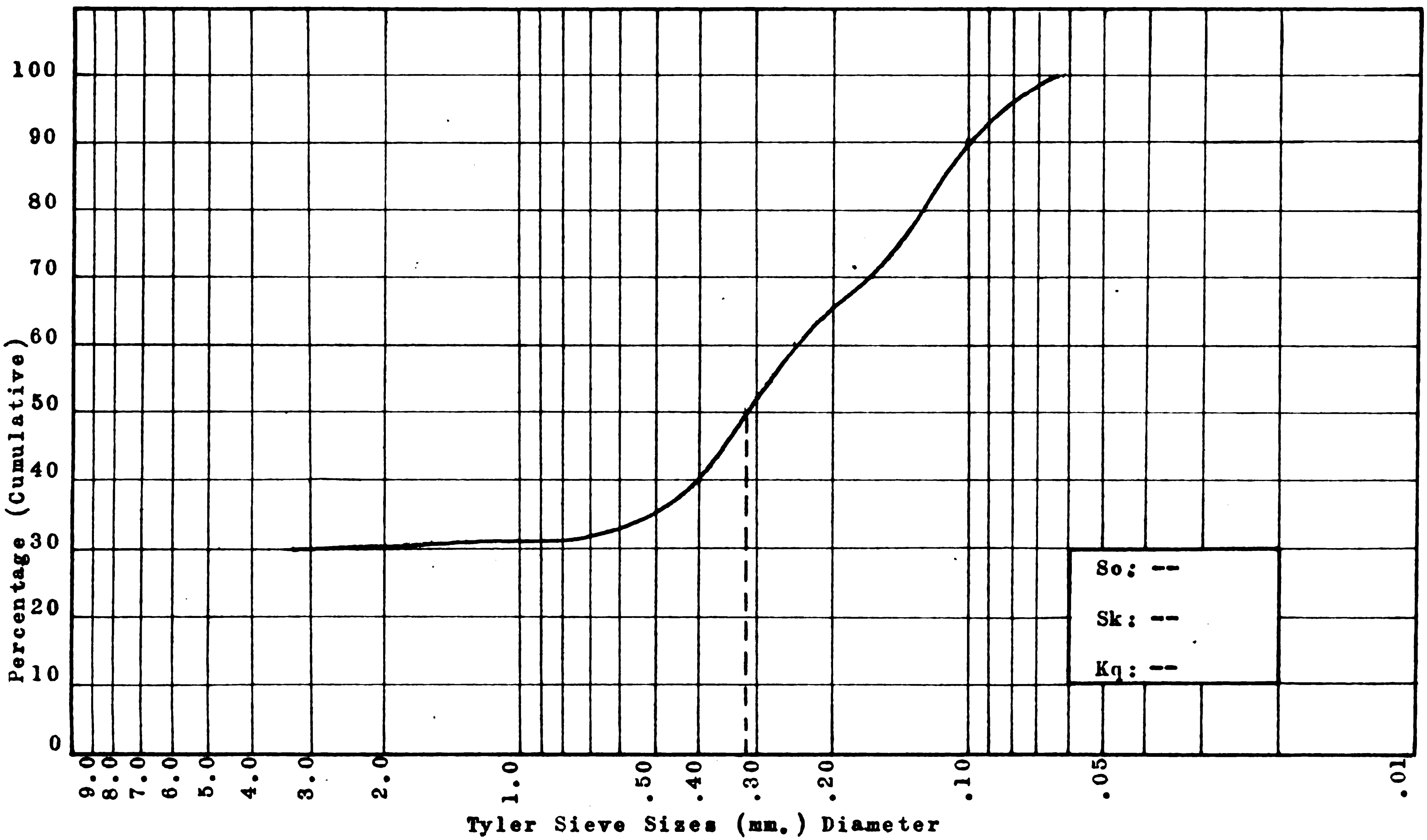


Table 99

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 39

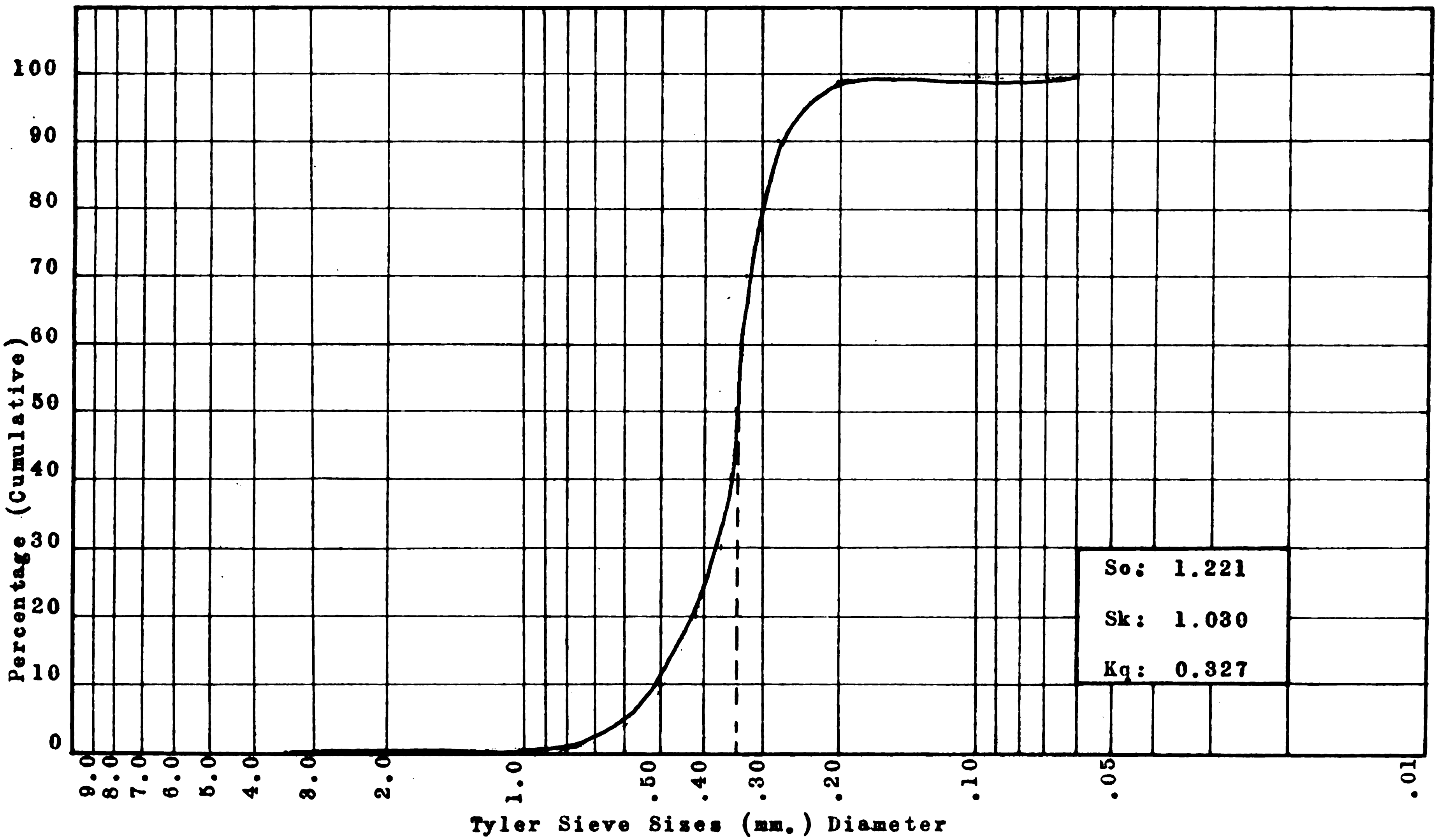


Table 100

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 41

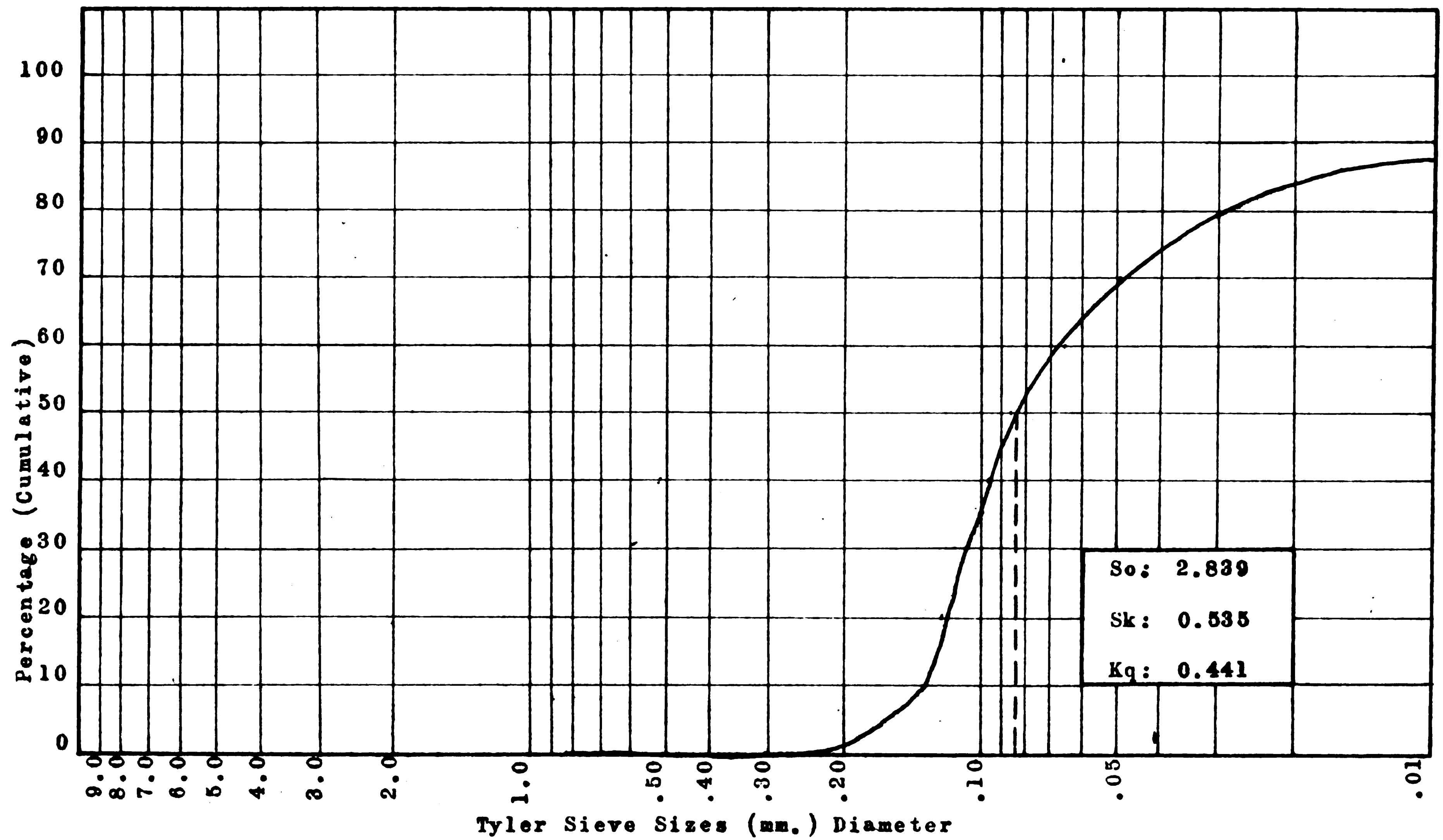


Table 101

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 42

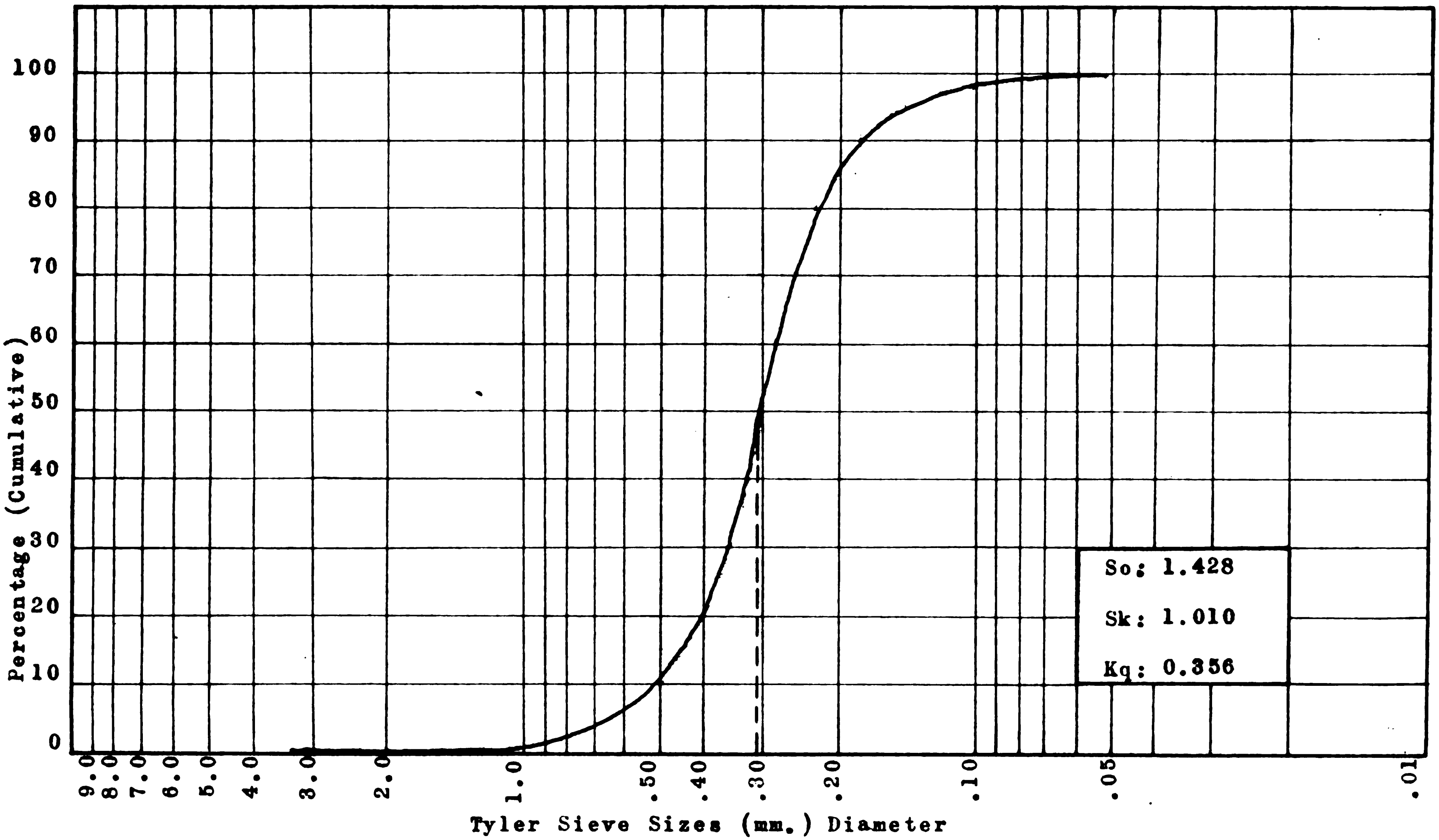


Table 102

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 43

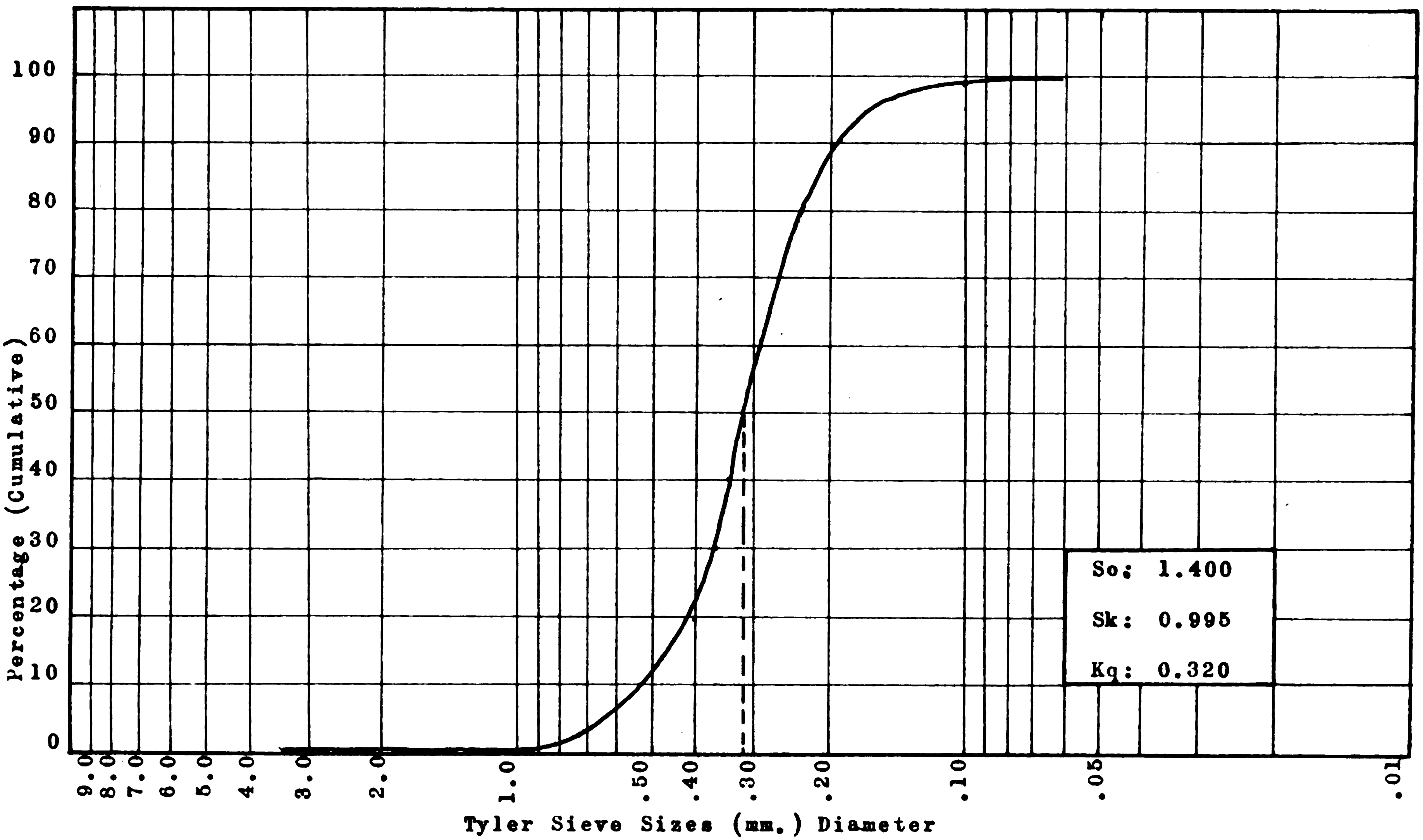


Table 103

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 45

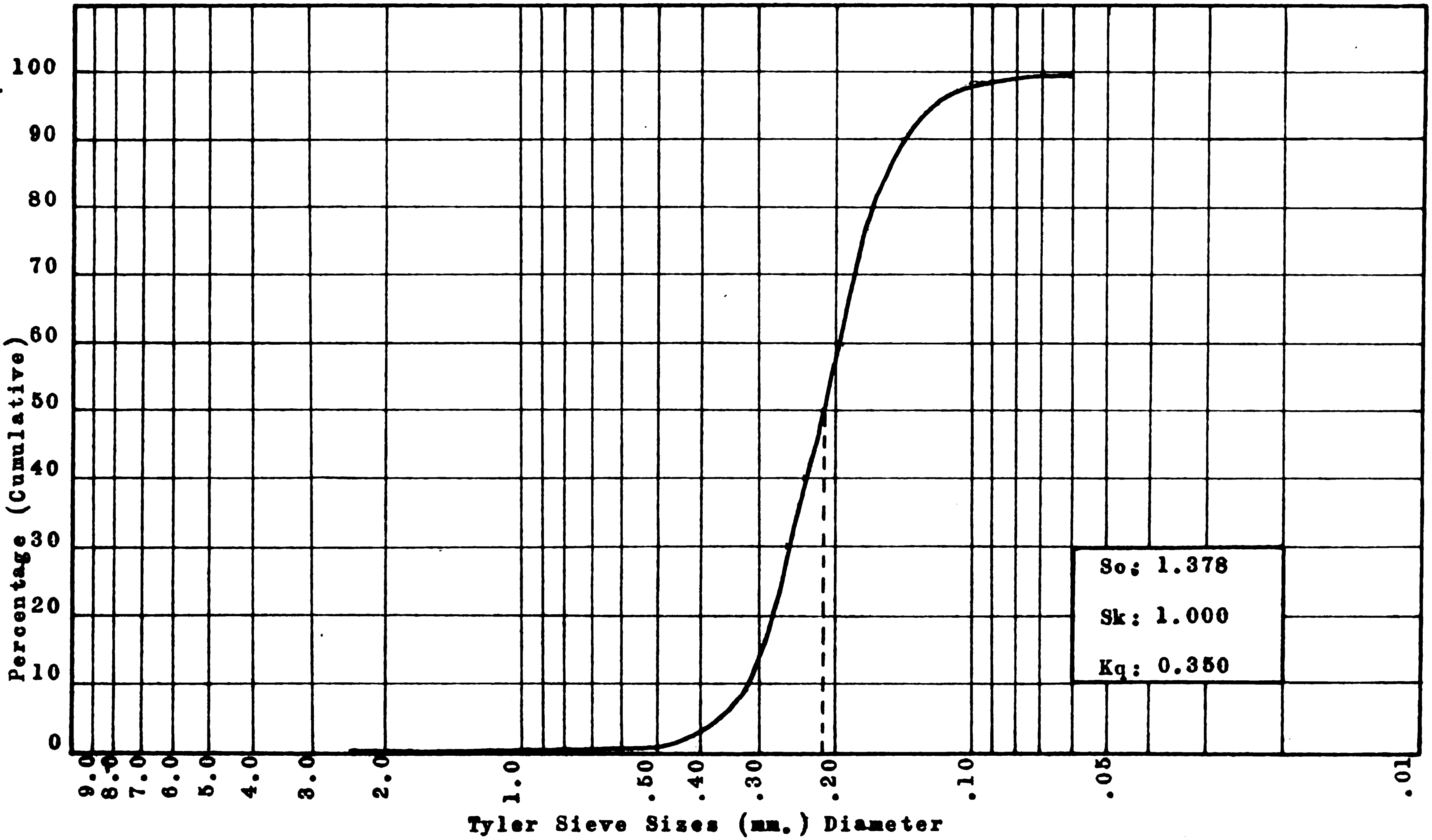


Table 104

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 46

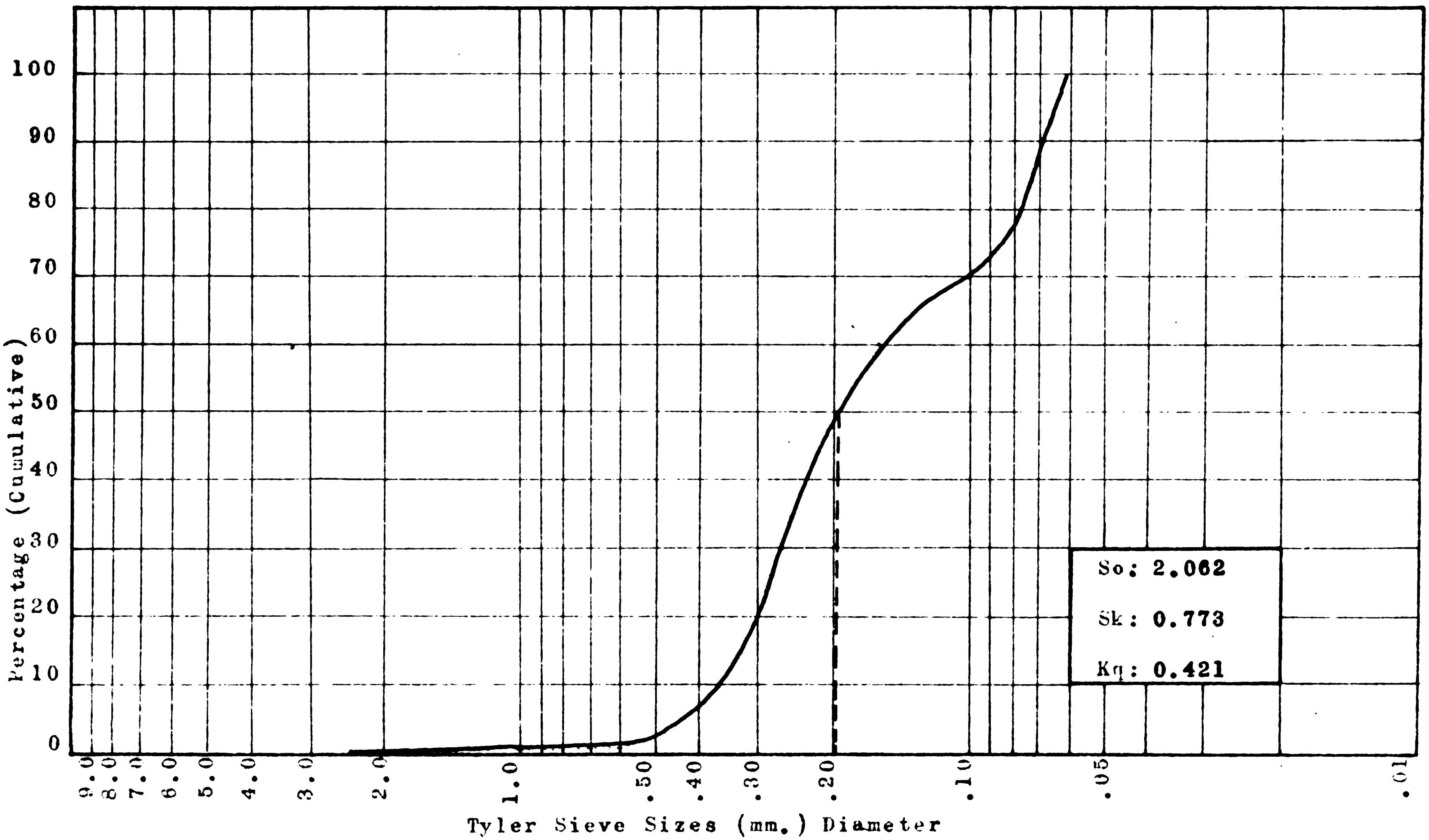


Table 105

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 47

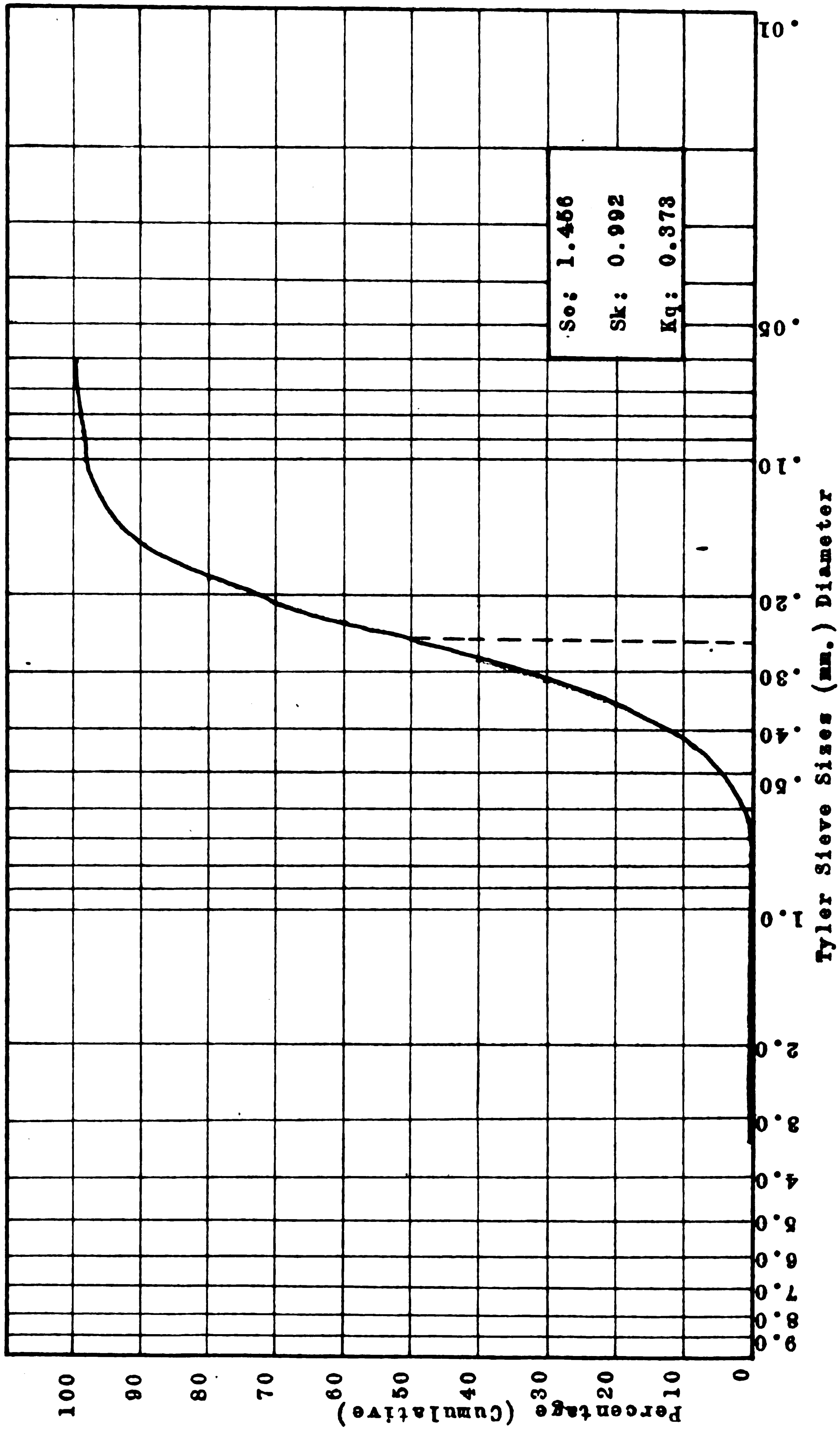


Table 106

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 49

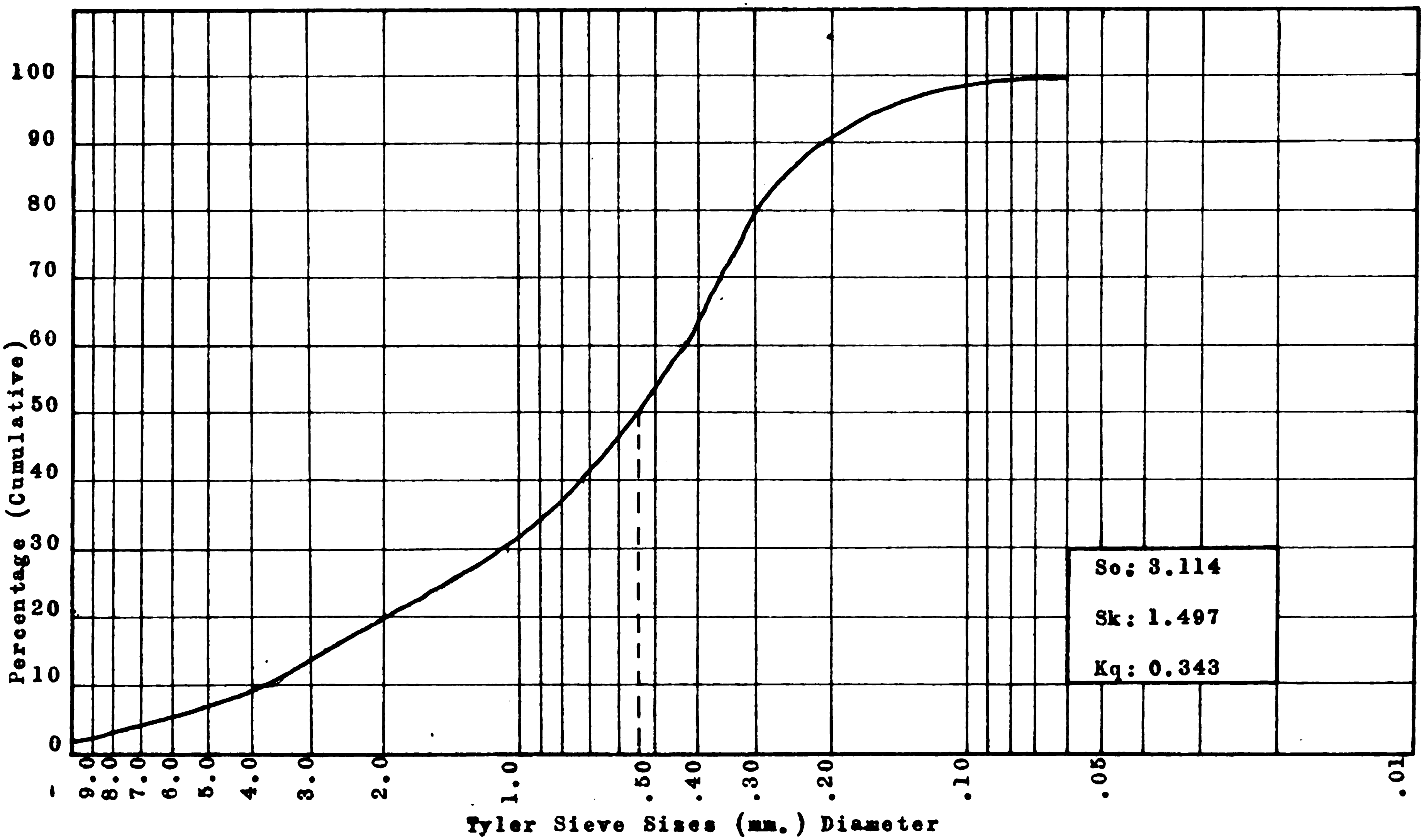


Table 107

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 50

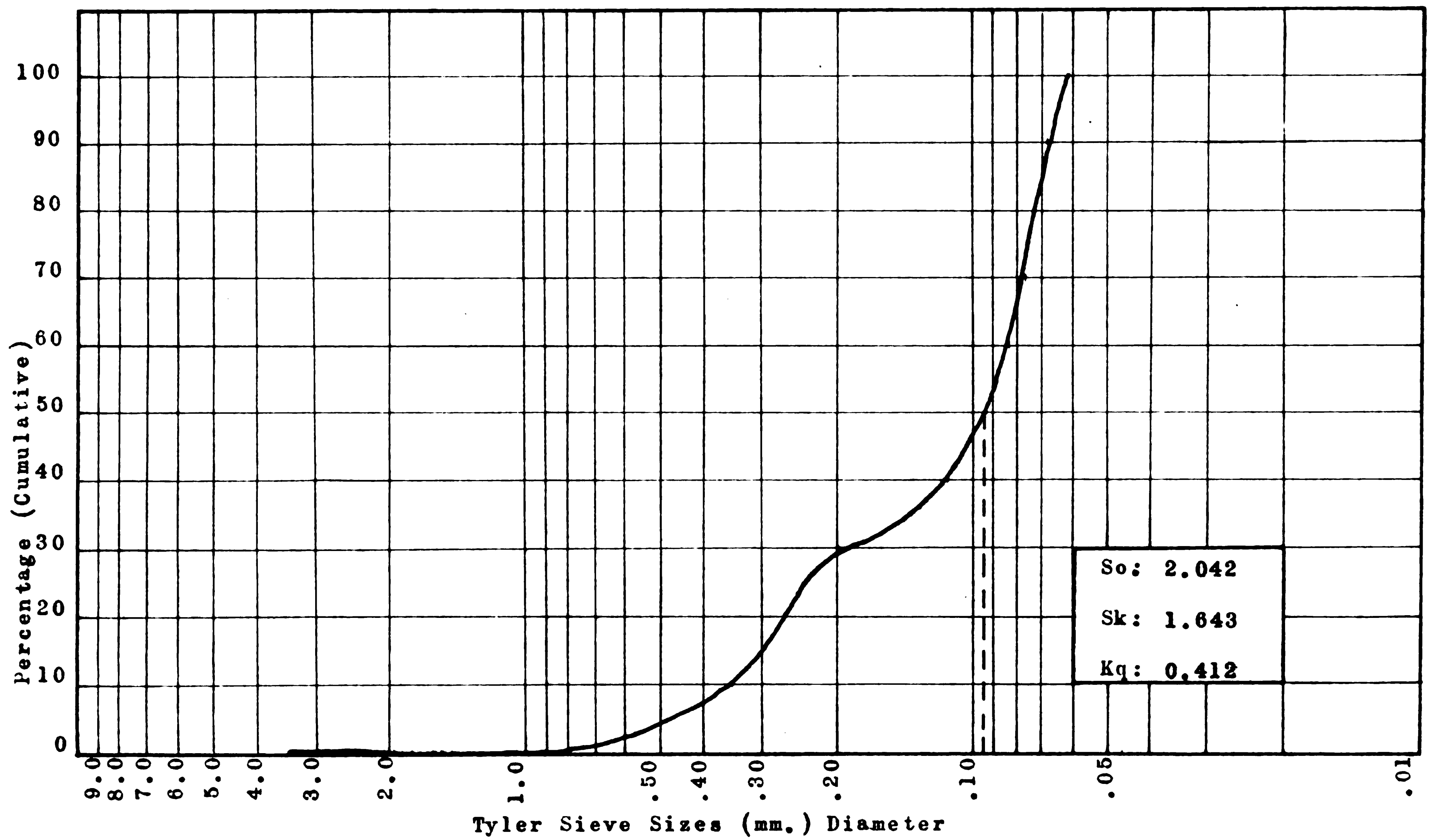


Table 108

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 51

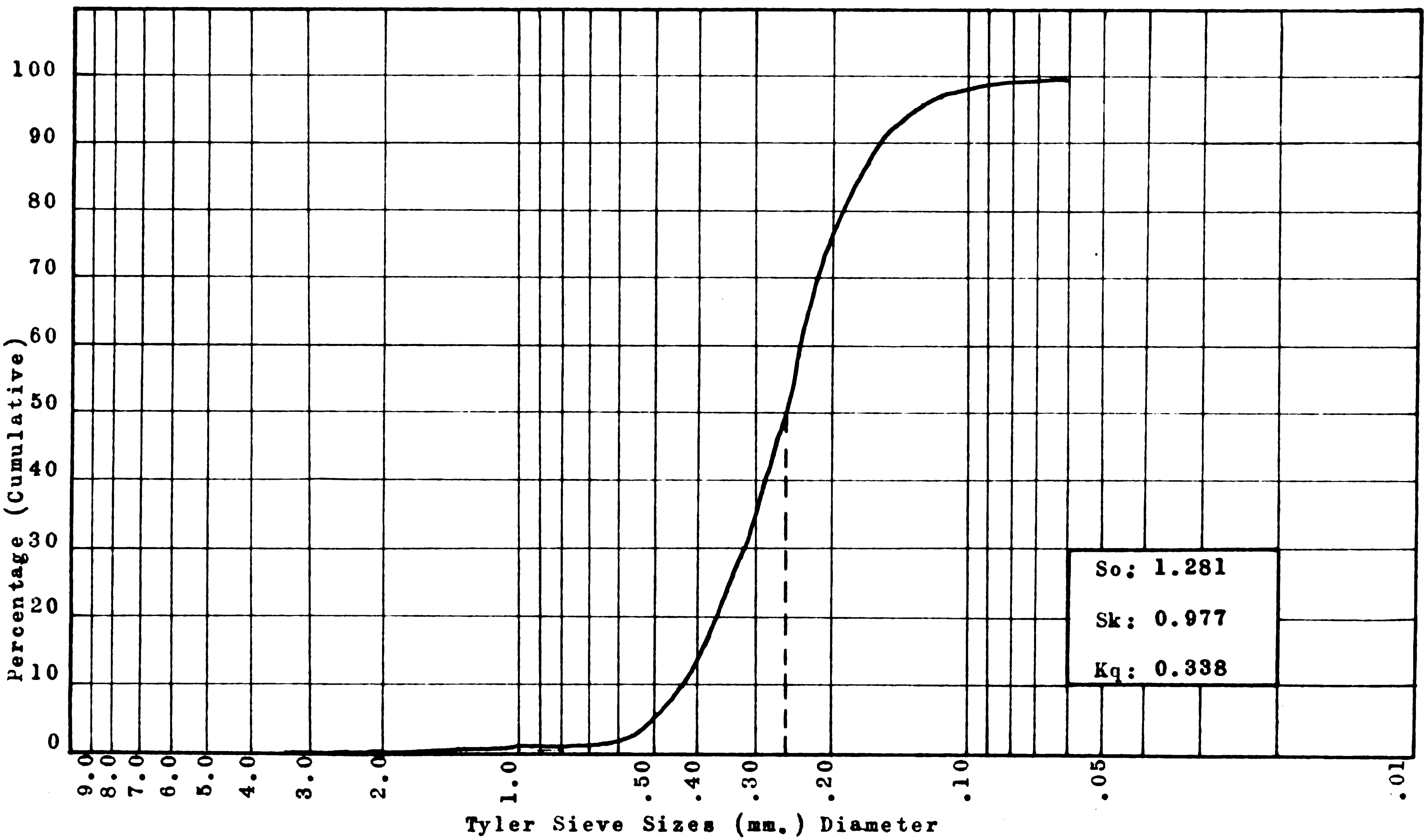


Table 109

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 52

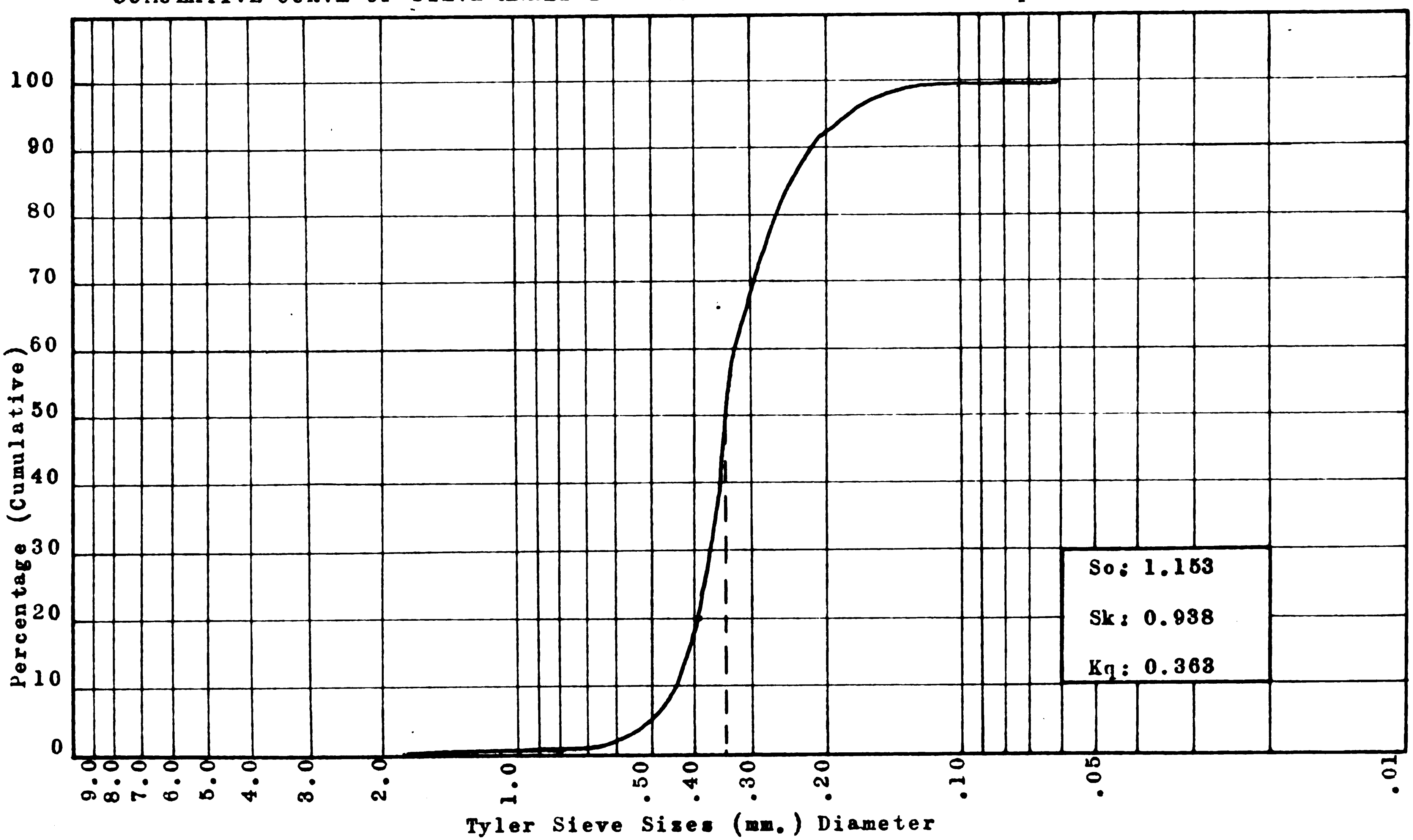


Table 110

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 53

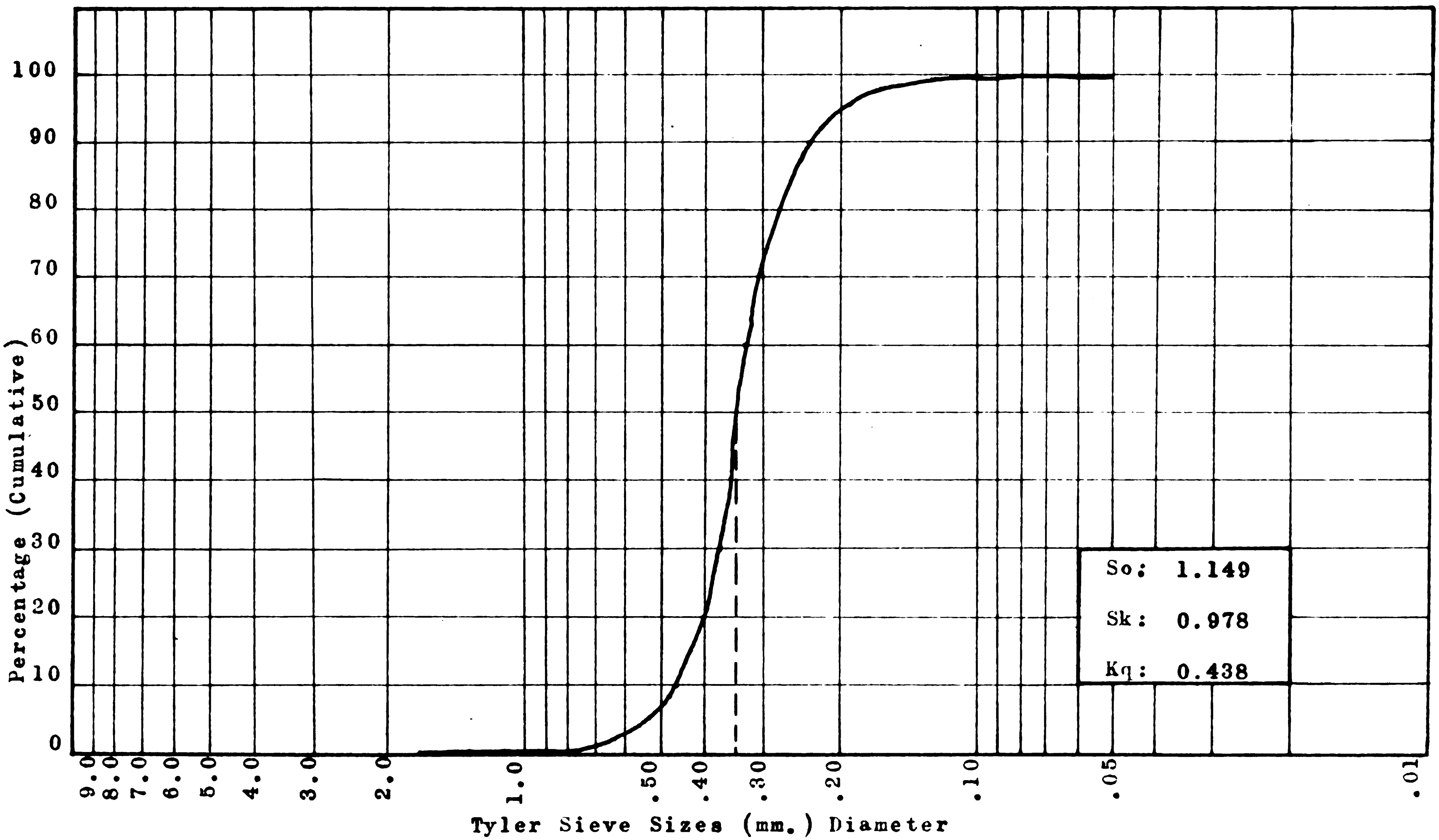


Table 111

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 54

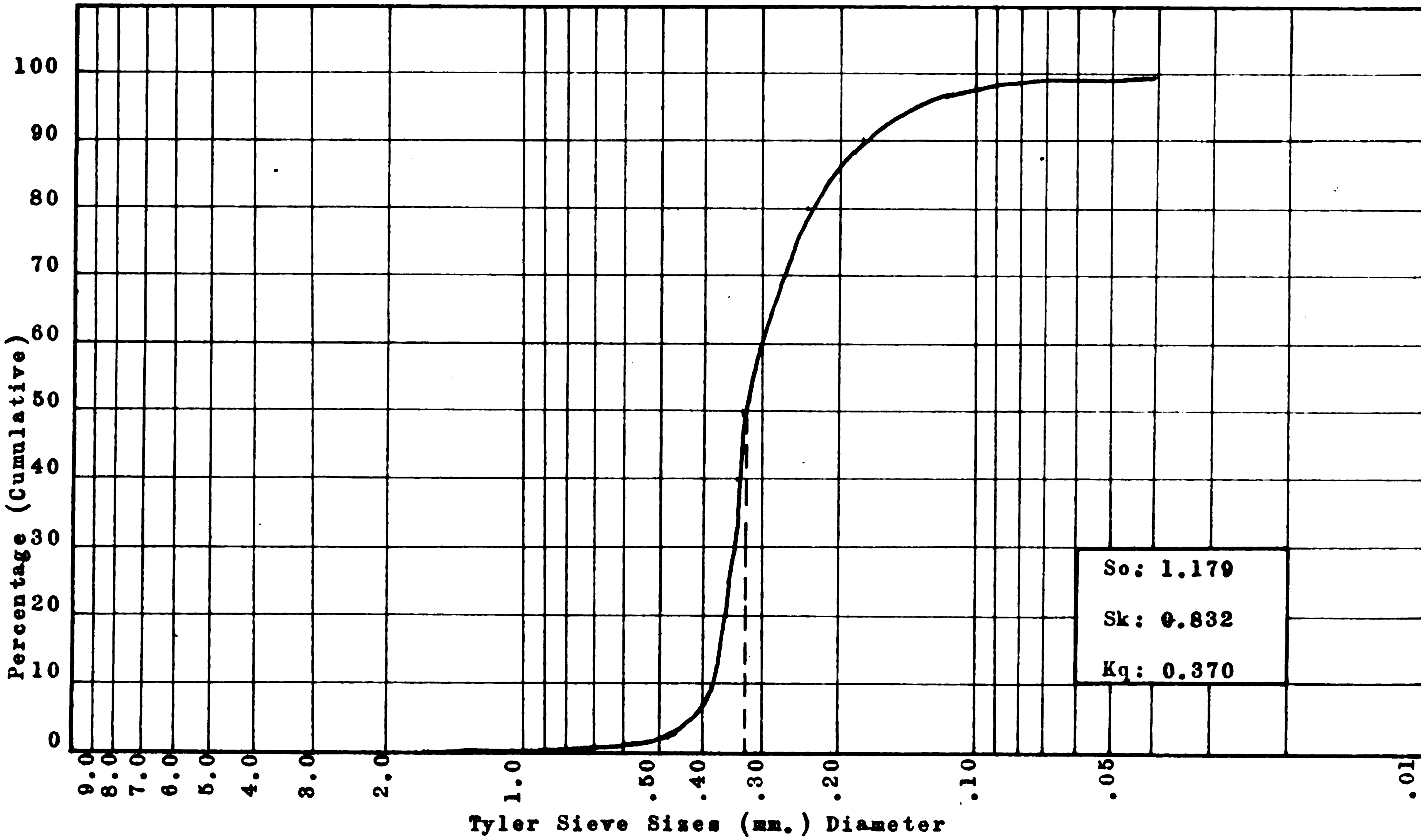


Table 112

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 55

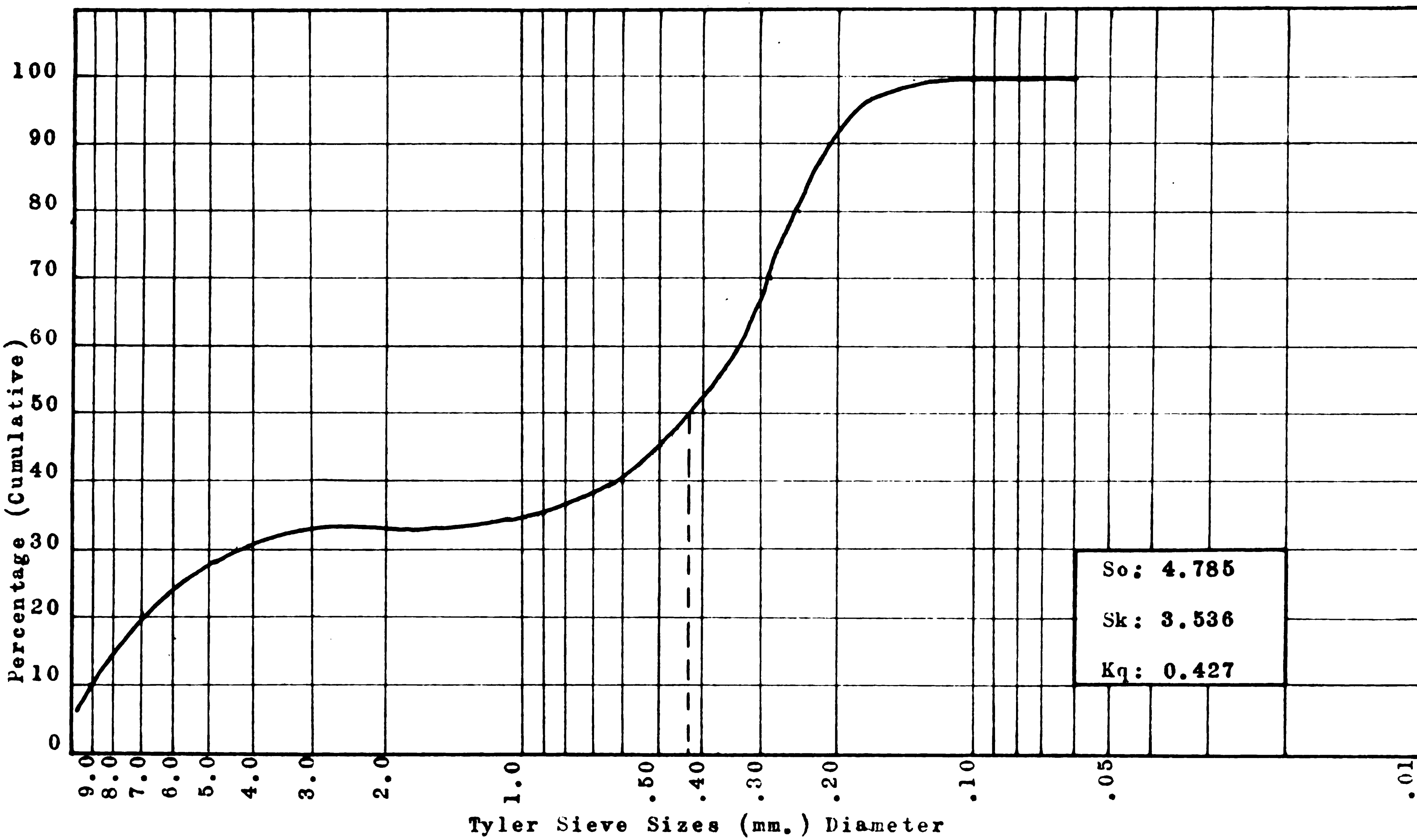


Table 113

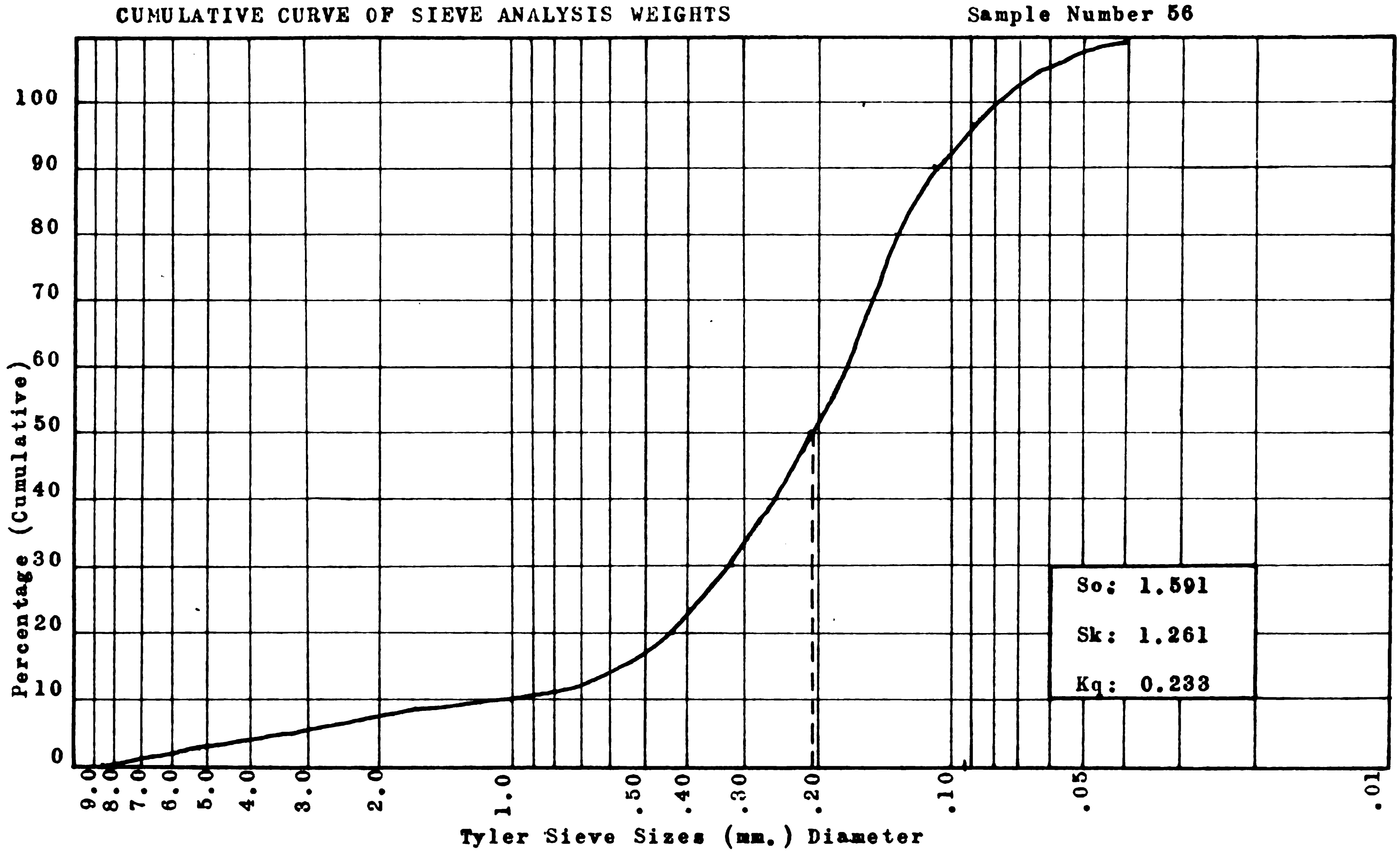

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS
Sample Number 56
So: 1.591
Sk: 1.261
Kq: 0.233
Percentage (Cumulative)
0
10
20
30
40
50
60
70
80
90
100
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.50
.40
.30
.20
.10
.05
.01
Tyler Sieve Sizes (mm.) Diameter

Table 114

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 59

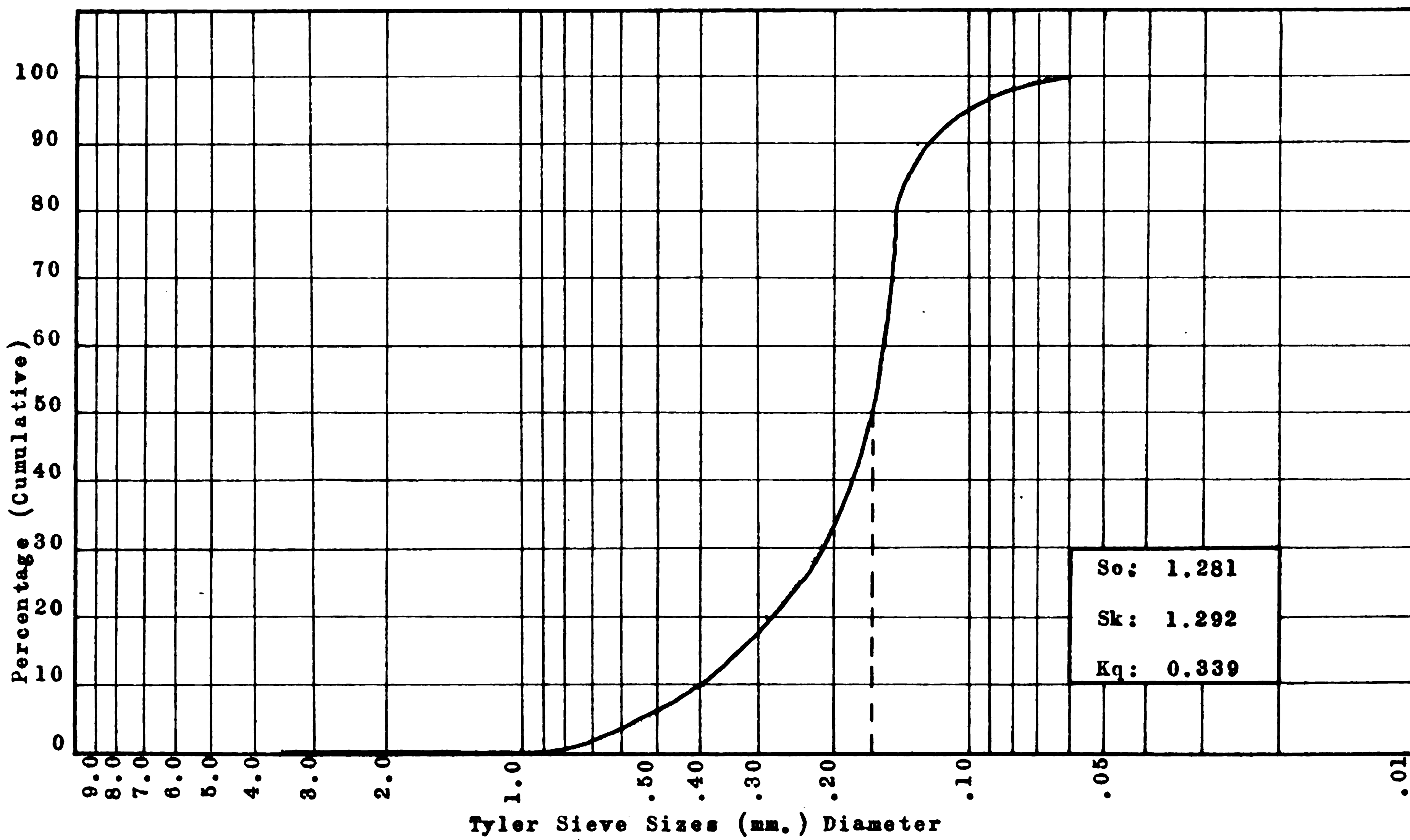
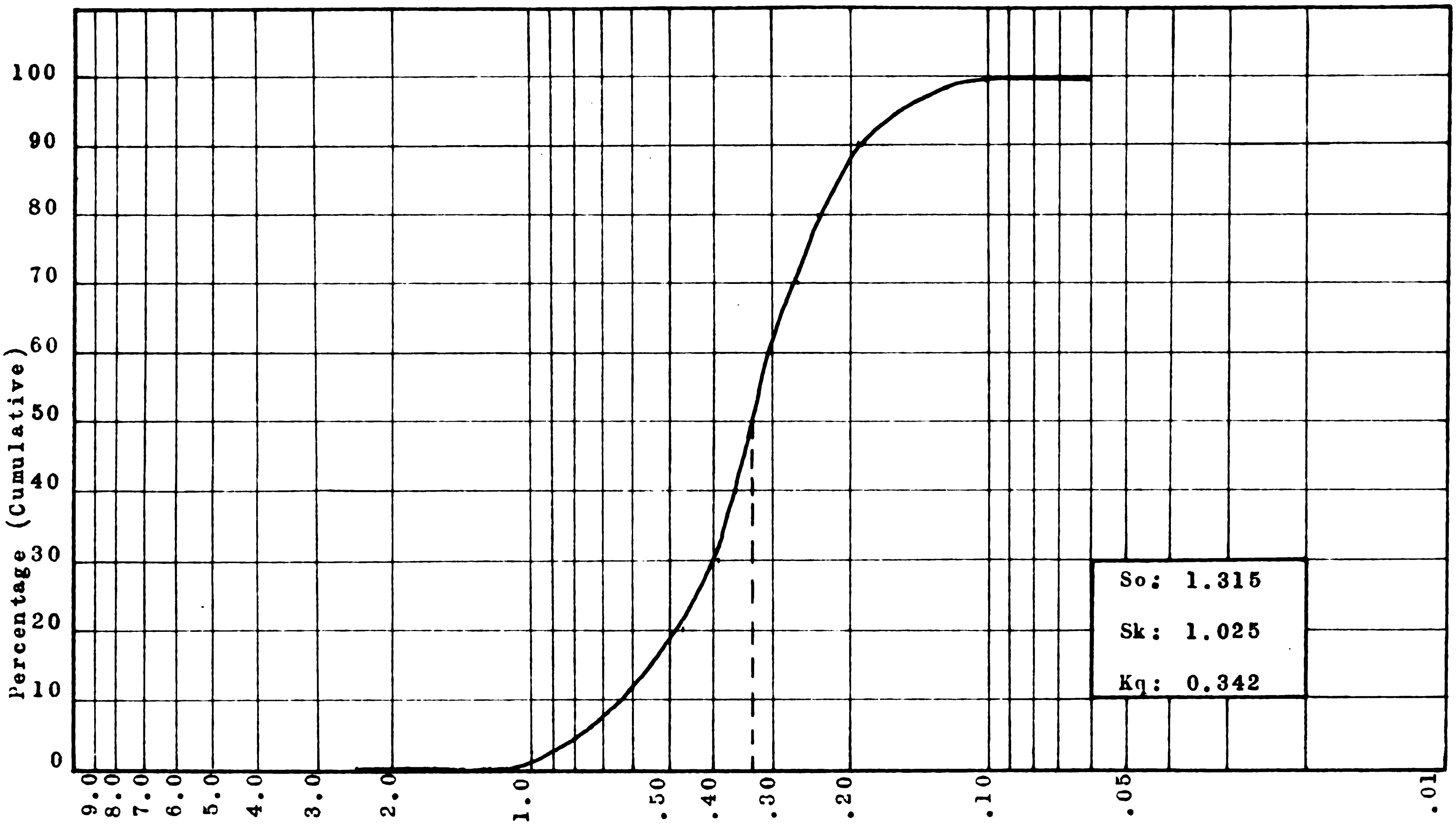


Table 115

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 61



Tyler Sieve Sizes (mm.) Diameter

Table 116

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 62

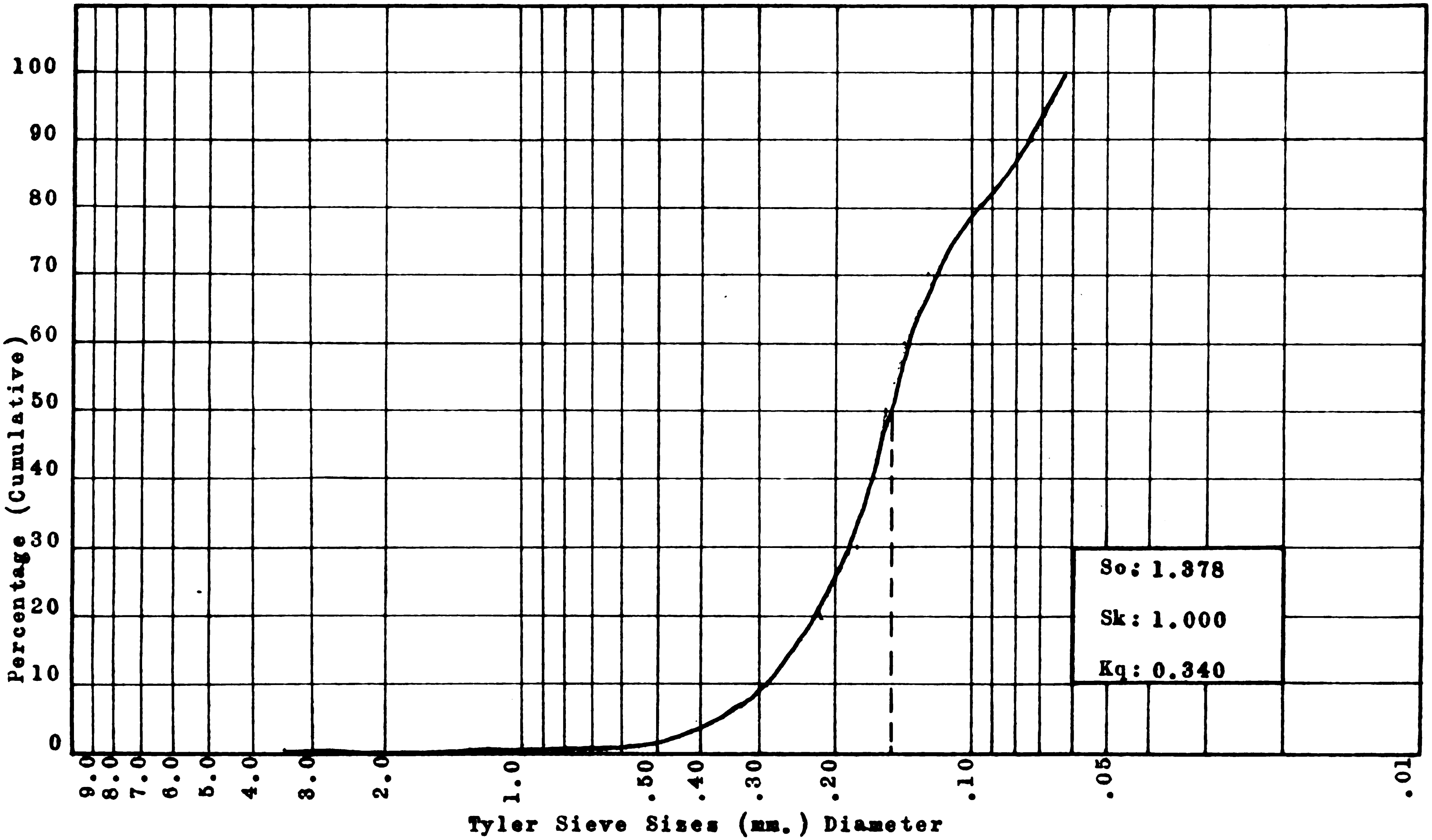


Table 117

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 63

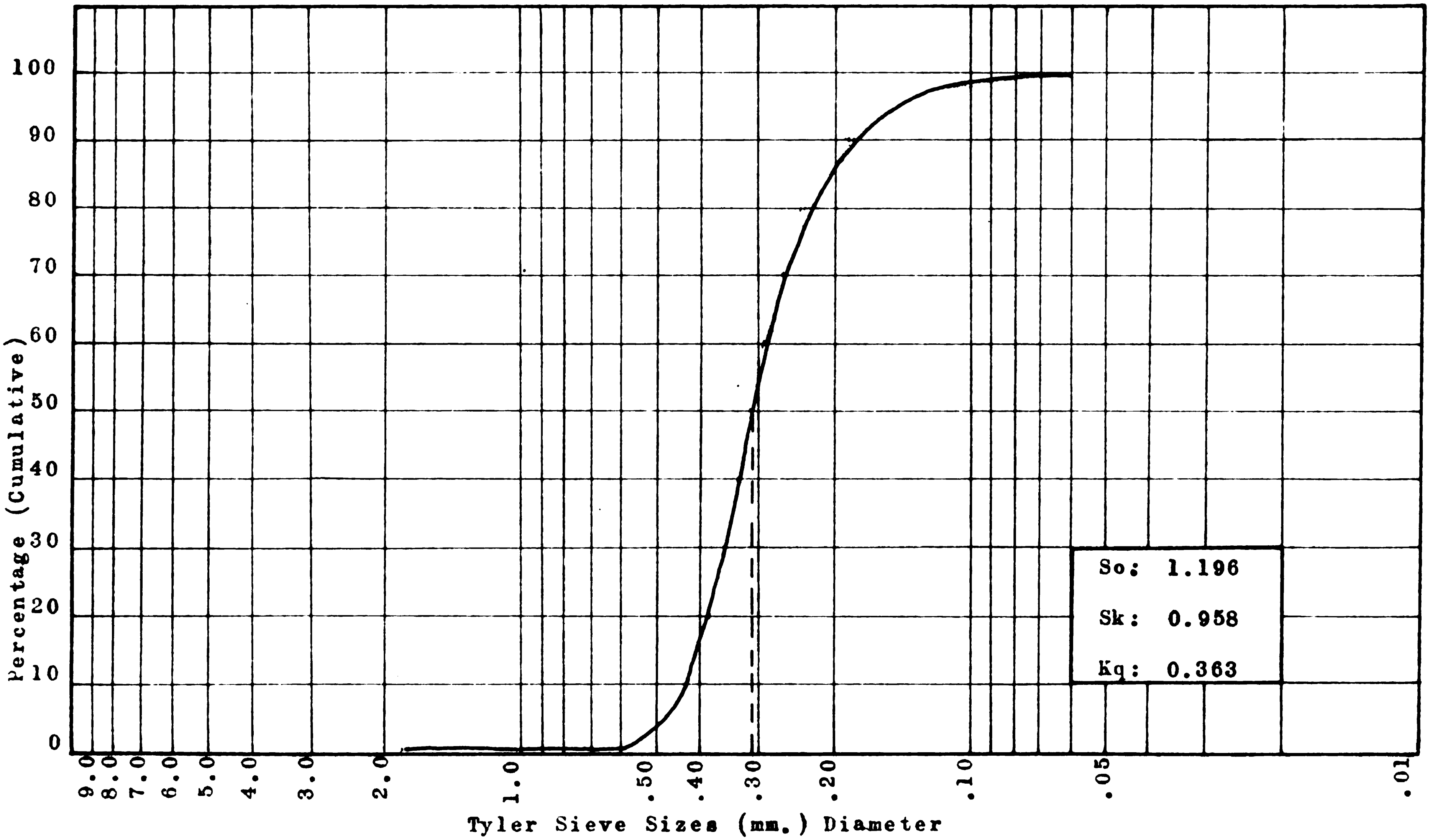


Table 118

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 64

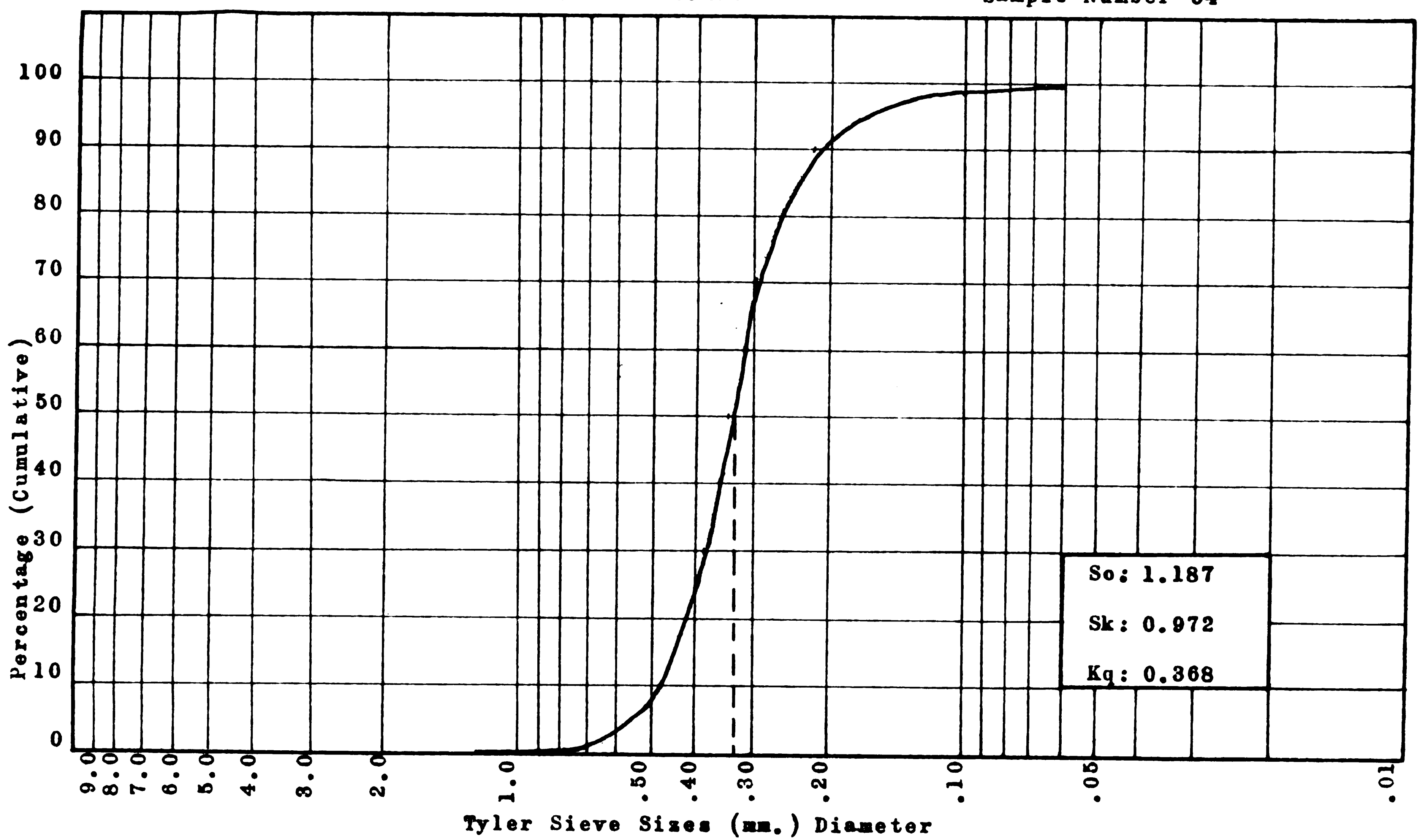


Table 119

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 65

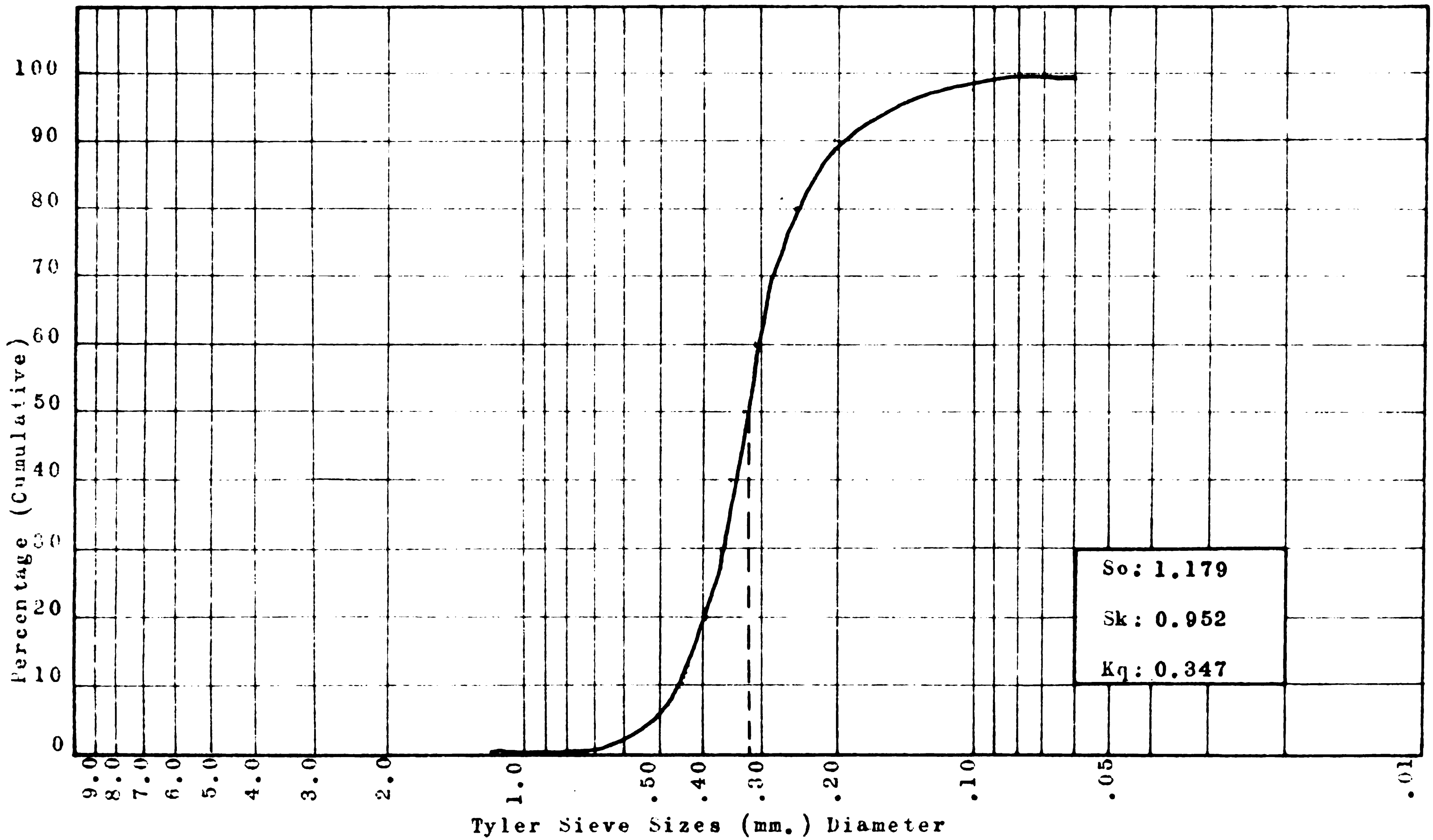


Table 120

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 66

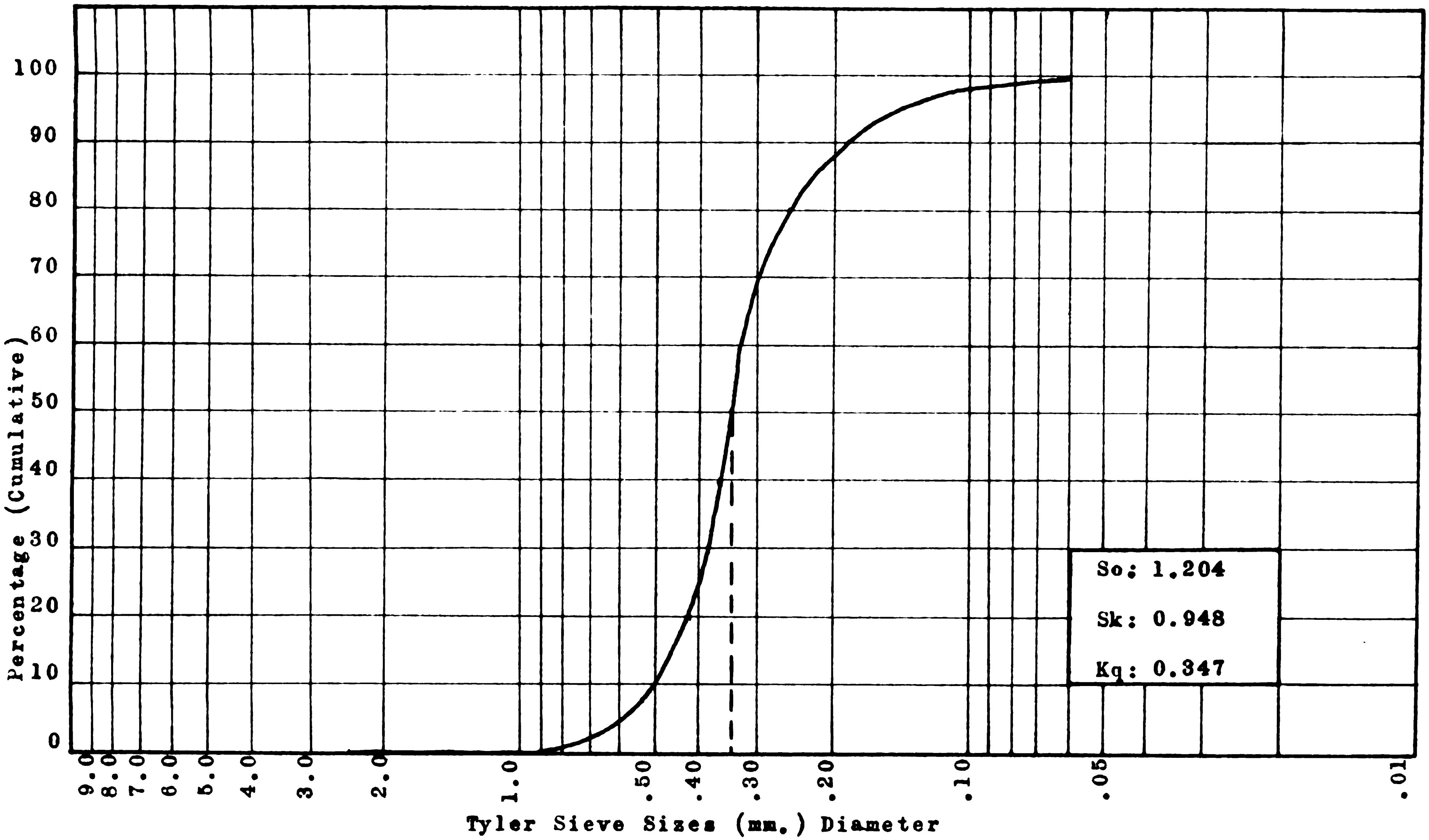


Table 121

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 67

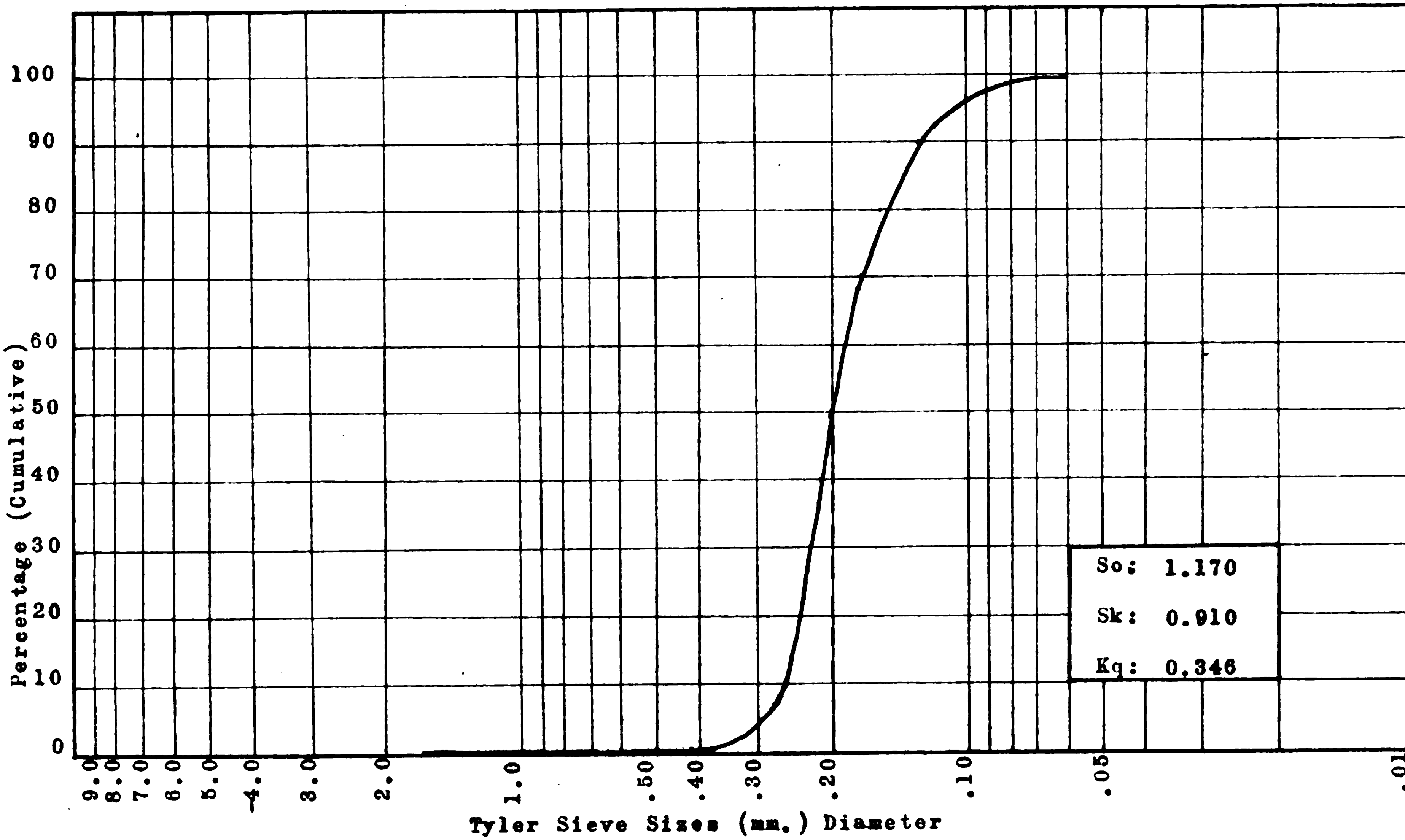
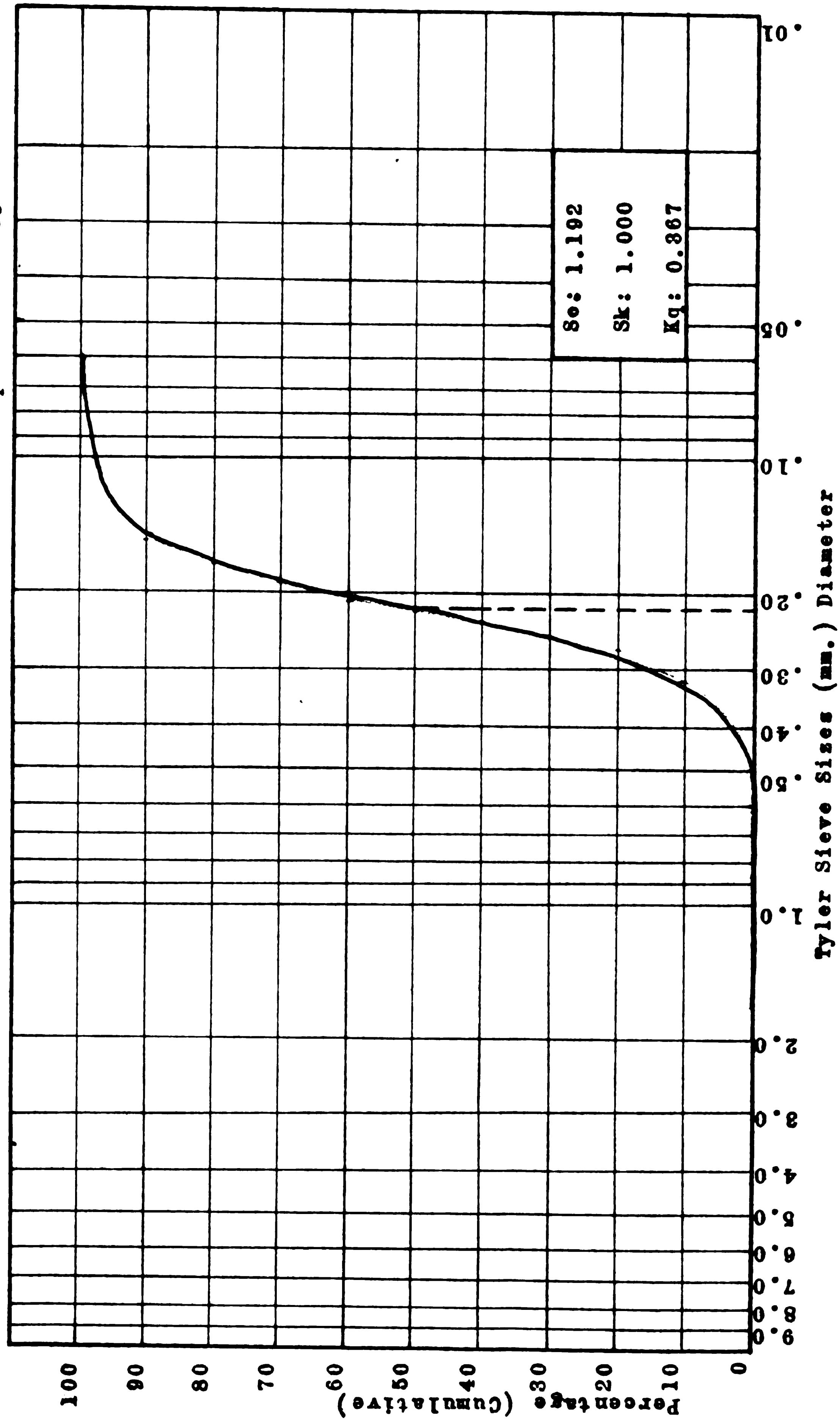
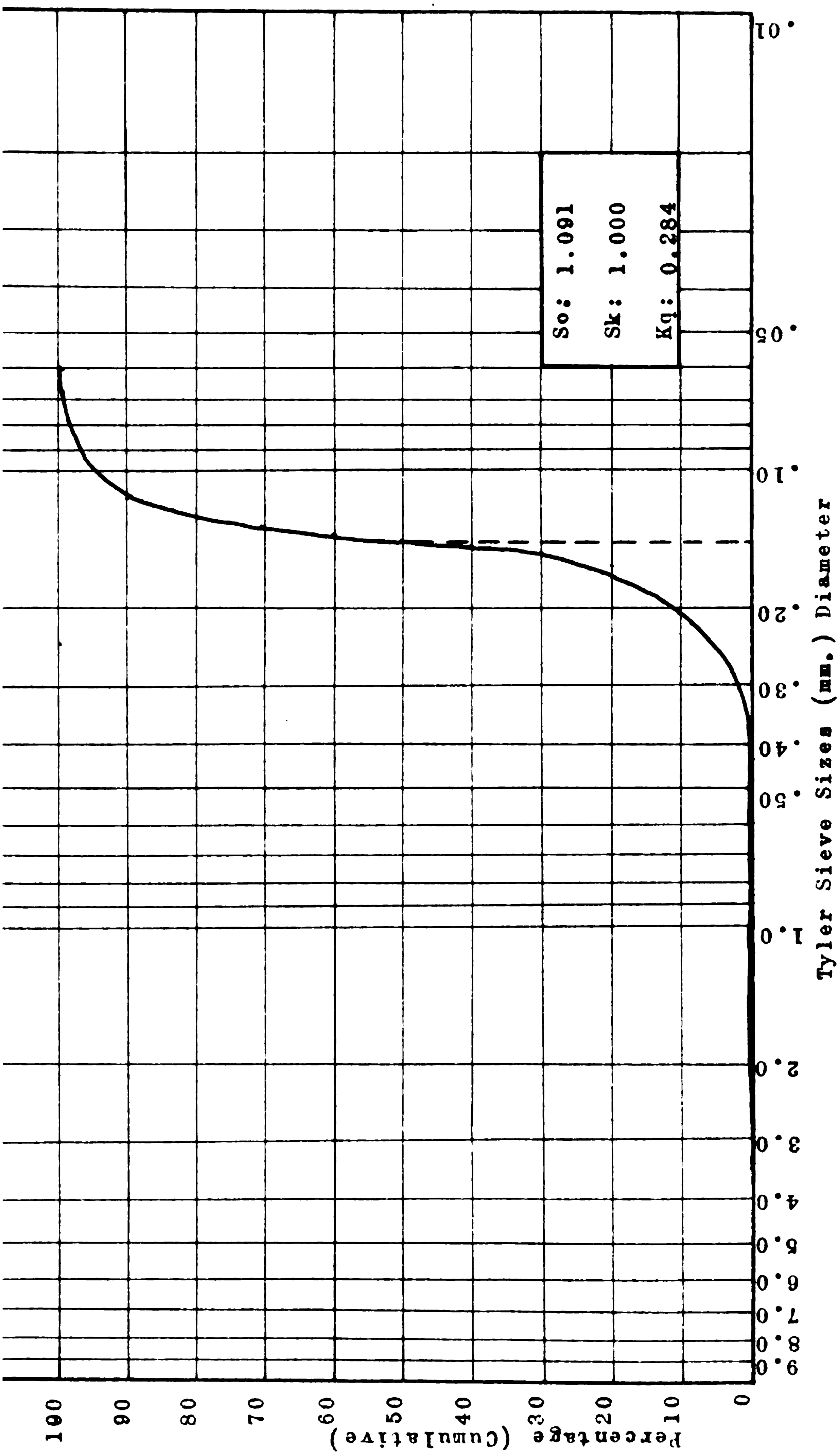


Table 122

CUMULATIVE CURVE OF SIEVE ANALYSIS WEIGHTS

Sample Number 68




So: 1.091
Sk: 1.000
Kq: 0.284
Tyler Sieve Sizes (mm.) Diameter
.01
.05
.10
.20
.30
.40
.50
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
Percentage (Cumulative)
100
90
80
70
60
50
40
30
20
10
0

MEDIAN DIAMETER

Median diameter is defined as the intersection of the 50 per cent line and the cumulative curve. This intersection splits the sediment into two fractions, 50 per cent finer than the median and 50 per cent coarser.

It is commonly recognized that grain size is one of the factors which controls sediment movement, dependent at least in part on current velocity, depth of water, shape, and density of the particle. The median diameter, therefore, often shows some characteristic relation to any one or all of the variables governing sediment movement.

Very little is known of the relationship between median diameter and current velocity owing to the sparcity of bottom current data. It is known that the current velocity at depth usually differs greatly from surface currents, and these currents at depth vary greatly in themselves from one locality to another. Bottom currents range from more than a meter per second to less than a centimeter per second and often are very difficult to record with accuracy (Keunen, 1950).

Laboratory data shows that several factors influence the movement of sand particles. Menard (1950) found that turbulence, depth of water, density, shape and sorting of the particles influence the relation between grain size and mean current velocity. In shallow water experiments, it was found that sand grains can be moved by a slower current if the bed is rippled rather than smooth. This agrees with experiments by Inman (1949) who discovered that fine material often tends to produce a smooth surface which reduces turbulence, thus resulting in greater resistance to movement of the grains. Menard recorded movement of grains 1.0 mm in diameter by current velocity of 18 cm/sec, and 3.0 mm in diameter by velocities of 30 cm/sec. On smooth surfaces, a velocity of 50 cm/sec was required to move a grain 3.0 mm in diameter. Twenhofel (1932) recorded similar data in his studies on currents.

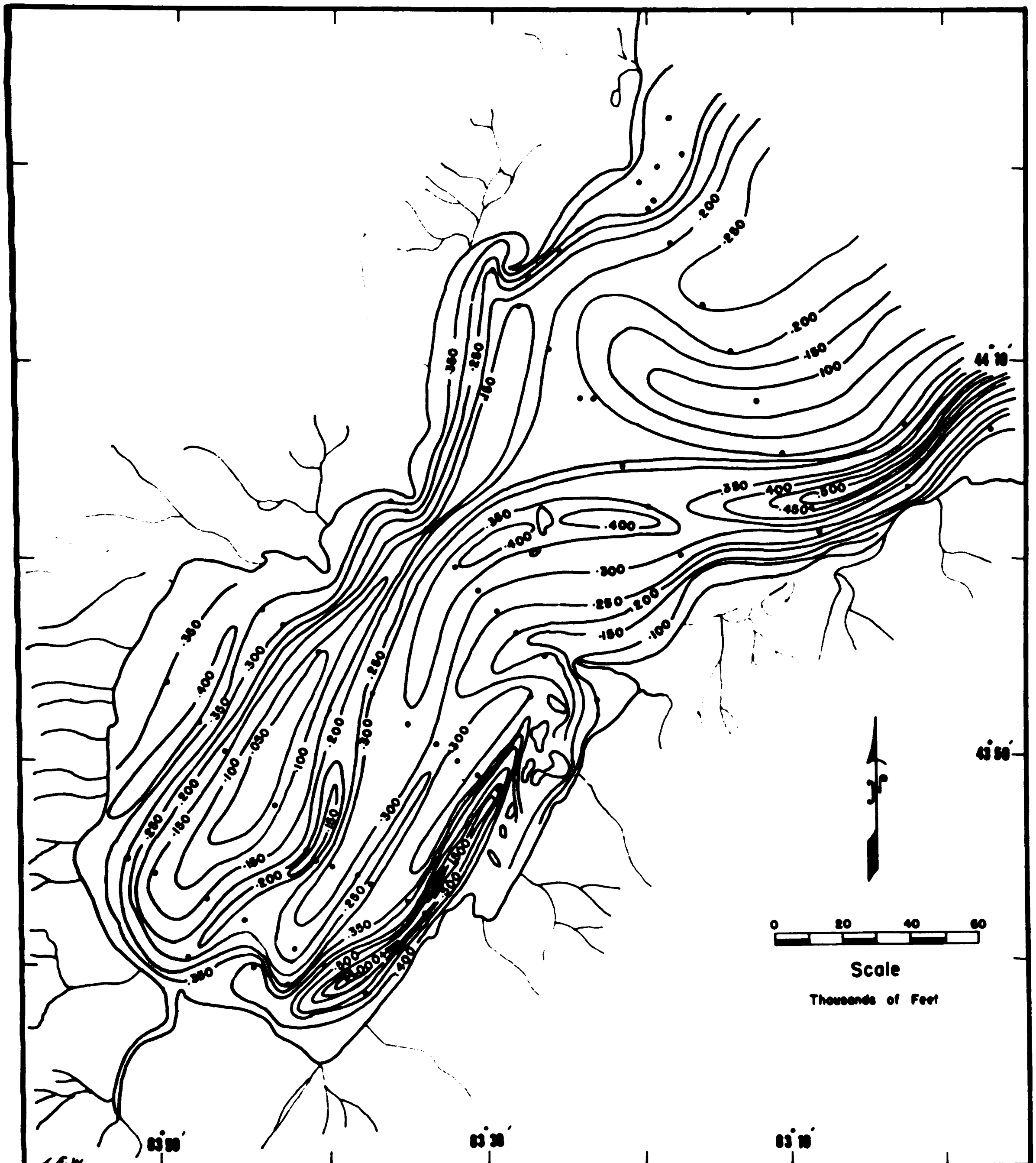
Physical variations in the grains alters any direct relationship between size and velocity, substantiating selective transportation as a result of size, shape, density, etc. It seems probable that water, like wind, is subject to "gusting" because of varying bottom conditions, and a great range in velocities might interrupt a current assumed to have uniform velocity and competency, thus complicating an already complex situation.

Inman noticed that fine sand averaging 0.180 mm was the optimum size for movement by water. Velocities required for movement of a grain increased as the grains became larger or smaller than 0.180 mm. In correlating transportation of sand particles and currents, a general relationship of grain size to tidal currents was observed in San Francisco Bay by Louderback (1939). Krumbein and Aberdeen (1937) report a

remarkable relationship between current and grain size and sorting in Barataria Bay, Louisiana. Currents are forced into a narrow entrance causing deposition of coarser, better sorted materials in the central portion of the bay. The fine, poorly sorted materials are deposited near the shores. Alexander (1934) recognized deposits of rounded quartz sand concentrated in a belt of known prevailing currents on the continental shelf

Plate 3 is an isopleth map of median diameters. Diameters range from near 10.000 mm at location 3 in the southeast corner of the bay, to 0.015 mm at location 27 in the deep water off Point Au Gres. Approximately 96 per cent of the samples fall within or less than the medium sand range. Of these, about 10 per cent are in the very fine sand or silt range. Sediments at locations 3, 21, and 49 are in the pebble, very coarse, and coarse sand range respectively. An area of relatively coarse material is in the southeast corner of the bay, extending eastward to Katechay Island. An area of generally small grain-size is circumscribed by locations 37, 27, 17, 7, and 16 on the northwest side of the bay.

<u>MEDIAN DIAMETER AND DEPTH OF WATER</u> -- In a body of water into which the influx of sediments is not too great, two types of sediment loads are carried. That which is coarse and is moved by traction (or possibly remain stationary) and the fine-grain sediment which is carried in



SAGINAW BAY

MEDIAN DIAMETER

ISOPLETH INTERVAL: .050 mm

PLATE 3

suspension. The very fine materials tend to remain in suspension as long as the water is in motion either by wave or current action.

Generally the optimum condition for settling out of fine sediment is in deep water. Current velocities are assumed to be very slight at depth, and unless the wave action is strong the bottom will remain undisturbed. Furthermore, it has been proved that once a layer of fine material is layed down, its surface offers more resistance to movement of an individual grain than a surface covered by coarse materials (Inman, 1949).

In Saginaw Bay, there is some question whether there is any deep water area not raked by wave or current action. Hough (1942) found coarse material deposits at depths of 140 feet in Cape Cod Bay which he attributed to wave action. Of course, wave action in open areas of large bodies of water is known to extend to greater depths.

A general correlation can be made when comparing contour-line patterns of the depth and the median diamater isopleth maps (Pls. 1 and 3). Fine sediments are found in deep water at locations 37, 27, 17, and 16; and in somewhat shallower water at locations 6 and 7 north of the mouth of the Saginaw River. Fine-grained samples are common in the central part of the open end of the bay. It does not hold true, however, that fine sediments are restricted to deep water as some near-shore sediments taken from shallow

water are fine to silty. These areas are protected and not swept by currents.

Sample 41 falls neither into the category of sediment from deep water nor protected area. It was taken from a depth of less than 20 feet a short distance off Oak Point in what appears to be an exposed area. The median diameter of the grains is 0.086 mm. This collection of fine-grained sediment near such an exposed shoreline may be explained by the projection of Sand Point and the islands to the west. It appears from the isopleth distribution of the data from the various physical properties of the sediments that the currents are deflected away from Sand Point toward Charity Island, swinging shoreward again in the vicinity of Hat Point. From Sand Point eastward, large accumulations of medium sand forms fine beaches. A few rocky prominences are the exception. It is thought that the sand accumulates on shore as a result of the prevailing winds constantly moving the sand shoreward. The shore east of Sand Point is relatively free from major bay currents and is not swept clear of sediment.

In a comprehensive and interesting report on Huron County, Lane (1900) discusses the area between Sand Point and Port Austin. He attributes the large amount of sand accumulation here to rapid deepening of water off shore in contrast to the area from Sand Point westward where there is no break in profile between bay bottom and surrounding lowland. The waves break quite some distance from shore, stranding the muds in marshes and flats.

From Sand Point eastward, however, wave action extends to the beach, and the undertow carries the mud back out to deeper water. The sand is left on the beaches. These shores trend northeast, facing for the most part the prevailing winds. The sand pushed up on the shore is carried inland and forms dunes from Port Austin to Port Crescent and Caseville. Dunes of lesser magnitude extend along the shore to the west of Caseville.

The concentration of sand is attrubuted to the long fetch and partly to the prevalence of "on-shore" winds. Lane suggested that the Mississippian sandstone which underlies much of the area might be a source of the material.

East of Port Austin, the shores become increasingly less sandy and the familiar rocky shore features of Point aux Barques are swept by waves and currents.

Figure 10 shows the relationship between median diameter and depth of water. No linear correlation was found, although there is a concentration of medium-grain sand in the shallow depts. Fine sediment from 3.0 phi diameters and above are scattered throughout the range of depth. From this evidence it is seen that local conditions involving currents, bottom topography, grain shape, sorting, and density are greater factors in grain size distribution than depth alone.

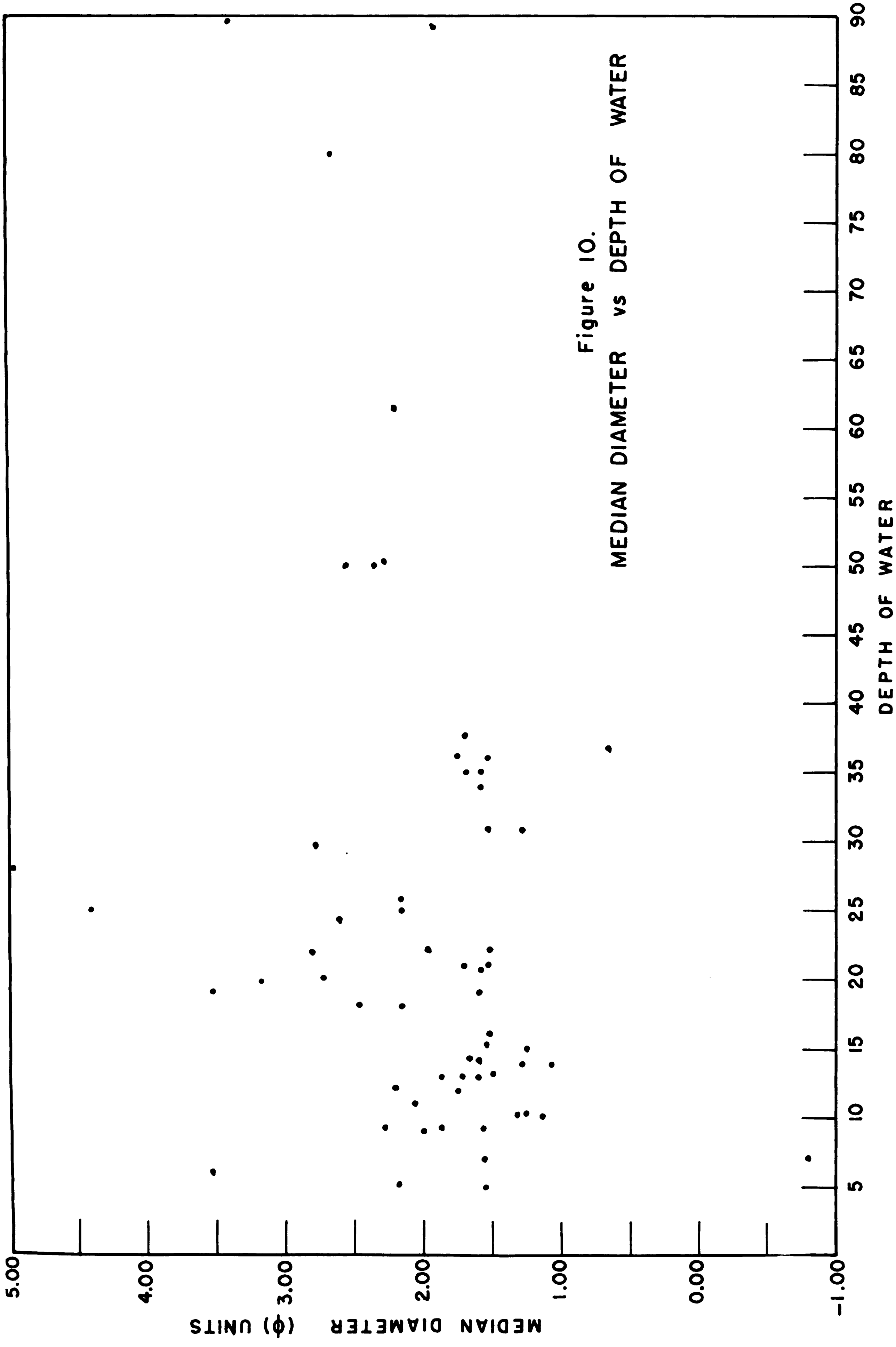


Figure 10.
MEDIAN DIAMETER vs DEPTH OF WATER

A similar condition exists in Buzzards Bay, Massachusetts where there is no correlation between depth and median diameter (Hough, 1940), emphasizing the factor of wave and tidal current action. The same situation holds true for Cape Cod Bay which is also relatively shallow for the most part. Here, local conditions play a greater role in the distribution of sediments than depth. Hough also noted in Cape Cod Bay that coarse material could be found anywhere, but the fines were restricted to deep water of the open bay and protected embayments.

Barataria Bay sediments, as previously mentioned, show a strong dependency on currents rather than depth. Two types of San Francisco Bay sediments discussed by Louderback (1937) include fine sediments deposited at depth under normal conditions and coarse materials deposited at depth as a result of hydraulic currents due to tidal action.

Lauf (1956) noted a distinct relationship between depth and median diameter in Grand Traverse Bay, Michigan, where the water reaches depths of over 500 feet.

MEDIAN DIAMETER AND SKEWNESS -- In the medium sand range (1.5 - 2.0 or 0.175 - 0.350 mm) the average skewness is very close to zero. Sands coarser than 0.350 mm show a strong positive skewness. The finer materials are skewed to both the positive and negative sides (Fig. 11).

MEDIAN DIAMETER AND CURRENTS -- The movement of sediment depends largely on particle size and current velocity.

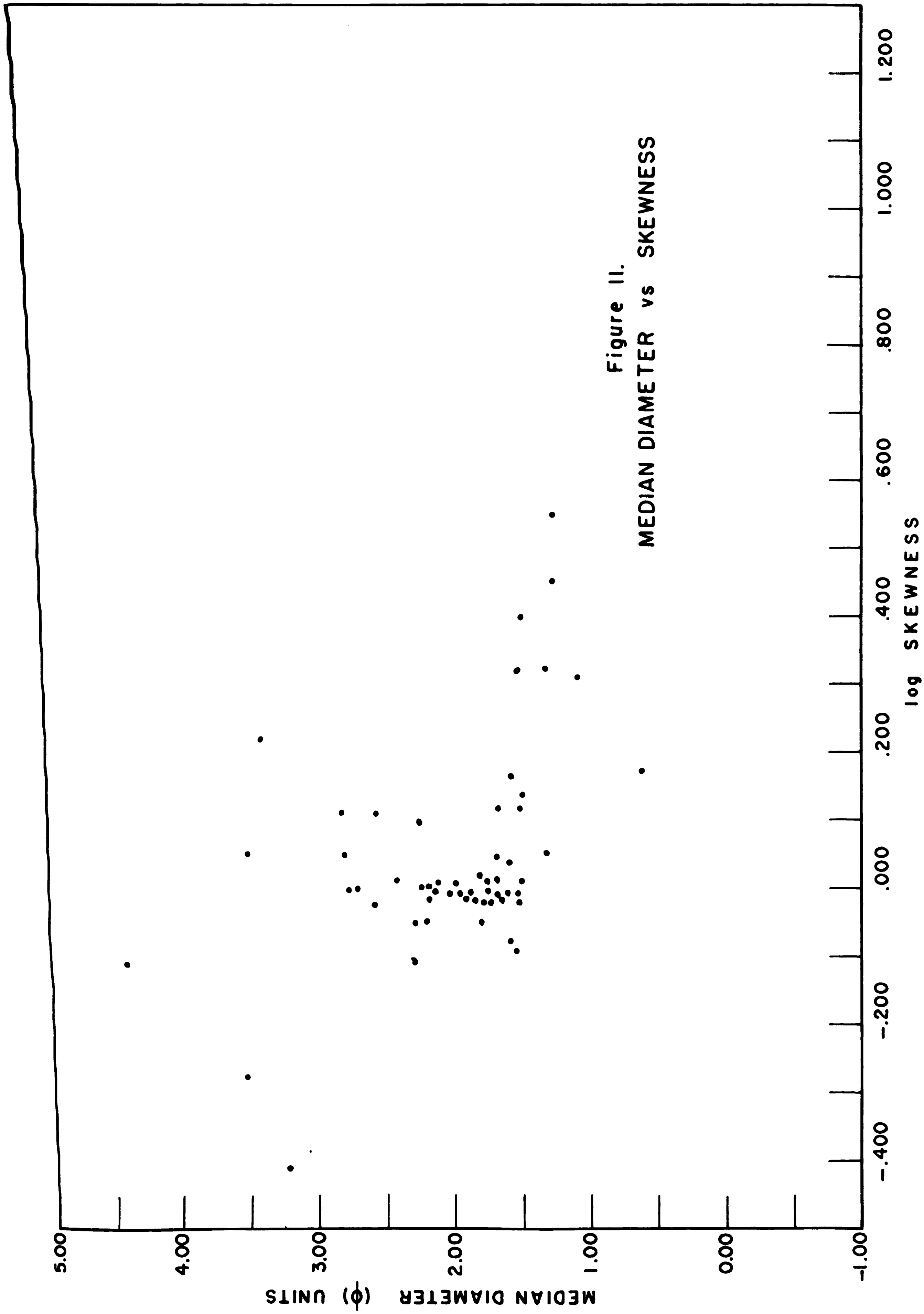


Figure 11.
MEDIAN DIAMETER vs SKEWNESS

So long as the sediment supply does not exceed the transporting power of the water and the depth of the water is not too great for sufficient current velocity to move a sediment resting on the bottom, a correlation between grain size and currents can be established.

In bodies of water in which there is a great range in depth, grain size acts as a depth indicator, decreasing as the depth increases. Grain size also serves as an indicator of current velocity, in which case it is commonly known that currents decrease in deep water. This, of course, is not necessarily true of surface currents.

Since the water in Saginaw Bay is shallow throughout, and there is relatively little relief in bottom topography, sediments entering the bay become a function of the different currents. At the same time, the currents are regulated with respect to bottom topography, shore features, river influence, and winds. As the currents are altered by these factors, so the sediments are moved and adjusted to the hydraulic conditions which most nearly equal physical characteristics of the sediments.

A general current pattern is outlined from a synoptic survey of Lake Huron by Ayers, et al, (1956). It is suggested that a current out of Lake Huron enters the north side of Saginaw Bay and emerges from the south side where it joins a current from the north as it passes around the tip of the "Thumb". In antithesis to this supposition, it

has been pointed out by Hooper (1958) that strong winds from the southeast may cause Lake Huron currents to enter Saginaw Bay at Point aux Barques and exit at Au Sable Point. In either instance, it is assumed that the main flow of water roughly parallels the shore around the bay. Ayers, et al, (1956) state that the outflow of the Saginaw River at Bay City is deflected to the south shore by, "...both prevailing west winds and the rotation of the earth" as well as currents coming from the northeast. It is also pointed out by Ayers that gravity and prevailing winds hold the current close to the shore during its eastward movement. The median diameter distribution follows such a pattern. Data obtained from the grain size analysis indicate that water is deflected toward Charity Island in the vicinity of Sand Point, then turns shoreward again near Hat Point. Coarse materials deposited in the southwest corner of the bay and eastward along the south shore verify the strong current deflection of the Saginaw River.

The currents in the central and northwest part of the western half of the bay are not fully understood. The glacial Saginaw River channel extends eastward along the north shore almost in line with what is believed to be the path of westward flowing currents from Lake Huron. Isopleth patterns in several analyses suggest that a west moving current is deflected away from the shore in the vicinity of Point Lookout. A large part is directed toward the center of the bay where it ultimately joins and probably helps deflect the Saginaw River inflow. A zone of coarse material seems to indicate that currents continue in part to the west end of the bay in the shallow water along the north shore; however, the current patterns are generally weak and it is difficult to explain currents swinging shoreward after being deflected away from Point Lookout. Intermittent southeast winds and local shore currents may supply the force for more sand in this area.

Drift bottle studies by Johnson (1958) indicate a very close correlation between surface currents and winds. He attributes the great variability in surface currents to constantly changing wind directions. This lack of definite surface current patterns was particularly apparent in the western half of the bay. It is difficult to determine how much effect these variations in daily surface currents have on the over-all pattern of sedimentary deposition in shallow water. Only a series of samples taken daily could possibly reflect changes of the order described by Johnson. It is my belief, however, that the gross picture alters very little and the distribution of sediments according to size coincides with the prevailing currents of the bay which may be altered locally. This cannot be traced accurately by drift bottles.

The median diameter pattern in the center of the open end of the bay suggests a lesser current which deflects the main current stream to the south shore near Hat Point.

Studies of Lake Huron indicate that currents penetrate into the outer reaches of the bay varying distances, but as yet their exact course has not been accurately determined. Ayres, et al, (1956) discusses Saginaw Bay in terms of a typical estuary. "In the spring there is usually a slowly rotating eddy in the center of an estuary and possibly the bay has a similar feature at that time of year." One can only speculate on the effect such an eddying would have on the sediments in moderately deep water.

Many variables are introduced which make interpretation difficult and unreliable at times. If it were possible to eliminate the depth factor, if all the grains were of equal density, shape, and texture, and if the current velocities were not altered by wind or surface features, correlations could be established.

It seems then that median diameter, when associated with current movement and interpreted in light of all the variables, can be a very useful tool in determining sediment distribution.

SORTING

Sorting, as defined on page 97, is a function of the deviation of the maximum and minimum grain sizes from the median. Sorting, therefore, may be directly related to the hydraulic conditions existing in a body of water as well as the physical properties related to the individual grains.

Russell (1939) divides sorting action into two types: One he terms "local" sorting which involves the assortment of particles at a particular locality, and the other is "progressive" sorting which is the assortment of particles in the direction of transportation. The latter seems to apply best to currents that are unidirectional and are not affected by varying winds. Rivers or longshore currents are related to this type of current. Russell states further that, "The most important factors involved in both types of sorting appear to be the size, shape, and specific gravity of the particles; the velocity, degree of turbulence, viscosity, and specific gravity of the transporting agent."

Trask (1930) set up values for degrees of sorting which are commonly accepted and much quoted. He determined that a value of 2.5 (log So 0.397) or less indicates a well sorted sediment, a value of 3.0 (log So 0.477) a sediment of average sorting, and any values greater than 4.5 (log So 0.653) were designated as poorly sorted sediments. It should be kept in mind that Trask's sorting is geometric and cannot be arithmetically compared.

An isopleth map of log Sorting is shown on plate 4. Sorting values range from very poor, 6.116 (log So 0.786) in Sample 2, to 1.179 (log So 0.072) in Sample 69. Nearly 75 per cent of the samples have a sorting value well above that considered good according to Trask's factors. It should be remembered that Trask used the 25 and 75 percentiles in his calculations of sorting, thus only 50 per cent of the sediment was taken into consideration. Sixty-eight per cent of the distribution, between the 16th and 84th percentiles, was used in this investigation. It was found that by using 18 per cent more of the distribution curve the sorting was decreased by nearly 50 per cent in many samples.

Poor sorting is restricted to two general areas. One zone parallels the north shore in the vicinity of Point Au Gres, outlined by locations 18, 29, and 38 (Sorting for Sample 38 is approximated).[1]

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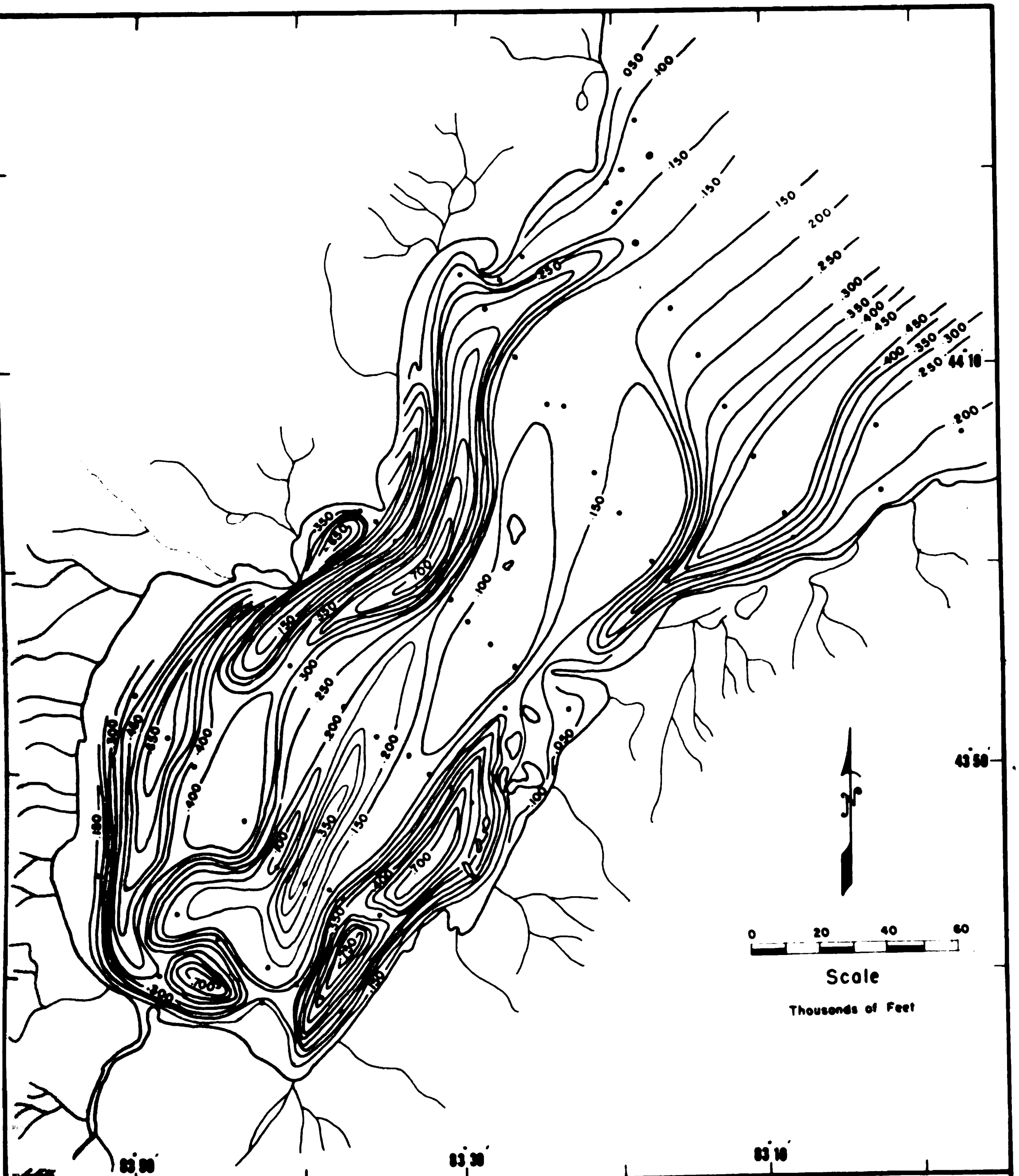
[1]When there is extremely coarse or fine material in a sample, often the cumulative curve does not intersect the 16 and 84 per cent lines respectively. Under such circumstances the cumulative curves are projected to the 16 and 84 per cent lines so that sorting can be estimated.



SAGINAW BAY

log SORTING DISTRIBUTION

ISOPLETH INTERVAL: 0.050 Units

PLATE 4

These three samples were taken from moderately shallow water on the edge of the glacial Saginaw River depression. A narrow band of poorly sorted sediments, in the vicinity of locations 27 and 36, lies within the trough (Sample 27 is approximated).

A second zone, somewhat more irregular, extends westward from Katechay Island at location 21 (sorting approximated) in a trough of somewhat deeper water to locations 1, 2, 3, and 4(?). Sample 3 is approximated and no sample was recovered from location 4. Sediments at locations 10 and 11, lying between locations 21 and 1, possess only average to below average sorting.

Samples 1, 2, and 3 are probably closely related to Sample 55, taken southeast of the mouth of the Saginaw River, and Sample 4. The explanation for this poor sorting will be discussed later.

An area of moderately poor sorting is circumscribed by locations 7, 16, 17, and 27. A similar area is outlined in the vicinity of Oak Point and Hat Point by locations 41, 48, 49, and BT-26. Sample 13 has only moderate sorting.

The area with best sorting lies in the shallow water off Sand Point toward Charity Island, where Samples 32, 33, and 34 were taken.

SORTING AND MEDIAN DIAMETER -- The relationship between sorting and median diameter has been discussed at considerable length by many students of sedimentation.

From the definition of sorting one can see that to have a well sorted sample the grain-size distribution must be small. Must of us have observed such conditions in uniform beach sands which have been worked by both waves and wind, and as a result the fine materials have been carried to deep water in suspension by the tides or have been blown farther inland by the wind. The sand particles found on the beach were deposited there by waves or currents suited to carrying that particular grain size.

There are many conditions which may alter this uniform distribution of particles, causing both coarse and fine materials to exist together. This may occur when the supply of material exceeds the capacity of the transporting agent (Kuenen, 1950); however, this is not likely to happen in Saginaw Bay where the surrounding lowland is drained by rivers with very low gradients. With the exception of the Saginaw River sediments, it is thought that other rivers carry silt and fine sand into the bay.

Figure 12 shows the relationship between sorting and median diameter. The concentration of medium sand, 1.5 to 2.5 ϕ, occurs in sediments with a log Sorting of 0.200 to 0.100. The finer sands generally possess somewhat poorer sorting; however, the poorest sorting occurs in sediments of 0.500 mm and coarser. (Sorting for Samples 2, 3, 4, 21, 27, and 38 are approximated and are not plotted on the graph.)

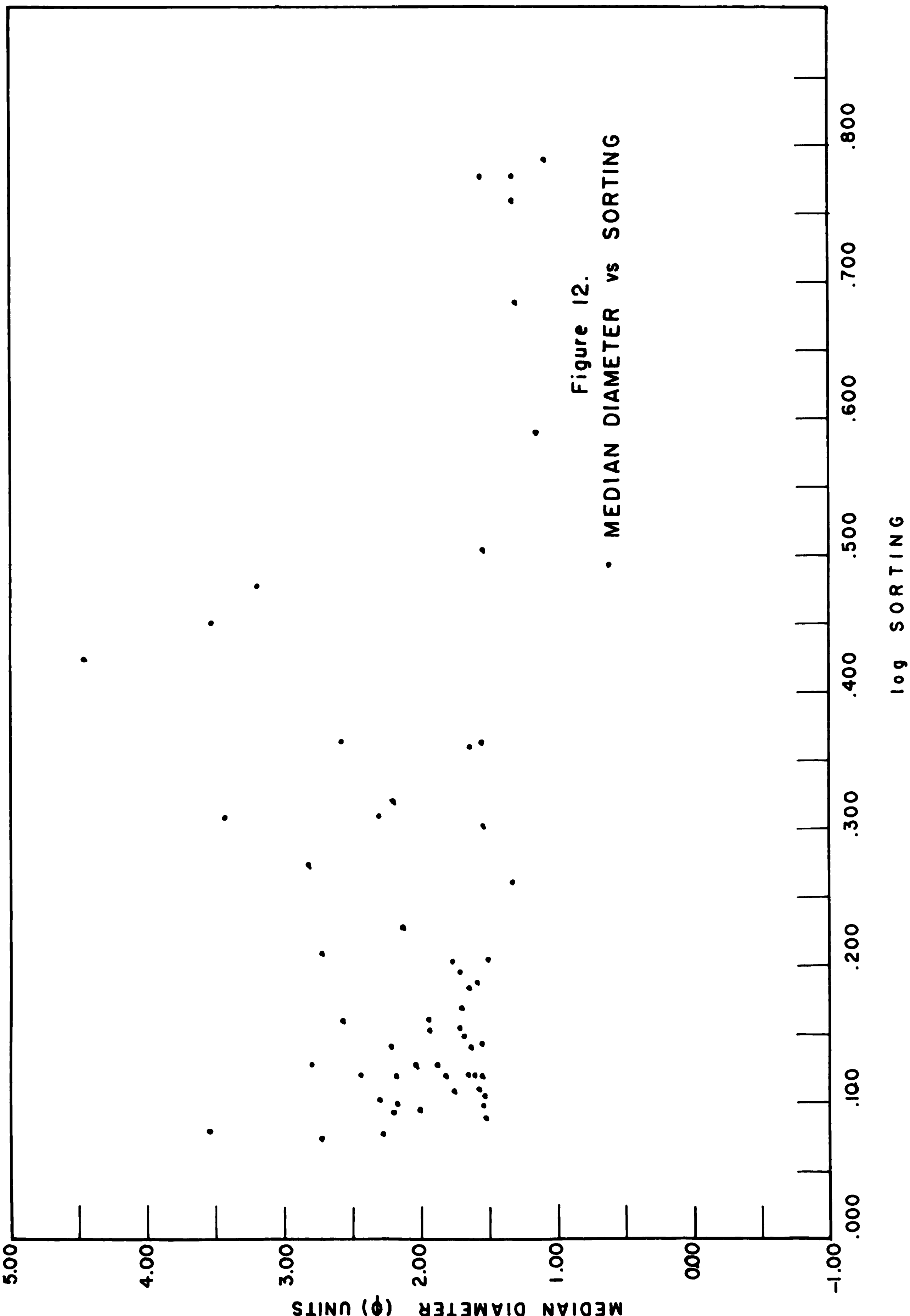


Figure 12.
• MEDIAN DIAMETER vs SORTING

It can be said with reservation that poorer sorting occurs most frequently in the finer sediments, or better sorting tends to occur in the medium sand range.

Inasmuch as grain size appears largely as a function of currents, the sorting in Saginaw Bay also can be related to these same factors. Inman (1949) relates the degree of sorting to the ability of a fluid to sort out one grain size from another. The variations in sorting of sands from the bay are due to local conditions resulting from changes in current velocity, source and amount of material supplied, and depth of water.

It is difficult to say how much material has been carried into the bay from the surrounding glacial drift. Cores removed from the navigation channel by the Corps of Engineers, Detroit, (1956) record upwards of 50 feet of sediment. One cannot say without further investigation whether the material is post glacial or not. It is suggested by some that a body of water receiving sediment from glacial drift, which is already poorly sorted, would necessarily have poorly sorted sediments. This might be expected in an area in which large quantities of material are being carried into the bay, but certainly this is not the case in Saginaw Bay. The sluggish streams probably sort the material to a considerable degree before they enter the bay.

It seems more probable that the zones of pebbles and cobbles represent remnants of coarse materials left by the glacier as it retreated. Since that time, wave and current action has been unable to move them any appreaciable distance. A more extensive investigation of the areas of coarse materials and "rock" bottom is needed before this question can be answered. Hough (1942) found a similar situation in Cape Cod Bay, Buzzards Bay (1940), and in Lake Michigan (1935). He interpreted the Lake Michigan sediments as a lag concentration of the coarser constituents of glacial till produced by wave and current action.

In each case it was difficult to determine whether the material was left by glaciers, represented an old beach, or concentrated since glaciation as a result of severe wave action.

In contrast to Saginaw Bay, Inman and Chamberlain (1955) noted in the bay areas of LaJolla, California; Rockport, Texas; and the Mississippi delt area that the distribution of sediment is dependent upon the type and amount of sediment and process of transportation. In areas where normal sand load is deposited into the bays, the fines are carried into deep, quiet water, and sandy beaches are built up where the fetch is sufficiently great to generate waves. In regions where the sediment load is greater than the transporting agents, such as in the confined areas near the Mississippi delta, both fine and coarse sediments occur together, and they reflect strongly the source area from which they came.

Studies made on several bodies of water throughout the world show a general relationship between grain size and sorting. It may be assumed with minor exceptions, depending largely on a third factor - depth of water, that good sorting is generally associated with sand particles (0.150 mm plus or minus), and poor sorting occurs in varying degrees toward the fine and coarse ends of the distribution.

Poor sorting in the fine sediments may be explained in this manner: During extreme conditions in a given body of water strong currents or wave action carry coarse materials into areas of normally quiet water. Large pebbles or cobbles are rolled down slopes into deep trenches or storm waves carry coarse material into protected areas. The coarse materials are destined to be forever mixed with the very fine sand and silt. Ice rafting may also introduce heterogenity to a uniform mixture of fine sediments.

Inman (1949) notes further that poor sorting in fine sediments often may be attributed to the fact that a fluid does not readily differentiate between the smaller diameters, but rather tends to carry particles ranging from clay to fine sand with equal ease. If good sorting in very fine sediments is prevelant, it may be due to the great differences in settling velocities of fine particles, although the depth factor in Saginaw Bay is likely to rule out such sorting.

Another phenomenon which may cause poor sorting is the transportation of very fine sediments by bubbles on or near the surface of the water. This has been observed by Menard (1950) and McKelvey (1941), and is regarded as a means of carrying sizeable quantities of material in agglomerates composed of bubbles and grains held together by surface tension. Transportation of this sort is controlled largely by surface currents and deposition occurs whenever and where-ever surface tension is broken by turbulence or some other disturbance. Deposition is independent of any subsurface hydraulic conditions.

The relation between poor sorting and fine grained sediments has been noted by many students of sedimentation. Trowbridge and Shepard (1932) found a general relationship between size and sorting in Massachusetts Bay sediments. Silts from the deeper water showed poorer sorting than the fine and medium sand near the beaches. This suggested two sediment loads carried under different conditions. Hough (1940) found poor sorting in the fine sediments in contrast to good sorting in the sand size particles in Buzzards Bay, Massachusetts. In his study of Cape Cod Bay (1942) he noted good sorting in coarse sediments. The fine sediments on the other hand were not so well sorted although the sorting factor was about 2.0 according to Trask's scale.

Griffiths (1951), in a study on some Caribbean unconsolidated sediments, found a good correlation between size and sorting. He noticed, however, that factors such as length of time and "intensity" of deposition tend to alter the relationship. In essence, this means the longer the sediment is under the effect of waves and currents the better the correlation. Thus when the supply of material exceeds the transporting power, the sediments never reach a state of equilibrium through long reworking. Griffiths suggests that poor sorting associated with coarse materials may be a result of immature sediments deposited after a short distance of aqueous transport. In analogy to this supposition, locations 1, 2, 3, 4, 54, and 55 represent an area which may intermittently receive large quantities of coarse materials from the Saginaw River as its sediment load is deflected upon entering into Saginaw Bay. This area is not only one of generally coarse, but one of very poorly sorted sediments. The effect of this deposition extends as far eastward as Katechay Island (Sample 21).

In the Red Sea sediments, Shukri and Higazy (1944) found good sorting in the 0.150 mm range. Sorting becomes poorer in the very fine sediments. Krumbein and Aberdeen (1937) related sorting with the same conditions which control median diameter, and noted a decrease in median diameter with a decrease in sorting.

It is likely that better sorting may be found in the extensive sand beaches from Sand Point toward Point aux Barques, including Oak Point and the Huron dunes area. This area, and the shoreline directly across the bay in the vicinity of Tawas City, are open to wave action as a result of greater fetch.

It is noted that near Oak Point on the southeast side of the bay where large quantities of sand have accumulated, Sample 41 from this locality is very fine-grained and has only moderate sorting. Sorting and median diameter isopleth maps suggest that the main currents deflected around Sand Point do not move shoreward again until in the vicinity of location 49 off Hat Point. Here, coarser material and a noticeable lack of sorting is present. The area around location 48 was too rocky to produce any sediment.

SORTING AND DEPTH OF WATER -- Wave action and currents are factors governing distribution and sorting of particles; and it is generally agreed that these factors are more active in shallow water. Better sorting on beaches or in shallow water results from waves or currents carrying away the fine particles. The sand particles are distributed according to current intensity and the hydraulic equivalent of the grains.

Figure 13 shows no linear correlation between depth of water and sorting. Most of the samples possessing a log Sorting of less than 0.200 were taken in water less than 50 feet deep. It is interesting to note that most of the sediments possessing poor sorting were in water less than 25 feet deep. From this information it must be concluded that sorting in Saginaw Bay is only locally related to depth of water, and where depth of water is related to sorting, the water is not disturbed greatly by currents or wave action.

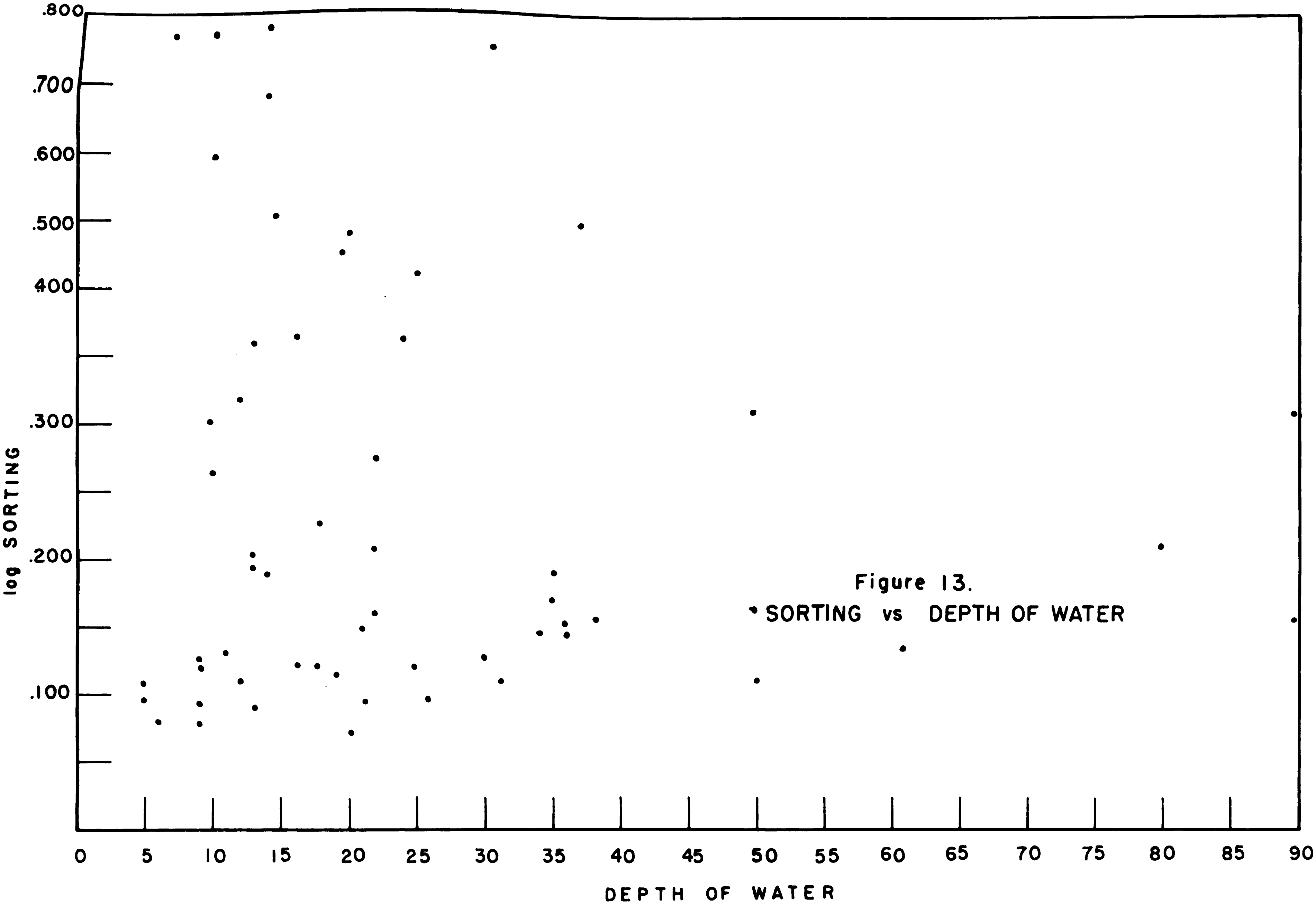


Figure 13.
SORTING vs DEPTH OF WATER

SORTING AND SKEWNESS -- There is no linear correlation between skewness and sorting (Fig. 14). Those samples which are highly skewed to the fine side also are poorly sorted. The preponderance of the samples which show very little skewness have very good sorting. Hough, during his work on Cape Cod sediments, also found good sorting in the samples which had log zero skewness and poor sorting in sediments which were skewed to the fine side.

SORTING AND CURRENTS -- Sorting and median diameter are similar in that they are dependent on many of the same variables. The "sorting out" or selecting of sand according to shape, size, and density by water action lends it well to current association when the various hydraulic properties necessary to assort the materials are known.

When the depth factor is not great, sorting becomes an important device in measuring current trends. But even though depth is always a factor to some degree it merely becomes another moment to which currents will conform and the sediments in turn will adjust. Sorting, therefore, may not only outline the current patterns as controlled by depth, winds, and surface features, but may indicate the kind of sediments which are being moved.

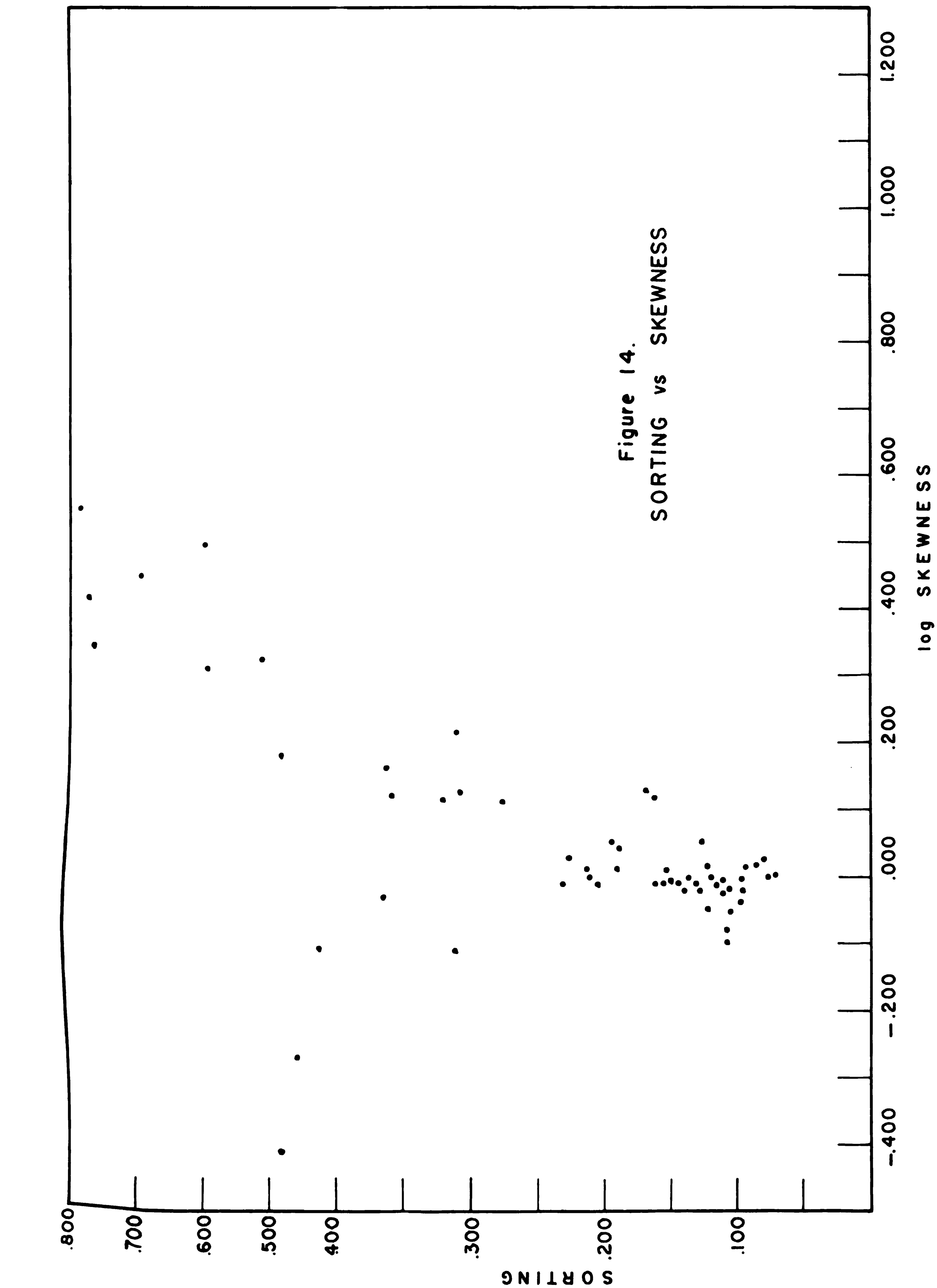


Figure 14.
SORTING vs SKEWNESS

HEAVY MINERALS

From a portion of sediment split from the original sample, two size-grade fractions were arbitrarily established. The 0.177 mm (80) sieve, which falls between fine and medium sand in the Wentworth scale, was chosen as the dividing line between "coarse" and "fine" fractions.

Each fraction consisted of two grams of sample, except where the sediment was either too fine or too coarse to allow collection of two grams of sample in both size grades. A heavy mineral separate was made by placing the sand in a funnel filled with bromoform (Sp. G. 2.68) and allowing the heavies to settle. This process is discussed in detail by Krumbein and Pettijohn (1938).

The heavies were weighed and the percentage of the two size-grades calculated. Data are shown in Tables 124 and 125. The total heavy mineral percentage for the entire sample is shown in Table 126. The light fractions were saved for roundness and sphericity determinations (p. 238).

The distribution of heavy mineral percentage is shown on Plate 5. Heavy mineral percentages range from 0.624 in Sample 27 to 11.508 in Sample 8. Nearly two-thirds of the samples contain between 1.000 and 3.000 per cent heavies. It is interesting to note that of the seven samples that contain more than 5.000 per cent heavy minerals, all but three are within three miles of the shore and all but two are within five miles of the shore.

Table 124

HEAVY MINERAL PERCENTAGES

Tyler Sieve Size:
(+) .177 mm diameter

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
1	2.0030	0.0184	0.919
2	2.0003	0.0191	0.955
3	2.0000	0.0194	0.970
5	2.0003	0.0071	0.355
6	2.0000	0.0057	0.285
7	2.0000	0.0182	0.910
8	2.0005	0.0159	0.795
9	2.0000	0.0093	0.465
10	2.0007	0.0211	1.055
11	2.0003	0.0157	0.785
12	2.0001	0.0129	0.645
13	2.0002	0.0136	0.680
14	2.0001	0.0109	0.545
15	2.0004	0.0080	0.400
16	0.5932	0.0026	0.438
17	2.0000	0.0059	0.295
18	2.0000	0.0158	0.790
19	2.0000	0.0094	0.470
21	2.0002	0.0200	1.000
22	2.0004	0.0036	0.180
23	2.0004	0.0073	0.365
24	2.0001	0.0143	0.715

Table 124

HEAVY MINERAL PERCENTAGES, continued

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
25	2.0000	0.0365	1.825
26	2.0001	0.0182	0.910
27	1.9560	0.0056	0.286
28	2.0001	0.0103	0.515
29	2.0004	0.0150	0.750
30	2.0002	0.1079	5.395
31	1.3792	0.0031	0.225
32	2.0003	0.0910	4.549
33	2.0000	0.1246	6.230
34	2.0001	0.0407	2.035
35	2.0002	0.0062	0.310
36	2.0003	0.0161	0.805
37	2.0001	0.0057	0.285
38	2.0000	0.0157	0.785
39	2.0008	0.0153	0.765
41	1.9583	0.0118	0.603
42	2.0004	0.0075	0.375
43	2.0001	0.0200	1.000
45	2.0002	0.0067	0.335
46	2.0000	0.0078	0.390
47	2.0007	0.0086	0.430
49	2.0007	0.0108	0.540
50	2.0005	0.0064	0.320
51	2.0008	0.0071	0.355

Table 124

HEAVY MINERAL PERCENTAGES, continued

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
52	2.0007	0.0124	0.620
53	2.0000	0.0214	0.070
54	2.0002	0.0134	0.670
55	2.0000	0.0082	0.410
56	2.0004	0.0219	1.095
59	2.0003	0.0106	0.530
61	2.0000	0.0133	0.665
62	2.0000	0.0068	0.340
63	2.0000	0.0021	0.105
64	2.0000	0.0181	0.905
65	2.0002	0.0140	0.700
66	2.0003	0.0130	0.650
67	2.0003	0.0144	0.720
68	2.0000	0.0076	0.380
69	2.0005	0.0010	0.050

Table 125

HEAVY MINERAL PERCENTAGES

Tyler Sieve Size:
(-) .177 mm diameter

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
1	2.0005	0.0830	4.149
2	2.0006	0.1192	5.958
3	2.0002	0.0978	4.890
5	2.0004	0.0641	3.204
6	2.0005	0.0647	3.234
7	2.0008	0.0692	3.459
8	2.0001	0.4445	22.224
9	1.5394	0.0560	3.638
10	2.0005	0.0669	3.344
11	2.0002	0.0836	4.180
12	1.9450	0.0669	3.440
13	2.0002	0.0846	4.230
14	2.0002	0.0557	2.785
15	2.0000	0.0977	4.885
16	2.0001	0.0234	1.170
17	2.0004	0.0712	3.559
18	2.0002	0.1130	5.649
19	2.0001	0.1342	6.710
21	2.0010	0.0966	4.828
22	2.0007	0.0434	2.169
23	2.0001	0.1983	9.915
24	2.0005	0.0589	2.944

Table 125

HEAVY MINERAL PERCENTAGES, continued

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
25	2.0004	0.0660	3.299
26	2.0000	0.0565	2.825
27	2.0007	0.9547	1.982
28	2.0001	0.1482	7.410
29	2.0006	0.1383	6.913
30	2.0005	0.0708	3.539
31	2.0006	0.0338	1.690
32	2.0003	0.3493	17.462
33	2.0001	0.1749	8.745
34	2.0002	0.2728	13.639
35	2.0001	0.0816	4.080
36	0.6966	0.0461	6.618
37	2.0003	0.0651	3.255
38	2.0000	0.0744	3.720
39	1.0563	0.1058	10.016
41	2.0007	0.0489	2.444
42	2.0004	0.0552	2.759
43	2.0001	0.1688	8.440
45	2.0002	0.0659	3.295
46	2.0007	0.0955	4.773
47	2.0004	0.0772	3.859
49	2.0006	0.0805	4.024
50	2.0000	0.0641	3.205
51	2.0002	0.0565	2.825

Table 125

HEAVY MINERAL PERCENTAGES, continued

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
52	2.0002	0.1826	9.129
53	1.3433	0.1510	11.241
54	2.0000	0.0526	2.630
55	2.0000	0.0508	2.540
56	2.0000	0.2523	12.615
59	2.0000	0.1229	6.145
61	2.0001	0.1077	5.385
62	2.0000	0.0529	2.645
63	2.0000	0.0790	3.950
64	2.0000	0.1276	6.380
65	2.0000	0.0967	4.835
66	2.0003	0.0941	4.704
67	2.0002	0.1843	9.214
68	2.0002	0.0533	2.665
69	2.0002	0.0335	1.675

Table 126

AVERAGE HEAVY MINERAL PERCENTAGES
± .177 mm Fractions

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
1	4.0035	0.1014	2.533
2	4.0009	0.1383	3.457
3	4.0002	0.1172	2.930
5	4.0007	0.0712	1.780
6	4.0005	0.0704	1.760
7	4.0008	0.0874	2.184
8	4.0006	0.4604	11.508
9	3.5394	0.0653	1.845
10	4.0012	0.0880	2.199
11	4.0005	0.0993	2.482
12	3.9451	0.0798	2.023
13	4.0004	0.0982	2.455
14	4.0003	0.0666	1.665
15	4.0004	0.1057	2.642
16	2.5933	0.0260	1.003
17	4.0004	0.0771	1.927
18	4.0002	0.1288	3.220
19	4.0001	0.1436	3.590
21	4.0012	0.1166	2.914
22	4.0011	0.0470	1.175
23	4.0005	0.2056	5.139
24	4.0006	0.0732	1.830

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Table 126

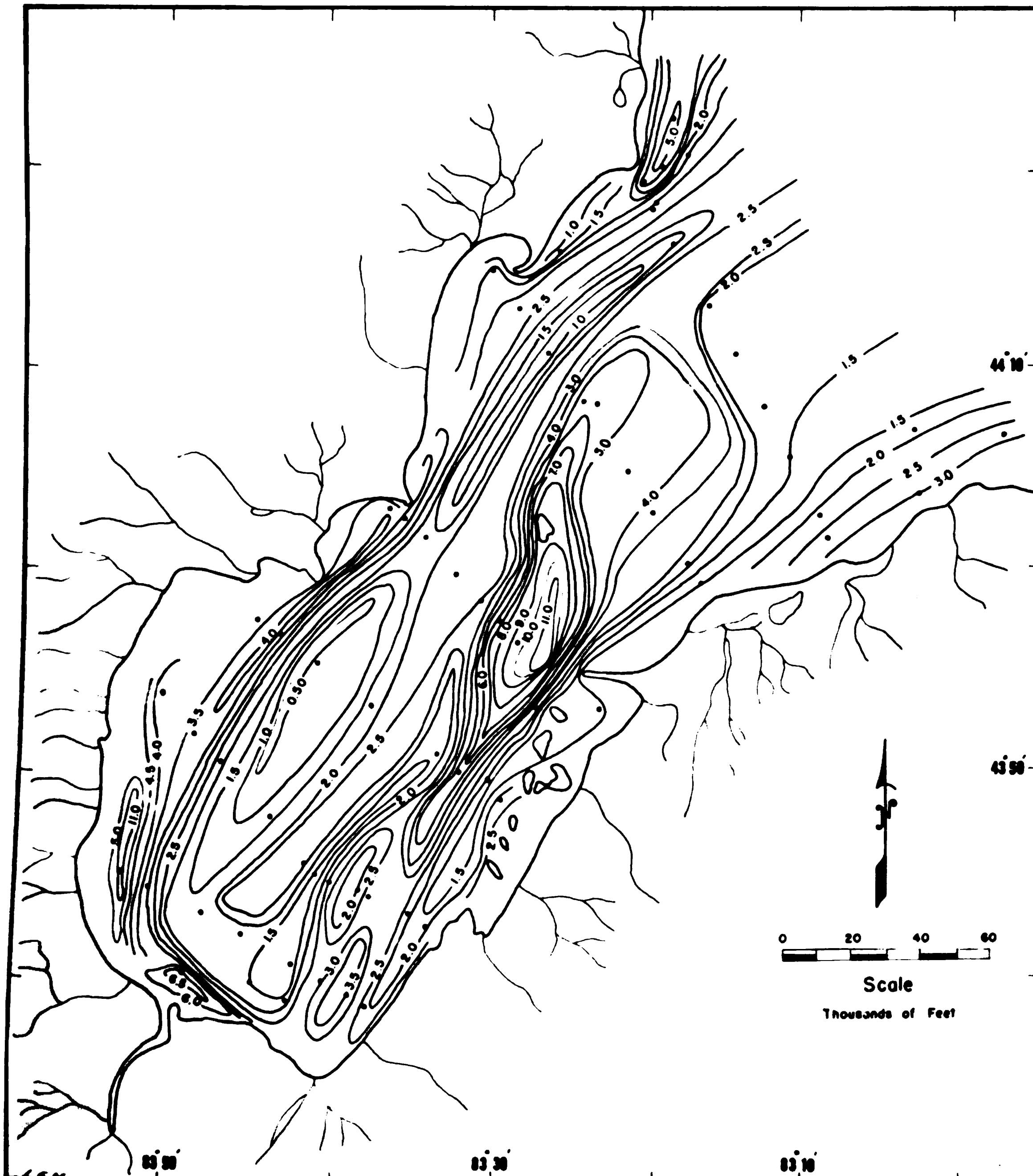
AVERAGE HEAVY MINERAL PERCENTAGES, continued
± .177 mm Fractions

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
25	4.0004	0.1025	2.562
26	4.0001	0.0747	1.867
27	3.9567	0.0247	0.624
28	4.0002	0.1585	3.962
29	4.0010	0.1533	3.832
30	4.0007	0.1787	4.467
31	3.3798	0.0369	1.092
32	4.0006	0.4403	11.006
33	4.0001	0.2995	7.487
34	4.0003	0.3135	7.837
35	4.0003	0.0878	2.195
36	2.6969	0.0622	2.306
37	4.0004	0.0708	1.770
38	4.0000	0.0901	2.253
39	3.0571	0.1211	3.961
41	3.9590	0.0607	1.533
42	4.0008	0.0627	1.567
43	4.0002	0.1888	4.720
45	4.0004	0.0726	1.815
46	4.0007	0.1033	2.582
47	4.0011	0.0858	2.144
49	4.0013	0.0913	2.282

Table 126

AVERAGE HEAVY MINERAL PERCENTAGES, continued
± .177 mm Fractions

Sample Number	Weight of Sample	Weight of Heavy Minerals	Percent of Heavy Minerals
50	4.0010	0.0705	1.762
51	4.0010	0.0636	1.590
52	4.0009	0.1950	4.874
53	3.3433	0.1724	5.157
54	4.0004	0.0660	1.650
55	4.0000	0.0590	1.475
56	4.0004	0.2742	6.854
59	4.0003	0.1335	3.337
61	4.0001	0.1210	3.025
62	4.0001	0.0597	1.492
63	4.0000	0.0811	2.028
64	4.0000	0.1457	3.643
65	4.0002	0.1107	2.767
66	4.0006	0.1071	2.677
67	4.0005	0.1987	4.967
68	4.0002	0.0609	1.522
69	4.0007	0.0345	0.862



SAGINAW BAY

HEAVY MINERAL DISTRIBUTION

ISOPLETH INTERVAL .500 Percent

PLATE 5

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Sample 8 near Nayanquing Point in the northwest corner of the bay contains 11.508 per cent heavies; and Sample 32 off Sand Point contains 11.006 per cent. In the fraction finer than 0.177 mm, Sample 8 contains 22.224 per cent heavies and Sample 32 contains 17.462 per cent.

An area of high heavy mineral content is outlined by locations 23, 33, 34, 43, and 67. Approximating Sample 32 are Samples 33 and 34 which contain nearly 7.000 per cent heavies. Sample 23, which was taken a few miles west of Katechay Island, contains 5.130 per cent, and Samples 67 and 43 north of Charity Island contain 4.967 and 4.720 per cent respectively. Other high values occur somewhat erratically throughout the bay.

HEAVY MINERALS AND MEDIAN DIAMETER -- The relationship between heavy minerals and median diameter is shown in figure 15. It is immediately obvious that there is no linear correlation between the two, and upon comparison of the distributions on Plates 3 and 5, no relationship is apparent.

Heavy minerals in quantities of over 3.000 per cent are restricted to sediments with diameters of 1.0 to 2.5 phi units (0.500 to 0.125 mm), but those sediments containing less than 3.000 per cent show no restrictions. It is interesting to note that the three samples which contain 1.000 per cent or less occur in sediments with median diameters smaller than 2.5 phi units (0.125 mm) which is contrary to what is commonly found of heavy mineral occurrence.

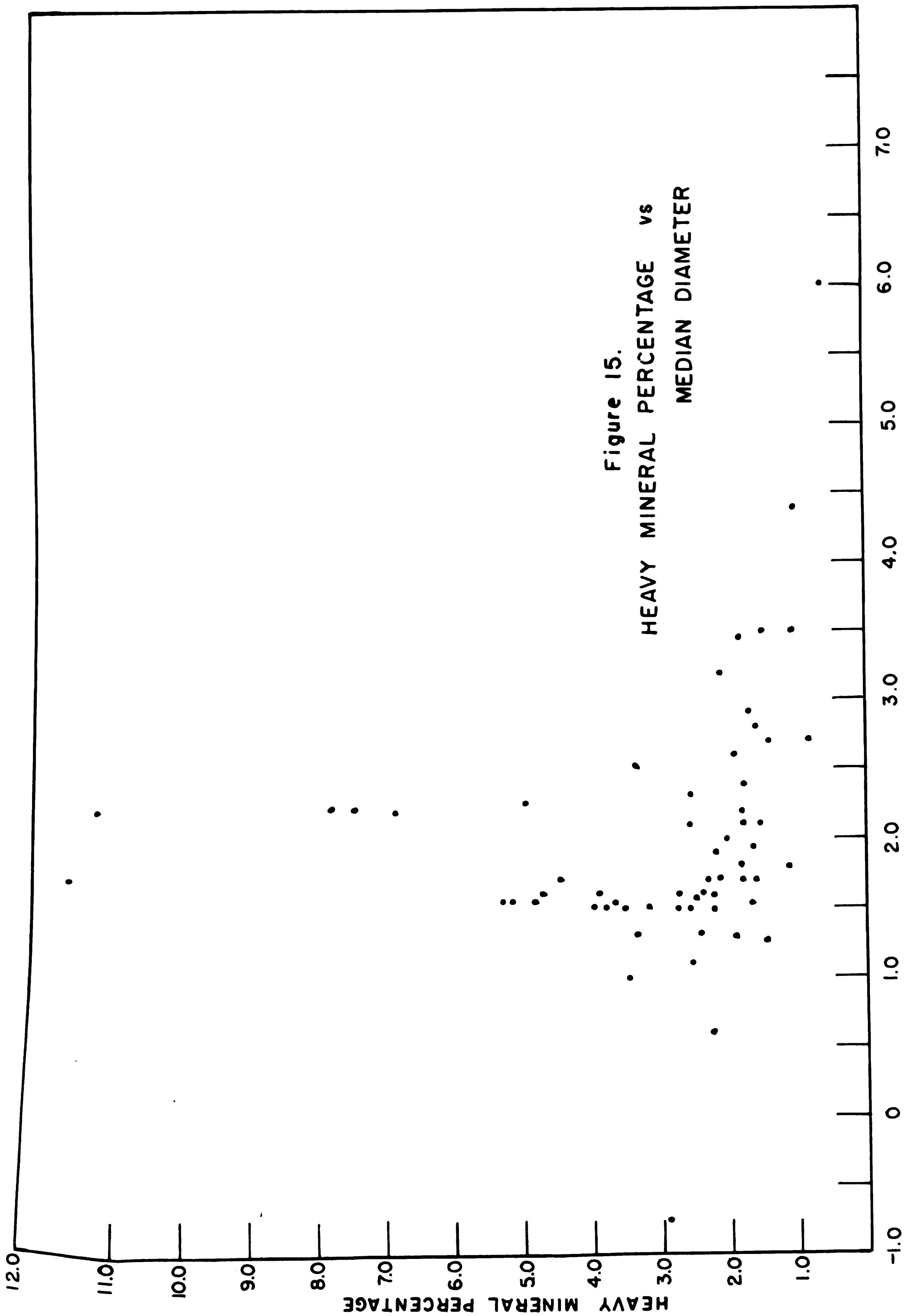

Figure 15.
HEAVY MINERAL PERCENTAGE vs
MEDIAN DIAMETER

An increase in heavy minerals with a decrease in grain size has been observed by many in the study of sediments. Russell (1936), Rittenhouse (1943) and Rubey (1933) found this to be generally true. Rubey also associated mineral accumulation as a result of other factors which include sorting, shape, specific gravity, abrasion, and amount and kind of minerals at the source.

Inasmuch as there is a higher percentage of heavy minerals in the coarse sediments in Saginaw Bay, it becomes obvious that size alone is not a strong factor in heavy mineral concentration. But the contrast in the data obtained from heavy mineral separates in the fractions coarser and finer than 0.177 mm shows plainly that the heavy minerals are concentrated in the finer fractions of each sample. This, in a large part, is due to the fact that zircon, rutile, apatite, and titanite, common in many sediments, occur as minute accessories in igneous rocks. Often these heavy minerals occur as aggregates in the coarser fractions and are identified as rock fragments. Russell (1936) found such minerals as pyroxenes and amphiboles in glacial derived sediments, increasing in the 100-150 sieve range (0.125 mm), then decreasing again in the finer sizes. Garnets have a similar tendency; calcite was found more abundant in the 200 (-) range (0.062 mm). The metallics, with a high specific gravity, increase in percentage in the smaller size ranges and then decrease in the very fine sizes.

Rubey (1933) contends that to separate all heavies less than a given size to determine heavy mineral ratios, tends to emphasize variations due to abrasion and size distribution at the source. Using one size-grade has certain advantages in that it eliminates variations caused by abrasion and size distribution, and the physical and optical properties of the minerals are nearly the same. But in choosing just one size, the sorting factor according to the particular size chosen enters into the problem. A possible solution may lie in the average of at least two different size fractions.

As a result of such variations, many feel that great care should be taken in making interpretations from heavy mineral data when samples are represented by a great range in size and sorting.

HEAVY MINERALS AND DEPTH OF WATER -- In comparing Plates 1 and 5, a marked relationship is noted between heavy minerals and depth. Figure 16 shows, in spite of any lack of linear correlation, that the higher heavy mineral percentages occur in the shallower depths. Of those samples containing 3.000 per cent or more heavies, 80 per cent occur in water less than 25 feet deep, and nearly 70 per cent in water less than 15 feet deep.

This tendency of heavy minerals to concentrate in shallow water is closely associated with the sorting factor of the sediments. Certain areas appear to be conducive to

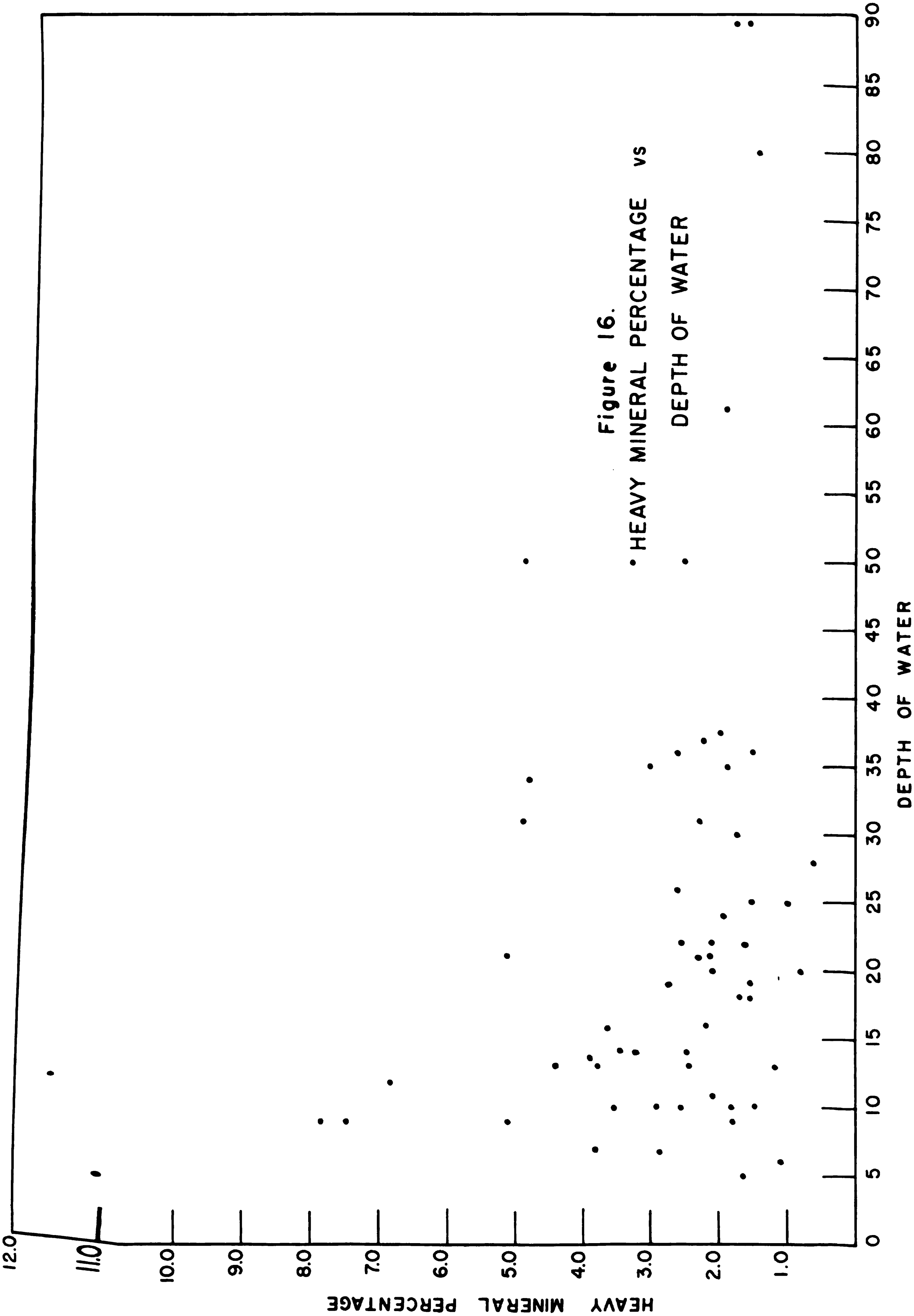

Figure 16.
HEAVY MINERAL PERCENTAGE vs
DEPTH OF WATER

"lag" concentration of minerals of high specific gravity, and these areas lie in the zones of strongest currents and shallowest water. This concentration also occurs in zones of sand accumulation. The fine and lighter particles are carried to areas of current shadows or deep water. In each case the "lag" concentrates may be associated with either a surface feature, such as shoreline irregularity or river entrance; or to a subsurface feature such as bottom topography. As a result of these agents, the hydraulic moments are altered and the carrying capacity of the water is either increased or decreased.

HEAVY MINERALS AND SORTING -- A broad relationship similar to that of depth of water and heavy minerals can be drawn between sorting and heavy mineral percentage (Fig. 17). Very little correlation can be shown in the samples containing less than 3.000 per cent heavies. Of those in the range of 3.000 per cent or over, 70 per cent have a log sorting factor of less than 0.150. It is interesting to note that 65 per cent of these occur in less than 15 feet of water and in areas of stronger currents. It can be seen in figure 17 that a high concentration of heavy minerals occurs in well sorted sediments, and the low heavy mineral concentration is associated with poorly sorted sediments. This is contrary to the theory that high heavy mineral content occurs in the fine sediments which usually are poorly sorted.

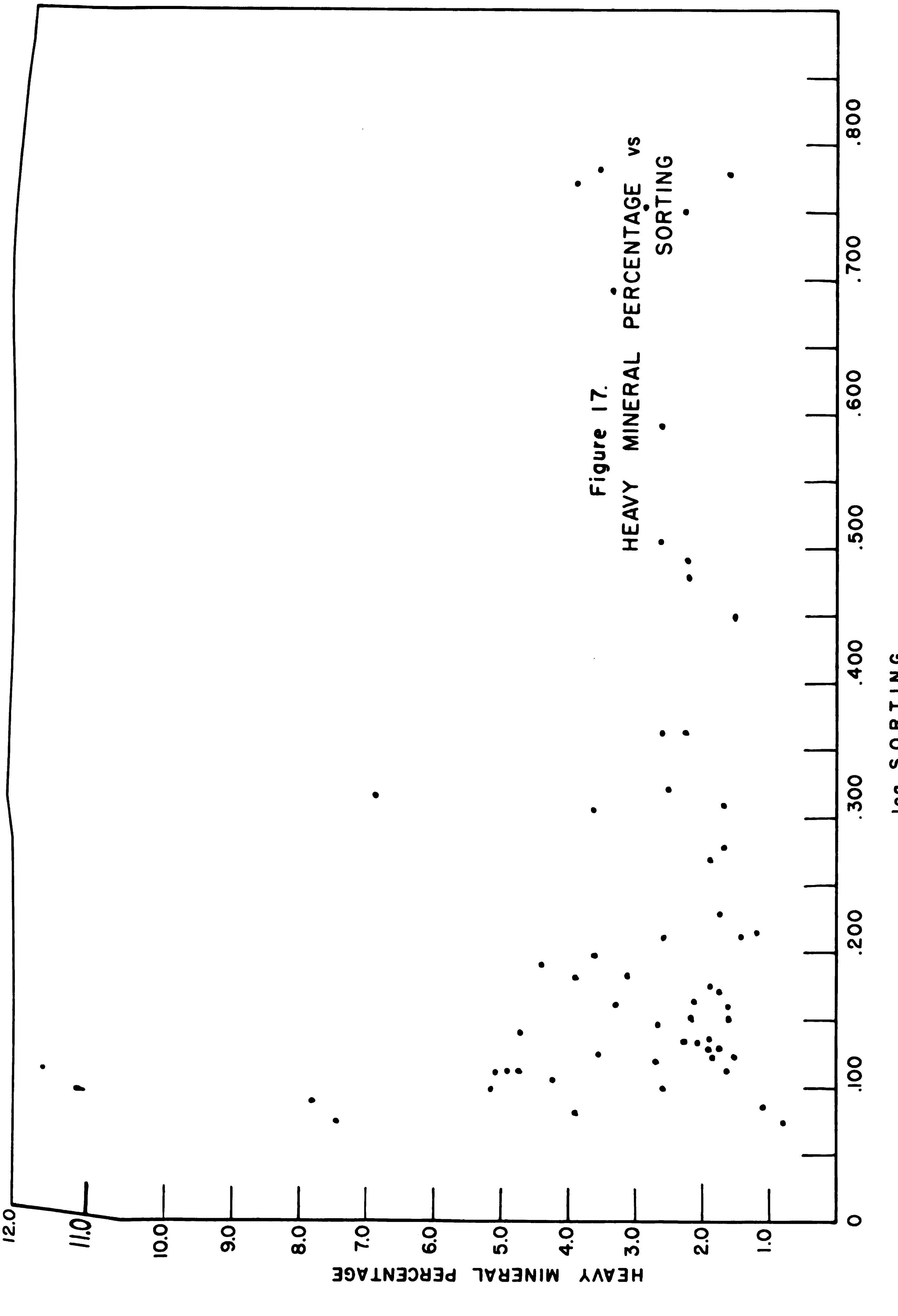

Figure 17.
HEAVY MINERAL PERCENTAGE vs SORTING

Selective sorting is a major factor in the accumulation of heavy as well as light minerals. Several factors are involved in selective sorting of light minerals. Such criteria as the depth, velocity, and carrying capacity of water, and the size, shape, and specific gravity of a mineral are important factors in sediment movement and deposition. In light minerals, which are predominantly quartz, there is little range of specific gravity or a great likelihood of a variety of shapes due to varying crystal forms and cleavages.

Heavy minerals offer more variation and each specie tends to react differently depending on its specific gravity. For example, a grain of magnetite, which has a specific gravity of 5.17, will require more force for movement than a grain of tourmaline of equal size which has a specific gravity of 3.00. Particle shape also varies according to specie. This is shown in apatite which rounds easily in comparison with actinolite whose cleavage and elongate character tends to form ragged elongate grains. Each mineral will react according to its physical properties whether it is being carried in suspension or is being transported in traction. One would, therefore, expect to find certain concentrates occurring under a given condition which suits each physical characteristic of the mineral. Extreme high percentages, such as found at locations 8, 32, 33, and 34, are undoubtedly a result of a combination of both supply and selective transportation.

HEAVY MINERALS AND SKEWNESS -- Little or no relationship can be drawn between skewness and heavy mineral concentration. Generally those sediments containing less than 3.000 per cent heavies show as much skewness as those which contain more than 3.000 per cent, although the lower percentages are skewed more to the fine sizes. The four samples which contain 7.000 per cent or more show little or no skewness. Correlation is shown in figure 18.

HEAVY MINERALS AND CURRENT -- Before using heavy mineral percentage as a measure of sedimentary environment, the factors which govern heavy mineral concentration should be considered. Since many factors which cause variation in heavy mineral concentration are not easily recognized or determined, percentage alone is unreliable as a key to environment and, therefore, should be used in conjunction with the other physical characteristics of a sediment.

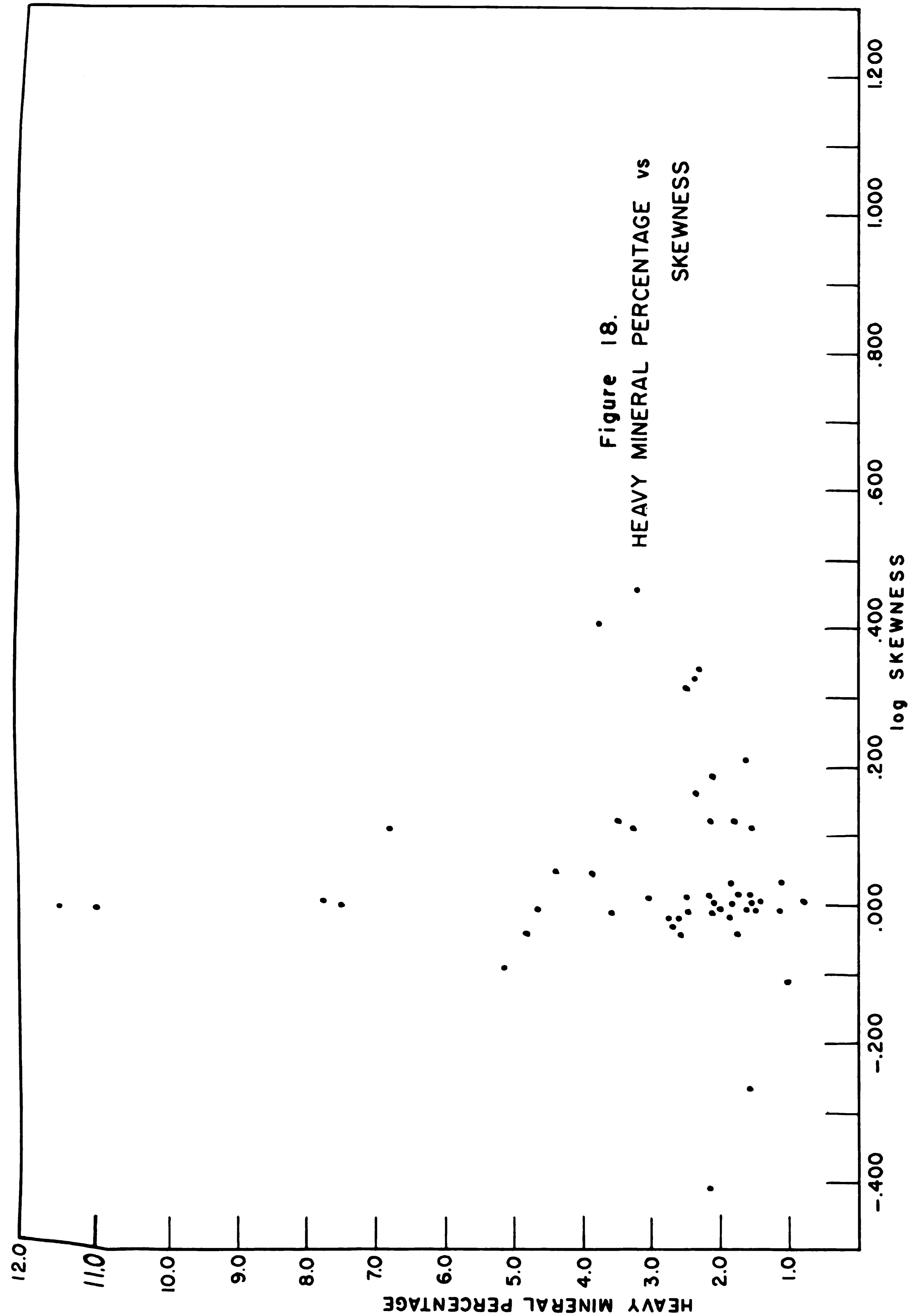

Figure 18.
HEAVY MINERAL PERCENTAGE vs SKEWNESS

PREPARATION FOR IDENTIFICATION -- A portion of the heavy mineral residue was cleaned and mounted in ARICLOR[1] (n:1.68). Care was taken to prevent a biased sample due to size variation, shape, density, and magnetic properties in the minerals. Several methods of heavy mineral sampling are discussed by Otto (1933).

The heavies were passed through the 80 sieve (0.177mm), and those remaining on the 100 sieve (0.149 mm) were mounted for identification. This provided a suite of heavy minerals in which the optical properties were uniform for any one specie. By eliminating some of the fine and coarse sizes there is a tendency to eliminate certain mineral species altogether. Certain species, as shown by Russell (1936), occur in greater frequency in the smaller sizes. The writer feels that by choosing a size grade common to all samples, relative mineral percentages may be established which might show some relationship to the physical environment in which they are presently adapted. This appears as the only logical approach since the minerals are derived from glacial drift and cannot be expected to show any definite arrangement with regard to their origin.

Standard methods for mounting heavy minerals for optical identification may be found in any textbook of sedimentary petrology.

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[1]ARACLOR #4465: Monsanto Chemical Corp., St. Louis, Mo.

HEAVY MINERAL GRAIN COUNT -- The degree of usefulness of data obtained from a heavy mineral analysis varies as the source of the heavy minerals varies. Thus, conclusions drawn from certain heavy mineral data are sometimes open to question. Unavoidable human errors may also be a factor, of which the three most prominent are involved in (1) sampling, (2) laboratory procedure, and (3) mineral identification.

Each sample at best represents only an infinitesimal part of the parent; therefore, great care should be taken in obtaining an unbiased sample which will best suit the needs of the problem. It is from these individual samples that the final gross relationships and conclusions will be drawn, and any error in sampling may be magnified many times in the final data.

When a large number of samples are involved, including a large mineral suite, errors in mineral identification are likely. Generally it is agreed that this error can be reduced by increasing the number of grains counted on each slide. The question then arises, how many grains should be counted? Counting large numbers of grains, 500 to 1000 per slide, is laborous and the results are not justifiably profitable if a smaller number can be counted with little or no addition to the error.

Many have proposed mathematical methods for determination of the optimum number of grains to be counted, including factors for sampling and laboratory errors. Dryden (1931), Krumbein and Rasmussen (1941), and Sindowski (1941) are some of the major contributors. In every new problem, the amount of error which can be justified must be a function of the sensitivity of the problem as regards the heavy mineral count.

As a means of determining the optimum number of grains to be counted, the writer chose at random one slide on which six areas were laid out. In each of these areas 100 grains were counted, making certain that no grains were counted twice. Four easily recognizable minerals were chosen for the count, and although all minerals crossed by the traverse were counted in each 100 unit, only four species were identified specifically.

To obtain an average for each grain count from 100 to 600, all possible combinations were taken for 100, 200, 300, 400, 500, and 600. These combinations were found to be 6, 15, 15, 12, 6, and 1 respectively. One can see at once that the mean for the six 100 grain counts will be the same as the mean for the one 600 grain count. To show a numerical difference in the counts only 100 to 500 were used in the final analysis.

An average for each combination was determined and a mean for the whole count calculated. The standard deviation for each group of combinations and the standard deviation of the mean of the combinations in each group was determined. The data are shown in figure 19.

Fiducial probability is often used by statisticians to express their confidence that the mean of a population will fall within given limits. Fiducial limits or "confidence limits" are merely limits within which a population mean might fall (Dixon and Massey, 1957) or, "the degree of confidence which the statistician has in his conclusions" (Croxten and Crowden, 1947). Confidence limits are not exact statements concerning the probability that the mean of the parent must fall within given limits.

The fiducial limits were determined by multiplying the standard deviation of the mean of 100 grains by 2.6, or three standard deviations from the mean. This defines the limits on either side of the mean, thus establishing the probability that 99.5 times out of 100 the sample mean will fall within these limits.

The standard deviation of the mean for 100 grains was determined by the equation:

$$\sigma_{\overline{100}} \cong P/\sqrt{n}$$

where: $\sigma_{\overline{100}}$ is the standard deviation of the mean of 100 grains,

P is equal approximately to the standard deviation of the parent distribution, and

n is the number of combinations which went into each sample

Data from two of the minerals in the grain count show that there is considerable room for deviation in the 100-count range, but the limits become quite narrow in the 200

Garnet

Unit	f/100	σ	$\bar{X}$	$\sigma_{\overline{100}}$	$2.6\,\sigma_{\bar{X}}$	Fiducial Limits	Range
100	3	2.79	6.83	1.14	2.96	3.87- 9.79	5.92
200	5	1.67	6.83	0.43	1.12	5.71- 7.95	2.24
300	6	1.21	6.77	0.31	0.81	5.96- 7.58	1.62
400	11	0.95	6.87	0.27	0.70	6.17- 7.57	1.40
500	8	0.57	6.85	0.23	0.60	6.25- 7.45	1.20

Hornblende

Unit	f/100	σ	$\bar{X}$	$\sigma_{\overline{100}}$	$2.6\,\sigma_{\bar{X}}$	Fiducial Limits	Range
100	13	2.76	13.0	1.13	2.94	10.06-15.94	5.88
200	13	1.64	13.0	0.42	1.09	11.91-14.09	2.18
300	15	1.10	12.9	0.28	0.73	12.17-13.63	1.46
400	10	1.14	12.9	0.33	0.86	12.04-13.76	1.72
500	17	0.84	13.1	0.34	0.88	12.22-13.98	1.76

Figure 19. Statistical data on Heavy Mineral Grain Count Determinations.

to 500-count range. It can be seen that the ratio between the 300 to 500-count and 200 to 300-count in the two minerals chosen is negligible. Although the ratio between the 200 to 500-count is larger, it falls well within the limits of necessary accuracy and does not merit counting 500 grains per slide.

HEAVY MINERAL SUITES -- A suite of twenty-eight mineral species were identified in the Saginaw Bay sediments. Mineral aggregates were identified as rock fragments. The minerals are shown in their relative percentages on Tables 127 and 128. Approximately half of the minerals were found in every sample, although many individuals occur in very small amounts.

Augite, hornblende, epidote, clear garnet, and white metallic opaques are most abundant. Of these, hornblende is present in frequency up to 50 per cent. The metallic opaques, which include largely magnetite, hematite, and a small quantity of ilmenite, occur in amounts up to 40 per cent. Clear garnets, epidote, and white opaques are rarely in excess of 25 per cent.

The amphiboles and pyroxenes are typically elongate for the most part and commonly are rounded on the ends. Many grains have been cleaved and are quite angular. Epidote is generally well rounded and in some grains the surfaces are severly pitted. Both clear and pink garnet ranges from sharply angular and irregular to well rounded grains.

Minerals which often occur as accessories in igneous rocks; apatite, zircon, tourmaline, and rutile are typically well rounded. In some samples euhedral to subhedral zircon crystals show only slight effects of abrasion. Micas are rare.

Most noticeably rounded, regardless of size, are the black (and red) metallic opaques. Grains so perfectly rounded that they resemble shot are common. This high degree of

Table 127

Percentage of Heavy Minerals in the 0.149-0.177 mm. grade from Saginaw Bay

Sample Number	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
1	8.5	20.0	8.0	7.0	4.0	15.5	2.5	4.5	3.0	4.0	5.0	7.0	2.5	1.5
2	10.0	15.5	10.0	14.0	5.0	17.5	1.0	5.5	2.0	2.0	3.0	3.5	2.5	3.0
3	14.0	17.5	11.5	7.0	4.5	14.5	5.0	6.5	2.0	3.0	x	1.0	1.5	3.5
5	10.0	24.5	10.0	5.5	3.0	13.5	1.0	4.0	4.0	3.0	2.0	2.5	2.0	3.5
6	14.0	14.5	10.0	10.5	4.5	11.5	x	8.5	2.0	2.5	3.0	4.0	2.0	3.5
7	10.0	33.5	12.5	4.0	x	5.5	x	6.5	4.5	3.5	2.0	5.0	1.0	3.0
8	8.5	16.5	9.5	9.0	5.5	26.5	1.5	9.0	1.5	2.5	x	1.0	1.5	x
9	11.5	20.5	5.5	9.0	4.0	25.5	3.0	9.5	x	x	x	1.5	x	2.0
10	9.5	21.5	11.0	7.5	2.0	10.5	6.5	10.0	1.5	2.5	1.5	1.0	1.5	3.0
11	15.0	16.5	8.0	7.5	3.5	12.0	8.0	11.5	1.0	2.0	2.0	3.0	2.0	2.5
12	9.5	21.0	11.0	5.5	1.5	7.5	5.5	24.5	x	2.0	2.0	2.5	1.0	x

Table 127, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
13	11.0	18.5	12.5	9.5	5.0	15.5	2.0	10.5	-	2.0	3.0	x	1.5	2.0
14	10.5	33.0	11.0	7.5	1.0	5.5	2.0	8.5	3.5	2.5	3.0	2.0	2.0	3.5
15	10.0	17.0	10.0	13.0	6.0	9.0	x	17.0	1.5	x	2.5	2.0	3.5	3.5
16	5.5	29.0	7.5	18.5	-	6.5	-	10.0	3.5	-	1.0	4.5	-	2.0
17	20.0	34.0	4.5	7.0	-	8.5	-	8.5	1.5	-	1.5	6.5	-	x
18	13.5	13.5	9.0	12.5	6.5	19.5	1.0	12.0	1.5	1.5	2.5	x	1.5	1.5
19	10.5	13.5	11.5	11.5	5.0	20.0	x	10.5	2.0	1.5	2.5	2.0	1.5	2.5
21	11.0	16.0	7.0	8.5	5.5	18.5	3.5	10.5	1.5	x	2.5	1.5	1.5	3.0
22	11.5	27.5	9.0	7.0	1.0	16.5	1.5	11.5	3.0	-	2.5	1.5	2.0	2.0
23	5.5	12.0	10.5	13.0	3.5	33.5	1.0	11.5	x	x	3.0	x	1.5	1.0
24	12.0	22.5	10.5	5.5	2.5	8.0	1.0	22.0	-	-	3.5	1.5	2.0	2.5

x Present but rare — Absent

Table 127, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
25	11.0	17.0	7.5	4.5	3.5	22.0	2.5	17.0	1.0	-	2.5	1.0	1.0	2.5
26	9.5	17.0	10.0	13.0	4.0	15.0	1.0	10.5	3.0	-	5.5	1.0	x	2.0
27	16.0	24.0	12.0	6.5	-	8.0	-	12.5	1.5	1.5	3.0	1.0	-	1.0
28	15.0	14.5	12.0	10.5	3.0	25.0	2.0	8.5	1.0	x	1.0	1.5	x	-
29	15.5	10.0	9.0	9.0	3.0	25.0	1.0	15.5	x	-	2.0	x	x	2.0
30	15.0	19.0	10.0	15.5	3.0	15.0	x	9.0	1.0	-	2.5	x	2.5	1.5
31	11.5	31.0	9.0	4.0	-	7.0	1.5	10.5	2.5	-	6.5	4.5	1.0	2.5
32	6.5	18.0	16.0	23.5	5.0	13.0	x	2.0	x	x	2.5	1.5	2.0	x
33	14.0	20.0	12.0	12.5	6.0	15.0	1.5	4.0	1.5	-	1.0	1.0	2.0	1.5
34	5.5	11.0	13.0	22.5	6.5	25.5	-	7.5	-	-	3.0	x	x	-
35	10.5	14.5	13.5	19.5	6.5	7.5	x	9.5	x	-	3.0	1.0	2.5	1.0

x Present but rare — Absent

Table 127, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
36	7.5	24.5	10.5	13.0	3.0	17.5	-	8.5	1.5	-	2.0	2.5	1.5	1.5
37	8.0	19.0	13.0	12.5	1.5	25.0	-	8.5	4.5	x	1.5	2.0	1.0	x
38	5.0	17.0	12.0	9.0	1.5	23.0	-	7.0	9.5	2.0	1.0	3.0	1.0	1.0
39	8.0	5.5	5.0	29.5	11.0	26.5	-	4.0	1.0	x	1.5	x	x	1.5
41	16.5	25.0	7.5	2.5	-	5.5	x	11.5	-	4.0	4.0	2.5	1.5	x
42	10.5	19.0	12.5	11.0	4.5	15.5	x	9.5	1.5	3.5	1.0	1.5	1.0	x
43	9.5	15.0	10.5	12.5	4.5	29.5	-	5.5	x	1.5	2.5	1.0	x	1.0
45	6.5	22.5	14.5	7.5	1.5	15.0	3.0	9.5	1.0	1.5	3.0	1.5	1.5	1.0
46	10.5	20.0	13.5	7.5	2.0	12.5	1.0	6.5	4.5	3.0	1.0	3.0	4.0	1.5
47	12.0	28.0	8.0	5.5	2.0	4.0	x	16.0	x	1.5	4.5	2.0	6.0	2.0
49	6.0	20.5	7.0	4.0	x	24.0	x	8.5	1.0	1.0	3.5	3.0	3.5	2.0

x Present but rare — Absent

Table 127, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
50	11.5	22.5	7.0	4.0	x	17.0	–	11.0	5.5	3.5	2.5	2.5	2.0	1.5
51	30.0	19.5	7.5	2.5	x	8.5	1.0	13.5	2.0	2.5	2.5	2.0	1.0	2.5
52	10.0	15.0	7.5	22.5	2.0	23.5	–	5.5	x	1.0	1.0	2.5	2.0	1.0
53	12.5	14.0	7.5	16.5	4.0	25.0	–	7.0	1.5	1.0	2.5	1.0	1.0	2.5
54	26.5	23.5	4.5	2.5	x	7.0	2.0	27.0	x	1.0	1.0	1.0	1.5	x
55	14.0	15.0	7.0	15.0	10.0	24.5	–	9.0	x	1.5	x	x	1.5	–
56	11.0	21.5	7.5	8.0	1.5	30.5	–	10.0	x	1.0	2.5	–	1.0	x
59	12.5	27.5	8.5	21.0	5.5	12.5	1.0	5.0	x	1.0	2.0	x	x	x
61	11.5	20.5	10.0	8.5	3.0	27.5	–	7.5	x	1.0	2.0	1.0	1.5	1.0
62	15.0	21.0	9.5	5.0	1.0	15.0	1.0	12.0	x	3.0	4.0	2.0	2.0	x
63	11.0	20.5	8.5	6.5	7.5	26.0	x	8.0	1.0	x	1.0	x	2.0	2.0

x Present but rare – Absent

Table 127, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
64	9.0	26.5	7.0	9.0	2.0	30.5	-	7.0	1.5	1.0	x	1.0	1.5	1.0
65	8.5	26.5	8.0	10.5	5.0	25.5	-	5.0	1.5	x	1.5	3.0	1.5	-
66	8.0	18.0	4.0	9.5	5.5	40.5	-	6.5	2.0	x	x	1.0	1.0	1.0
67	13.0	32.5	9.0	6.5	2.5	16.0	-	8.5	1.0	2.0	1.0	1.0	2.5	-
68	18.0	43.5	5.5	2.5	1.0	7.5	1.0	14.0	x	1.0	1.0	1.0	2.0	x
69	17.5	48.5	3.5	x	x	2.0	1.5	14.0	2.0	1.5	1.0	2.0	1.5	-

x Present but rare — - Absent

Table 128

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from

Saginaw Bay

Sample Number	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
1	x	–	2.0	x	x	–	–	x	–	–	2.0	–	–	–
2	x	x	1.0	x	1.0	–	x	x	x	–	x	1.5	–	–
3	x	2.5	–	–	x	x	1.5	–	–	–	2.0	x	x	–
5	3.0	–	1.0	–	2.5	1.5	x	–	x	–	2.5	x	–	–
6	1.0	x	x	1.0	1.5	x	1.0	–	–	–	3.5	x	x	–
7	3.0	1.0	x	1.0	2.5	x	–	–	–	–	x	x	x	–
8	1.0	–	x	1.5	x	x	x	x	x	–	2.5	x	x	–
9	x	2.5	1.0	1.5	x	–	–	–	–	–	x	1.0	x	–
10	2.0	x	1.0	2.0	x	–	x	–	–	–	1.5	1.0	–	–
11	x	1.5	x	x	x	x	–	x	x	–	2.0	x	x	–
12	x	–	1.5	2.0	1.5	–	–	–	–	–	x	x	x	–

x Present but rare – Absent

Table 128, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
13	x	1.5	x	2.0	–	x	–	–	–	–	1.5	–	1.0	–
14	3.0	x	x	x	x	x	–	–	–	–	–	x	–	–
15	x	x	1.0	x	1.0	–	x	–	x	–	1.5	–	x	–
16	3.5	5.0	–	x	1.0	–	–	x	–	–	–	–	–	–
17	5.5	–	x	–	1.0	–	–	–	–	–	–	–	–	–
18	x	x	x	x	x	–	–	–	–	–	–	–	x	–
19	1.5	x	x	1.5	x	–	–	–	–	–	–	x	–	–
21	2.0	1.5	x	4.0	x	–	x	–	–	–	x	–	–	x
22	2.0	x	x	x	x	–	x	x	–	–	x	–	–	–
23	x	–	x	2.0	x	–	x	–	x	–	x	–	–	–
24	x	–	1.5	3.5	x	x	–	–	–	–	x	x	–	–

x Present but rare — Absent

Table 128, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
25	1.5	x	1.5	x	x	-	-	-	-	2.0	-	-	-	-
26	1.0	-	1.5	3.0	1.0	-	-	-	-	-	-	-	-	-
27	3.5	1.0	1.5	-	1.5	-	-	2.5	-	-	-	-	-	-
28	1.0	-	1.0	2.5	-	-	x	-	-	x	x	-	-	-
29	x	-	1.5	3.5	x	-	x	-	-	-	-	x	x	-
30	2.0	x	1.0	1.0	x	-	-	-	-	-	-	-	-	-
31	3.0	1.0	-	x	3.0	-	x	-	-	-	-	x	x	-
32	x	-	x	2.0	x	-	x	-	-	-	-	x	3.5	-
33	-	x	1.0	1.0	x	-	-	-	-	-	-	x	1.0	-
34	-	-	2.0	1.0	-	-	x	-	-	-	-	-	x	-
35	3.5	x	1.0	3.5	-	-	-	-	-	-	-	-	1.0	-

x Present but rare — Absent

Table 128, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
36	1.0	-	1.0	2.0	x	-	x	-	-	-	x	x	1.0	-
37	1.0	-	-	-	1.0	-	-	-	-	-	-	-	x	-
38	3.5	x	x	-	1.0	-	-	-	-	-	-	x	1.5	-
39	1.0	-	1.5	2.0	x	-	-	-	x	-	-	-	-	-
41	2.5	4.0	1.0	5.0	2.5	-	-	-	-	-	x	-	2.0	-
42	1.5	-	1.0	2.5	1.0	-	x	-	-	-	1.5	x	x	-
43	x	x	x	4.5	x	x	x	-	-	-	x	-	1.0	-
45	1.5	x	x	5.5	-	-	-	-	x	-	x	-	1.0	-
46	3.5	-	1.5	1.5	2.0	-	-	-	-	-	x	-	-	-
47	1.0	2.0	1.5	1.0	1.0	-	-	-	-	-	-	-	-	-
49	1.0	6.0	x	4.5	1.0	x	-	-	-	2.0	-	-	-	-

x Present but rare — - Absent

Table 128, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
50	2.0	2.0	-	1.5	2.0	-	-	-	x	-	-	-	-	-
51	-	x	x	1.5	x	-	-	-	-	-	1.5	-	-	-
52	x	-	x	2.0	-	-	-	-	-	-	-	-	-	-
53	x	x	x	1.0	1.5	-	-	-	-	-	x	-	-	-
54	x	-	x	-	1.0	-	-	-	-	-	-	-	x	-
55	x	-	-	x	-	-	x	-	-	-	-	-	-	-
56	1.5	-	1.5	1.0	-	-	-	-	x	-	-	-	x	-
59	-	-	1.0	1.0	-	-	x	-	x	-	-	-	x	-
61	x	-	x	2.5	-	-	-	-	x	-	x	-	x	-
62	1.5	-	x	5.0	1.0	-	x	-	x	-	-	-	-	-
63	1.0	-	1.0	1.5	x	-	-	-	-	-	1.0	-	-	-

x Present but rare — Absent

Table 128, continued

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Saginaw Bay

Sample Number	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
64	x	-	x	1.0	-	-	x	-	-	-	x	-	-	-
65	1.0	-	x	1.5	-	-	x	-	-	-	x	-	-	-
66	x	-	1.0	-	-	-	-	-	-	-	-	-	-	-
67	1.0	-	x	1.0	x	-	-	-	-	-	-	-	-	-
68	x	-	-	x	-	-	x	-	-	-	-	-	-	-
69	1.0	-	x	2.5	x	-	-	-	-	-	-	-	-	-

x Present but rare - Absent

rounding in the heavier metallics suggest severe abrasion by rolling or saltation. This is in contrast to little or no abrasion of quartz or even the heavy minerals of low specific gravity which are prone to transportation by suspension.

The concentration of these heavy minerals in varying amounts at different locations throughout the bay may well indicate the hydraulic conditions at a given location. Pettijohn (1933) was able to associate the various physical properties of minerals to the movement of sediments by water. He found that the concentrates of one mineral at one place in contrast to another may be a result of its physical properties, such as: angularity, elongation, and specific gravity. Some minerals which are rounded easily may be transported by rolling, and the more angular grains either remain behind to be concentrated or are carried in suspension depending on their own physical properties and given hydraulic conditions. An entirely different set of transporting conditions may result from a change in the physical environment of the bay, then conditions previously adapted to transportation of rounded grains may be altered until they are best suited for movement of angular grains.

It is interesting to note in light of this inference, that in comparing the more elongate, somewhat tabular hornblende to the heavier, well-rounded and spherical metallic opaques, that almost without exception those samples showing a high percentage of hornblende contain a low percentage of metallic opaques.

Leucoxene, in most samples, varies from a slightly altered ilmenite to a proceline-like mineral.

The white opaques, excluding leucoxene, represent a group of minerals opaque or nearly so under polarized light, but white in reflected light. Many are stained. Upon isolating a few of these minerals some were identified as fluorite.

Heavy-mineral separates were made of eight river sands in an attempt to determine if individual mineral concentrations were derived from one particular area. Tables 129 and 130 show the mineral suites from eight rivers entering into Saginaw Bay. It is apparent from this data that no mineral or suite of minerals is unique to any river. Rivers flowing in glacial drift are not expected to show any selectivity of mineral suites.

Only the Rifle River shows an exceptional accumulation of one group of minerals, and that of metallic opaques.

Table 129

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Selected Rivers

Samples	Augite	Hornblende	Epidote	Clear Garnet	Pink Garnet	Metallic Opaques	Brown Opaques	White Opaques	Zircon	Titanite	Leucoxene	Topaz	Tourmaline	Tremolite
A	12.5	25.5	8.5	1.5	x	5.0	-	30.5	1.0	x	2.0	1.0	1.5	x
B	2.0	38.5	7.5	6.0	2.0	6.5	2.5	10.5	1.0	1.0	4.0	2.0	3.0	x
C	10.5	36.0	8.5	5.5	1.0	7.5	1.5	12.5	1.0	-	2.0	1.0	3.0	-
D	10.5	35.5	8.5	2.5	1.5	12.0	1.0	13.5	x	-	2.0	1.5	4.0	1.0
E	15.0	33.5	8.5	8.0	3.0	7.0	-	7.0	1.0	-	5.0	1.0	3.0	1.0
F	7.5	29.0	6.5	8.0	4.0	24.0	2.0	9.0	1.5	x	1.5	1.0	2.5	-
G	14.5	18.0	7.5	3.5	2.0	4.5	1.5	13.5	2.0	x	2.0	1.0	3.0	1.0
H	11.5	38.5	5.0	6.5	4.0	8.0	x	11.5	1.0	x	1.5	1.0	6.5	x

x Present but rare　　- Absent

A Pigeon River　　E Pine River
B Pinnebog River　　F Rifle River
C Sebewaing River　　G Tawas River
D Saginaw River　　H Au Sable River

Table 130

Percentage of Heavy Minerals in the 0.149-0.177 mm grade from Selected Rivers

Samples	Apatite	Calcite	Rutile	Rock Fragments	Barite	Biotite	Monazite	Glaucophane	Staurolite	Pyrite	Diopside	Actinolite	Hypersthene	Native Copper
A	x	5.0	-	4.0	-	-	-	x	-	x	-	-	x	-
B	x	4.0	x	6.0	x	x	-	x	-	-	-	-	-	-
C	x	4.0	x	2.5	1.5	-	-	-	-	-	-	-	-	-
D	-	3.0	-	2.5	x	-	-	-	-	x	-	-	-	-
E	x	-	x	5.0	x	-	-	-	-	x	-	-	-	-
F	-	-	x	1.0	x	-	-	-	-	-	-	-	-	-
G	-	x	x	2.5	1.5	x	-	-	-	-	x	-	-	-
H	-	-	-	2.0	x	-	1.0	-	-	-	-	-	-	-

x Present but rare — Absent

A Pigeon River
B Pinnebog River
C Sebewaing River
D Saginaw River

E Pine River
F Rifle River
G Tawas River
H Au Sable River

ROUNDNESS AND SPHERICITY

Grains from the light mineral fraction in the 0.177 mm (-) range were mounted in Canada balsam for roundness and sphericity determinations. The grains of each sample were projected by conventional methods onto a sheet of paper and the outlines of 50 were traced. Riley's method (1941) for determining sphericity and Wadell's method (1932) for determining roundness were used.

Riley's formula is defined as the diameter of the largest inscribed circle that can be drawn inside the grain outline, divided by the diameter of the smallest circumscribed circle, where the square root of the product is the degree of sphericity of the grain.

This may be expressed mathematically as:

$$S = \sqrt{i/C}$$

where: i = radius of maximum inscribed circle,

C = radius of smallest circumscribed circle.

The student using this or any of the methods which require measurement of projected grains should be aware that true three-dimensional sphericity cannot be measured in this manner, and this provides at best only a mathematical estimate of sphericity.

Wadell's formula, which measures the angularity of the corners of a sand grain, is expressed as the arithmetic average of the radii of curvature of its individual corners, divided by the maximum inscribed circle. As the roundness is increased, thus the radius of curvature of the corners is also increased.

This may be expressed mathematically as:

$$P = \frac{\sum r/n}{R}$$

where:

R = radius of maximum inscribed circle

r = radius of curvature of individual corners

n = number of corners measured

Unless the grains are measured directly from the projections, great care should be taken in tracing the outline so as not to accentuate the angularity or roundness of the individual corners.

Roundness and sphericity are factors commonly related to the movement of sedimentary particles, and are often used as an aid in determining environmental conditions. Much information on roundness and sphericity has been published, but few conclusions have evolved. Russell (1939) discussed roundness and sphericity with regard to sorting, grain size, and sand movement, shedding some light on the misinterpretations of their association. Further work by Pettijohn and Lundahl (1943) and Twenhofel (1945) support Russell's theories on abrasion and sediment movement. Average roundness and sphericity of a sediment may vary as a result of any single factor or combination of factors. Each will be discussed in light of these variables.

A graphic presentation of roundness and sphericity frequency is shown in Tables 131 to 146. The modal class in the roundness determinations is 0.500 in most samples, whereas in sphericity the modal class is in the range of 0.800 to 0.850.

Table 131

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

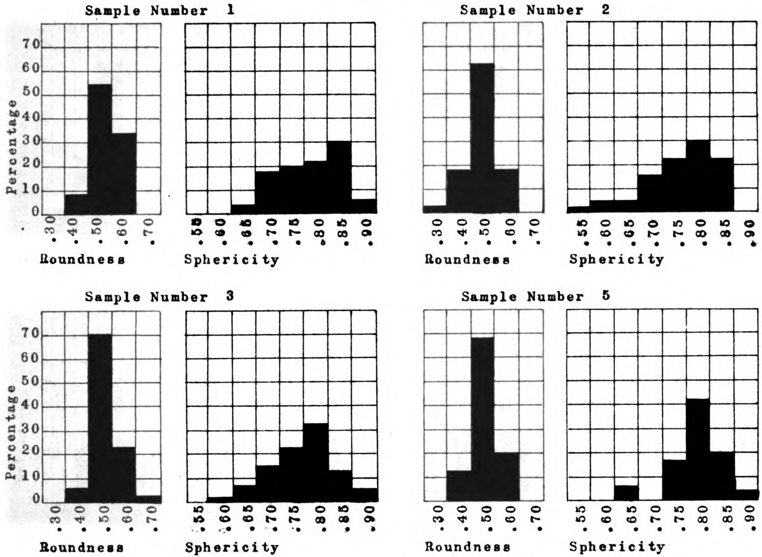


Table 132

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

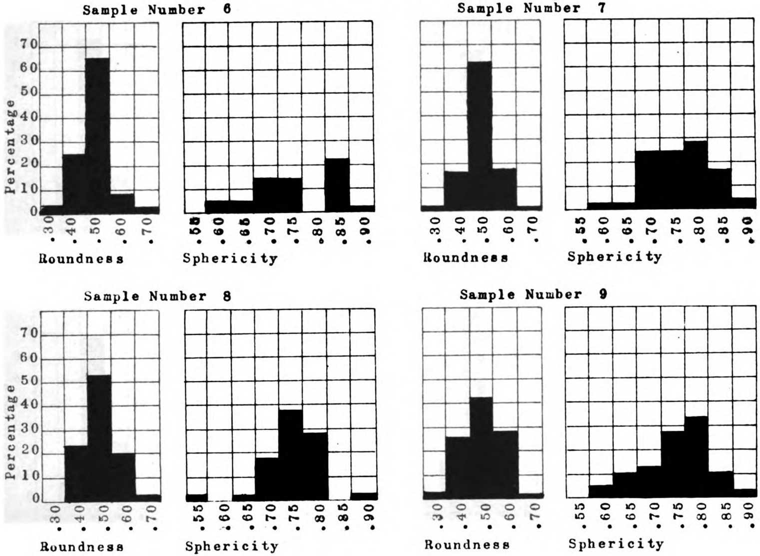
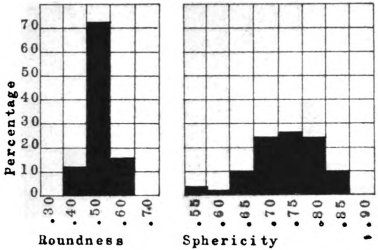


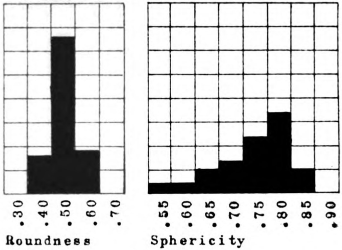
Table 133

*H*ISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

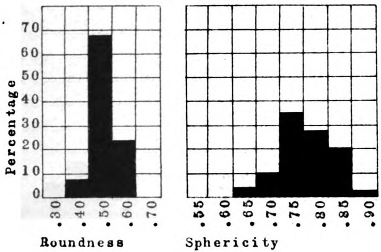
Sample Number **10**



Sample Number **11**



Sample Number **12**



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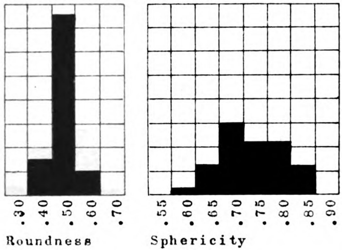
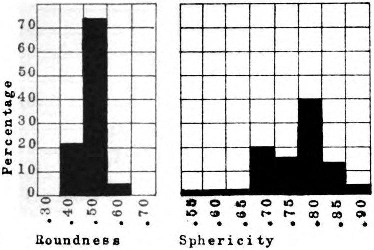


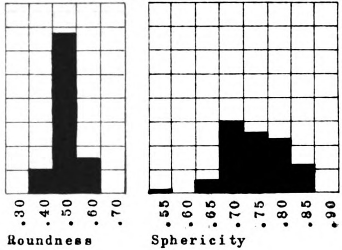
Table 134

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

Sample Number 14



Sample Number 15



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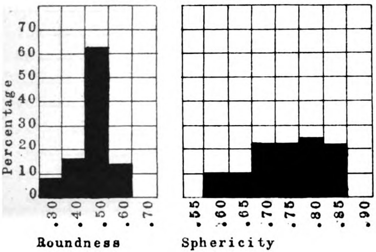


Sample Number 17

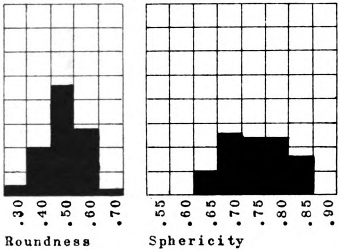
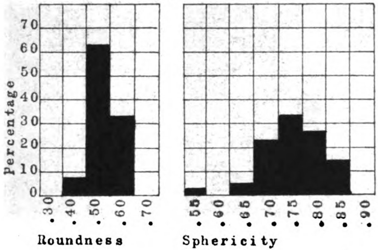


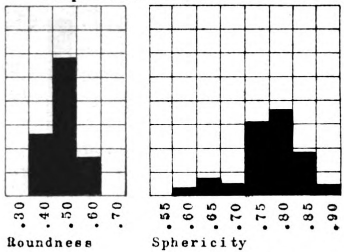
Table 135

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

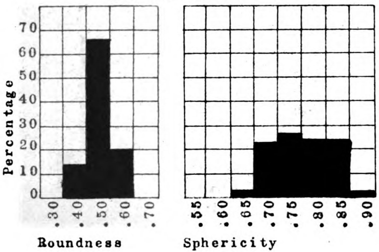
Sample Number 18



Sample Number 19



Sample Number 21



Sample Number 22

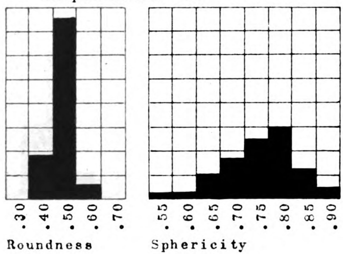
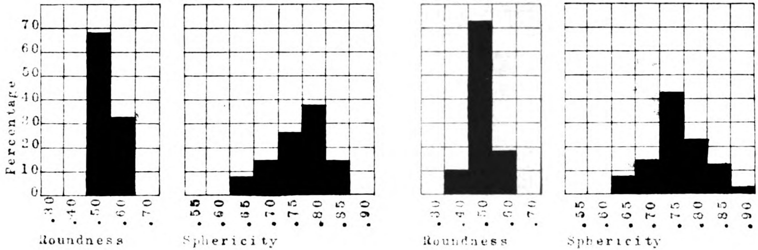


Table 136

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

Sample Number **23** Sample Number **24**



Sample Number **25** Sample Number **26**

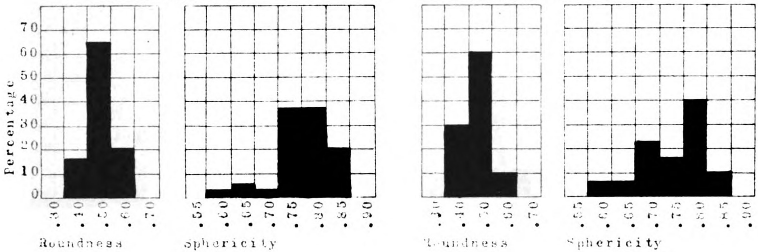
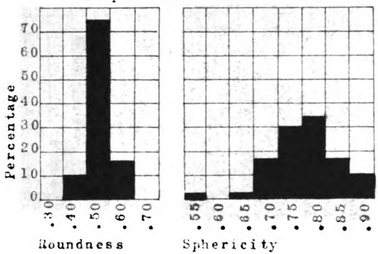


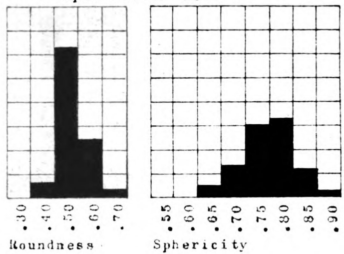
Table 137

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

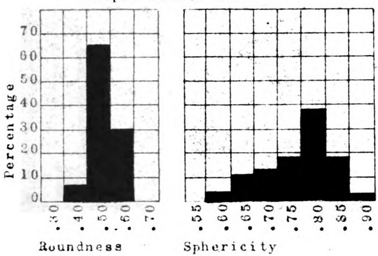
Sample Number **27**



Sample Number **28**



Sample Number **29**



Sample Number **30**

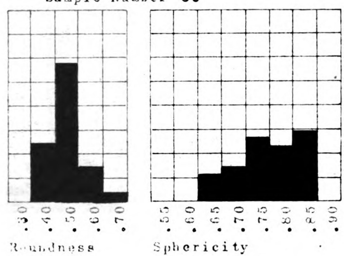
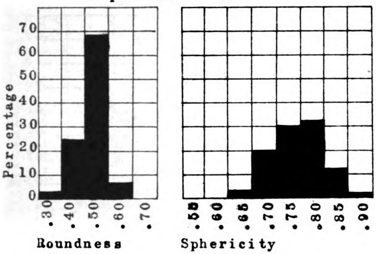


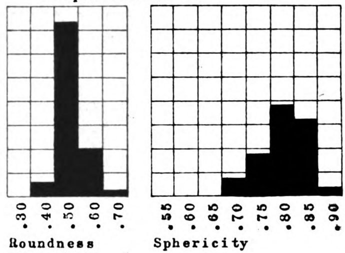
Table 138

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

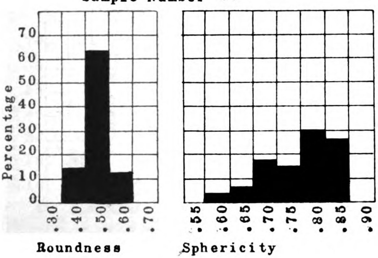
Sample Number 31



Sample Number 32



Sample Number 33



Sample Number 34

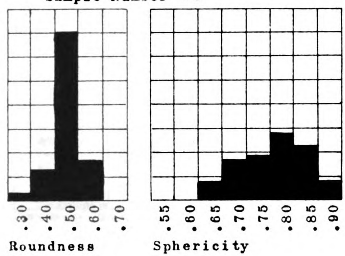
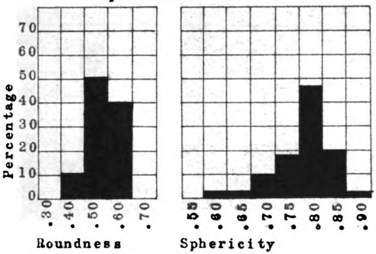


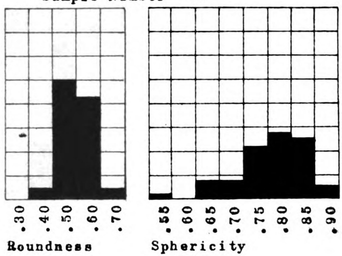
Table 139

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

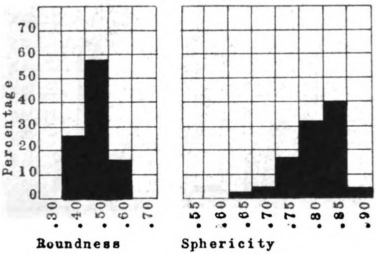
Sample Number 35



Sample Number 36



Sample Number 37



Sample Number 38

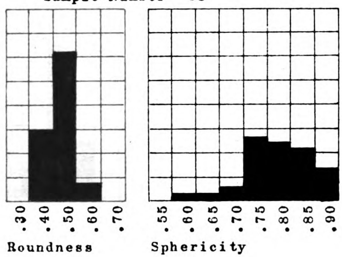


Table 140

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

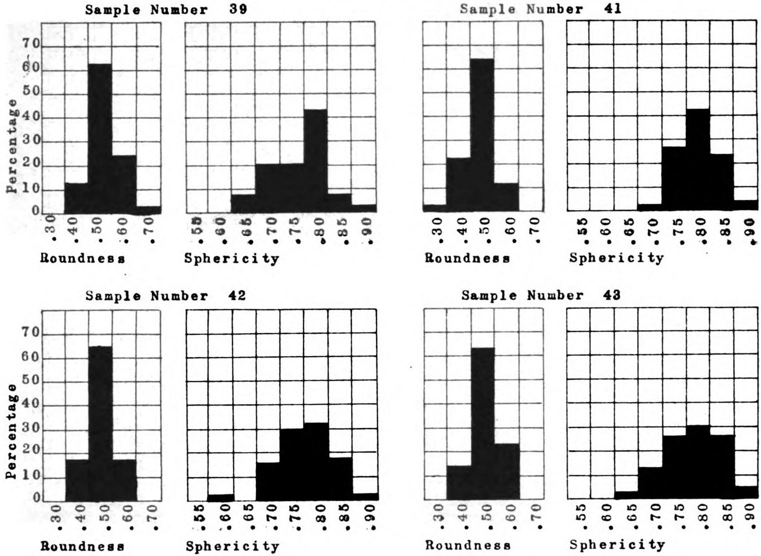
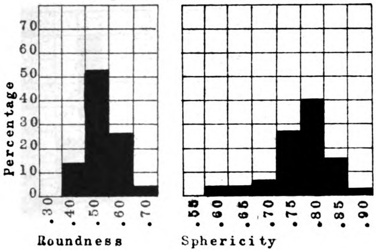


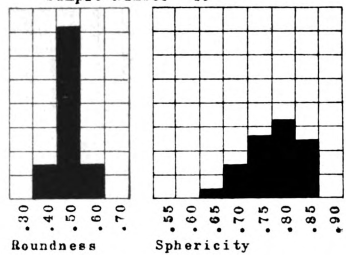
Table 141

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

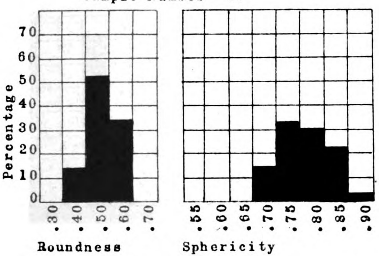
Sample Number 45



Sample Number 46



Sample Number 47



Sample Number 49

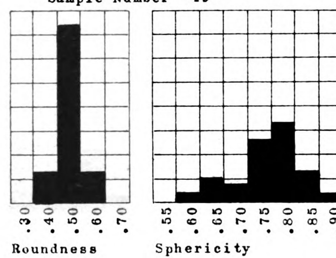


Table 142

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

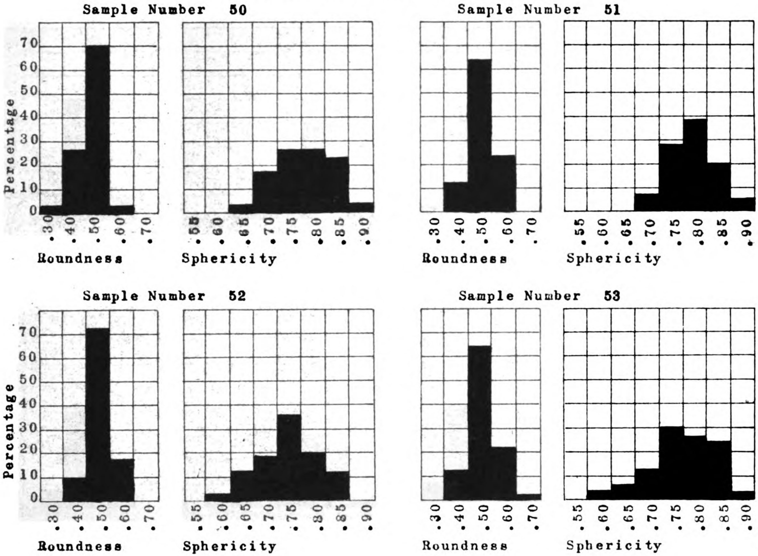


Table 143

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

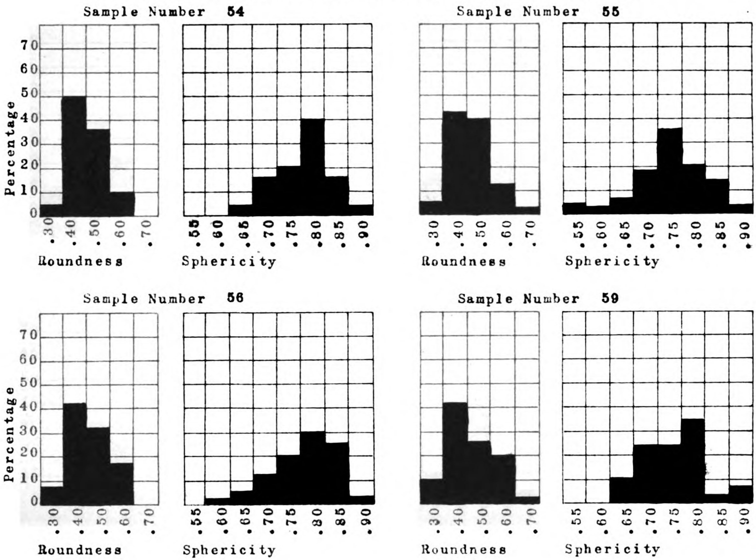
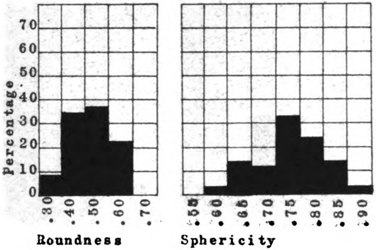


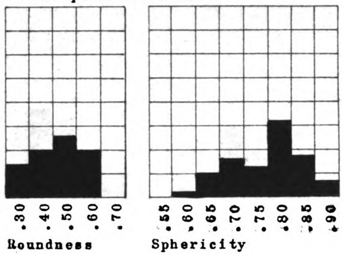
Table 144

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

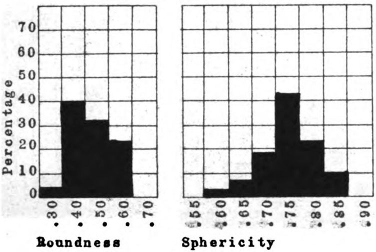
Sample Number 61



Sample Number 62



Sample Number 63



Sample Number 64

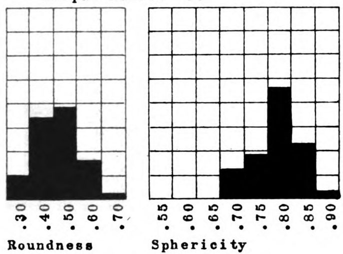


Table 145

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

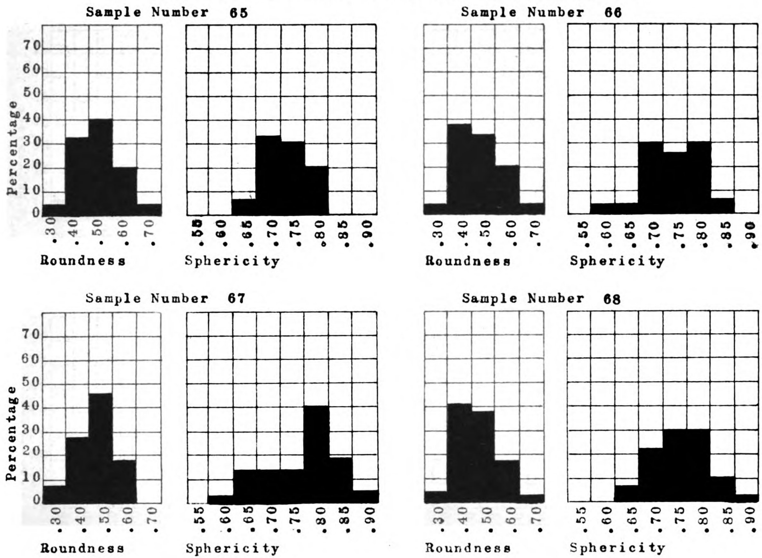
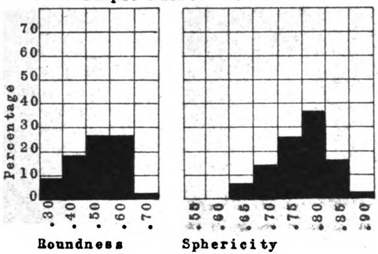


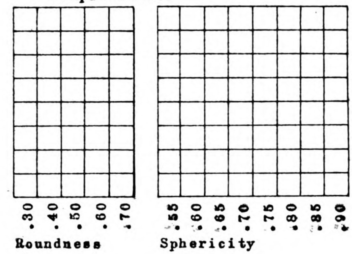
Table 146

HISTOGRAMS OF ROUNDNESS AND SPHERICITY DISTRIBUTION

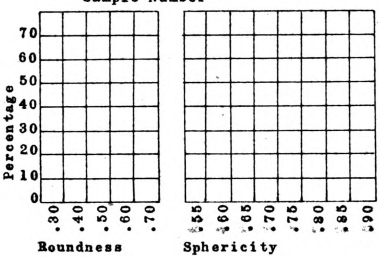
Sample Number 69



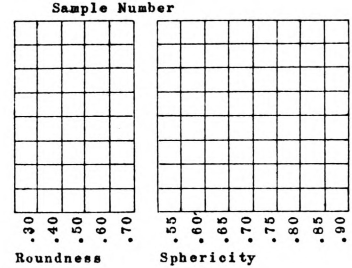
Sample Number



Sample Number



Sample Number



ROUNDNESS

Only general statements can be made with regard to roundness of grains in Saginaw Bay. High roundness values are noted in the vicinity of Charity Island and Point Au Gres on the north side of the bay. High values of roundness parallel the south shore as far east as Sand Point and Charity Island. Average roundness data are shown in Table 147, and average roundness distribution is on Plate 6.

ROUNDNESS AND DEPTH OF WATER -- Little or no areal relationship is noted between depth of water and roundness (Pls. 1 and 6), although roundness is generally less in the areas of deep water at both ends of the bay. A high degree of roundness is recorded in the sediments in a southeast line across the center of the bay a few miles west of Charity Island. Other roundness highs are found at locations 28 and 29 which are partially shielded from the currents by Point Au Gres. Samples 28 and 29 were taken from 5 to 15 feet of water on the north edge of the east-trending depression of the glacial Saginaw River channel. High roundness is recorded at locations 22, 10, and 2 which border the small trench in the southwest corner of the bay. A low is noted at location 31 in the area shielded by Sand Point and the islands along the south shore. The information plotted in figure 20 illustrates the lack of linear correlation between depth of water and roundness.

Table 147

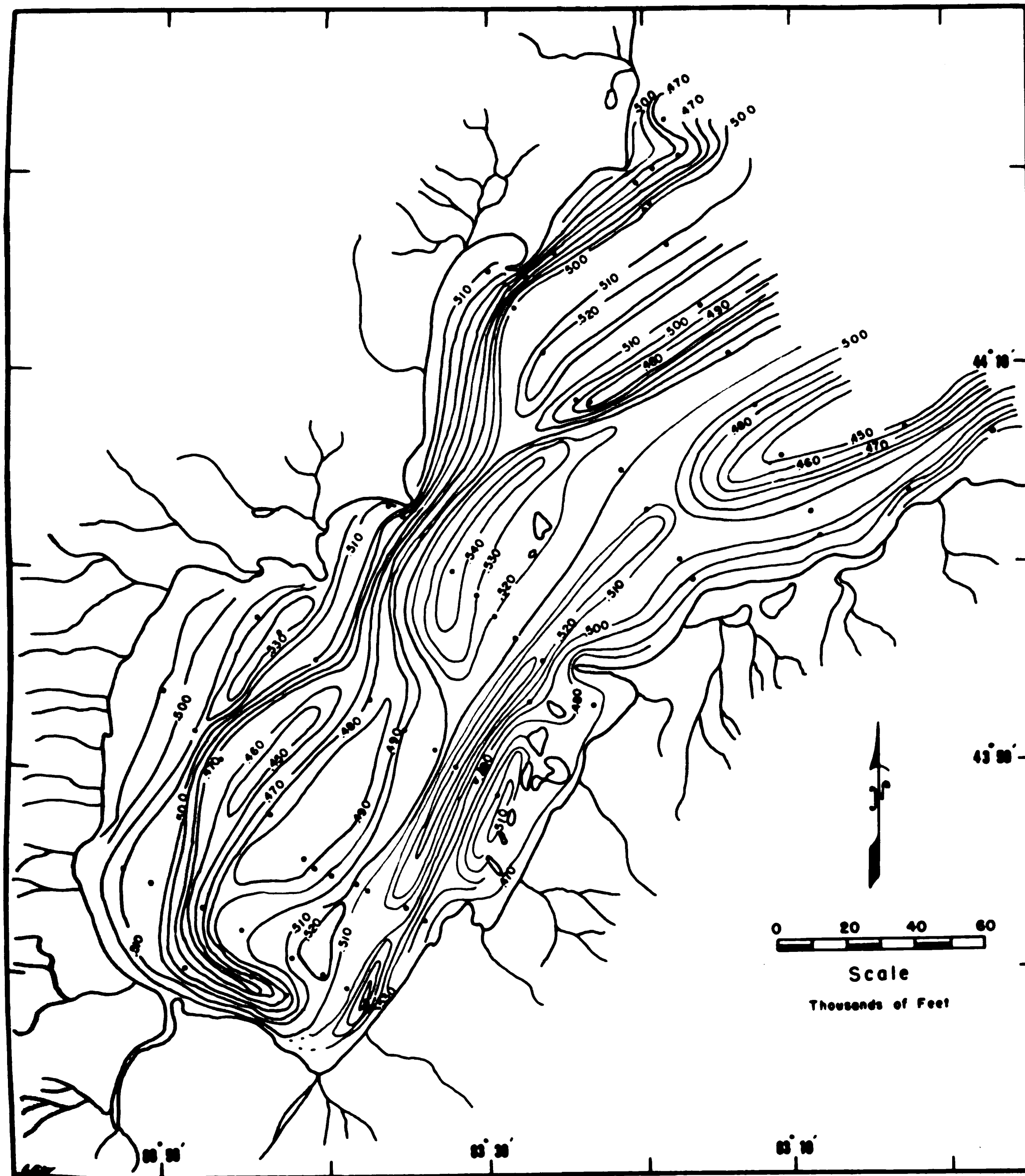
ARITHMETIC AVERAGES OF ROUNDNESS AND SPHERICITY

Sample Number	Roundness	Sphericity	Sample Number	Roundness	Sphericity
1	0.522	0.815	26	0.480	0.780
2	0.496	0.785	27	0.506	0.793
3	0.520	0.793	28	0.538	0.792
5	0.508	0.811	29	0.524	0.794
6	0.486	0.803	30	0.500	0.794
7	0.504	0.792	31	0.478	0.792
8	0.506	0.784	32	0.520	0.815
9	0.462	0.784	33	0.510	0.790
10	0.504	0.764	34	0.520	0.804
11	0.502	0.767	35	0.530	0.809
12	0.516	0.785	36	0.546	0.807
13	0.496	0.768	37	0.490	0.830
14	0.484	0.792	38	0.478	0.820
15	0.494	0.772	39	0.516	0.785
16	0.482	0.783	41	0.486	0.826
17	0.464	0.780	42	0.500	0.798
18	0.526	0.778	43	0.508	0.811
19	0.490	0.792	45	0.520	0.800
21	0.506	0.801	46	0.500	0.803
22	0.488	0.776	47	0.520	0.806
23	0.532	0.790	49	0.504	0.785
24	0.508	0.785	50	0.492	0.803
25	0.504	0.805	51	0.512	0.818

Table 147

ARITHMETIC AVERAGES OF ROUNDNESS AND SPHERICITY, CONT'D

Sample Number	Roundness	Sphericity
52	0.508	0.771
53	0.516	0.800
54	0.452	0.806
55	0.466	0.775
56	0.460	0.809
59	0.462	0.782
61	0.472	0.782
62	0.450	0.799
63	0.476	0.780
64	0.466	0.811
65	0.488	0.799
66	0.482	0.771
67	0.474	0.797
68	0.472	0.789
69	0.476	0.794



SAGINAW BAY

AVERAGE ROUNDNESS DISTRIBUTION

ISOPLETH INTERVAL: .010 Units

PLATE 6

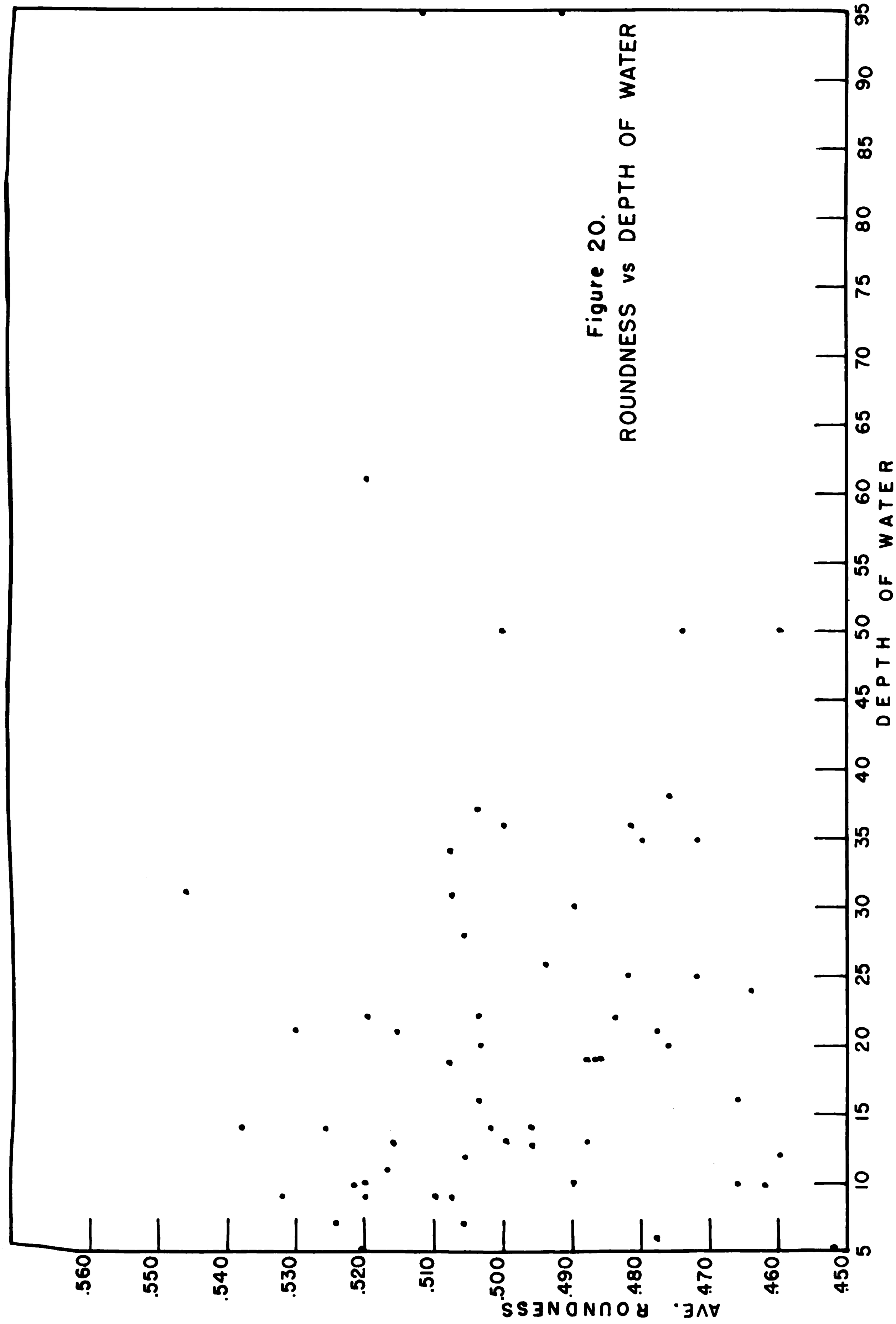


Figure 20.
ROUNDNESS vs DEPTH OF WATER

ROUNDNESS AND MEDIAN DIAMETER -- Inasmuch as the depth of water and median diameter of the sand are generally related, there is an interrelationship involving depth of water, median diameter, and roundness. The fine sediments from areas of deep water in the western half of the bay show a noticeable lack of roundness. The sediments in the deep water east of Charity Island show a considerable variation in grain roundness from one sample to another. Figure 21 indicates that there is no linear correlation between roundness and median diameter, although those grains with a roundness of 0.500 and above occur in the sand-size sediment.

It is generally agreed that little abrasive action takes place on very fine particles in deep water where slower currents are prevalent. Many writers believe that solution is as important as abrasion in the process of rounding of particles of sand size and smaller.

ROUNDNESS AND SORTING -- The sediments of Saginaw Bay show little or no relationship between roundness and sorting (Fig. 22). One might expect to find a general area correlation in which the finer, poorly rounded sediments from deep water have poor sorting. This holds true for some samples in Saginaw Bay, but it has been shown that there are many exceptions where sorting is more a factor of currents than depth.

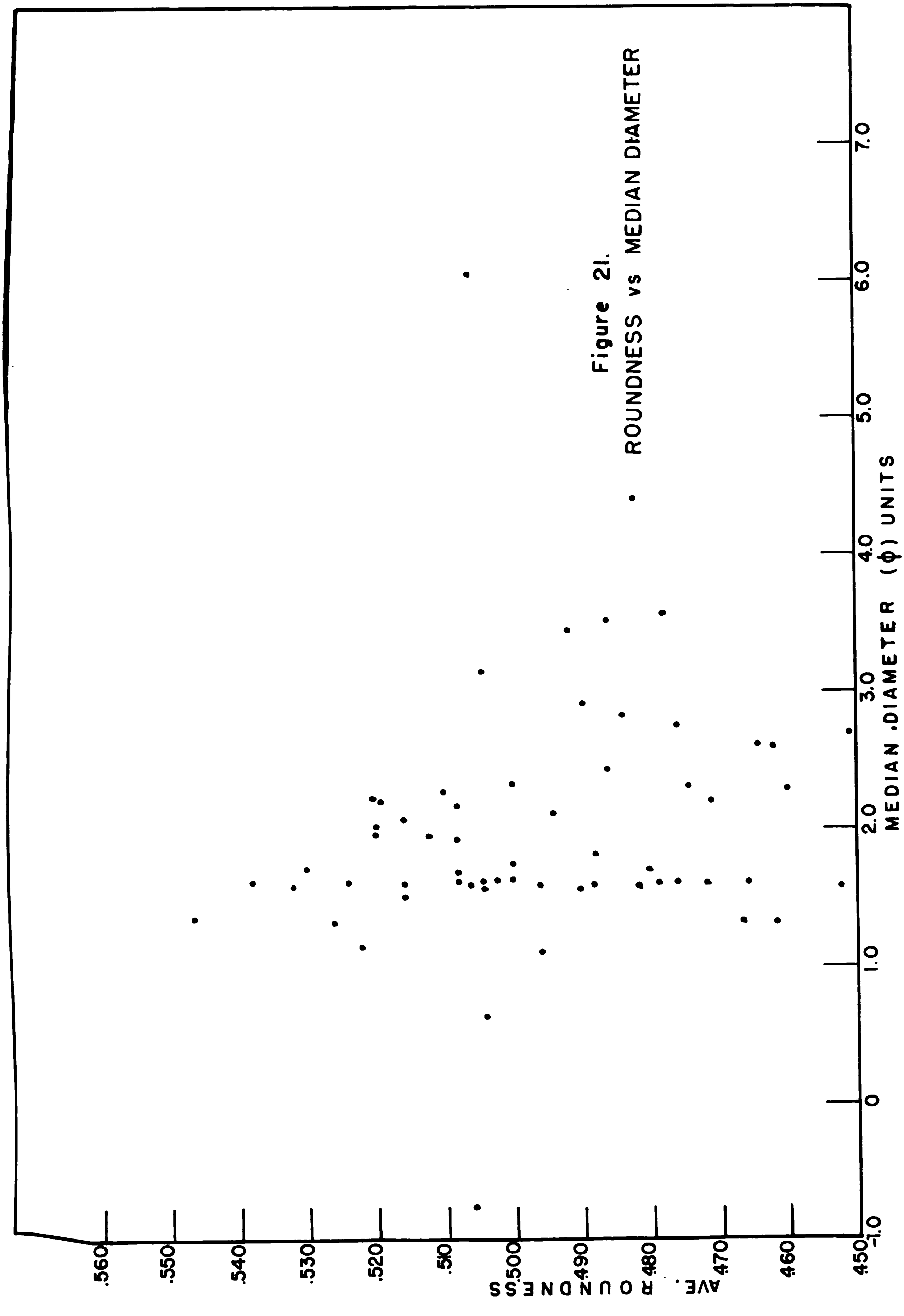


Figure 21.
ROUNDNESS vs MEDIAN DIAMETER

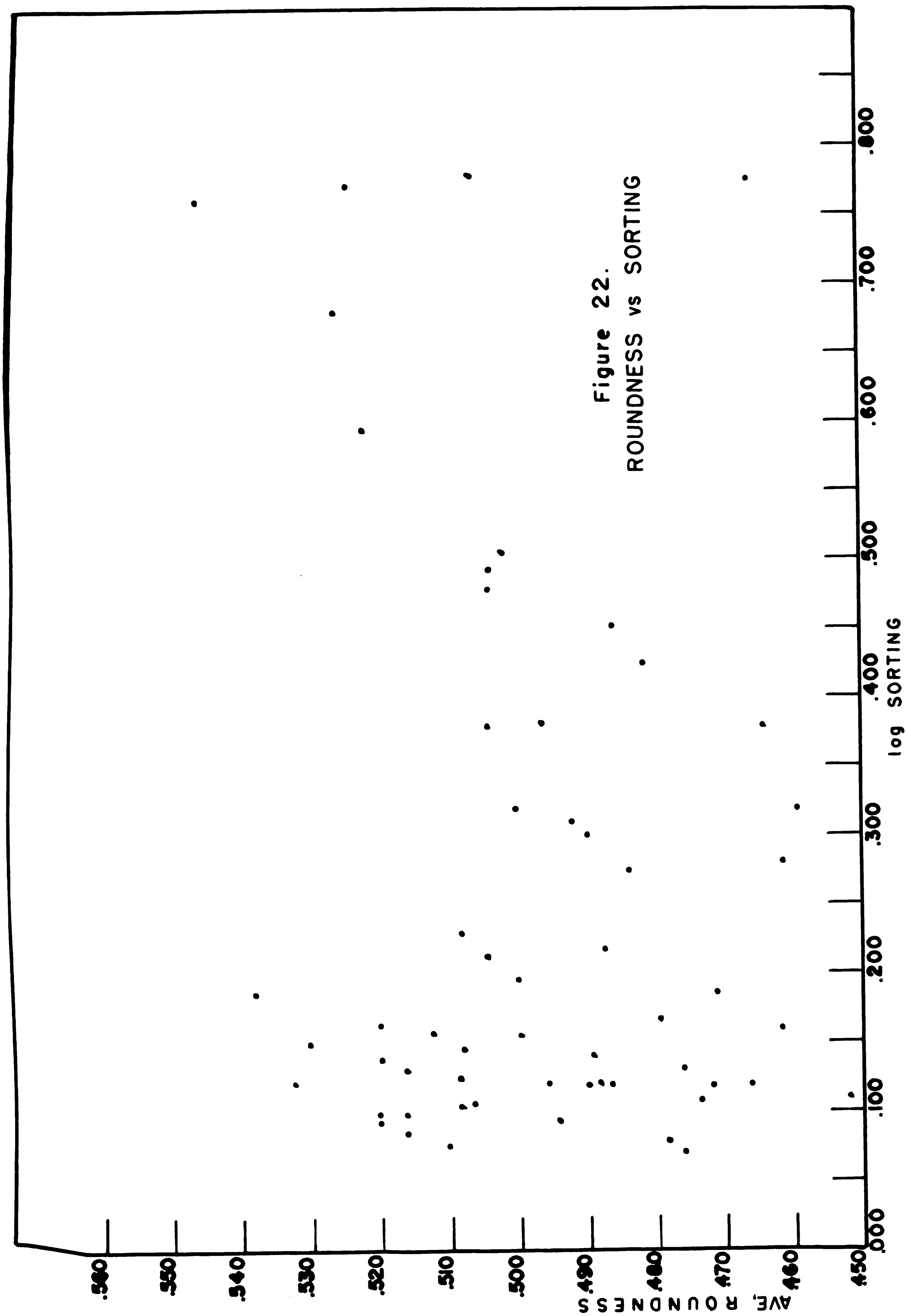


Figure 22.
ROUNDNESS vs SORTING

<u>ROUNDNESS AND SKEWNESS</u> -- There is no linear correlation between roundness and skewness. Figure 23 shows that the sediments which possess high roundness tend to be skewed more to the fine side.

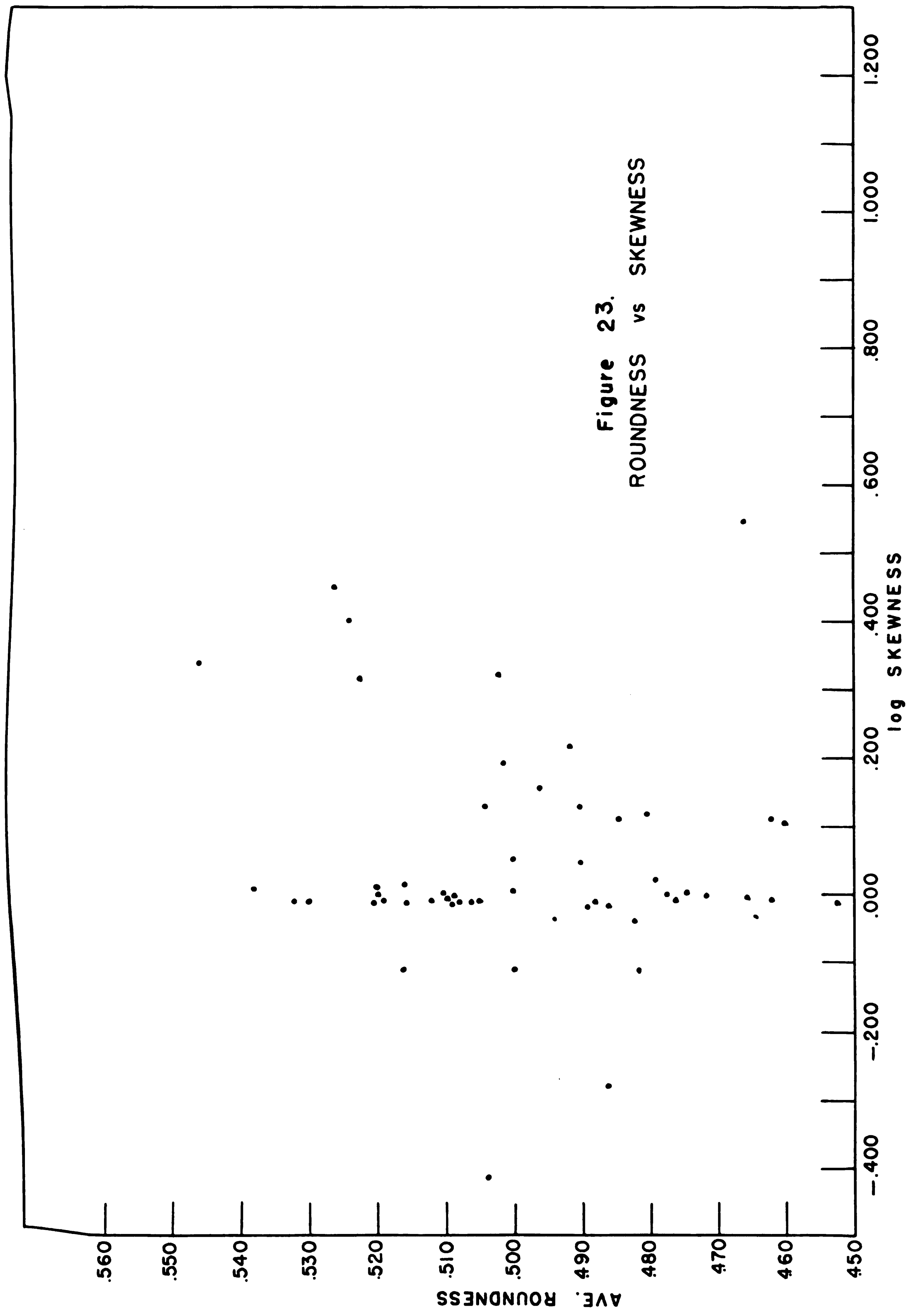


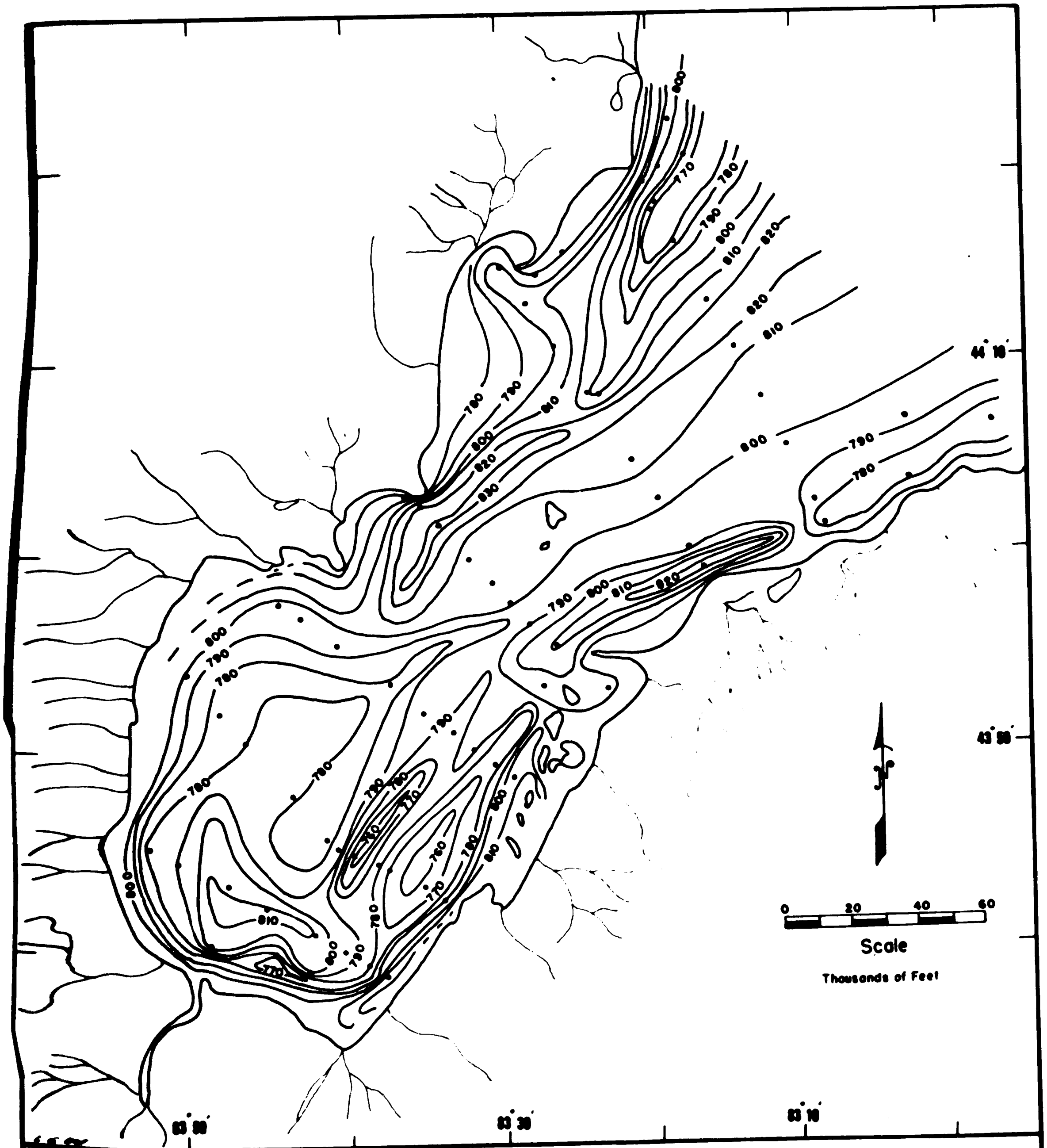
Figure 23.
ROUNDNESS vs SKEWNESS
log SKEWNESS
-.400
-.200
.000
.200
.400
.600
.800
1.000
1.200
AVE. ROUNDNESS
.560
.550
.540
.530
.520
.510
.500
.490
.480
.470
.460
.450

SPHERICITY

High sphericity is recorded in the sediments off Point Lookout near the north shore. This zone of high sphericity may be extended southeast across the bay in the vicinity of Charity Island to Sand Point and then along the southern shore. Other areas of sediment with high sphericity occur with less regularity throughout the bay.

Average sphericity data are shown in Table 147. Average sphericity distribution is shown on Plate 7.

SPHERICITY AND DEPTH OF WATER -- Sand particles with high sphericity are more common in shallow portions of the bay. High sphericity values are noted in shallow water west of Charity Island, and on the south shore from Sand Point to Hat Point. Values somewhat higher than average are found close to the south shore west of Sand Point. Low sphericity values are recorded from samples in the narrow trench which parallels the south shore. High sphericity, comparable to that along the south shore, follows the shallow water between the north shore and the glacial Saginaw River channel. In deep water at the open end of the bay, high sphericity is inconsistent with the highs normally associated with shallow water. Values are fairly equal in the deep water of the western half of the bay and no linear trend is apparent.



SAGINAW BAY

AVERAGE SPHERICITY DISTRIBUTION

ISOPLETH INTERVAL: .010 Units

PLATE 7

Figure 24 shows sphericity as a function of depth. No linear correlation is apparent, therefore, it is felt that the distribution of sediments according to shape is a result of some factor other than that of depth alone.

SPHERICITY AND MEDIAN DIAMETER -- Since there is a general areal relationship between depth and sphericity and depth and median diameter, one might also expect a general areal relationship to exist between sphericity and median diameter. Sphericity, like roundness, is not a product of abrasion in the fine-grained sediments, or at least not so in one sedimentary cycle. In the areas of sand concentration, sphericity for the same reason as roundness might be expected to increase; however, coarser materials, including granules, pebbles, and cobbles are capable of fracturing the smaller grains. This fracturing may bring about a decrease in sphericity.

Figure 25 shows sphericity plotted as a function of median diameter. No linear correlation is apparent.

SPHERICITY AND SORTING -- There is no relationship between the degree of sorting of a sediment and its sphericity in Saginaw Bay. This is verified in figure 26 in which sphericity is plotted as a function of sorting. Nevertheless, it is thought that grains are transported and distributed according to their shape as a result of so-called selective transportation.

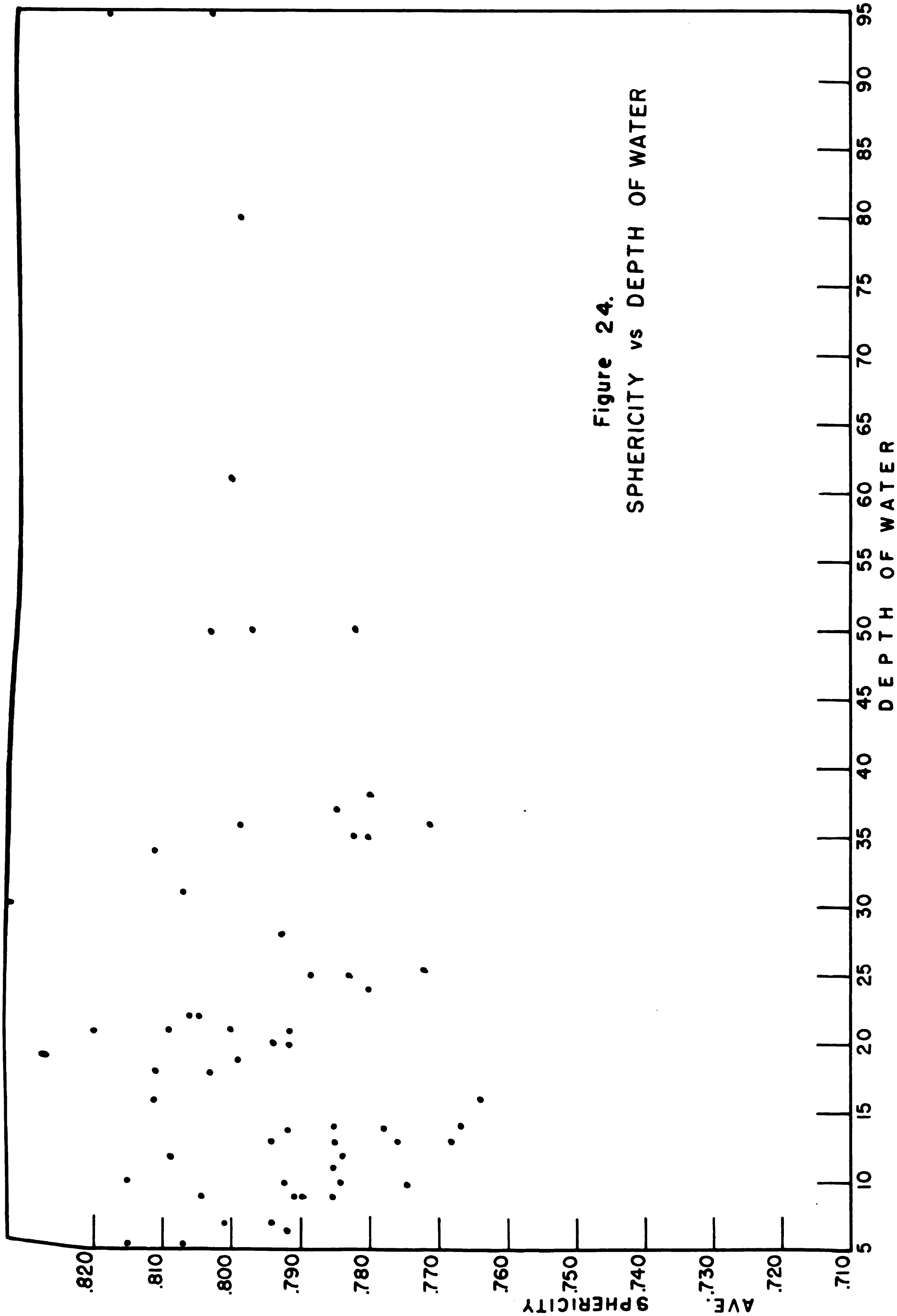


Figure 24.
SPHERICITY vs DEPTH OF WATER

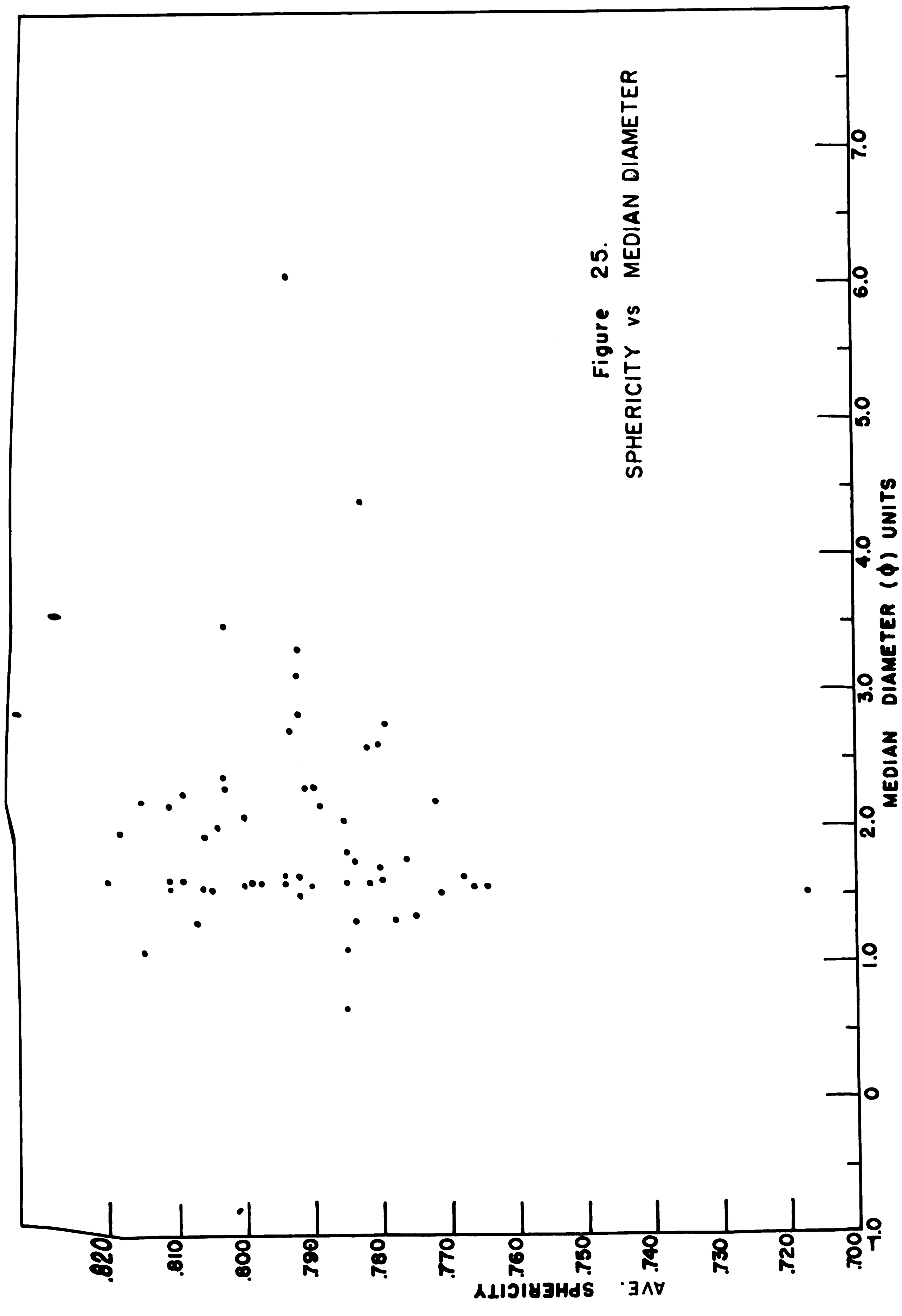


Figure 25.
SPHERICITY vs MEDIAN DIAMETER

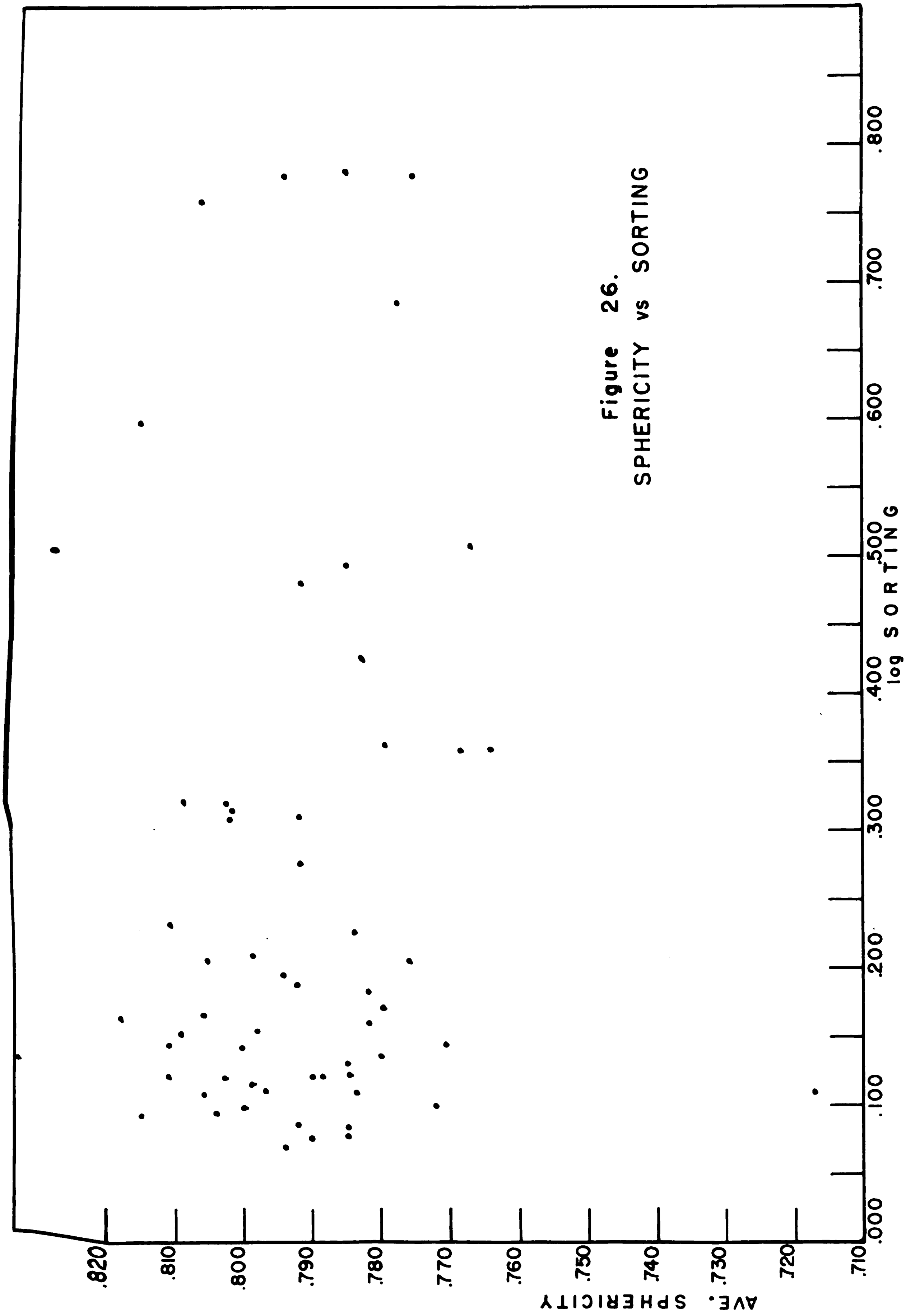


Figure 26.
SPHERICITY vs SORTING

<u>SPHERICITY AND SKEWNESS</u> -- There is no linear correlation between sphericity and skewness as shown in figure 27. Those grains which are highly spherical tend to be somewhat less skewed than those having less sphericity.

<u>SPHERICITY AND ROUNDNESS</u> -- There is no apparent relationship between roundness and sphericity (Fig. 28), although a slight linear trend can be seen along the north and south shores in areas of supposed constant currents and greater sand accumulation (Pls. 6 and 7).

Russell (1937) points out that grains showing a high degree of roundness and sphericity might be expected to occur in areas of greater concentrations of sand-size grains. On the other hand, should these same areas contain larger granules or pebbles along with sand-size grains there is a likelihood that the smaller grains may be fractured if strong wave or current action should cause the sediments to be agitated. This results in factors of lower roundness and sphericity in the smaller grains. Russell does not propose a high degree of rounding by abrasion even in the areas of sand accumulation.

Hough (1942), in his study of the sediments of Cape Cod Bay, found no relationship between sphericity and median diameter, and roundness and sphericity. He found a slight correlation with depth and sphericity and roundness and depth.

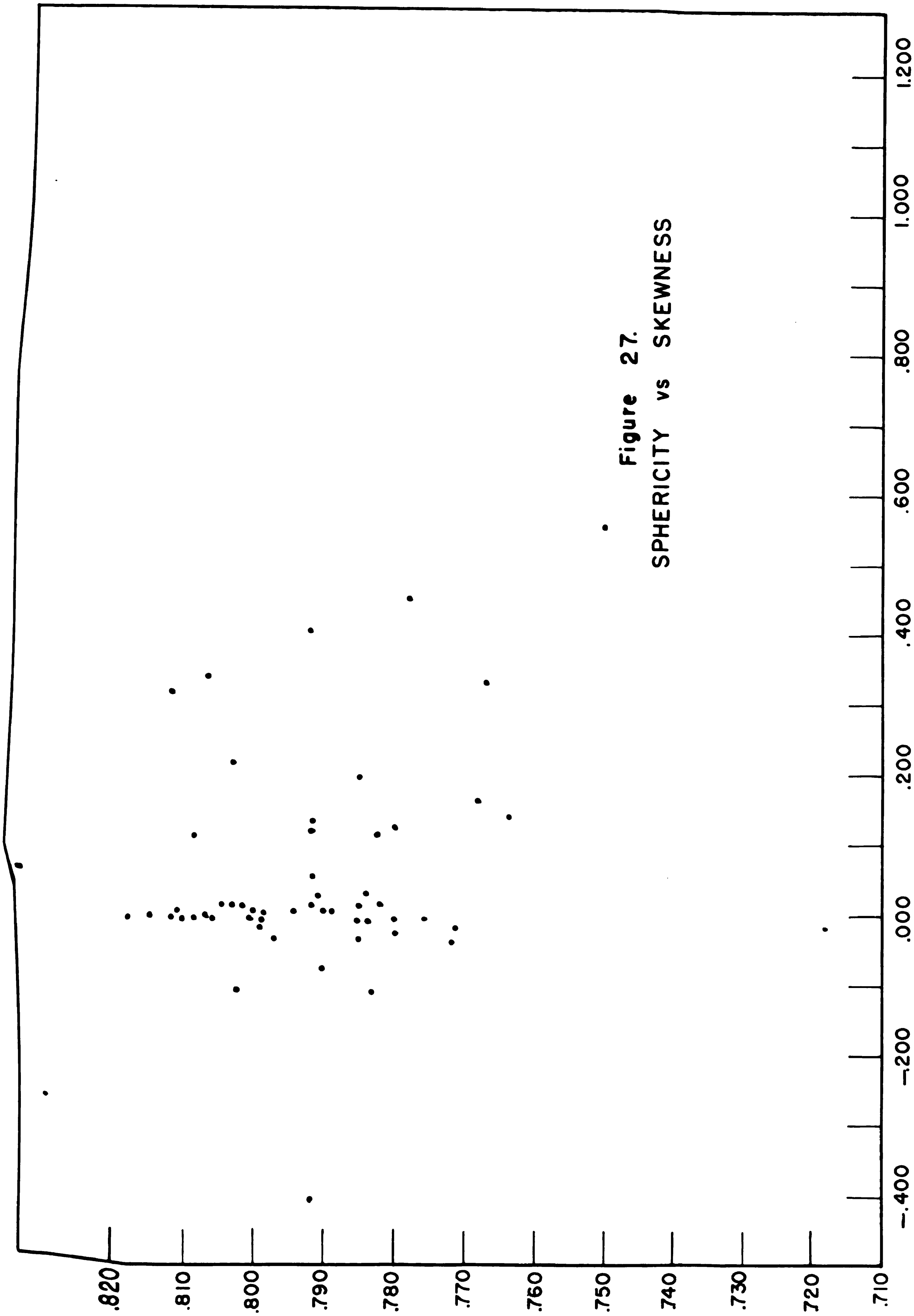


Figure 27.
SPHERICITY vs SKEWNESS

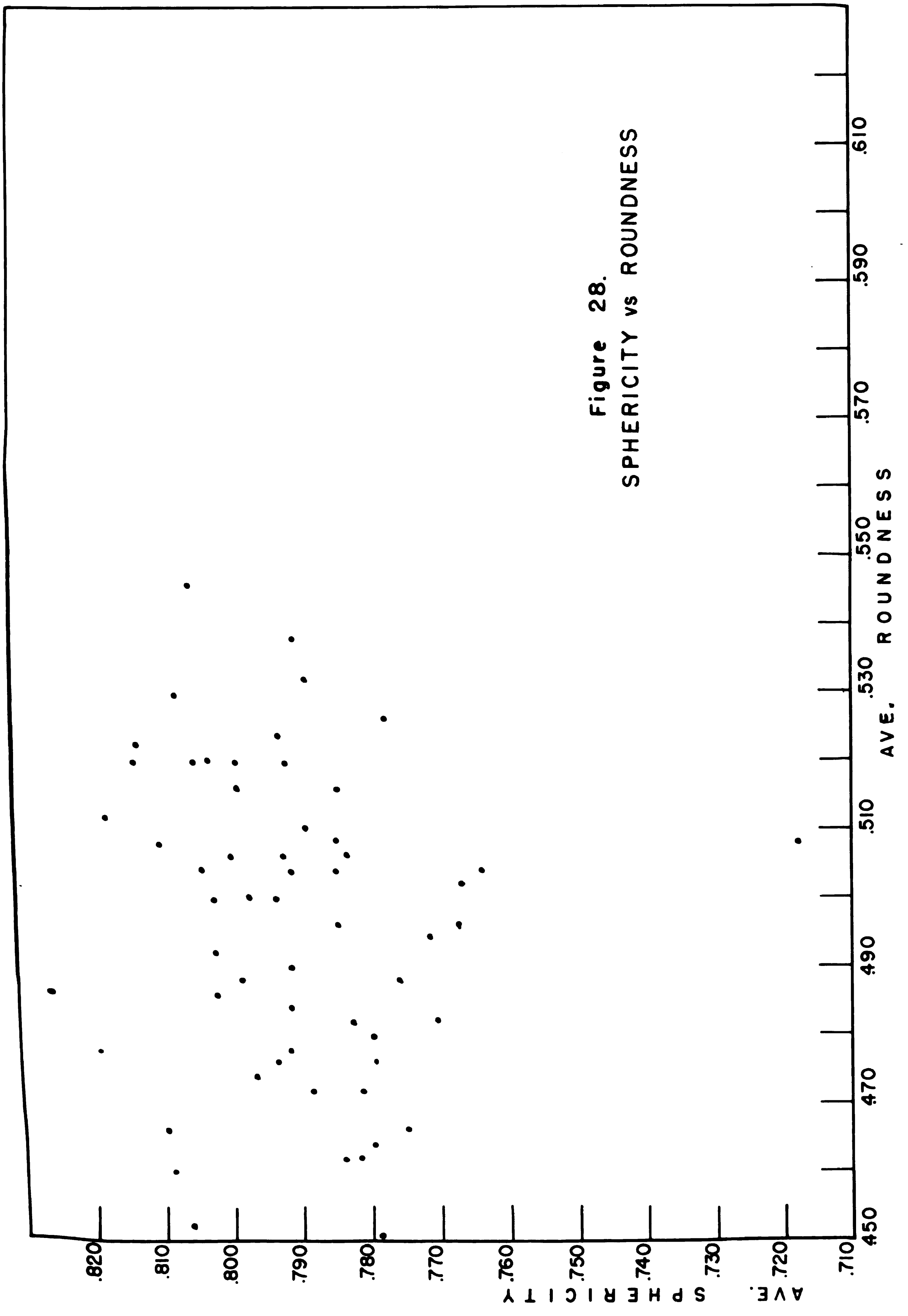


Figure 28.
SPHERICITY vs ROUNDNESS

CONCLUSIONS -- At best only very general conclusions can be established with regard to roundness and sphericity in Saginaw Bay. The average roundness and sphericity distribution shown on Plates 6 and 7 indicates a somewhat linear trend corresponding to known current patterns. The writer does not believe that current alone can be the main factor in producing roundness or sphericity in any grain. This same fact has been suggested by many students studying sediments occurring under similar environments.

Russell (1939), Pettijohn and Lundahl (1943), Twenhofel (1945), and Beal and Shepard (1956) agree that it is very improbable that abrasion has much effect on rounding of grains of sand-size or smaller. That if rounding does occur, it takes place in areas of sand concentration. Twenhofel states that traction is the main agent, if not the sole agent in abrasion of sand grains. The grains of less than one-quarter millimeter in diameter are rounded very little on sea or lake shores, whereas those grains larger than one-half millimeter appear to be rounded fairly easily during traction transportation as judged by the abundance of rounded grains of this dimension. High roundness and sphericity values in Saginaw Bay are too erratic to state any such specific conclusions. Furthermore, it can be said with reasonable certainty that solution is an equally important factor in producing roundness and sphericity in some mineral grains.

Kuenen (1950) and Russell (1939) cited evidence for believing that grains with higher roundness and sphericity values are more easily transported by rolling in contrast to the less spherical and less round grains which tend to be transported more easily in suspension. Morris (1957), in relating roundness and sphericity with fluid velocity, found that in high fluid velocity, angular grains move faster and farther than those rounded because of local turbulence set up around the angular grains. This local turbulence impedes rapid settling of particles. In low fluid velocities, rounded grains move faster and farther than angular grains because of their ability to roll. There is no evidence to prove which is the dominant factor in carrying sediments in Saginaw Bay.

It may be said with reasonable certainty that currents and wave action in Saginaw Bay are strong enough to move sediments, regardless of shape, by rolling, saltation, and suspension. Any local distribution which shows some uniformity is probably a result of selective transportation which, because of other varying factors, does not carry throughout the bay.

The Saginaw Bay sands are of glacial origin, the materials of which are derived from a great variety of rocks dating to Precambrian. Those sediments already deposited and those presently being deposited in the bay have survived one or more sedimentary cycles. Therefore, a considerable range in roundness and sphericity may exist in the grains before they are acted upon by the mechanical processes within the bay.

Twenhofel (1945) in support of his conclusions on rounding by recent wave and current action cites this history of a single sand:

> "Most sands on most beaches and in most dunes have been successively transported by wind and water. This is illustrated by sands collected in dunes on Camp McCoy in western Wisconsin. The sands for these dunes were brought to them from the flood plain of the LaCrosse River to the west. The river obtained the sands from Cambrian sandstone across whose outcrops the river flows, from the St. Peter sandstones which once overlay the region, and from outwash sands of the Wisconsin glacier. Grains in Cambrian and St. Peter sandstones are well rounded in many beds. The St. Peter sands seem best interpreted as water deposited after reworking sands of dunes, the dunes having been formed in early Ordovician time following emergence of the Prairie du Chien limestone. The dunes probably obtained the sands from Cambrian sandstones. The outwash sands were derived from all formations over which the glacier moved from the oldest system of rocks to the Pleistocene. Ultimately many of the sands were derived from the Precambrian formation. With this complexity of history, of what value is any expression of roundness accomplished during the last transportation?"

Inasmuch as most of the material in the bay is sand or smaller, it is entirely possible that little or no change has taken place in the sediments since the formation of glacial Lake Saginaw.

Variations in selective roundness and sphericity distribution are due to a combination of selective transport, current velocity, bottom topography, quantity of sediment, river influence, depth of water, and grain size. This selective distribution is not a result of abrasion as a function of length of time and intensity of wave and current action on the sediments in Saginaw Bay.

ACID SOLUBLES

Two grams of sample, dried at room temperature, were placed in an evaporating dish. Acid solubles were removed by a solution of .1N HCl, titrated to a pH of approximately 4.4. Methyl purple was used as the pH indicator. After approximately 24 hours the sediment was washed with distilled water, decanted, and dried. The residue was assumed to be the acid insolubles, which included organic carbon. It was hoped that by using this method the carbonates could be easily removed.

Certain minerals other than calcite and dolomite are affected somewhat by the HCl solution, but the sand of Saginaw Bay is predominantly quartz and the other minerals occur in such small quantities that very little solution is likely to take place.

Several other methods for determining acid soluble content were considered, but in most instances the procedures were too lengthy and the reliability of the results did not justify the time they required.

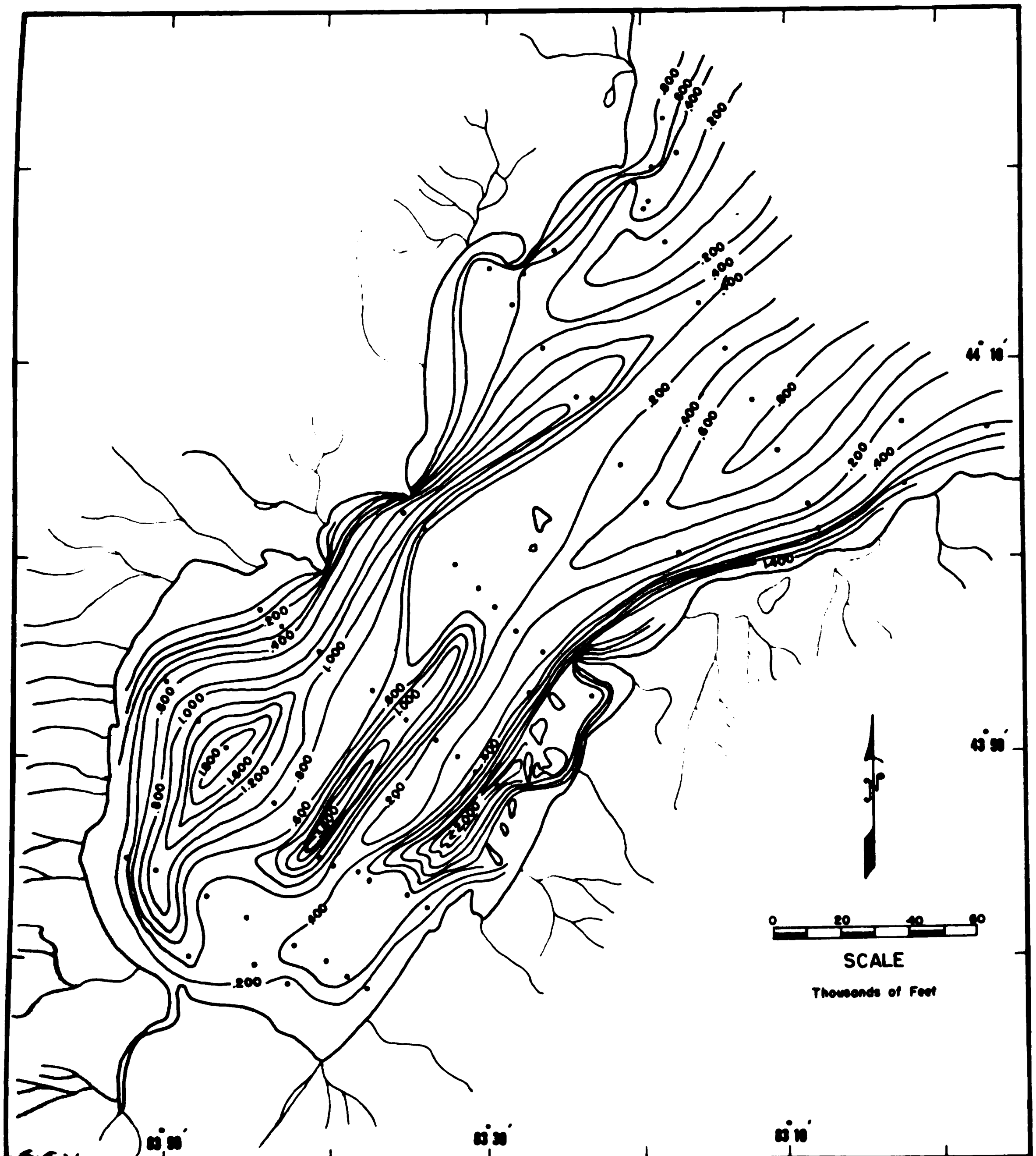
Acid solubles are in all the samples. They range in amounts from 0.062 per cent in Sample 24 to 3.680 per cent in Sample 14. The latter amount is not in context with the average of the other data and the sample from which the results were obtained may not be valid. The acid solubles or carbonates appear to be derived largely from detrital calcite, dolomite and shell fragments. Nearly half of the 61 samples contain less than 0.400 per cent acid solubles and 85 per cent contain less than 1.000 per cent.

There appears to be no uniform distribution from which definite conclusions can be expressed relating the acid solubles to current patterns, although it may be seen by the isopleth arrangement on Plate 8 that high percentages occur in an elongate belt close to the shore in line with the prevailing currents.

These areas of high acid soluble percentage are located on the flanks of the glacial Saginaw River channel in the western half of the bay at locations 7, 14, 17, 25, and 38. Similar high amounts are found close to the south shore at location 21, 31, and 41.

Acid soluble data are shown in Table 148.

ACID SOLUBLES AND MEDIAN DIAMETER -- No linear correlation results when acid solubles are plotted against median grain diameter (Fig. 29). Samples taken from the west end of the bay in areas of generally fine-grained sediments show relatively high acid soluble content. This is noticeably so in Samples 7, 16, 17, 18, and 27 which outline the trench of fine sediments extending northeast from the mouth of the Saginaw River. Samples 14, 31, 41, and 67,



SAGINAW BAY

ACID SOLUBLE DISTRIBUTION

ISOPLETH INTERVAL .200 Percent

PLATE 8

Table 148

ORGANIC-ACID SOLUBLE PERCENTAGES

Sample Number	Weight of Sample (Grams)	Acid Soluble Loss	Acid Soluble Percent	Organic Loss	Organic Percent
1	5.0153	0.0134	0.267	0.0522	1.041
2	5.0124	0.0225	0.449	0.0686	1.369
3	5.0004	0.0236	0.472	0.0531	1.062
5	5.0017	0.0184	0.368	0.0201	0.402
6	5.0000	0.0196	0.392	0.0148	0.296
7	5.0050	0.0510	1.019	0.2402	4.799
8	5.0010	0.0151	0.302	0.0182	0.364
9	5.0000	0.0106	0.212	0.0800	1.600
10	5.0143	0.0299	0.596	0.0500	0.997
11	5.0043	0.0216	0.432	0.0410	0.819
12	5.0008	0.0264	0.528	0.0304	0.608
13	5.0070	0.0147	0.294	0.0484	0.967
14	5.0000	0.1842	3.684	0.3936	7.872
15	5.0037	0.0248	0.496	0.0221	0.442
16	5.0155	0.0429	0.855	0.2491	4.967
17	5.0007	0.0932	1.864	0.1010	3.020
18	5.0000	0.0632	1.264	0.0398	0.796
19	5.0133	0.0226	0.451	0.0395	0.788
21	5.0000	0.0970	1.940	0.0650	1.300
22	5.0009	0.0270	0.540	0.0399	0.798
23	5.0019	0.0183	0.366	0.0177	0.354
24	5.0007	0.0031	0.062	0.0026	0.452
25	5.0005	0.0599	1.198	0.0308	0.616

Table 148

ORGANIC-ACID SOLUBLE PERCENTAGES, continued

Sample Number	Weight of Sample (Grams)	Acid Soluble Loss	Acid Soluble Percent	Organic Loss	Organic Percent
26	5.0007	0.0599	0.654	0.0687	1.374
27	5.0007	0.0327	0.826	0.3180	6.359
28	5.0000	0.0413	0.078	0.0260	0.520
29	5.0012	0.0039	0.644	0.0370	0.740
30	5.0006	0.0322	0.570	0.0145	0.290
31	5.0020	0.0285	1.555	0.0862	1.723
32	5.0000	0.0778	0.224	0.0119	0.238
33	5.0007	0.0112	0.164	0.0199	0.398
34	5.0012	0.0082	0.396	0.0242	0.484
35	5.0010	0.0198	0.216	0.0185	0.370
36	5.0008	0.0108	0.334	0.0166	0.332
37	5.0000	0.0167	0.400	0.0255	0.510
38	5.0007	0.0200	1.196	0.0722	1.444
39	5.0008	0.0598	0.124	0.0101	0.202
41	5.0010	0.0710	1.420	0.1653	3.305
42	5.0000	0.0080	0.160	0.0093	0.186
43	5.0000	0.0075	0.150	0.0243	0.486
45	5.0012	0.0231	0.462	0.0085	0.170
46	5.0000	0.0271	0.542	0.1167	2.334
47	5.0007	0.0263	0.526	0.0160	0.320
49	5.0002	0.0397	0.079	0.0445	0.890
50	5.0002	0.0333	0.666	0.0356	0.712
51	5.0000	0.0214	0.428	0.0178	0.356

Table 148

ORGANIC-ACID SOLUBLE PERCENTAGES, continued

Sample Number	Weight of Sample (Grams)	Acid Soluble Loss	Acid Soluble Percent	Organic Loss	Organic Percent
52	5.0000	0.0148	0.296	0.0095	0.102
53	5.0001	0.0081	0.162	0.0051	0.102
54	5.0001	0.0082	0.164	0.0422	0.844
55	5.0000	0.0194	0.387	0.0333	0.666
56	5.0002	0.0217	0.434	0.0270	0.540
59	5.0000	0.0336	0.672	0.0058	0.116
61	5.0000	0.0472	0.944	0.0098	0.196
62	4.9998	0.0160	0.328	0.0674	1.348
63	5.0000	0.0192	0.284	0.0097	0.194
64	5.0002	0.0413	0.826	0.0100	0.200
65	5.0002	0.0432	0.864	0.0072	0.144
66	5.0000	0.0229	0.458	0.0085	0.170
67	5.0005	0.0473	0.946	0.0042	0.084
68	5.0001	0.0205	0.410	0.0106	0.212
69	5.0001	0.015	0.302	0.0171	0.342

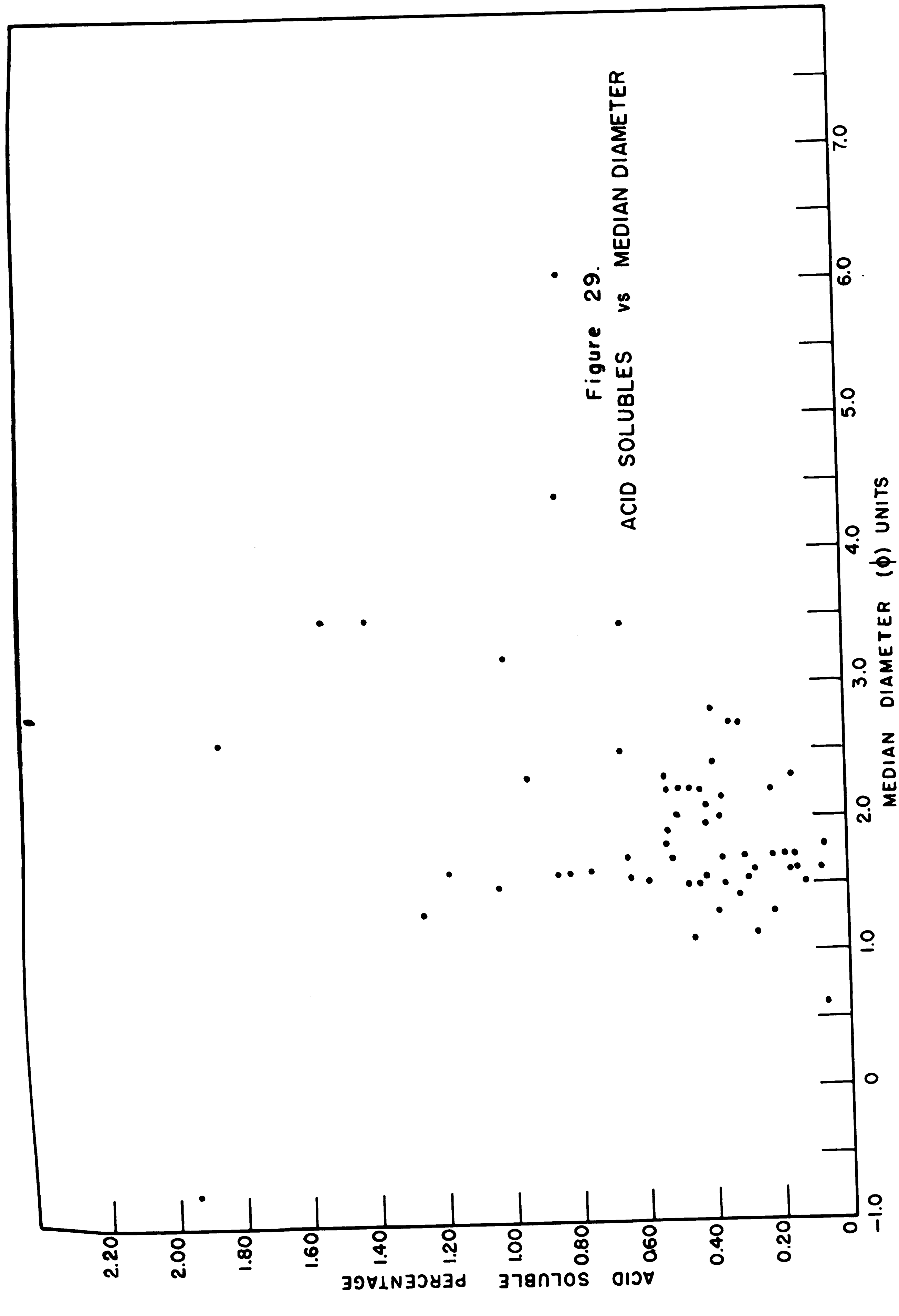


Figure 29.
ACID SOLUBLES vs MEDIAN DIAMETER

high in acid solubles, possess very small median diameter. However, if one considers all 61 samples taken from the bay, it can be readily seen that the establishment of acid solubles as a function of median diameter is more of an exception than a rule.

Any correlation that exists between fine-grained sediments and high acid soluble content may be attributed to fine shell fragments accumulating in areas of deep or restricted water. A high that occurs in the coarse-grained sediments near Katechay Island is associated with selective transportation of certain sizes containing shell fragments or detrital carbonates.

Caldwell (1940) found a general increase in carbonates with a decrease in grain size in the sediments from Barataria Bay, Louisiana. Carbonate percentage in Barataria Bay ranges from approximately 2.0 to nearly 90.0 per cent. Here shell fragments account for most of the carbonate.

In contrast to what has been said, Shukri and Higazy (1944) noticed an increase in carbonates in the Red Sea with an increase in grain size, but they did not discuss their observation.

Hough (1940) draws no comparison between carbonates and grain size in Buzzards Bay. He notes only a slight increase in carbonate with depth of sediments. He attributed this lack of carbonate to solution taking place over a considerable period of time. This same effect has been noted in many deep water deposits.

The sediments at locations 21, 25, and 61 on the southeast side of the bay, and locations 38 and 65 along the northwest shore are coarse-grained and contain substantially high acid soluble content. These samples contain a few shell fragments which may easily account for the amount of acid solubles.

The marked variation in acid solubles in a given grain size may be attributed to two possible factors. First, it may be established that in areas of coarse material the shell fragments are crushed and broken in part by wave action. The small pieces are subsequently carried in suspension or by saltation to areas of accumulation in quiet water, which may be either deep water or shallow protected areas. The somewhat larger fragments, which are not easily moved, accumulate in certain localities as a result of selective transportation. A lack of any appreciable amount of acid solubles in a given grain size indicates a lack of source of shell fragments or an agent suitable of carrying the material containing the acid solubles to a specific locality.

A second source of soluble materials, as shown in Samples 21 and 38, (median diameters of 1.690 and 0.320 mm respectively) can be explained by weathering of limestone outcrop or boulders along some of the shoreline. Sample 21 was taken adjacent to Katechay Island and Stony Island which are composed of Bayport limestone (Fig. 4). Much of the coarse sand and pebbles are derived from the weathered limestone on these islands or from rocky accumulations along the shore. The sands in Sample 38 are considerably finer, but they also contain a few small pebbles and rock fragments which might be derived from Point Lookout Bayport limestone.

One cannot exclude the possibility that the great flocks of wildfowl which inhabit the islands on the southeast side of the bay carry considerable quantities of shell animals into these waters.

ACID SOLUBLES AND DEPTH OF WATER -- It has been shown in the discussion up to this point that a general relationship exists between grain-size and acid-soluble content in the sediments, and on this basis one might expect to find some correlation between depth of water and acid solubles. Although no linear correlation can be established, a concentration of points in the shallow depths and low acid soluble range are shown by figure 30.

ACID SOLUBLES AND ORGANIC CARBON -- It is generally accepted that organic carbon is more abundant in the fine-grained sediments. In Saginaw Bay these fine-grained sediments show for the most part a high acid soluble content. Figure 31 shows a slight relationship between sediments containing low acid soluble content and low organic carbon. Trask (1942) found no correlation between carbonates and organic carbon in deep sea sediments.

In spite of the fact that the relation between organic carbon and acid solubles is not always present under all

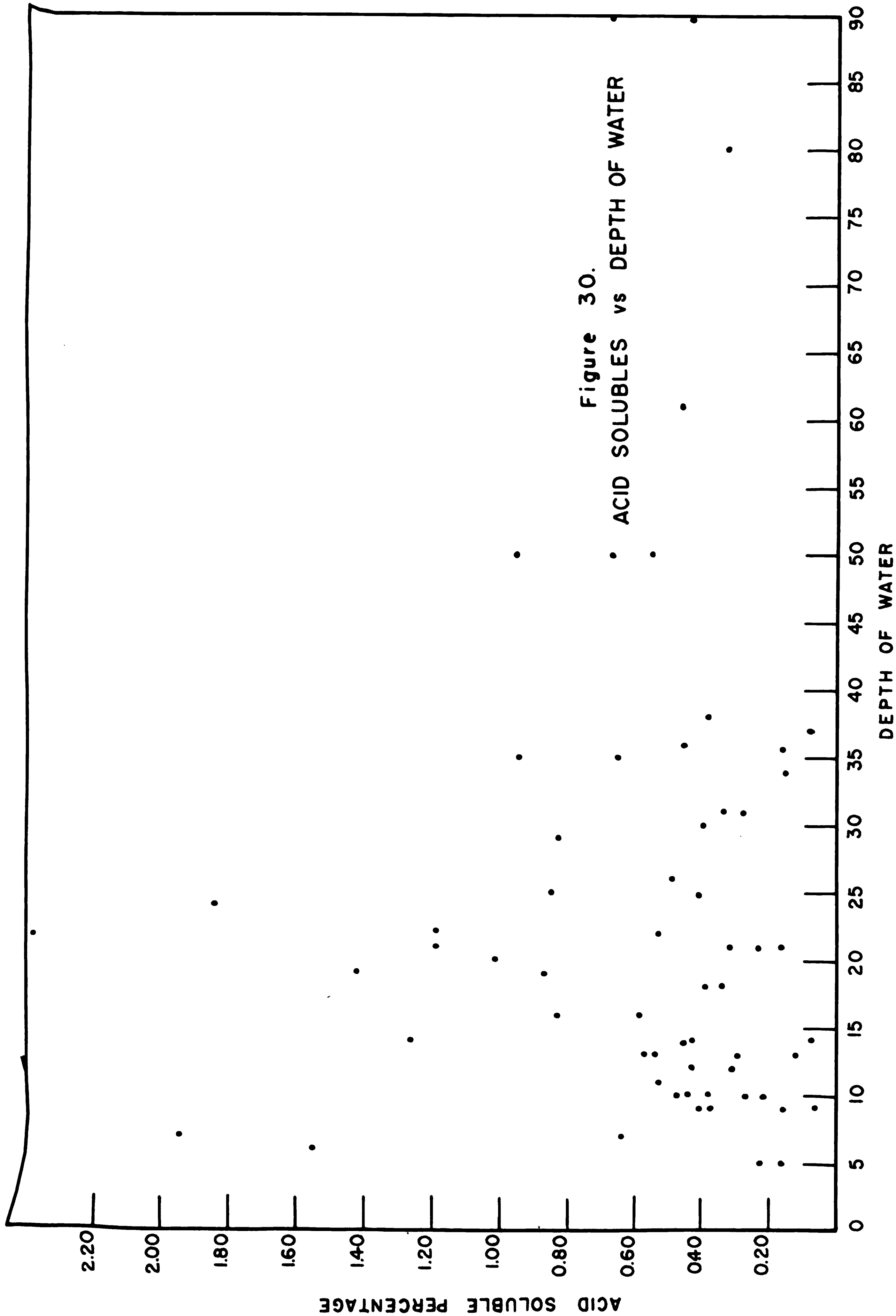


Figure 30.
ACID SOLUBLES vs DEPTH OF WATER

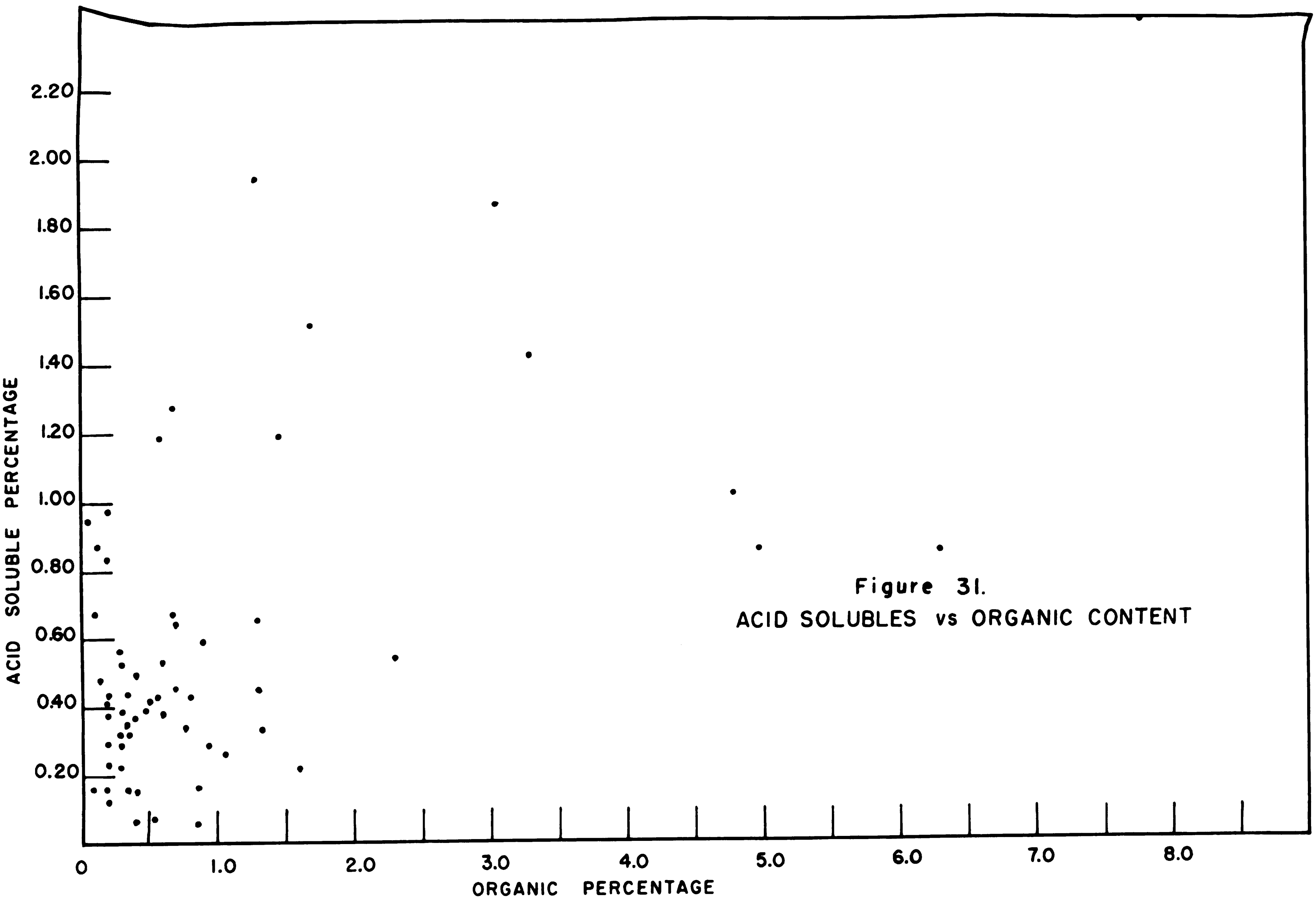


Figure 31.
ACID SOLUBLES vs ORGANIC CONTENT

circumstances, it is interesting to note that a slight correlation generally exists between grain-size, depth of water, acid solubles, and organic carbon. This association is a reflection of the physical environment of the bay, and when considered in light of recent sedimentary deposition it might be utilized in the interpretation of the physical environments at the time of deposition of ancient sediments.

ACID SOLUBLES AND SORTING -- The relationship between sorting and acid solubles is shown by figure 32. The relation between grain-size, sorting, and acid solubles is only slightly apparent. However, low acid soluble percentage usually is associated with good sorting and the high acid soluble percentage is to some extent more prominent in the more poorly sorted sediments. This agrees with the correlation of fine sediments, which generally are poorly sorted and have high acid soluble content.

ACID SOLUBLES AND SKEWNESS -- Figure 33 shows the relationship between acid solubles and skewness. For the most part sediments which show nearly zero skewness or are skewed to the fine side of the curve contain less than 0.800 per cent acid solubles. Gnerally those skewed far to the coarse side contain more than 0.800 per cent acid solubles.

ACID SOLUBLES AND CURRENTS -- Only general relationships between acid solubles and grain-size, depth, and sorting are established. The amount and source of acid soluble

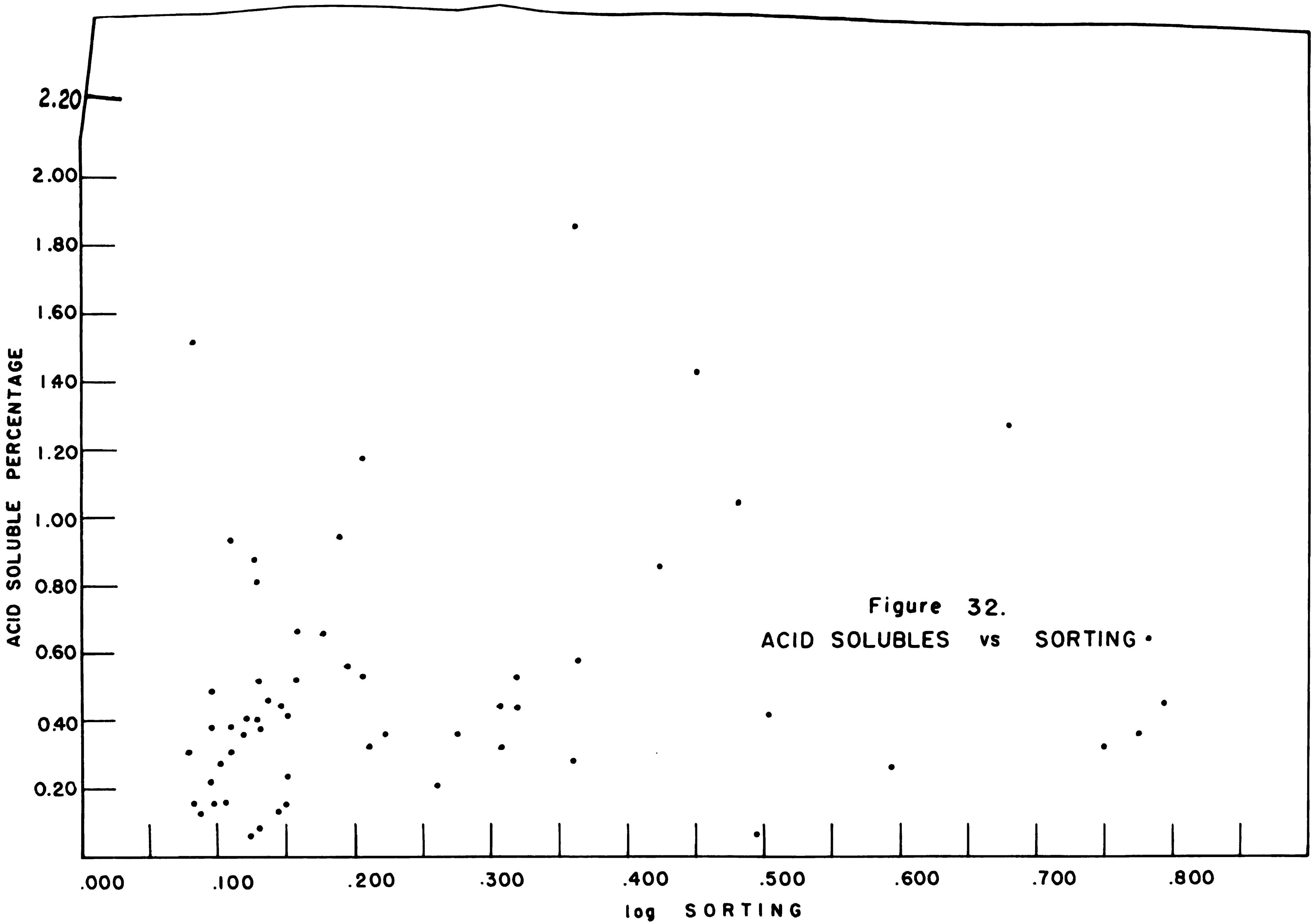


Figure 32.
ACID SOLUBLES vs SORTING.

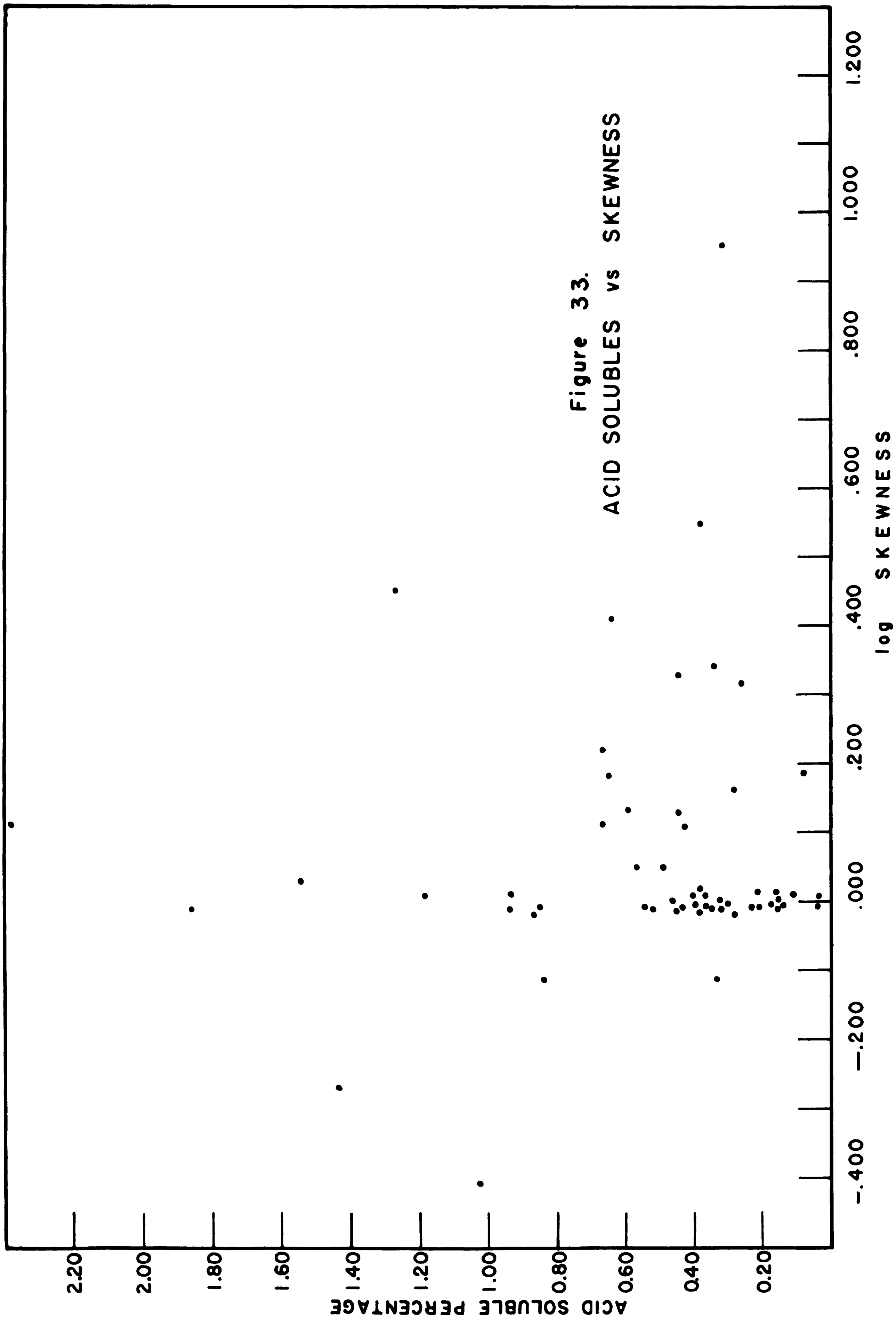


Figure 33.
ACID SOLUBLES vs SKEWNESS

material appears to be the greatest factor in determining its distribution; although, some acid soluble materials are probably sorted locally according to the physical properties and environment of the sediment in which they exist.

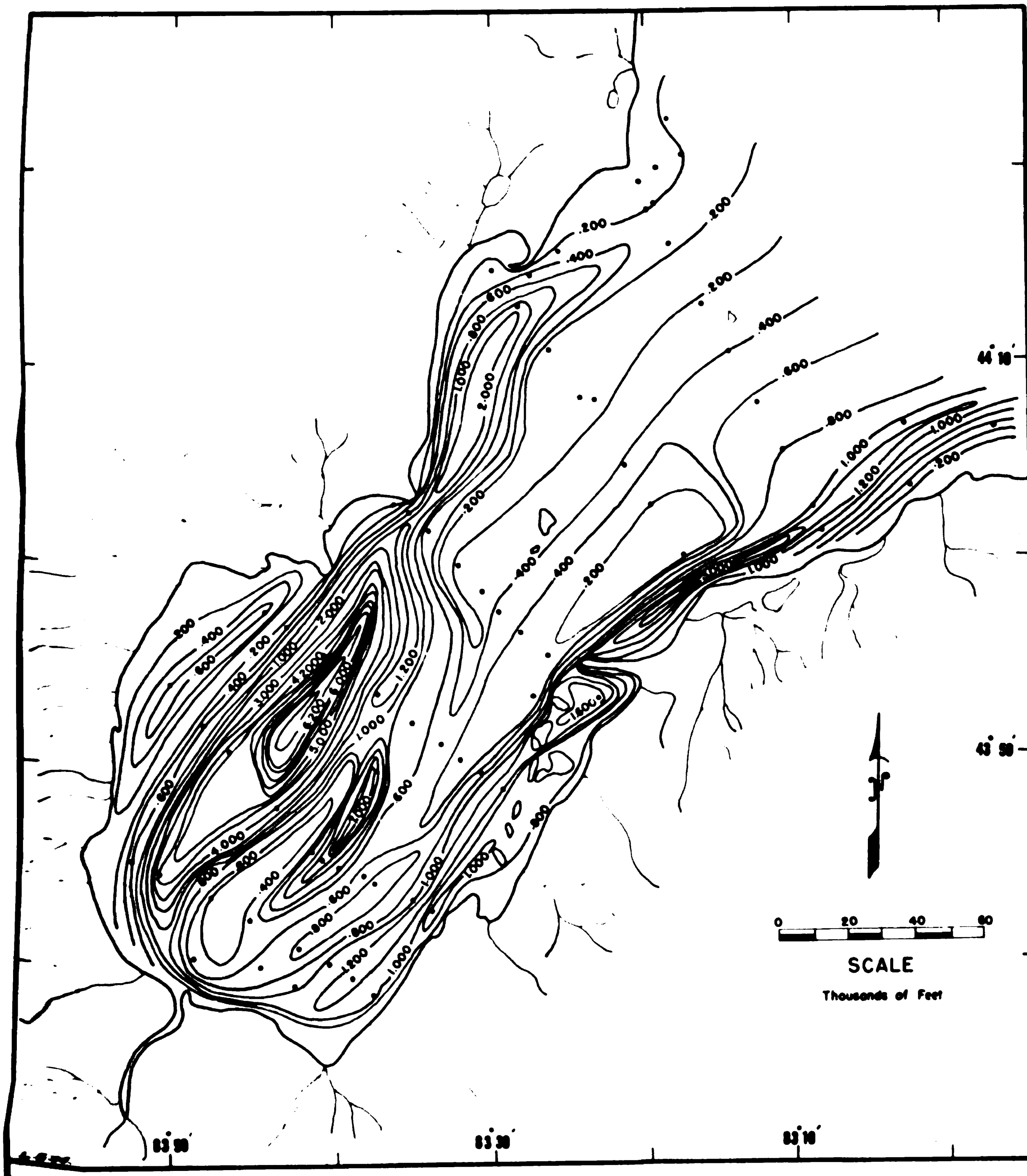
From the data available, current patterns cannot be established upon the acid soluble content of the sediment.

ORGANIC CARBON

After the insoluble residue from the two gram sample was weighed, the evaporating dish containing the residue was placed in a muffle furnace and fired slowly at 650°C. Upon cooling, the sample was weighed again to determine the amount of organic carbon which had been ignited. From this information, the percentage of organic carbon was calculated and plotted on an isopleth map (Pl. 9). Data of organic carbon percentages are shown in Table 148.

There is no agreement as to the best method to determine the amount of organic carbon in sediments. Trask (1939), for example, states that the reliability of the data decreases with the increase in calcium carbonate in the sediment. Clay content may be another source of error when igniting a fine sediment. Certain clays lose their lattice water at moderately low temperatures, and if clays are present in large amounts this error may be considerable.

Ignition seems to be the most practical method, in light of the amount of organic content present in most of the samples, to determine the amount of organic carbon present since the acid solubles have been previously removed. Several methods of extraction were investigated, including those discussed by Robinson (1927), Alexander and Byers (1932),



SAGINAW BAY

ORGANIC DISTRIBUTION

ISOPLETH INTERVAL .200 Percent

PLATE 9

Schellenberger (1945) and Walkley (1947). But most of the procedures were too lengthy to justify their accuracy.

A great range in organic carbon percentage in the Saginaw Bay sediments produces marked patterns in areas of concentration.

Percentages range from 0.084 at location 67 to 7.872 at location 14. Approximately 50 per cent of the sediments contain less than 0.500 per cent organic carbon, and 25 per cent between 0.500 and 1.000 per cent. Nearly 10 per cent possess 3.000 to 8.000 per cent organic carbon. The latter figures are considered substantial even for deep sea sediments.

Gripenberg (1939) reported between 3 and 10 per cent organic content in the Baltic Sea sediments. He considered this a high ratio. Kuenen (1950) recorded as little as one per cent carbon 1000 km off shore, increasing to two and one half per cent within 100 to 200 km from shore. In confined bodies of water, such as fiords, the organic content may be about 35 per cent.

It is generally agreed that organic carbon is derived largely from plant and animal life in the water, but there is a definite lack of plant growth in Saginaw Bay. The normal turbulence of the water tends to hinder any organic concentration. Hooper (1958), however, has pointed out that the organic content probably stems from the small floating type of planktonic plant life rather than from the common weeds known to most of us.

Sediments containing a high percentage of organic carbon are found at location 46 south of the Tawas hook and location 38 near Point Lookout. An area of generally high percentage of organic content is circumscribed by locations 7, 16, 17, 26, and 27. Sample 14, which contains abnormally high percentages of acid solubles, has an unusually high amount of organic carbon.

Sediments close to the south shore, including locations 1, 2, and 3 in the southeast corner of the bay and location 9 near Fish Point, contain a high percentage of carbonaceous material. Samples 21 and 31 taken in the vicinity of Katechay Island and Sample 41 taken near Oak Point are high in organic carbon. Samples 31 and 41 lie in what might be termed areas of current shadows.

In contrast to Sample 14 which contains 7.872 per cent organic carbon, is Sample 13 on one side containing 0.967 per cent carbon; and Sample 15 on the other side containing 0.442 per cent carbon (Pl. 9). The sediment of Sample 14 consists of silty organic material and has a median diameter of 0.142 mm. The sediments of Samples 13 and 15 are clean, medium sands of 0.325 and 0.219 mm diameters respectively.

This abnormal concentration of organic carbon is explained by selective deposition by currents which may be deflected somewhat at a point where the Saginaw River enters the bay. Sample 5 does not show a high percentage of organic carbon because of its location in shallow water in the direct path of currents on the west end of the bay. It is possible that there is more of a tendency for organic matter to be removed from the sediments in the face of strong currents. Sample 14 was taken from 20 to 25 feet of water at the edge of the glacial Saginaw River trench.

ORGANIC CARBON AND MEDIAN DIAMETER -- High organic carbon content is usually associated with fine-grained sediments. Most organic carbon has nearly the same specific gravity as water, thus undisturbed water is necessary for complete settling out. Quiet water environment, of course, is a prerequisite for fine-grained sediment accumulation.

A correlation between median diameter and organic carbon is shown in figure 34. Data show that the preponderance of the sediments are low in organic carbon, and those which have high percentages are fine to very fine sediments.

Kuenen (1950) established a relationship between fine-grained deposits and high organic content. He explained that the fine-grained sediments tend to enclose the organic matter and protect it against oxidation to a greater degree than would be possible in coarse-grained sediments. The coarse sands offer greater permeability which allows water to circulate freely, introducing fresh oxygen into the deposit. The organic matter is more easily decomposed and carried away.

Trask, et al, (1940) expressed a relationship between texture and organic content in which both were directly related to movement of water. In areas of strong currents, coarse materials were generally present and the organic content very low. In contrast, in areas of weak currents typical of protected areas or in waters of considerable depth the sediments were generally fine-grained and the organic content high.

The gross relationship of organic carbon, currents, and depth of water can be extended to Saginaw Bay with few exceptions. Particularly is this true of locations 7, 16, 17 and 27 where somewhat quieter water allows fine-grained sediments to settle. Samples 31 and 41 represent fine-grained sediments deposited in quiet water areas not affected by strong currents. It appears that the Sand Point projection deflects the main body of current away from shore, thus allowing relatively quiet water deposition at location 41 (See discussion on median diameter, p. 171). Sample 38, taken from moderately deep water below Point Lookout, consists of medium grains and contains a moderately high amount of organic carbon. Sample 39, also protected from longshore currents by Point Lookout, falls into the same grain size range as Sample 38, but it is practically void of organic carbon.

Numerous authors have shown relationships between organic carbon and grain size. Krumbein and Caldwell (1939)

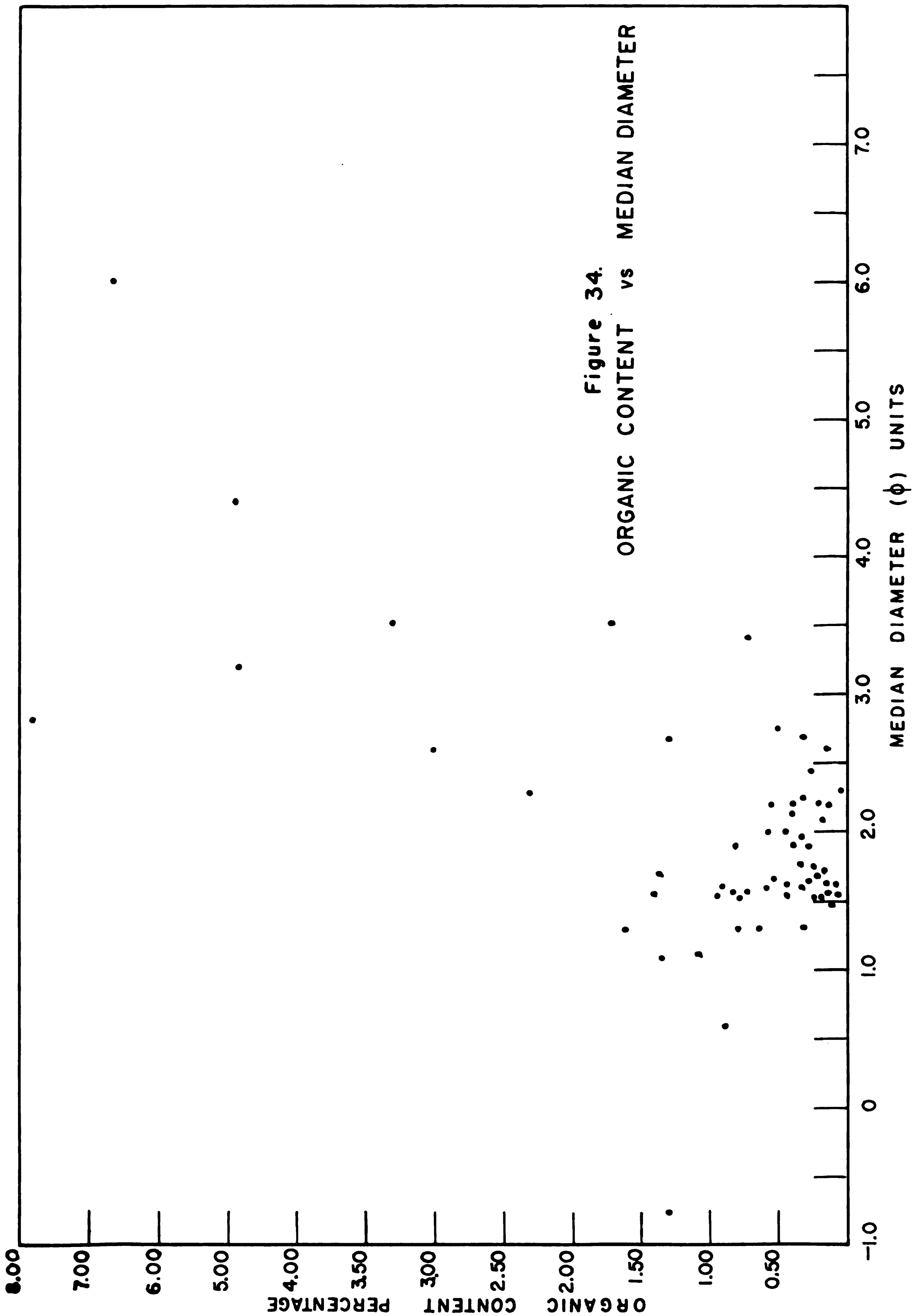


Figure 34.
ORGANIC CONTENT vs MEDIAN DIAMETER

in their analysis of the sediments of Barataria Bay concluded, "...that both carbon content and grain size are functions of the quietness of the water, inasmuch as the finer sediments and the organic matter are deposited under similar conditions." Hough (1940) found about 2.0 per cent organic carbon in the fine-grained sediments in Buzzards Bay, Massachusetts. This relationship is expected to hold true more consistently in larger, deeper bodies of water. The relationship between particle size and organic carbon has been established in many lakes throughout the country.

The organic content is relatively low in the central portion of the bay, extending from a line a few miles west of Charity Island eastward to the entrance of Lake Huron. This broad expanse of water, ranging from a few feet to 100 feet deep, comprises an area free of littoral currents. Very little organic carbon has accumulated in the sands, thus the carbon which has concentrated in other parts of the bay stands out.

ORGANIC CARBON AND DEPTH OF WATER -- It is easily understood that if there is a relationship between organic carbon and grain size, then depth of water is also a factor. Figure 35 indicates that those sediments which contain low percentages of organic carbon are more abundant in shallow water. It has been previously suggested that the sediments in Saginaw Bay are more of a function of current than depth, and little correlation between depth and organic content

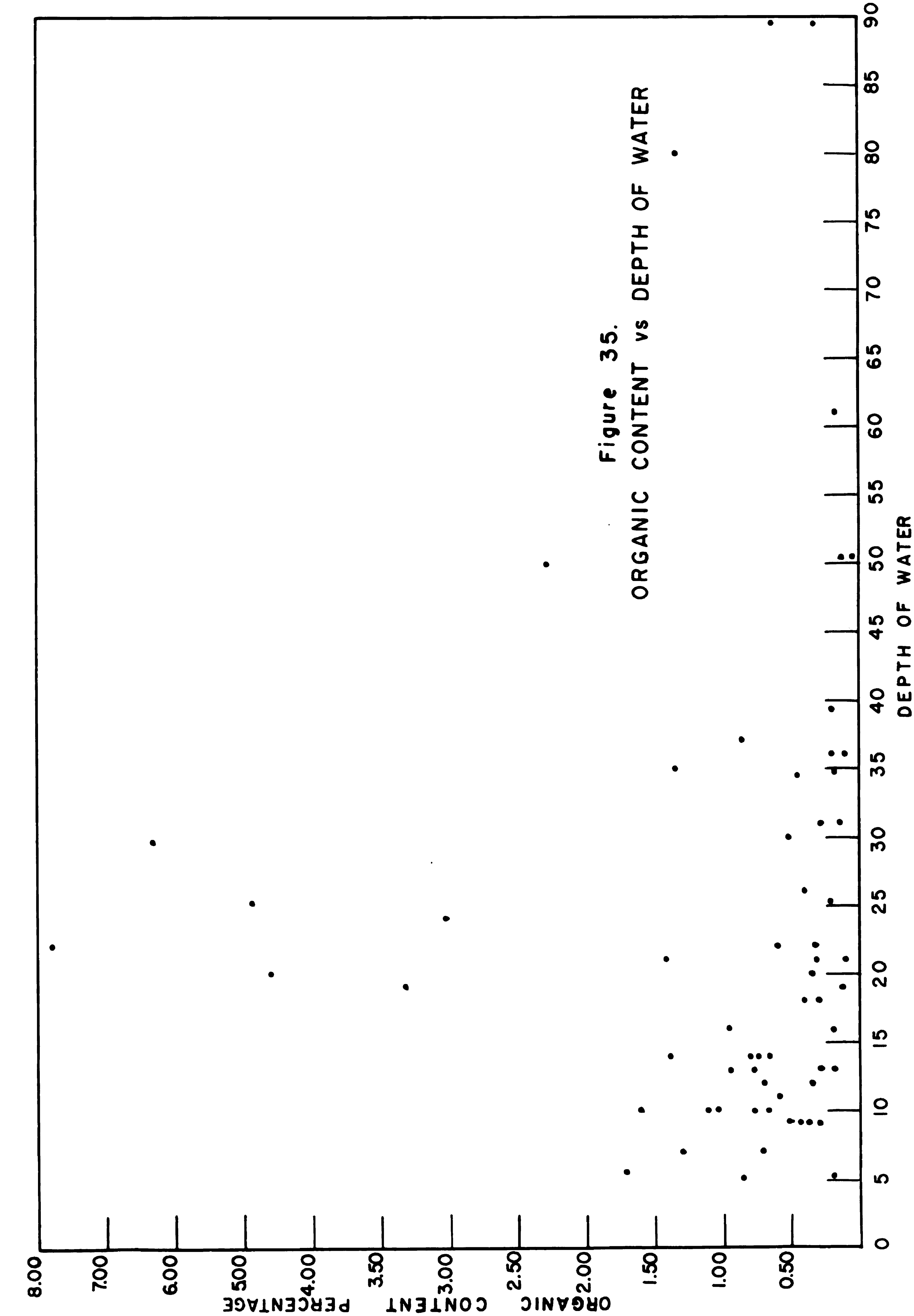


Figure 35.
ORGANIC CONTENT vs DEPTH OF WATER

can be expected. The relationship between current and organic carbon is well expressed by the similarity in the isopleth patterns of median grain and organic content (Pls. 3 and 9).

The fact still remains that whenever an analysis of bottom sediments is made there is hardly an exception to the relationship drawn between depth and organic carbon.

ORGANIC CARBON AND SORTING -- The relationship between organic carbon and sorting is shown in figure 36. As in acid solubles, an interrelationship between grain-size, sorting, and organic carbon is seen. Low organic carbon percentage is found in sediments which are well sorted. A high amount of organic carbon, which normally occurs in the fine-grained materials, is associated with the more poorly sorted sediments. Local factors alter this correlation.

ORGANIC CARBON AND SKEWNESS -- Figure 37 shows the relationship between organic carbon and skewness. Sediments skewed far to the coarse side contain more than 2.00 per cent organic carbon. Those with near zero skewness or skewed to the fine side contain less than 2.00 per cent organic carbon.

ORGANIC CARBON AND CURRENTS -- Inasmuch as Saginaw Bay is practically void of plant life, there is some question as to how much organic material is being built up in sediments by planktonic type growth. It seems probable that a great portion of the organic carbon is derived from humus from the fertile lowlands. Although it is carried into the bay through

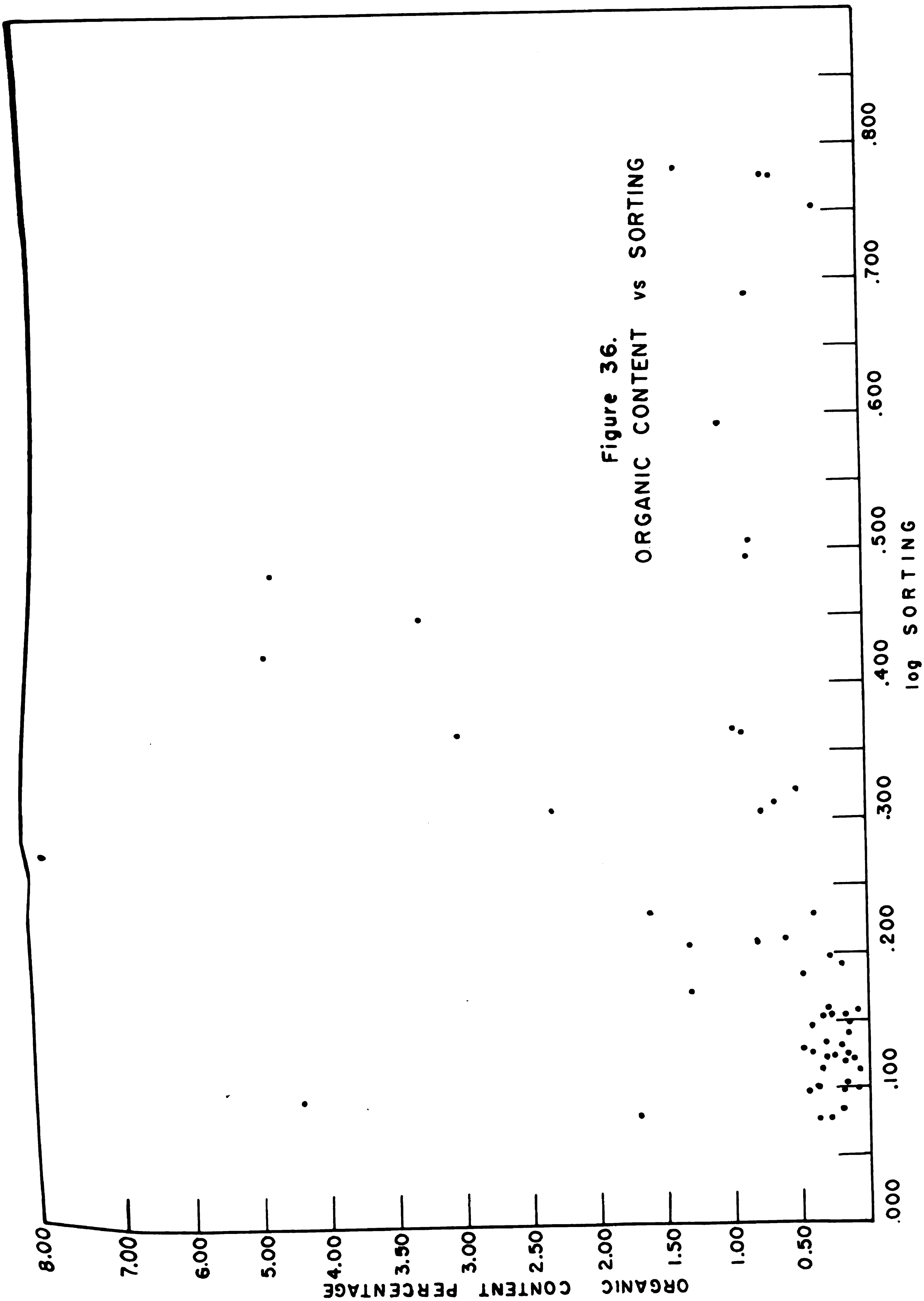


Figure 36.
ORGANIC CONTENT vs SORTING

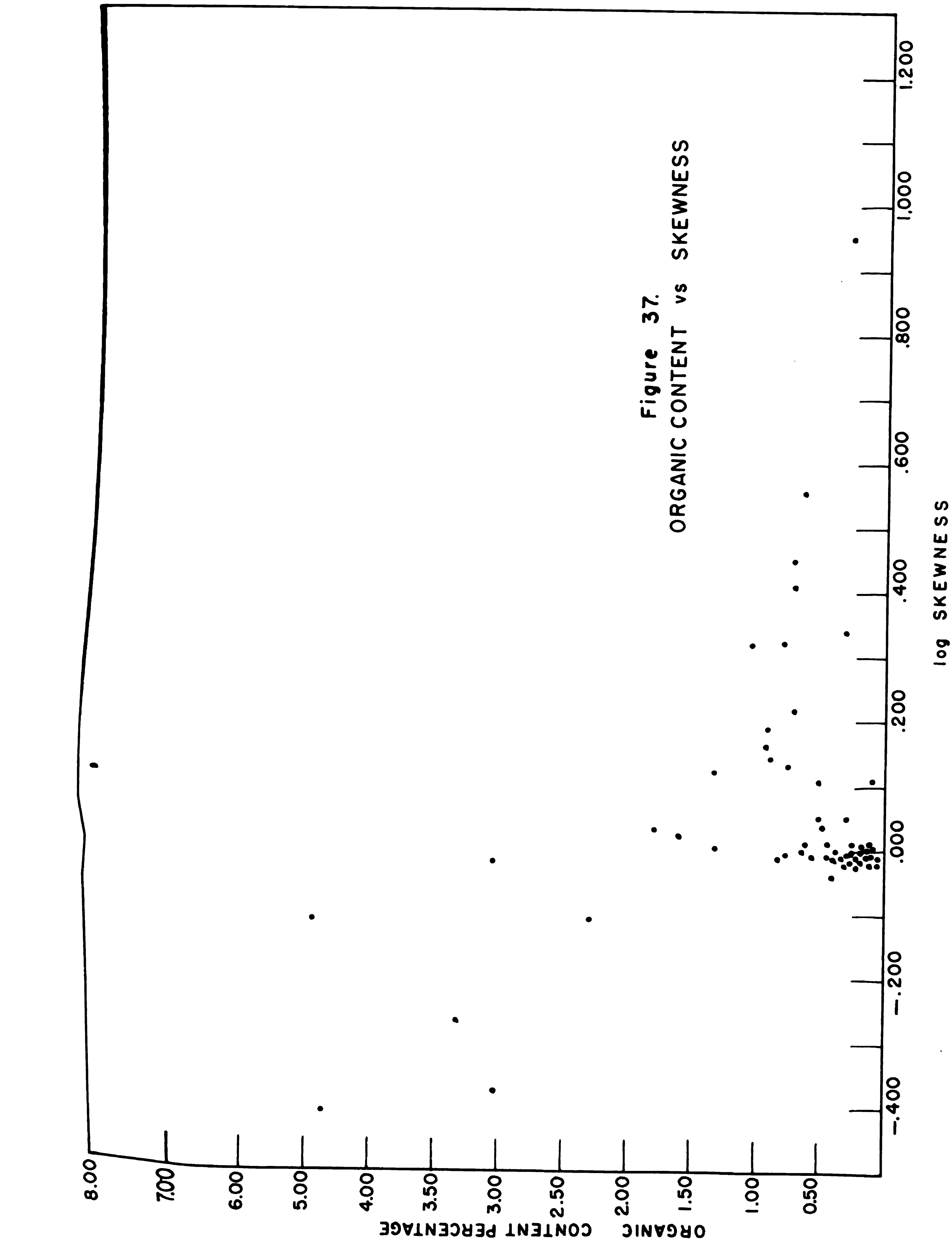


Figure 37.
ORGANIC CONTENT vs SKEWNESS

rivers in flood stage, it is agreed that very little material of any kind is contributed by the rivers under normal conditions.

Revelle and Shepard (1939), in their study on San Francisco Bay sediments, found that the organic carbon could be traced in part to the humus from the surrounding soils.

The extent of the concentration of organic carbon depends on the supply of organic material and the rate at which it is deposited. Equally important is the rate at which the inorganic materials are being deposited at the same time as the organics, and the rate at which decomposition occurs.

In Saginaw Bay the factors, rate of deposition of organics and inorganics and the decomposition of organics, are in some respect related to current patterns. Since few sediments are being added to the bay, the concentration of any sediment, organic or inorganic, is controlled by the movement of water. Either there is movement strong enough to keep bottom materials in constant motion, or the water is quiet and complete settling takes place. Winds and currents control the movement of the water.

SUMMARY AND CONCLUSIONS

Sixty-one bottom samples from Saginaw Bay were analyzed mechanically, statistically, and chemically. The data obtained was correlated with the physical environments present in the bay at the time of sampling.

A body of water into which the incoming sediment load is not too great for the transporting power of the water, and the depth does not exceed that which can be swept by normal current action, contains sediments which tend to be closely related to the prevailing current directions. If currents were the single factor regulating the deposition of a quantity of sediment, a uniform distribution would result, that is, if the sediment were in itself also of uniform size, shape, and density distribution.

It is apparent then that maps or data of any kind which show sediment properties in a body of water cannot express visually the many variables which are in effect, therefore, sediments must be interpreted in light of a number of factors on which the particular data are dependent. Factors which must be interpreted include those pertaining to the individual grain, such as: size, shape, and density. Under special conditions still another factor, grain orientation, is included. The physical characteristic of a grain is very important in the response of that grain to a given hydraulic situation. Factors related to the physical properties of the bay and its adjacent environment are, depth of water, current velocity, incoming streams (including size and gradients), source of sediments (including amount of sediments), shoreline features, subareal and subaqueous topography, and prevailing winds.

Each factor may play an important part in the movement and deposition of a single grain of sand. No one physical characteristic of a sand grain may act independently of another, although the dependency is not always perceptible. Each attribute must be considered or interpreted with regard to its relation to one or more of the many variables. Thus, it is through the study of the physical characteristics and depositional environments of recent sediments that mere is learned of the environment of ancient sediments.

Saginaw Bay, with the exception of its open end where the floor slopes off sharply into Lake Huron proper, is very shallow. The bottom sediments, therefore, are subject to constant turbulence caused by wave and current action.

Median diameter distribution corresponds closely to the pattern of current flow outlined by Ayres, et al, (1956). It is thought that the main current enters Saginaw Bay from the north around Au Sable Point, continues to the west end of the bay where it is deflected to the south shore, then leaves the bay to the south around Point aux Barques. Minor variations are noticeable in the west half of the bay, including the area of deep water which fills the old Saginaw River channel. Currents, for the most part, appear to be deflected toward the center of the west half of the bay. There is evidence of minor littoral currents along the northwest shore from Point Lookout to Nayanquing Point. A belt of coarse material along the southeast shore, west of Katechay Island, suggests that the Saginaw River is deflected in a southward direction. In the vicinity of Sand Point the main path of currents is deflected further toward Charity Island. This leaves the shoreline between Sand Point and Hat Point open to sand accumulation. The currents move landward in the vicinity of Hat Point. The southward deflection of the main current at Hat Point may be a result of either prevailing winds or lesser currents which enter Saginaw Bay from Lake Huron. Johnson (1958) noted a variation in the currents as a result of wind action. Drift bottle studies did not indicate prevailing currents.

Closely related to the distribution of grains according to size is the sorting of grains according to shape and density. The same factors which affected grain-size distribution play an important role in the sorting of particles. Poor sorting is more prominent in fine sediments in deep water. This poor sorting may be the result of strong currents, wave action, or ice rafting. Glacial lag concentrates may result in mixing of coarse with fine materials in quiet water.

A zone of very poorly sorted coarse sediments is along the extreme southeast shore. Materials coming from the Saginaw River in floer stage are added constantly to this zone and the sediments never assort themselves. Sorting in Saginaw Bay in general is more of a function of currents than depth. This is true in spite of the relation between fine-grained sediments and poor sorting.

The concentration of heavy minerals closely parallels the paths of stronger currents. Local deviations in currents are common. Heavy mineral percentages are generally less than five percent throughout the bay. Up to 11 per cent are present locally.

Heavy minerals derived from the surrounding drift are not likely to display any sign of orderly distribution according to species. Species distribution is more obvious in areas which are hydraulically suited to a given mineral characteristic. For example, magnetite and hematite show a high degree of sphericity and roundness and, because of their high specific gravity, they probably adjust to traction transportation. These minerals concentrate where elongate, tabular, and less dense amphiboles and pyroxenes are infrequent. The reverse relationship holds true in that where amphiboles and pyroxenes are plentiful, the metallic opaques are sparse. This seems to suggest that a mineral characteristic can be related to a given hydraulic condition.

Heavy mineral suites from rivers entering into the bay display the same randomness as observed in the bay sediments. Metallic opaques from the Rifle River are an exception.

Roundness and sphericity factors are remetely related to the current direction. Such a relation is probably a result of selective sorting due to the ability of a grain to be moved according to its shape, either by suspension or traction, and not to the degree of abrasion as a result of strong currents. Grains, for the most part, are only moderately rounded, but they show a fairly high degree of sphericity. No obvious relation exists between the two factors. Only a small amount of material is fed into the bay by the streams, and that which is deposited is derived from glacial drift and the few outcrops near the bay shores, thus the sand represents an undeterminable number of erosional and depositional cycles. In this respect, depositional environments cannot be determined from the interpretation of roundness and sphericity data. Roundness and sphericity should instead be viewed in light of their aid in selective sorting of sand grains.

Acid soluble material in the sediments is low, averaging for the most part below one per cent. In places more than three per cent was determined. Acid solubles are correlated with the fine shell fragments accumulated in fine sediments. Relatively high acid soluble content in coarse sediments particularly in the southeast corner of the bay, may be accounted for by detrital limestone weathered from outcrops and boulders along the shore and from shell fragments carried in by large populations of waterfowl.

Organic content in the bay sediments may amount to as much as seven per cent. Generally, however, the average is less than one per cent. Carbonaceous material is more prevalent in the fine-grained sediments. Its source is largely from planktonic material and humus of the surrounding farmland. There is very little weed plantlife in the bay. Organic carbon appears more nearly related to depth than any other factor. However, the distribution and rate of deposition of organic and inorganic sediments is largely a function of winds and currents.

Krumbein (1945) noted that, "The relations between sediment patterns and energy or process patterns (waves, currents, winds) afford an insight to the combinations of factors which produce sediments of given characteristics." In Saginaw Bay the physical properties of the sediments are ultimately controlled by wind, current, or wave action. Shepard and Moore (1955) defined a sedimentary environment as a, "...spatial unit in which external physical, chemical and biological conditions and influences affecting the development of a sediment are sufficiently constant to form a characteristic deposit."

Thus it may be said that the sediments in Saginaw Bay, and other bodies of water of similar hydraulic characteristics, conform to the current patterns, with local exceptions, and produce a sedimentary deposit which may be described in light of these hydraulic conditions. This must be qualified by saying that the local variation in the sediments of Saginaw Bay is a result of depth, source and supply of sediments, and surrounding physiography. One should expect that the shallow water deposits which are controlled largely by wave and current action to vary according to these same factors. Consequently, a transition of sedimentary characteristics will occur which show a degree of complexity proportional to the complexity of the surrounding controlling agents.

It was found that sediments correlative of certain conditions in shallow water were more likely to be the exception in deep water environments. The final deposit may respond not only to depth of water, source and supply of material, but to the environment of the body of water into which it is being deposited. Is the body of water receiving the sediments an open bay, a protected lagoon; and is the surrounding topography gentle or rugged?

An example of this association is shown by a series of bays along the southern California coast which are not only in the same climatic zone but are geographically closely related and are bordered by a similar rock. A great

difference in topography has provided a striking difference in organic carbon, acid soluble content, and median grain size distribution of the sediments in each bay (Emery, et al, 1957).

It is from the study of recent sediments that one can establish, with qualification, laws of sedimentary deposition applicable to ancient sediments. Uniform conditions which produce fine-grained deposits in deep water farthest from the shore, a transition of coarse to fine sediments according to depth and distance from shore or source, and sorting related to distance from source of material are virtually nonexistent. Correlation on the basis of such supposition should be restricted to small areas.

However, once one has established the variables to which sedimentary deposition conforms, and when the characteristic deposit that is formed according to these variables is determined, then a sedimentary environment may be conceived. Recent sediments should provide the key to the solution of this problem.

As a result of the analysis of the bottom sediments of Saginaw Bay the following conclusions are made with regard to shallow water deposition:

1. Median diameter may reflect prevailing currents since the distribution of a given size grain is more a function of current than depth of water.
2. Sediments respond to environments through selective sorting according to shape, density and size.

3. Heavy minerals, whose source is from glacial sediments, are not distributed according to mineral suites.

4. The concentration of heavy minerals may be a function of current velocity.

5. Roundness and Sphericity are not a measure of abrasion by currents. Distribution of rounded and spherical grains is probably a result of selective sorting.

6. The distribution of organic carbon in the sediment is primarily a function of currents and grain size.

7. The amount of acid solubles in the sediment is probably related to source of material rather than current or depth.

8. It is evident from this study that an interpretation of a depositional environment on the basis of physical or chemical analyses is uncertain in a heterogenous shallow water environment such as that of Saginaw Bay. Depositional environments comparable to Saginaw Bay are rare.

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