A PETROGRAPHIC INVESTIGATION OF VERTICAL DEPOSITION WITHIN THE MASON ESKER RELATIVE TO ITS ORIGIN

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A PETROGRAPHIC INVESTIGATION OF VERTICAL DEPOSITION WITHIN THE MASON ESKER RELATIVE TO ITS ORIGIN

by

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A THESIS

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Introduction

The differences of opinion among glacial geologists regarding the origin of eskers has prompted the writer to undertake this investigation in an effort to discover whether petrographic methods of study of sediments will be of value in determining the origin of a particular esker.

The general term esker is applied to a rather wide variety of ridge-like accumulations of stratified glacial drift. Although alike in having been formed during a stage of deglaciation, they almost certainly have a number of different origins.

The characteristic esker is a steep-sided, narrow-crested and more or less sinuous ridge, which rises as much as 150 feet above the surrounding country. In general, the lateral slopes approximate the maximum angle of repose for gravel. In some localities the ridge is uninterrupted for long distances, but in other places it is discontinuous. An esker system, including all the esker ridges attributable to a single glacial river or drainage system, may be as much as 150 miles in length. Sand and gravel are the chief constituents of most eskers although silt and boulders are present in some.

A variety of hypotheses have been formulated to account for the formation of eskers, although most

authorities are agreed that they were deposited by glacial streams during some phase of deglaciation.

The chief proponent of the subglacial channel theory is W.M. Davis.*

* Davis, W.M., The subglacial origin of certain eskers: Boston Society of Natural History, Proceedings, vol. 25, 1893. pp. 477-499.

His explanation assumes a stagnant marginal zone of the ice sheet. Water from basal and surface melting of the ice flows into subglacial streams through crevasses. A considerable amount of englacial and subglacial detrital material is gathered into these streams. Some of this material is deposited in the stream bed as a result of overloading or through the sorting action of water. In the event that the stream is diverted, the deposit will be left in the abandoned tunnel. Protected by the surrounding ice walls, it will gradually develop the lateral slopes characteristic of eskers, and be left intact as the mass of ice melts down by ablation.

Opposing Davis's subglacial channel theory is the superglacial stream theory, proposed by Crosby.*

* Crosby, W.O., The origin of eskers: Boston society of Natural History, Proceedings, vol. 30, 1902. pp. 375-411.

Like Davis, however, he propesed that eskers were formed

near the marginal zone of a stagnant ice sheet. At the outer border of the ice the gradient of a superglacial stream is controlled by a barrier of rock or till against which the ice may temporarily terminate. This barrier determines a base level below which the stream cannot cut by mere mechanical erosion. Thus a main stream, accumulating the detritus of its tributaries, becomes clogged and aggraded. As the ice thins and finally disappears, the stream bed is gradually lowered in toto to the ground surface.

Still another possibility for the origin of eskers is offered by Trowbridge.*

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* Trowbridge, A.D., The formation of eskers: Science, n.s. vol. 40, 1914. p. 145, abstract.

He suggested that eskers are in reality nothing more than drawn-out kames. The term kame is applied to small outwash cones built out from ice which later collapsed, isolating the masses in irregular mounds. Since kames are usually associated with interlobate moraines, while eskers are related to ground moraines formed during intervals of stagnation or retreat, he concluded that the development of esker forms is dependent upon the rate of recession of the ice front. Thus, streams discharging from the ice front build up small outwash cones at the ice margin. As the ice retreats the cones form successive segments of a serpentine-like ridge, called an esker.

A further explanation of eskers is suggested by R.F. Flint,*

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* Flint, R.F., Glacial Geology and the Pleistocene Epoch, Appleton-Century Co., 1947. p. 153.

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who notes that several glacial deposits which have been described as eskers are actually crevasse fillings.

Undoubtedly several or all of these theories must be employed to account for the large variety of esker types found scattered over glaciated areas.

Location

The Mason esker, approximately twenty miles in length, is one of the longest observed in Michigan. It heads in a gravel pit at the corner of Main and Shepard streets in southeastern Lansing, and extends southeastwardly through Holt and Mason. Its southern terminus is obscured in the Charlotte morainic system southeast of Mason. The ridge varies in height from thirty to fifty feet above the adjoining till plain, and often extends thirty to forty feet below the water table, where it widens as much as 400 feet. The esker has been described at some length by Leverett,*

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* Leverett, F., and Taylor, F.B., The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U.S.G.S. Monograph 53, 1915. pp. 209-211.

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who writes:

> "The esker, wherever opened, is composed of stratified and more or less perfectly assorted material. It gives evidence of the action of a stream which varied greatly in the rapidity of flow in different places along a given horizon, both longitudinally and from side to side, as well as at different horizons. The phenomena displayed are not unlike those found in the beds of existing streams flowing subaerially. The esker is evidently a stream-bed deposit, though probably deposited within ice walls."

The present investigation is limited to a single vertical section through the Mason esker at a point approximately mid-way between the northern and southern termini. A recent cut, located just east of the intersection of Aurelius and Miller roads in Lansing Township, was selected as affording the best site for the sampling of a complete and nearly vertical section. Samples were collected from the north face of the cut. After the slumped and weathered material had been scraped away, channel samples approximately six inches wide were collected from top to bottom, beginning at the top of the cut, immediately below the deepest zone of soil development. Each five foot sample was placed in a quart jar, covered, and labeled. Ten different samples, represent-

ing fifty feet of section, were collected.

Laboratory Procedure

Splitting

The field samples were numbered from one to ten, with sample one representing the first five feet from the top, and so on. Approximately one half of the field sample was taken for study, and the remainder retained for reference. The samples were quartered by hand, using the method described by Krumbein.*

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* Krumbein, W.C., Manual of Sedimentary Petrography, Appleton-Century Co., 1938. p. 44.

The sample was poured into a conical pile on a large sheet of smooth paper and cut with a small spatula into four quarters. Alternate quarters were retained and recombined. Wherever necessary, the process was repeated until a workable amount was obtained. This method was followed whenever splitting of the sample was necessary.

Washing

The sample thus obtained was washed in a solution of potassium hydroxide to remove the clay particles. The solution was decanted, taking care not to remove the fine sands, until the water ran clear. The washed samples were air dried and then passed through a twenty mesh sieve to remove the gravel. Each sample was thus concentrated to contain only the sand sizes.

Sieving

The sediment which passed through the twenty mesh sieve was quartered to 100 gram samples and sieved in the Ro-Tap automatic shaker for eight minutes. The shaker was equipped with five sieves having 48, 65, 100, 150, and 200 openings per square inch. A pan was placed at the bottom to catch the material passing through the 200 mesh sieve. The sands were thus separated into six grade sizes, each of which was weighed and placed in properly labeled vials. The mechanical composition of the ten samples is shown in Figure 2. Grade sizes are designated according to the mesh of the various sieves.

The results of the weight percent analysis show a decided difference from sample to sample. Such changes in curves may be expressed in terms of quartile deviations. Krumbein *

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* Krumbein, W.C., The use of quartile measures in describing and comparing sediments: American Journal of Science, vol. 32, 1936. pp. 98-111.

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gives a good resume of the application of statistical methods to description of sediments. Three attributes of the normal curve are considered, namely, sorting, skewness, and kurtosis. Conventionally, the geometric measures of these properties are used, as they yield results which are independent of the size factors and units of measurement.

Five values usually suffice for the computation of the measures. They are the median, the first and third quartiles, and the tenth and ninetieth percentiles. The relationships of these values are shown in Figure 3. Each is read directly from the cumulative curve of the size distribution. The median, M, is defined as that diameter which is larger than fifty percent of the diameters in the distribution and smaller than the other fifty percent. Its value corresponds to the point where the fifty percent line crosses the cumulative curve. The first quartile, Q_1, is that diameter which has 25 percent of the distribution larger than itself and 75 percent smaller than itself. It corresponds to the frequency line of 25 percent. The third quartile, Q_3, is that diameter which has 25 percent of the distribution smaller than itself and 75 percent larger than itself, and corresponds to the 75 percent frequency line. Accordingly, the tenth percentile corresponds to the ten percent frequency and the ninetieth percentile to the ninety percent frequency line.

Sorting is defined as the square root of the ratio of the two quartiles and is found by the formula:

$$So = \sqrt{\frac{Q_1}{Q_3}}$$

On the basis of nearly two hundred analyses, Trask *

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* Trask, P.D., Origin and Environment of Source Sediments of Petroleum, Houston, Texas, 1932. pp. 67 ff.

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found that a value of "So" less than 2.5 indicates a well sorted sediment, a value of about 3.0 a normally sorted sediment, and a value greater than 4.5 a poorly sorted sediment. The sorting values of the ten samples from the Mason esker are shown in Table I, and indicate a well sorted sediment at each horizon.

Skewness is a measure of the extent of departure of the median, or fifty percent frequency, from the point half way between the two quartiles. It is developed from the formula:

$$Sk = \sqrt{\frac{Q_1 Q_3}{M^2}}$$

When the curve is symmetrical, skewness is equal to unity. Values less than one indicate that the curve is skewed to the left, or larger sizes, of the distribution. Values greater than one indicate skewness to the right. Thus the skewness values indicate whether the bulk of the sediment is composed of larger or smaller size grades. The values for the Mason esker samples are shown on Table I. The results indicate that the sediment is concentrated in the larger sizes to a considerable degree.

Kurtosis is a measure of the degree of peakedness of a curve. It involves a comparison of the spread of the central position of the curve to the spread of the curve as a whole. Kurtosis is the ratio of the quartile deviation to that part of the size range which lies between the tenth percentile, P_{10}, and the ninetieth percentile, P_{90}. Hence the formula:

$$K = \frac{Q_1 - Q_3}{2(P_{10} - P_{90})}$$

The equation yields values which decrease with increasing peakedness. The kurtosis values for the ten samples are shown in Table I. They indicate a high degree of peakedness for each sample.

Leaching

Each fraction of sand was digested in dilute hydrochloric acid to remove any carbonate, the presence of which is objectionable in petrographic studies. The samples were then washed, dried, and reweighed. The amount of carbonate present was computed from the weight loss in each sample. These results are shown in Figure 4.

Gravity Separation

Approximately two grams of each of the four smallest size grades in the ten samples were placed in funnels containing bromoform (Sp. Gr. 2.87 at 20°C.). Due to the presence of dissolved alcohol, commercial bromoform is usually low in specific gravity, often below that of quartz. It is thus necessary to wash commercial bromoform

with water in order to raise the specific gravity sufficiently to effect the separation of quartz and feldspar from the heavier minerals. The method used was that described by Ross.*

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* Ross, C.S., Methods of preparation of sedimentary materials for study: Economic Geology, vol. 21, 1926. pp. 454 ff.

A large volume of water was added to the bromoform-alcohol mixture in a two liter bottle. After vigorous shaking the heavy bromoform phase separated out and the alcohol remained in the water phase. The water was then decanted and the process repeated two or three times. After the third decantation, the bromoform-water mixture was poured into a separatory funnel. The bromoform was then drawn off and run into a funnel fitted with several thicknesses of filter paper, which served to absorb any dispersed water which may have been present.

The stems of the funnels used for the gravity separation were fitted with short lengths of rubber tubing with pinch-cock attachments. Below each was another funnel, fitted with filter paper, which in turn drained into a beaker. The sand was placed in bromoform in the top funnel, which was covered with a watch glass to prevent evaporation. The sand was stirred occasionally with a glass rod to separate the individual grains and assure

a thorough separation of light and heavy minerals. Each fraction was then allowed to pass onto a filter paper in the funnel below. It was washed with alcohol, dried, and weighed. The bromoform washings retained in the beakers were combined and the bromoform was recovered as described above. The weight percent of heavy minerals in each sample is shown in figure 5.

Mounting Slides

Before mounting the mineral specimens on the slides, the magnetite present in the heavy fraction was removed with a small magnet.

A random sample from the heavy fraction of each of the four smallest size grades was selected for mounting. The two larger grades were discarded for this purpose, as they were seen to contain a large proportion of broken rock fragments. Only the one largest grade was discarded in mounting the light minerals.

The samples were mounted in a synthetic resin having a refractive index of 1.66. This medium was selected for two reasons. First, the index of 1.66 divides the range of indices of the heavy minerals into two more or less equal parts. Secondly, since the index of the resin, 1.66, is much higher than that of quartz, 1.54-1.55, the clear quartz grains mounted in this medium possess considerable negative relief and thus show sharper outlines. This aided in making the projection tracings from which the sphericity and roundness results were obtained.

Microscopic Investigation

General

The microscopic study of this detrital sediment consists of identifying and counting heavy minerals, and determining the roundness and sphericity of the quartz grains in the light mineral fraction. A polarizing microscope was used as an aid in determining the minerals present in each mounted sample. This type of microscope permits observation of the object by means of plane polarized light as well as by ordinary light. The slides were placed on a mechanical stage for counting the heavies. By means of two thumb screws the object slide could be moved in two directions for any given distance. This permitted changing from one field to another while counting without danger of overlapping.

Heavy Minerals

Of a total of twenty-two heavy minerals identified, only seven were common to all slides. The three smallest size grades for each of the ten samples were selected as most convenient for identifying individual minerals. An average of 300 grains per slide was counted, for a total of 9000 grains in all. The results of the count were converted to percentage frequency, and the figures are shown in Tables II, III, and IV. Cumulative histograms were drawn for the ten most common constituents and are shown in Figures 7, 8, and 9.

It may be interesting to note here some research carried out by Dryden.*

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* Dryden, A.L., Accuracy in percentage representation of heavy mineral frequencies: National Academy of Science Proceedings, vol. 17, 1931. pp. 233-238.

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concerning the probable error made in counting only a limited number of grains from a random sample. He developed a formula which permitted the construction of curves showing the probable error in frequency percentages for counts ranging from 25 to 750 grains. Due to the nature of the curve, accuracy is shown to increase very slowly after a certain point. In most cases, a count of 300 individual grains per slide will yield satisfactory results.

Since variations in frequencies of the minor constituents of heavy mineral suites are often significant, Rittenhouse *

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* Rittenhouse, G., Curves for determining probable errors in heavy mineral studies: National Research Council, Report of the Committee on Sedimentation, 1940. pp. 97-101.

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constructed curves showing probable errors for mineral

frequencies between 0.1 and 20 percent. The probable error increases considerably for the frequency of the rarer constituents. For example, with a frequency of ten percent computed for a single mineral and a total count of 300 grains, the observed frequency may deviate 1.3 percent from the actual or "true" frequency. However, with a computed frequency of only one percent and the same 300 grain count, the deviation from the actual frequency may be as much as 3.9 percent.

Since samples for this study were collected under the same conditions and in one area only, it may be assumed that such errors will be constant throughout the investigation, and may safely be disregarded in interpreting the results. This probability of error is discussed here for the purpose of pointing out that the mineral frequency percentages are only relative to the number of grains counted, and do not represent absolute values.

The general term "aggregate" has been applied to a large proportion of the material encountered on the heavy mineral slides. Upon investigation under high power, this material was found to be rock fragments cemented by quartz and hematite. Such compound aggregates are frequently encountered in the heavy fraction, and often included in the counts, even though the individual minerals are indistinguishable.

Mineral Descriptions

Following is a list of the minerals found in the investigation of sediment taken from the Mason esker. The identifying characteristics have been compiled from several sources.*

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* Dana, E.S., Descriptive Mineralogy, John Wiley and Sons, Inc. 1914.

Johannsen, A., Essentials for the Microscopical Determination of Rock-forming Minerals and Rocks, University of Chicago Press, 1914.

Krumbein, W.C., op. cit. pp. 414 ff.

Milner, H.B., Sedimentary Petrography, D. Van Nostrand Co., 1929. pp. 97 ff.

Hornblende: complex silicate of Ca,Na,Fe,Al,Mg

Crystal system : Monoclinic
Color : Var. Arfvedsonite- blue-green
Var. Common hbl.- green to brown
Birefringence : .026-.027
Optic figure : biaxial negative
Elongation : positive
Pleochroism : marked
Distinctive features : grains elongate, prismatic; color; pleochroism

Garnet: complex silicate of MgFe,Al,Mn,Cr

Crystal system : Isometric
Color : colorless,pink,red,orange
Distinctive features : isotropic; high relief; conchoidal fracture; color.

Zircon: $ZrO_2 . SiO_2$

Crystal system : Tetragonal

Color : colorless to yellow
Birefringence : .055-.059
Optic figure : uniaxial positive
Elongation : positive
Distinctive features : crystal form; high index; inclusions; parallel and complete extinction.

Monazite: $(Ce,La,Nd,Pr)_2O_3 \cdot P_2O_5$

Crystal system : Monoclinic
Color : yellow,brown,red
Birefringence : .049-.051
Optic figure : biaxial positive
Pleochroism : faint
Distictive features : color between crossed nicols same as in ordinary light; light yellow color; high relief.

Hypersthene: $(Mg,Fe)SiO_3$

Crystal system : Orthorhombic
Color : pale pink and green
Birefringence : .009-.016
Optic figure : biaxial negative
Elongation : positive
Pleochroism : faint to marked
Distinctive features : high relief; low birefringence; parallel extinction; pleochroism pink to green.

Hematite: Fe_2O_3 (opaque)

Distinctive features : irregular powdery aggregates; indian red by reflected light.

Leucoxene: composition uncertain; alteration product of Ilmenite. (opaque)

Distinctive features : rounded grains, often with unaltered core of Ilmenite; dead white color in reflected light.

Epidote: $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$

Crystal system : Monoclinic
Color : greenish to lemon yellow
Birefringence : .028-.051
Optic figure : biaxial negative
Pleochroism : distinct

Distinctive features : color; distinct pleochroism; high index.

Topaz: $2(Al,F)O.SiO_2$

Crystal system : Orthorhombic
Color : colorless
Birefringence : .008
Optic figure : biaxial positive
Distinctive features : irregular fractured grains; basal grains common; high relief; optic character.

Staurolite: $2FeO.5Al_2O_3.4SiO_2.H_2O$

Crystal system : Orthorhombic
Color : yellow,gold,brown
Birefringence : .010
Optic figure : biaxial negative
Pleochroism : marked
Distinctive features : irregular, somewhat platy grains, determined by cleavage and subconchoidal fracture; color; pleochroism

Rutile: TiO_2

Crystal system : Tetragonal
Color : yellow,reddish brown,red
Birefringence : .287
Optic figure : uniaxial positive
Elongation : positive
Pleochroism : faint
Distinctive features : grains elongate, commonly prismatic; high relief reulting in broad dark borders on grains; deep color; inclusions common.

Titanite: $CaO.TiO_2.SiO_2$

Crystal system : Monoclinic
Color : pale yellow,light brown
Birefringence : .134
Optic figure : biaxial positive
Elongation : negative
Pleochroism : weak
Distinctive features : color; high index; extreme birefringence; euhedral grains chipped and marked by conchoidal fracture; negative elongation; lack of pleochroism.

Chlorite: complex hydrous silicate of Mg,Al,Fe

Crystal system : Monoclinic (?)
Color : dirty yellow green to green
Birefringence : .003-.009
Optic figure : biaxial, negative and positive
Pleochroism : marked in thin section only
Distinctive features : grains flat, rounded, irregular cleavage flakes; pale green color; weak birefringence; micaceous habit.

Zoisite: $4CaO.3Al_2O_3.6SiO_2.H_2O$

Crystal system : Orthorhombic
Color : colorless,rose,green,brown
Birefringence : .006
Optic figure : biaxial positive
Pleochroism : faint
Distinctive features : colorless grains; high index; abnormal ultra-blue interference color.

Tourmaline: complex silicate of Na,Ca,Al,Fe,Mg, with Li,Mn,Cr,B,and OH

Crystal system : Hexagonal
Color : yellow brown,dark brown,black
Birefringence : .019-.032
Optic figure : uniaxial negative
Elongation : negative
Pleochroism : strong
Distinctive features : color;pleochroism; negative figure; grains usually irregular fractured pieces; east-west absorption.

Biotite: complex hydrous silicate of K,Mg,Fe,Al

Crystal system : Monoclinic
Color : brown,rarely green
Birefringence : .050-.064
Optic figure : biaxial negative
Pleochroism : marked in thin section only
Distinctive features : In flakes varying from hexagonal to irregular; grains always yield perfectly centered pseudo-uniaxial negative cross; deep brown color; lack of pleochroism; inclusions with halos.

Kyanite: Al_2SiO_5

Crystal system : Triclinic

Color : colorless, pale blue
Birefringence : .016
Optic figure : biaxial negative
Elongation : positive
Pleochroism : faint
Distinctive features : Elongate grains of marked rectangular outline; conspicuous cross-cleavage; low birefringence; inclined extinction

Olivine: $(Mg,Fe)_2SiO_4$

Crystal system : Orthorhombic
Color : colorless to pale yellow
Birefringence : .037
Optic figure : biaxial positive
Distinctive features : fragments irregular; colorless with bright interference colors; clouded by decomposition products; rare except in recent sediments.

Augite: complex silicate of Ca,Mg,Fe,Al

Crystal system : Monoclinic
Color : pale brownish grey
Birefringence : .018-.043
Optic figure : biaxial positive
Distinctive features : grains usually elongate, worn cleavage fragments; high index; high birefringence; high extinction angle; brown color.

Apatite: $Ca_5(F,Cl)(PO_4)_3$

Crystal system : Hexagonal
Color : colorless
Birefringence : .003-.005
Optic figure : uniaxial negative
Elongation : negative
Distinctive features : grains oval or nearly circular; low birefringence.

Metals: includes - Magnetite: Fe_3O_4, Marcasite: FeS_2, and Pyrite: FeS_2

Distinctive features : opaque in transmitted light; metallic luster in reflected light.

Roundness and Sphericity

Roundness and sphericity are two factors of impor-

tance in the petrographic study of sediments. Wadell *

* Wadell,H., Volume,shape, and roundness of rock particles: Journal of Geology, vol. 40, 1932. pp. 443-451.

apparently was one of the first investigators to distinguish between these two characteristics. He pointed out that roundness is a measure of the sharpness of the corners of grains, whereas shape is the measure of the form of the grains independent of the sharpness of the corners. Wadell used the sphere as a standard of reference and employed the degree of sphericity as a measure of the approach of the form of other solids to the sphere. He also developed a method for measuring roundness and sphericity of quartz grains, which proves to be very time consuming. A more rapid and accurate method for measuring sphericity by means of projecting images of quartz grains was devised by Riley.*

* Riley, N.A., Projection sphericity: Journal of Sedimentary Petrology, vol. 11, 1941. pp. 94-97.

Geology students at Michigan State College combined the ideas of Wadell and Riley. Mr. G.T. Schmitt,*

* Schmitt, G.T., personal communication

a graduate assistant at Michigan State College, devoted

considerable time and effort investigating the problem, and is partly responsible for the development of the method used in this paper. He drew a concentric circle protractor similar to the one used by Wadell, but on white paper rather than on celluloid. By means of the camera lucida the images of the quartz grains were projected to the concentric circle protractor which was inclined at such an angle as to prevent distortion of the images. It was then a simple matter to measure the diameter of the inscribed and circumscribed circles (sphericity) and the arc of the corners of each grain (roundness) directly. The size grade 65 was found to be the most desireable with which to work. About fifty grains, with an average of ten corners each, were measured for each slide.

Roundness values were computed from Wadell's *

* Wadell, H., op. cit., p. 448.

formula:

$$\frac{(r/R)}{N} = P \text{ , where}$$

r is the radius of the corners
R is the radius of the inscribed circle
N is the number of corners measured
P is the total degree of roundness

For sphericity, the formula used by Riley *

* Riley, N.A., op. cit., p. 96.

is:

$$\sqrt{\frac{d}{D}} = \phi, \text{ where}$$

d is the diameter of the inscribed circle
D is the diameter of the circumscribed circle
ϕ is the sphericity of the grain

The roundness and sphericity values thus obtained were averaged for each sample, and the results are shown in Figure 6.

Conclusions

In examining the results of the mechanical and petrographic analyses of the ten samples, representing a fifty foot vertical section through the Mason esker, it will be noted readily that each sample differs from the other in all of the characteristics investigated. All samples differ in their mechanical composition, as shown by the size grade analyses. Accordingly, the total weight percent of heavy minerals in each sample also varies. The wide variations observed in the carbonate content are undoubtedly due to the leaching action of ground water.

An examination of the results of the heavy mineral counts hinges on two outstanding differences. Aside from their relative frequency, the suite of minerals found in each sample is distinctive. Of the twenty-two minerals identified, only seven are common to all slides. The remaining fifteen minerals occur irregularly throughout

all the slides. Further, there is a wide divergence in relative abundance of the seven minerals which are present in all slides.

The roundness and sphericity averages show a similar lack of consistency throughout each five feet of sample.

Thus, in all the characteristics investigated, the various samples appear to be quite different from each other. This suggests that some sort of zoning or layering exists in the esker deposit from top to bottom, and the material in the deposit is consequently heterogeneous in character. All evidence tends to support the theory that eskers are stream bed deposits, built up in subsequent layers by simultaneous deposition throughout their length. Whether these streams were subglacial or superglacial cannot, of course, be determined from the data available.

Regarding the hypothesis that eskers are in reality "drawn-out kames", there is little in the results obtained in this investigation to indicate that this is true of the Mason esker. The origin of kames necessitates deposition in a very short interval of time. Consequently the material encountered in a vertical section would be expected to be somewhat homogeneous. However, since no records exist of petrographic studies of kamic sediments, few conclusive comparisons may be made in this instance. Possibly a great deal of light might be shed on the problem if similar studies of other glacial deposits were carried out.

This investigation does show that petrographic methods of studying and comparing detrital sediments may very well aid in determining the mode of formation of an individual esker, although studies of other types of glacial sediments would be of great value for purposes of comparison.

TABLE I

Sample Number	Sorting	Skewness	Kurtosis
1	1.46	.306	.291
2	1.52	.340	.283
3	1.52	.308	.290
4	1.51	.308	.292
5.	1.66	.306	.282
6	1.53	.305	.284
7	1.66	.317	.269
8	1.64	.303	.272
9	1.54	.308	.269
10	1.65	.303	.252

SORTING, SKEWNESS, AND KURTOSIS

computed from cumulative curves
of size grades

TABLE II

HEAVY MINERAL FREQUENCY - SIZE 100

Mineral	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Metals	22.2 %	7.5 %	22.2 %	17.3 %	20.7 %	17.6 %	29.6 %	14.6 %	3.4 %	5.8 %
Aggregates	22.2	23.1	19.6	16.7	15.1	17.6	18.7	23.6	31.4	33.7
Hornblende	10.6	15.3	16.1	18.4	18.2	18.7	13.0	22.4	22.7	22.3
Arf'sonite	6.2	13.5	9.0	14.3	11.7	7.2	7.5	11.2	8.5	10.7
Garnet	19.6	15.7	15.4	12.2	17.0	9.7	14.5	9.0	6.0	6.1
Zircon	0.9	1.5	1.9		0.9		0.6	0.4		1.3
Monazite	3.6	6.0	5.5	2.6	5.6	8.5	6.9	4.7	1.3	0.6
Hypersthene	7.7	3.0	3.0	7.0	0.9	1.1	0.6	4.3	4.1	3.9
Hematite	1.0	3.7	3.6	3.8	3.8	2.3	3.1	0.9	3.8	5.2
Leucoxene	0.5	6.0		2.6	2.8	2.3	1.2	4.7	1.3	
Epidote	3.2	2.2	3.6	2.6	0.9	5.1	2.5	1.9	3.8	2.6
Topaz	1.3		0.5				0.6			
Staurolite					1.9	0.5	0.6	0.4	0.6	1.9
Rutile	0.5	1.5	0.5	0.6		1.7				
Chlorite									0.6	0.6
Zoisite	0.9								0.6	0.6
Spodumene				0.6					6.6	3.3
Tourmaline									0.3	
Biotite						1.1		0.4	0.9	1.3
Kyanite						1.7	0.6			
Olivine						4.5	0.6			
Augite				0.6						
total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

TABLE III

HEAVY MINERAL FREQUENCY - SIZE 150

Mineral	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Metals	27.8 %	22.7 %	21.4 %	27.4 %	13.7 %	19.9 %	22.1 %	10.6 %	6.3 %	28.7 %
Aggregates	20.0	21.6	17.4	13.5	13.7	14.7	16.3	19.5	24.4	13.9
Hornblende	12.5	11.3	13.7	15.9	23.5	19.4	19.8	19.6	21.3	14.0
Arf'sonite	10.6	10.0	6.3	11.0	8.2	9.7	8.1	18.4	18.8	9.6
Garnet	13.9	14.4	11.3	7.2	10.3	11.7	12.4	10.2	9.1	8.9
Zircon	2.3	3.4	3.3	2.9	1.0	0.9	2.5	0.4	0.9	3.1
Monazite	5.2	2.6	11.3	8.2	8.3	7.7	1.9	3.4	1.8	1.5
Hypersthene	1.7	5.3	4.0	4.3	4.0	2.1	2.2	9.7	4.2	4.6
Hematite	1.0	3.0	3.3	3.9	5.0	3.0	4.4	2.9	6.3	1.9
Leucoxene	1.0	3.0	2.0	0.8	1.0	4.3	2.7	2.9	1.4	2.7
Epidote	2.3	2.2	4.7	3.4	4.7	2.7	2.7	3.8	1.8	3.5
Topaz				0.5						0.4
Staurolite					1.0	0.9	0.3		0.6	1.2
Rutile	0.5		0.6		1.7	0.9	1.4	0.8	0.3	0.8
Titanite								3.8		
Chlorite	2.6					0.3			0.6	1.5
Zoisite					0.3	0.6	1.1			0.6
Spodumene		0.4						0.3	2.1	3.1
Tourmaline						0.3				
Kyanite					2.7		0.5			
Olivine							1.4	0.3		
Augite	0.5	0.4	0.6	0.5	0.6			0.3		
total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

TABLE IV

HEAVY MINERAL FREQUENCY - SIZE 200

Mineral	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Metals	32.1 %	28.6 %	23.9 %	24.9 %	14.6 %	25.7 %	16.2 %	18.9%	28.0 %	30.5 %
Aggregates	10.0	15.5	9.2	19.3	17.8	8.7	16.4	14.7	6.8	5.2
Hornblende	8.2	4.7	14.4	13.7	22.5	10.6	20.1	25.4	14.7	9.3
Arf'sonite	4.7	8.3	14.8	6.2	10.4	5.9	11.0	12.6	12.1	8.6
Garnet	8.6	15.5	7.7	9.2	11.3	8.7	9.6	7.6	8.0	9.4
Zircon	14.1	11.9	13.5	8.3	4.5	6.2	6.0	2.9	6.3	9.4
Monazite	4.4	1.9	5.4	2.4	5.0	6.2	3.3	2.0	3.7	1.4
Hypersthene	4.6	2.5	4.5	3.0	4.3	3.0	0.7	5.5	4.8	1.9
Hematite	1.0	1.1	0.4	3.2	2.0	1.0	1.4	1.7	2.0	3.8
Leucoxene	1.0	2.5	0.9	3.5	0.3	6.2	3.3	2.0	2.8	2.3
Epidote	5.5	4.9	1.9	3.2	3.8	3.0	3.0	1.4	2.8	2.3
Topaz	0.2				0.5	0.3	0.2			
Staurolite					0.7		0.5			
Rutile	2.2	1.4	0.9	0.6		1.3	1.0		0.5	0.4
Titanite						0.5	1.4			
Chlorite	4.8					0.3	2.5	1.1	1.1	2.3
Zoisite	0.2		0.4	1.2	1.0	0.7	1.5	0.2	0.8	0.4
Spodumene		0.5				0.3	6.5	2.5	2.8	1.9
Biotite						0.3	0.2		0.2	
Kyanite						0.5		0.2		
Augite	0.4	0.7	1.5	0.3	0.3					
Apatite						0.3				
total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

FIGURE 1

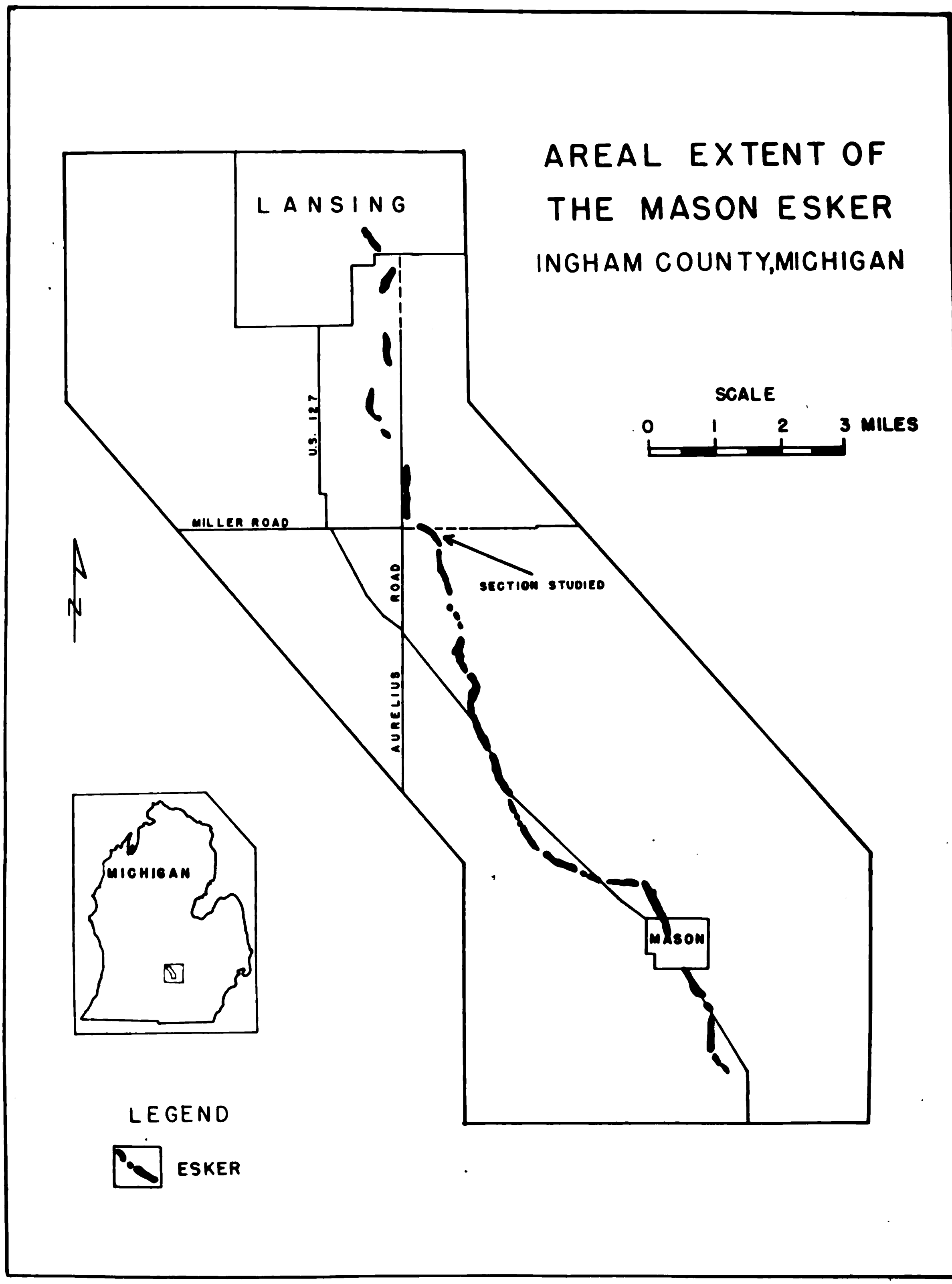

AREAL EXTENT OF
THE MASON ESKER
INGHAM COUNTY, MICHIGAN
LANSING
SCALE
0 1 2 3 MILES
U.S. 127
MILLER ROAD
SECTION STUDIED
AURELIUS ROAD
N
MICHIGAN
MASON
LEGEND
ESKER

FIGURE 2

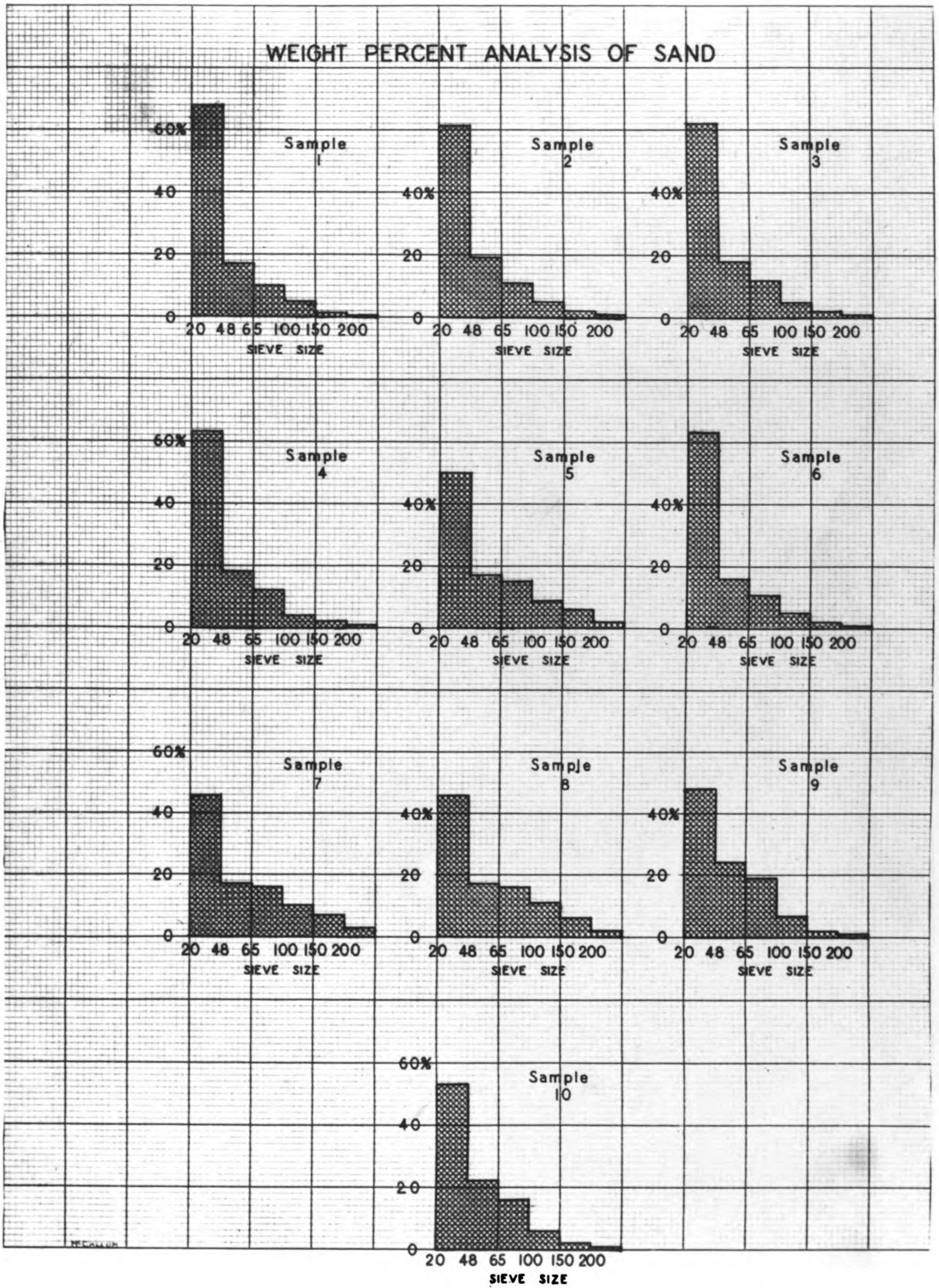

WEIGHT PERCENT ANALYSIS OF SAND
Sample 1
60%
40
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 2
40%
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 3
40%
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 4
60%
40
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 5
40%
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 6
40%
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 7
60%
40
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 8
40%
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 9
40%
20
0
20 48 65 100 150 200
SIEVE SIZE
Sample 10
60%
40
20
0
20 48 65 100 150 200
SIEVE SIZE

FIGURE 3

GENERALIZED CUMULATIVE CURVE OF WEIGHT PERCENT

showing relationships of percentiles
quartiles and median as described in
the text

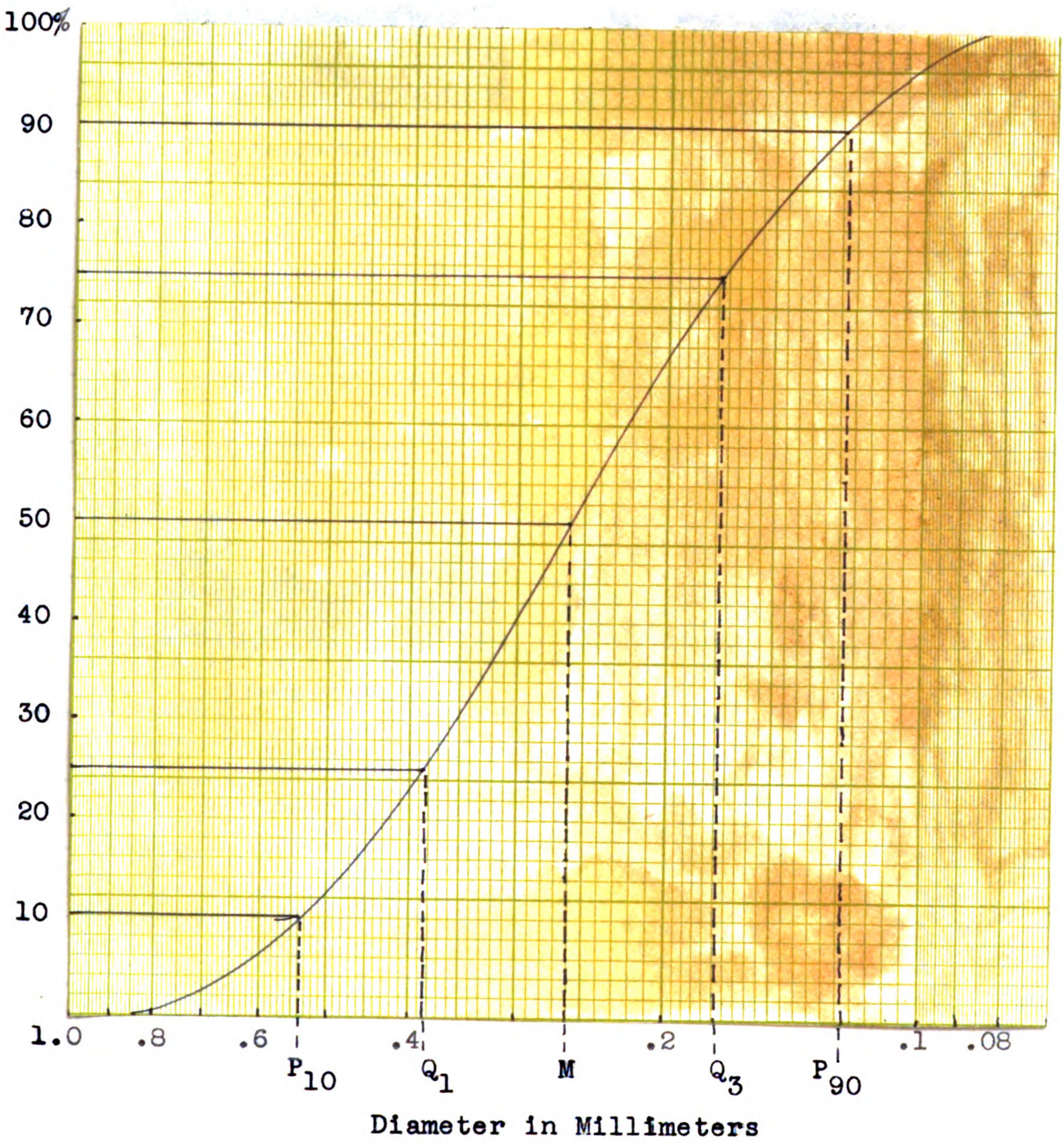
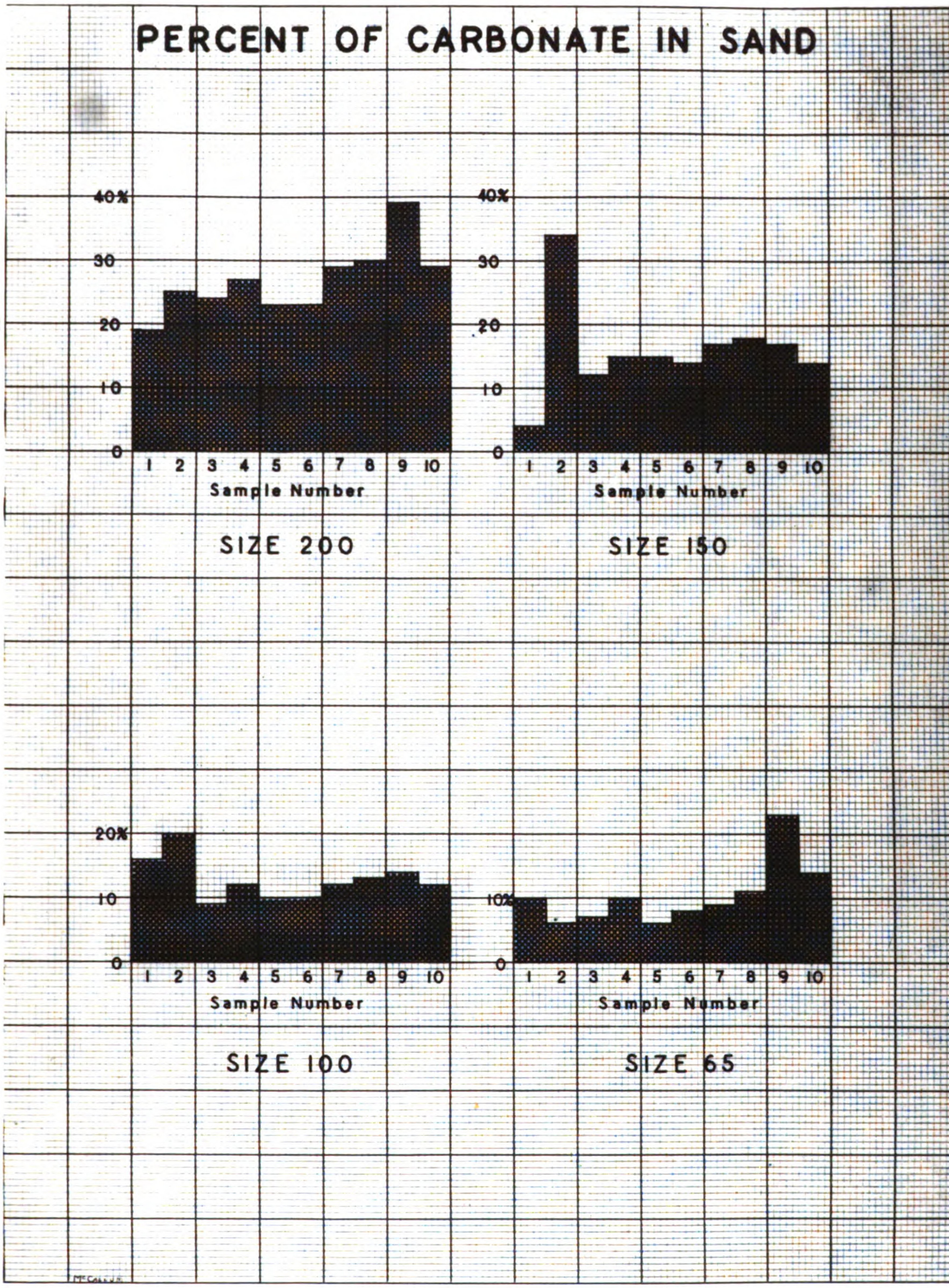
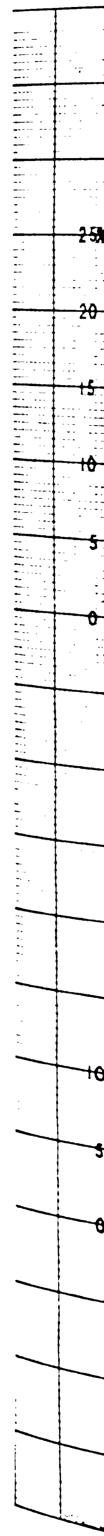


FIGURE 4


PERCENT OF CARBONATE IN SAND
40%
30
20
10
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 200
40%
30
20
10
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 150
20%
10
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 100
10%
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 65



25
20
15
10
5
0
10
5
0

FIGURE 5

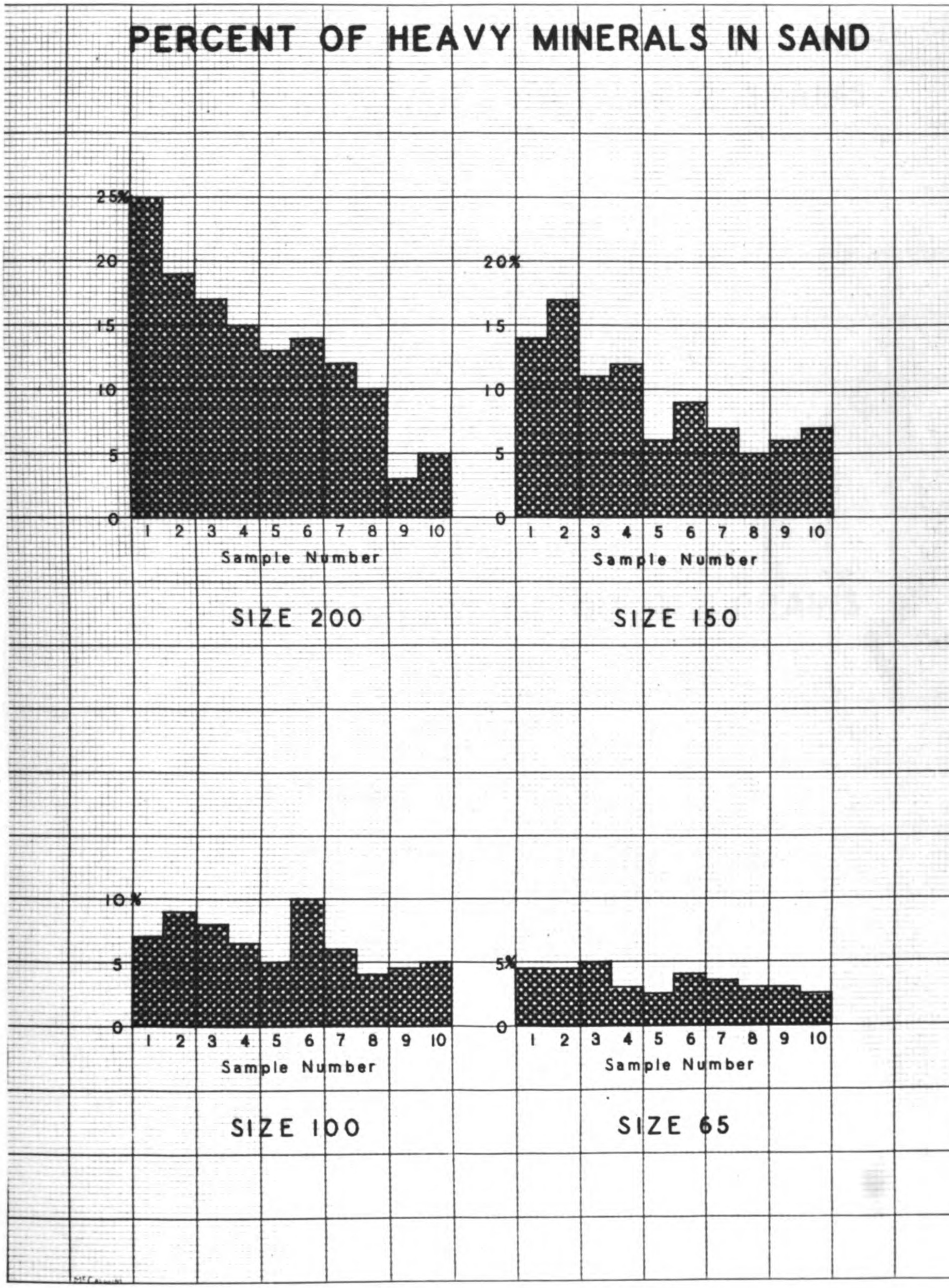
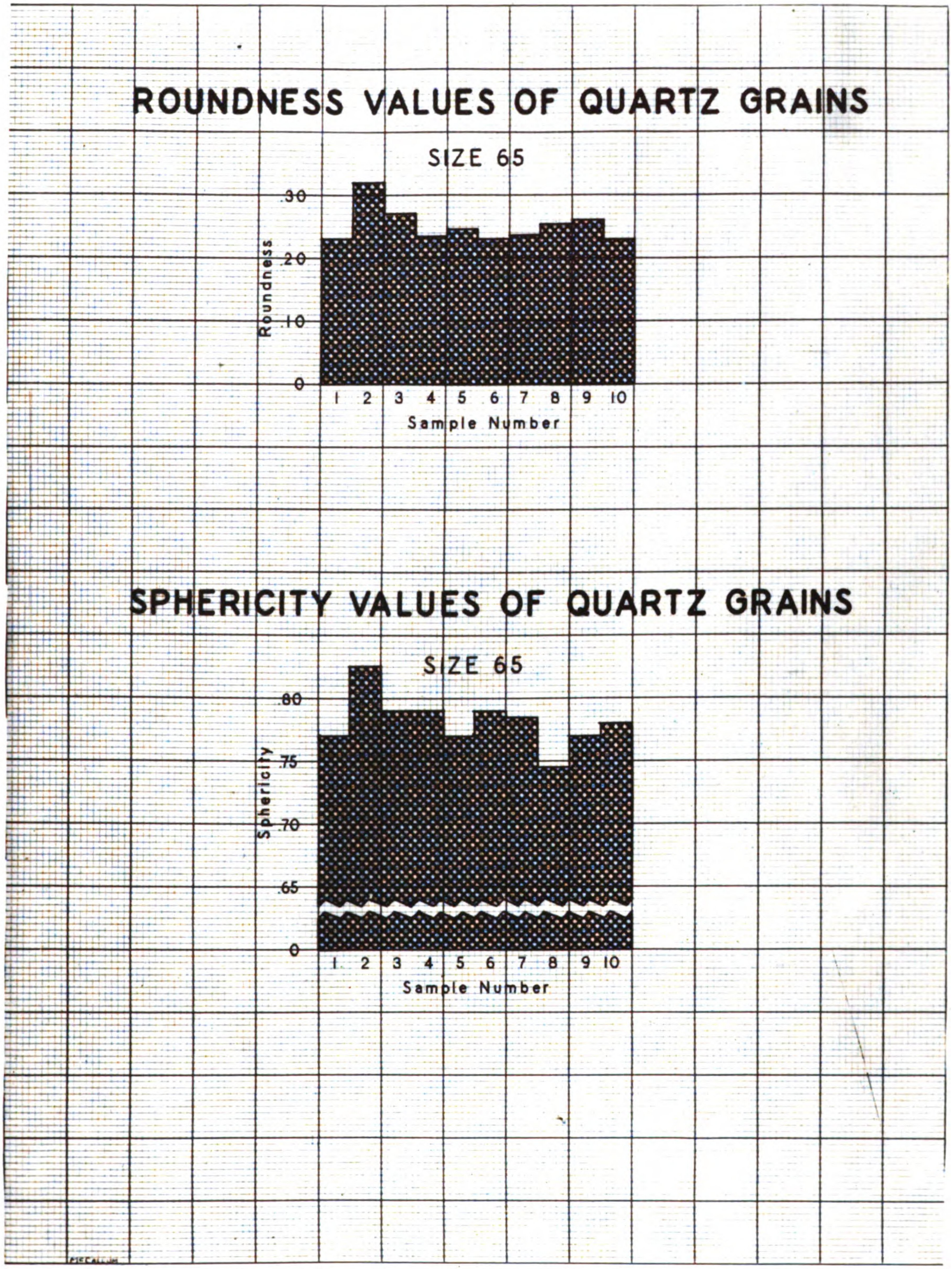

PERCENT OF HEAVY MINERALS IN SAND
25%
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 200
20%
15
10
5
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 150
10%
5
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 100
5%
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SIZE 65

FIGURE 6


ROUNDNESS VALUES OF QUARTZ GRAINS
SIZE 65
Roundness
.30
.20
.10
0
1 2 3 4 5 6 7 8 9 10
Sample Number
SPHERICITY VALUES OF QUARTZ GRAINS
SIZE 65
Sphericity
.80
.75
.70
.65
0
1 2 3 4 5 6 7 8 9 10
Sample Number

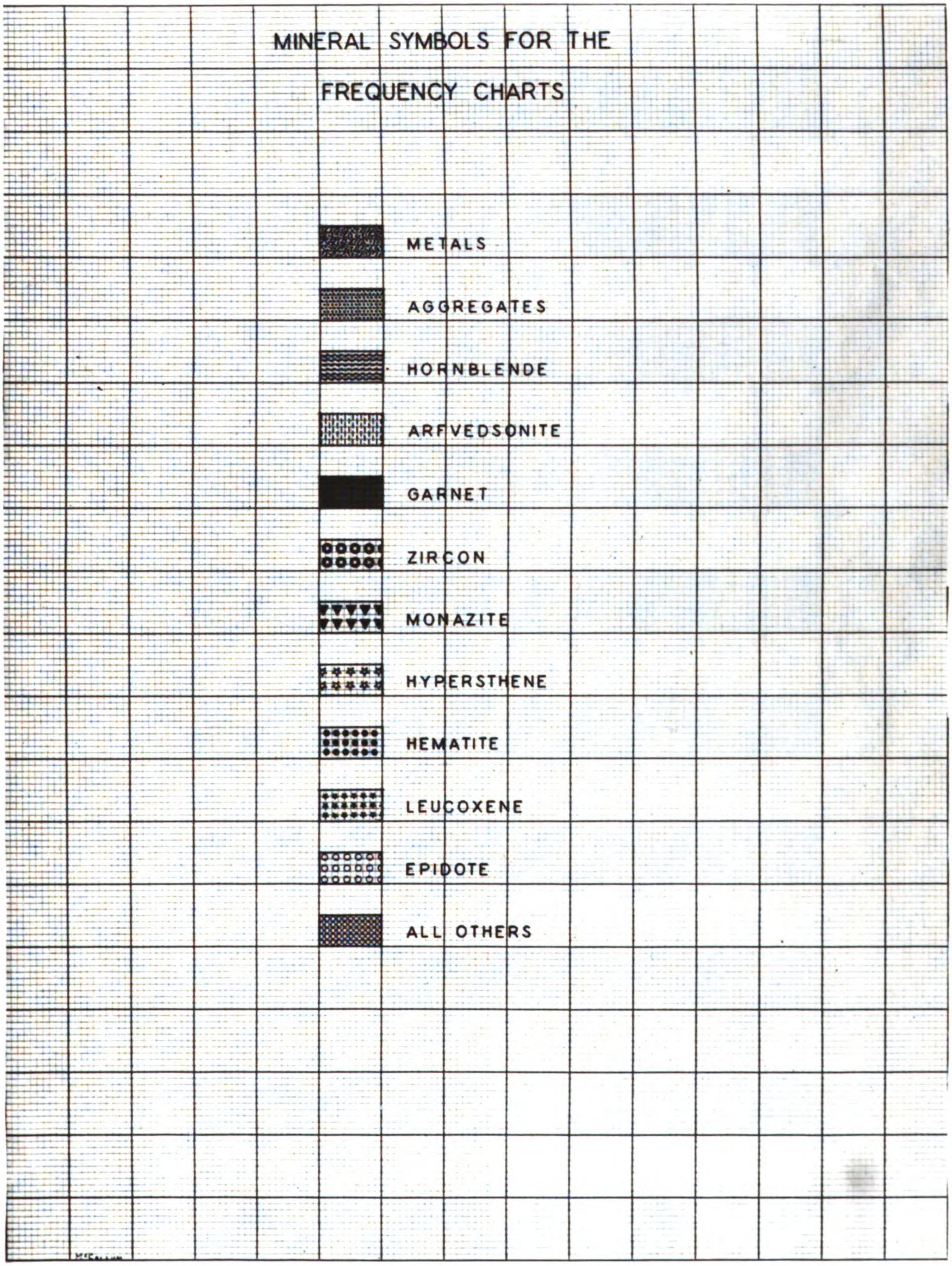

MINERAL SYMBOLS FOR THE
FREQUENCY CHARTS
METALS
AGGREGATES
HORNBLENDE
ARFVEDSONITE
GARNET
ZIRCON
MONAZITE
HYPERSTHENE
HEMATITE
LEUCOXENE
EPIDOTE
ALL OTHERS

FIGURE 7

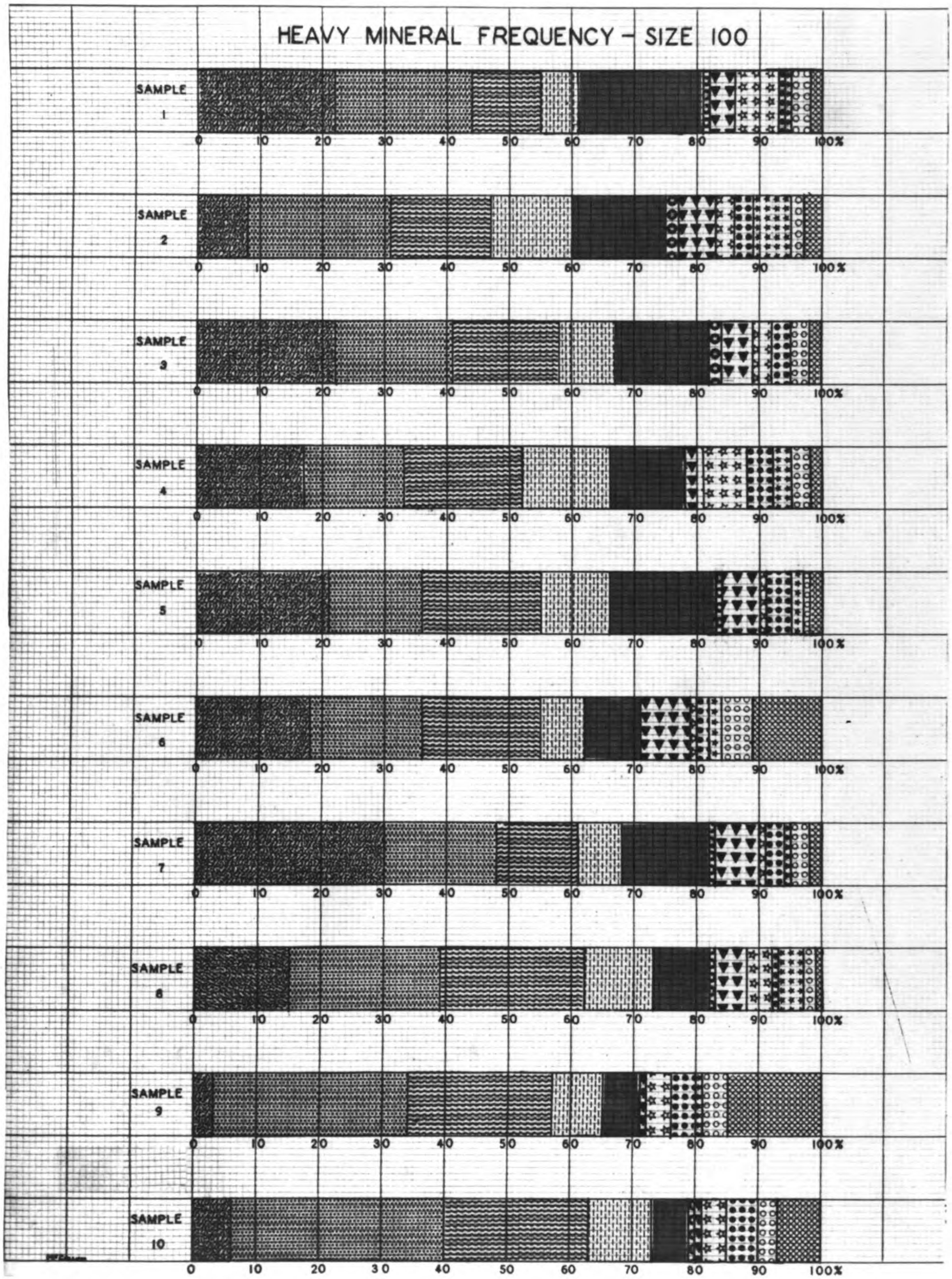
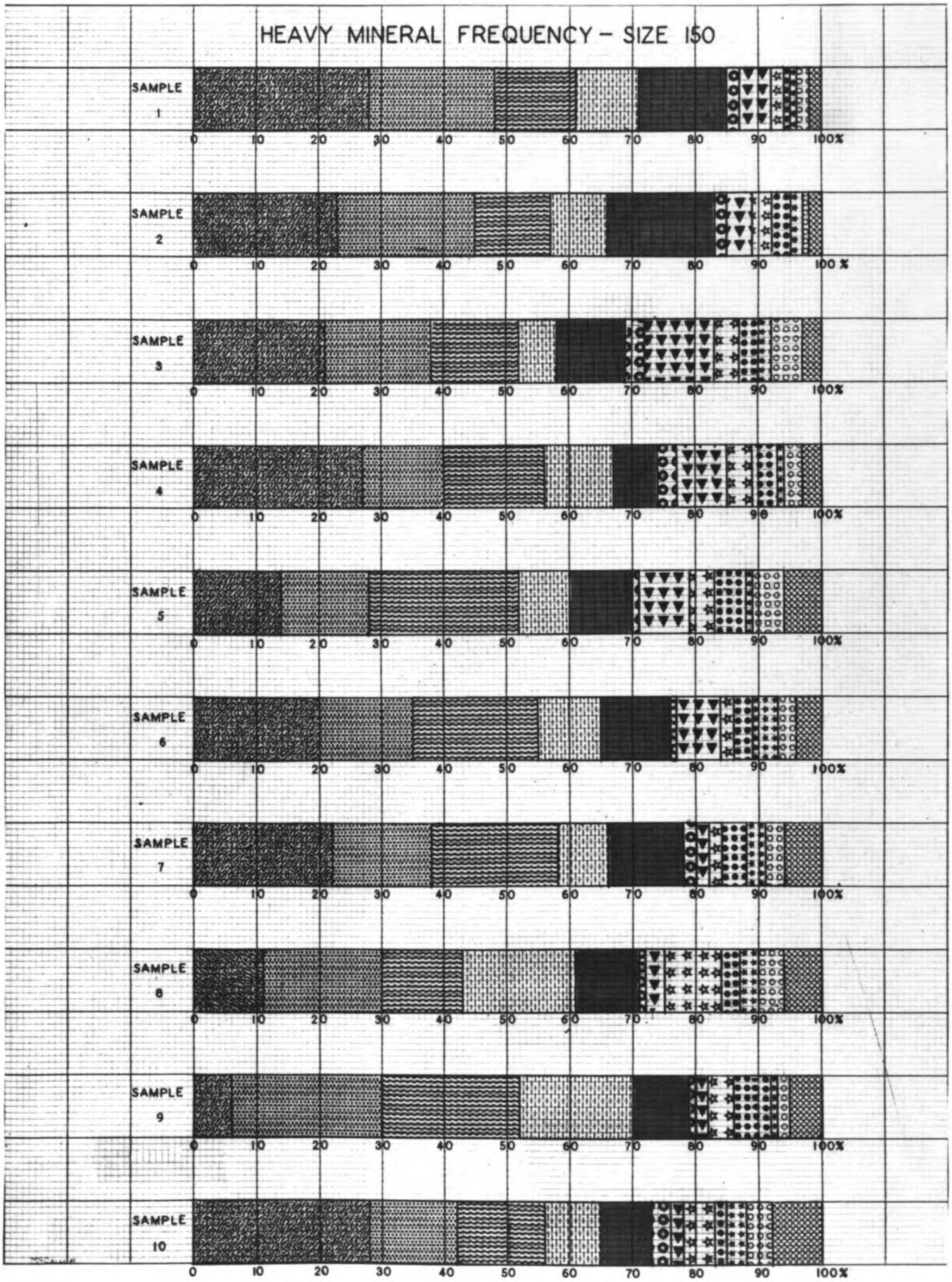

HEAVY MINERAL FREQUENCY - SIZE 100
SAMPLE 1
SAMPLE 2
SAMPLE 3
SAMPLE 4
SAMPLE 5
SAMPLE 6
SAMPLE 7
SAMPLE 8
SAMPLE 9
SAMPLE 10
0
10
20
30
40
50
60
70
80
90
100%

FIGURE 8


HEAVY MINERAL FREQUENCY - SIZE 150
SAMPLE 1
SAMPLE 2
SAMPLE 3
SAMPLE 4
SAMPLE 5
SAMPLE 6
SAMPLE 7
SAMPLE 8
SAMPLE 9
SAMPLE 10
0 10 20 30 40 50 60 70 80 90 100%

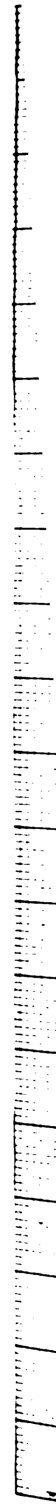
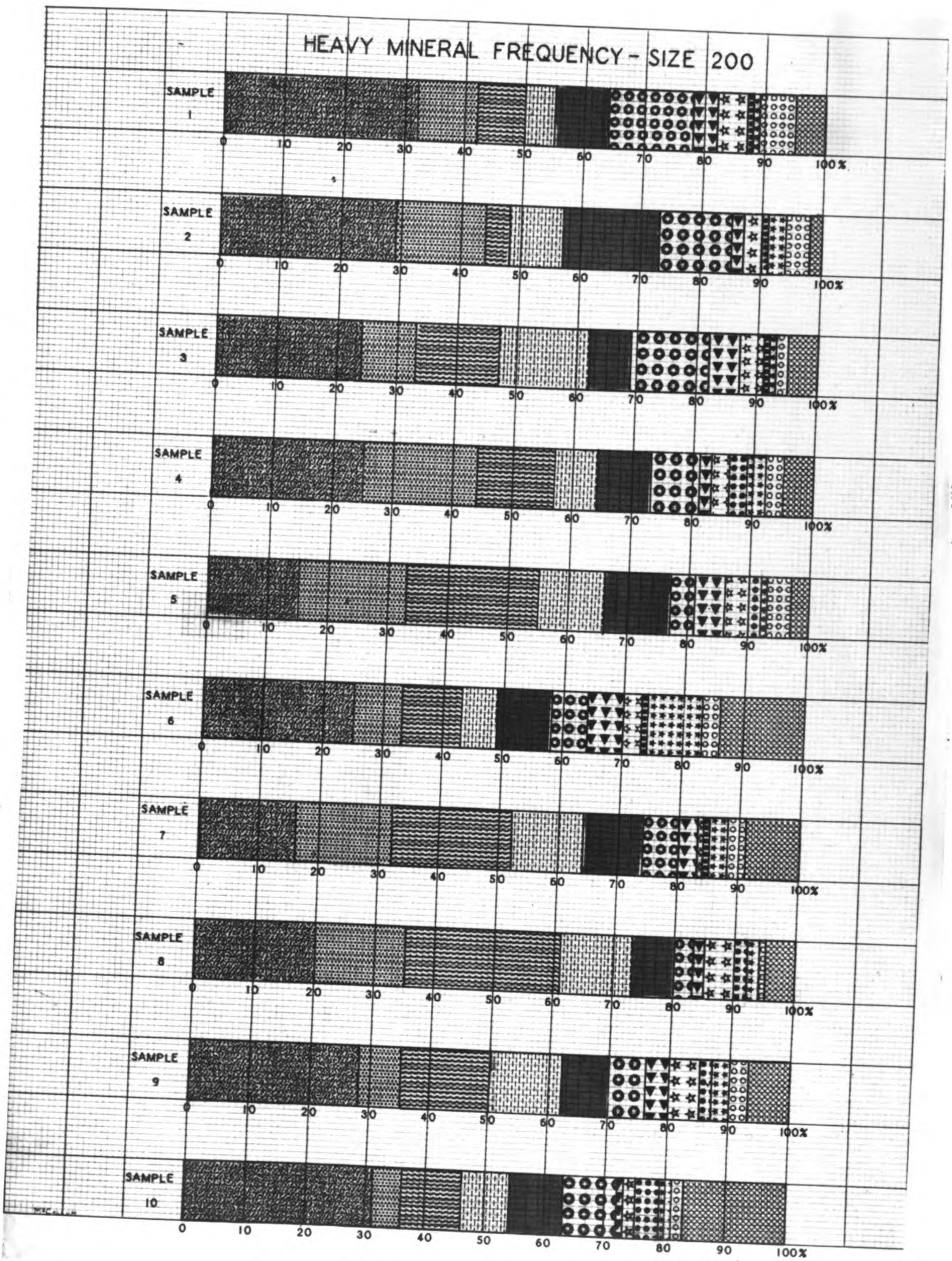


FIGURE 9


HEAVY MINERAL FREQUENCY - SIZE 200
SAMPLE 1
SAMPLE 2
SAMPLE 3
SAMPLE 4
SAMPLE 5
SAMPLE 6
SAMPLE 7
SAMPLE 8
SAMPLE 9
SAMPLE 10
0 10 20 30 40 50 60 70 80 90 100%