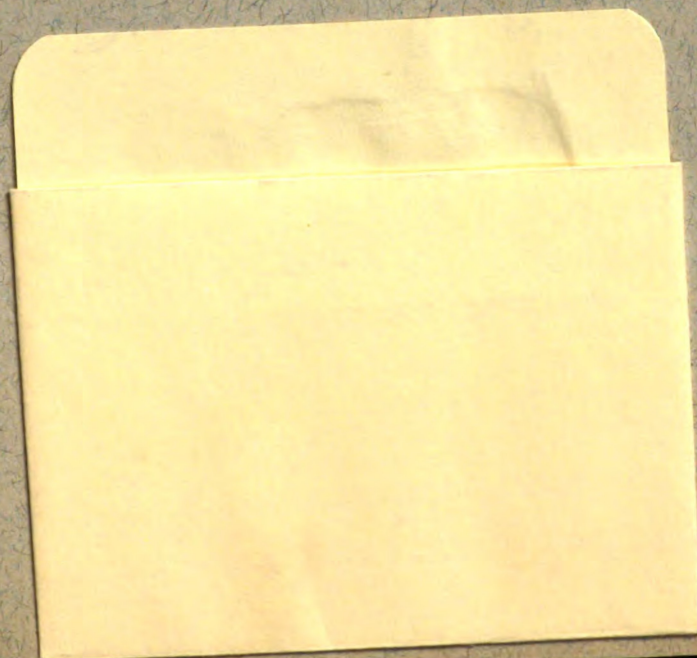


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A PETROGRAPHIC INVESTIGATION OF THE RELATIONSHIP
OF DEPOSITION OF SEDIMENTS IN A GROUP
OF ESKERS RELATED TO THE CHARLOTTE
TILL PLAIN

by

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A Thesis

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THESIS

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INTRODUCTION

The esker is an interesting glacial deposit in the form of a long sinuous ridge and composed chiefly of stratified drift. Flint*

*Flint, R. F., Eskers and Crevasse Fillings: American Journal of Science, 5th Series, Vol. 15, 1928, pp. 411-412.

has written a summary of the external features, composition, and structure of eskers:

Position

1. Commonly bear a definite relationship to terminal or recessional moraines, lying within and tributary to them.

External Features

2. May be very long, length commonly several miles. More than one individual in Maine has a length of 100 to 150 miles. Eskers in eastern Connecticut vary from 12 to 45 feet in height . . .
3. Usually trend in a direction parallel to the direction of ice movement.
4. Commonly broken and discontinuous, so that the entire length of any one esker must be measured by restoring the portions between the isolated remnants . .
5. Commonly sinuous in plan, suggesting the winding of streams.
6. Arranged, not infrequently, in tributary and distributary systems, like those characteristic of normal streams.
7. Trend uphill and cross divides, in many cases with no change in volume or texture of deposit.
8. Crests in many instances knobby and hummocky or gently undulatory; rarely level for any long distance.
9. Elevations of crests bear no definite relation to the tops of surrounding forms.

Composition and Structure

10. Component material predominantly coarse.
 Fine sand and clay are rare.
11. Bedding exceedingly variable and irregular, with common development of semi-stratified to non-stratified lenticular masses.
12. Transverse sections of every esker suitably exposed in eastern Connecticut, as well as sections of scores of eskers described from other localities, invariably exhibit irregular bedding paralleling the side slopes of the esker

Crosby*

*Crosby, W. O., The Origin of Eskers: Boston Society of Natural History, Proceedings, Vol. 30, 1893, pp. 375-411.

observed that in areas of the earth's surface now covered by glaciers, no conditions exist that are similar to those of the Pleistocene Ice Age. The glaciers of today are primarily of the valley and piedmont types with subglacial drainage. Ridges definitely identified as eskers are not found which have formed recently in the areas of these glaciers. The eskers identified with Pleistocene time were formed on country which had been nearly peneplained by glaciation.

Crosby*

*Crosby, W. O., op. cit., pp. 375-411.

has proposed a superglacial theory for the origin of eskers. A large amount of englacial material was exposed on the surface of the glacier by melting of the top of

the ice sheet. The base level of the superglacial streams was determined by the water table within the ice, produced in many cases by a lake barrier formed at the edge of the glacier. This may have caused the base level of the superglacial streams to be above the base of the ice. Crosby states:*

*Crosby, W. O., op. cit., p. 393.

"In view of these considerations, there seems to be no escape from the conclusion that the ice floor of the superglacial stream will be lowered by the superglacial as well as the basal melting of the ice; that the superglacial melting will be more active and efficient in proportion to the extent of aggrading of the channel and the volume of stagnant water saturating the gravel; and that the stream will be lowered at least as rapidly as the interstream surfaces"

This theory may explain the manner in which the eskers conform to the topography on which they lie.

Upham*

*Upham, W., Evidences of the Derivation of the Kames, Eskers, and Moraines of the North American Ice Sheet Chiefly from its Englacial Drift: Bulletin of the Geological Society of America, Vol. 5, 1894, pp. 71-86.

suggested that eskers were derived chiefly from englacial and finally superglacial drift. This material was gathered by the surface melt water and deposited in ice walled channels as eskers, or at the mouths of glacial rivers as

kames. In the vicinity of Winnipeg, Manitoba, which is the center of a vast flat region Upham observed that englacial drift was borne to heights of 500 feet above the surrounding plain.

The subglacial theory as postulated by Davis presents the origin of eskers as follows:*

*Davis, W. M., The Subglacial Origin of Certain Eskers: Boston Society of Natural History, Proceedings, Vol. 25, 1893, pp. 477-499.

A sand plateau, which formed in a glacial lake or above the water table at the edge of the ice sheet, served as an outlet for the esker stream. The building of the sand plateau caused the esker stream to become choked, and aggradation took place in the tunnel or crevasse. Davis does not adequately explain the origin of the tunnel or crevasse in which the esker stream flowed.

In a study of certain eskers in Denmark, Anderson*

*Anderson, S. A., The Waning of the Last Continental Glacier in Denmark as Illustrated by Varved Clay and Eskers: The Journal of Geology, Vol. 39, No. 7, 1931, pp. 609-624.

postulated that any crevasses formed during an interval of ice stagnation would not be further compressed for the reason that the flow had ceased. These crevasses acted as tunnels

or channels in which the melt water escaped to the ice border. During the stagnant stage a water table which sloped in the direction of flow, developed within the ice, and lowered each time the englacial melt water found a lower escape. This water table represented the ultimate upper limit of deposition of the glacio-fluvial material. When the surface of the ice melted until coincident with this table there was a tendency for the whole border zone of the glacier to be buoyed up. With the lifting of the ice there would be no limit to the width of the tunnels developed beneath it.

Trowbridge*

*Trowbridge, A. D., The Formation of Eskers: Science, New Series, Vol. 145, 1914, p. 145, abstract.

believes that eskers were formed by the drawing out of kames into long sinuous ridges during the recession of the glacier. A ridge of this type was built by the deposition of successive segments, each segment marked by a delta where the esker stream entered a glacial lake.

There is a disagreement among geologists relative to the origin of the drift contained in eskers. Trefethen*

*Trefethen, J. M., and H. B., Lithology of the Kennebec Valley Esker: American Journal of Science, Vol. 242, 1944, pp. 521-527.

showed that the bulk of both the fine and coarse material comprising the Kennebec esker of Maine is dominantly of local

origin. This is evidenced by the fact that at various points along the ridge the material consists largely of small fragments derived from the bed rock over which the ice moved.

LOCATION OF AREA

General

The Labradorean ice sheet was responsible for the development of two large lobes to the west of the Appalachian mountains, namely: the Lake Michigan and Huron-Erie lobes.*

*Leverett, F., The Pleistocene of Indiana and Michigan:

United States Geological Survey, Monograph 53, 1915, p. 24.

Between these lobes was developed the smaller Saginaw tongue which occupied a large area in central Michigan and extended south into Indiana and Ohio. The features produced by these two lobes are considerably different. The Lake Michigan lobe, whose axis was deeply keeled in a preglacial valley, developed a series of similar bulky, but rather smooth morainic ridges as it retreated from Illinois. The moraines of the Huron-Erie lobe lack the strong bold ridges of the Michigan lobe.

The Lake Michigan lobe deployed southward through the Lake Michigan basin into central Indiana and east-central Illinois. The Huron-Erie lobe extended across northeastern Ohio into Indiana. The Saginaw tongue advanced southwestward from Saginaw Bay into northeastern Indiana. The three lobes were coalesced until the Saginaw tongue receded from the district south of Kankakee, Illinois. Its recession was more rapid than that of the adjacent lobes because the original

advancement was over more elevated country producing a thinner ice sheet.

The Saginaw tongue developed the following glacial deposits in order of decreasing age: Maxinkuckee, Bremen, New Paris, Middlebury, Lagrange, Sturgis, and Tekonsha moraines and the Kalamazoo and Charlotte morainic systems.

Charlotte Morainic System

The ice was nearly stagnant during the formation of the Charlotte morainic system, indicated by the large number of eskers on the till plain. Towards the east, in the southeastern part of Livingston and the southwestern part of Oakland counties this system connects with the Fort Wayne morainic system of the Huron-Erie lobe. In the west, through western Kent county, it connects with the Valparaiso morainic system of the Lake Michigan lobe. The eskers on the till plain extend southward into the Charlotte morainic system. Leverett says:*

*Leverett, F., op. cit., p. 206.

"This morainic system, includes perhaps, more small eskers than any other in Michigan, and it receives the southern terminal of some of the most conspicuous eskers of the state. Some of the esker ridges have a nucleus of gravel and sand with a thin capping of till, a feature which suggests that they were formed near the base of the ice sheet at a horizon low enough to permit the deposition of the englacial material on them."

Distribution of Eskers

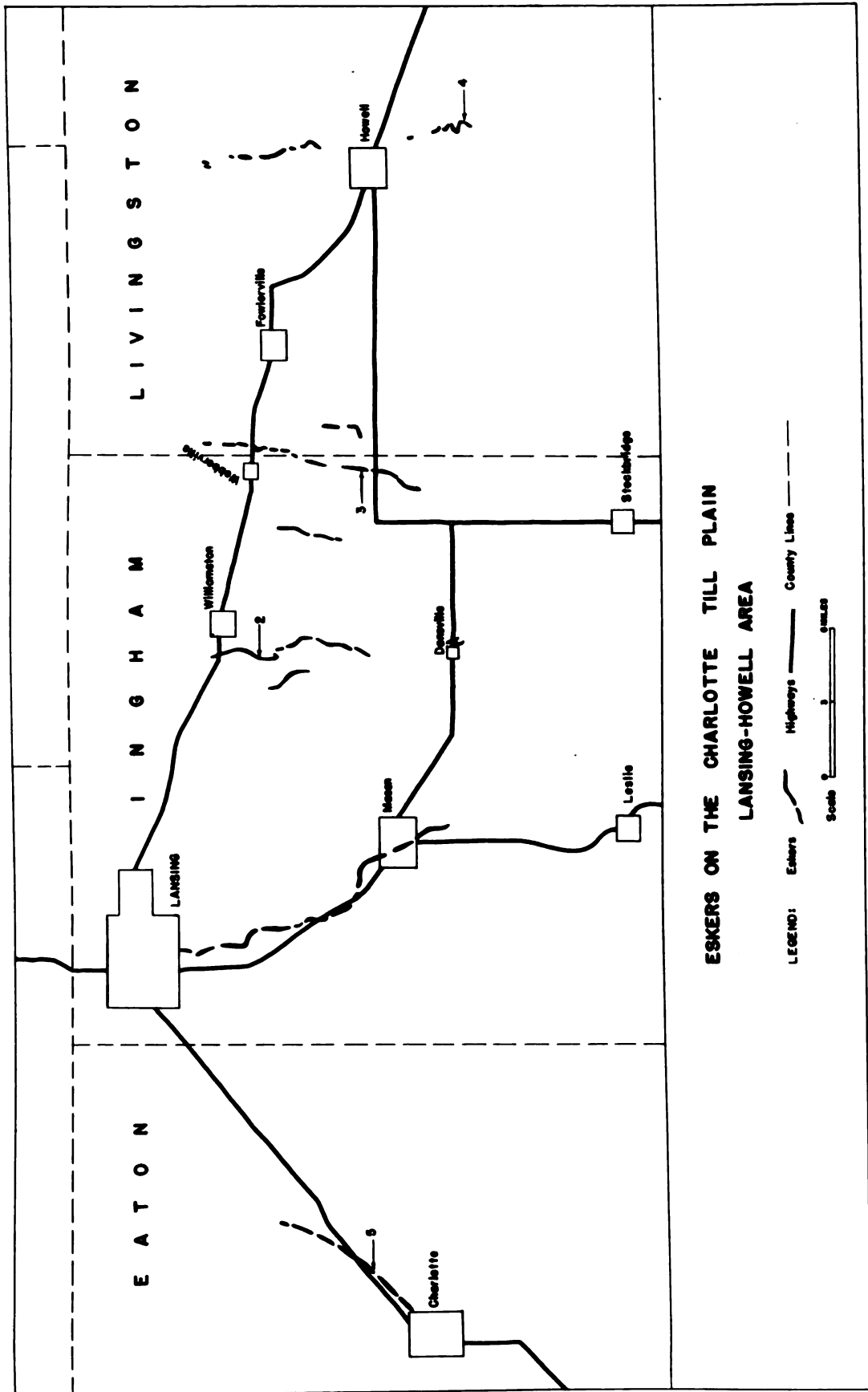
Ingham and Livingston counties are covered principally by the Charlotte till plain. This area is traversed by several eskers, which for the most part lie in shallow swampy depressions or esker troughs. The larger eskers extend southward over it, into the outer border of the Charlotte morainic system. Figure 1 shows the distribution of the eskers in the Lansing-Howell area.

Charlotte Esker

The Charlotte esker heads in Section three, Benton Township, on the north side of Thornapple River and extends south-southwesterly for a distance of nine miles. It terminates in a fan shaped delta directly east of Charlotte. In some localities there are wide gaps in the esker, but in other places it is continuous for over one mile. The maximum relief of the esker is 20 feet above the till plain; the width varying from 270 to 300 feet. Except for two or three miles at the northern end it crosses the Charlotte morainic system. The esker is composed of medium-coarse gravel.

Mason Esker

The Mason esker is the longest esker in Michigan. The entire esker lies in a well defined trough 20 miles long, which heads in southeastern Lansing and terminates in a delta plain southeast of Mason. The course of the stream, as shown by the attitude of the bedding, was from north to south, which is reversed to the direction of the present drainage. The ridge varies from 10 to 50 feet in relief, and from 150



to 300 feet in width. There is a rise of approximately 85 feet from the northern to the southern end. It is composed mainly of sand and gravel which are well sorted and stratified. Leverett states:*

*Leverett, F., op. cit., p. 210.

"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. Much significance is attached to the fact that the coarse pebbles are so largely of local derivation, as some suppose, eskers were formed by superglacial streams, they would have contained less material (this being for the most part beyond their reach) and the coarse rocks would be largely granites and other distantly derived material which had been brought to the surface by ablation."

Williamston Esker

The Williamston esker extends for a distance of approximately 10 miles southward from Williamston past Dansville. It is nearly continuous throughout its entire length, and has a maximum relief of 50 feet. The esker is composed largely of sand and gravel.

Webberville Esker

The esker extends from the Cedar River valley, approximately one quarter of a mile east of the Ingham-Livingston county line, south-southwestward for a distance of approximately eight miles. In some portions of the esker, double and even treble ridges have formed. The relief varies from

15 to 40 feet. The northern portion of the esker appears to contain coarser gravel than the southern end.

Howell Esker

This esker is a combination of two and possibly three eskers in an end to end series and has a combined length of approximately 15 miles. The southernmost esker is probably the oldest. For a distance of two and a half miles east of Howell, along Bogue Creek, there are no esker ridges. North of Howell there is a well defined esker which continues northward for about five miles along Bogue Creek. The esker between Howell Junction and Chilson is very sinuous. The series of eskers vary from 10 to 40 feet in relief.

PURPOSE OF STUDY

In the past very little detailed work has been done on the fine sands of glacial deposits by modern petrographic methods. Since there are several different theories for the possible origin of eskers an investigation of the sands from several eskers might help to clarify the problem of their origin. Also, a petrographic examination of several eskers on the same till plain, may or may not show a close correlation between neighboring eskers, since they may or may not have originated at the same time and under similar conditions. This study should prove their similarity or dissimilarity.

SYSTEMATIC PROCEDURE FOR SIMULTANEOUS ANALYSIS OF SEDIMENTS FOR
SHAPE MEASUREMENTS AND HEAVY MINERAL IDENTIFICATION

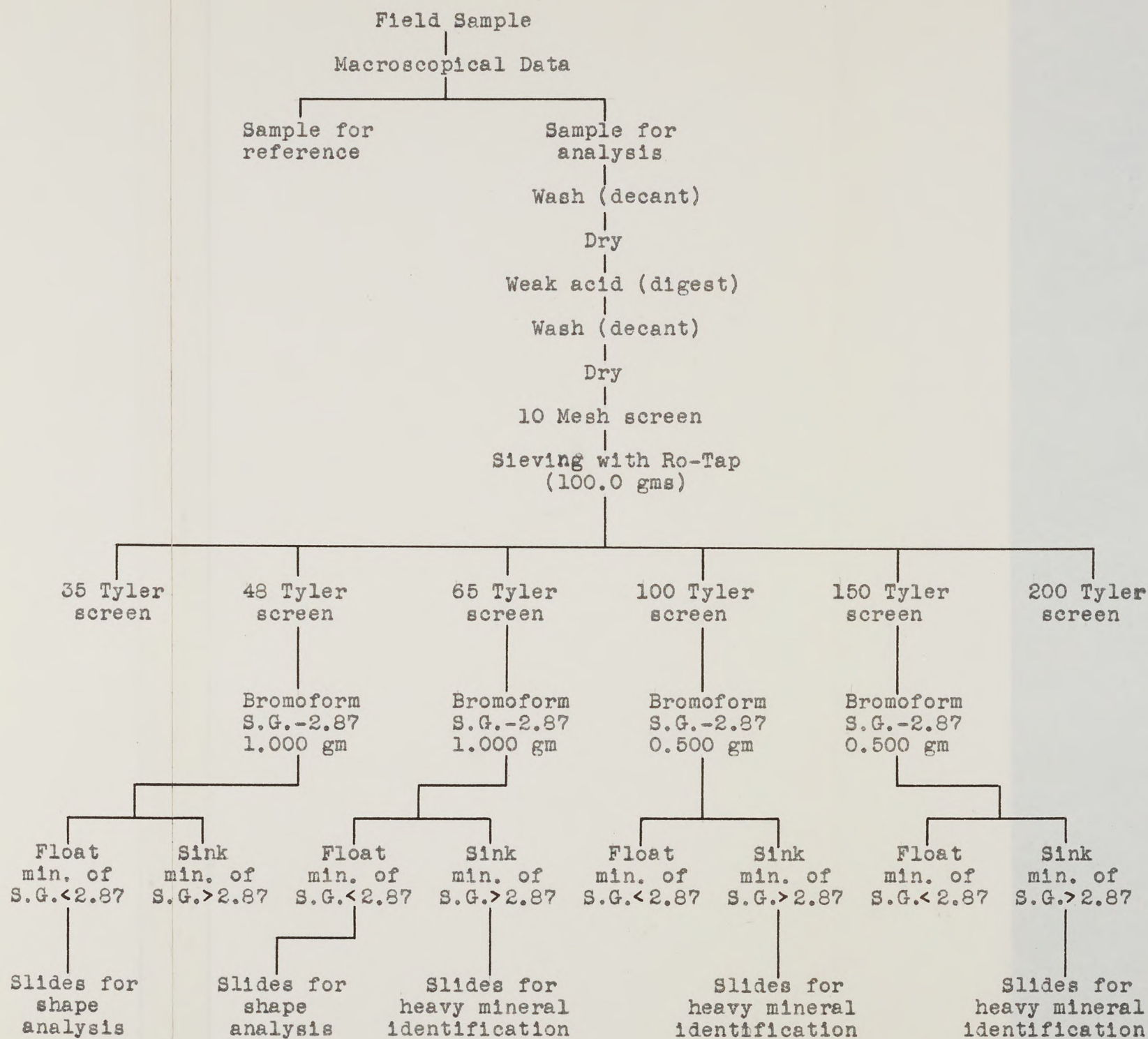


Fig. 2

Origin. Unpublished Master's thesis. Department of Geology and Geography, Michigan State College, 1948, pp. 25-27.

showed that the heavy mineral suites and shape measurements remain nearly the same throughout the length of the Mason esker, one of the eskers on the Charlotte till plain.

A vertical channel sample, of approximately five gallons, was taken from each exposure, and before collecting the material all slump was carefully removed. This material was thoroughly mixed, and with the aid of a Jones splitter was reduced until one quart of the original sample remained.

Laboratory Sampling

Since the composition of the eskers is predominately sand and gravel it was not necessary to disaggregate the material. One half of the field sample was taken for laboratory analysis and the remainder retained for reference. The very fine muds were removed by washing and decanting. All material smaller than 200 mesh was discarded. The mixture was decanted carefully to insure no loss of the particles to be used in the analysis. Krumbein*

*Krumbein, W. C., Manual of Sedimentary Petrography, D-Appleton-Century Company, New York, 1939, p. 110.

has shown that, according to Stoke's law, particles one sixteenth millimeter in diameter have a settling velocity of .305 centimeters per second. One minute was ample time for all the particles used in the analysis to settle to the

bottom before decanting.

Leaching

The unweighed sample was dried in a Sargent's electric drying oven, divided into eight parts, to each of which dilute HCl (10% solution) was added. They were then allowed to stand in the acid for several days, with frequent stirrings, until the carbonates had been completely dissolved, after which the sample was thoroughly washed and dried. Erickson*

*Erickson, R. L., op. cit., p. 20.

showed there was no correlation in the percentage of carbonates in each sample.

Sieving

The pebbles were removed with the aid of a 10 mesh screen. The sample was reduced with a Jones splitter until 100 grams of the sample remained. The 100 gram sample was sieved in a Ro-Tap automatic shaking machine for a period of eight minutes. The shaker was equipped with six sieves having 35, 48, 65, 100, 150, and 200 openings per inch. Krumbein states*

*Krumbein, W. C., op. cit., pp. 118-119.

that there were disadvantages in the use of sieves for the mechanical analysis of sediments. Sieves not only sort grains according to size, but also according to shape. A

lath-shaped grain, with the same cross section as a spherical grain, will pass through a given sieve. Despite this disadvantage, sieving is used widely in mechanical analysis, and the data obtained may be employed for a number of purposes. After sieving, each size was weighed, placed in a bottle and labeled. Figure 3 shows the weight percentage of the sands from the various eskers.

Separation

Before proceeding with the separation of the light from the heavy minerals, the sample for each size was quartered. This was done by placing four pieces of rectangular paper in such a way that each overlapped one half of the other forming a square. The sample was carefully poured on the center of the square, and alternate quarters were pulled out and combined. This process was continued until the desired volume of the sample was obtained. One gram samples from the 48-65 and 65-100 sizes, and one half gram samples from the smaller sizes were used. These weights for each sieve size used in the analysis were sufficient to give a representative fraction for the heavy and light materials.

The heavy liquid, bromoform (tribro-methane) with a specific gravity of 2.87 at room temperature, was used for the separation of the minerals. This liquid separated the minerals having a specific gravity less than 2.87 from those having a specific gravity greater than 2.87. The apparatus

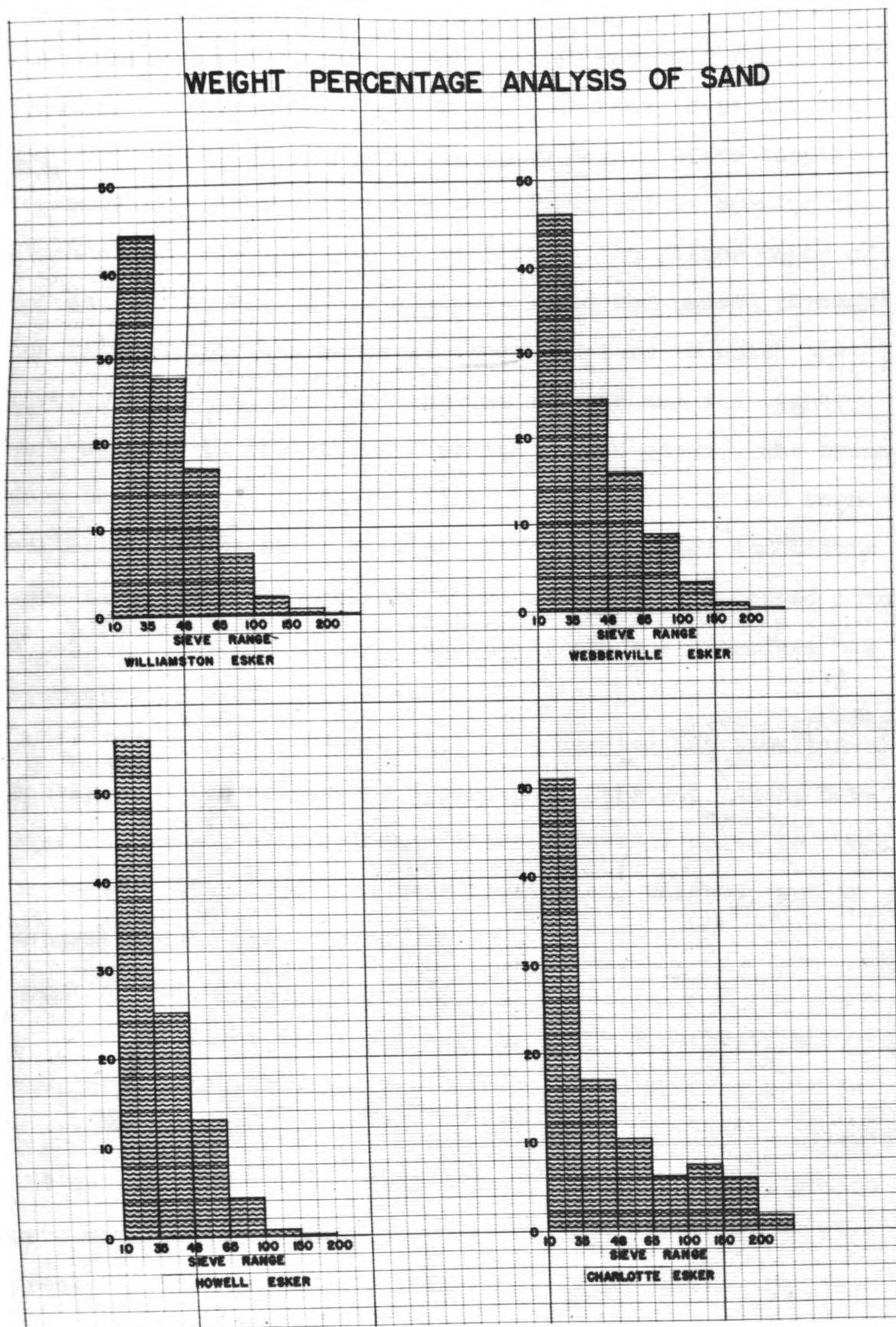


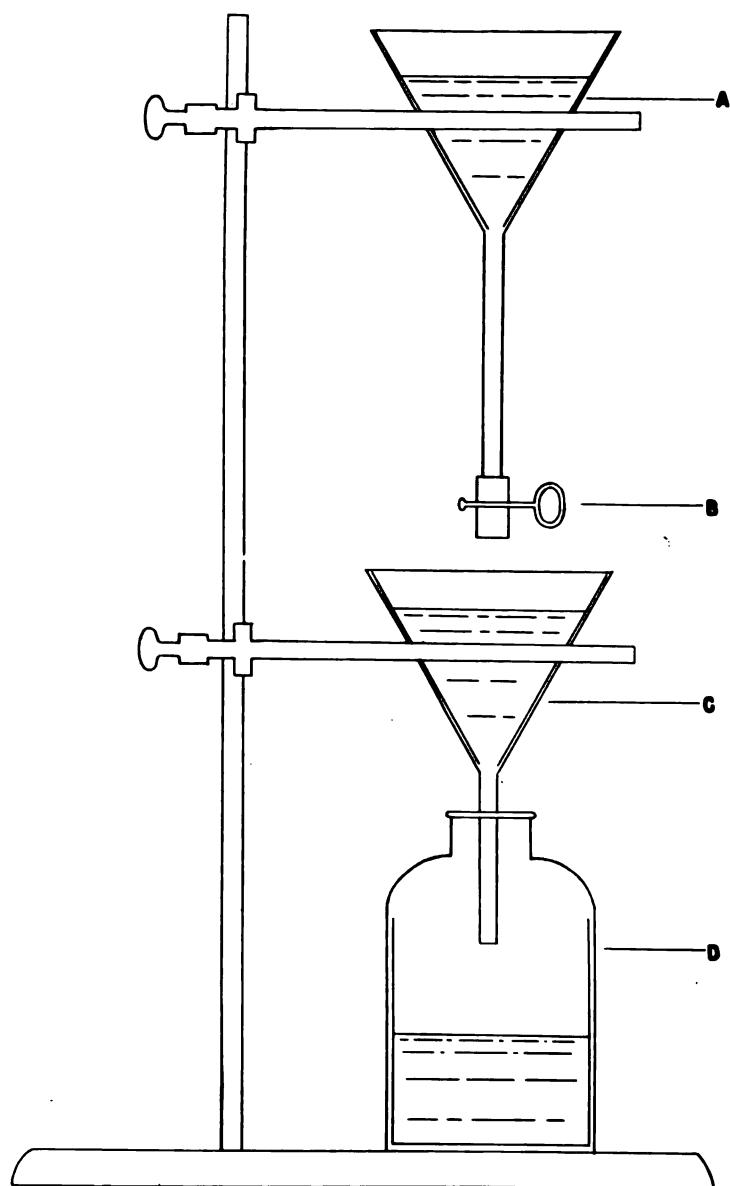
Fig. 3

used for all separations is shown in Figure 4. The sand was poured into the upper funnel, which was half filled with bromoform, and thoroughly stirred. The heavy minerals sank and were concentrated above the pinch cock. After complete separation the heavy minerals were drawn off by opening the pinch cock, allowing them to collect on the filter paper of the second funnel. After all the liquid had passed through the filter paper was removed. The bromoform in which the lighter minerals were floating was run off and the lights were allowed to collect on a second filter paper. The bromoform was returned to the original bottle after it had been collected in the lower bottle. Both the heavies and lights were rinsed with alcohol and these washings were poured into a bottle marked "bromoform washings", and the bromoform was recovered by washing.

Twenty-four separations were carried out simultaneously in a funnel-battery apparatus. Care was taken, however, to mark the individual filter papers in order to avoid confusion. The fractions were then dried, weighed, put in separate vials and labeled.

Mounting for Microscopic Study

The light fractions were used for sphericity and roundness measurements. The refractive index of quartz is 1.544-1.553, whereas for Canada balsam it is 1.537. Because the quartz shows little relief in Canada balsam, the grains were mounted in a synthetic resin ($n=1.66$) in order to show greater relief and detail. To reduce the tendency for the



A FUNNEL WITH HEAVY LIQUID
B RUBBER TUBE AND PINCH-COCK
C FUNNEL FITTED WITH FILTER-PAPER
D BOTTLE TO COLLECT USED HEAVY LIQUID

formation of bubbles, the resin was melted in an evaporating dish. The slide on which the quartz grains were mounted was also heated and a small amount of the resin was poured on to the slide. Any bubbles produced in the resin remained in the evaporating dish when the resin was poured on to the slide.

The heavy minerals were mounted in Canada balsam which is common practice.*

*Pettijohn, F. J., Manual of Sedimentary Petrography, D-Appleton-Century Company, New York, 1938, p. 360.

Identification of Heavy Minerals

The petrographic microscope is an instrument which aids in the identification of heavy minerals present in sands. A full description of the microscope can be found in one of several works on microscopy.*

*Wahlstrom, E. R., Optical Crystallography, John Wiley and Sons, Inc., New York, 1943.

*Chamot, E. M. and Mason, C. W., Handbook of Chemical Microscopy, Vol. 1, Principles of Microscopes and Accessories, 1st ed., John Wiley and Sons, Inc., New York, 1931.

*Johannsen, A., Manual of Petrographic Methods, 2nd ed., University of Chicago Press, Chicago, 1918.

A mechanical stage, fastened to the revolving stage, greatly facilitated the counting of the heavy minerals. With the mechanical stage the object slide may be moved in two directions at right angles, the component of each

movement indicated on the scales. Certain minerals, because of slight alteration, had properties which made them difficult to identify in the mounted slide. When this was the case, it was necessary to remove the grains of this unknown mineral from the unmounted sand, immerse in index oils, and make accurate identification.

Three sizes, namely: 65-100, 100-150, and 150-200, were used in the identification of the heavy minerals. Sizes larger than 65-100 contained an appreciable amount of rock fragments which could not be used satisfactorily in the statistical analysis.

Twenty three minerals were identified from samples taken from the eskers studied. Following is a list of the most important minerals with descriptions as compiled from several sources:*

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

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

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

*Milner, H. B., Sedimentary Petrography, Thomas Murby and Co., New York, 1929, pp. 97 ff.

Hornblende: Complex silicate of Fe, Mg, Ca, Al, and Na.

Crystal system: monoclinic
 Color : var. common hornblende, green to brown
 Index : a, 1.658-1.698; b, 1.670-1.719;
 c, 1.679-1.722

Birefringence : .026-.027
 Optic figure : biaxial negative
 Elongation : positive
 Pleochroism : marked

Distinctive features: grains elongate; prismatic;
 Inclined extinction; marked pleochroism; common.

Clinopyroxene: (Augite, diallage, diopside)
 $\text{Ca (Fe, Mg, Al) (SiO}_3)_3$

Crystal system: monoclinic
 Color : brownish-gray to gray-green
 Index : a, 1.696-1.700; b, 1.702-1.718;
 c, 1.714-1.742
 Birefringence : .018-.043
 Optic figure : biaxial positive
 Extinction : 44-49 degrees

Distinctive features: grains usually elongate; worn
 cleavage fragments; poorly rounded; high index; high
 birefringence; large extinction angle.

Garnet: $\text{R}'\text{R}''\text{R}''' (\text{SiO})$ where R' is Mg, Fe'' , Ca, Mn
 and R'' is Al, Fe''' , Cr

Crystal system: isometric
 Color : pink and colorless
 Index : 1.70-1.90

Distinctive features: high relief; isotropism;
 conchoidal fracture.

Chloritic Matter: Essentially silicates of Al, Fe, Mg, and
 hydroxyl

Crystal system: monoclinic
 Color : dirty green
 Birefringence : .003-.009

Distinctive features: "ultra-blue" abnormal interfer-
 ence color; compound polarization; pale green color;
 low birefringence.

Zircon: ZrSiO_4

Crystal system: tetragonal
 Color : colorless
 Index : e, 1.985-1.991; o, 1.926-1.936
 Birefringence : .0443

Optic figure : uniaxial positive
 Elongation : positive
 Extinction : parallel

Distinctive features: euhedra common; pyramidal terminations; basal grains rare; rod-shaped inclusions; high index.

Hypersthene: (Mg, Fe) SiO₃

Crystal system: orthorhombic
 Color : pale pink and green
 Index : a, 1.665-1.715; b, 1.669-1.728;
 c, 1.674-1.731
 Birefringence : .009-.016
 Optic figure : biaxial negative
 Elongation : positive
 Pleochroism : marked, X-pink, Y-yellow, Z-green

Distinctive features: worn elongate cleavage fragments; highly colored; thin, brown, plate like inclusions (Schiller structure); low birefringence; parallel extinction; striking pleochroism.

Orthopyroxene: (enstatite, bronzite) (Mg, Fe)SiO₃

Description same as hypersthene except that enstatite is nearly colorless and is biaxial positive. Enstatite, bronzite, and hypersthene are members of an isomorphous series in the orthorhombic pyroxene group.

Staurolite: 2 FeO.5Al₂O₃.4SiO₂.H₂O

Crystal system: orthorhombic
 Color : yellow, brown
 Index : a, 1.736; b, 1.741; c, 1.746
 Birefringence : .010
 Optic figure : biaxial negative
 Pleochroism : marked, X-colorless, Y-pale yellow,
 Z-golden yellow

Distinctive features: marked by hackly to sub-conchoidal fracture; well formed crystals rare; inclusions numerous; exhibits bright interference colors.

Epidote: Ca₂(Al, Fe)₃Si₃O₁₂(OH)

Crystal system: monoclinic
 Color : bottle green
 Index : a, 1.722-1.729; b, 1.742-1.763;
 c, 1.750-1.780

Birefringence: .028-.051
 Optic figure : biaxial negative
 Pleochroism : distinct, X-colorless, Y-bottle-green
 Z-colorless
 Extinction : 2-5 degrees

Distinctive features: grains equidimensional; sub-rounded; distinct pleochroism; bottle green color; high index.

Titanite: $\text{CaO.TiO}_2\text{SiO}_2$

Crystal system: monoclinic
 Color : pale yellow, light brown
 Index : a, 1.900; b, 1.907; c, 2.034
 Birefringence : .134
 Optic figure : biaxial positive
 Elongation : negative
 Pleochroism : weak
 Extinction : 51 degrees

Distinctive features: conchoidal fracture; diamond shaped euhedral grains; exhibit same color under crossed nicols as in ordinary light owing to high birefringence; many grains fail to show complete extinction in white light due to high dispersion; the grain changes to a blue color as the extinction position is reached.

Sillimanite: $\text{Al}_2\text{O}_3.\text{SiO}_2$

Crystal system: orthorhombic
 Color : colorless
 Index : a, 1.659; b, 1.660; c, 1.680
 Birefringence : .021
 Optic figure : biaxial positive
 Extinction : parallel
 Elongation : positive

Distinctive features: grains irregular to short prismatic; marked by longitudinal splitting and striae parallel to length.

Topaz: $2(\text{AlF})\text{O.SiO}_2$

Crystal system: orthorhombic
 Color : colorless
 Index : a, 1.619; b, 1.620; c, 1.627
 Birefringence : .008
 Optic figure : biaxial positive

Distinctive features: irregular fractured grains; basal grains give well-centered interference figure; interference colors bright.

Tourmaline: $(\text{Na,Ca})\text{R}_3(\text{Al,Fe})_6\text{B}_3\text{Si}_6\text{O}_{27}(\text{O,OH,F})_4$ with
R Mg, Fe^{II}, Fe^{III}, Al, Li, Mn and Cr

Crystal system: hexagonal-rhombohedral
Color : yellow-brown, dark brown
Index : e, 1.621-1.658; o, 1.636-1.698
Birefringence : .019-.032
Optic figure : uniaxial negative
Pleochroism : strong, dark brown to honey yellow
Extinction : parallel
Elongation : negative

Distinctive features: characterized by color and strong pleochroism; negative uniaxial figure.

Monazite: $(\text{Ce,L a,Nd,Pr})_2\text{O}_3 \cdot \text{P}_2\text{O}_5$

Crystal system: monoclinic
Color : yellow
Index : a, 1.786-1.800; b, 1.788-1.801;
c, 1.837-1.849
Birefringence : .049-.051
Optic figure : biaxial positive
Pleochroism : faint, X-light yellow, Y-dark yellow,
Z-greenish
Extinction : 2-10 degrees
Cleavage : perfect basal

Distinctive features: grains rounded; equidimensional often lying on 001; euhedra rare; exhibit same color between crossed nicols as in ordinary light owing to high birefringence; high relief; light yellow color.

Leucoxene: Decomposition product of ilmenite, as yet ill-defined.

Crystal system: non-crystalline
Color : translucent to opaque; white to light yellow under reflected light.

Distinctive features: commonly occurs as rounded grains; opaque in transmitted light, white or yellowish-white in reflected light.

Less than one percent of the grains counted were olivine, biotite, apatite, anatase, and rutile. The predominant grain counted was a composite aggregate which was difficult to determine because of its lack of optical properties. Milner describes a composite aggregate as:*

*Milner, H. B., op. cit., p. 100.

"The attachment of iron-ore to quartz, mica to quartz, rutile to ilmenite, pyrite to chert, and such compound minerals as leucoxene, perthitic intergrowths of feldspar, mica-chlorite-serpentine aggregates, shimmer aggregates, etc., are common occurrences in sediments, whose diagnosis may occasionally be troublesome."

The results of the heavy mineral counts for the three sieve sizes are presented in tables 1, 2, and 3. Histograms showing the frequency percentage of the heavy minerals are shown in figures 5, 6, and 7.

TABLE 1
Frequency Percentage of Heavy Minerals
65-100 Range

Mineral	Esker				
	Mason	Williamston	Webberville	Howell	Charlotte
Composite aggregate	27.4	26.8	20.0	18.0	23.8
Chloritic matter	23.2	19.6	22.1	24.0	22.8
Hornblende (green)	11.2	14.0	16.9	12.3	21.0
Clinopyroxene	8.0	6.0	8.1	8.0	3.8
Epidote	6.5	7.1	7.4	5.7	6.8
Garnet (colorless)	4.0	8.5	5.7	7.0	2.8
Garnet (pink)	6.5	3.2	4.3	9.3	3.8
Orthopyroxene	4.0	5.6	4.3	4.3	2.0
Hornblende (brown)	1.4	1.8	4.8	4.3	4.3
Hypersthene	2.9	1.1	3.3	3.3	1.5
Sillimanite	0.0	0.0	0.8	2.4	0.8
Monazite	1.0	1.3	0.8	0.6	1.3
Staurolite	0.8	0.7	0.0	0.6	2.3
Leucoxene	1.9	1.1	0.5	0.0	0.8
All others	1.0	3.3	1.0	0.2	2.2

TABLE 2
Frequency Percentage of Heavy Minerals
100-150 Range

Mineral	Esker				
	Mason	William- ston	Webber- ville	Howell	Char- lotte
Composite aggregate	23.0	29.3	26.1	23.2	33.6
Hornblende (green)	14.4	10.2	24.4	18.6	21.0
Chloritic matter	8.8	9.1	6.4	8.5	11.2
Clinopyroxene	12.5	7.9	7.2	6.4	5.1
Epidote	5.5	6.6	4.6	7.7	8.1
Garnet (colorless)	6.6	7.7	6.3	8.3	1.1
Orthopyroxene	5.9	4.3	7.8	3.8	3.8
Garnet (pink)	4.4	4.1	3.6	7.6	1.3
Hornblende (brown)	4.1	6.8	4.4	2.2	3.3
Monazite	2.6	3.2	4.1	4.9	1.8
Hypersthene	5.5	2.3	2.5	3.4	1.8
Staurolite	2.2	0.7	0.0	0.0	1.5
Zircon	2.2	0.7	0.0	0.0	0.6
Topaz	0.0	1.1	1.2	2.7	2.2
Tourmaline	0.0	1.3	1.0	0.9	1.5
All others	2.2	4.7	0.4	1.5	2.1

TABLE 3
Frequency Percentage of Heavy Minerals
150-200 Range

Mineral	Esker				
	Mason	Williamston	Webberville	Howell	Charlotte
Hornblende (green)	19.5	19.7	20.0	14.6	22.0
Composite aggregate	19.2	18.6	17.4	16.4	19.0
Garnet (colorless)	5.9	9.0	11.1	14.7	4.3
Hornblende (brown)	6.1	2.3	11.1	9.7	9.5
Clinopyroxene	7.5	6.4	8.1	4.5	10.2
Orthopyroxene	6.1	5.1	5.1	5.3	6.7
Epidote	9.3	7.2	4.0	8.2	7.8
Chloritic matter	5.3	7.5	5.6	4.7	4.8
Monazite	5.9	5.5	4.6	2.7	1.9
Zircon	4.3	3.6	2.8	6.8	0.6
Garnet (pink)	2.4	3.0	1.9	6.0	2.2
Hypersthene	2.1	1.8	0.5	1.7	1.9
Leucoxene	1.6	3.5	1.1	1.6	2.8
Topaz	0.0	3.5	2.3	1.0	0.0
Titanite	3.2	0.0	0.0	0.0	0.9
Staurolite	1.1	0.0	0.7	0.0	2.2
All others	0.5	2.3	3.7	2.1	3.2

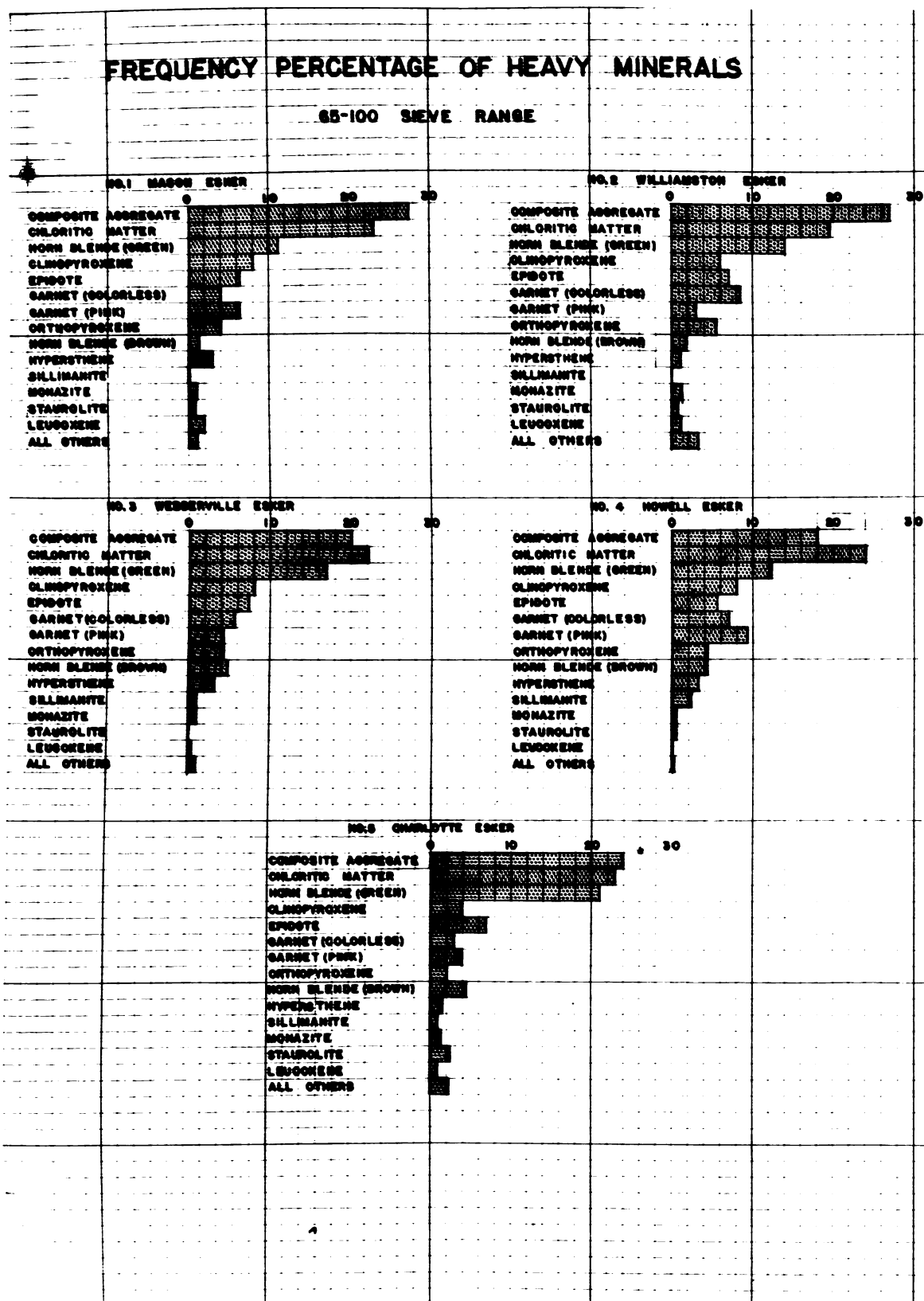


Fig. 5

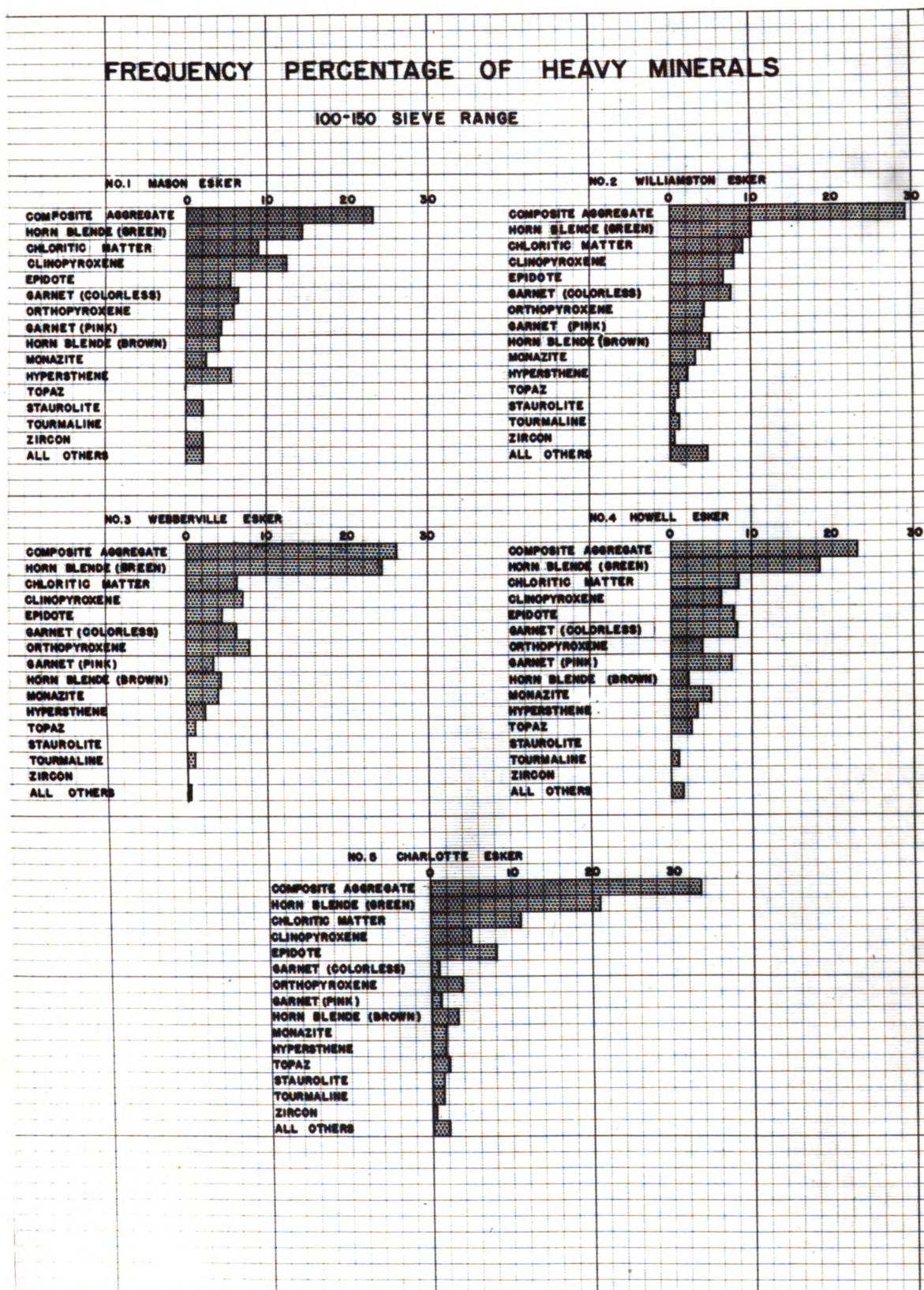


Fig. 6

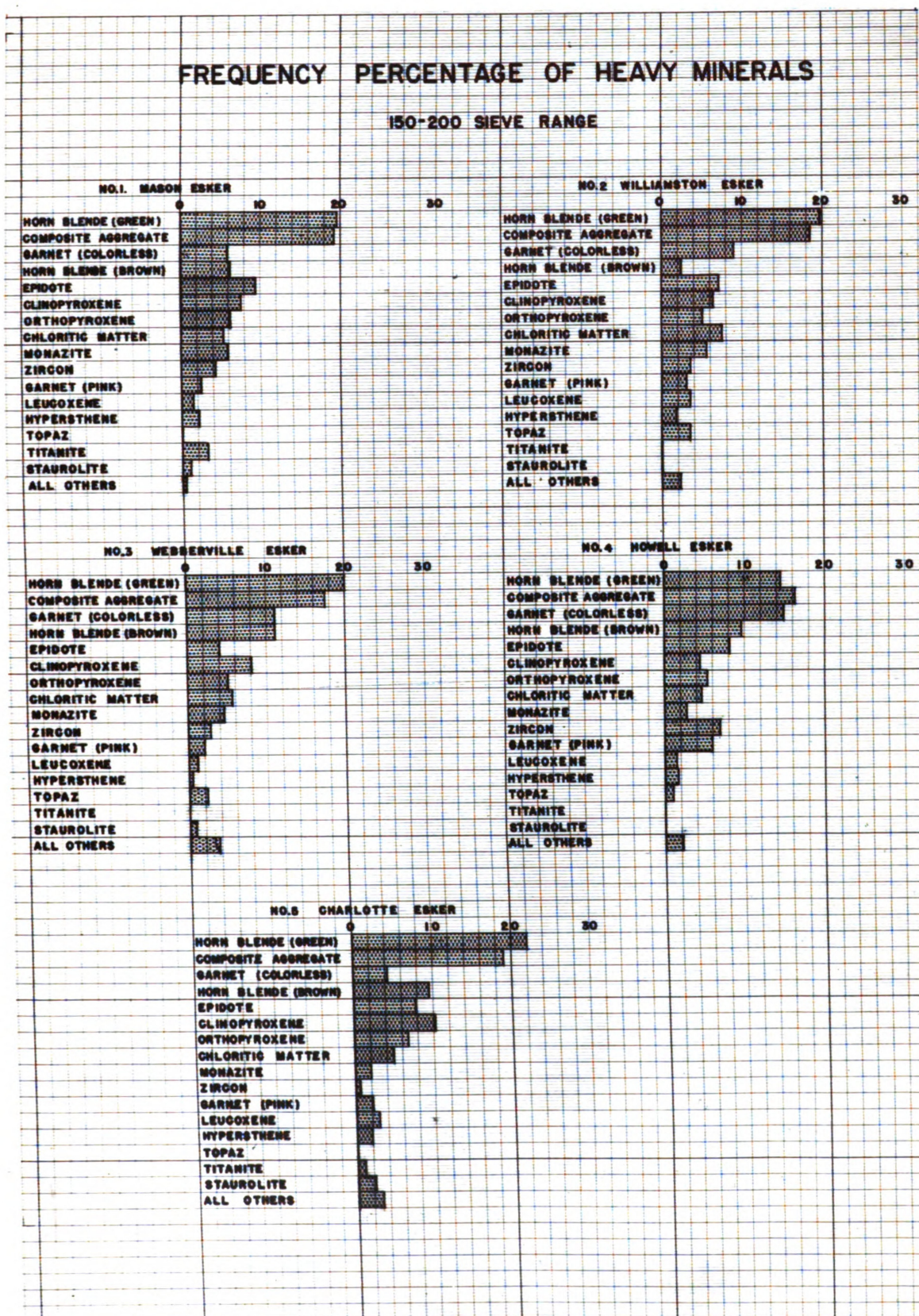


Fig. 7

STATISTICAL METHODS OF CORRELATION

Quartile Measures of the Cumulative Weight Percentages

Quartile measurements may be used to describe sediments statistically. These measurements are confined to the central 80 percent of the frequency distribution curve and therefore the values are not influenced by extreme particle sizes. Three expressions of quartile measures can be used to describe a sediment. They are quartile deviation, quartile skewness, and quartile kurtosis. Each describes a characteristic of the sediment which may be used as a comparison between samples.

The median, first and second quartile, and the tenth and ninetieth percentiles are used in the computations of these measurements. Each is read directly from the cumulative curves of the weight percentages as shown in figures 8, 9, 10, and 11. The median, M , is the point on the curve where 50 percent of the particles have larger and 50 percent of the particles have smaller diameters. The first quartile, Q_1 , is the diameter which has 25 percent of the distribution smaller and 75 percent larger than itself. The third quartile, Q_3 , has 25 percent of the distribution larger and 75 percent smaller than itself. The tenth and ninetieth percentiles correspond to the ten and ninety percent frequency lines.

Quartile deviation*

*Krumbein, W. C., op. cit., p. 230.

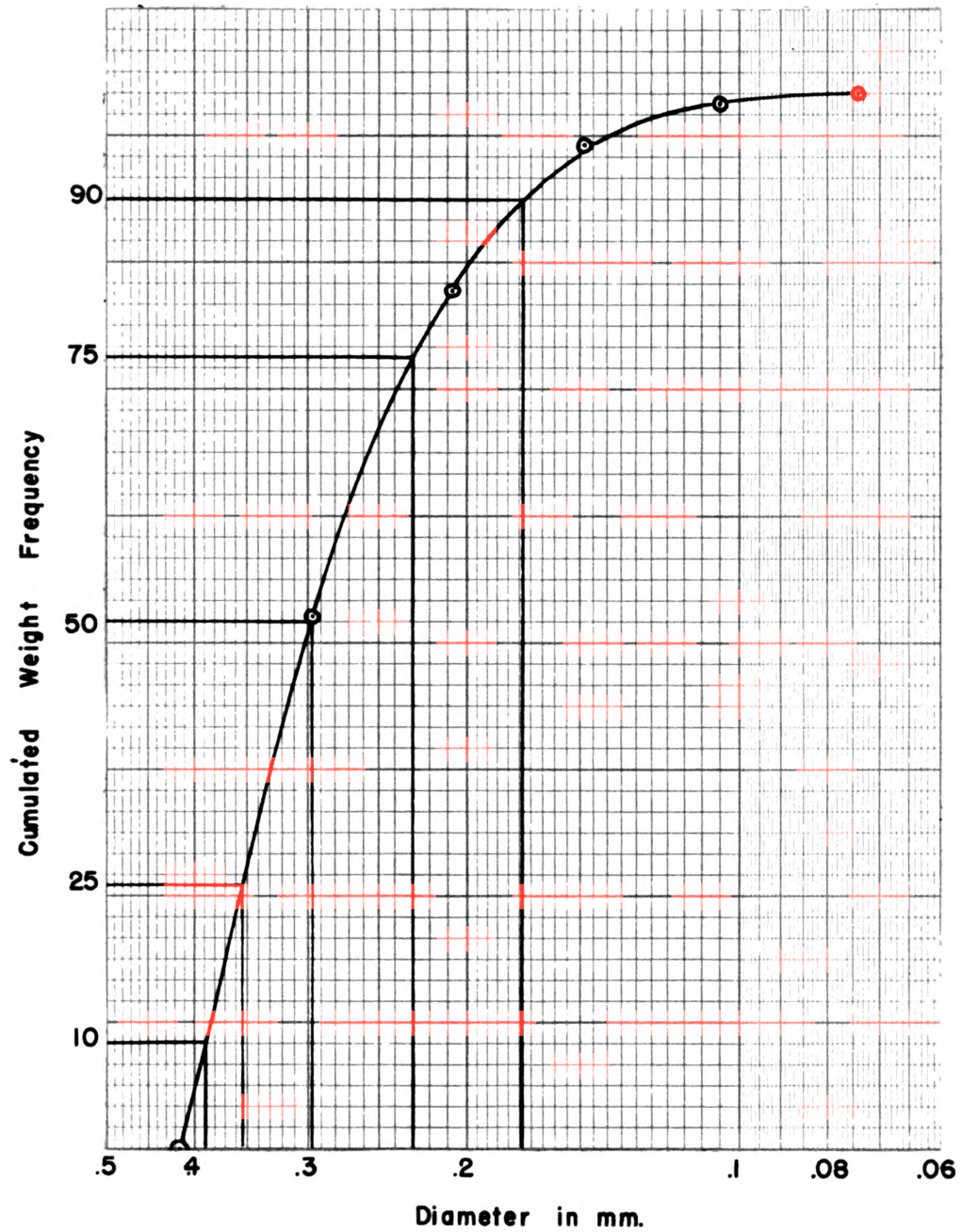


Fig.8. Cumulative Curve of the Weight Percentage for the Williamston Esker

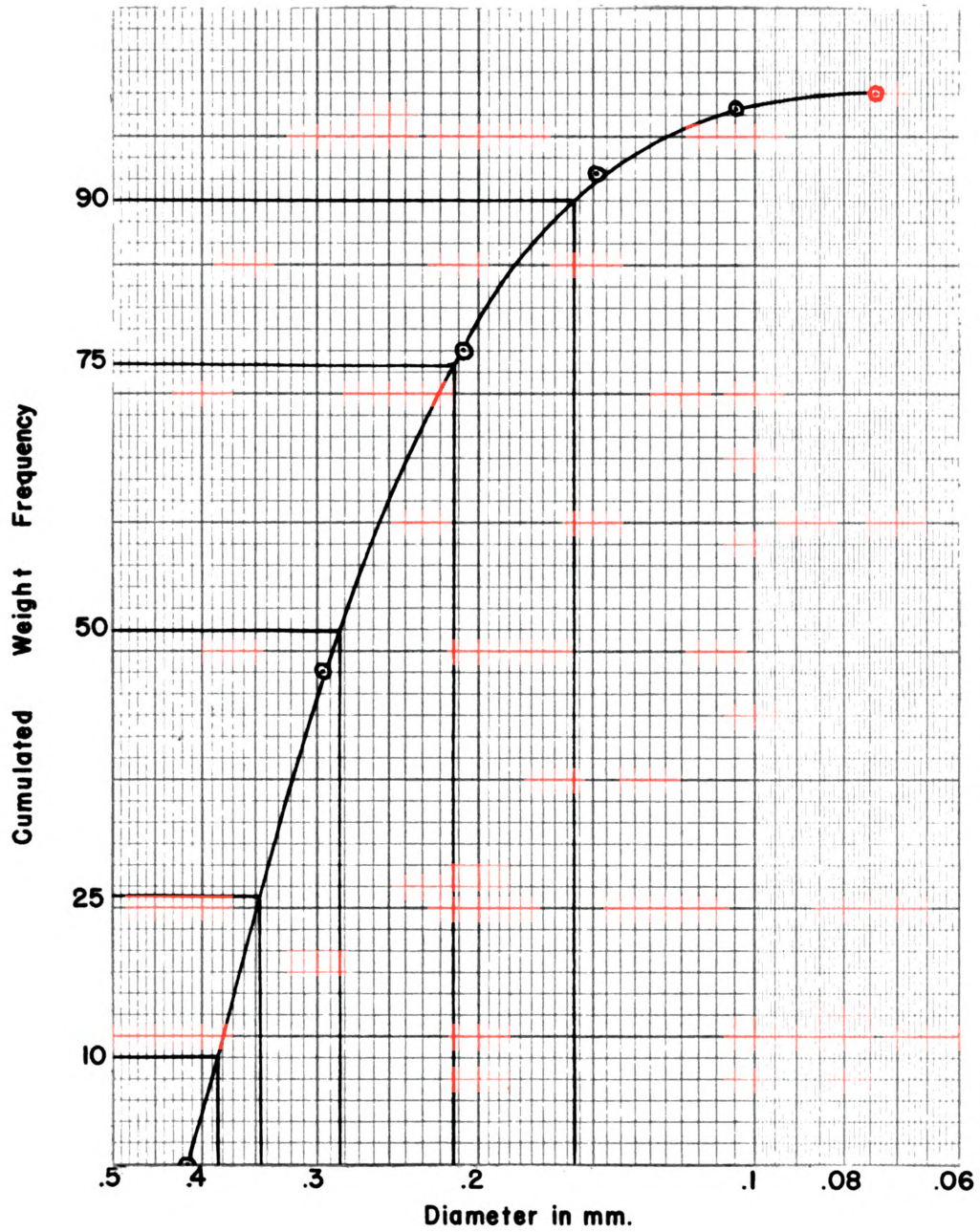


Fig.9. Cumulative Curve of the Weight Percentage for the Webberville Esker

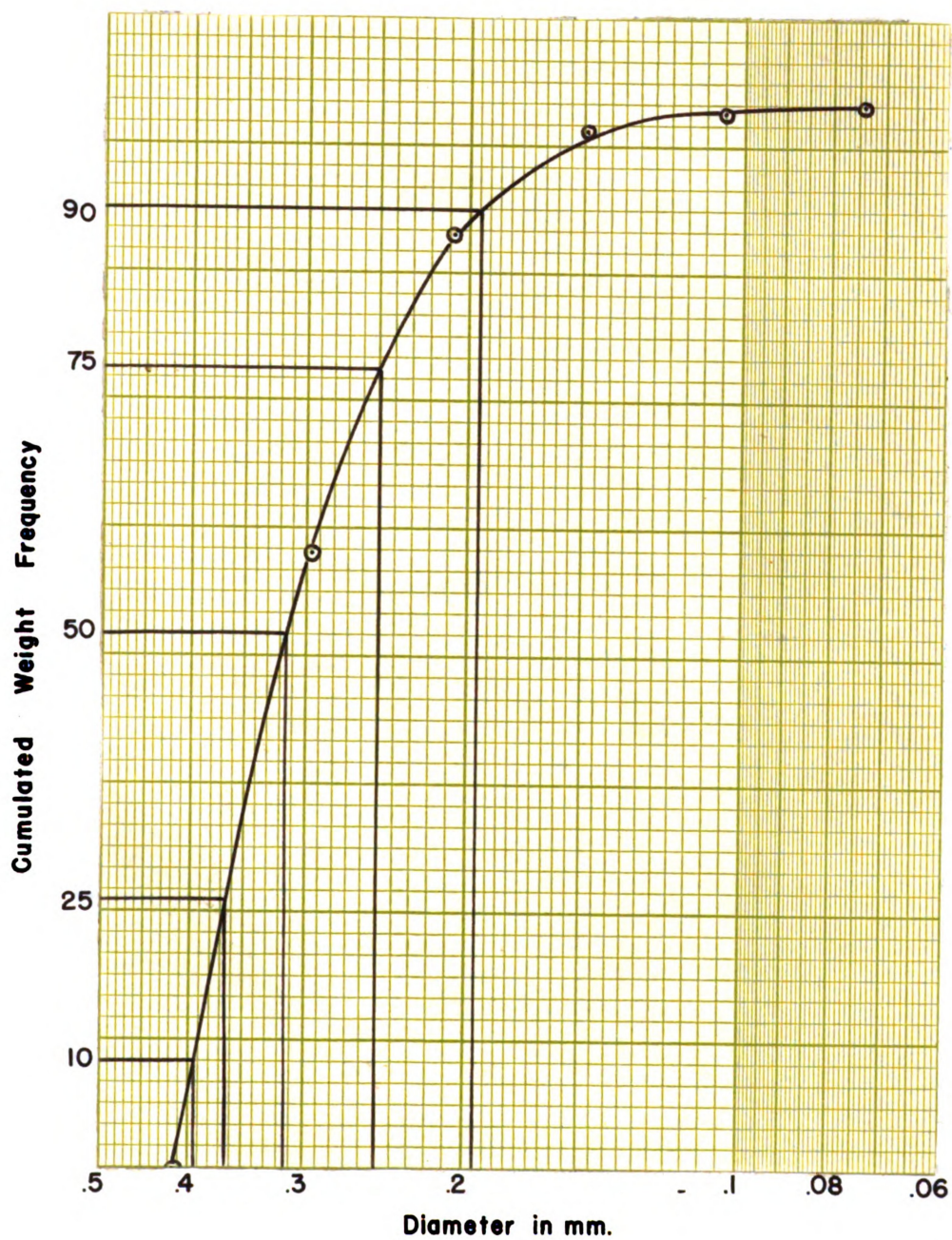


Fig.10. Cumulative Curve of the Weight Percentage for the Howell Esker

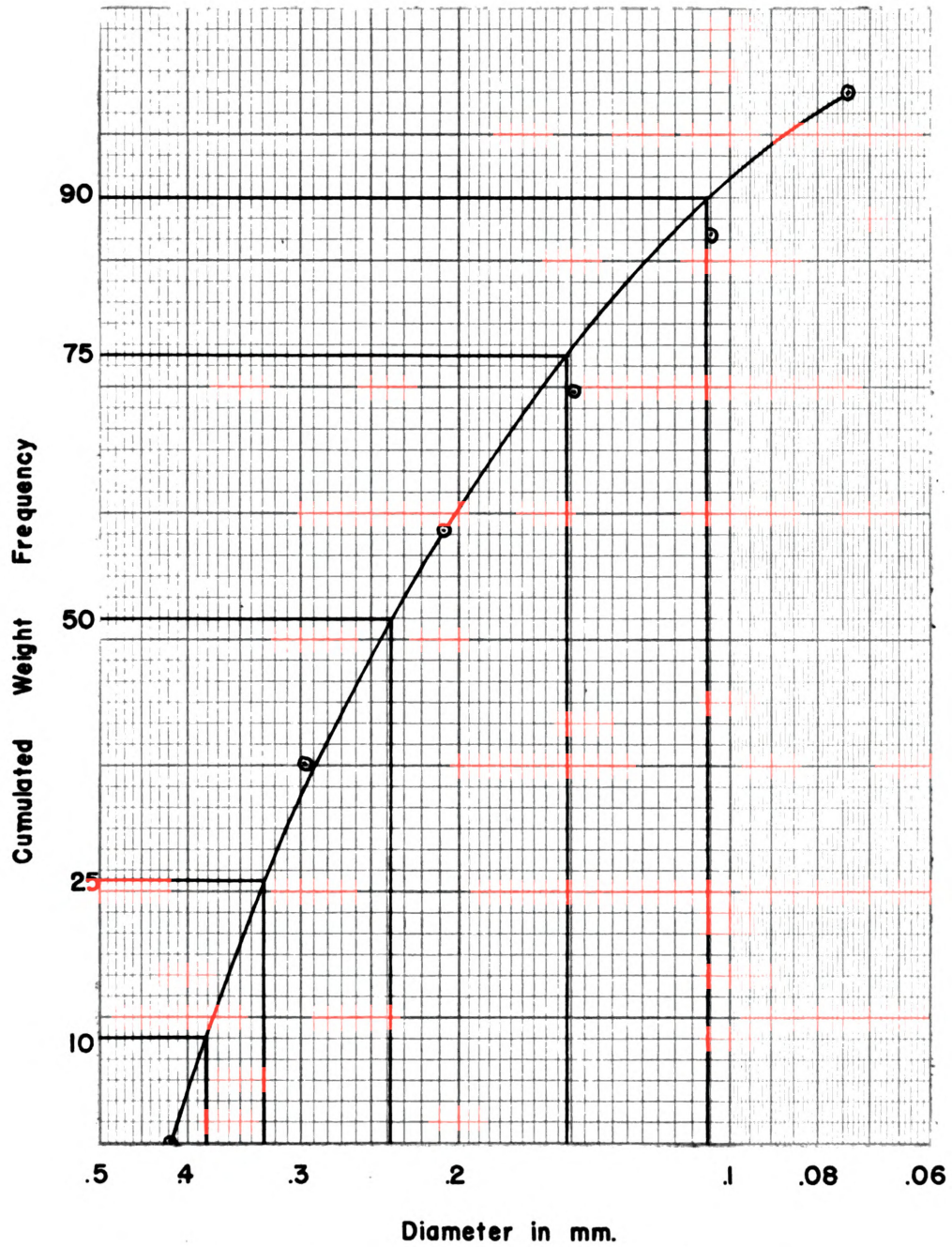


Fig.11. Cumulative Curve of the Weight Percentage for the Charlotte Esker

is the measure of the average spread which is commonly used with the median. The geometric quartile and log quartile deviations were used in this analysis. The geometric quartile deviation was introduced by Trask*

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

and is expressed by the formula:

$$QD_g = \sqrt{Q_3/Q_1}$$

It may also be described as the "sorting coefficient", 'So'. The log quartile deviation is shown by the following formula:*

*Krumbein, W. C., op. cit., p. 231.

$$\log QD_g = \log So = \frac{(\log Q_3 - \log Q_1)}{2}$$

The geometric quartile deviation eliminates the size factor and the units of measurement. Because the values of 'So' are geometric rather than arithmetic it can not be said that an 'So' value of 3.0 is half as well sorted as another sediment with an 'So' value of 1.5. The logs of the 'So' may be compared directly because they form an arithmetic series.

Quartile skewness is the departure of the arithmetic mean of the quartile diameter from the median. In addition to an arithmetic expression it may be described geometrically and logarithmically. The arithmetic

expression is:*

*Krumbein, W. C., op. cit., p. 235.

$$Ska = \frac{1}{2}(Q_1 + Q_3 - 2M)$$

If the value of the skewness is negative the skewness of the curve is shifted to the left, and conversely if the value is positive the skewness is shifted to the right of the median. If the curve is perfectly symmetrical the skewness value will be zero. The geometric form is as follows:*

*Krumbein, W. C., op. cit., p. 235.

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

When the curve is symmetrical the value of skewness is one.

Quartile kurtosis is the degree of peakedness of the frequency curve, and involves a comparison of the central portion of the curve to the spread of the curve as a whole. It is described by Kelly's equation:*

*Kelly, T. L., Statistical Methods, London, 1924, p. 77.

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

As the curve becomes more peaked the value for kurtosis approaches zero. Table 4 is a summary of the results of the quartile measures.

TABLE 4
Sorting, Skewness and Kurtosis

Eskers	So	log So	Sk _a	Sk _g	Kq _a
Williamston	1.234	.0945	-.007	.953	.279
Webberville	1.282	.1089	-.006	.948	.300
Howell	1.190	.0766	-.007	.960	.278
Charlotte	1.450	.1622	-.002	.926	.312

Comparison of Heavy Mineral Suites

It is rather difficult to determine the degree of similarity between two heavy mineral suites in which a correlation is desired. A statistical method for the comparison of heavy mineral suites was used by Dryden.*

*Dryden, L., A Statistical Method for the Comparison of Heavy Mineral Suites; American Journal of Science, Vol. 29, No. 173, 1935, pp. 393-408.

For the value obtained he used the term "coefficient of correlation". The word "correlation" must not be confused with the term as used geologically. Pettijohn states:*

*Pettijohn, F. J., op. cit., p. 487.

"The term 'correlation' must not be confused with correlation in the geological sense. Statistical correlation implies no time relationship nor any other causal relation. It only states objectively similarity or mathematical dependence of one set of data upon another set."

Dryden uses the following formula to determine the "coefficient of correlation".

$$r = \frac{\sum(XY) - nM_xM_y}{\sqrt{[\sum(X)^2 - nM_x^2] [\sum(Y)^2 - nM_y^2]}}$$

- $\sum$ - sign for the summation of that to which prefixed.
- n - number of pairs of percentages to be used, in this work, the number of mineral species.
- M - mean of that to which it is prefixed.
- X - any percentage from the Mason esker.
- Y - corresponding percentage, i.e., of the same mineral species, from the sample being compared to the Mason esker.

Dryden states:*

*Dryden, L., op. cit., p. 399.

"By using r^2 instead of r we can finally drop the word 'correlation' in a statistical sense, but, more important, we now get a simple percentage as an expression of the proportion of elements common to the two samples or suites."

The "coefficient of determination" was computed by comparing the heavy mineral suites of the Mason esker with those of the Williamston, Webberville, Howell, and Charlotte eskers. The sieve sizes 65-100, 100-150, and 150-200 were used. These values were plotted on a graph, shown in figure 12, with r^2 as the y-axis and each esker as the x-axis.

The value of the heavy mineral suite for the Williamston esker as compared to that of the Mason esker is .882, showing that the percentage of elements of the Williamston esker not common to the Mason esker is .118, by

simple subtraction. Table 5 shows a sample calculation of the "coefficient of determination".

The reliability of any statistical study increases with an increase in the number of observations. In this work only five samples were used, but the study shows the percentage of elements from the four eskers common to the Mason esker which is not very easily shown by histograms. The final result is a number, but with histograms the comparison of the various samples is shown by a picture which in some cases is misleading.

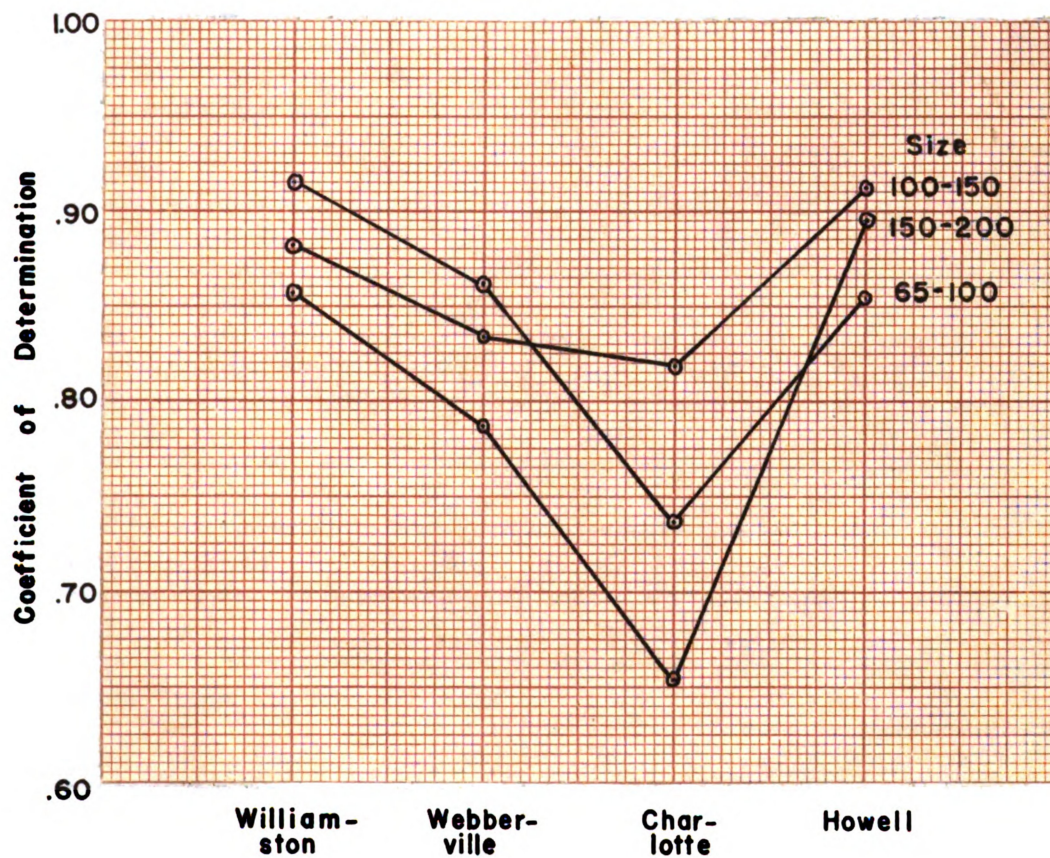


Fig.12. Comparison of the Heavy Mineral Suites of the Williamston, Webberville, Charlotte, and Howell Eskers with the Mason Esker by means of the "Coefficient of Determination".

TABLE 5

Comparison of the Heavy Mineral Suite of the Williamston esker with the Mason esker by use of the "Coefficient of Determination" for 100-150 Sieve Size

Minerals	Mason Esker		Williamston Esker		
	X	X ²	Y	Y ²	XY
Green hornblende	19.5	380	19.7	388	384
Composite aggregate	19.2	368	18.6	345	357
Garnet (colorless)	5.9	35	9.0	81	53
Brown hornblende	6.1	37	2.3	5	14
Epidote	9.3	86	7.2	52	67
Clinopyroxene	7.5	56	6.4	41	48
Orthopyroxene	6.1	37	5.1	26	31
Chloritic matter	5.3	28	7.5	56	40
Monazite	5.9	35	5.5	30	32
Zircon	4.3	18	3.6	13	15
Garnet (pink)	2.4	6	3.0	9	7
Leucoxene	1.6	3	3.5	12	6
Hypersthene	2.1	4	1.8	3	4
Topaz	0.0	0	3.5	12	0
Staurolite	1.1	1	0.0	0	0
Titanite	3.2	10	0.0	0	0
Totals	99.5	1104	97.7	1074	1058

$$M_x = \frac{99.5}{16} = 6.2$$

$$M_y = \frac{97.7}{16} = 6.1$$

$$nM_x = 16(6.2) = 615$$

$$nM_y = 16(6.1) = 596$$

$$nM_x M_y = 16(6.2)(6.1) = 604$$

$$r = \frac{1058 - 604}{\sqrt{(1104 - 615) - (1074 - 596)}} = .939 \quad r^2 = (.939)^2 = .882$$

Sphericity and Roundness Measurements

The shape is one of the fundamental properties of sand grains and is the most recent to be studied quantitatively and statistically. There are many geologic factors involved in the development of the shape of a particle. Pettijohn lists several of these factors:*

*Pettijohn, F. J., op. cit., p. 278.

1. The original shape of the fragment.
2. The structure of the fragment.
3. The durability of the material.
4. The nature and violence of the action to which the fragment is subject.
5. The time or distance through which the action is extended.

According to Wadell *

*Wadell, H., Volume, Shape and Roundness of Quartz Particles, Journal of Geology, Vol. 43, 1935, pp. 250-280.

roundness is the measure of the angularity of the corners, and sphericity is the ratio between the length and breadth of grains. Wadell uses the following formula to compute the sphericity of quartz grains:

$$\phi = \frac{d_c}{D_c}$$

- ϕ - degree of sphericity
 d_c - diameter of a circle equal in area to the area of the grain obtained by planimeter measurement
 D_c - diameter of the smallest circle circumscribing the particle

This method of measuring sphericity is accurate but very time-consuming because each individual grain must be drawn before any measurements can be made.

Rittenhouse*

*Rittenhouse, G., A Visual Method of Estimating Two Dimensional Sphericity, Journal of Sedimentary Petrology, Vol. 13, No. 2, 1943, abstract, pp. 79-81.

suggested a visual means of measuring sphericity which is more rapid but not as accurate as the method proposed by Wadell.

Riley*

*Riley, N. A., Projection Sphericity, Journal of Sedimentary Petrology, Vol. 11, 1941, pp. 94-97.

devised a method which is both accurate and rapid. A concentric circle protractor is placed in the ocular of the microscope. Measurements may be read directly, thus eliminating the drawing of individual grains. He used the formula:

$$\phi = \sqrt{\frac{1}{D_c}}$$

1 - diameter of the largest inscribed circle of the sand grain.

D_c - diameter of the smallest inscribed circle.

This sphericity approaches the accuracy of the value obtained from Wadell's formula.

For the measurement of roundness Wadell uses the formula:

$$P = \frac{\sum \left(\frac{r}{R} \right)}{N}$$

P - total degree of roundness.
 r - radius of curvature of the corner.
 R - radius of the maximum inscribed circle.
 N - number of corners measured.

The individual grains must be projected and drawn with the aid of a camera lucida before the roundness measurements can be made.

Combining Riley's method for measuring sphericity with Wadell's method for measuring roundness an accurate and rapid method was devised by the writer for the measurement of these values simultaneously. A camera lucida attached to the ocular of the microscope projected the grains on Wadell's concentric protractor which had been drawn on a large sheet of white paper rather than plexiglass. The radius of curvature of all the corners and the diameter of the inscribed and circumscribed circles were measured simultaneously. The results of the shape measurements are shown in figure 13.

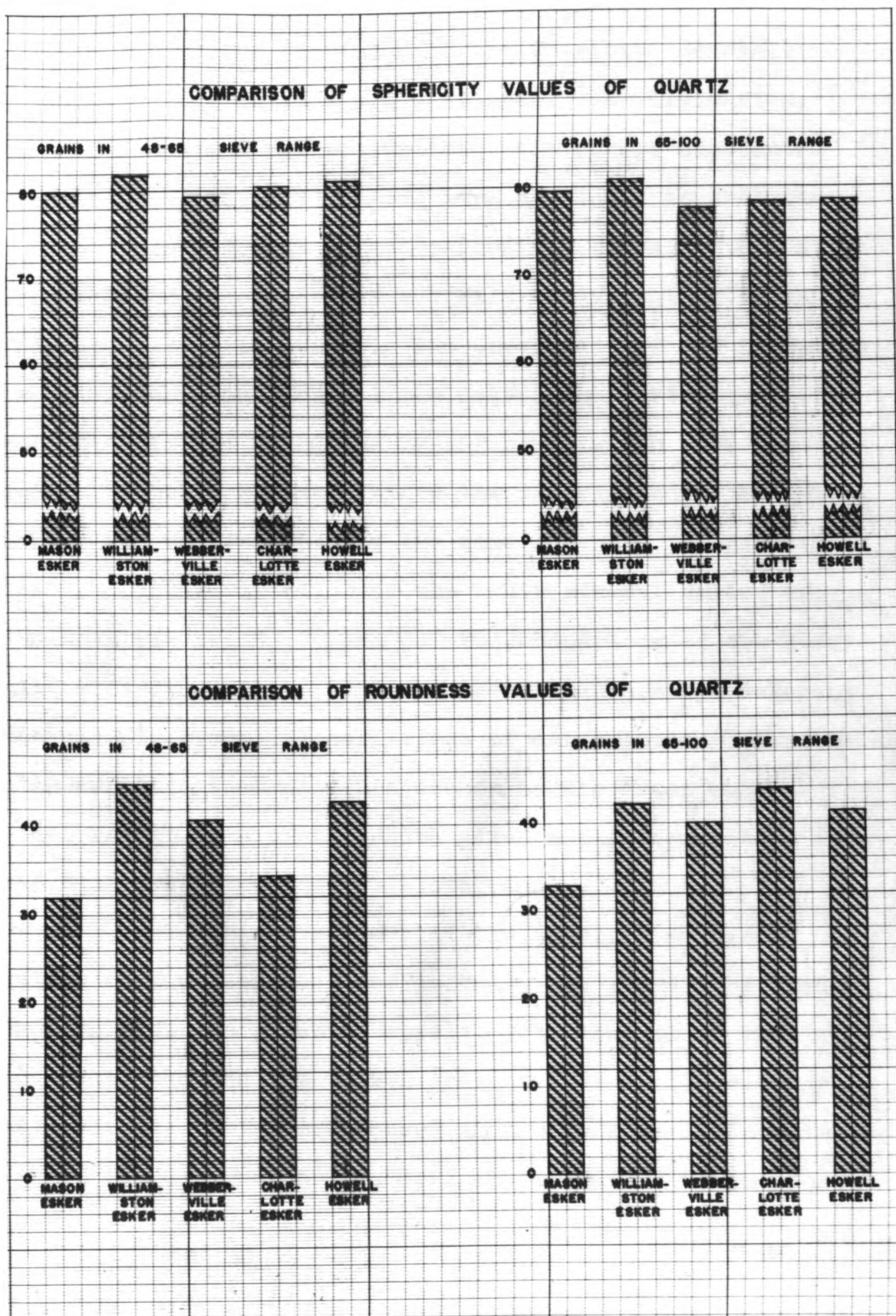


Fig. 13

CONCLUSIONS

During the formation of the Charlotte morainic system the Saginaw tongue was stagnant over Livingston, Ingham, Eaton and Barry counties. The eskers associated with the Charlotte till plain were developed at that time.

Figure 3, the weight percentage of each sieve size from all the eskers, shows a similar distribution of sands from one esker to another. The sphericity of the particles is nearly constant for all the eskers, but there is a slight variation in the roundness measurements which does not appear to be significant since the material comprising the eskers was not transported the same distance in each case.

Little variation of the heavy mineral suites is shown in Figures 5, 6, and 7. The comparison of the heavy mineral suites of the various eskers to the Mason esker by the use of Dryden's "coefficient of determination" depicts a high percentage of elements common to the Mason esker. The final result is a number which gives a clearer picture of the similarity than do the histograms.

Table 4 is a summary of the quartile measures. The values of the "sorting coefficient", 'So', are very similar, showing that the relative spread of the curves is very much the same, and the low values indicate the sands are very well sorted. This work showed that the sands of the Howell esker, the maximum sorted, were approximately twice as well sorted as those of the Charlotte esker, the minimum sorted.

In all cases the arithmetic and geometric skewness values show a slightly higher percentage of coarser grains, and for each esker the values are nearly identical. There is a close relationship of kurtosis indicating a similarity in the peakedness of the frequency curves for each of the eskers.

From these facts the following conclusions may be drawn:

1. The sands of the various eskers used in this analysis are very similar.
2. The eskers associated with the Charlotte till plain were formed under similar conditions.
3. There is a close correlation between the individual eskers.
4. A petrographic investigation of sands to which statistical methods of correlation are applied, may be used advantageously in the examination of other glacial deposits.

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