THE APPLICATION OF ROUNDNESS AND SPHERICITY MEASUREMENTS TO SUB-SURFACE SAMPLES OF THE MARSHALL FORMATION OF WESTERN MICHIGAN

Thesis for the Degree of M. S.

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This is to certify that the

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THE APPLICATION OF ROUNDNESS AND SPHERICITY MEASUREMENTS TO SUB-SURFACE SAMPLES OF THE MARSHALL FORMATION OF WESTERN MICHIGAN

by

Robert Adelbert Hobbs

A Thesis

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The writer wishes to express his sincere appreciation to Dr. B. T. Sandefur for his direction, aid, and criticisms throughout this problem. Also to Dr. W. A. Kelly for his suggestions and criticisms.

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Introduction

The shape of sedimentary particles for stratigraphic correlation has not been used extensively in Michigan. Early observers noted the modification of grain shape that takes place by transportation and abrasion. Several factors control this "modification of shape", namely:

(1) cleavage or bedding of the fragment.

(2) the durability of the material.

(3) the rigor of the geologic agent.

(4) the original shape.

(5) the time through which the action is extended.

It is assumed generally that sand grains become progressively more round in direct relation to the distance they are transported by water. If this assumption is correct, and sand grains along a beach do become more round as they are transported seaward, a statistical determination of this roundness within a series of samples taken from a definite horizon within a formation, should indicate their position relative to an old shore line. Careful work may reveal a buried beach.

The petroleum geologist is constantly on the search for buried beaches, since many have proved to be important reservoirs for oil.

Erickson* showed that the relationship of the heavy mineral distribution within esker sands was a good criterion for determining the direction of flow of the parent glacial stream, and that shape measurements furnished additional proof to that determination.

*Erickson, R. L., A Petrographic Investigation of the Longitudinal Deposition within the Mason Esker Relative to its Origin. Unpublished Master's Thesis, Department of Geology and Geography, Michigan State College, 1943.

From his conclusions it seems logical that shape measurements could be applied to any water-transported sand to determine the direction from which it came.

For the present study, the sand at the top of the Mississippian Marshall formation in Newaygo County was chosen because of the readily distinguishable quartz grains with their characteristic reddish iron oxide stain, and the easily identified sedimentary break between these red sands and the overlying Michigan formation. (figure 1.) The use of such a locally prominent horizon provided a maximum of control for the investigation which followed.

Although it has been recognized by Monnett* that a red color in the Marshall deposits is of little value as a regional stratigraphic marker, and that the red sediments are more characteristic of the lower Marshall strata, it is significant that they do occur at the top of the Marshall in local areas of western Michigan.

*Monnett, V. B., Mississippian Marshall Formation of Michigan: Bulletin of the American Association of Petroleum Geologists, Vol. 32, No. 4, April 1948, pp. 661-662

System-Series	Formation or Member	Section	Lithology	Thickness
Quaternary	Wisconsin		gravel, sand, and clay	400'
Mississippian	Michigan		shale, gypsum, sand, and limestone	345'
	Marshall		sand, red and white	160'
	Coldwater		red shale, gray shale, limestone, dolomite	620'
	Sunbury		dark gray shale	20'

Figure 1.- Stratigraphic Column of Mississippian Formations, Newaygo County, Michigan.

Location of Area

General

The area involved in this study is limited to a single section of Garfield Township in Newaygo County, in the west-central part of the lower Peninsula of Michigan. (figure 2.)

Distribution of Wells

Three wells were selected in section 11 of Garfield Township. For convenience they will be referred to as wells No. 1, No. 2, and No. 3.

Well No. 1, is in the SW 1/4, SE 1/4, NW 1/4, section 11, T. 12 N., R. 13 W., 370' from the south and 990' from the east line of the quarter section.

Well No. 2, is in the SW 1/4, SW 1/4, NW 1/4, section 11, T. 12 N., R. 13 W., 330' from south and 330 ' from west line of the quarter section.

Well No. 3, is in the SW 1/4, NE 1/4, SW 1/4, section 11, T. 12 N., R. 13 W., 990' from north and 990' from east line of the quarter section.

The plot of the wells is shown in figure 3.

Purpose of Study

This investigation was undertaken in an effort to prove or disprove the feasibility of applying shape measurements to sub-surface sands in order to determine the direction of sedimentation and thus the position and direction of old shore lines along which may be found stratigraphic traps of economic importance. Also, certain

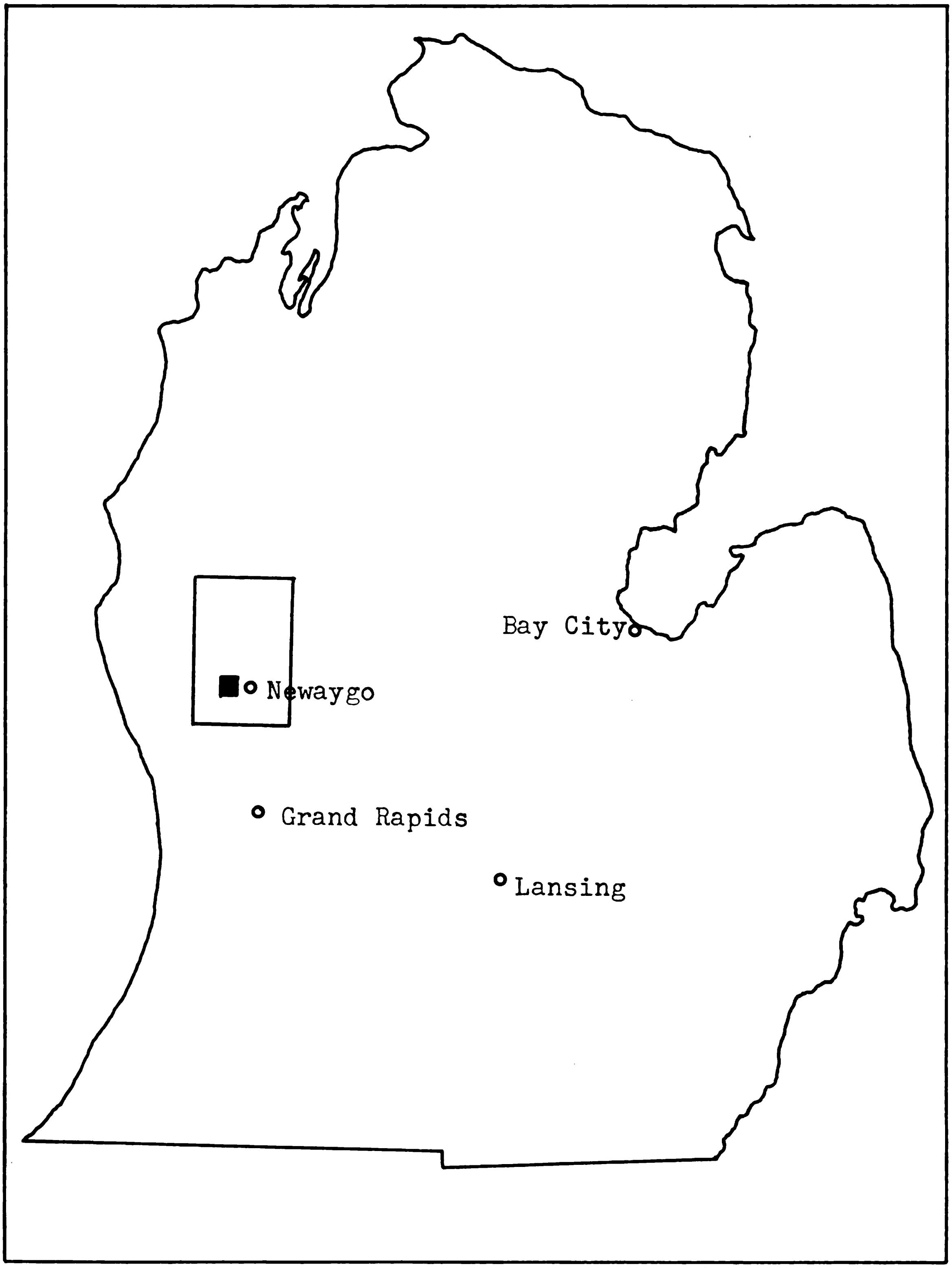

Figure 2.- Map Showing Location of Area. Blacked-in Portion Represents Garfield Twp., Newaygo County.

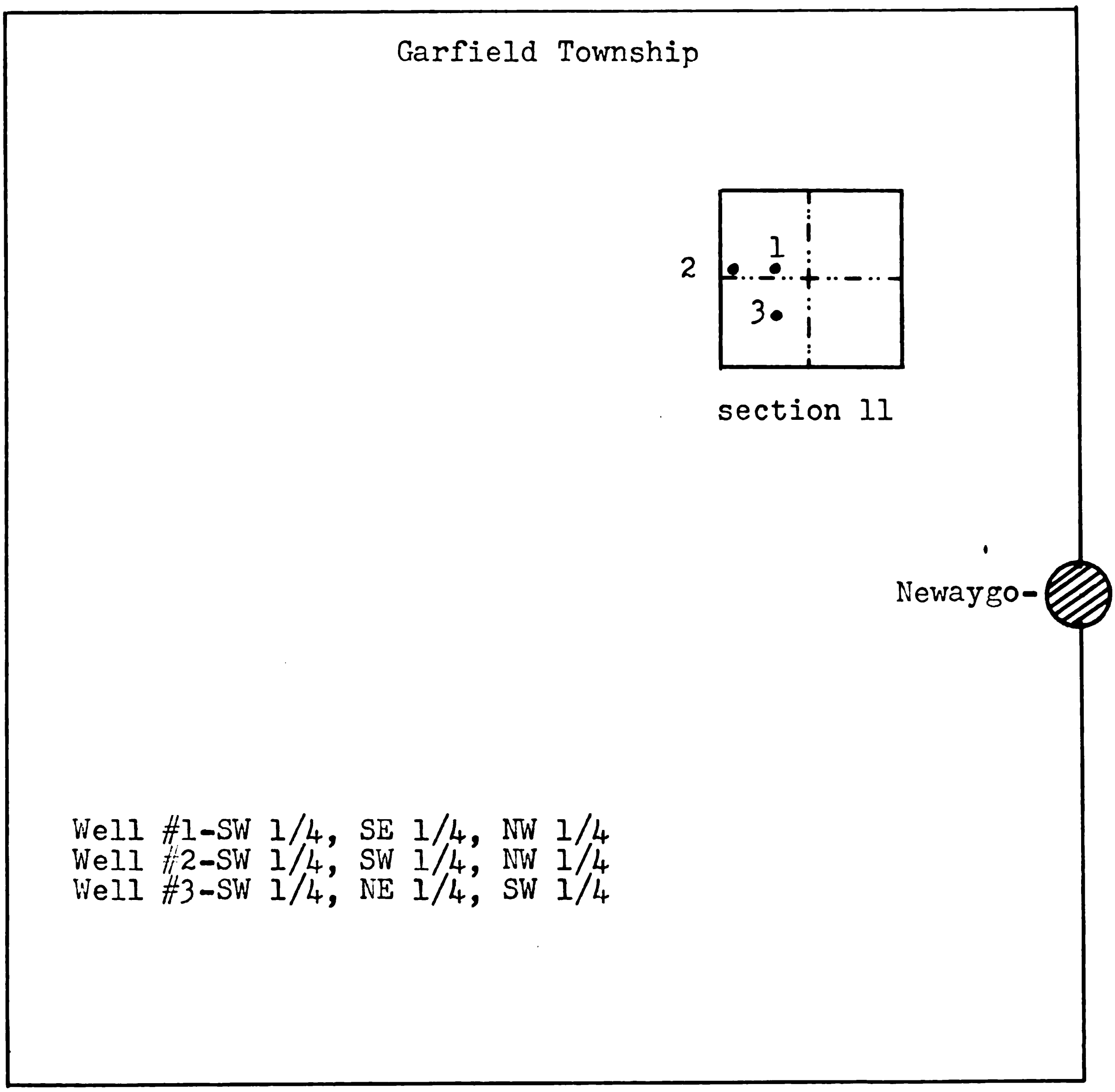

Figure 3.- Plot of Wells in Garfield Township, Newaygo County.

"shape-horizons" might be found within the sand which may be consistent throughout a limited area and thus used to determine the structure.

Method of Investigation

General

The investigation involved a statistical study of the quartile measurements, and the measurement of the shape of the quartz grains. The well samples were taken at vertical intervals of five feet and placed in bottles of approximately 10 grams each. The sands in each well were completely separated and did not have to be disaggregated artificially.

As previously mentioned, the sand grains in the Marshall formation are stained red by iron oxide. It is possible to remove the iron stain by treating the grains with a solution of 1:1 hydrochloric acid and hydrogen peroxide and heating over a burner.*

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*Salutsky, Murrell; Graduate Council Fellow, Chemistry Department, Michigan State College. Personal Communication.

The methods described by Krumbein* to remove iron stains were not successful when applied to the Marshall sands.

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*Krumbein, W. C., Manual of Sedimentary Petrography, D-Appleton-Century Company, New York, 1939, pp. 314-315.

It was found, however, that the iron stain in no way altered the shape of the quartz grains so it was not absolutely necessary to remove it before making the shape measurements.

As pointed out by Stearns*, the heavy minerals contained in the Marshall sands are neither abundant nor diversified.

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*Stearns, M. D., The Petrology of the Marshall Formation of Michigan: Journal of Sedimentary Petrology, Vol. 3, No. 3, December 1933, pp. 99-112.

Therefore, no heavy mineral separation was necessary since minerals other than quartz were readily discernible with the aid of the petrographic microscope.

Sieving

Owing to the relatively small amount of sample available, the entire content of each 10 gram bottle was weighed and then sieved in a Ro-Tap automatic shaking machine for a period of eight minutes. The shaker was equipped with six sieves having respectively 35, 48, 65, 100, 150, and 200 openings per inch. After sieving, each sieve size was weighed, placed in an individual vial, and labelled. The material caught on the 35 mesh sieve was disregarded in the final analysis as it consisted largely of shale and gypsum which is presumed to have been due to caving from the overlying Michigan formation.

Mounting for Microscopic Study

After a thorough examination of each individual fraction of one sample, it was found that the 65-100 size proved to be the most desirable for taking measurements. This is a function of the optical system of an individual microscope and may not prove the desirable size in every case. After deciding on the 65-100 size as being the

most useable, all other fractions were returned to the original bottles.

Quartz (refractive indices 1.544-1.553) shows little relief in Canada balsam (n- 1.537) therefore, a synthetic resin (n- 1.66) was used as a mounting medium in order to produce greater relief and detail.

A glass slide was heated on a metal plate over a micro-burner before pieces of the resin (n- 1.66) were placed upon it. Continued heating of the resin from one to two minutes drove out the majority of the bubbles while the remaining few could be eliminated easily by means of a sharp teasing needle.

After the mounting medium had reached the proper consistency, the 65-100 size samples were mounted on slides for roundness and sphericity measurements.

Roundness and Sphericity Measurements

Wadell* defines roundness as the measure of the angularity of the corners, and sphericity as the ratio between the length and breadth of grains. (figure 4.)

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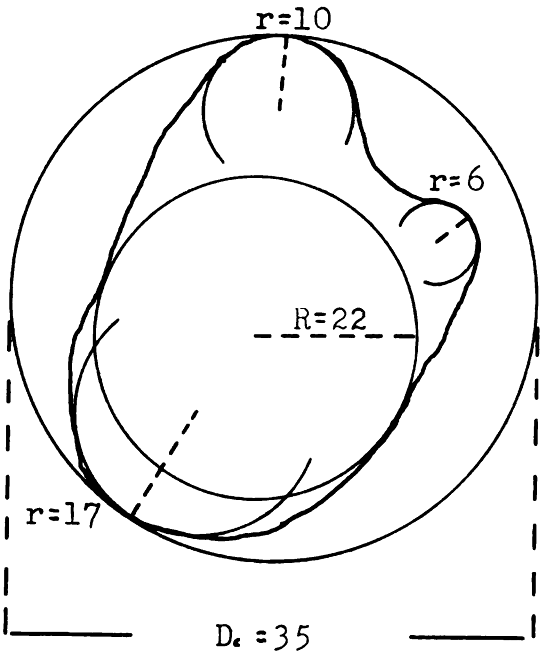
*Wadell, H., Volume, Shape and Roundness of Quartz Particles, Journal of Geology, Vol. 43, 1935, pp. 250-280.

For the measure of roundness Wadell employs the formula:

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

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



Wadell's Roundness (P):

$$P = \frac{\Sigma\left(\frac{r}{R}\right)}{N} = \frac{1.49}{3} = .49$$

Wadell's Sphericity (ϕ):

$$\phi = \frac{R}{D_c} = \frac{22}{35} = .63$$

D_c = radius of circumscribed circle.
R = radius of inscribed circle.
r = radius of curvature of corner.
N = number of corners measured.

Figure 4.- Wadell Method of Determination of Shape and roundness.

For the measurement of sphericity he uses the formula:

$$\emptyset = \frac{d.}{D.}$$

$\emptyset$- degree of sphericity.
d.-diameter of a circle equal in area to the area of the grain obtained by planimeter measurement.
D.-diameter of the smallest circle circumscribing the particle.

The measurements were made with the aid of a concentric circle protractor drawn on transparent plastic.

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

Riley* devised a method for measuring sphericity which is both accurate and fairly rapid.

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

A concentric circle protractor is placed in the occular of the microscope. Measurements may be read directly, thus eliminating the drawing of individual grains. Riley used the formula:

$$\emptyset = \sqrt{\frac{i}{D.}}$$

$\emptyset$- degree of sphericity.
i- diameter of the largest inscribed circle of the grain.
D.-diameter of the smallest circumscribed circle.

The accuracy thus obtained closely approached that of Wadell.

The writer, however, used a combination of Riley's method for measuring sphericity and Wadell's method for measuring roundness as devised by Schmitt*.

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*Schmitt, G. T., A Petrographic Investigation of the Relationship of Deposition of Sediments in a Group of Eskers Related to the Charlotte Till Plain. Unpublished Master's Thesis, Department of Geology and Geography, Michigan State College, 1949, p. 47.

A camera lucida attached to the occular of the microscope projected the grains on Wadell's concentric circle protractor which had been drawn on a sheet of white paper rather than plexiglass. The various measurements could then be made simultaneously without drawing the individual grains.

Using this method, the writer measured the roundness and sphericity of fifty quartz grains per slide of each 5 foot sample taken from the three wells. A total of 1,700 grains were measured.

Statistical Methods of Correlation

Quartile Measures of the Cumulative Weight Percentages

Quartile measures are widely used for describing and comparing sediments statistically. The first use of quartile measures in sedimentary data was by Trask* in 1930.

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*Trask, P. D., Mechanical Analysis of Sediments by Centrifuge: Economic Geology, Vol. 25, 1930, pp. 581-599.

Three expressions of quartile measures can be used to describe a sediment. They are quartile deviation, quartile skewness, and quartile kurtosis.

The first and second quartile, the median, and the tenth and ninetieth percentiles are used in the computations of these measurements. The great advantage of quartile measures is that each can be read directly from the cumulative curves of the weight percentages as shown in figures 5-14.

The median diameter, M, is defined as that diameter which is larger than 50 percent of the diameters in the distribution, and smaller than the other 50 percent. The quartiles lie on either side of the median and are the diameters which correspond to the frequencies of 25 and 75 percent.

The tenth and ninetieth percentiles correspond to the diameter values at the intersection of the ten and ninety percent lines with the cumulative curve. They are the diameters which correspond to frequencies of 10 and 90 percent.

Trask* used the geometric quartile deviation as a "sorting coefficient", applying the formula:

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

So- sorting.
Q_1- first quartile (the larger size).
Q_3- third quartile (the smaller size).

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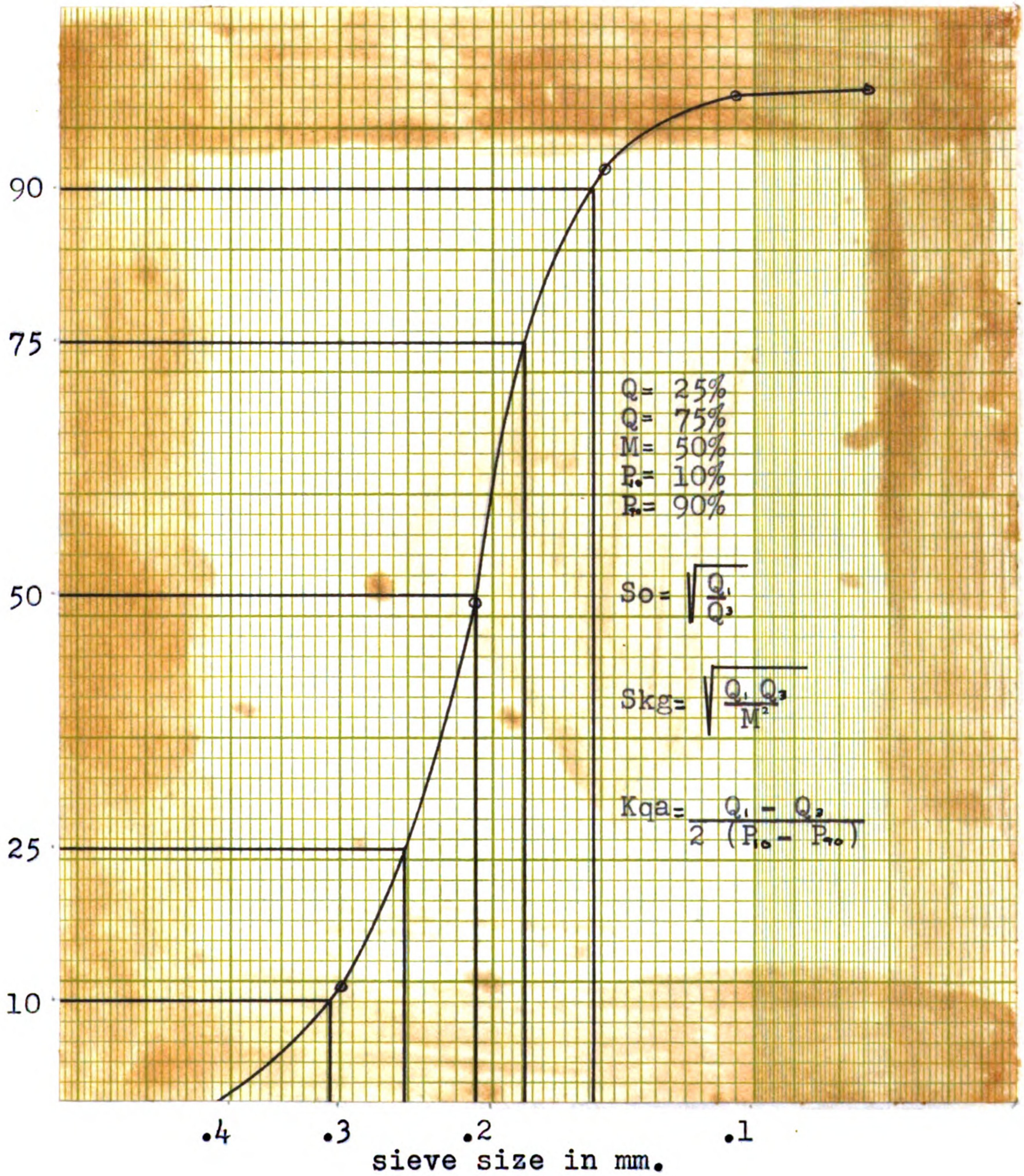
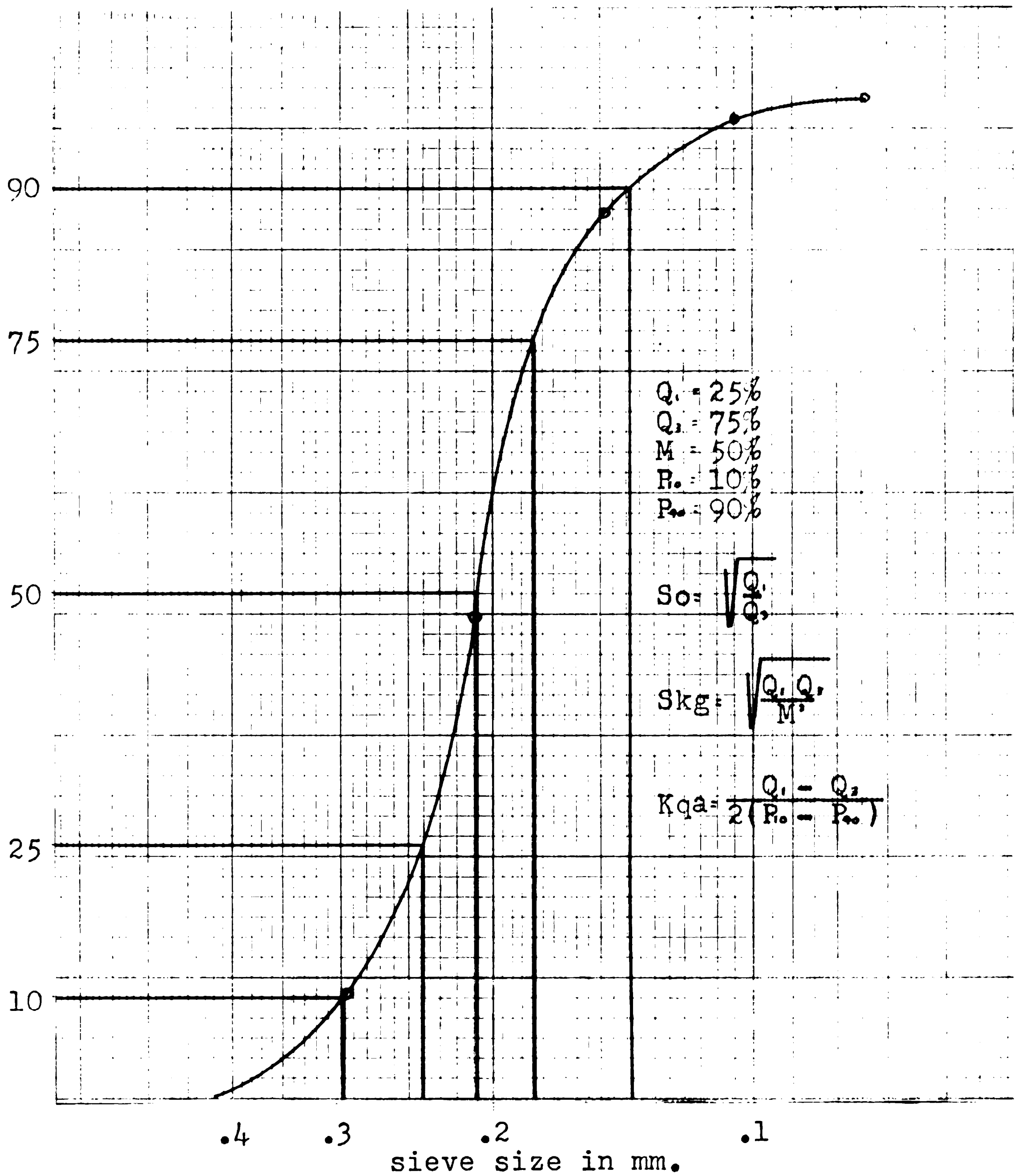
*Trask, P. D., Origin and Environment of Source Sediments of Petroleum, Houston, Texas, 1932, pp. 67ff.

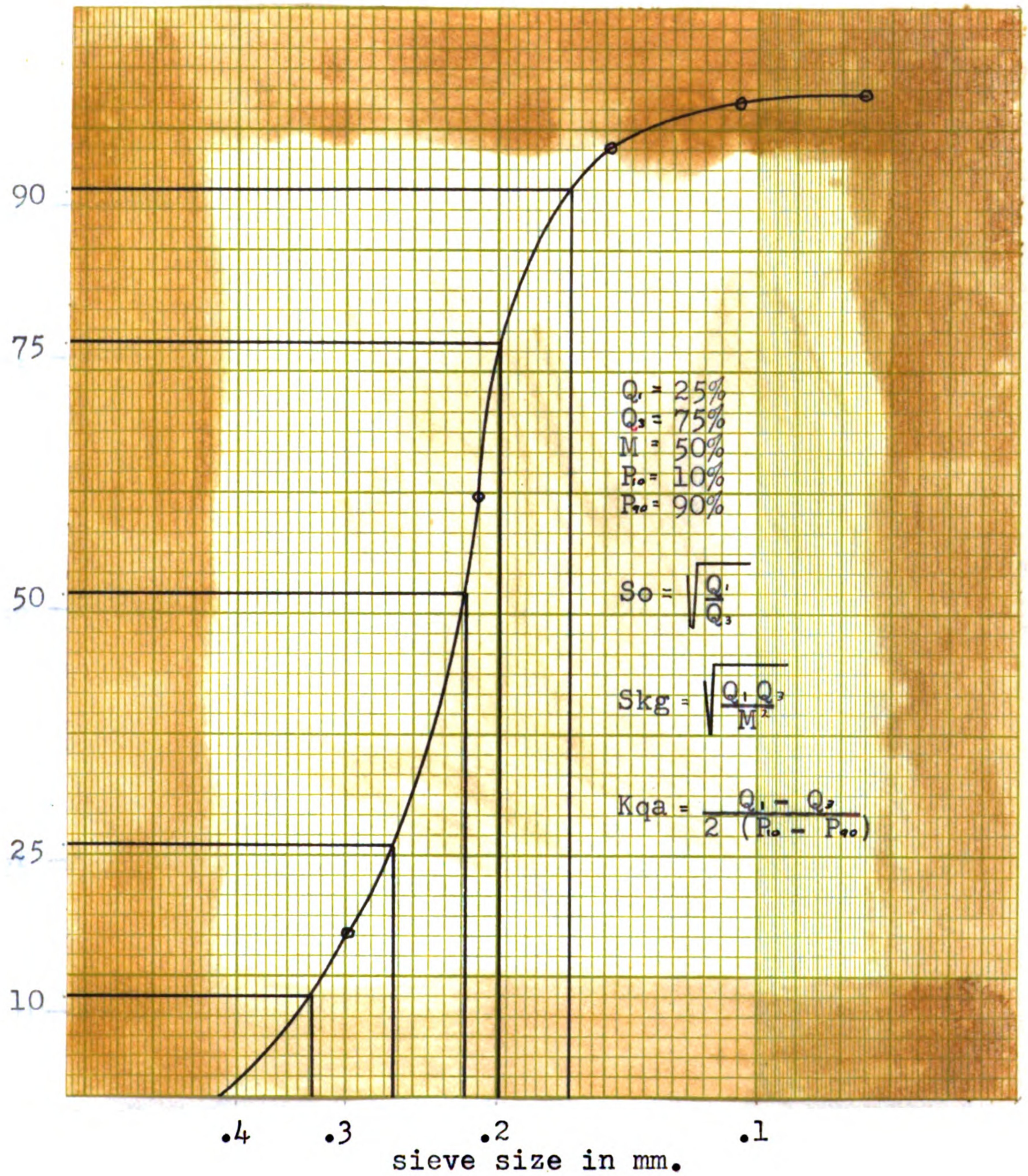
In general, 'So' is a convenient measure to use for describing the spread of the curve because it is a ratio and eliminates the size factor and the units of measurement.



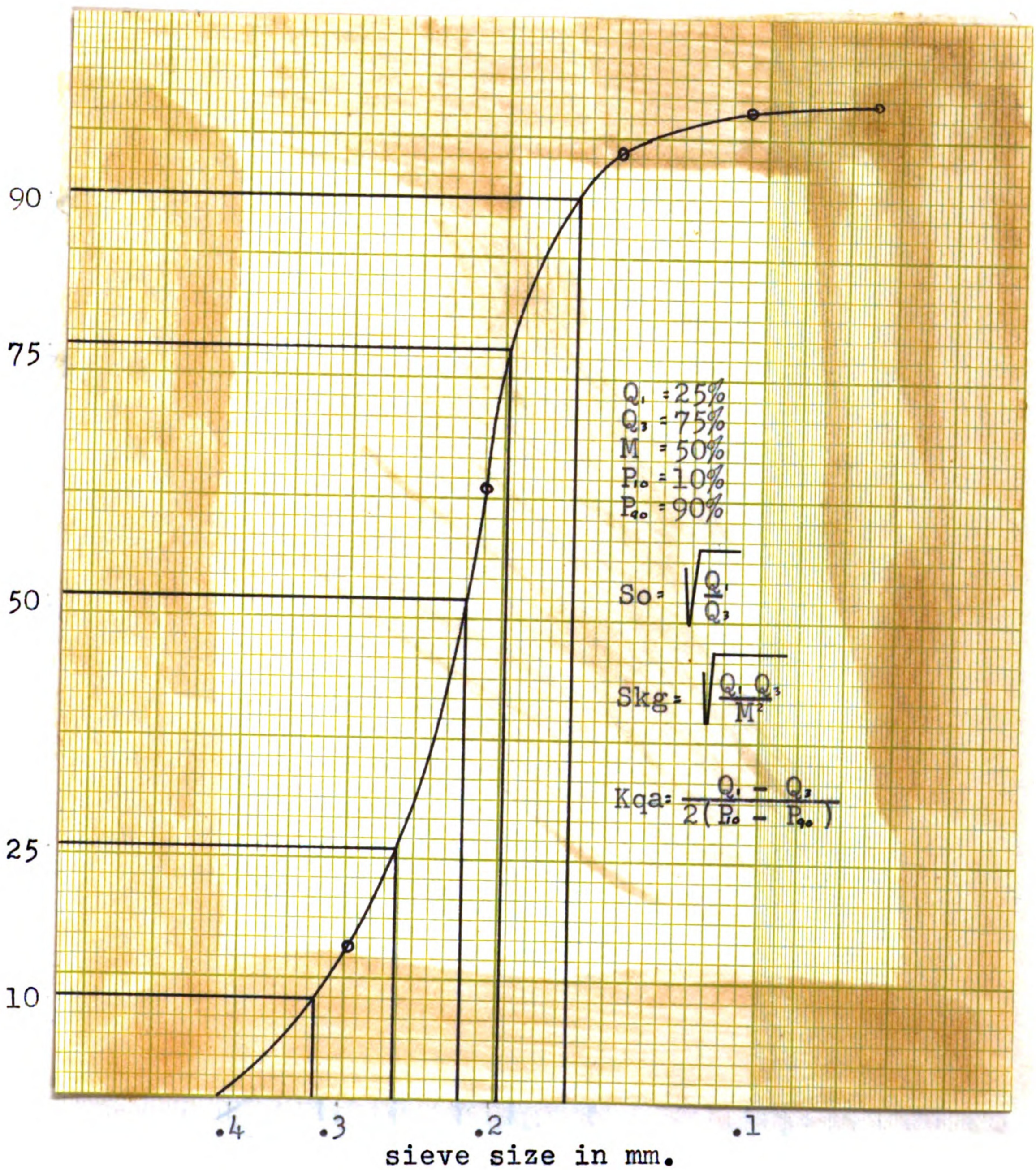
Cumulative Curve, Well No. 1, 780-785'



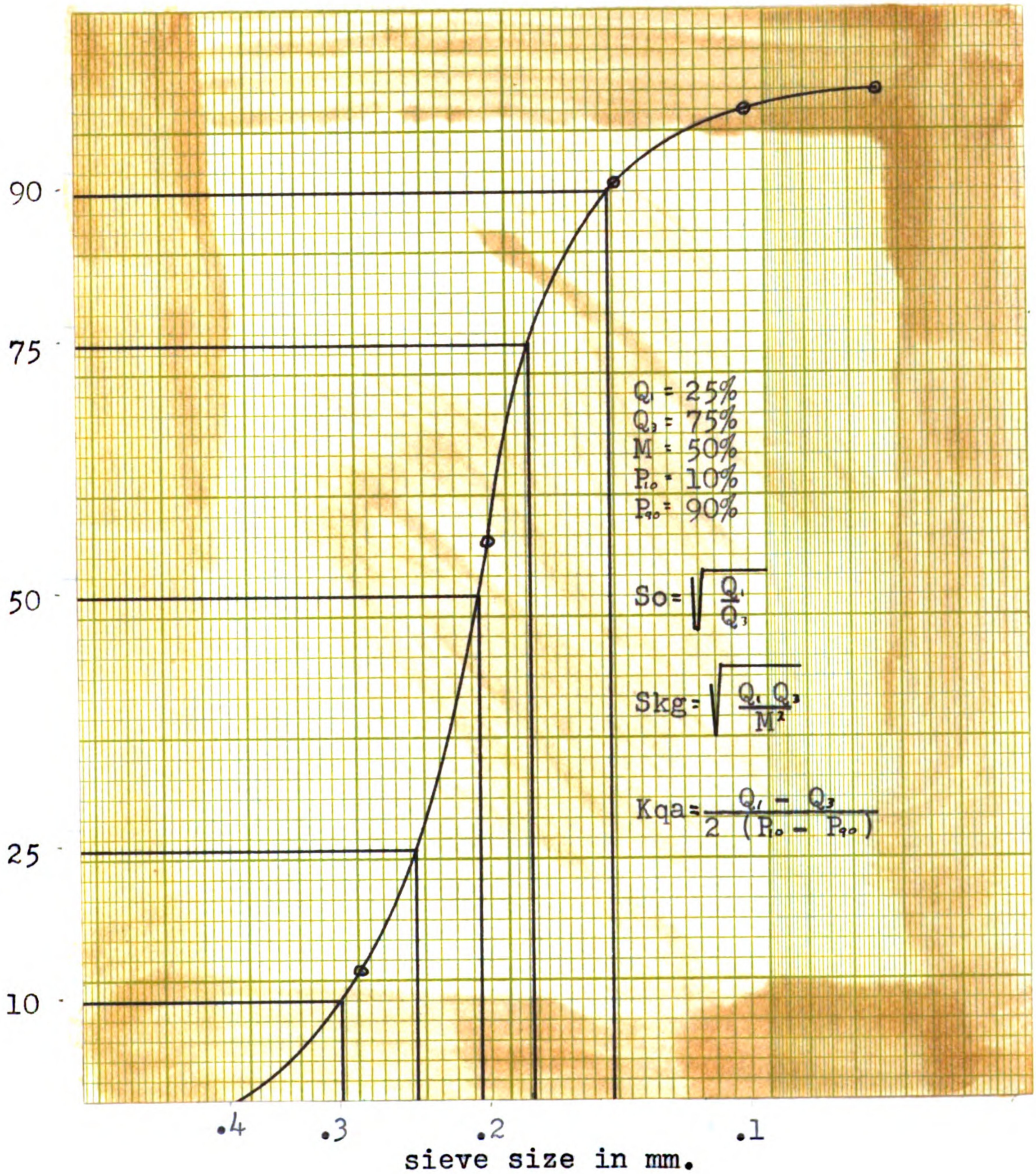
Cumulative Curve, Well No. 1, 785-790'



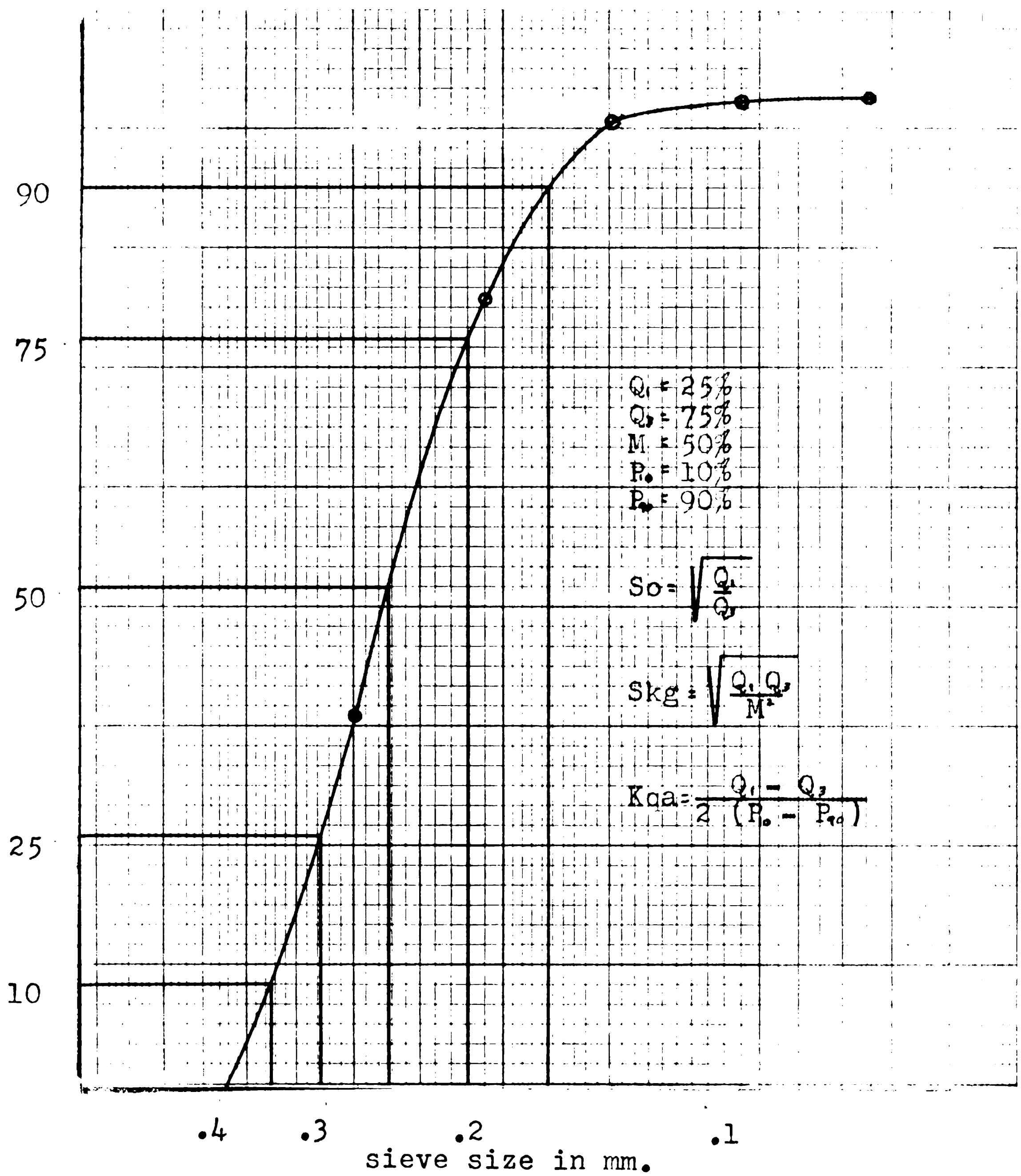
Cumulative Curve, Well No. 1, 790-795'



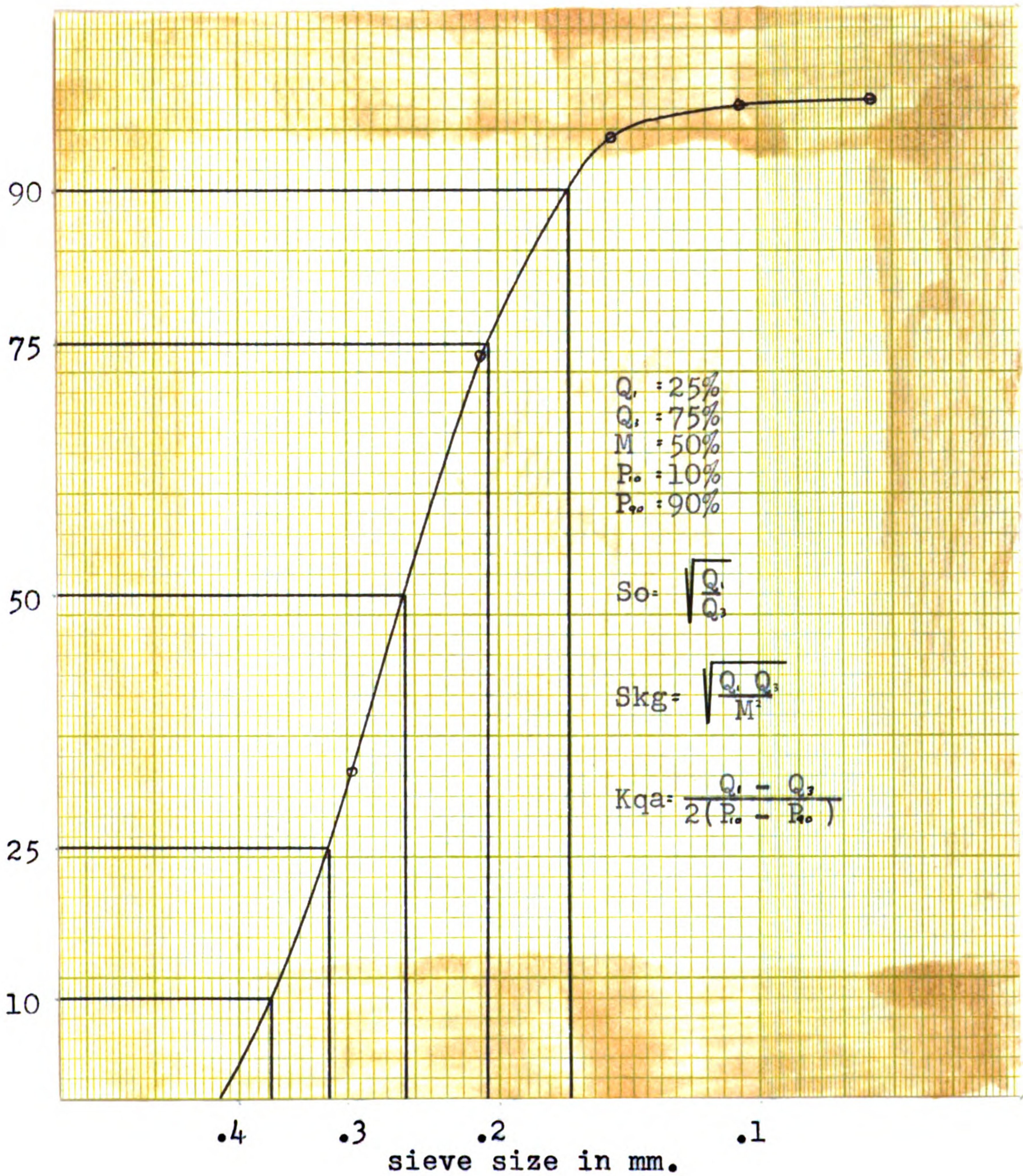
Cumulative Curve, Well No. 1, 795-800'



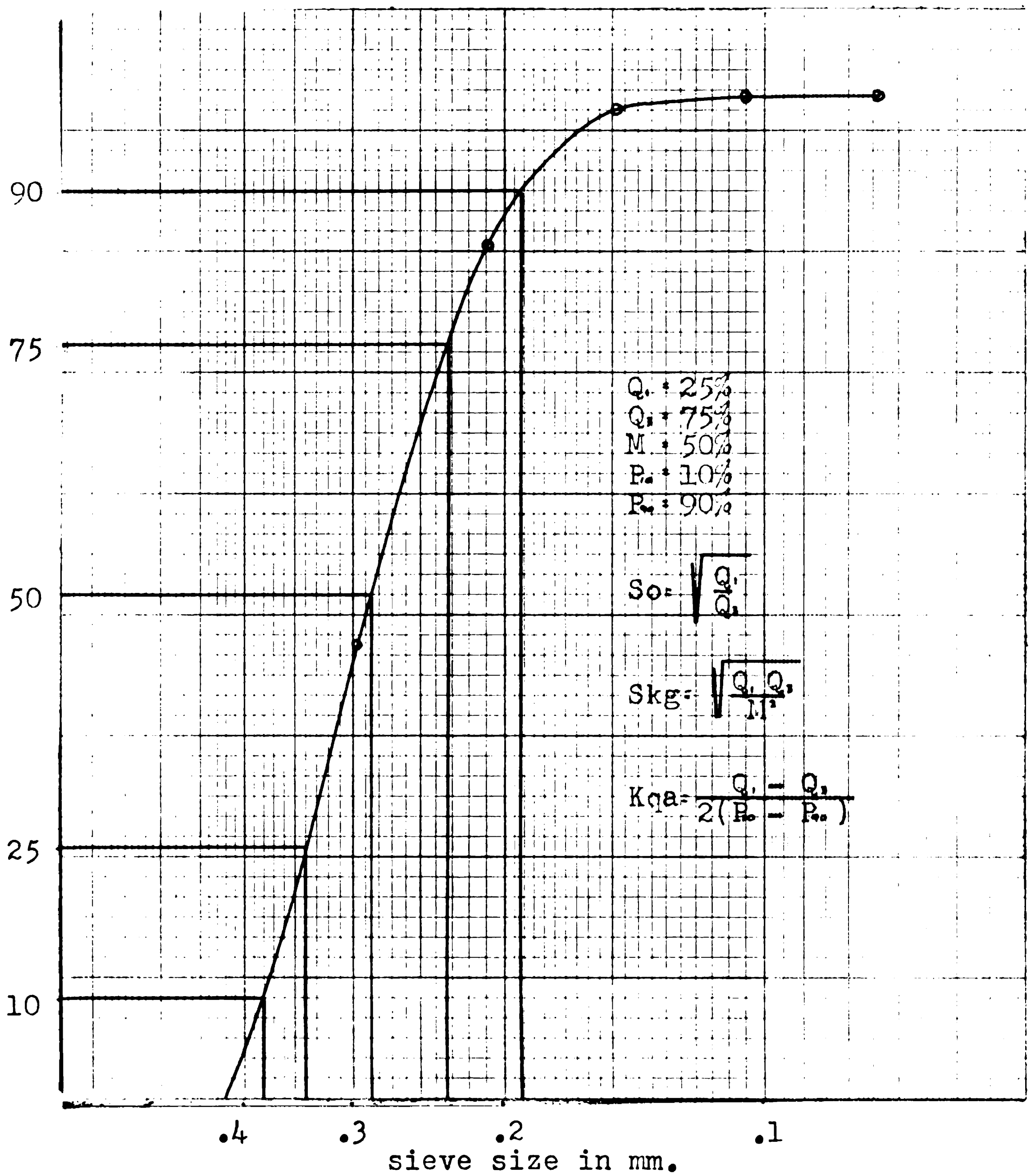
Cumulative Curve, Well No. 1, 800-805'



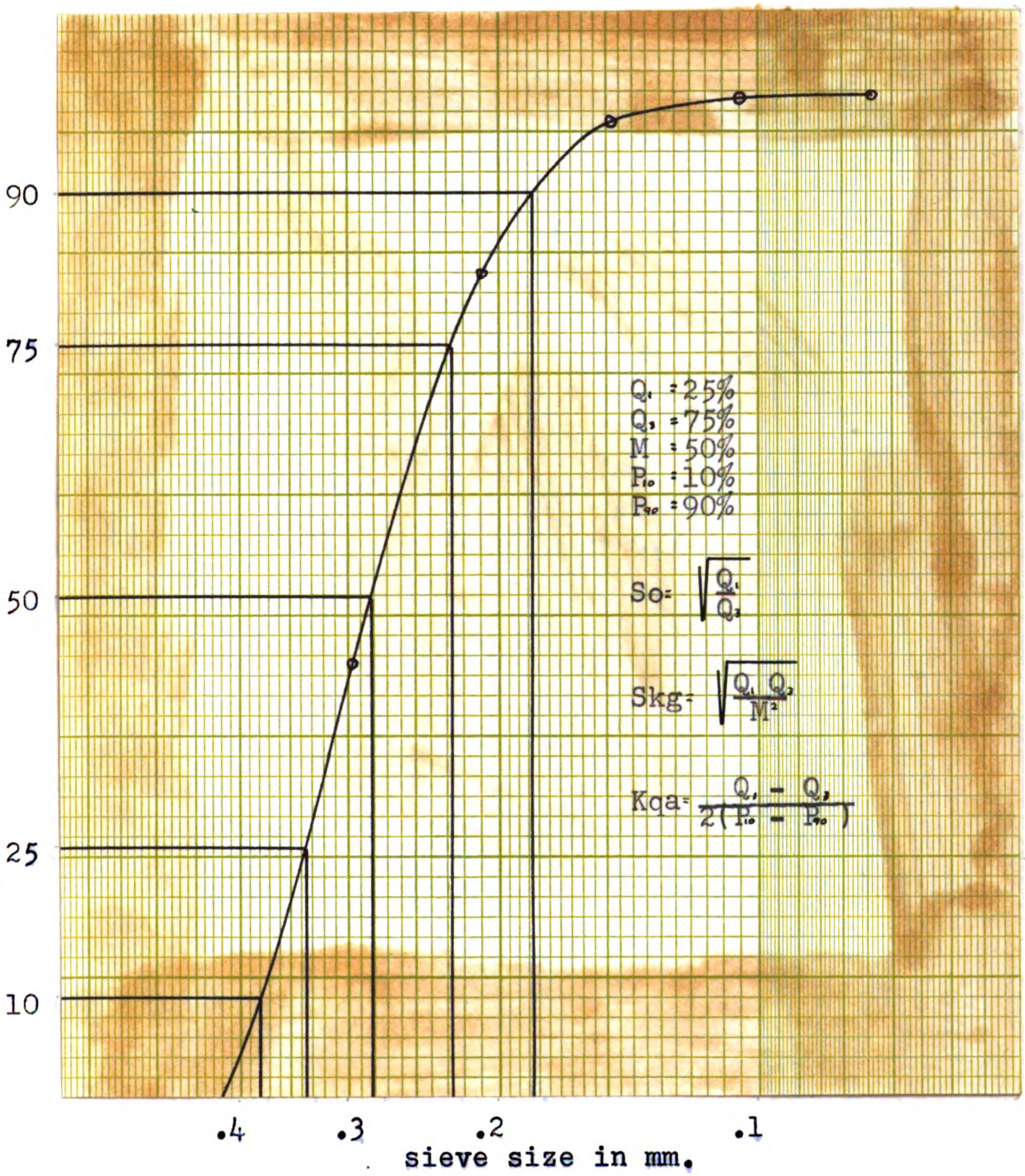
Cumulative Curve, Well No. 2, 780-785'



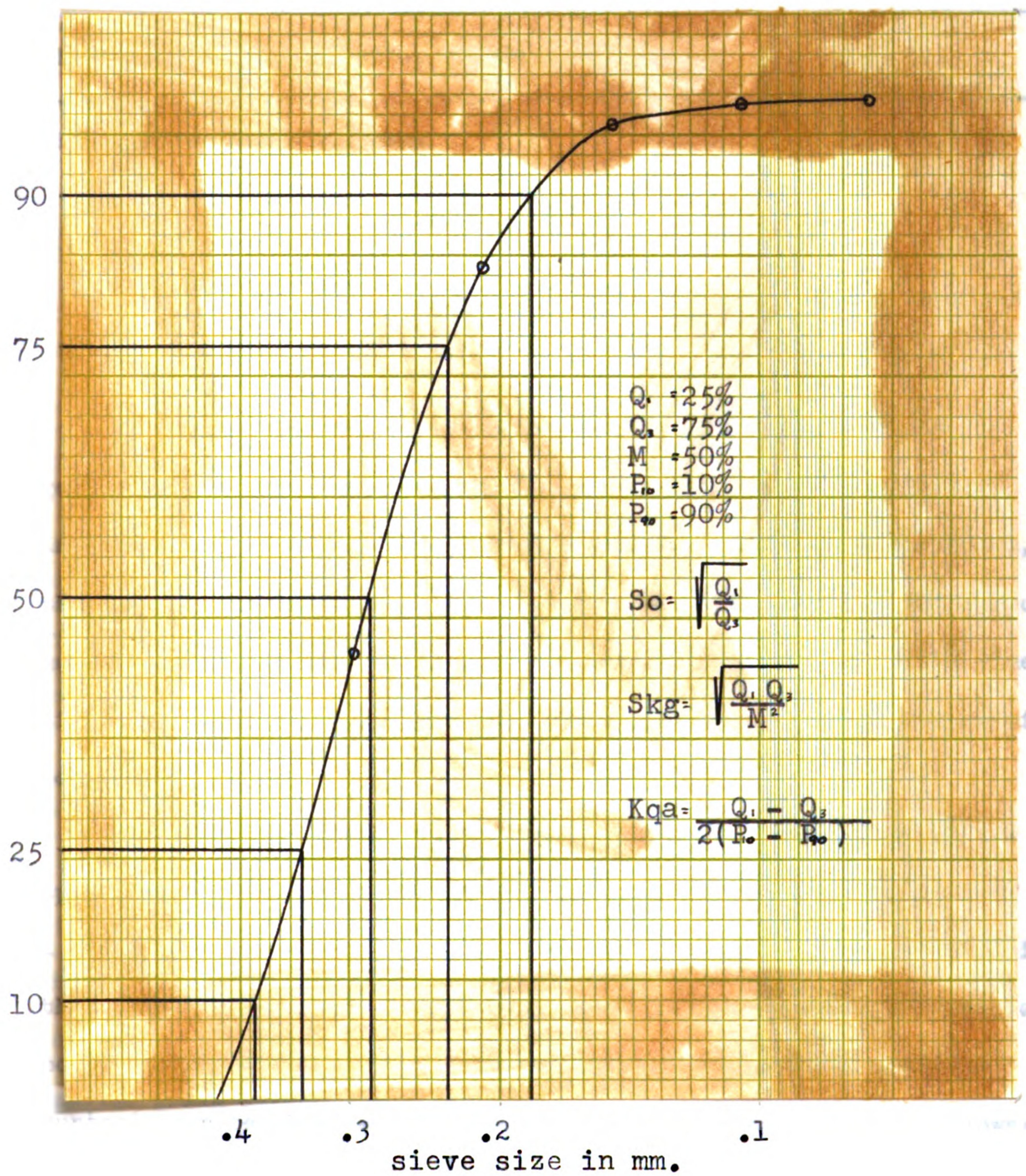
Cumulative Curve, Well No. 2, 785-790'



Cumulative Curve, Well No. 2, 790-795'



Cumulative Curve, Well No. 2, 795-800'



Cumulative Curve, Well No. 2, 800-805'

Quartile skewness is a measure of the departure of the arithmetic mean of the quartiles from the median. The quartile skewness may also be expressed in geometric form as shown by Krumbein*.

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

The equation is as follows:

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

Skg - skewness.
Q_1 - first quartile.
Q_3 - third quartile.
M - median.

The geometric skewness has the same advantages as the geometric quartile deviation in that it eliminates the size factor and the units of measurement. When a frequency curve is symmetrical, the value of skewness is unity. Other values obtained will range from numbers less than one, which show a greater concentration in the fine sizes, to numbers larger than one, which indicate a larger percent of coarse sand.

Quartile kurtosis essentially involves a comparison of the spread of the central position of a frequency curve to the spread of a curve as a whole. It is the measure of the degree of peakedness of the curve. A well sorted sand would show marked kurtosis, whereas, a poorly sorted sediment would have negligible peakedness. Quartile kurtosis can be obtained from Kelley's equation* which is as follows:

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

Kqa - kurtosis.
Q_1 - first quartile.
Q_3 - third quartile.
P_{10} - tenth percentile.
P_{90} - ninetieth percentile.

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

Comparison of Quartile Measurements

A summary of the quartile measures of the samples examined in this study may be seen on table 1. The quartile measures of the samples from well No. 2 may now be compared with those from well No. 1.

On the basis of approximately 200 analyses, Trask found that an 'So' value less than 2.5 indicates a well sorted sediment. From the results shown in table 1, it is apparent that the Marshall sand from the wells examined is very well sorted.

The values for kurtosis are quite consistent and show a maximum deviation of only .08, which is considered insignificant.

The skewness values of the samples from well No. 1 are slightly greater than one, indicating sorting toward the larger sizes. The skewness of samples from well No. 2 is just less than one. This would indicate that the sorting of the sand in well No. 2 is in the smaller grain sizes.

Comparison of Sphericity and Roundness Measurements

A graphic presentation of the roundness is shown in figure 15. It is readily seen that the roundness of the quartz

Depth	Q_1	Q_3	M	P_{10}	P_{90}	So	Skg	Kqa
760-765	2.85	1.92	2.29	3.41	1.36	1.22	1.02	0.26
765-770	2.82	1.88	2.26	3.42	1.58	1.23	1.02	0.25
770-775	2.70	1.75	2.13	3.33	1.47	1.24	1.02	0.25
775-780	2.74	1.80	2.17	3.39	1.52	1.24	1.02	0.25
780-785	2.52	1.84	2.09	3.09	1.54	1.18	1.03	0.22
785-790	2.41	1.80	2.08	2.96	1.39	1.16	1.00	0.19
790-795	2.65	2.00	2.19	3.28	1.65	1.15	1.05	0.20
795-800	2.61	1.99	2.20	3.24	1.66	1.15	1.04	0.20
800-805	2.57	1.89	2.16	3.13	1.52	1.17	1.02	0.21
805-810	2.60	1.92	2.19	3.20	1.57	1.16	1.02	0.21
810-815	2.41	1.96	2.12	3.08	1.66	1.12	1.02	0.16
815-820	2.58	1.87	2.18	3.18	1.51	1.18	1.01	0.21
820-825	2.99	1.86	2.38	3.58	1.51	1.27	0.99	0.27
825-830	2.99	1.92	2.39	3.55	1.58	1.25	1.00	0.27

Well No. 1

Depth	Q_1	Q_3	M	P_{10}	P_{90}	So	Skg	Kqa
780-785	3.27	2.21	2.72	3.74	1.77	1.22	0.99	0.27
785-790	3.13	2.07	2.58	3.66	1.66	1.23	0.99	0.26
790-795	3.39	2.33	2.87	3.80	1.91	1.21	0.98	0.28
795-800	3.37	2.28	2.82	3.79	1.85	1.22	0.98	0.28
800-805	3.36	2.28	2.81	3.79	1.84	1.22	0.98	0.28

Well No. 2

Table 1.- Summary of Quartile Measures.

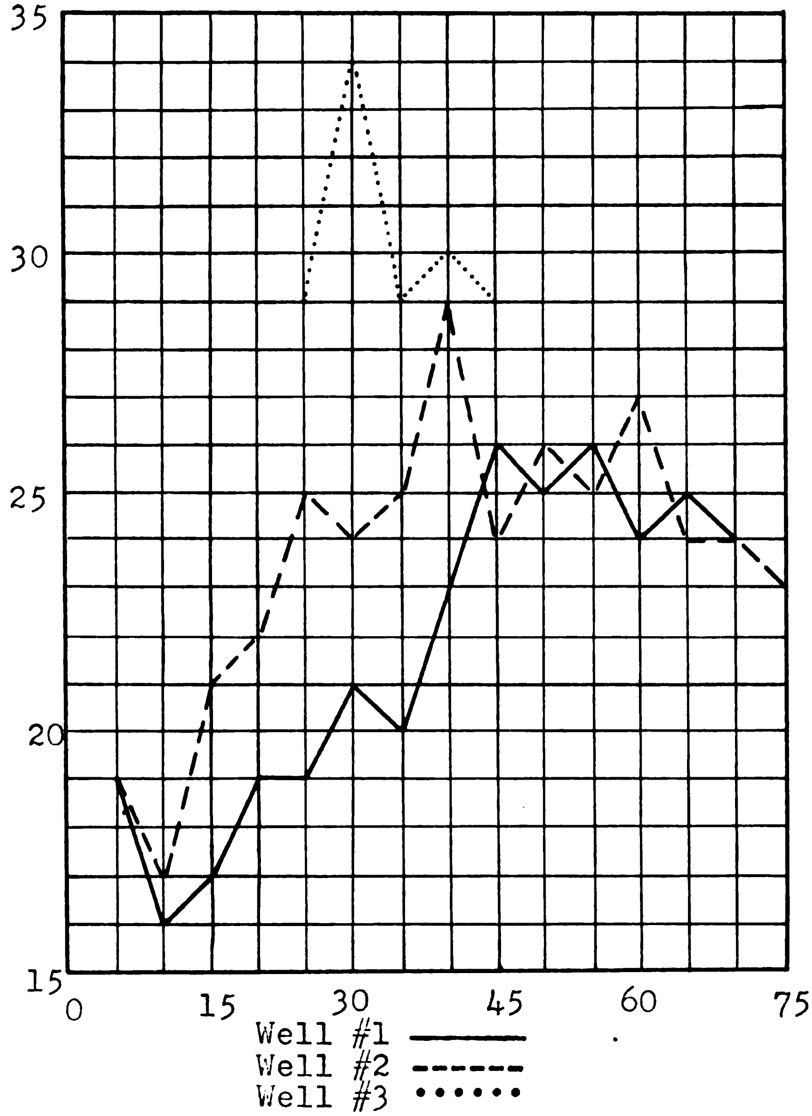

Figure 15.- Graphic Comparison of the Roundness of the Marshall Sand, Newaygo County.

particles in well No. 2 closely follows the pattern of those in well No. 1, but in almost every instance, is greater. Also, the roundness values for the 25 feet examined in well No. 3 again reflect the general pattern of the other two. The curve representing well No. 3, however, more closely resembles that of well No. 2 than that of well No. 1.

It should be noted that the maximum roundness values differ somewhat in each well. The maximum value for the samples from well No. 1 is .26, for well No. 2, .29, and well No. 3, .34. It is interesting to note that the horizons that gave maximum roundness values in each case are not at the same depths. In well No. 1, the maximum value of .26 is found 45 feet below the top of the Marshall. In well No. 2, the maximum value of .29 is located 40 feet below the top of the formation. A maximum value of .34 was found 30 feet below the top of the formation in well No. 3. This shows, that with an increase in the maximum roundness value, the position of the horizon is nearer the top of the formation. The significance of the position change of maximum roundness will be discussed in the conclusions.

The sphericity results are shown graphically in figure 16. The results of the sphericity measurements do not exhibit the same clear-cut comparisons that are shown by the roundness. However, it may be seen that the sphericity of the samples from well No. 2 is less than those of well No. 1. Most authorities agree that with an increase of roundness the sphericity decreases*.

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*Wentworth, C. K., The Shapes of Pebbles: U. S. Geol. Survey Bull. 730-c, 1922, pp. 91-114.

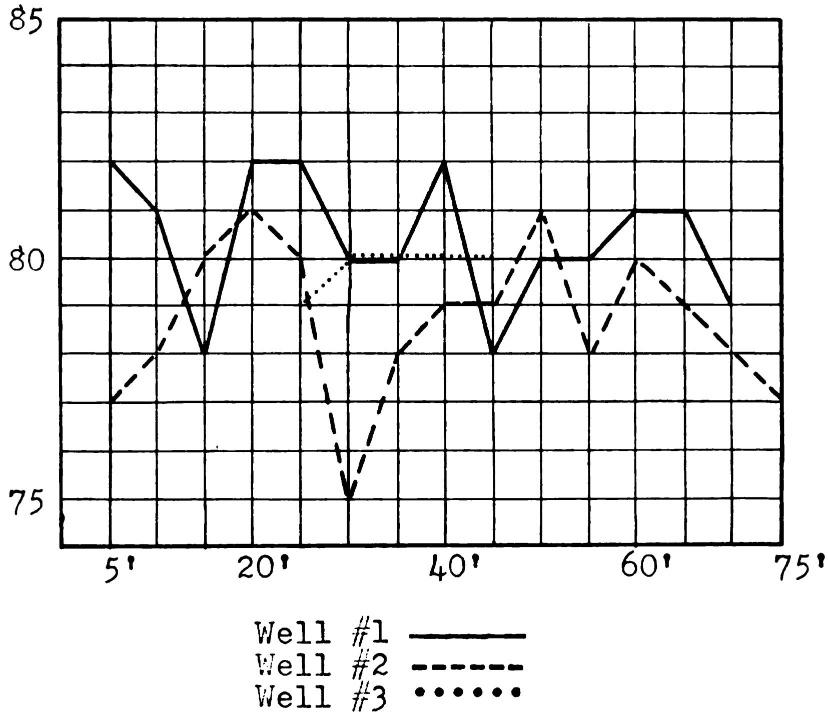

Figure 16.- Graphic Comparison of the Sphericity of the Marshall Sand, Newaygo County.

The curve for the 25' of samples examined from well No. 3 does not seem to bear any relation to the other two, although it appears to be less than well No. 1 and greater than well No. 2.

The sphericity values obtained in this limited study appear to have little significance.

Conclusions

It is concluded from the data accumulated for this problem that roundness and sphericity measurements can be applied to sub-surface samples to determine the direction of the sedimentation and thus the direction of old shore lines.

It is generally accepted that sediments near the source are blocky or angular with a very low roundness value but with relatively high sphericity. As the sediments are transported farther from their source, abrasion tends to remove sharp corners thus causing the fragments to become more round. On the contrary, the particles tend to flatten by abrasion, the result of which is a decreased sphericity.*

*Wentworth, C. K., op. cit.

The degree of roundness of water-borne quartz grains is a direct function of the distance transported. The degree of sphericity, conversely, is an inverse function of the distance the grains are transported.

Following this line of evidence, the sand from well No. 1, having the lowest roundness values, the highest degree of sphericity, and maximum sorting in the coarse sizes, is obviously the nearest of the three wells to the source of sand supply in the area.

The sands of well No. 2 have a greater degree of roundness, lower values of sphericity and maximum sorting in finer sizes. These factors indicate that the sands are farther removed from the source than are those of well No. 1.

The maximum roundness values are found in the samples from well No. 3, indicating that they are the farthest from the source. The sphericity is higher than expected. This may be due to a secondary increase caused by the wearing away of the thin peripheral edges of the grains thus causing them to become more equidimensional. The fact that the roundness curve of the fractions from well No. 3 more closely resemble the curve of the samples from well No. 2, would indicate that it is in the line of sedimentation from well No. 2 rather than from well No. 1.

The "shape-horizons", depicted by the apices of the roundness curves, occur at a different depth in each of the three wells. It is interesting to note that, with an increase in the maximum roundness values, the "shape-horizons" are located nearer the top of the formation. This evidence might also be an indication of increasing distance from the source of the sediments.

Figure 17 is a paleogeographic map of Marshall sedimentation as constructed from the roundness values shown in figure 15. The exact shoreward distance to the source material is not definitely known. However, the excellent sorting, the high degree of roundness, together with the paucity of heavy minerals which possibly may have been destroyed by abrasion, would seem to indicate the source to be a considerable distance away.

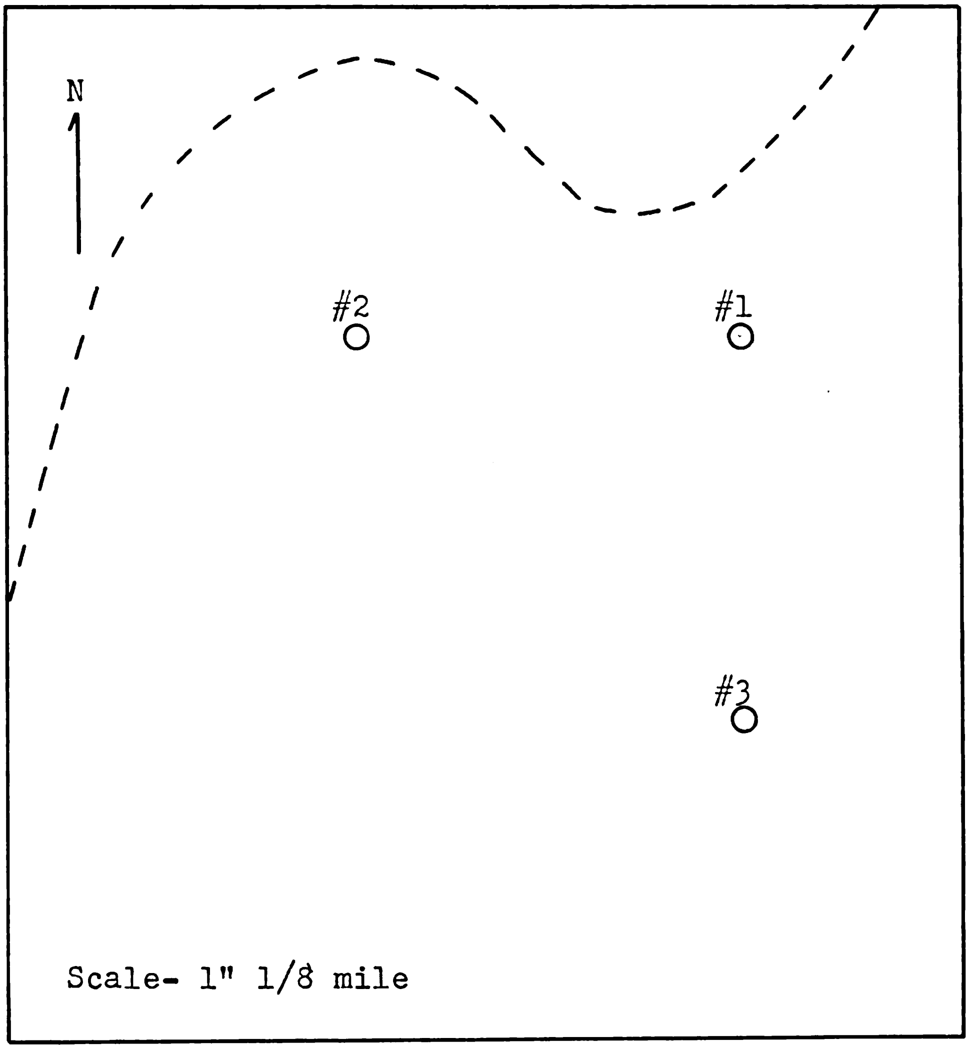

Figure 17.- Paleogeographic Map of Marshall Deposition Indicating Shore Line and Source to the North-west.

The outstanding peaks on the roundness graphs indicate a horizon that could be picked out readily at least locally, (figure 15). The elevations of these peaks are reduced to a sea level datum plane in table 2, and plotted on a structural diagram as shown in figure 18. This diagram shows a slight increase in elevation from well No. 1 to well No. 2, and a greater increase to well No. 3. This indicates a local high just to the south of well No. 3 which is actually the case in this area.*

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*Grant, R., Oil and Gas Geologist, Michigan State Geological Survey, 1949. Personal Communication.

A summary of the conclusions is as follows:

1. Sphericity and roundness measurements have proved to be of practical value when applied to sub-surface sands of the Marshall formation of western Michigan. These factors indicate the direction of source material from which the sediments were derived in the sedimentation process.
2. Cumulative curves and quartile measures as prepared give additional proof of the value of roundness and sphericity in determining the direction of source material for the Marshall sands.
3. The determination of the direction of the source material focuses attention to a limited area, such as an old shore line, which may prove of economic importance in the deep seated storage of petroleum.
4. Locally prominent "shape-horizons" may be recognized and contoured in such a manner as to suggest the presence of structure within limited and restricted areas.

Well	Elevation of Peak	Elevation of Surface	Elevation from Datum
#1	800	842.2	42.2
#2	800	848.0	48.0
#3	765	836.3	71.3

Table 2.

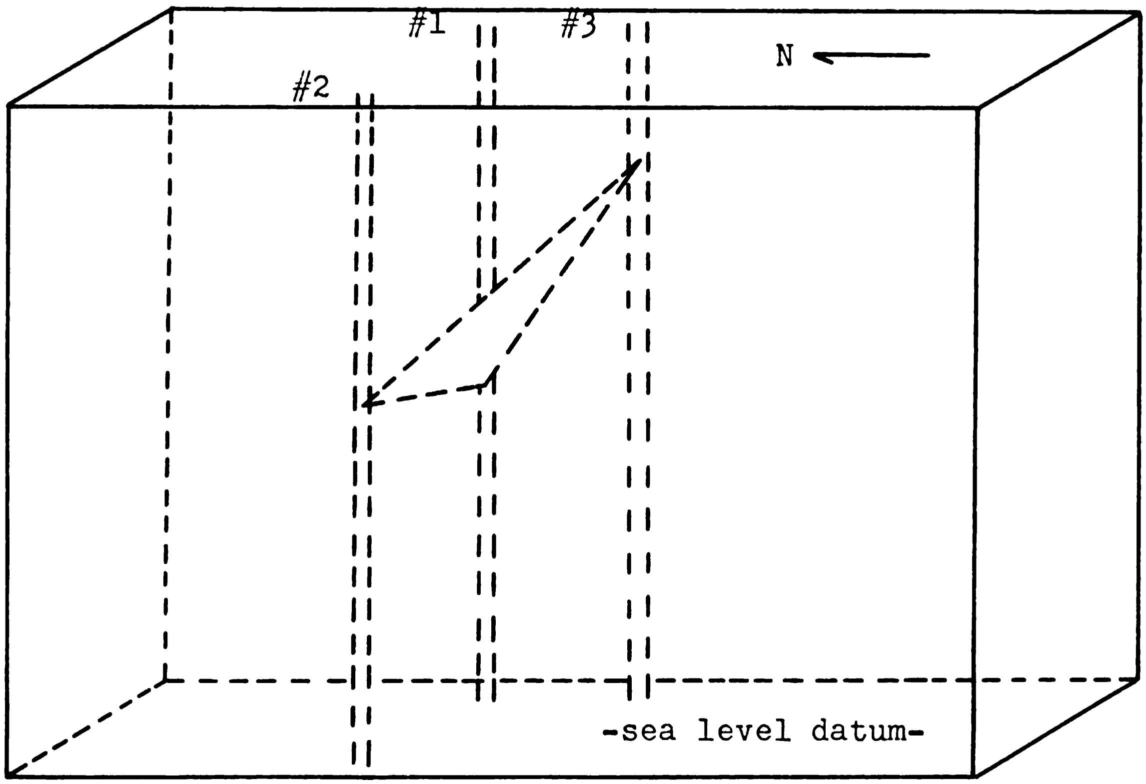

Figure 18.- Diagrammatic View of Marshall Structure in Garfield Twp., Newaygo County.

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