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A Textural Analysis of the Bedford Shale of Lorain County, Ohio

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A TEXTURAL ANALYSIS OF THE BEDFORD SHALE
OF
LORAIN COUNTY, OHIO

By

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PART I

INTRODUCTION

PRELIMINARY STATEMENT

Throughout the course of the school year 1947-48 the writer has collected specimens of the Bedford shale from various localities within Lorain County, Ohio. Textural and mineralogical analyses have been made of the specimens in order to determine the textural and petrologic variation between the two facies, and whether each of the facies was deposited under similar conditions.

ACKNOWLEDGEMENTS

The writer is indebted to Dr. Fred Foreman, who first suggested this topic of study, for his general supervision of the investigation and of the preparation of the manuscript. Many of the photographs used in this thesis were contributed by Dr. Foreman.

Thanks are due to Mr. Duncan Goldthwaite for his kind assistance in the collecting of some of the specimens from the several outcrops throughout the county.

GENERAL DESCRIPTION OF THE BEDFORD SHALE

The Bedford shale was named by J. S. Newberry[1] in 1870 from the excellent section that is exposed in Tinkers Creek gorge near Bedford, Cuyahoga County, Ohio. The thickness here is about 85 feet, and the rock is chiefly a soft blue shale with bands of thin flagstone and of hard, calcareous concretions.

[1]Geological Survey of Ohio, Part I, Report of Progress, p. 21, 1869.

From Euclid southwestward into and up the Cuyahoga Valley beyond Breckville, a 20-foot light blue-grey, fine grained sandstone (the Euclid sandstone lentil) lies near the base of the formation. Also, in, and for some distance to the west of Cleveland many sections show some black shale in the basal part of the Bedford. This shale has every appearance of being reworked black mud, and on this account it is included in the Bedford shale instead of in the underlying Cleveland shale.[2]

[2]Cushing, Leverett, and Van Horn - Geology and Mineral Resources of the Cleveland District, Ohio; U. S. Geological Survey, Bulletin 818, pp. 40-42, 1931.

In Lorain County, the Bedford shale consists of two general facies, a lower blue-gray and an upper chocolate-red. At the contact with the underlying Cleveland shales are two thin sandstone layers (up to six inches in thickness), separated by thin sandy blue-gray shale.

These basal sandstone layers contain a great deal of carbonate, and locally, as for example in the outcrop at North Amherst, have sufficient amounts of carbonates (principally calcium) that they might be classed as limestone.

As far as the writer is aware, no chemical analysis has been made of these basal layers in Lorain County. However, an analysis of the same basal sandstone layers from the section at Tinkers Creek near Bedford, Ohio, by Professor D. J. Demorest[3] of Ohio State University, will serve to show the high carbonate content:

Silicious residue	Clay	17.5%
	Quartz	5.8
	Feldspar	10.8
Al_2O_3		2.03
Fe_2O_3		9.30
$Ca\ CO_3$		34.60
$Mg\ CO_3$		17.05

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[3] Prosser, C. S. - The Devonian and Mississippian Formation of Northeastern Ohio; Geological Survey of Ohio, Fourth Series, Bulletin 15, p. 82, 1912.

From two to five feet above these two sandstone beds, small lenses of sandstone (not more than 1/4 inch in thickness) may be found. Both the shale and the sandstone lenses weather to a buff color but are blue-gray when unweathered.

On exposure the shale breaks into very small rectangular fragments (approximately 1/8 by 1/4 inch) that suggest shrinkage-cracked mud. This rapid weathering is because of the high content of silts and clays which make the shale very soft and tender when wet, though it becomes fairly firm on thorough drying.

This blue-gray facies varies in thickness up to approximately 18 feet, where it grades into the much thicker overlying red facies.

So gradual is this change in color in some localities that a mottled effect is apparent, due to small layers and lenses of the gray facies interbedded within the red facies.

The only apparent difference in the two facies in hand specimens is in color, although, as shown by the accompanying histograms and cumulative curves, the blue-gray facies in general has a greater percentage of grains in the coarser grades than does the red facies. The red facies, then, is even weaker than the blue, so that its characteristic occurrence in outcrop is as a red mud, and hand specimens of the unweathered rock can be collected only when an excavation is being made.

Because of the uneven contact with the overlying Berea sandstone, the Bedford shale varies greatly in thickness in Lorain County. Well records of Lorain County show it to vary from 8 to 196 feet in thickness.[4]

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[4]Wenberg, E. H. - The Paleozoic Stratigraphy of Lorain County, Ohio; Masters Thesis, Oberlin College, p. 31, 1938.

GEOLOGIC AGE OF THE BEDFORD SHALE

Geologists are in no general agreement as to the age of the Bedford shale. For many years the Bedford was classified as Carboniferous. G. H. Girty[5], in 1912,

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[5]New York Academy of Science, Annals, Volume 22, p. 295, 1912.

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was one of the first geologist to map the Bedford as Devonian in age. The same year C. S. Prosser assigned it to the Devonian on the basis that "this disconformity between the Bedford and Berea formations together with fact that Chemung fossils in northeastern Ohio and northwestern Pennsylvania occur nearly to the base of the Berea sandstone is regarded.... as evidence in favor of drawing the line of separation between the Devonian and

Carboniferous systems at this horizon."[6]

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[6]Prosser, C. S. - op. cit., p. 511

Many geologists[7], however, continue to classify

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[7]Chadwick, G. H. - The Great Catskill Delta, and Revision of Late Devonian Succession; Pan-American Geologist, Volume 60, p. 280, 1933.

Moore, R. C. - Historical Geology; p. 270, 1933.

Burroughs, W. G. - The Unconformity Between the Bedford and the Berea Formations of Northern Ohio; Journal of Geology, Volume XIX, Number 7, p. 655, 1911.

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the Bedford as Carboniferous in age.

In 1914 the United States Geological Survey adopted Devonian or Carboniferous as the age designation of the Bedford shale, and still classifies it thus.[8]

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[8]Wilmarth, M. G. - Lexicon of Geologic Names of the United States; U. S. Geological Survey, Bulletin 896, Part I, p. 142, 1938.

Most geologists of today follow this classification.

BEDFORD - BEREA CONTACT

The irregular contact of the Bedford shale with the overlying Berea sandstone has received much discussion, and geologists are not yet in agreement as to the significence of this break.

W. G. Burroughs in discussing this irregular contact, proposes that "During the period that the Bedford horizon was above the level of the sea, its surface was dissected, streams cutting deep channels and wide valleys. The lower portions of these valleys became drowned. In the quiet water thus formed, the rivers deposited sediment which later became a blue shale, logically belonging to the Berea formation. The entire Bedford land area gradually was submerged, and the Berea sandstone formation was laid down."[9]

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[9]Burroughs, W. G. - op. cit., p. 659.

Prosser states simply that the Bedford and the Berea formations "are separated by an erosional plane."[10]

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[10]Prosser, C. S. - op. cit., p. 511.

Others[11] believe this contact to be because of

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[11]Cushing, Leverett, and Van Horn - op. cit., p. 47.

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irregular wearing away of the upper beds of the Bedford into "channels" by the currents that brought in the sands of the Berea formation.

FAUNA OF THE BEDFORD

Most of the Bedford shale is barren of fossil remains. At the outcrop in Beaver Creek at North Amherst a few fragments of small pelecypods and brachiopods were found in the very basal layers. In the geology museum at Oberlin College are several fossils reported to have been collected from this basal layer at the North Amherst locality and from equivalent beds near Elyria. Among these fossils are Modiomorpha subalata (Conrad), Chonetes sp., Parallelodon hamiltoniae (Hall), Camarotoechia sappho Hall, Rhynchonella sp., and Lingula melie Hall.

ECONOMIC IMPORTANCE

In past years the Euclid sandstone lentil of the Bedford shale in Cuyahoga County was quarried for flagstone purposes, particularly at Euclid. It is there known commercially as the Euclid bluestone.[12]

[12] Cushing, Leverett, and Van Horn, ibid., p. 42.

As far as the writer is aware, in Lorain County the Bedford is important only as a soil derivative.

LOCATION OF SAMPLED OUTCROPS

Specimens were collected from a total of eight outcrops of the Bedford shale (Fig. 1). Six of these

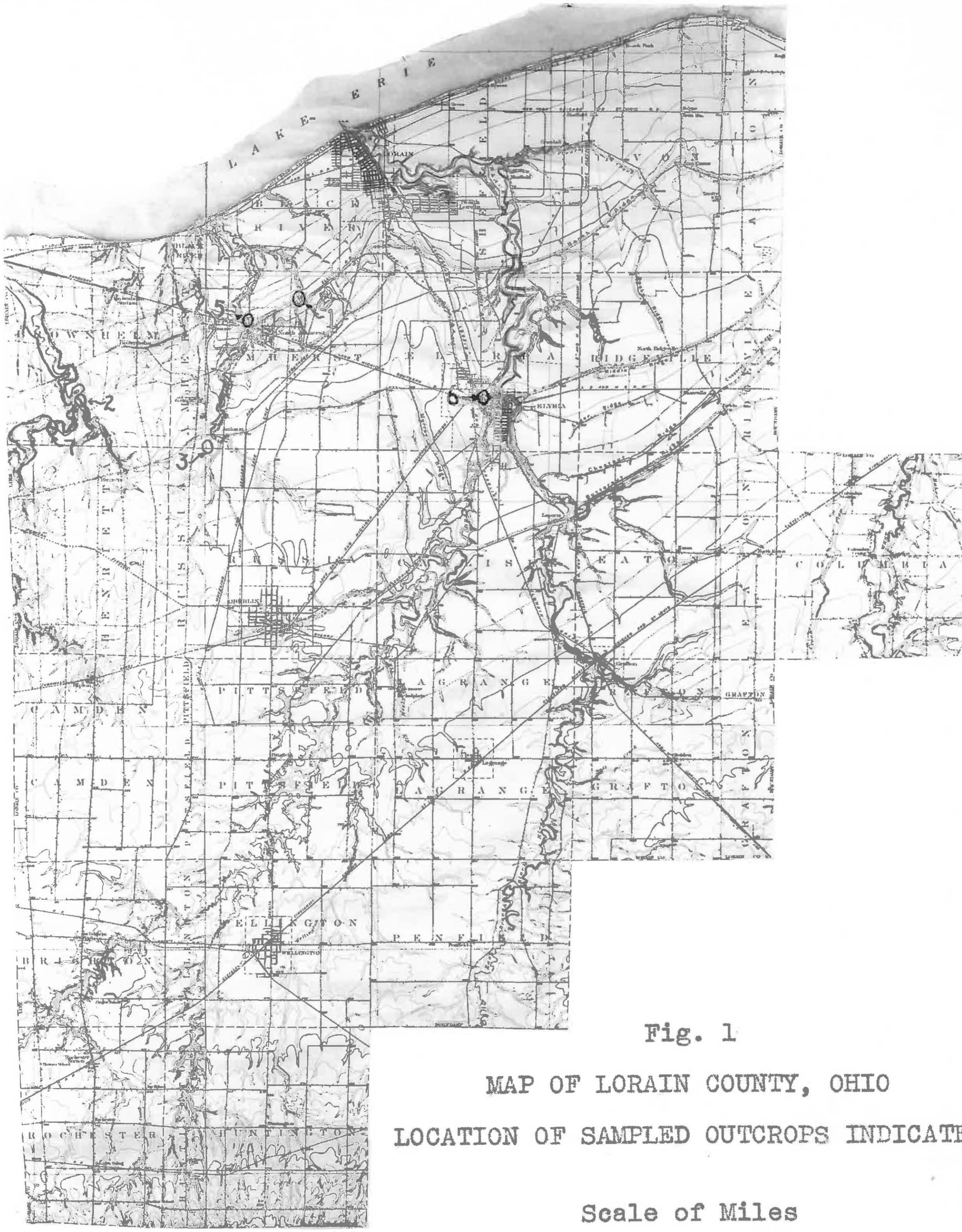

Fig. 1

MAP OF LORAIN COUNTY, OHIO

LOCATION OF SAMPLED OUTCROPS INDICATED

Scale of Miles

outcrops are located in Lorain County, one in Cuyahoga County, just to the east of Lorain County, and one in Erie County approximately 4 1/2 miles to the west of Lorain County.

Locality 1 - east bank of small stream (tributary to Beaver Creek) approximately 400 yards northeast of Pleasant View Sanantorium on North Ridge Road. Both blue-gray and red facies are exposed there. The following specimens were collected at this locality:

Specimen 1 - blue-gray facies at stream level (apparently near base of Bedford). Shale weathers to a buff color but is light to blue-gray on unweathered surfaces. Many small sandstone lenses occur here.

Specimen 2 - sandstone lens 1 1/2 feet above stream level. Sandstone is fine grained, steel-gray in color, and 3/16 - 1/4 inch in thickness.

Specimen 5 - chocolate-red to reddish-brown shale 9 1/2 feet above stream level. This is the lowest bed of the red facies at Locality 1.

Specimen 6 - chocolate-red shale 15 feet above stream level. On weathering, this shale breaks into small rectangular pieces approximately 1/8 inch by 1/4 inch.

Specimen 7 - chocolate-red shale 20 feet above stream level. An additional exposure of four feet of red shale occurs above the location from which this specimen was taken, and this is in turn overlain by two feet of slumped glacial drift and road bed filling.

Locality 2 - at confluence of Chance Creek and Vermilion River, two miles north-northwest of Henrietta. At this locality the contact with the underlying Cleveland shales is exposed high up on the inaccessible east bank of the Vermilion River. Only one specimen was collected at this locality.

Specimen 1 - basal sandstone layer. This fine grained, light gray sandstone consists of two layers (each approximately six inches in thickness) separated by a thin zone of typical blue-gray shale.

Locality 3 - west side of road leading to cemetary at South Amherst (Amherst on Oberlin Quadrangle, Ohio, 1/62,500). Only the chocolate-red facies (overlain by one foot of glacial drift) is exposed here. Wenberg[13]

[13] Wenberg, E. H. - op. cit., pp. 31-32.

interprets this exposure as an inlier of the Bedford shale appearing through the Berea sandstone. Only one specimen was collected at this locality.

Specimen 1 - chocolate-red shale. Near the surface the shale is weathered to a reddish, very sticky clay, and it is necessary to dig in for approximately four feet before the unweathered rock is reached.

Locality 4 - West Branch of Rocky River, approximately 500 yards downstream from Lake Shore and Michigan Southern Railway bridge, at Olmstead Falls, Cuyahoga County. The contact with the Berea sandstone is observed on east bank of the stream. Specimens were collected here to determine if any great variation occurs in the Bedford immediately to the east of Lorain County.

Specimen 1 - chocolate-red shale three feet above stream level. On exposed surface this shale weathers into small rectangular pieces approximately 1/8 by 1/4 inch.

Specimen 2 - blue-gray shale 10 feet above stream level, and at contact with overlying Berea sandstone.

Locality 5 - east bank of Beaver Creek approximately 150 yards north of bridge in North Amherst. The contact with the underlying Cleveland shales is exposed two feet above stream level.

The following specimens were collected at this locality:

Specimen 1 - basal layer of Bedford two feet above stream level. Here the carbonate content is sufficient to classify these fine grained, blue-gray layers (six inches total thickness) as limestone.

Specimen 4 - blue-gray shale with thin interbedded sandstone lenses four feet above stream level.

Specimen 5 - blue-gray shale six feet above stream level. This shale continues upward, without variation, for ten feet, where it is overlain by two feet of drift.

Locality 6 - 100 yards downstream from falls on West Branch Black River at Elyria. The contact with the overlying Berea sandstone is exposed in the east valley wall. The following specimens were collected at this locality:

Specimen 1 - blue-gray shale at contact with Berea sandstone 18 1/2 feet above stream level.

Specimen 3 - chocolate-red shale 3 1/3 feet below contact with Berea sandstone (15 feet above stream level). Slumping of the beds in vicinity of Specimen 3 makes it necessary to dig in for approximately 3 - 4 feet before the firm rock is reached.

Locality 7 - 1/4 mile upstream from junction of Vermilion River and Chance Creek, along small stream tributary to Vermilion River from the east. The following specimens were collected at this locality:

Specimen 1 - blue-gray shale immediately above basal sandstone layers. Below the two six inch sandstone layers underlying Specimen 1 a series of water falls have developed on the underlying Cleveland shales. The blue-gray shale of this locality grades upward into the red facies.

Specimen 2 - chocolate-red shale 30 feet above basal sandstone layers. An occasional grayish colored lens gives this facies a slightly mottled effect.

Locality 8 - in road cut north of bridge over Chappel Creek, approximately six miles south-southwest of Vermilion, Erie County. At this locality much greater folding is apparent than is observed in the Lorain County outcrops. Specimens were collected here in order to determine if any great variation occurs in the Bedford immediately to the west of Lorain County.

Specimen 1 - chocolate-red shale near north end of outcrop. There is a gradational zone of approximately four inches between the red and the blue facies.

Specimen 3 - blue-gray shale near south end of outcrop, approximately 75 yards north of Chappel Creek.

OUTCROPS OF THE BEDFORD SHALE IN LORAIN COUNTY

Fig. 2. Locality 2 - Contact with underlying Cleveland shales approximately 1/3 distance from top of cliff.

Fig. 3. Downstream from Locality 2. Contact with underlying Cleveland shales approximately 1/3 distance from top of cliff.

OUTCROPS OF THE BEDFORD SHALE IN LORAIN COUNTY

Fig. 4. Locality 7 - Contact with underlying Cleveland shales marked by hammer.

Fig. 5 - Locality 1 - Blue-gray shale overlain by chocolate-red shale.

A TEXTURAL ANALYSIS OF THE BEDFORD SHALE

OF LORAIN COUNTY, OHIO

PART II

METHODS USED IN MAKING MECHANICAL ANALYSIS

A TEXTURAL ANALYSIS OF THE BEDFORD SHALE OF LORAIN COUNTY, OHIO

PART II

METHODS USED IN MAKING MECHANICAL ANALYSIS

Were the number of methods at present available for mechanical analysis discussed in detail, an entire volume would result, for no one method can be used, to the exclusion of others, to analyze the varying types of sediments. In the present chapter those methods found most applicable to the study of the Bedford shale are enumerated and described at length.

COLLECTION OF SAMPLES

The physical impossibility of analyzing an entire sedimentary formation, or for that matter, even an appreciable part of one, renders it necessary to work with samples. A sample is assumed to be representative of that part of the formation from which it is taken. As pointed out by Wentworth,[14] there is a strong tendency

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[14] Wentworth, C. K. - Methods of Mechanical Analysis of Sediments; University of Iowa Studies in Natural History, Volume XI, Number 11, p. 32, 1926.

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to collect an ideal specimen rather than one typical of the outcrop.

It is especially important when dealing with a very fine grained sediment such as the Bedford, that weathered surfaces be avoided. If the sample is to be representative, care must be taken that all weathered material is cleaned away from the point of collection. In all cases this has made it necessary to dig well into the deposit before the sample is collected.

The writer has in general used two sampling methods, a spot sample in areas of apparent homogeneity of the deposit and a series of spot samples where variations occur vertically or laterally.

A container was kept close at hand so that none of the sample was spilled or lost. Cloth bags of fine woven muslin fitted with a draw-string were satisfactorily used as containers. These were preferred over other types containers because of their light weight and ease of handling, the absence of a breakage risk, and the ease of cleaning.

PREPARATION FOR DISAGGREGATION

In the laboratory the samples were carefully transferred to flat cardboard boxes, which were left uncovered so that samples might be air dried before splitting.

A preliminary disaggregation was necessary to obtain the material in such form that it might be quartered into smaller samples. This was accomplished with a wooden pestle, using a gentle tapping (not a rotary grinding) motion so as not to break the individual grains. The samples were then quartered with the Jones sample splitter, one part being subjected to further disaggregation and the remainder reserved for any need that might arise.

DISAGGREGATION OF THE SAMPLES

A preliminary study of several methods of disaggregation was made on both the blue-gray and the red facies. It is believed that a discussion of these methods will be useful to others in the study of similar sediments.

Prolonged soaking in water - This method was found useful by Rubey[15] in the study of Cretaceous

[15] Rubey, W. W. - Lithologic Studies of Fine Grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region; U. S. Geological Survey, Prof. Paper 165A, pp. 1-54, 1930.

shales of the Black Hills region. In this paper he pointed out that the ease of disintegration varies with the moisture content of the sample.

The writer found that even after a period of two weeks' soaking (with occasional stirring) specimens of the Bedford shale showed but little disaggregation, and that under the microscope a large percentage of aggregates remained uneffected.

Prolonged soaking in sodium oxalate or sodium carbonate solution - The writer found this method to effect a greater percentage of disaggregation than an equivalent time of soaking in water alone. It is, however, far from ideal. For complete disaggregation, this method must be supplemented by brushing the particle with a stiff brush, which increases the chances of loss in the fine grades.

Stirring in water - This method, combined with frequent decantations, served to disaggregate a specimen only after a combined stirring time of some 65 hours. It is believed that if the circular motion of the suspension were prevented, the time element for disaggregation by this method would be greatly reduced. Bouyoucas[16] found

[16] Bouyoucas, G. J. - The Hydrometer as a New and Rapid Method for Determining the Colloidal Content of Soils; Soil Science, Volume 23, pp. 319-331, 1927.

this method effective for dispersing soils. It is not recommended, however, because of the economical aspect, for disaggregation of sediments similar to the Bedford shale.

Passing hydrogen sulfide gas through a water solution - There is much to be said in favor of this method. Disaggregation is usually completed in a matter of a few hours, and the ferric iron content is reduced to a ferrous nature which aids in later determination of mineralogical content under the petrographic microscope. However, unless a good hood is available the fumes are very displeasing, in some cases producing extreme cases of nausea.

Alternate heating and cooling in a sodium thiosulphate (photo "hypo") solution - "Hanna suggests the use of sodium acetate or sodium thiosulphate (photo "hypo"), the salt, and a small quantity of water being added to the sample, which is heated until the sample absorbs the saturated solution. Cooling and adding a small crystal of the salt to act as a nucleus will cause the salt to crystallize within the sample, thus promoting disaggregation".[17]

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[17] Tickell, F. G. - The Examination of Fragmental Rocks, p. 51, 1939.

This method was used by the writer with very favorable results. There are some important points, however, that must be discussed here.

The solubility of "hypo" in hot water solutions is vastly greater than in cold water solutions (74.7 parts "hypo" per 100 parts water, by weight, at 0° C.; 301.8 parts "hypo" per 100 parts water, by weight, at 60° C.)

If this alternate heating and cooling of the saturated solution is accomplished in glass beakers, it will probably result in breaking the beaker. The writer found this to be true even though a good grade of pyrex beakers was used. Small porcelain or enamelware dishes serve well for this purpose, and the danger of loss from breakage is eliminated.

The greatest difficulty encountered by this method is the removal of the "hypo" after disaggregation is accomplished. This is best accomplished by several filtrations. In many cases it was found that the smallest grains passed through even a number one filter paper. A porcelain filter, however, was found to be quite satisfactory for this purpose.

One of the great advantages of this method is its economy, for the filtrate is retained and used again and again. Too, the original cost of the "hypo" is small.

This method is not a time consuming one, but rather calls for only short intermittent attention.

It is on these bases that this method was adopted by the writer for disaggreation of the several samples analyzed in this paper, and it is recommended for use in sediments similar in nature to the Bedford shale.

ANALYSIS OF PARTICLE SIZE AND FREQUENCY

After disaggregation had been accomplished the specimen was split into two equal parts. (This may be accomplished by the Jones sample splitter or by "quartering".) One of these parts, properly labeled, was reserved as an alternate, while the second portion was subjected to a size analysis.

Although the percentage of coarse grain in the Bedford shale is usually very small, it must be treated as a sediment having a range of sizes from coarse to fine. As such, a composite method of size analysis is necessary. In accordance with the general practice, the line between coarse and fine sediments was chosen at 1/16 mm. This is the lower limit of the sand size in Wentworth's classification (here adopted), and sieves may readily be obtained with meshes fine enough to separate material at approximately this dimension. Also, 1/16 mm. is near the upper limit of applicability of Stokes' law and so furnishes a convenient line of demarcation.[18]

[18] Krumbein and Pettijohn - Manual of Sedimentary Petrography, p. 136, 1938.

As with all composite sediments the coarse and fine particles were analyzed separately (coarse particles by sieving and fine particles by the pipette method).

ANALYSIS BY SIEVING

The Wentworth scale for grades of sediments was adopted for use in the present analyses. This classification is given in Table I.

TABLE I

THE WENTWORTH SCALE FOR GRADES OF SEDIMENTS

Sediment	Size of Particles (mm)	Sediments	Size of Particles (mm)
Boulder gravel		Coarse sand	
	256		1/2
Cobble gravel		Medium sand	
	64		1/4
Pebble gravel		Fine sand	
	4		1/8
Granule gravel		Very fine sand	
	2		1/16
Very coarse sand		Silt	
	1		1/256
		Clay	

The W. S. Tyler Company, Cleveland, Ohio, has placed on the market a series of woven wire screens with openings to correspond very closely with the Wentworth grade scale. This comparison is shown in the following table:

TABLE II

COMPARISON OF WENTWORTH AND TYLER SIZES

Wentworth Scale (mm)	Nearest Corresponding screen in mm.	Tyler Screen Mesh
4	3.962	5
2	1.981	9
1	0.991	16
1/2	0.495	32
1/4	0.246	60
1/8	0.124	115
1/16	0.061	250

In analysis by sieving, the verious sieves were arranged in one nest, the finest opening through which all grains would pass (in the present case the 1.981 mm. sieve) at the top and the 0.061 mm. sieve at the bottom. A carefully weighed quantity of the disaggregated sediment was then placed in the top sieve. A small jet of water under low pressure was directed upon the sediment until all material with its smallest diameter less than the sieve opening had passed through the sieve. The material that remained upon the sieve was then dried and carefully weighed.

The same process was repeated with the sieve having the next smallest opening at top of nest.

As noted by Krumbein and Pettijohn[19], the

[19] Krumbein and Pettijohn - ibid., p. 142.

film of water in the wet sieve prevents some small particles from passing through, so that in all cases the wet sieve separates should be resieved through the same sieves when dry, in order to remove the finer particles.

All the material which ultimately passed through the 0.061 mm. sieve was reserved for analysis by the pipette method.

ANALYSIS BY THE PIPETTE METHOD

The pipette method was used for grades less than 0.061 mm., both because of its convenience and accuracy, and because of the small amount of equipment required. This equipment consists of a liter graduate, a 20-cc. pipette, several 50 or 100-cc. beakers, a hot plate, and an analytical balance.

The pipette method is based on Stokes' Law of settling velocities, proposed in 1851. This law applies to those particles (between fine sand and colloidal dimensions) upon which the properties of the medium (especially the density and the viscosity) exert a large influence in determining the rate of settling. The law states that:

$$v = \frac{2\ (d_1 - d_2)\ \ gr^2}{9\ \ \ \ n}$$

where v = the rate of settling

d_1 = density of the sphere

d_2 = density of the fluid

g = acceleration due to gravity (980 cm. sec.$^{-2}$)

r = radius of the sphere in cm.

n = viscosity of the fluid.

The error that enters due to the assumption that all the particles finer than 0.061 mm. are spheres is claimed by Krumbein and Pettijohn to be not very large.

For practical purposes of analysis the principles on which the pipette method is based may be considered as follows: "If a suspension is thoroughly shaken so that the particles are uniformly distributed and is then set at rest, all particles having a settling velocity greater than h/t will have settled below a plane of depth h below the surface, at the end of an interval of time t. All particles having a velocity less than h/t , however, will remain in their original concentration at depth h, because they will have settled only a fraction of this distance in time t. A small sample is taken from depth h at time t and evaporated to dryness. The weight of the residue, multiplied by a proportionality factor based on the ratio of the pipette volume to the total suspension volume, will represent the total amount of material having settling velocities less than h/t.

"After the first pipette sample has been withdrawn, the suspension is again shaken and a greater period of time is allowed to elapse, so that particles of a next smaller size may settle below depth h. The second pipette sample will then contain a residue smaller than that of the first sample by an amount equal to the weight of material lying between the two chosen sizes or settling velocities. This process may obviously be repeated and by simple subtracting the weights of successive residues (each multiplied by the proportionality factor) the amount of material in any grade may be determined directly."[20]

[20] Krumbein and Pettijohn - ibid., pp. 163-164.

The following table lists the time of settling for the various grades as computed by Stokes' Law:

TABLE III

TIMES OF SETTLING COMPUTED ACCORDING TO STOKES' LAW*

Diameters in mm.		Velocity (cm./sec.)	h (cm)	Hr.	Min.	Sec.
1/32	0.0312	0.0869	10	0	1	56
	.0221	.0435	10	0	3	52
1/64	.0156	.0217	10	0	7	44
	.0110	.0109	10	0	15	..
1/128	.0078	.00543	10	0	31	..
	.0055	.00272	10	1	1	..
1/256	.0039	.00136	10	2	3	..
	.00276	.00068	10	4	5	..
1/512	.00195	.00034	10	8	10	..
	.00138	.000168	10	16	21	..
1/1024	.00098	.000085	5	16	21	..
	.00069	.000043	5	32	42	..
1/2048	.00049	.000021	5	65	25	..
	.00033	.000011	5	126	15	..
1/4096	.00024	.000006	5	231	30	..

*The values in this table are based on temperature of 20°C. and an average specific gravity of the sediment equal to 2.65. Seconds are neglected in lower part of table. (Table modified from Krumbein and Pettijohn.)

In case pipetting cannot be done at the correct time, the additional depth required for any delay can easily be computed, time and depth being directly proportional.

Rapid rises in temperature will make for an increased amount of settling. Corrections may be made, however, for temperature changes during sedimentation. A temperature difference between opposite sides of the graduate will make for a circulating motion of the suspension, a condition which must be avoided.

Also, the pipette should be dried each time before filling, and care must be taken to empty the entire contents into the weighing dish.

CALCULATIONS

Once separation into the various size grades has been accomplished, it is necessary to compute the percentages which fall into each of the size grades. This data is necessary for plotting histograms and cumulative curves of the specimens.

It is well to use a good form for compiling the results so that others referring to the experimental data may find it easy to interpret.

The following report of a sieve analysis (form modified from Krumbein and Pettijohn) will serve to show the method of computing the percentage which fall into grades coarser than 0.061 mm.

REPORT OF SIEVE ANALYSIS

Sample Number: Locality 7 Specimen 1   Description: Bedford shale Blue-gray facies

Wt. of test sample: 40.471 g. Method Used: Wet sieving

Screen Openings	Grade Size mm.	Wt. retained g.	Wt. Per cent	Cumulative Per cent
0.495	0.991-.495	0.048	0.119	0.119
0.246	0.495-.246	0.055	0.136	0.255
0.124	0.246-.124	0.053	0.131	0.386
0.061	0.124-.061	0.040	0.099	0.485
	<0.061	40.096	99.073	99.558
		40.292	99.558	
Sieve loss		0.179	0.442	
		40.471	100.000	

The following example of the first several separations will indicate the computational routine of weights and percentages of materials falling in the grade sizes less than 0.061 mm: One liter of suspension contains 40.471 grams of sediment less than 0.061 mm. This sediment was dispersed with N/50 $Na_2 CO_3 \cdot 10 H_2O$ solution. This means that there are 2.86 grams $Na_2 CO_3 \cdot 10 H_2O$ per liter of suspension. On evaporation over the hot plate the sodium carbonate crystallized out as the anhydride (determined by several experiments), so that each 20-cc. of the suspension yielded 0.021 grams of $Na_2 CO_3$ upon evaporation. This value must be subtracted from the weight of the residue in the first beaker to correct for the dispersing agent. (Since the succeeding weights are subtracted one from the other, it is not necessary to correct for the dispersing agent - each residue containing the same amount of calcium carbonate.) Too, the weights must be converted into terms of the original volume. (Volume of pipette, 20-cc. is 1/50 the volume of the suspension.)

With these several points in mind, a table is set up as follows, showing the amount of material in the successive grades. (These weights may be converted into percentages of the total sample weight for histograms and cumulative curves.)

Residue in beaker # 1 (smaller than 1/32 mm)...	0.801 g.
Sodium carbonate in beaker # 1	0.021 g.
Difference: Sediment alone in beaker # 1	0.780 g.
Factor for conversion to original volume	50
Material finer than 1/32 mm.	39.000 g.
Material finer than 1/16 mm.	40.096 g.
Difference: Amount in 1/16-1/32 mm. Grade ...	1.096 g.

Residue in beaker # 1 (smaller than 1/32 mm.)..	0.801 g.
Residue in beaker # 2 (smaller than 1/64 mm.)..	0.755 g.
Difference:	0.046 g.
Factor for conversion to original volume	50
Amount in 1/32-1/64 mm. grade	2.300 g.

Residue in beaker # 2 (smaller than 1/64 mm.) ..	0.755	g.
Residue in beaker # 3 (smaller than 1/128 mm.) .	0.670	g.
Difference:	0.085	g.
Factor for conversion to original volume	50	
Amount in 1/64-1/128 mm. grade	4.250	g.

Etc.

PLOTTING

Once analysis is complete, the results should be presented in a graphical manner which is easily understandable. Of the many graphical methods that have been proposed, the writer has made use of the histogram and the cumulative curve in the present analysis.

HISTOGRAMS

Histograms (also called frequency pyramids) are the simplest manner of showing the results of mechanical analysis. Diameters in millimeters was used as the independent variable, and frequency (percentage of total weight) as the dependent variable. The class limits were drawn on a logarithmic scale so that each horizontal bar is equal in width, regardless of the original difference in absolute class interval.

CUMULATIVE CURVES

A cumulative curve is a curve based on the original histogram data. A frequency scale from 0 to 100 per cent was plotted along the horizontal axis and the size scale along the vertical axis. Again the size limits were drawn on a logarithmic scale rather than on an arithmetic scale.

A cumulative curve is constructed by plotting ordinates which represent the total amount of material larger or smaller than a given diameter. In short, this is equivalent to setting one histogram block above and to the right of the preceding one, so that the base of each block is the total height of all preceding blocks.

There are two types of cumulative curves in general use today - the "more than" and the "less than" curve. The present analysis employs the "more than" type curve, although it is immaterial which is used, since either furnishes the same type of information.

ERRORS IN MECHANICAL ANALYSIS

As previously noted, the tendency to collect an <u>ideal</u> specimen rather than a <u>typical</u> one, will result in errors which are probably quite large. Other errors in collecting can be largely reduced by care in the technique.

For purposes of interpretation Wentworth believes that "errors in any grade amounting to less than 1/4 per cent of the whole sample times the square root of the per cent of the grade (an arbitrary rule) may be regarded as negligible."[21]

[21] Wentworth, C. K. - op. cit., p. 34

Wentworth's table of errors in mechanical analysis is reproduced (without modification) as Table IV of this thesis.

TABLE IV

ERRORS IN MECHANICAL ANALYSIS.
(after Wentworth)

	Source	Result
COLLECTING	Sample not well located.	General error.
	Sample too small.	Large errors in coarse grades.
	Outcrop not well cleaned.	Increase in either fine or coarse grades.
	Selective accidental loss in collecting.	Decrease in either fine or coarse grades.
	Subsequent loss from containers.	Decrease in either fine or coarse grades.
PREPARATION	Unsound splitting method.	Increase in either fine or coarse grades.
	Faulty splitting practice.	Increase in either fine or coarse grades.
	Splitting to too small fraction.	Large errors in coarse grades.
	Loss of fine grades on cloth or from blowing.	Decrease in fine grade.
	Error in assumption that fine grades washed from aggregates are normal.	Probable decrease in finest grades with increase in intermediate.
ANALYSIS	Errors in sieve opening ratings.	Local errors between grades.
	Nonuniform sieve openings.	Local errors between grades.
	Incomplete shaking.	General increase in coarseness indicated.
	Loss of fine grades by lodgement in sieves or elsewhere.	Decrease in finest grades.
	Errors in weighing	Local large error, small general error.
Computation and Plotting	Errors due to use of slide rule.	Small local errors
	Errors in plotting.	Small local errors

A TEXTURAL ANALYSIS OF THE BEDFORD SHALE
OF LORAIN COUNTY, OHIO

PART III

RESULTS OF THE INVESTIGATION

A TEXTURAL ANALYSIS OF THE BEDFORD SHALE OF LORAIN COUNTY, OHIO

PART III

RESULTS OF THE INVESTIGATION

INTERPRETATION OF HISTOGRAMS

As stated in Part II of this thesis, percentages of the total weight for the various grades vary, depending on the diameters in millimeters. For convenience in presentation, however, the diameters in millimeters were plotted along the vertical _y_-axis and the percentage by weight along the horizontal _x_-axis in both histograms and cumulative curves.

Much may be learned about a sediment from the study of histograms alone. In the first place, a histogram will show that there is a particular class which has the greatest frequency of grains, and that the frequency decreases on either side. This class of greatest frequency is called the modal class. Too, a histogram will show whether the rest of the grains tend to cluster about the modal class or to spread symmetrically or unsymmetrically on either side.

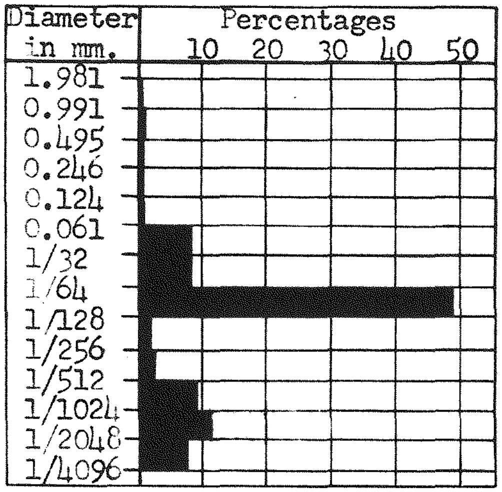
The small sandstone lenses found in the lower beds of the blue-gray facies of the Bedford shale have a conspicuous modal class in the sieve sizes - in a grade corresponding to Wentworth's "coarse sand." It should be noted, however, that the grains falling in this modal class (0.991 - 0.495 mm.) are for the most part aggregates. These aggregates are so firmly cemented as to act as a unit, and it is probable that they were in aggregate form on original deposition.

As may be seen from the histogram of one of these sandstone lenses (Fig.12a - Locality 1 - Specimen 2), there is no tendency for the grains to cluster around the most prevalent size, but they are spread widely in the finer grades, showing a poor degree of sorting.

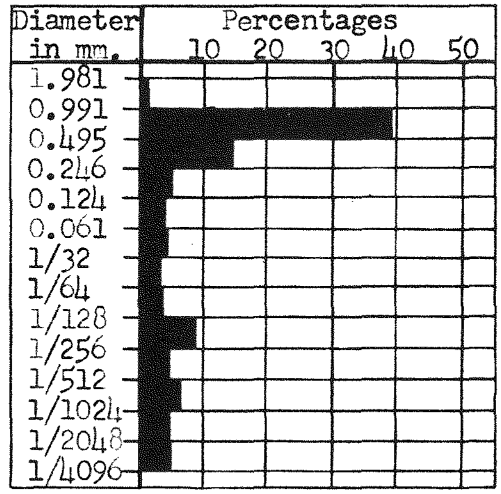
The shale layers of the blue-gray facies of the Bedford show much variation with outcrop, with the modal class ranging from silt to clay sizes. The grains show more grouping around the prevalent size than is true of the sandstone lenses. Generally, however, this grouping is not symmetrical, and this facies of the Bedford cannot be considered as well sorted.

The red facies of the Bedford shows much better grouping around the modal class, which in general is located in the clay sizes. The red facies as a whole, then, consists of smaller grains and shows a better degree of sorting than either the sandstone lenses or the blue-gray shale.

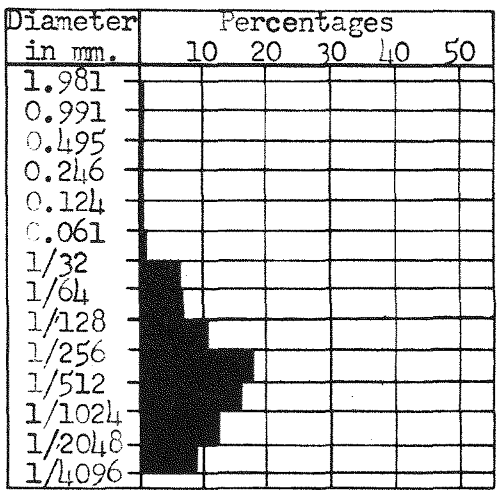
TEXTURAL ANALYSIS -- HISTOGRAMS



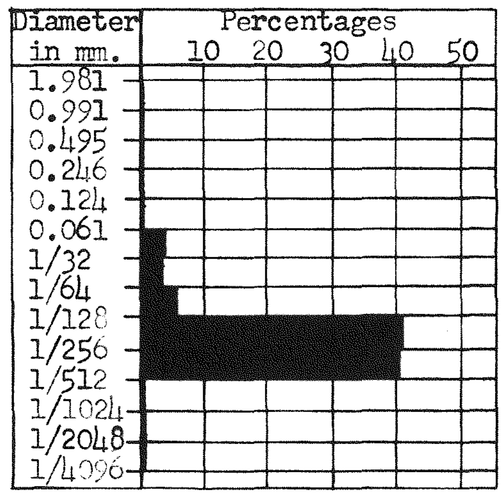
Locality 1 - Specimen 1



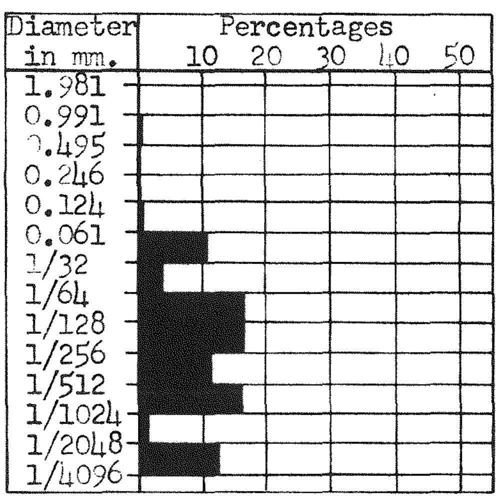
Locality 1 - Specimen 2



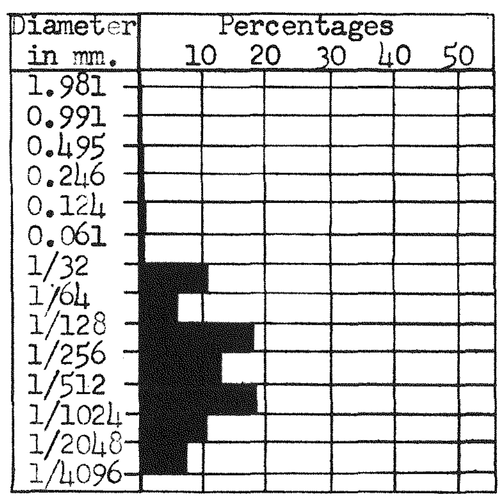
Locality 1 - Specimen 5



Locality 1 - Specimen 6



Locality 1 - Specimen 7



Locality 3 - Specimen 1

Fig. 6a

TEXTURAL ANALYSIS -- HISTOGRAMS

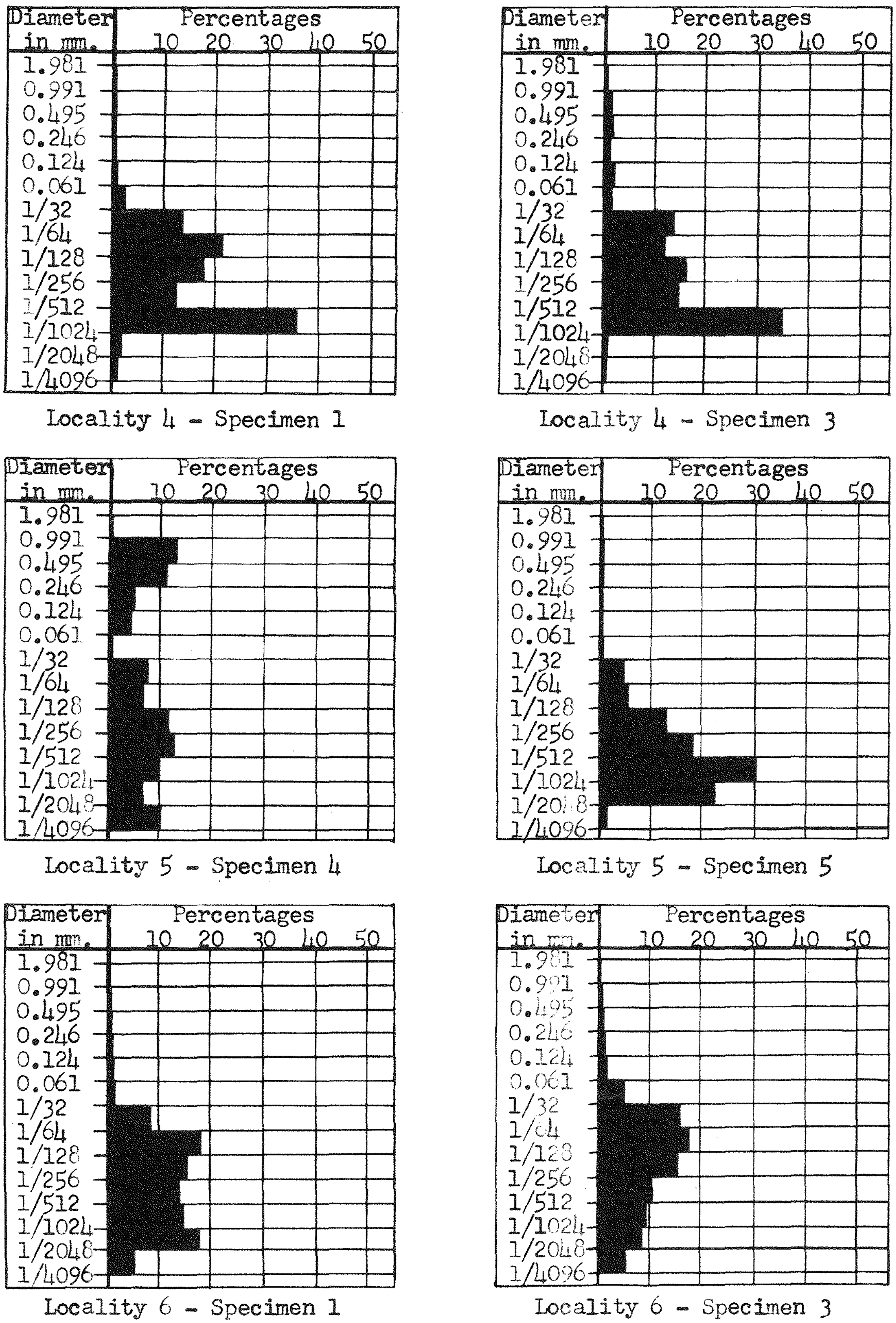
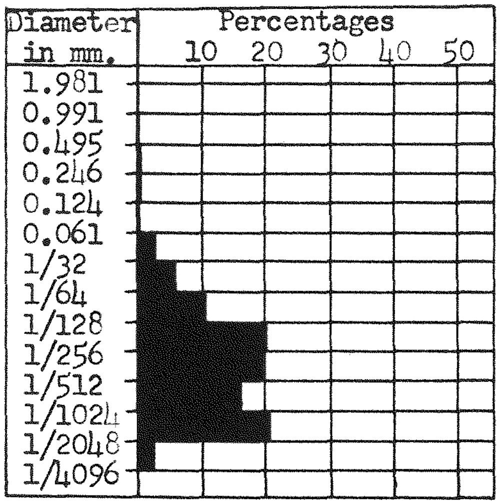
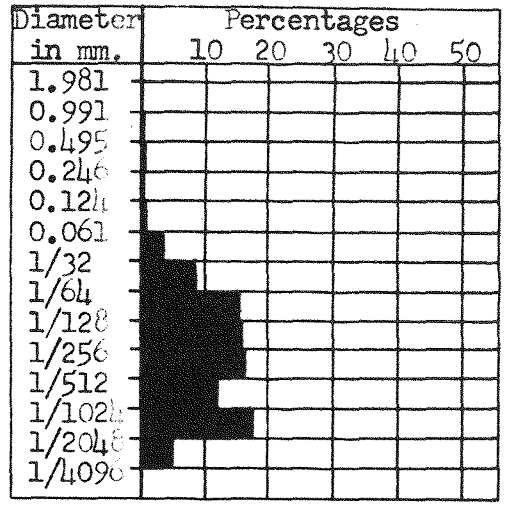


Fig. 6b

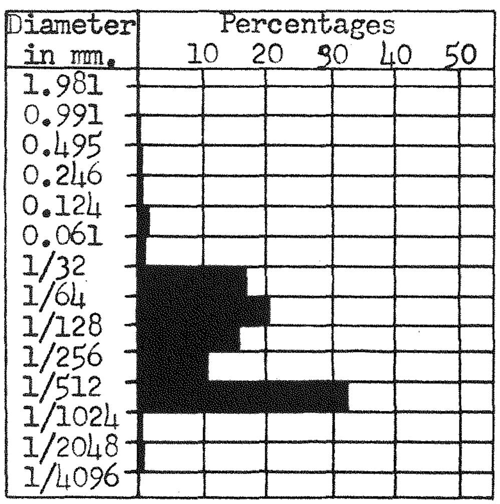
TEXTURAL ANALYSIS — HISTOGRAMS



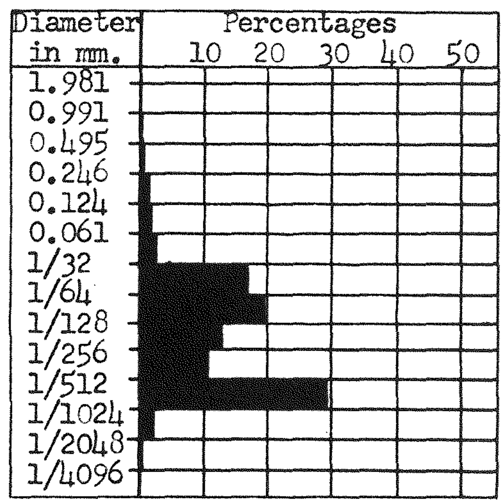
Locality 7 - Specimen 1



Locality 7 - Specimen 2



Locality 8 - Specimen 1



Locality 8 - Specimen 3

Fig. 6c

INTERPRETATION OF CUMULATIVE CURVES

Although based on the original histogram data, the cumulative curve is more useful than the histogram. From the cumulative curve one may determine the coefficient of sorting, the quartile intervals, coefficient of skewness, and other such statistical measures. In other words, the cumulative curve is a more reliable index of the nature of the continuous frequency distribution than is the histogram.

The cumulative curves are constructed with the smallest grain sizes at one end of the y-axis and a continuous gradation upward to the largest size at the other end. With such an arrangement it is possible to use the quartile method of statistical measures.[21]

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[21] Krumbein and Pettijohn - op. cit., p. 223

The average sized particle is represented by the middlemost of the group, and is called the median. One-half the weight of the analyzed sample is composed of grains larger in diameter than the median, and one-half of grains smaller in diameter. The median may be quickly determined from a cumulative curve (broken line lettered M in accompanying cumulative curves).

Two other particles are measured in order to determine the coefficient of sorting and of skewness (measure of degree of asymmetry). The first is just larger than one-fourth of the distribution (the first quartile - Q_1 on cumulative curves), and the second is just larger than three-fourths of the distribution (the third quartile - Q_3 on cumulative curves). Thus, one-fourth of the specimen is composed of grains larger in diameter than Q_1, and one-fourth of grains smaller in diameter than Q_3.

The first quartile, median, and third quartile divide the size distribution into four equal parts, called quartile intervals.

It is also very desirable to know the degree of sorting of the sediment. It is obvious that the closer Q_1 and Q_3 are to each other, the better the specimen is sorted. The coefficient of sorting, So, is the measure of the degree of sorting of the specimen. So is computed according to the following formula:

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

Trask[22] found from a study of 170 sediments that

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[22]Trask, P. D. - Origin and Environment of Source Sediments of Petroleum; p. 71-72, 1932.

---

a value for So of less than 2.5 indicated a well-sorted sediment; that a value greater than 4.5 indicated a poorly sorted sediment; and that a value of about 3.0 indicated a normally sorted sediment.

While the coefficient of sorting indicates the degree of plentifulness of particles of approximately the same size as the median diameter, it does not help to determine the position of the mode. The mode is defined as the point of maximum sorting in the sample. The coefficient of skewness indicates the position of the mode.

The coefficient of skewness, Sk, is computed according to the formula

$$Sk = Q_1 \times Q_3/M^2$$

It is also necessary to give the logarithm of the coefficient of skewness, else it is difficult to know in just which quartile interval the mode lies.

Trask summarizes the interpretation of the coefficient of skewness as follows: "if Sk is greater than 1.0 or log Sk positive, the maximum sorting of the constituents lies on the fine side of the median; if Sk is less than 1.0, or log Sk negative, the mode is on the coarse side of the median; if Sk is about 1.0 or log Sk near 0, the maximum sorting corresponds approximately with the median; and the greater the divergence of Sk from 1.0, or log Sk from 0, the farther the mode lies from the median."[23]

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[23] Trask, P. D. - *ibid.*, p. 73

Table V lists the above details of mechanical analyses. For convenience in comparison, the values for the sandstone lens are listed at the top of the table, followed by the values for the blue-gray facies and the red facies in that order. Under Sample the first number applies to the locality, the second number to the specimen.

TABLE V

DETAILS OF MECHANICAL ANALYSES

Sample	Q_1 in mm.	M. in mm.	Q_3 in mm.	So.	Log Sk.	Sk.
B-1-2	0.71500	0.33500	0.00650	10.50	-1.383	0.041
B-1-1	0.01460	0.01200	0.00134	3.51	-0.870	0.135
B-4-3	0.01090	0.00359	0.00154	2.66	0.115	1.302
B-5-4	0.20990	0.00698	0.00164	11.31	0.849	7.065
B-5-5	0.00368	0.00172	0.00091	6.35	0.054	1.132
B-6-1	0.00868	0.00272	0.00089	3.12	0.018	1.042
B-7-1	0.00610	0.00252	0.00096	2.52	-0.035	0.922
B-8-3	0.01380	0.00484	0.00153	3.00	-0.045	0.902
B-1-5	0.00363	0.00142	0.00041	2.98	-0.132	0.738
B-1-6	0.00584	0.00408	0.00322	1.34	0.053	1.130
B-1-7	0.00946	0.00301	0.00070	3.67	-0.136	0.731
B-3-1	0.00684	0.00204	0.00066	3.22	0.035	1.085
B-4-1	0.01140	0.00482	0.00166	2.62	-0.089	0.814
B-6-3	0.01450	0.00508	0.00100	3.81	-0.250	0.562
B-7-2	0.00858	0.00292	0.00086	3.16	-0.064	0.865
B-8-1	0.01225	0.00450	0.00147	2.89	-0.051	0.889

The small sandstone lens with a value for So equal to 10.50 and a value for Sk equal to 0.041 (log Sk equal -1.383), is a poorly sorted sediment with the mode on the coarse side of the median. The mode is farther from the median in this specimen than in any other.

The blue-gray facies of the Bedford has values for So ranging from 2.52 to 11.31, with the average value of 4.78 (or if specimen B-5-4 is disregarded, an average value of 3.53). In either case, a comparison with Trask's results indicate that the blue-gray facies of the Bedford are, as a whole, only poorly to moderately sorted.

The average coefficient of skewness for the blue-gray facies is 1.786 and the corresponding logarithm is 0.252. This indicates that the maximum sorting of the constituents lies on the fine side of the median.

Two of the specimens listed above (B-4-3 and B-6-1) as being a part of the blue-gray facies were collected at the contact with the overlying Berea sandstone, and above the red facies rather than below as is the usual order. The average So value of these two specimens is 2.89, and the average Sk value is 1.172, with the corresponding logarithm of 0.069. These values would indicate that these two specimens are much more like the red facies than they are like the blue-gray facies of the Bedford. If these specimens should be treated as an altered part of the red facies (as proposed in "Conclusions"), the average So value for the blue-gray facies would be increased to greater than 5, indicating an even less degree of sorting than given above. A similar increase would result in the Sk value, indicating that the maximum sorting of constituents lies even more on the fine side of the median than is shown above.

The red facies of the Bedford has values for So ranging from 1.34 to 3.81 with the average value of 2.96. A comparison with Trask's results show this facies to be normally sorted.

The average coefficient of skewness for the red facies is 0.852 with the corresponding logarithm being -0.069. This would indicate that the maximum sorting of the constituents lies but slightly on the coarse side of the median.

That the mode of the red facies will lie on the coarse side of the median might have been deduced directly from the cumulative curves, for in most of the specimens the median is closer to Q_1 than to Q_3. Similarly, it may be seen that the mode lies on the fine side of the median if the maximum concentration of particles of similar diameter occurs in the third quartile interval.

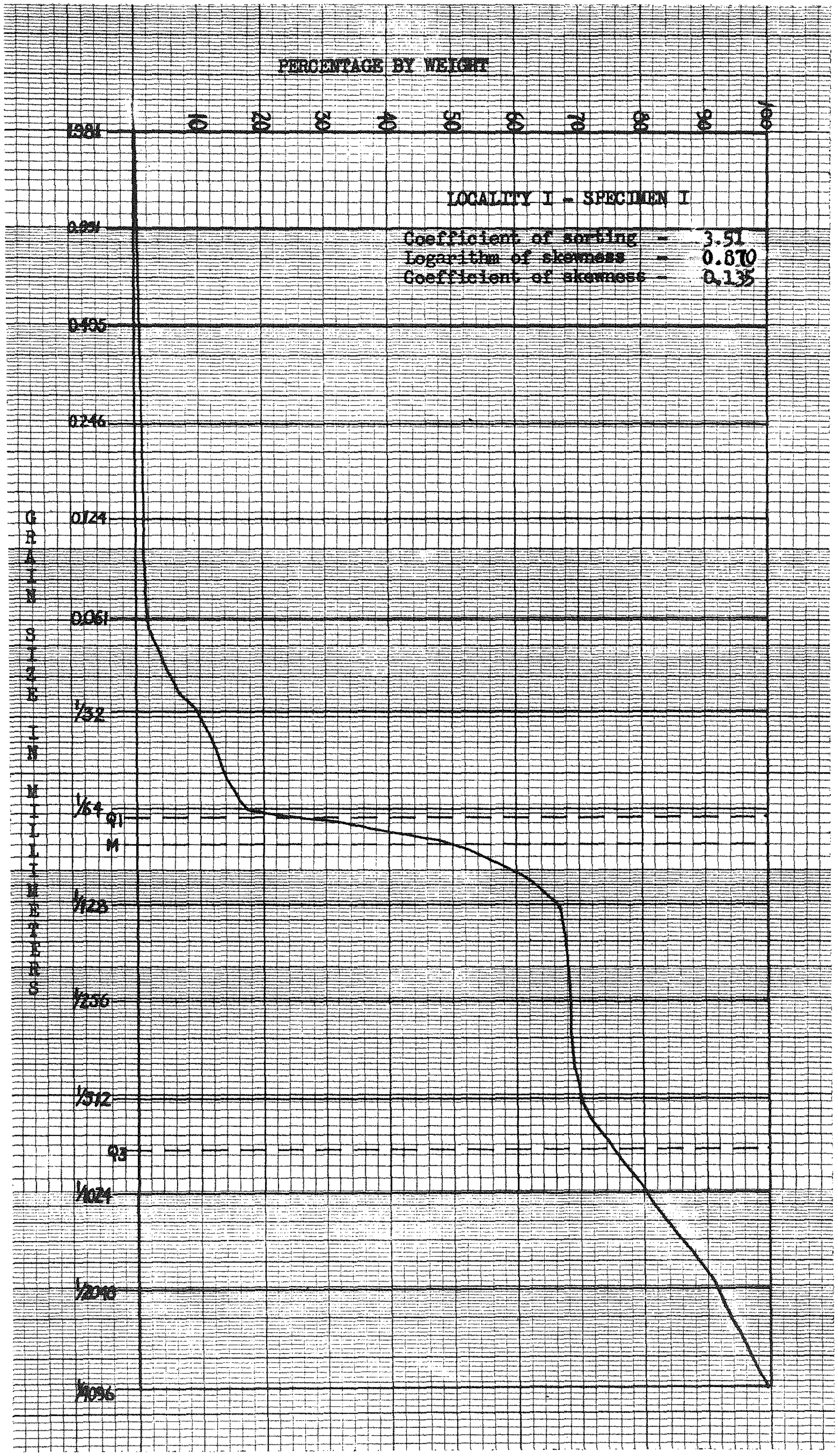
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY I - SPECIMEN I
Coefficient of sorting - 3.51
Logarithm of skewness - 0.810
Coefficient of skewness - 0.135
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
M
1/128
1/256
1/512
Q3
1/1024
1/2048
1/4096

Fig. 7

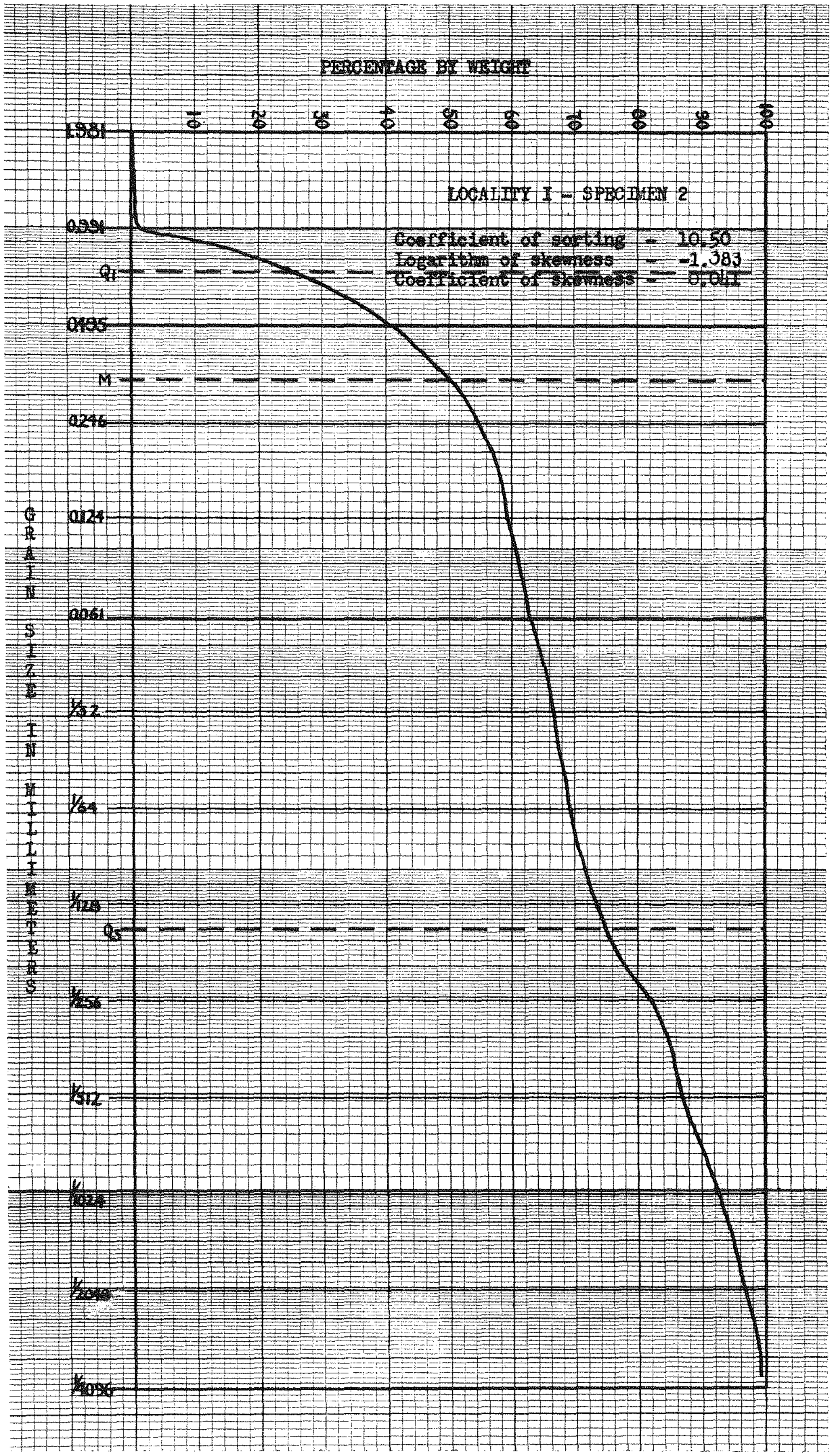
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY I - SPECIMEN 2
Coefficient of sorting - 10.50
Logarithm of skewness - -1.383
Coefficient of skewness - 0.041
1.981
0.991
Q1
0.495
M
0.246
0.124
0.061
1/32
1/64
1/128
Q3
1/256
1/512
1/1024
1/2048
1/4096
GRAIN SIZE IN MILLIMETERS

Fig. 8

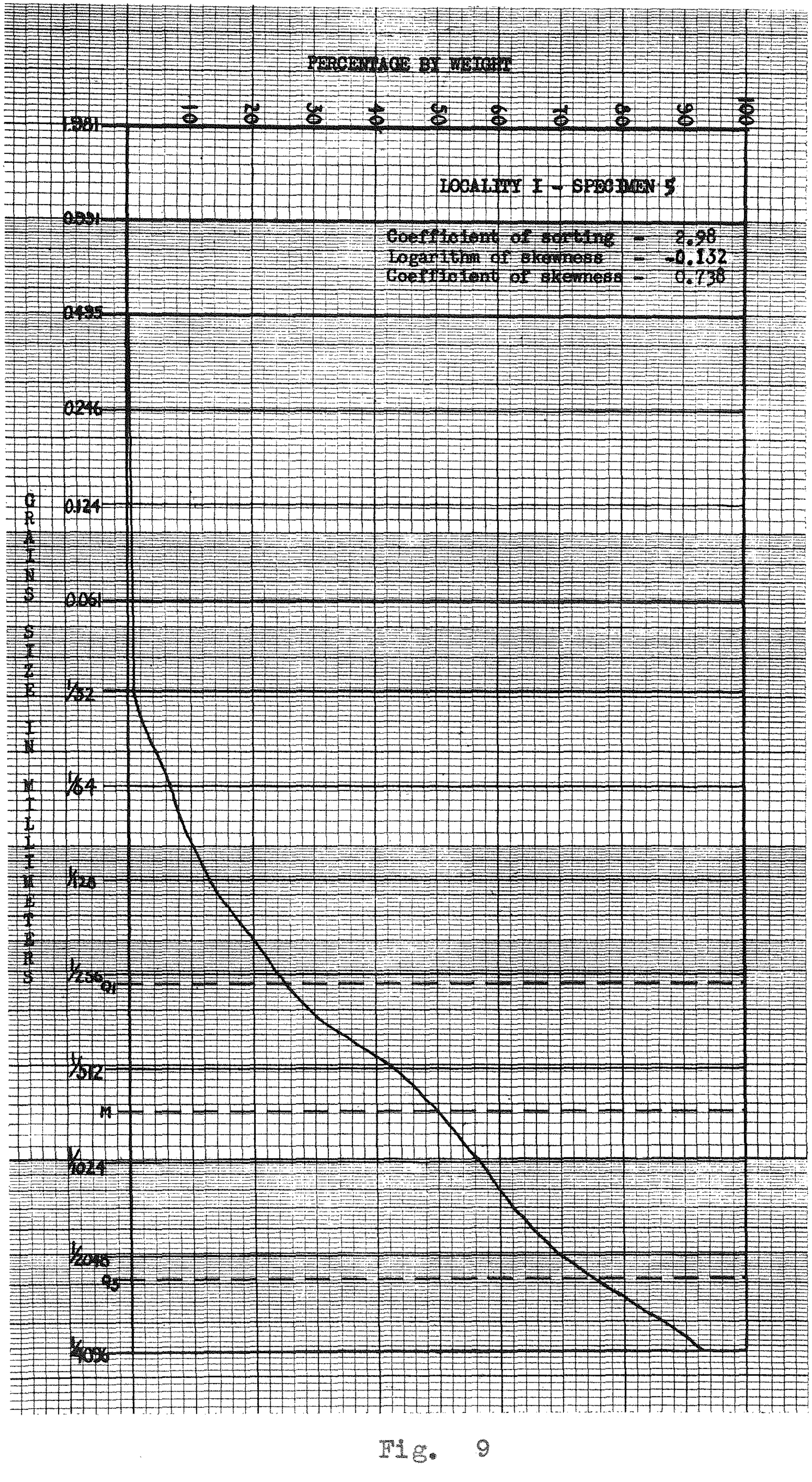
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY I - SPECIMEN 5
Coefficient of sorting - 2.98
Logarithm of skewness - -0.132
Coefficient of skewness - 0.738
GRAINS SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
1/256
Q1
1/512
M
1/1024
1/2048
Q3
1/4096

Fig. 9

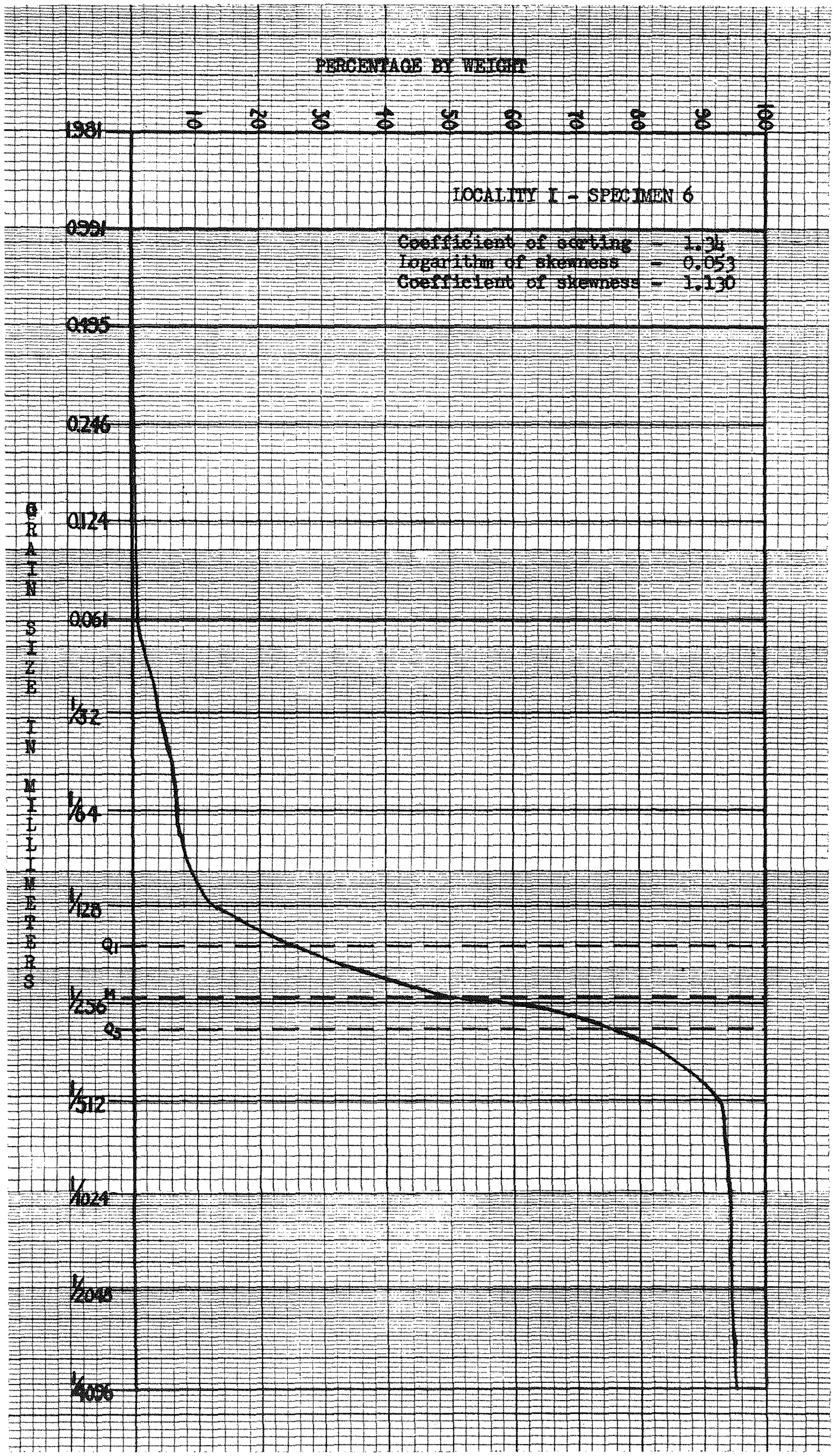
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY I - SPECIMEN 6
Coefficient of sorting - 1.34
Logarithm of skewness - 0.053
Coefficient of skewness - 1.130
GRAIN SIZE IN MILLIMETERS
1981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
Q1
1/256
M
Q3
1/512
1/1024
1/2048
1/4096

Fig. 10

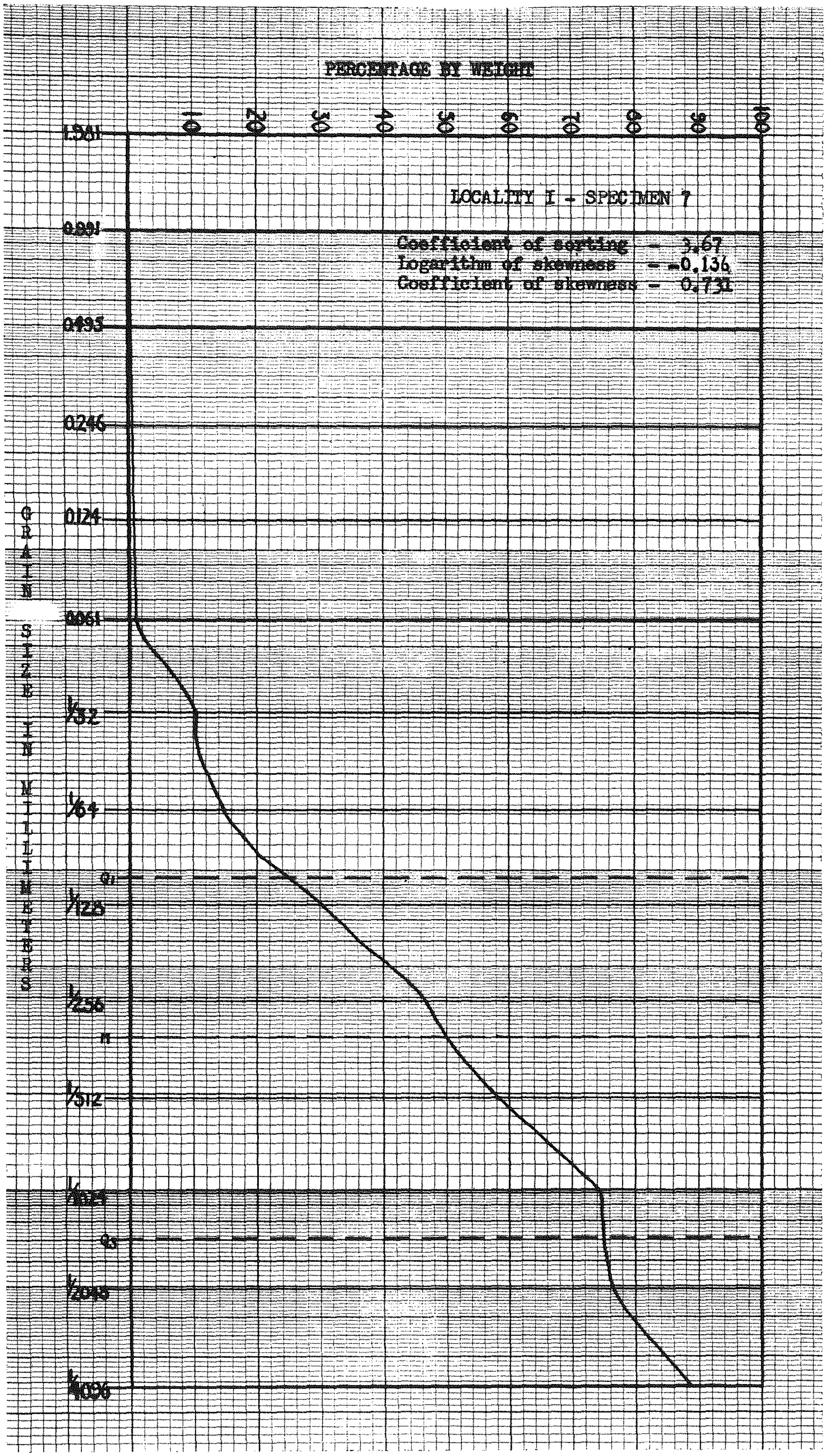
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY I - SPECIMEN 7
Coefficient of sorting - 3.67
Logarithm of skewness - -0.136
Coefficient of skewness - 0.731
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
1/256
M
1/512
1/1024
Q3
1/2048
1/4096

Fig. 11

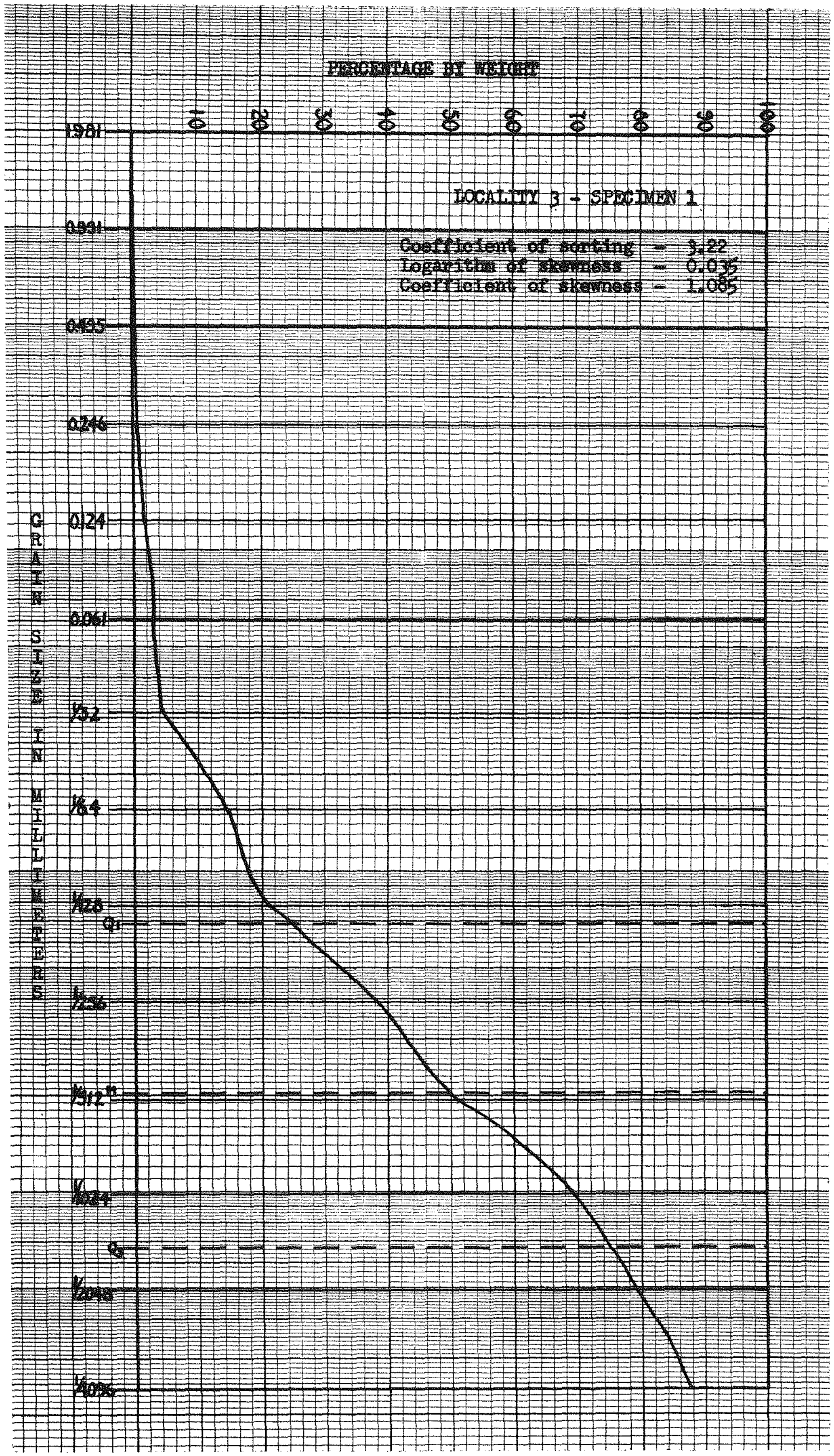
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 3 - SPECIMEN 1
Coefficient of sorting - 3.22
Logarithm of skewness - 0.035
Coefficient of skewness - 1.085
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
Q1
1/256
1/512
M
1/1024
Q3
1/2048
1/4096

Fig. 12

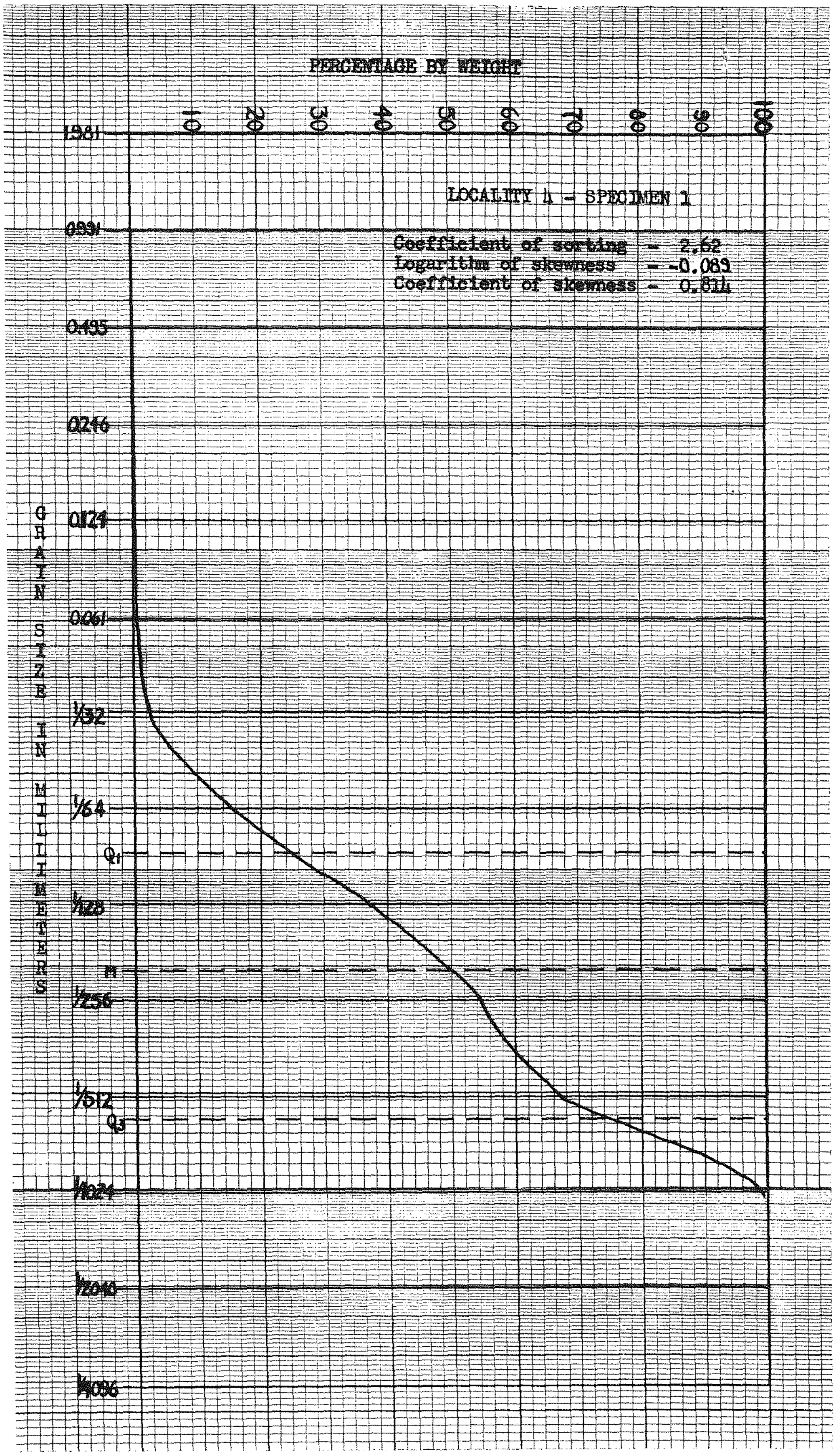
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 4 - SPECIMEN 1
Coefficient of sorting - 2.62
Logarithm of skewness - -0.089
Coefficient of skewness - 0.814
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
M
1/256
1/512
Q3
1/1024
1/2048
1/4096

Fig. 13

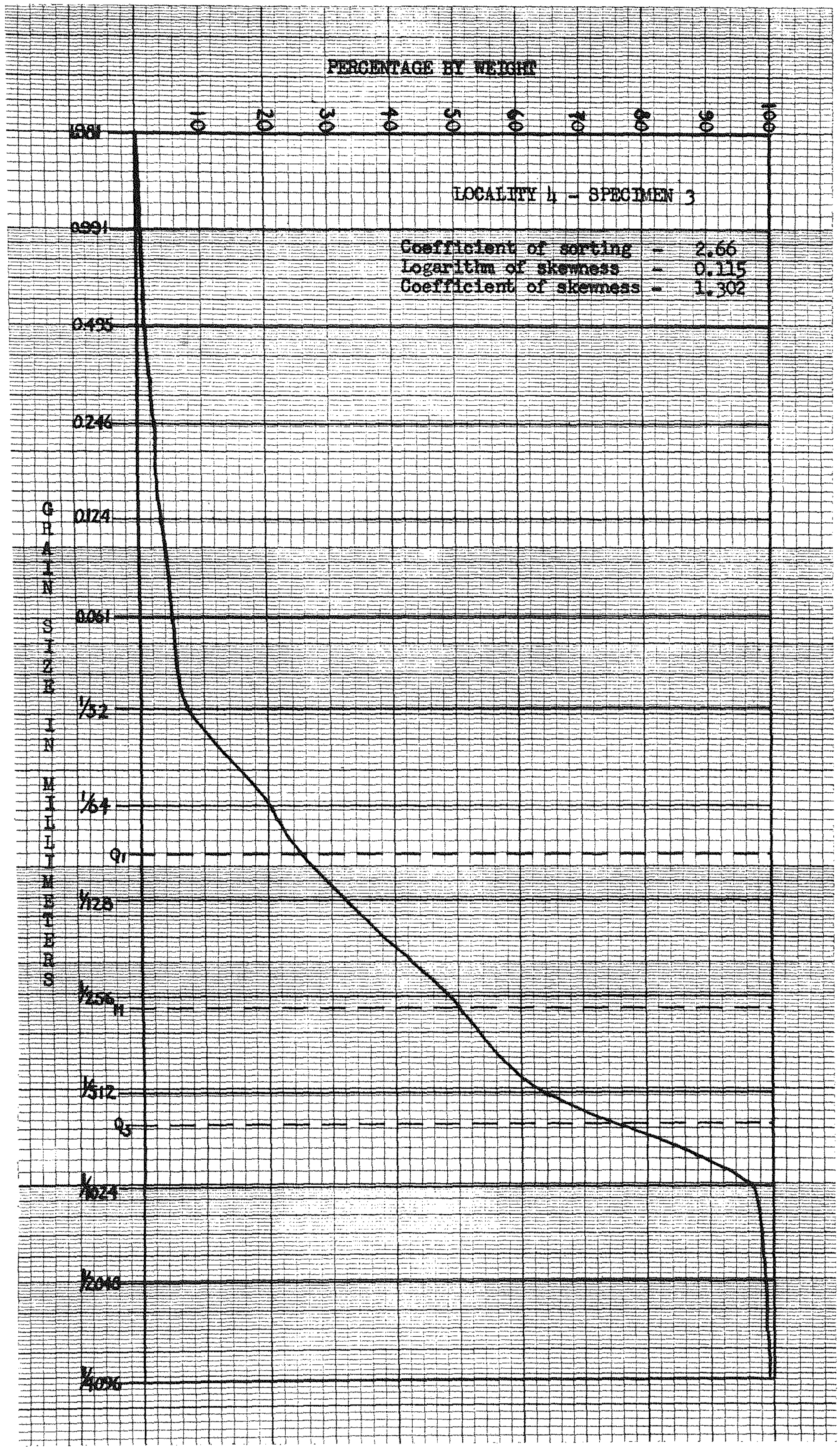
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 4 - SPECIMEN 3
Coefficient of sorting - 2.66
Logarithm of skewness - 0.115
Coefficient of skewness - 1.302
GRAIN SIZE IN MILLIMETERS
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
1/256
M
1/512
Q3
1/1024
1/2048
1/4096

Fig. 14

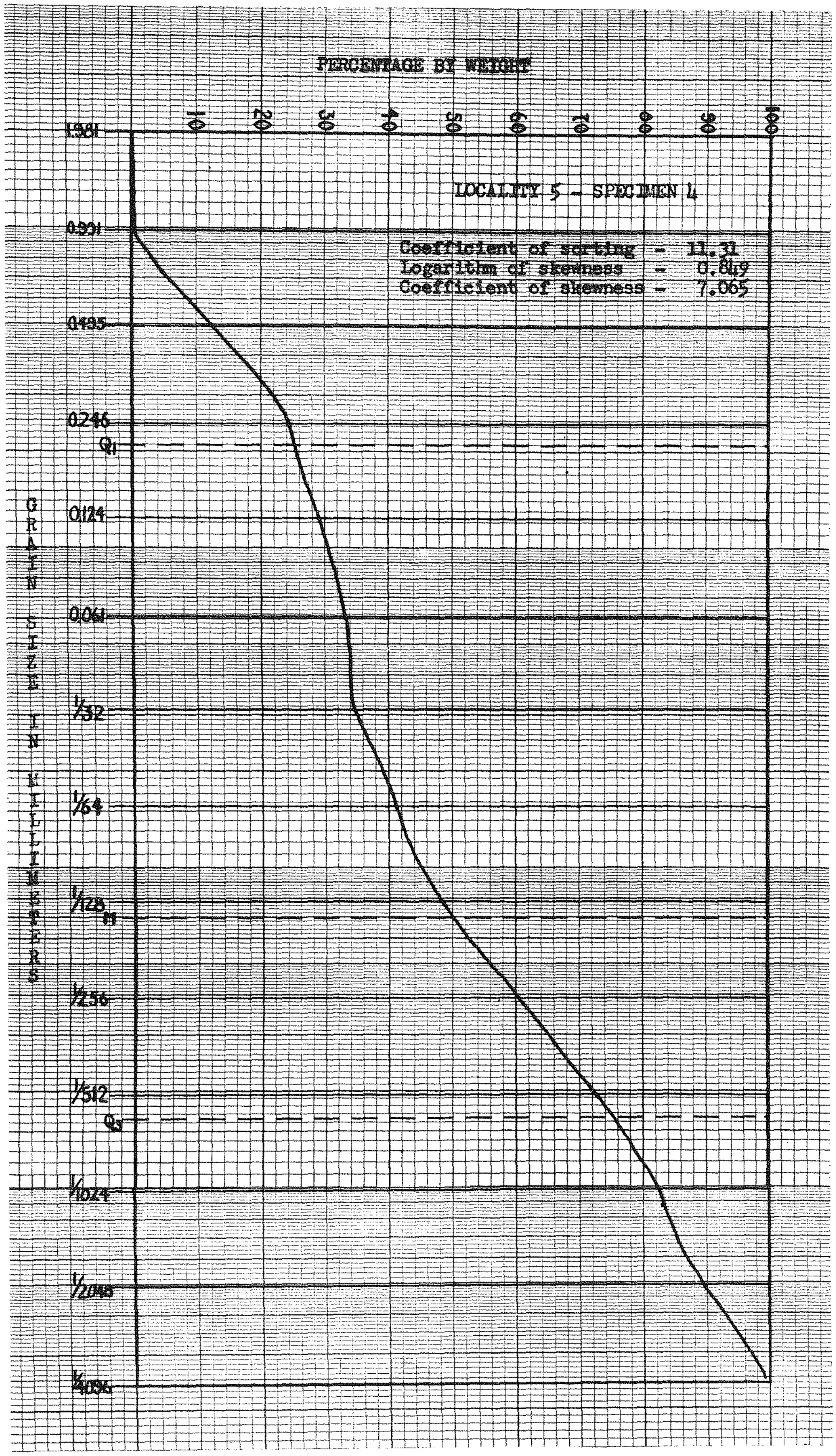
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 5 - SPECIMEN 4
Coefficient of sorting - 11.31
Logarithm of skewness - 0.849
Coefficient of skewness - 7.065
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
Q1
0.124
0.061
1/32
1/64
1/128
M
1/256
1/512
Q3
1/1024
1/2048
1/4096

Fig. 15

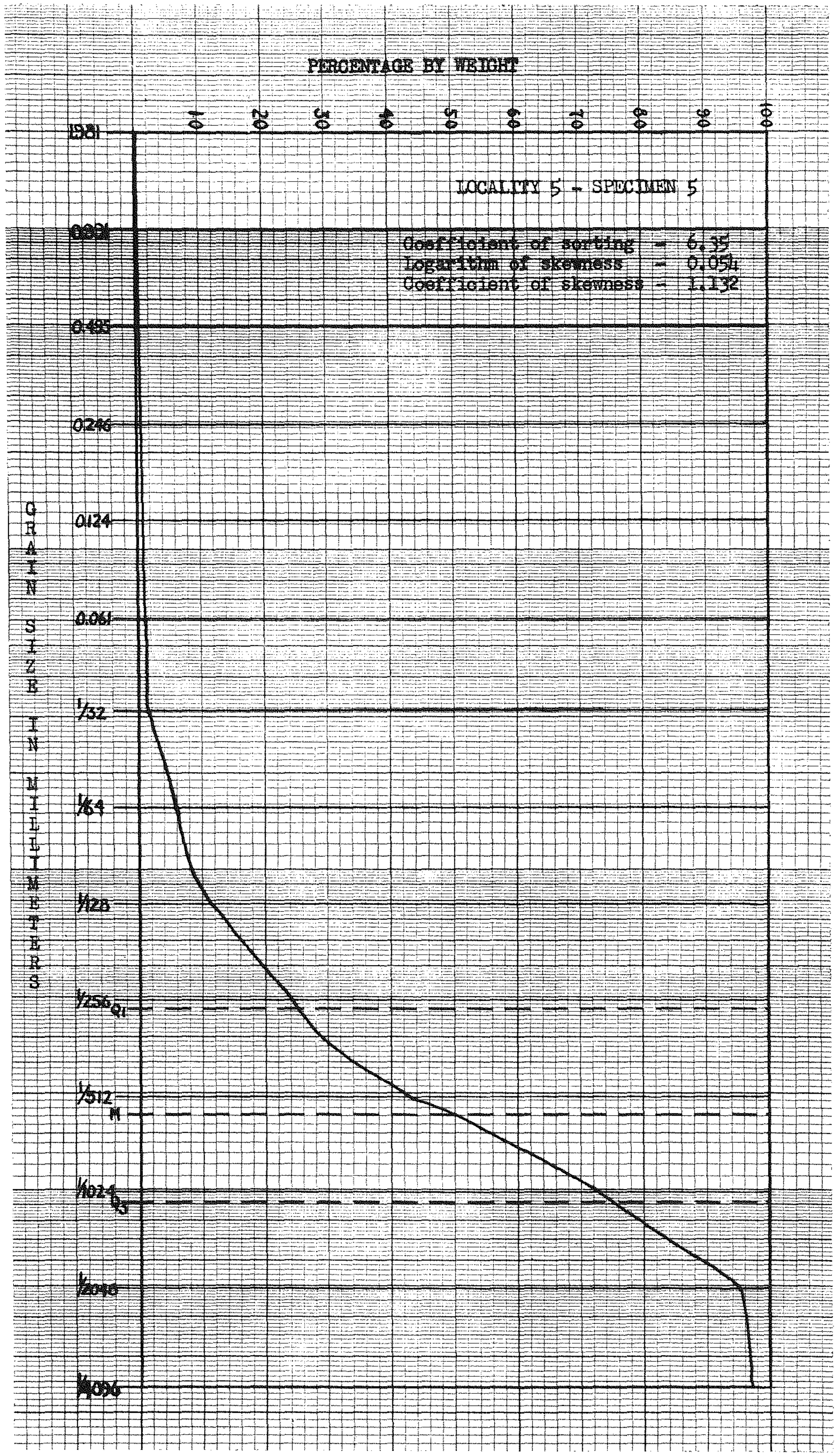
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 5 - SPECIMEN 5
Coefficient of sorting - 6.35
Logarithm of skewness - 0.054
Coefficient of skewness - 1.132
GRAIN SIZE IN MILLIMETERS
0.495
0.246
0.124
0.061
1/32
1/64
1/128
1/256
Q1
1/512
M
1/1024
Q3
1/2048
1/4096

Fig. 16

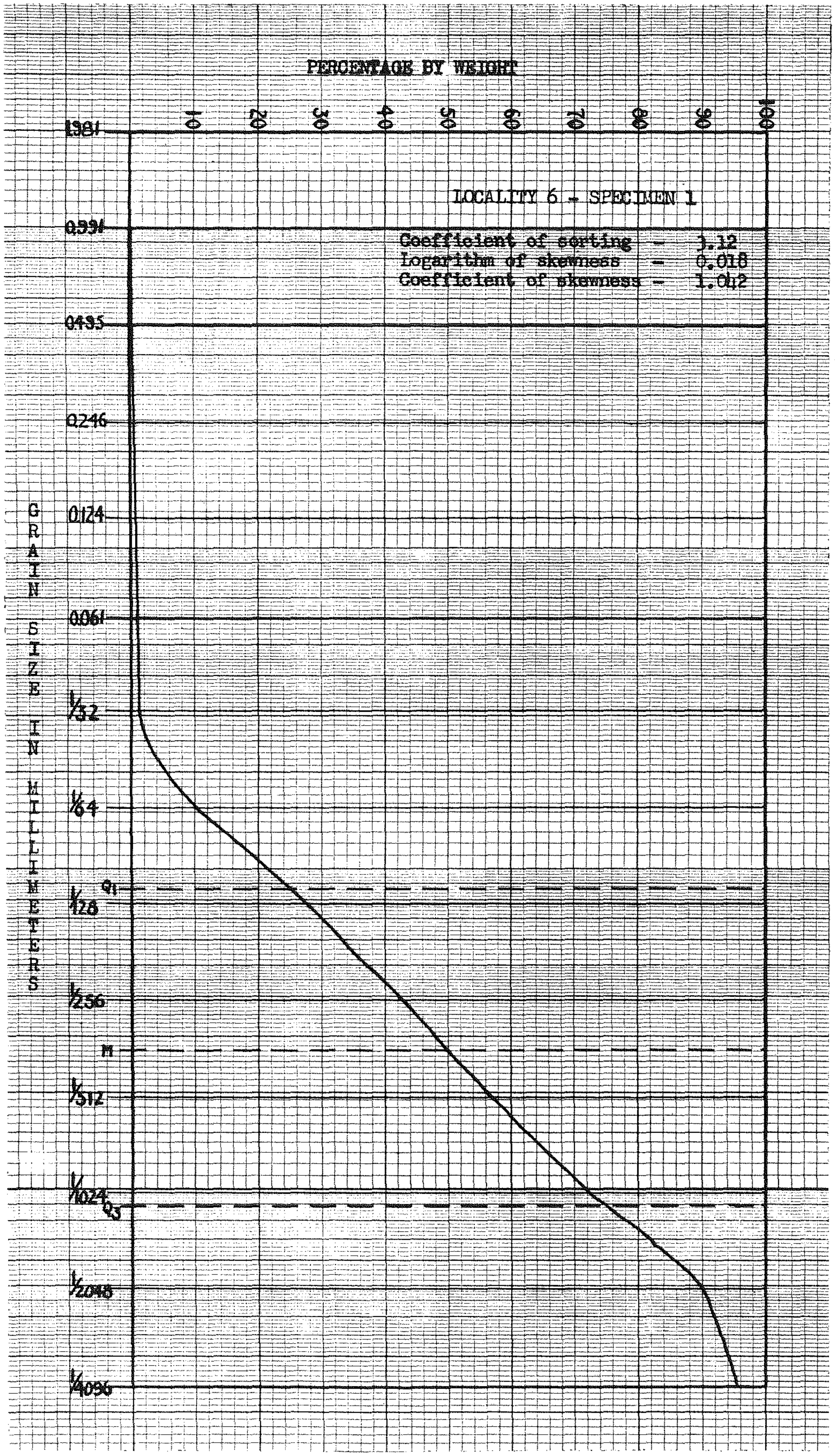
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 6 - SPECIMEN 1
Coefficient of sorting - 3.12
Logarithm of skewness - 0.018
Coefficient of skewness - 1.042
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
1/256
M
1/512
1/1024
Q3
1/2048
1/4096

Fig. 17

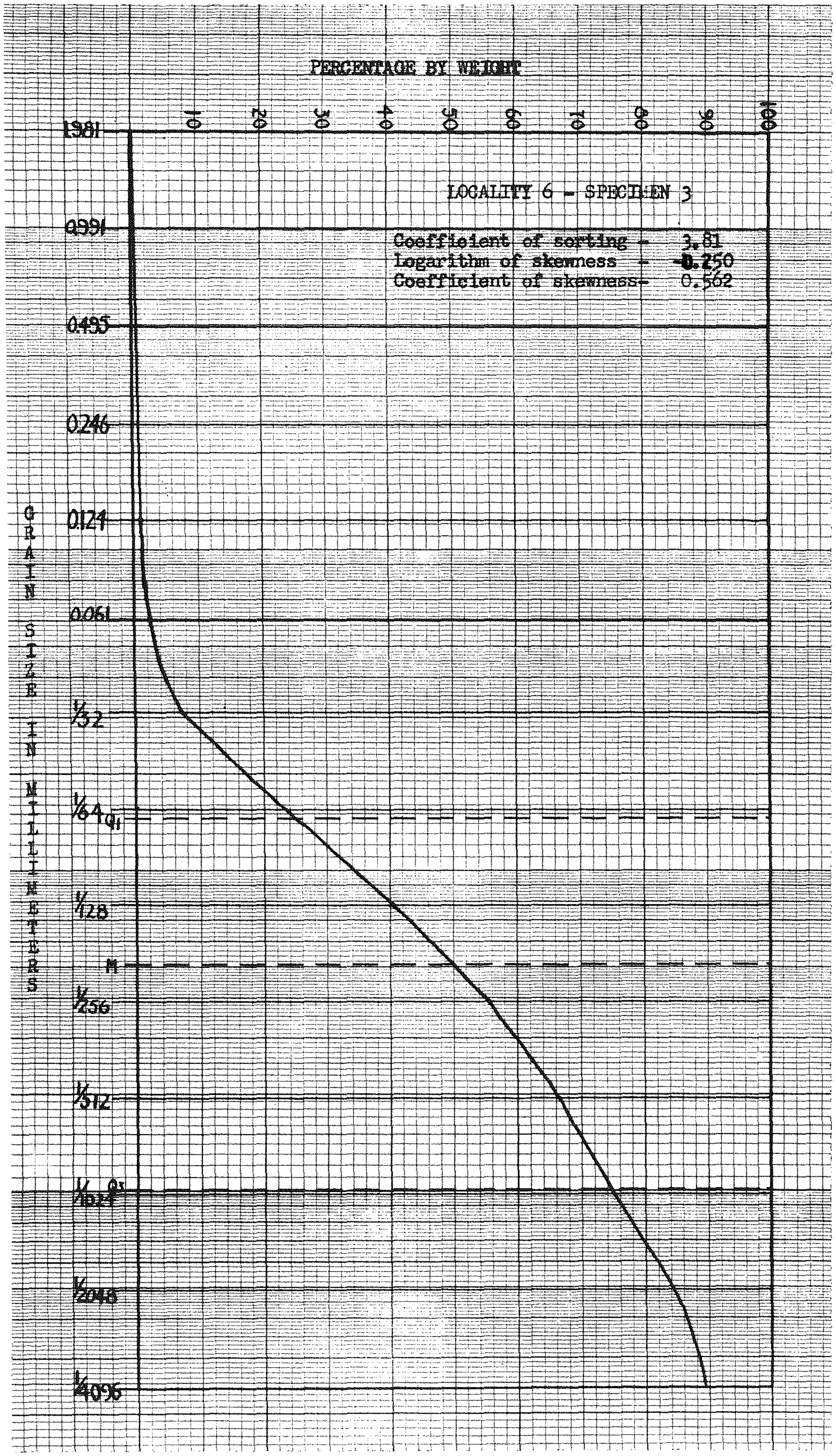
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 6 - SPECIMEN 3
Coefficient of sorting - 3.81
Logarithm of skewness - -0.250
Coefficient of skewness- 0.562
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
M
1/256
1/512
1/1024
Q3
1/2048
1/4096

Fig. 18

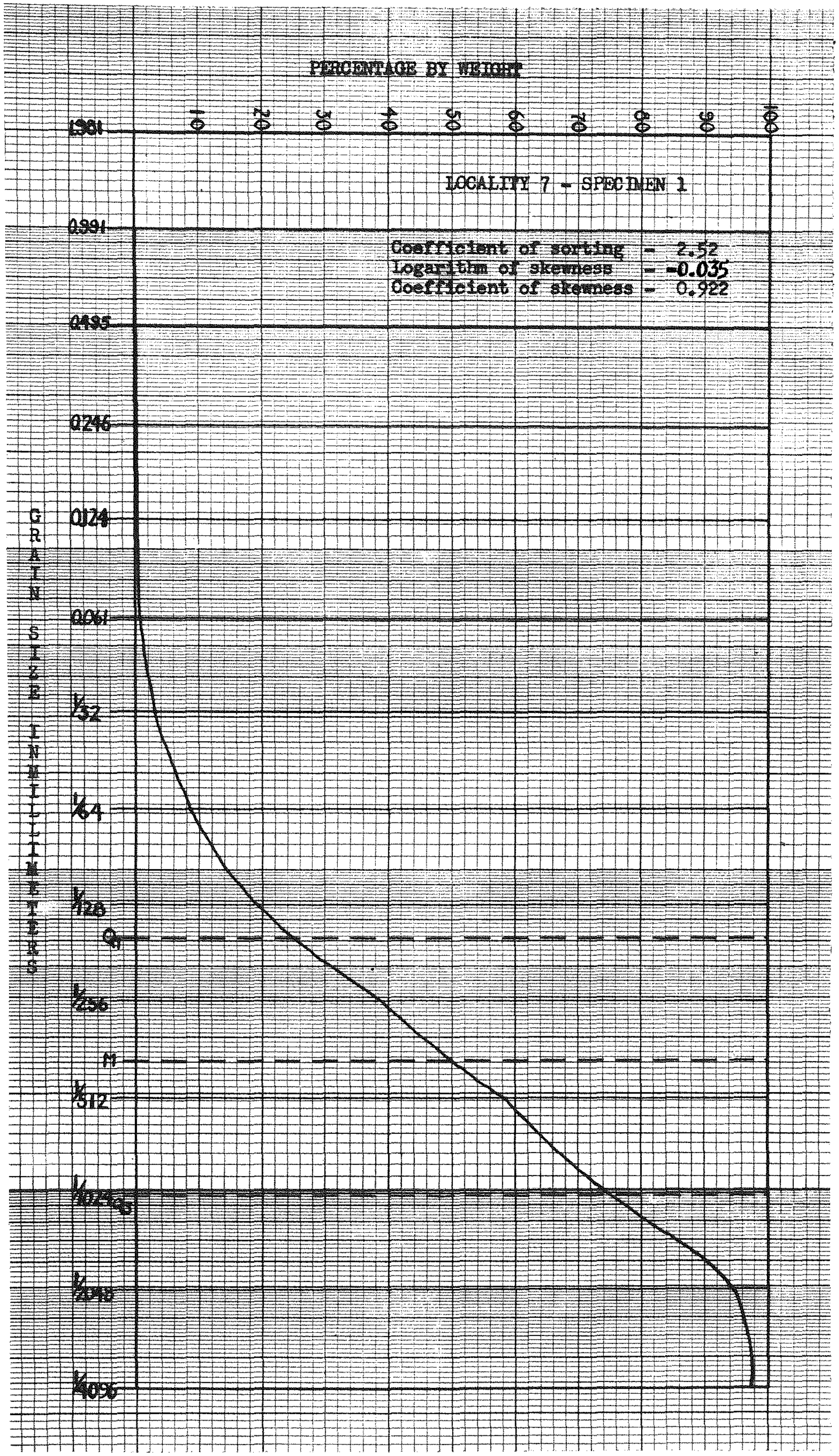
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 7 - SPECIMEN 1
Coefficient of sorting - 2.52
Logarithm of skewness - -0.035
Coefficient of skewness - 0.922
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
Q1
1/256
M
1/512
1/1024
Q3
1/2048
1/4096

Fig. 19

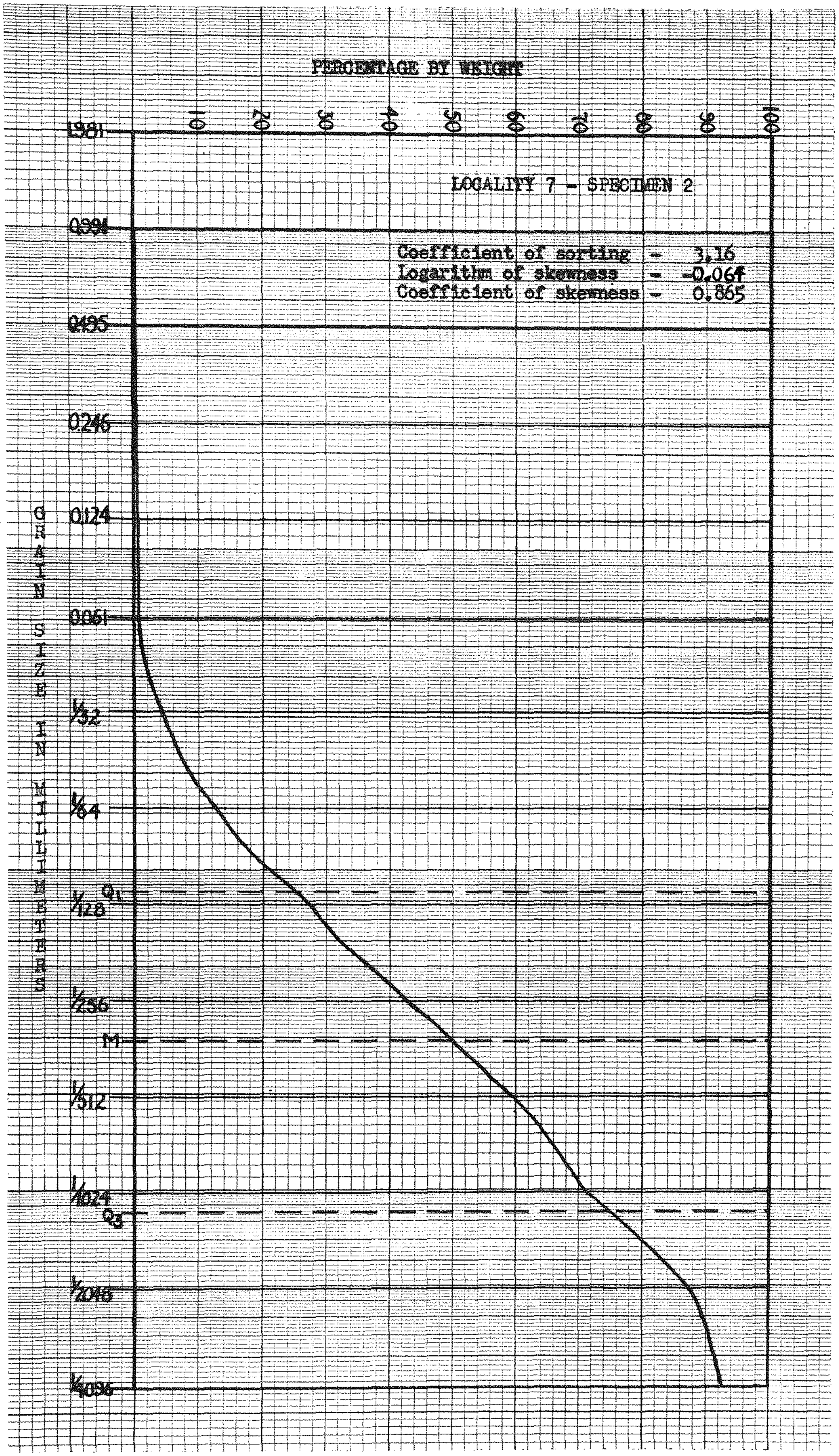
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 7 - SPECIMEN 2
Coefficient of sorting - 3.16
Logarithm of skewness - -0.064
Coefficient of skewness - 0.865
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
Q1
1/256
M
1/512
1/1024
Q3
1/2048
1/4096

Fig. 20

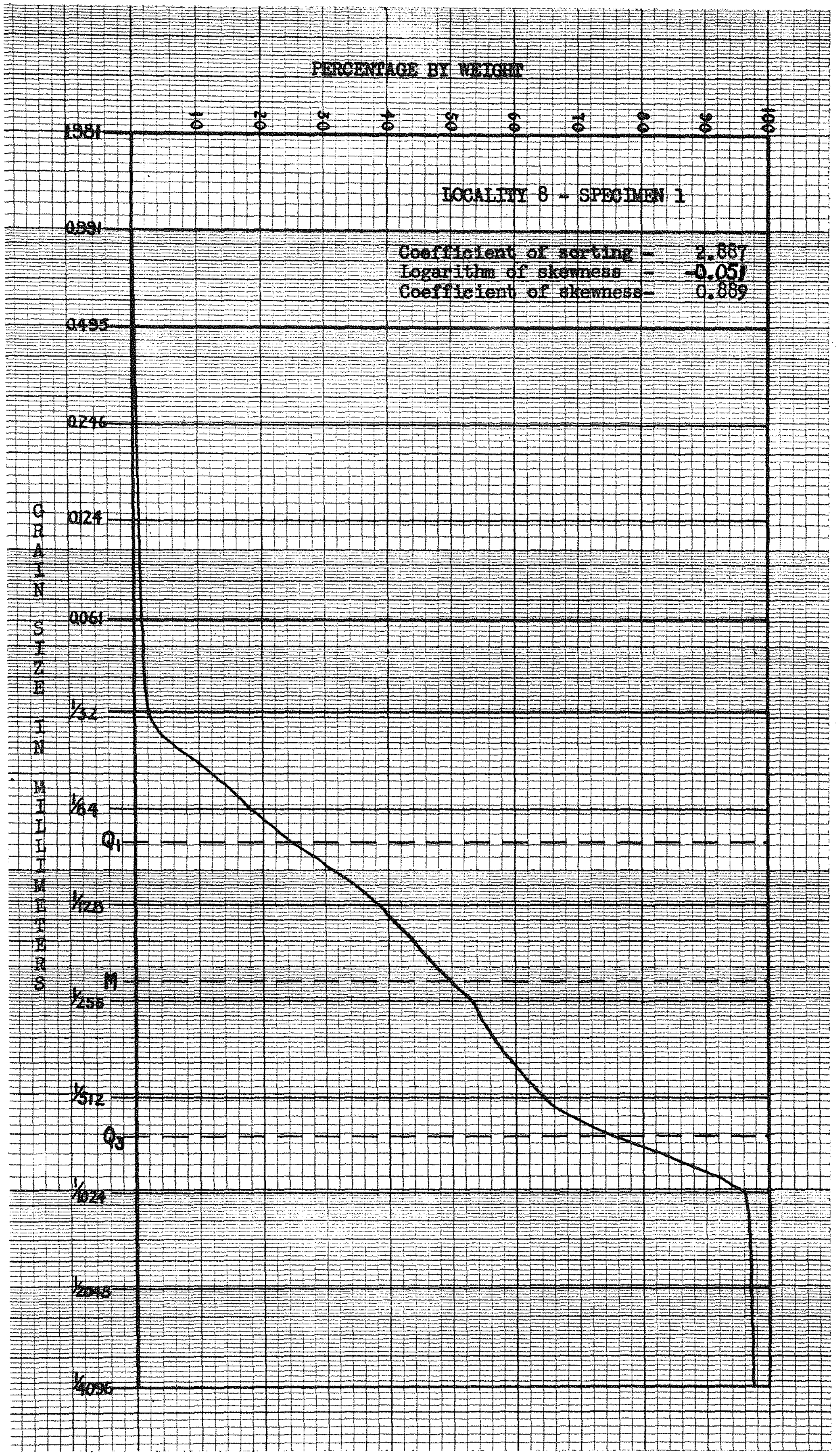
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 8 - SPECIMEN 1
Coefficient of sorting - 2.887
Logarithm of skewness - -0.051
Coefficient of skewness- 0.889
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
M
1/256
1/512
Q3
1/1024
1/2048
1/4096

Fig. 21

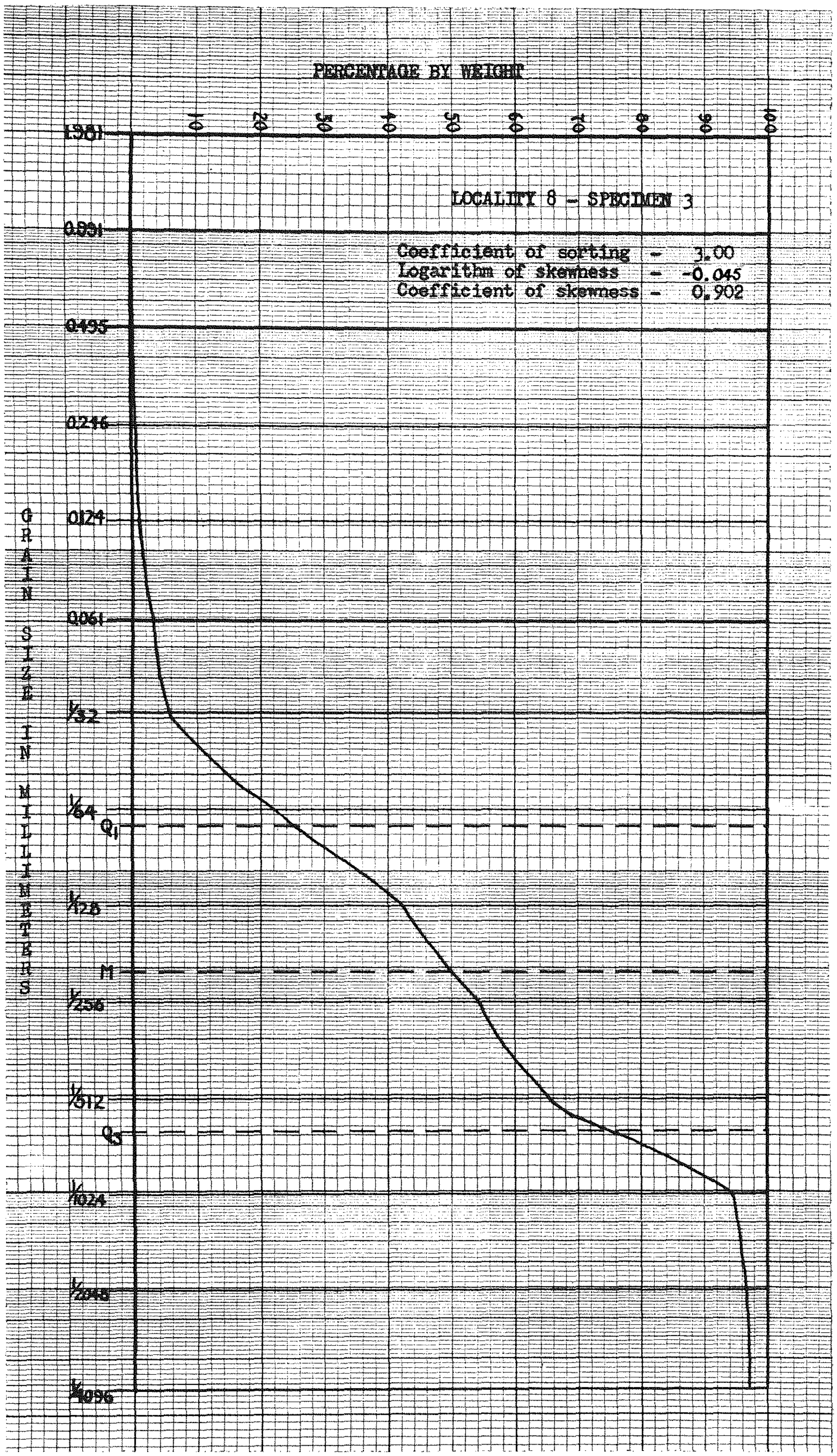
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
LOCALITY 8 - SPECIMEN 3
Coefficient of sorting - 3.00
Logarithm of skewness - -0.045
Coefficient of skewness - 0.902
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
Q1
1/128
M
1/256
1/512
Q3
1/1024
1/2048
1/4096

Fig. 22

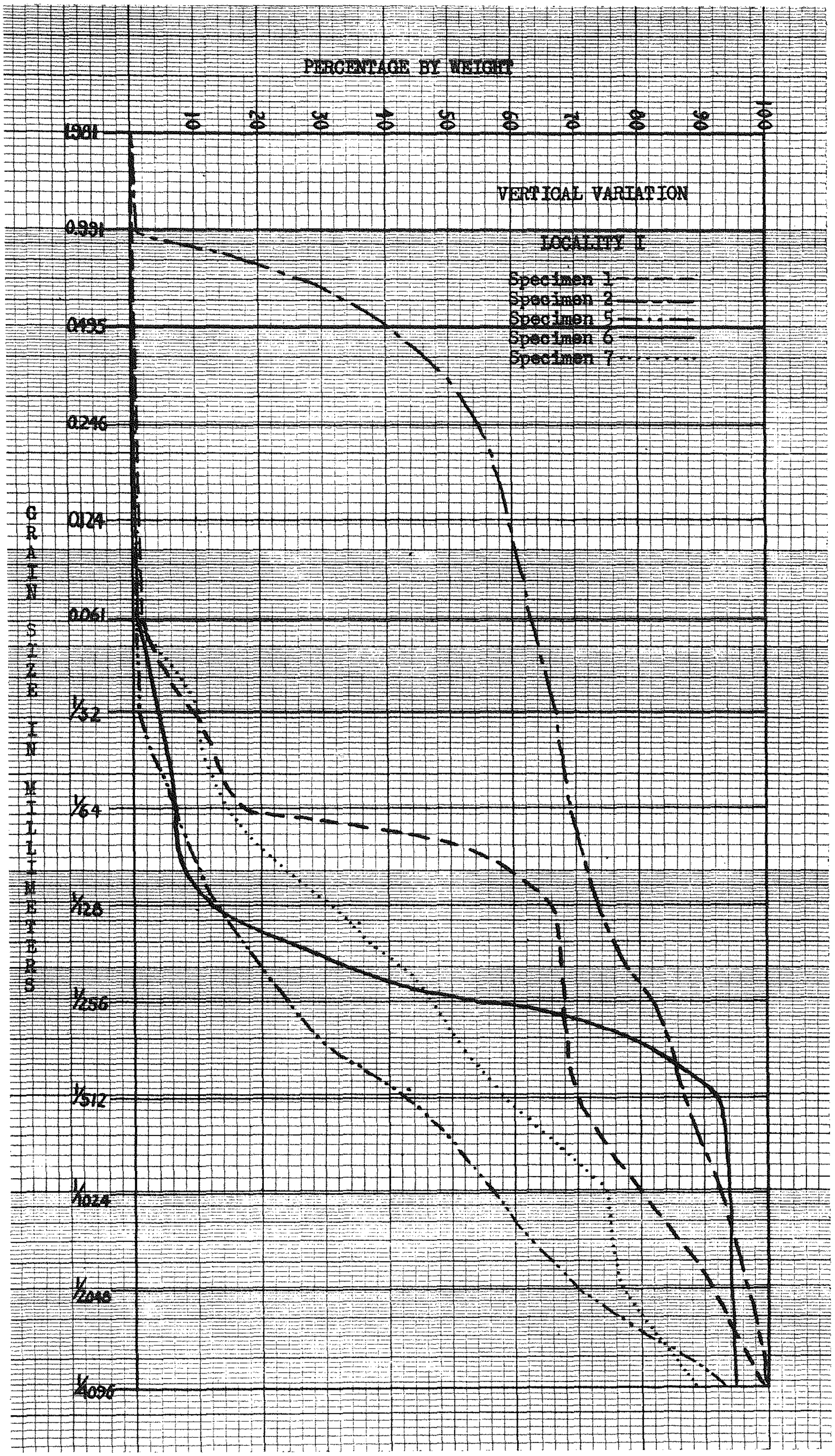
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
VERTICAL VARIATION
LOCALITY I
Specimen 1
Specimen 2
Specimen 5
Specimen 6
Specimen 7
GRAIN SIZE IN MILLIMETERS
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
1/256
1/512
1/1024
1/2048
1/4096

Fig. 23

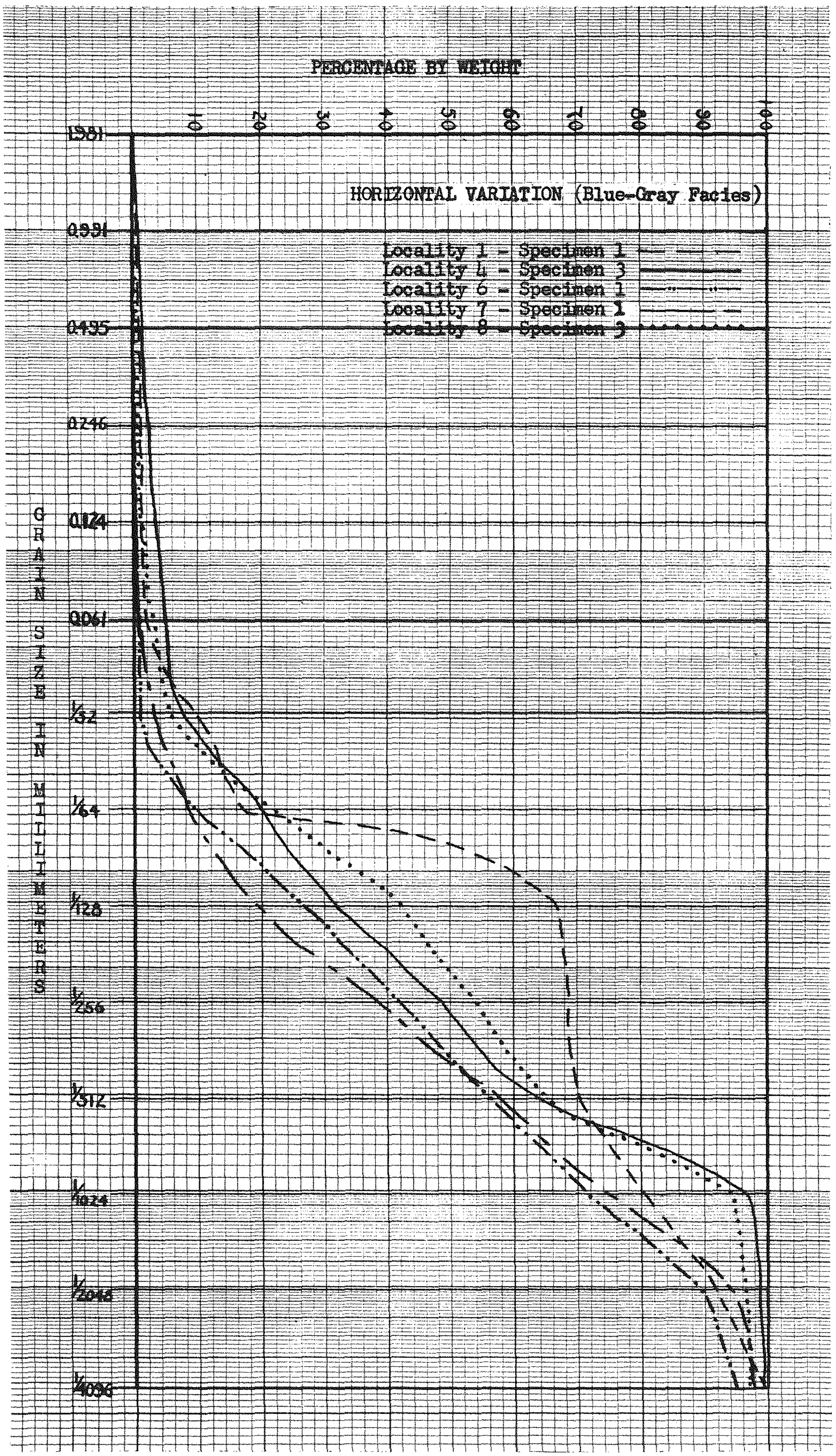
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
HORIZONTAL VARIATION (Blue-Gray Facies)
Locality 1 - Specimen 1
Locality 4 - Specimen 3
Locality 6 - Specimen 1
Locality 7 - Specimen 1
Locality 8 - Specimen 3
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
1/256
1/512
1/1024
1/2048
1/4096
GRAIN SIZE IN MILLIMETERS

Fig. 24

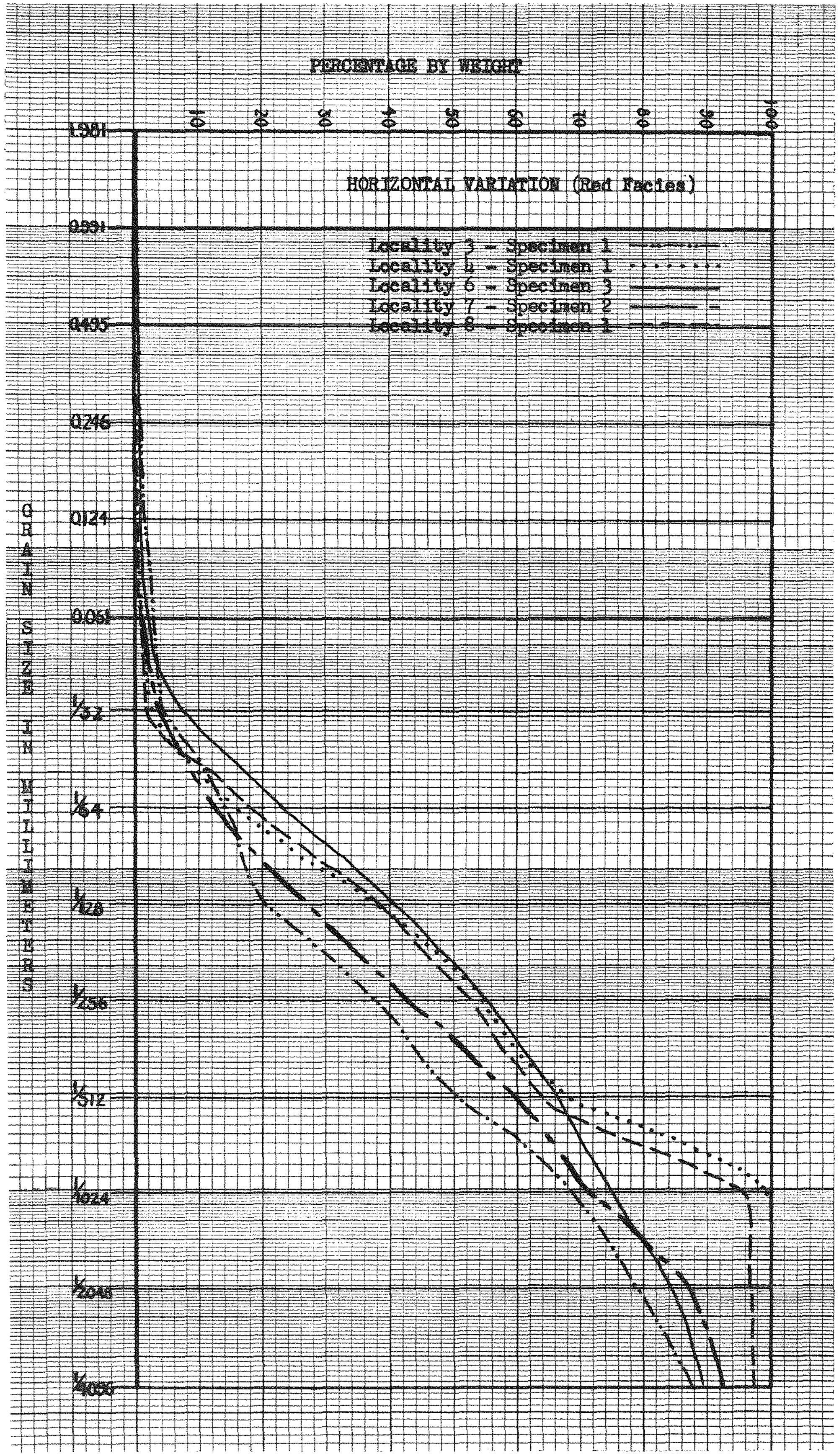
PERCENTAGE BY WEIGHT
10
20
30
40
50
60
70
80
90
100
HORIZONTAL VARIATION (Red Facies)
Locality 3 - Specimen 1
Locality 4 - Specimen 1
Locality 6 - Specimen 3
Locality 7 - Specimen 2
Locality 8 - Specimen 1
1.981
0.991
0.495
0.246
0.124
0.061
1/32
1/64
1/128
1/256
1/512
1/1024
1/2048
1/4096
GRAIN SIZE IN MILLIMETERS

Fig. 25

DEGREE OF ROUNDNESS OF GRAINS

Trowbridge and Mortimore[24] have done much to standardize that phase of sedimentary analysis which is concerned with shape of grains. In their paper (as Plate I) are microphotographs of rounded, fairly well-rounded, subangular, and angular grains.

[24] Trowbridge and Mortimore - Correlation of Oil Sands by Sedimentary Analysis; Economic Geology, Volume XX, Number 5, 1925.

A comparison with these microphotographs shows that the Bedford shale particles as a whole should be classified as angular to subangular. (This classification is one of comparison only and is not based on quantitative data.)

STUDY OF THIN SECTIONS

Thin sections were made of the basal sandstone layers collected at Locality 2. Sections were also made of these basal layers collected at Locality 5, where a local variation makes for such a high carbonate content that they might be classed as limestone. For study of these thin sections, a mechanical stage attachment and a screw micrometer ocular were found very useful.

Results of this study are presented in a method proposed by August Rosiwal. "His method is based on the principle that the total length of all measured lines bears the same relation to the portions intercepted on these lines by each constituent, as the volume of the whole rock does to that of each constituent."[25]

[25]Johannsen, Albert - Manual of Petrographic Methods; p. 291, 1918.

Of the slides of the specimen from Locality 2, basal sandstone layer, by far the greatest percentage of mineral occurrences is that of quartz, followed by calcite (stained with iron oxide), barite, and mica. Among those minerals which may be listed as rare are tourmaline, zircon, leucoxene, and a plagioclase feldspar. The following table lists the average percentages of these minerals as determined from four thin sections (those of rare occurrence being listed together under the heading Others).

TABLE VI

MICROSCOPIC ANALYSIS OF THE BASAL SANDSTONE LAYERS OF THE BEDFORD SHALE AT LOCALITY 2

Minerals	Total Diameters	Relative Volumes
Quartz	3,084	70.57
Calcite	789	18.05
Barite	291	6.67
Mica	181	4.14
Others	25	0.57
	4,370	100.00

MICROPHOTOGRAPHS

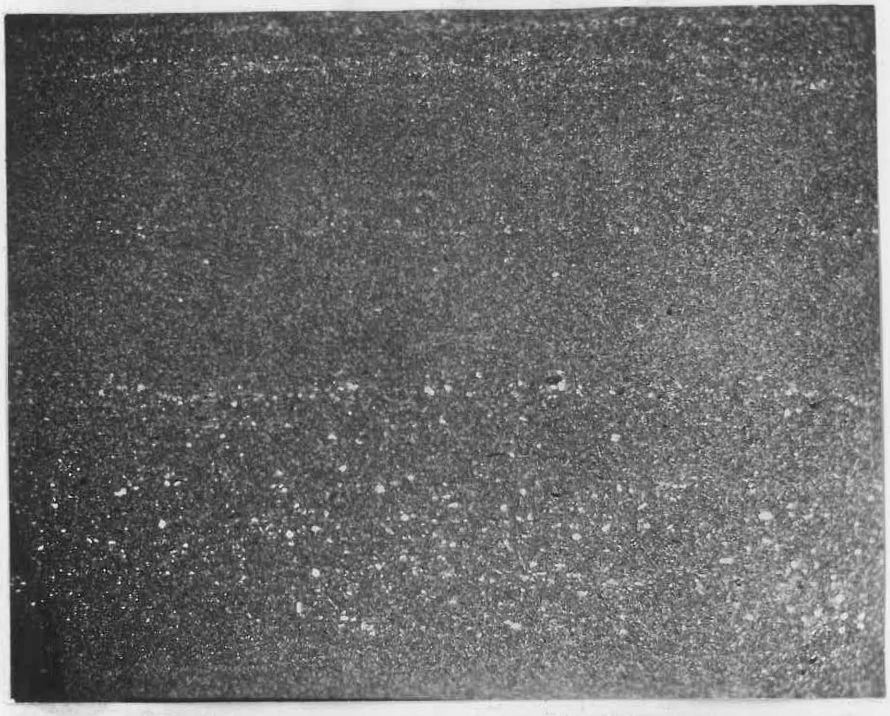

Fig.26 and Fig.27. (X-25, crossed nicols). Locality 5 - Basal layers containing much carbonate; quartz grains alined in narrow bands along plane of bedding.

MICROPHOTOGRAPHS

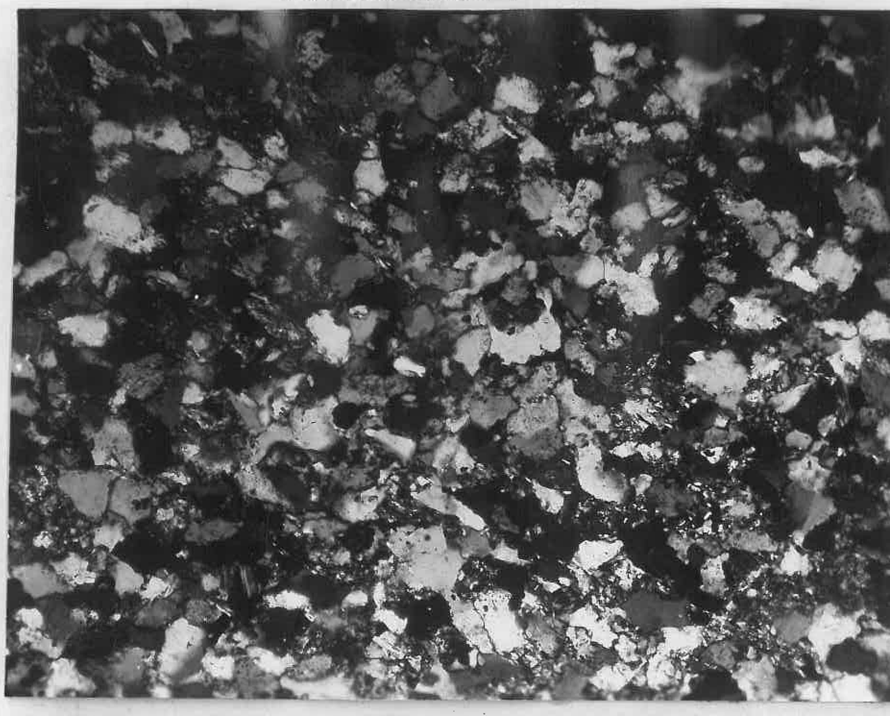

Fig.28. (X-103, crossed nicols). Locality 2 - characteristic of the sandstone slides; slide cut perpendicular to bedding.

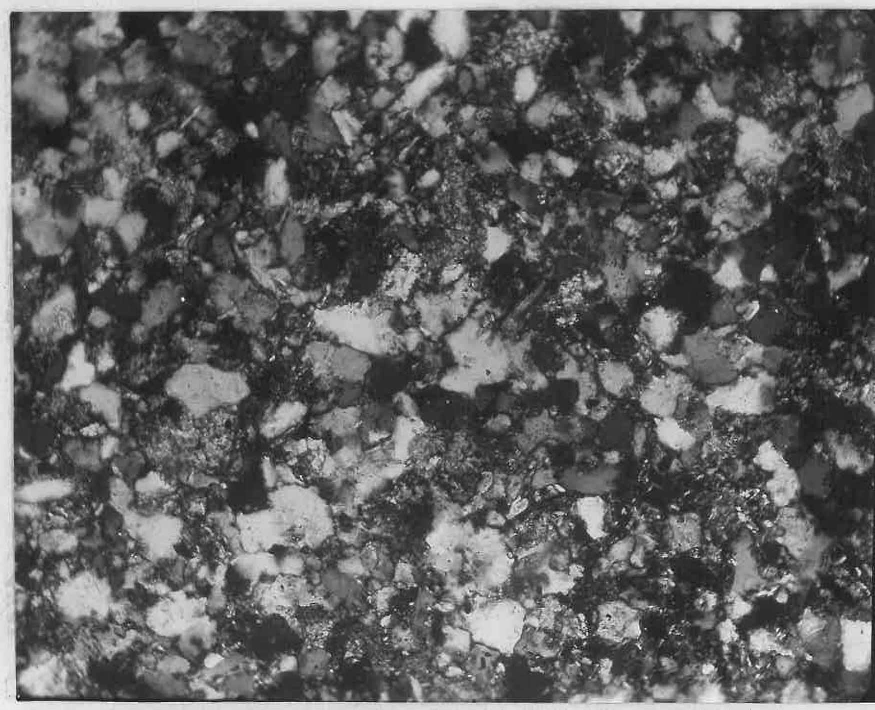

Fig.29. (X-103, crossed nicols). Locality 2 - characteristic of the sandstone slides; slide cut parallel to bedding.

MICROPHOTOGRAPHS

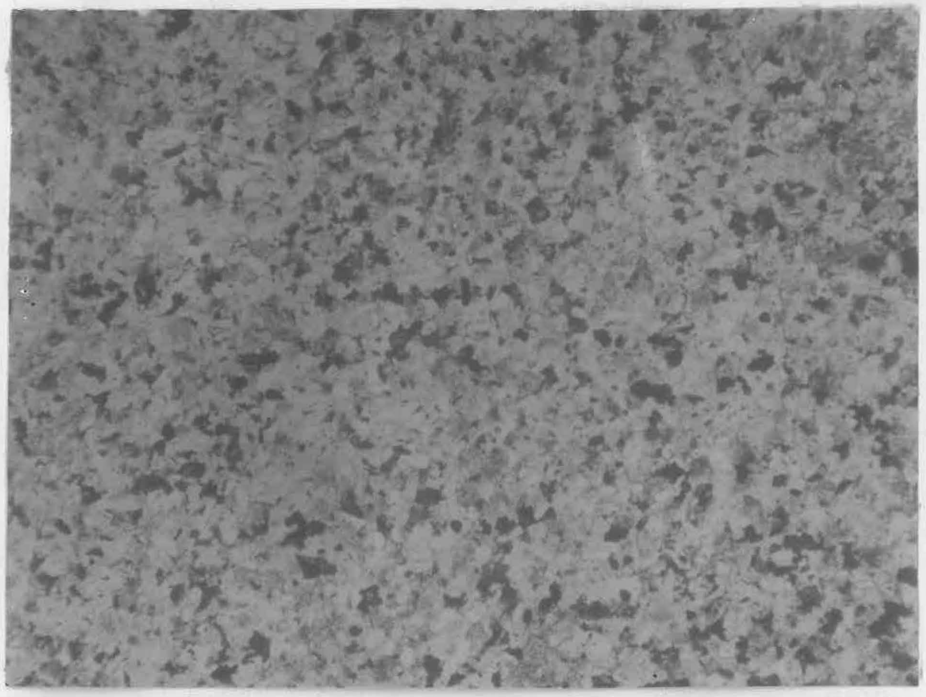

Fig. 30. (X-35). Locality 2 - sandstone showing much iron stained calcite.

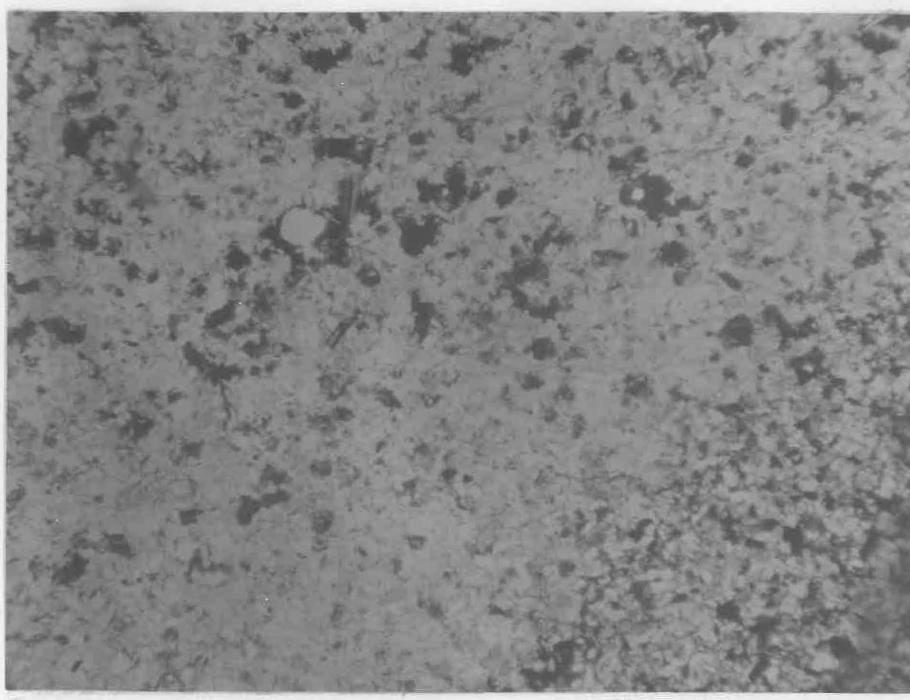

Fig. 31. (X-37). Locality 2 - sandstone showing much pyrite in lower right corner.

In the thin sections made from the basal layers at Locality 5, it was noted that the larger grains, principally quartz, tend toward arrangement in narrow parallel bands following the bedding planes (see microphotographs).

Of the total length of all the measured lines on these thin sections (Locality 5), 1,010 divisions (6.9%) were quartz, 36 divisions (0.2%) mica, and 24 divisions (0.1%) leucoxene. The remainder were carbonates, principally calcium. These larger grains ranged in size from 0.022 to 0.005 mm. in diameter with the median particle being about 0.01 mm. in diameter.

STUDY OF HEAVY MINERAL SEPARATES

Heavy minerals are minerals of high specific gravity, approximately 2.8 + in these investigations, which occur in minor amounts in all facies of the Bedford shale. To facilitate the examination of the heavy minerals with the petrographic microscope, they were separated from the quartz and other light minerals with which they were associated. The method of separation is as follows:

Bromoform of specific gravity 2.87 (at 20°C.) is placed in a glass funnel to the stem of which is attached a piece of rubber tubing closed by a pinch clamp. The sample is introduced, and the mixture stirred at intervals, until all the heavy minerals have settled into the neck of the funnel (care must be taken that they do not settle on the sloping sides of the funnel). The heavy minerals are then washed onto a filter paper in a second funnel by opening the pinch clamp. After the heavy liquid filtrate has been drained back into the stock bottle, the heavy minerals are washed several times with alcohol. These washings are retained for the recovery of the bromoform. On drying, the heavy minerals may be mounted on glass slides for study.

The light minerals are washed into a second filter paper and treated as described for the heavy minerals.

The percentage of heavy minerals in each specimen was determined by an analytical balance, weights being made to the nearest one-thousandth of a gram.

These weights show that there is a general tendency for the blue-gray facies to contain a very slightly higher per cent of heavy minerals than the red facies. Also, there is no general tendency toward increase or decrease in heavy mineral content between the various grade sizes of any one specimen.

The heavy minerals were next split with a microsplitter and mounted in a mounting medium with an R.I. of 1.65. Each slide was marked with a diamond pencil as to locality and specimen number, size grade, and R.I. of mounting medium.

Under the petrographic microscope, the heavy minerals were found to consist chiefly of from reddish to buff, irregular, angular to subangular grains of iron oxide, and calcite and quartz containing sufficient amounts of iron oxide to cause them to sink in the heavy liquid.

In many cases mica, mostly biotite or damourite (small optic angle, usually less than 10°), was present. In a number of the slides the mica grains contained apatite inclusions.

Tourmaline occurred occasionally, but in most of the specimens it must be treated as a rare mineral. Zircon was very rare, usually no more than a trace, and missing altogether in many cases.

One interesting, rather common occurrence is that of quartz grown around the edges of other grains. In most cases these were iron oxide grains, but there were cases of zircon and pyrite grains with quartz grown around the edges.

The important cementing materials of the Bedford would appear from this study to be calcite and silica.

Table VII lists the minerals observed and their occurrence in the various specimens. In each case under <u>Specimen</u>, the first number refers to locality and the second number to the specimen from that locality. Unless otherwise indicated, all grains are in the 0.124 - 0.061 mm. grade.

TABLE VIIa

HEAVY MINERALS OF THE BEDFORD SHALE

Specimen	Mica Undiff.	Damourite	Sericite	Biotite	Pyrite	Leucoxene	Iron stained calcite
B-1-1	R			T			O
B-1-2	R				O		F
B-1-5	R			T			O
B-1-7	R						O
B-1-7 0.246-.124 mm.							F
B-1-7 0.495-.246 mm.					O		F
B-1-7 0.991-.495 mm.							F
B-3-1	R			R			O
B-4-1	O			R	O		R
B-4-3	O				O		F
B-5-4							F
B-5-5			T		O		F
B-6-1	R	O			R	T	
B-6-3							
B-7-2	R						
B-8-1	T						
B-8-3		F		O			

F - Frequent
O - Occasional

R - Rare
T - Trace

TABLE VIIb

HEAVY MINERALS OF THE BEDFORD SHALE

Specimen	Iron oxide w/calcite or quartz	Chlorite	Tourmaline	Zircon	Pistacite	Quartz grown on to other grains
B-1-1	F		R			
B-1-2	F			R		
B-1-5	F					O
B-1-7	F	R	O	T		
B-1-7 0.246-.124 mm.	R			R		
B-1-7 0.495-.246 mm.	O					
B-1-7 0.991-.495 mm.	T					
B-3-1	F	O	O			
B-4-1	F	R	R			O
B-4-3	R	R	O			
B-5-4	O					O
B-5-5	F		R			
B-6-1	O	R	R			
B-6-3	F		O	R		R
B-7-2	O	R			R	O
B-8-1	F		O			O
B-8-3	O					

F - Frequent
O - Occasional

R - Rare
T - Trace

CONCLUSIONS

As a rule, it is not possible to come to a conclusion in regard to the direction from which a sediment is deposited, the type of contributing topography, prevailing climate at time of deposition, and like points, unless a formation is studied over a rather extensive area.

Such is the case in the present investigation. Since only a relatively small amount of the Bedford shale is exposed in Lorain County, it is not possible to note variations that would provide solutions to the above stated problems. Some of the data, however, suggests hypotheses which afford explanations of certain points of interest even when dealing with such a limited area.

As noted in the study of the heavy minerals, many of the mica grains carry apatite inclusions. This would indicate that, in part at least, the sediments were derived from igneous rocks.

The color difference in the two facies of the Bedford is obviously a function of the chemical composition, the blue-gray color signifying a low portion of ferric oxide and usually a preponderance of ferrous over ferric compounds.

Carbon has long been recognized as important in bringing about the reduction of ferric oxides to the ferrous form. This would indicate that at most only a small amount of organic matter was deposited in the sediment now recognized as the red facies of the Bedford.

The ferruginous material of the red facies was evidently deposited contemporaneously with the sediment. No association with igneous intrusions was found in the area, so the hypothesis of introduction of iron from igneous magmas must be discarded. Too, it is hardly logical that a formation as impervious as the Bedford shale may have received its color from later introduction of iron by meteoric waters.

It was noted that in certain localities the presence of blue-gray lenses in the otherwise red shale gives this facies a mottled effect. It is probable that these "spots" of blue-gray were originally red sediment, reduced by some organic agent which was present in the original sediment. (However, no actual remnants of organic matter were found in the red facies in any part of Lorain County.)

In other localities (especially central and southern Ohio) the Bedford shale is said to contain many ripple marks indicating shallow waters at time of deposition. No such ripple marks were observed in any of the several exposures of the Bedford shale in Lorain County.

In the localities where the Bedford-Berea contact was exposed, a thin blue-gray shale similar in appearance to the blue-gray facies of the Bedford was found to overlie the red facies. This thin blue-gray shale has been interpreted by Burroughs[26] as logically belonging to the Berea sandstone. The average coefficient of sorting, average coefficient of skewness, and percentage of total weight in each size grade, however, indicate that this thin blue-gray shale should be treated as a continuation of the red facies of the Bedford shale, with the ferric iron content reduced to ferrous nature through leaching by the waters from the basal pyrite and marcasite zones of the Berea sandstone.

[26] Burroughs - op. cit., p. 659.

Generally speaking, the blue-gray facies of the Bedford is not so well sorted as is the red facies. This is to be expected, since the blue-gray facies as a whole is coarser grained than the red facies. Too, one would expect the maximum sorting of the constituents to lie on the fine side of the median in the facies that has a comparatively higher percentage of grains in the coarser grades, and such was found to be the case.

UNSOLVED PROBLEMS STATED

Contributing Landmass - Before the questions of location and type of contributing topography, prevailing climate at time of deposition, type of source rock, and others of this nature can be correctly answered, the Bedford shale must be studied in more extensive outcrops than was the case in the present investigation. As is the case with practically all other shales, there is no general trend from coarse to fine grains in such a limited area of outcrop.

Geologic Age of the Bedford - This problem has long been one on which geologists are in no general agreement. Nothing is here offered to throw any light upon this problem, for such was not within the scope of the present investigation.

Berea-Bedford Contact - Whether the uneven contact between the Berea and the Bedford formations is due to erosion by streams when the Bedford horizon stood above sea level, to erosion by the currents which brought in the sands of the Berea formation, to gradual sinking of the heavy sand into the soft mud of the Bedford as deposition continued, or to some factor not as yet proposed, is a problem requiring a great deal more study.

Heavy Mineral Analysis - More extensive analysis of the heavy minerals of the Bedford shale (as to the relative percentages of each of the minerals, degree of roundness of grain, degree of freshness) will no doubt do much to answer many of the yet unsolved problems of conditions under which deposition occurred.

SUMMARY

The present investigation has been logically divided into three parts. Part I has considered the general geology of the Bedford shale, with an enumeration and detailed description of the several localities from which samples were obtained; Part II has been concerned with the methods used in making the mechanical analysis, and each method has been discussed with the hope that it may be a source of information to others who work with sediments similar to the Bedford; Part III has been presented in a manner that can be correlated with similar studies of the Bedford shale in other localities, and thus help to determine the conditions under which original deposition occurred.

BIBLIOGRAPHY

Bouyoucas, G. J. - The Hydrometer as a New and Rapid Method for Determining the Colloidal Content of Soils; Soil Science, Volume 23, 1927

Burroughs, W. G. - The Unconformity Between the Bedford and the Berea Formations of Northern Ohio; Journal of Geology, Volume XIX, 1911

Chadwick, G. H. - The Great Catskill Delta, and Revision of Late Devonian Succession; Pan-American Geologist, Volume 60, 1933

Cushing, H. P., Leverett, Frank and Van Horn, F. R. - Geology and Mineral Resources of the Cleveland District, Ohio; U. S. Geological Survey, Bulletin 818, 1931

Girty, G. H. - Geologic Age of the Bedford Shale of Ohio; New York Academy of Science Annals, Volume 22, 1912

Hyde, J. E. - The Ripples of the Bedford and Berea Formations of Central and Southern Ohio, with notes on the Paleogeography of that Epoch; Journal of Geology, Volume XIX, Number 3, 1911

Johannsen, Albert - Manual of Petrographic Methods; 1918

Krumbein, W. C. and Pettijohn, F. J. - Manual of Sedimentary Petrography; 1938

Moore, R. C. - Historical Geology; 1933

Olmstead, L. B., Alexander, L. T., and Middleton, H. E. - A Pipette Method of Mechanical Analysis of Soils Based on Improved Dispersion Procedure; U. S. Department of Agriculture, Technical Bulletin, Number 170, 1930

Prosser, C. S. - The Devonian and Mississippian Formations of Northeastern Ohio; Geological Survey of Ohio, Fourth Series, Bulletin 15, 1912

Prosser, C. S. - The Disconformity Between the Bedford and Berea Formations in Central Ohio; Journal of Geology, Volume XX, Number 7, 1912

Rittenhouse, Gordon - The Pipette Method Modified for Mass Production; Report of the Committee on Sedimentation, Exhibit G, 1938-39

Rubey, W. W. - Lithologic Studies of Fine Grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region; U. S. Geological Survey, Professional Paper 165A, 1930

Thomsen, H. - Textural Variations of the Berea Sandstone; Master's Thesis, Oberlin College, Oberlin, Ohio, 1935

Tickell, F. G. - The Examination of Fragmental Rocks; 1939

Trask, P. D. - Origin and Environment of Source Sediments of Petroleum; 1932

Trowbridge and Mortimore - Correlation of Oil Sands by Sedimentary Analysis; Economic Geology, Volume XX, Number 5, 1925

Wenberg, E. H. - The Paleozoic Stratigraphy of Lorain County, Ohio; Master's Thesis, Oberlin College, Oberlin, Ohio, 1938

Wentworth, C. K. - Methods of Mechanical Analysis of Sediments; University of Iowa Studies in Natural History, Volume XI, Number 11, 1926

Wilmarth, M. G. - Lexicon of Geologic Names of the United States; U. S. Geological Survey, Bulletin 896, 1938

Geological Survey of Ohio, Part I, Report of Progress, 1869