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A Mechanical Analysis of the Oriskany Sandstone in Northwestern Virginia

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A MECHANICAL ANALYSIS OF THE ORISKANY SANDSTONE
IN
NORTHWESTERN VIRGINIA

A Thesis

Submitted to the Faculty of Oberlin College
in partial fulfillment of the requirements
for the degree of Master of Arts

By

Selma L. Goldstone

Oberlin College

Oberlin, Ohio

1938

PREFACE

The primary purpose of this paper is to present specific data as a means of explaining the sedimentation conditions at the time of deposition of the Oriskany Sandstone. The data were obtained through the use of laboratory methods upon specimens taken from several outcrops in the vicinity of Monterey, Virginia (see Darton's U. S. G. S. folio No. 61). In addition to the presentation of objective results, the author has attempted to make tentative interpretations of them, based primarily upon textural and shape analysis of the sediments. The writer realizes that the investigation is inadequate in many respects, due to lack of time available for field study and collection, and the little experience with similar types of problems. It is to be hoped, however, that a more complete report may be forthcoming in the near future.

The writer wishes to acknowledge the assistance given to her by Dr. Reuel B. Frost and Dr. Erwin C. Stumm of Oberlin College for helpful suggestions throughout the course of this study; she is indebted also, to Dr. Marcellus H. Stow, Washington and Lee University, for information dealing with the mineralogy of the Oriskany sediments; and to Dr. Arthur Bevan of the Virginia Geological Survey for maps and valuable information as to the location of outcrops. Above all, she wishes to express her appreciation to Dr. Fred Foreman of Oberlin College, at whose suggestion and under whose direction this study has been carried on, for his constant interest and assistance in every phase of the work.

S. L. G.

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CHAPTER I

GENERAL GEOLOGY OF ORISKANY SANDSTONE

Correlation and Regional Stratigraphy

The Oriskany sandstone is of Lower Devonian age and is believed to have received its name from Oriskany Falls in Oneida County in east-central New York, where it occurs as a nearly pure quartz sandstone not exceeding 20 feet in thickness.

In the folded Appalachians the term Oriskany has come to be applied to a series made up of two distinct phases shown to be somewhat related faunally but decidedly unlike in lithology: the Lower, or Ridgely Sandstone member and the Upper, or Huntersville Chert. The sandstone or Ridgely member, called the Monterey Sandstone by Darton,[1] is the formation dealt with in this paper. It is correlated with the Ridgely sandstone unit in eastern Pennsylvania, New York, West Virginia, and Gaspe Canada, but its type locality is believed to be in Cumberland, Maryland. Although its thickness is greatly decreased and it contains many more impurities, its general lithologic character, and the type fauna, is retained in the Monterey vicinity.

There have been several other views as to the subdivisions of

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[1] United States Geological Survey, Folio No. 61.

the Oriskany series. Although the West Virginia Survey[1] refers to the aforementioned Ridgely and Huntersville divisions named in ascending order, in Maryland, the Oriskany formation consists of a lower, black cherty layer overlain by a calcareous sandstone, and these units named in ascending order are known as Shriver Chert and Ridgely Sandstone.[2] In the Monterey, Warm and Hot Springs area of Virginia, however, the Monterey sandstone, corresponding to the Ridgely sandstone of Maryland and West Virginia, is the principal division of the Oriskany Formation. In the Monterey vicinity, also, the New Scotland limestone member of the underlying Helderberg formation is immediately overlain by black cherty beds containing few fossils, which formation, according to Swartz,[3] is the southernmost extension of the Shriver Chert of Cumberland. This chert is in turn overlain by the Oriskany sandstone, and has been the subject of extensive controversy as to whether it is actually to be considered Shriver Chert, and as such, a lower division of the Oriskany, or whether it is part of the Becraft limestone and, as such, one of the divisions of the upper Helderbergian.

According to Swartz, the stratigraphic positions of the Shriver and Becraft formations can perhaps be considered alike, for in sections of Virginia especially, the displacement of the one lithologic unit

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1 West Virginia Geological Survey County Reports, 1929, Pocahontas County, p. 232.

2 Maryland Geological Survey, Lower Devonian, p. 91.

3 Frank McKim Swartz, Helderberg Group of Parts of West Virginia and Virginia, Shorter Contributions to Geology, Geological Survey Professional Paper, 158, 1929, p. 47 et. seq.

by the other, is quite common. He has also suggested the possibility that the Shriver chert is nothing more than a muddy bottom phase equivalent in time to the Becraft limestone, this statement being based upon faunal and stratigraphic relationships between the two. However, the problem is still an open one, since the fauna of the Shriver Formation tends to tie it in more closely with the Oriskany than the fauna of the Becraft would permit with that same formation.

The writer had the opportunity of studying the lower contact of the Oriskany sandstone both in the Back Creek Mountain west of Warm Springs, and in Monterey vicinity. In the Warm Springs section the sandstone rested upon a limestone that seemed essentially chert-free, but further north, just east of Monterey, and in the Strait Creek vicinity, cherty contact phases were evident, which, due to the lack of indicative fossils, could not definitely be classed as either Shriver or Becraft.

The upper contact of the Oriskany sandstone with the Romney Shale, in the several places that permitted study, appeared almost knife-edged in sharpness. Until recently it was generally believed that the Oriskany series marking the end of the Lower Devonian showed a striking hiatus of considerable magnitude between the Lower and Middle Devonian and in this respect, Darton[1] points out an erosional

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[1] Op. cit.

unconformity between the Romney and Oriskany formations. Kindle,[1] however, in a rather comprehensive study, called attention to the presence of Onondaga fauna in basal sections of Romney, and thus stimulated further investigation into the problem with the result that today, while such evidences as the abrupt lithologic change from Oriskany to Romney, evidence of erosion in some sections of the uppermost Oriskany beds, and iron deposits in these same horizons, does give some weight to Darton's theory, the current belief is that a rather short but definite erosional period did occur at that time.

Summarily then, the Oriskany Sandstone forms the upper division of the Lower Devonian Rocks, lying beneath the Romney of Middle Devonian time and above the Helderberg Group of Lower Devonian time. In this paper only the sandstone phase of the Oriskany formation was studied in the laboratory, and although the cherty phases are considered in a later discussion of the conditions of sedimentation, their occurrences in the region under consideration appeared spasmodic and variable, sometimes appearing at the base of the formation, other times at the top of the formation, and at a few places at both the bottom and top of the series.

Regional Geology

As the index map accompanying this paper (Plate I) indicates, the specimens analyzed were taken mainly from the vicinity included

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[1] E. M. Kindle, Onondaga Fauna of Allegheny Region, United States Geological Survey, Bulletin 508: 1912, p. 5 et seq.

in the eastern section of Monterey Quadrangle of Darton's folio,[1] only one sample, marking the southernmost limit of investigation, occurred $3\frac{1}{2}$ miles south of Hot Springs on the Natural Bridge Quadrangle.

Structure

This region is part of the larger Appalachian Mountain Province and therefore the dominant structures are the typical ones of the province, where the strata are distorted into long narrow folds generally in parallel arrangement with frequent overturned limbs and thrust faults, which fact makes field study and accurate placement of sample with reference to upper, middle, or lower part of series, extremely difficult. The folds strike in a northeast-southwest direction and the individual folds show a tendency to overturn to the northwest. As is to be expected, such anticlinal and synclinal structures are topographically manifested by parallel ridges and valleys with the major streams frequently cutting across the general strike in the form of deep gorges or gaps through the ridges; the tributaries eroding the valleys, which are cut in the less resistant limestone or shale.

Physiographic history

The physiographic history may be told from the three peneplanes in evidence there today,i.e., monadnocks of the Cretaceous peneplane;

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[1] Op. cit.

subsequent uplift and dissection to the stage of maturity, with reduction to a new peneplane level known as the Tertiary peneplane. This peneplane with its monadnocks was again uplifted, and at the present day is being further dissected below the level of the former peneplane. For a more detailed discussion of the structure and history of this region the reader is referred to any one of the numerous papers given over to these particular subjects.[1]

Topography

Topographically the Oriskany is frequently expressed covering gentle slopes and low ridges, and occasionally gives rise to knobs and arches. The samples here used were found along sides, east and west, of the synclinal valley in which the town of Monterey is located, and also at the nose of this same synclinal valley in the vicinity of Strait Creek. For comparison sake several specimens were also taken further south, in Warm and Hot Springs sections where the Oriskany was found flanking the east limb of the Back Creek and Bolar Mountain anticline, and the southernmost extension of the Jack Mountain anticline. The extremely variable occurrence of Oriskany as established both by outcrops and well-drillings,[2] presented numerous difficulties in the field, since in some places

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[1] The author suggests for this purpose: Frank Wright, Physiography of Upper James River; Bailey Willis, Mechanics of Appalachian Structure, United States Geological Survey, 13th Annual Report, 1892.

[2] Personal Communication with Dr. Arthur Bevan, Virginia Geological Survey.

the formation seemed almost to disappear, and in others, it appeared to have a rather extensive distribution. This is one of the problems for which an explanation is later attempted aided by the following mechanical analysis.

Lithology of Oriskany Sandstones

Physical Characteristics

The Oriskany in this section of Virginia is a light-colored buff-grey sandstone essentially quartzitic, more rarely calcareous, in character. In sections it appears to be quite friable, and weathers to an almost white, or light buff color on the surface but it is found to be iron-stained within. On some of the gentler slopes it was seen to disintegrate into sand and loose fragments -- and in other places it appeared well cemented and quite resistant. It is quite thick-bedded and in places appears massive.

Local Structures

One mile west of Monterey on the road to Hightown, the phenomenon of cross-bedding was in evidence, reappearing again further south just south of Cobbler Mountain. Other local structures found in the sandstone were iron and manganese "nodules" or pockets. An attempted explanation of these deposits is given at a later time in this paper.

Horizons

The formation also seems to possess variable "horizons" -- cherty, pebbly, or conglomeritic being the most frequent. The possibility of the conglomeritic phase being a weathering effect has been favorably considered by the writer. This seems a likely explanation in view of the fact that these horizons seem so irregular in their occurrence and because it is quite possible that where the sandstone is of calcareous nature, the cement might easily be weathered out leaving quartz pebbles outstanding, and giving the rock a conglomeritic character. The original source of the quartz pebbles, however, is still not considered by such a theory.

Thickness

As heretofore mentioned, the thickness of the Oriskany is extremely variable. It appears to attain its greatest thickness just east of Monterey where it outcrops in the first foothills of Jack Mountain, and has a thickness of about 235 feet. In the Hot Springs section south of the nose of the Jack Mountain anticline, it is believed to be 125 feet thick. Generally, it is reported[1] to vary from 0 to 200 feet, but in most of the sections studied it ranges from 100 to 150 feet.

Fossils

The Oriskany sandstone was found to contain numerous marine fossil pits but many were too poor in character to permit identifi-

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[1] Darton, op. cit.

cation. Also in some localities, where the sandstone seemed somewhat friable, the shells were almost entirely silicified, so that the external markings, and frequently the internal structures, were quite well preserved, the interior being either hollow or filled with loose sand. In these localities (Warm Springs Section), cavities of large gastropods were found, and more commonly, the internal mould of a brachiopod was perfectly preserved. It is possible that such leaching was begun at a time soon after the deposition of the sediment and continued by the percolating effect of the water from the Jackson River and its tributaries, which might carry away any of the calcareous material of the Oriskany and replace the latter with silica.[1] This then causes weathering out of the actual fossil leaving only the silicified shell.

Fossil evidence of marine life in the Oriskany, however, is numerous. Spirifer arenosus is the guide fossil of the series, and a form of frequent occurrence. This has a large somewhat trigonal shell with coarse rounded corrugations even in the area of the faint lobe and sinus; and where a cast of the interior is exposed, a prominent extension reaches beneath the beak of the shell. Hipparionyx proximus is also a guide fossil to the series but not quite as abundantly represented. The mark of the muscle attachment within the shell is a conspicuous feature and closely resembles the footprint of

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[1] Maryland Geological Survey, Lower Devonian, p. 94.

a colt, thus the origin of its name. Other common forms identified were:

Diaphorostoma desmatum
Leptaena rhomboidalis
Orbiculoidea ampla
Schuchertella woolworthana
Diaphorostoma ventricosum
Spirifer intermedius (?)
Eatonia sinuata
Rensselaeria ovoides

Chemical Composition

Nothing was done in the laboratory along the lines of any actual chemical analysis of the sandstone, but the author feels that Twenhofel's composite sandstone analysis[1] might prove helpful:

SiO_2	78.66%
TiO_2	.25
Al_2O_3	4.78
Fe_2O_3	1.08
MnO	Trace
FeO	.30
CaO	5.52
MgO	1.17
K_2O	1.32
Na_2O	.45
Li_2O	Trace
CO_2	5.04
H_2O	1.64 (includes organic matter)

It must be remembered that the above represents a very general sandstone analysis and no doubt presents numerous discrepancies with the actual composition of the Oriskany. Several variations are evident to the writer at a glance, i. e., the great amount of manganese and iron oxide actually present in the stone under consideration as

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[1] William H. Twenhofel, Treatise on Sedimentation, p. 3.

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contrasted with the "trace" and the 1.08% Fe_2O_3 listed in the above analysis. These facts will be further discussed at a later time with a view to determining whether or not they are indicative of the conditions under which the deposition of the sediments took place.

Economic Aspects of Oriskany Sandstone

The name Oriskany has been given to limonite ore in Virginia since it was formerly believed that the ore occupied the position of the Oriskany sandstone. It has since been established, however, that the Oriskany iron-ores occur in the upper beds of the Helderberg limestone and only rarely in the Oriskany sandstone.[1] It is generally believed that these ores are secondary in origin, occuring as replacements and cavity fillings in which the iron in solution has been carried by meteoric waters descending through the highly ferruginous Romney shales. The Oriskany in the Hot Springs area appeared very much more ferruginous than the outcrops further north -- but the actual value of the Oriskany sandstone in Virginia as a source of iron ore is not of great importance.

In Pennsylvania the Oriskany sandstone has frequently been found to yield oil and natural gas in commercial quantities, and several studies of the sandstone as a source bed have been made.[2,3,4]

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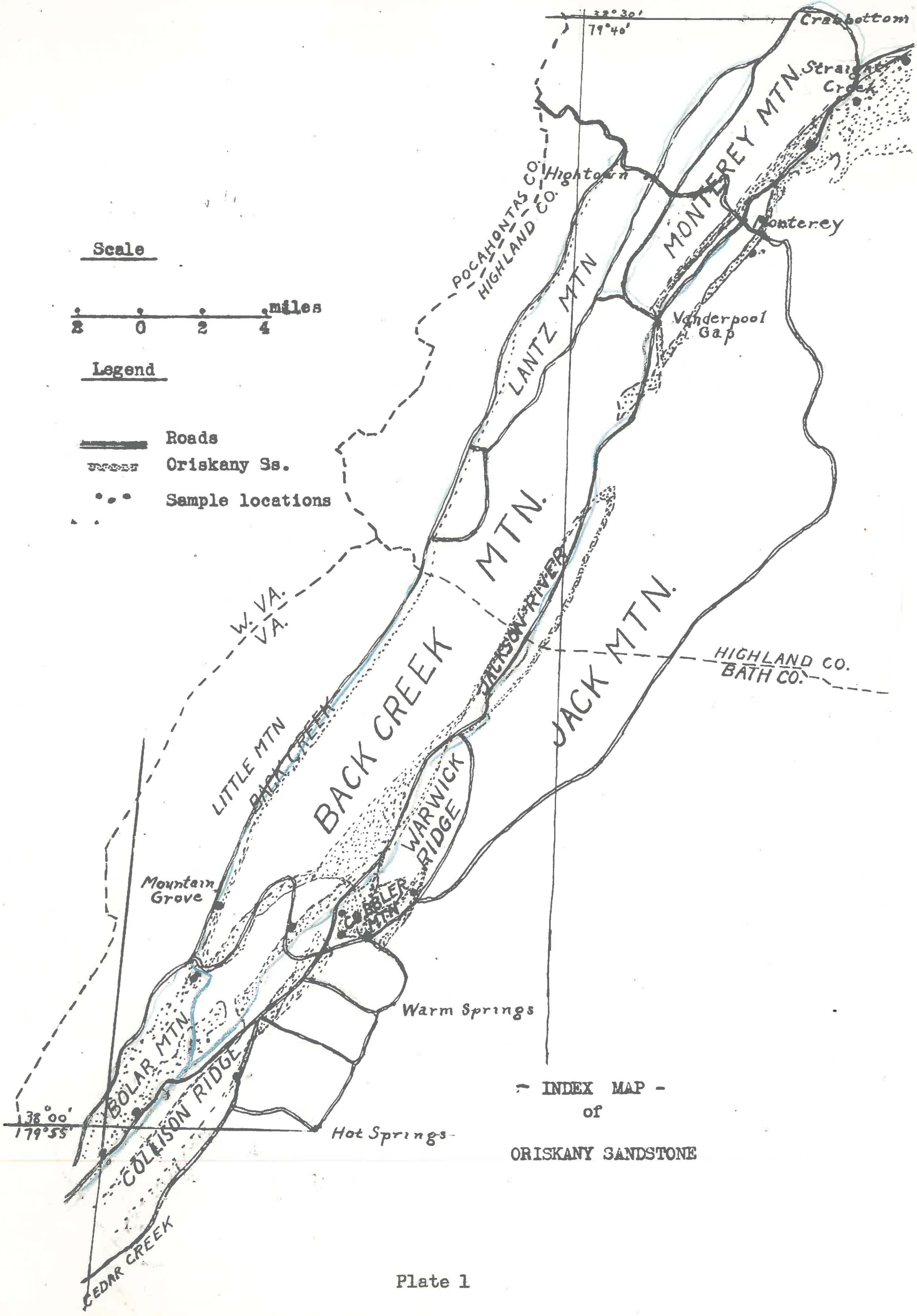
[1] Samuel E. Doak, The Oriskany Iron Ores of Virginia, Engineer and Mining Journal, Vol. III, No. 9, p. 386.

[2] S. H. Hamilton, Oriskany Explorations in Pennsylvania and New York,



- INDEX MAP -
of
ORISKANY SANDSTONE

Plate 1

In Cambridge, Ohio, in 1923, oil in commercial quantities was encountered in the Oriskany horizon, and subsequent discoveries of large volumes of gas in the same horizon in Schuyler County, New York, called attention to this formation as a possible source of gas in the Appalachian province. In the section under consideration no explorations have yet been attempted but in view of the present structural conditions in Virginia, it is hardly likely that any such attempts would prove successful.

The Oriskany sandstone presents other economic aspects aside from the iron ores, oil and gas. In Franklin County, West Virginia, the material is mined for a low grade manganese ore; and in sections where the rock is somewhat calcareous and it becomes friable upon weathering, it yields quartz sand which in Berkeley Springs, West Virginia, is quarried extensively as a glass sand. Some of the less pure beds are used for building purposes.

It will be seen from the foregoing discussion that the extremely variable occurrence of the Oriskany, along with other characteristics

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(con't.)
American Association of Petroleum Geologists, Bulletin 21, Part 2, October, 1937, pp. 1582-1591.

[3] Paul D. Torrey, <u>Natural Gas from Oriskany Formations in Central New York and Northern Pennsylvania</u>, American Association of Petroleum Geologists, Bulletin 15, Part 1, 1931, p. 671-681.

[4] Charles R. Fettke, <u>Oriskany as a Source of Gas and Oil in Pennsylvania and Adjacent Areas</u>, American Association of Petroleum Geologists, Bulletin Volume 22, March 1938, p. 241.

peculiar to this stone, suggest somewhat exceptional conditions of sedimentation. In the interpretations to be made based upon the data secured from the following analysis, some attempt is made to explain some of these conditions.

CHAPTER II

METHODS USED IN INVESTIGATION

The mechanical composition of a sedimentary rock refers to the relative proportions of particles of different specified sizes, which is one of its most significant lithologic characteristics. A knowledge of such proportions serves as an index not only of the general appearance and behavior of the rock under ordinary conditions, but as heretofore suggested, of its economic value and geologic history.

Mechanical Analysis

The mechanical analysis of a sediment involves four more or less distinct problems:

1. Collection of specimens
2. Preparation of sample
3. Measurement of particle size and determination of frequency distribution, the latter being measured in terms of weight-percentages
4. Presentation of data in readily usable form

Collection of Samples

The irregular surface distribution of Oriskany sandstone and the dearth of available outcrops of the stone presented several difficulties in the collection of specimens in the field. Samples were taken from Strait Creek Region south to Hot Springs (see Plate I for exact locations) following along both sides of the Monterey synclinal valley and also along Back Creek Mountain and the southernmost extension of Jack Mountain. Wherever possible an attempt was made to take samples from upper, middle, and lower beds, thereby attaining vertical as well as horizontal distribution.[1] Not all of the localities, however, permitted such collecting. The writer at several outcrops could not locate either its upper or lower contact, and in many instances it became necessary to estimate roughly the proximity of the chosen specimen to such contacts.

In every case the sample chosen was believed to be representative of the larger area from which it was taken. In a few cases, however, a sample was taken because it exhibited some unusual feature of interest that might furnish some clue as to conditions of sedimentation. Care was taken to avoid erosional and severely weathered surfaces, and each outcrop was cleared of superficial material before the sample was taken.

The sample was labelled immediately upon recovery and note was made upon a topographic map as to its exact location. Also a general description of the outcrop was recorded in the field book as to proximity of contacts, field occurrence or relations, and fossils and organic deposits, the presence or absence of which might aid in the later interpretations.

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[1] C. K. Wentworth, Methods of Mechanical Analysis, University of Iowa Studies in Natural History, Vol. XI, No. 11, 1926, p. 9 et seq.

The size of the samples taken ranged from two hundred to five hundred grams, depending upon the relative coarseness of the grains, i.e., the coarser the grain, the larger the sample. In any case the sample was large enough to yield 100 grams upon disintegration in addition to a good-size hand specimen for reference purposes.

Preparation of Samples

A piece of the sample judged to weigh about 100 grams was broken off from the larger sample. Many of the samples were difficult to separate into their constituent grains and required chemical aid as a preliminary to the mechanical treatment.

For this purpose several methods suggested by Krumbein[1] were experimented with. Boiling in sodium carbonate (Na_2CO_3), soaking in sodium hydroxide (NaOH), and boiling in sodium thiosulfate ($Na_2S_2O_3$), were found to be equally ineffective. In some of the specimens, however, soaking in dilute hydrochloric acid seemed to be of some aid. These evidently contained some carbonate in the cementing material, which, by such soaking would be dissolved out, loosening the grains considerably. Other specimens seemed untouched by the acid, and these facts were recorded to be utilized in later interpretation. When the specimens were soaked, the time allowed for soaking varied from two to five days, but in most cases the maximum

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[1] W. C. Krumbein, The Mechanical Analysis of Fine-Grained Sediments, Journal of Sedimentary Petrology, December, 1932, p. 145.

benefit derived was attained at the end of two or three days, after which time the soaking offered no further help in disintegration. This is explained by the fact that as soon as the carbonate was dissolved, the acid did not affect any of the other constituents. Silica, of course, is insoluble in dilute HCl.

If the specimen seemed soft enough to enable elimination of the aforementioned procedure, it was subjected immediately to mechanical disintegration. The specimens requiring such soakingwere washed thoroughly with cold water and allowed to dry overnight before attempting further disintegration.

Mechanical Disintegration

A large white sheet of paper was placed under a mortar and pestle to recover grains that might otherwise be lost in the pounding. To begin the breaking up of the larger pieces, an unglazed procelain pestle was used and the pieces were pounded, not ground, using a moderate amount of pressure upon them. By trial and error method mainly, the amount of pressure that could be applied without breaking the grains was determined. When the larger fragments were reduced in size, a wooden pestle was substituted for the porcelain one. It was constructed similarly to a dumb-bell in shape and was found to be superior to the porcelain one at this stage of disaggregation, since it distributed the weight more evenly amongst the grains and thus lessened the possibility of cracking them. Additional care was taken in this respect, by tapping the fragments rather than pounding them as was done earlier in the procedure, and here again the pressure was regulated by frequent examinations of the grains under the microscope to determine whether any were being broken.

Since few aggregates were found in the material passing through the 60 mesh sieve, it was simpler to crush a small amount of material at a time and sift it by hand through this sieve, thereby separating the coarser material which, as a rule, contained numerous aggregates and had to be subjected to re-tapping.

A definite tendency existed for the smaller grains to adhere to those of $\frac{1}{2}$ mm. or larger. Separation of such aggregates was effected by rubbing them by hand over clean heavy paper, since pestling in this case broke too many of the grains.

Quartering

When approximately 100 grams of the sample had been completely disintegrated and found by microscopic examination to be devoid of aggregates, the sample was reduced to 25 grams by quartering process as described by Wentworth.[1]

In this method of quartering the 100 gram sample was poured through a glass funnel that was fastened about three inches above a large sheet of white paper. The resulting conical pile of fairly well-mixed materials, was then flattened out to form a circular pile

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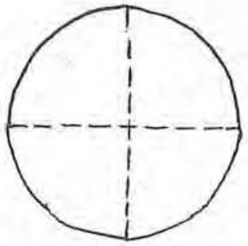
[1] Op. cit., p. 18.

of uniform thickness, and cut into quarters by two incisions made at right-angles to each other:



The alternate quarters were then selected for repeated quartering. From these chosen quarters a new conical pile was formed and divided as before. This time, two alternate quarters were chosen to be the final sample used in the mechanical analysis, and the rejected material of both times was bottled, labelled "unsifted" with the sample number, and filed away for comparison with the separates.

Weighing

The selected material was placed in a tared beaker and its weight, which was approximately 25 grams, was recorded to the fourth decimal place. In the specimens taken from Warm Springs and Hot Springs districts, however, weighing was only made to the second decimal place. The futility of any greater accuracy in the laboratory was realized, in view of the numerous possibilities of error in the original collecting and subsequent analyses, for in view of this, in the final analysis, accuracy to the second decimal place would still far surpass accuracy in subsequent interpretation. This is discussed in greater detail immediately after this section.

Sieving

The weighed sample was then placed in the tower of a previously standardized Tyler Sieving outfit, and placed upon a mechanical shaker. The sieves used were regulation size, 6 inches in diameter, and the following scale shows their openings in millimeters and the number of meshes to the square inch:

Mesh	Mm.	Mesh	Mm.
16	.991	80	.175
32	.495	115	.124
42	.351	150	.104
60	.246	250	.061

The results of the separation, though attained in millimeters, could be easily reduced to the Wentworth scale.[1] This is universally used and is therefore employed constantly for reference and descriptive purposes in the presentation and interpretation of these data:

Sediment	Size of Particle in Mm.
Bowlder........................	256
Cobble........................	64
Pebble........................	4
Granule........................	2
Very coarse sand................	1
Coarse sand....................	$\frac{1}{2}$
Medium sand....................	$\frac{1}{4}$
Fine sand......................	1/8
Very fine sand.................	1/16
Silt...........................	1/256
Clay...........................	Less than 1/256

The weighed sample in the tower of the sieves was shaken for ten minutes and then the material in each sieve was examined under the

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[1] *Op. cit.*, pp. 21-24.

microscope for aggregates which were removed, broken up, and replaced in the tower for an additional 30 minutes. (This was the minimum time found by experiment to produce efficient sifting.) The material from each sieve was weighed and placed in a small glass vial labelled with the specimen number, size of the separate, and its weight. The weight of size groups for each specimen were also recorded in a notebook. Plate 2 (p.27) shows a typical calculation sheet from the laboratory notebook. The loss during disintegrating and sieving, usually not greater than .1%, was divided amongst all the grades and the per cent by weight of each grade was computed.

Throughout the entire sifting process, the sieves were examined at infrequent intervals to determine whether or not the holes were being enlarged and special care was taken when the material from each sieve was removed, to clean the sieve by means of stiff metal brushes and a very fine needle. This also prevented contamination of samples.

Sedimentation

The dry-sieving method though effective for separating material coarser than 1/16 millimeter, did not provide for the separation of silt and clay particles, which constituted the material passing through the finest sieve (.061 mm.). Where the amount of this material was greater than 10% by weight of the entire sample, it was subjected to sedimentation process described here.[1]

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[1] Chosen after consideration of several other methods, at the suggestion of Dr. Fred Foreman, since this was most adaptable to available laboratory equipment.

The Pipette Method of Sedimentation suggested by Krumbein[1] is based upon the rate of subsidence of particles in a liquid. When grains are permitted to settle freely in a liquid, they do so under the influence of gravity, the rate of subsidence of a particle being controlled by its density, size, and shape, and also by the density and viscosity of the liquid employed. Thus such a separation approaches those conditions under which the sediments were formed if they are of aqeous origin.[2]

In order to achieve satisfactory results in the pipette method, it is important that the sediment be completely dispersed in the solution. To aid in this the material to be so separated was boiled in approximately 250 cc. of distilled water and .5 gm. of Na_2Co_3, the time of boiling not exceeding twenty minutes, since a longer period is likely to cause the formation of colloidal particles. The sample was then allowed to cool overnight, and if the supernatant liquid retained much of its turbidity, this was usually taken to indicate successful dispersion. Complete cooling is necessary to avoid any convectional current effect, for if a particle should encounter a rising current of warm water in the liquid, its settling velocity would be materially reduced.

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[1] Op. cit., p. 18.

[2] Separation by sifting does not actually approach the original conditions, for in such a separation only the cross-sectional size of the particles controls the divisions into grades, the density, shape and volume being of no account. Therefore, in the same grades, the constituent particles will not necessarily act in a similar way in streams or on beaches under natural conditions.

When the solution was cool, it was transferred to a 1000 cc. graduated cylinder, diluted to that volume, shaken well for one minute to attain a uniform distribution of the particles throughout the suspension, and then allowed to settle. To determine the time required for settling of the particles, Krumbein's[1] Table which follows was consulted:

Table Showing Time Required for Settling of Particles

Diameter in Mm.	Velocity in cm sec.	h in cm.	Hrs.	Min.	Sec.
1/32	.08688	10	0	1	55
1/64	.02172	10	0	7	40
1/128	.00543	10	0	30	40
1/256	.001357	10	2	2	40

Assumed conditions: Temp. = 20°C. Sp. Gravity 2.65

To quote from Krumbein:

> "The principles upon which this method was based rest upon the assumption that in a dilute suspension the particles settle as individuals, an assumption which is inherent in any method of analysis. If a suspension is thoroughly shaken so that the particles are uniformly distributed and 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 time interval 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."[2]

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[1] *Op. cit.*, p. 18.

[2] Ibid., p. 18.

Therefore, if a small sample is taken from this depth at progressively larger time intervals, concentrations of successively smaller particles may be found, and, by subtraction, the amount of material in any grade size may be computed.

In translating settling velocity into diameters, Krumbein took recourse to Stokes' Law which in abbreviated form reads as follows:

$$v = Cr^2$$

Where $v = h/t$, and C is a constant under any given set of conditions.

The conditions here used were the same as those given at the bottom of Krumbein's Table. Krumbein evaluated the constant and then multiplied it by the square of the radius in centimeters, thereby obtaining the settling velocity in centimeters per second. The velocity may then be converted into hours, minutes, and seconds, required for a particle to settle a depth of 10 centimeters by using the formula

$$v = h/t$$

and then

$$t = \frac{h}{Cr^2}.$$

After thorough shaking, then, a pipette was inserted to a depth of 10 centimeters when the suspension had been allowed to settle for 1 minute and 55 seconds, and 20 cc. of the suspension were drawn into it. The contents of the pipette were transferred to a tared beaker and evaporated to dryness over a steam bath, after which it was weighed and the computation made as noted on the calculation sheet. The process was repeated but the second time the suspension was allowed

TYPICAL CALCULATION SHEET

Or 4C

Total Time of Shaking: 40 minutes

Weight of Beaker and Sample: 56.1138 gms.

Weight of Beaker alone: 32.7688

Weight of Sample: 23.3450 gms.

Separation by Sifting

Grade Size in Mm.	Wt. of Beaker & Sand	Wt. of Beaker	Wt. of Sand	% of Whole	Cumulative %
495-351	34.2896	32.7688	1.5208	6.52	0
351-246	36.7475	32.7688	3.9787	17.10	6.52
246-175	37.0480	32.7688	4.2792	18.21	23.62
175-124	39.2738	32.7688	6.5050	27.80	41.83
124-104	34.8064	32.7688	2.0376	8.58	69.63
104-061	35.2868	32.7688	2.5180	10.50	78.21
Less than 061	35.4122	32.7688	2.6434	11.30	88.71
Totals			23.2827	100.01	

Plate 2

Typical Calculation Sheet (continued)

Sedimentation

Amount of Material used: 2.6434 gms. (Less than 061 mm.)

1. Time of Settling: 1 min. 55 secs.

Wt. of Beaker + material:	32.8054
Wt. of Beaker alone:	32.7688
Wt. of material in 20 cc. =	.0366
Wt. of material in 1000 cc. =	1.8330 gms.
Wt. of Na_2Co_3 in 1000 cc. =	.5
Wt. of actual sediment less than 1/32 mm. =	1.3330 gms.
Wt. of material less than 1/16 mm.:	2.6434 gms.
Wt. of material less than 1/32 mm.:	1.3330
Wt. of material from 1/16 - 1/32 mm. =	1.3104 gms.

2. Time of Settling: 7 min. 40 secs.

Wt. of Beaker + material:	40.1432
Wt. of Beaker alone:	40.1252
Wt. of material in 20 cc. =	.0180
Wt. of material in 1000 cc. =	.9000
Wt. of Na_2Co_3 in 1000 cc. =	.5
Wt. of actual sediment less than 1/64	.4000 gms.
Wt. of sediment less than 1/32 =	1.3330
Wt. of sediment less than 1/64 =	.4000
Wt. of sediment in 1/32 - 1/64 mm. =	.9330 gms.

3. Time of Settling: 30 min. 40 sec.

Wt. of Beaker + material:	42.7712
Wt. of Beaker alone:	42.7560
Wt. of material in 20 cc.=	.0152
Wt. of material in 1000 cc. =	.6600
Wt. of Na_2Co_3 =	.5
Wt. of actual sediment less than 1/128 mm. =	.1600 gms.
Wt. of Sediment less than 1/64 mm. =	.4000 gms.
Wt. of sediment less than 1/128 mm. =	.1600
Wt. of sediment 1/64 - 1/128 =	.2400 gms.

Plate 2

Typical Calculation Sheet (Continued)

Data Showing Percentage Frequency of Size Grades Obtained by Above Sedimentation Method

Grade Size	% of Whole	Cumulative %
1/16 - 1/32	5.7	88.71
1/32 - 1/64	3.9	94.41
1/64 - 1/128	1.2	98.31
1/128 - 1/256	.4	99.51
1/256 -	.0	99.91

Plate 2

to settle 7 minutes and 40 seconds, and the third time, if the remaining amount of sediment warranted further separation, the suspension was allowed to settle 30 minutes and 40 seconds.

It will be noted that in the computations allowance is made for the .5 gm. of Na_2Co_3 used to aid in the dispersion. Thus the final computation gives the frequency of the sand particles in terms of diameters as determined by the sieving, and of the silt and clay particles on the basis of equivalent diameters representing settling velocities.

Sources of Error

In carrying out a mechanical analysis, it will be seen that the chances for, and sources of error are manifold, coming from any one or all of the aforementioned phases of the work, i.e., collecting, mechanical and chemical disintegration, sifting, and sedimentation; not to mention the errors of subsequent plotting and interpretation. Wentworth has assembled all the possibilities for error into the table that appears on the following page.[1] However, it is believed that even with all these chances of error, the results obtained with the use of reasonable care and accuracy in the laboratory will still surpass the degree of accuracy attained in the collection and interpretation of the data.

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[1] Chart taken from Wentworth, op. cit., p. 21.

ERRORS IN MECHANICAL ANALYSIS
(after C. W. 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 container.	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 grades.
	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.
	Non-uniform 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.

Plate 3

During the analysis several factors entered which in some cases interposed serious difficulties. Where there was much manganese in the sample, especially in the finer grades, it tended to cause flocculation of the grains. Also, during the pestling it was almost impossible to keep the iron and manganese from being ground up to the degree where it would increase the weight of the smaller sediments. The problem arose as to whether or not the weight of iron and manganese ought to be included in the final calculation of percentage-frequency for each grade. After several experiments with mechanical and chemical methods,[1] however, it was found that no satisfactory method for the separation of manganese without affecting the composition of the rest of the sample was available, and therefore when the results did not depart too greatly from those of the specimens lacking such material, they were used.

Another problem was that presented by enlargement of many of the grains due to secondary growth. This would, of course, tend to introduce errors in the final results, but here again it was felt that since this condition did not exist very extensively, results might still be attained which would closely approach the exact ones.

Methods for the Presentation of Data

After the sediment had been separated into grades or classes based upon its dimensions, and the percentage-weight of each grade

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[1] Private conference with Dr. Werner Bromund, Department of Chemistry, Oberlin College.

in relation to the whole had been computed,[1] a satisfactory form had to be chosen for presentation of the data thus secured. Since the problem that was undertaken by this paper is to deduce from the data conditions of sedimentation with special reference to agencies responsible for, and the origin of, the composing sediments, graphs must be used that will permit rapid study and ease in such interpretations. Several possibilities presented themselves, and it is here considered advisable to discuss, very briefly, the relative advantages and disadvantages of each, thereby explaining the factors leading to the final choice of graphical methods used in this report.

Histogram

The histogram is a rectangular plot in which the per cent by weight of each grade size with reference to the whole sample is represented by a shaded column. In the card used, the abscissa represented per cent, and the ordinates, the grade size in millimeters. A typical one may be seen on Plate 4. From it, it is evident that such a plot is a strict presentation of numerical facts. No interpretation is necessary and the results can be readily visualized even by those unaccustomed to its use. For this reason alone, many petrologists have been inclined toward their use, despite the fact that they bring with them many disadvantages.

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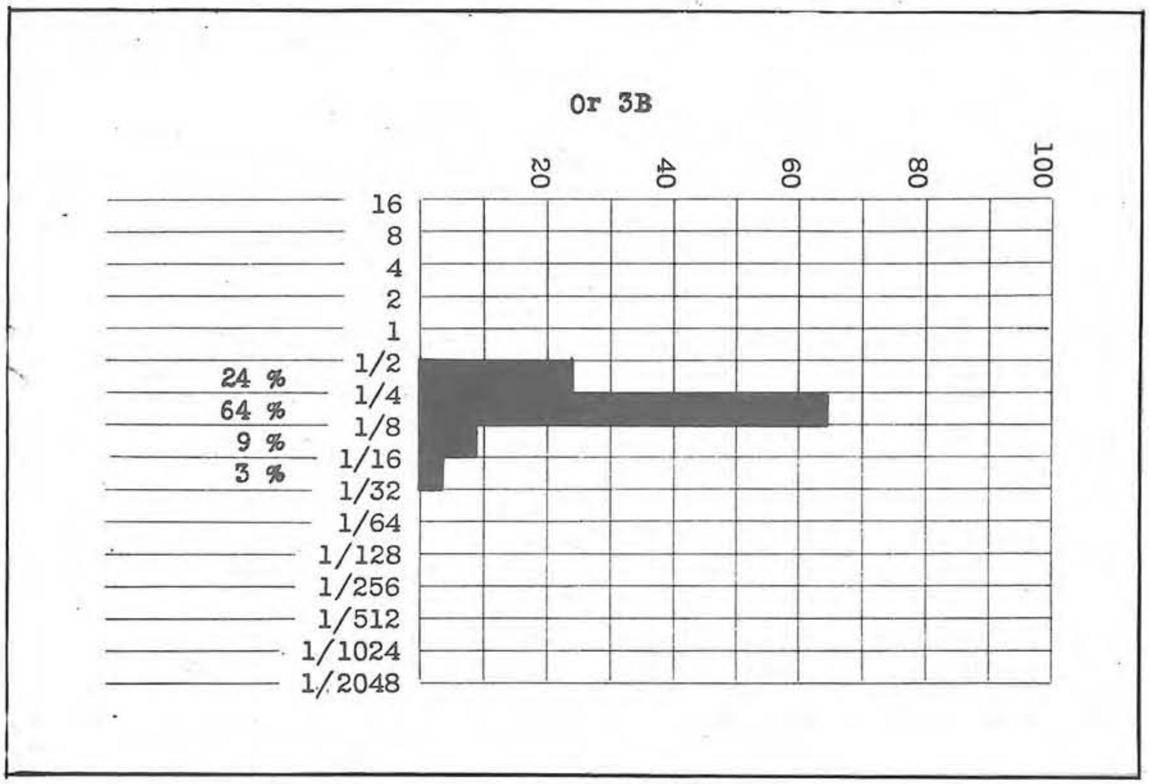
[1] During calculations occasional check was made on the slide rule results, but for most computations the degree of accuracy obtained from its use was acceptable.

TYPICAL HISTOGRAM



(Front)

Taken approximately 2 feet from Romney contact, 2¼ miles south of Monterey on west limb of syncline. Slight surface deposit of manganese evident. Specimen effervesced slightly in acid.

(Back)

Plate 4

An outstanding disadvantage of the histogram plot is that the size of the grade limits used definitely affects the form of the resulting graph, so that the same sediment can be altered beyond the point of recognition. Such sharp variability in a graphical picture of the same specimen would, of course, make its use as an exclusive method of plotting, highly unsatisfactory. Another disadvantage presented by the histogram is that it implies from its form, that there is a sharp break between grade sizes, which, of course, is not the case.

To overcome this difficulty many petrologists have used the Frequency Curve, which, aside from the fact that there can only be one such curve for each specimen, also seems to achieve greater accuracy of presentation in the form of a smooth curve which emphasizes the continuous variation in particle size. The importance of such an advantage as this cannot be overlooked.

In graphing results of a mechanical analysis, the independent variable is, of course, the diameter of the particle. From the nature of the particles composing a sample, it is evident with perhaps a few exceptions, that the diameters vary by infinitesimal amounts along the entire range of sizes represented, rather than by abrupt changes from one size to the next, as suggested by the histogram. In statistical nomenclature,[1] such a distribution is known as a "continuous" one and it is, therefore, generally conceded that a

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[1] F. C. Mills, Statistical Methods, p. 85.

smooth continuous curve is best suited to represent such a gradation in particle size.

In the frequency curve the choice of grade limits or class intervals are somewhat arbitrary, and are usually determined by the nature of the data and the number of units[1] best adapted to the presentation of a smooth curve of reasonable accuracy.

A few points of comparison between the histogram and frequency curve might here be worth considering.

1. The histogram is in reality an approximation of the frequency curve, but, while it is subject to error by the introduction of changing grade limitations, the frequency curve is not susceptible to such error and is therefore a more reliable index to the true character of the sediment.

2. Any type of histogram may be developed from a definite frequency curve and conversely, a frequency curve may be developed from a histogram.

3. In the frequency curve the proportion of material in <u>any</u> size range may be determined, while in a histogram the areal relations are confined to the particular class interval.

From the foregoing, it should be evident that a combination of both of the above graphical methods ought to prove satisfactory.

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[1] Each unit becomes a point on the curve.

Cumulative Curves

The cumulative curve has been found to be of great value for expression of results from routine analysis. Such a curve when plotted, uses the cumulative per cent along the ordinate, as the dependent variable, and the grade size as the independent variable, along the abscissa. Cumulative per cent is calculated by computing the per cent by weight of the product that would remain on a testing sieve if only one sieve were used in the separation of the entire sample. Thus the addition of the weight-percentages of all material coarser than the one sieve used, will give the cumulative per cent, and then on the cumulative curve, each point plotted will represent the per cent by weight of the entire sample that is larger than the particular size plotted. Such a curve will, of course, be a smooth, continuous one and its interpretation should prove fairly simple, i.e., if the curve tends toward the vertical, there is a preponderance of the size indicated, whereas if the curve tends toward the horizontal, it would suggest a relatively small proportion of the material of the size indicated. Also, if the curve occupies the left-hand section of the diagram, a preponderance of coarse-grained sediments may be assumed, or, if the curve becomes prevalent toward the right-hand side, it is fine-grained.

While the cumulative curve was found to be useful for simple plotting, the similarity of the curves for many of the specimens made it necessary to use an additional plot that would give some basis for contrast, by permitting the adoption of such measures as means, standard deviation, and skewness of the distribution. Such a curve was derived directly from the cumulative curve according to the method given by Krumbein[1] and was plotted on the same sheet as the cumulative curve. Since a correct interpretation of the curve requires some understanding of its derivation, a brief explanation is here given. The reader, however, is advised to refer to Krumbein's article for a more complete discussion.[2]

In calculus it may be demonstrated that there is a definite relationship between the two types of curves, for every continuous curve has associated with it an integral and derivative curve. In the integral curve the ordinate at any point represents the area under the given curve up to that point. Thus the cumulative curve may be considered the integral of its corresponding frequency curve. In the derivative curve, the ordinate at any point represents the slope of the curve at that point. Thus the frequency curve becomes the derivative of the cumulative curve.

An attempt to show this relationship has been made in Plate 5A, where the same sediment has been plotted in three different ways. A single ordinate on the cumulative curve enables one to read the total percentage of grains larger or smaller than the designated

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[1] W. C. Krumbein, Size Frequency Distribution of Sediments, Journal of Sedimentary Petrology, August, 1934, pp. 71-75.

[2] The greater part of that which follows is taken directly from Krumbein, but it is felt that the reader who is not already acquainted with the use of this type of curve would benefit from the reading of the more complete explanation.

diameter. It will also be noted that, in accordance with the preceding discussion, the frequency curve reaches its greatest height where the slope of the cumulative curve is steepest. The actual plotting of the curve is based upon a tangential relationship of the two, and is given in detail in the aforementioned article by Krumbein.

In the presentation of the data of this analysis all three curves were utilized, since it was felt that a combination of these methods should give a reliable picture of the physical composition of the sediment so far as the size of the grains and relative proportions of the latter are concerned.

"Phi" Notation

In the plots that follow it will be noted that the ordinates in all cases represent the cumulative per cent and the latter is plotted against the size of diameter represented along the abscissae or horizontal axis. The diameters of the sand grains may be plotted directly as the independent variable. However, since the data were assembled in terms of Wentworth's grade scale (p. 22) and each succeeding grade is one-half as large as its predecessor ($\frac{1}{2}$, $\frac{1}{4}$, 1/8, 1/16 mm.etc.), the resulting graph necessarily appears quite unsymmetrical and a poorly sorted rock would require a very large diagram. (See Plate 5B.) Thus to increase the symmetry, a plot in which the class intervals are equal in width, producing a more compact graph, would seem advantageous. This was achieved by plotting the negative logs of the diameters. The *negative* log was used because all results of the analysis were in terms of particle diameters of less than 1 mm., and its use avoids the necessity of plotting negative numbers.

A scale based on the negative logs would necessarily be one that would increase to the right as ordinary scales do, in contrast to the direct plot which decreases to the right. (See Plate 5A and 5B.) This method evolved by Krumbein, is known as the phi method[1] where the symbol ϕ equals the negative log of the diameter-size to the base 2, thus yielding a series of values free from the objections and inconveniences of a geometric scale. Here an increase of one phi unit means the reduction of the diameter size by one-half, and, as previously mentioned, the divisions between the class intervals are equal to each other and to one phi unit. The table which follows is taken in part from Krumbein[2] and shows the ease with which the phi scale may be converted to the Wentworth grade limits. (See Plate 5D for the mathematical relationship.)

Grade Limit in Mm.	ϕ
1	0
$\frac{1}{2}$	+1
$\frac{1}{4}$	+2
1/8	+3
1/16	+4
1/32	+5
1/64	+6
1/128	+7
1/256	+8

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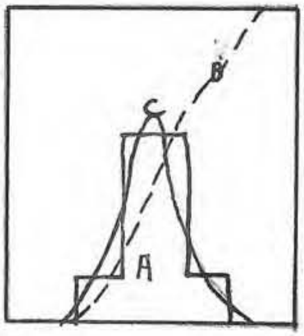
[1] W. C. Krumbein, Application of Logarithmic Moments to Size Frequency Distributions of Sediments, Journal of Sedimentary Petrology, April, 1936. p.36.

[2] Ibid., p. 38.

Plate 5

A

A Cumulative, Frequency, Histogram Plot of the Same Sediment[1]



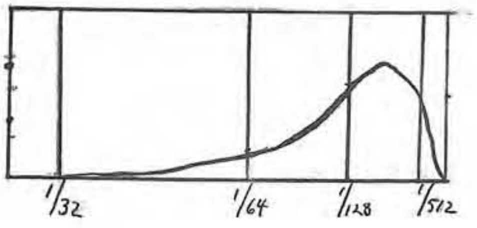
A = Histogram

B = Cumulative Curve

C = Frequency Curve

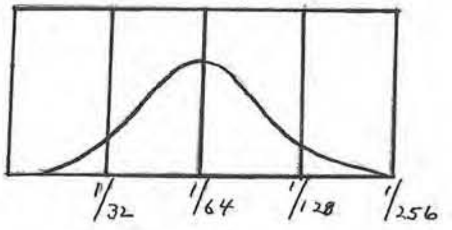
B

Grade Sizes Plotted Directly[2]



C

Sediment Plotted with Diameters Measured as Negative Logs[2]



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[1] W. C. Krumbein, Size Frequency Distribution of Sediments, Journal of Sedimentary Petrology, August, 1934, p. 68.

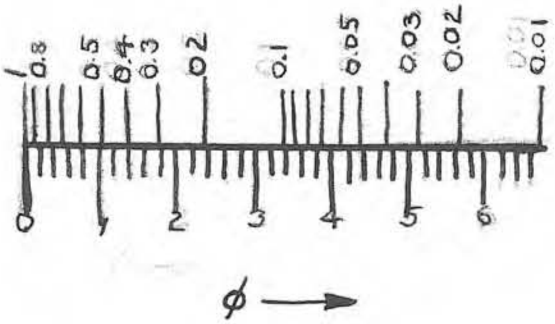
[2] W. C. Krumbein, Application of Logarithmic Moments to Size Frequency Distribution, Journal of Sedimentary Petrology, April, 1936, p. 37.

Plate 5 (Continued)

D

Relation Between Diameters and Independent Variable ϕ[1]

DIAMETERS



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[1] W. C. Krumbein, Use of Quartile Measures in Describing and Comparing Sediments, American Journal of Science, Vol. 232, 1936, p. 105.

But the graphical expressions by themselves are singularly ineffective unless they can show the reader at a glance the degree of sorting of the sediment, the distribution of the particle size, the average diameter, and any other facts pertaining to the distribution of the particles that might render interpretation of the material more complete and possibly more effective. Therefore, measures that would describe the sediments with respect to the above features were plotted upon the curves. These, however, will be discussed in the next section of this paper.

Heavy Mineral Separation

Because the study of heavy minerals in a sediment gives major clues to the identification of its source rock, the previously graded samples were submitted to such separation[1] in the hope that their study would aid in the ensuing discussion on the conditions of sedimentation. Heavy mineral separation was preceded by chemical treatment of grains to remove iron, which in many of the specimens coated the grains and tended to make them heavier and caused them to act as heavy minerals during the separation. To avoid this, the grains which indicated by their color that they possessed a fair amount of iron, were boiled in 50 cc. solution of stannous chloride and 5 cc. of dilute hydrochloric acid. The amount of stannous chloride used depended upon the individual sample and the relative amount of iron

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[1] The procedure that follows was carried on according to method suggested by Dr. Fred Foreman.

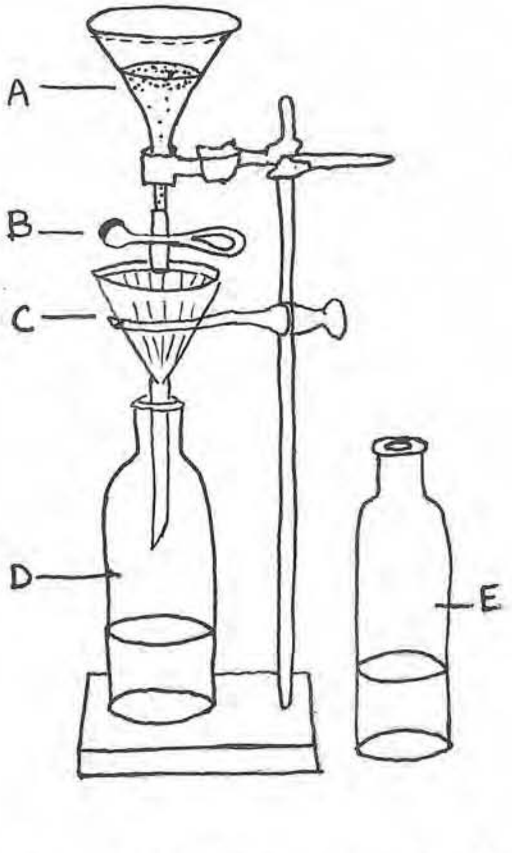
present. The chemical action here involved the reduction of ferric iron to ferrous condition in order to make it soluble and able to be washed off from the surface of the grains.

The sample was boiled until the color disappeared or the grains became perceptibly lighter in color. Such boiling usually did not last longer than fifteen or twenty minutes in order to avoid the formation of colloidal particles in the suspension. The suspension was then filtered, the filter paper having been previously marked as to specimen and grade size, washed thoroughly with hot water, and allowed to dry overnight or longer.

Many of the samples were weighed both before and after such cleaning and the loss in weight evidently due to the iron, varied from an almost negligible amount to 4% of the original weight of that particular grade size. As heretofore suggested, this presented the problem of re-considering the original weight of the individual grain sizes since such a weight necessarily included the iron. However, this loss in weight was found to be equally distributed throughout all the grade sizes when it did occur, and therefore it would not appreciably alter a graphical picture of the sediment designed to show the relative proportions of each grade size to the whole.

After the specimen had been thoroughly dried, the sample was subjected to the heavy mineral treatment. In this, the sediments are floated in a heavy liquid, and here bromoform, which has a specific gravity of 2.9, was used. The particles were thoroughly mixed in the liquid and then allowed to settle for several minutes. Those that sank of course had a specific gravity higher than that of the heavy liquid and those that floated, lighter than 2.9.

The apparatus used conformed somewhat generally to the following sketch which is self-explanatory. As a rule, however, more than one separation was carried on at a time.



[1]
A = Funnel containing the bromoform and sample from which the heavy grains are settling.
B = Pinch-cock on rubber tubbing attached to funnel stem.
C = Labelled filter paper for retaining the heavy minerals. This filter paper is later replaced for a clean one labelled with specimen number, grade size and L.M.S. into which the lighter minerals are later emptied.
D = Brown bromoform bottle to prevent action of light upon the bromoform.
E = Bottle into which alcohol and bromoform washings are poured.

When separation was believed to be complete, the stop-cock was released long enough to allow only the heavy minerals to drop into the filter paper and the bromoform was recovered in its original bottle.

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[1] H. B. Milner, *Sedimentary Petrography*, p. 43.

The minerals were then washed with ethyl alcohol and the washings, which also include some bromoform, were collected in a bottle labelled as such and these were kept for subsequent distillation and recovery of the bromoform. This procedure was repeated for the collection of the lighter separates.

One of the major objections to this method of separation is the rapid evaporation rate of the bromoform, its reaction to light, and the fact that it is quite expensive to employ. Precautionary measures were therefore taken. For example, the funnels containing the bromoform were kept well-covered with watchglasses, and the brown bottles tightly stopped. Also several times during the procedure the bromoform was recovered from the alcohol washings.

To accomplish such recovery,[1] the wash solution was diluted with water, well-shaken, and allowed to settle. The bromoform under these conditions would settle out, and by pouring off the supernatant liquid, most of it could be recovered. It was heated to its boiling point (151°C.) to drive off any water or alcohol that it may have retained.

Several difficulties were encountered during the operations. Some of the specimens containing a great deal of manganese, had their heavy mineral separate greatly contaminated with manganese fragments.

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[1] Modification of procedure described by George V. Cohee, Inexpensive Equipment for Reclaiming Heavy Liquids, Journal of Sedimentary Petrology, April, 1937.

Several methods were attempted, both mechanical and chemical, for separation of the manganese, but mechanical methods did not give the desired results, and any chemical procedure which would remove the manganese, would also have been detrimental to the quartz and other minerals present. Also in a few of the samples where the manganese particles were present in sufficient numbers, they tended to bring down with them some of the lighter minerals. Again, if the earlier chemical treatment was not 100% effective, quartz grains were carried down with the heavier minerals due to their coating of iron oxide.

Roundness of Grains

It is generally conceded that studies made upon sand grains to determine their roundness or sphericity, can be of inestimable value in determining the origin of such sediments. It is still, however, a matter of universal conjecture as to the relative efficiency in accomplishing such study by use of the several methods available.

The writer has herself studied several of these methods[1] and at the suggestion of Dr. Fred Foreman finally adopted Cox's method of assigning numerical and percentage values to the degree of roundness of sand grains.[2]

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[1] F. J. Pettijohn, Determinations and Calculations of Sphericity Values of Pebbles, Journal of Sedimentary Petrology, December, 1936; Allen C. Tester, The Measurement of the Shapes of Rock Particles, Journal of Sedimentary Petrology, May, 1931; G. E. Anderson, Experiments on the Rate of Wear of Sand Grains, Journal of Geology, V. 34, p. 144-158.

[2] E. P. Cox, A Method of Assigning Numerical and Percentage Values to the Degrees of Roundness of Sand Grains, Journal of Paleontology, Vol. 1, December, 1927, p. 179-183.

It might be well to note here the essential difference in the uses of the terms "roundness" and "sphericity," for although many petrologists have used the term "roundness" to designate simply the degree to which the sharp edges and corners have been worn away, Cox uses the term to describe the degree to which a three-dimensional body approaches a sphere. The measurements made to determine this factor present somewhat of a problem, for while the volume of the grain may be fairly easily measured, the measurement of its surface presents a more difficult problem, the solution of which is based upon the theory that if a number of random sections are taken through a large number of grains, the average of all such sections will approximate the average section for the average grain and the degree to which this average section approaches a circle, will be the measure of the roundness of the grains. Thus the roundness would be measured by the degree to which the ratio of the area to the circumference approaches the same ratio for a sphere, which expressed mathematically would read as follows:

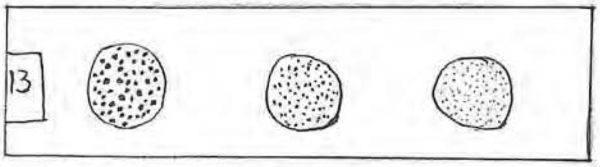
$$\frac{\text{area}}{(\text{perimeter})^2} = \text{a constant}$$

In a circle the constant, "K" is $\frac{1}{4}\pi$. Then multiplying the equation by 4π:

$$K = \frac{\text{area } 4\pi}{(\text{perimeter})^2}$$

In a sphere K = 1, but for any other shape the value decreases as the percentage of the area of the figure to be measured, decreases with relation to the area of a circle of the same perimeter. In other words, if a right isosceles triangle were measured according to the above, it would be found to have a "roundness" figure of .54 which means simply that that triangular form contains 54% of the area that a circle with the same perimeter would contain. Thus it is evident that the figure computed would be the same for all figures of the same shape regardless of size, i.e., a circle 1 inch in diameter will give the same value, which a 4-inch circle will give, namely 1.

In order to measure these values for the grains that have just been analyzed, slides were made for three size-grades in each sample, i.e., $\frac{1}{2}$-$\frac{1}{4}$ mm., $\frac{1}{4}$-1/8 mm., and 1/8-1/16 mm. These were referred to as grades 1, 2, and 3 respectively (in terms of ϕ units), and small portions of the grains from each grade were sprinkled over slides covered with Canada balsam, so that a series of slides were made, one for each sample, and each one containing grains from each of the three grade-sizes.



Form of Typical Slide for Study of Roundness of Grain

The grains were then projected upon a sheet of paper attached to a screen, and the outlines of approximately 25 grains from each size-group were traced directly onto the paper. The area of each grain was measured by means of a planimeter, and the perimeter by means of a cyclometer, or map-measure.

Many arguments have been proferred as to the relative value of such a procedure in the measurement of the roundness of the grains. As was stated by Tester,[1] such a study does not consider the original shape of the sand grains before abrasion was begun. For example, Cox does not consider that the fragment just broken from a parent rock actually starts with zero roundness as far as its abrasional history is concerned, but rather if it should happen to be broken in the shape of the aforementioned isosceles right triangle, it immediately assumes a "roundness" figure of .54. However, in view of the fact that no other methods were available that were as feasible for ordinary laboratory equipment, this one was utilized with full realization of its drawbacks.

In tabulating the results of this study as they appear in the following section of this report, the author deliberately neglected to compute the average roundness of the entire sample. It was considered more pertinent to determine only the average roundness for each <u>grade-size</u> and to record the deviation from the mean in each case. A cursory glance at the data should prove sufficient to convince the reader that such a figure as the average roundness for the sample would not only be singularly useless, but might lead to serious misconceptions as to the true character of the sediment.

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[1] <u>Op. cit.</u>, p. 4-5.

CHAPTER III

PRESENTATION OF DATA

The results of the mechanical analysis of 45 specimens, by sifting and sedimentation processes, were plotted and recorded, but for final discussion, it was considered expedient to eliminate eleven specimens. The samples eliminated were done so for the following reasons:

1. Two yielded results that could not possibly be taken as approximating the true nature of the sediment due to the inordinate amount of manganese present in all size grades. This was located three miles south of Strait Creek on the road to Monterey.

2. One sample, taken south of Warm Springs, could not be accurately located with reference to upper, middle, or lower beds of the formation and therefore was useless in this study.

3. One sample taken east of Monterey was highly cherty and could not be disintegrated.

4. Seven samples were eliminated to avoid repetition, since in the field, specimens were taken at one-fourth mile intervals from Strait Creek to Monterey, and they did not differ enough from those chosen from that same region for this presentation, to warrant their inclusion.

As heretofore mentioned, vertical as well as horizontal distribution of samples was sought. In several instances the writer was successful in this attempt, but in an equal number of instances, the irregular distribution and peculiar topography of the region made such a vertical collection impossible. In several of the latter cases, attempts were made to make the distribution as near a vertical one as possible. For example: Specimen No. 16 was taken 2¼ miles south of Monterey, at the Romney or upper contact, but here collection of samples from middle and lower beds was not possible and specimens from the latter two beds were taken one-half mile further south where an outcrop permitted such collection.

In the Warm Springs section, especially, were these difficulties encountered and here only two sets of specimens give any sort of vertical distribution. In this region, however, since samples were taken here mainly for comparison purposes, and such specimens were available, the writer took samples from different parts of the anticlinal and synclinal structures, i.e., limbs and center, to note any possible textural differences between these.

Again, due to the irregular distribution of the Oriskany sandstone and its extreme local thickening and thinning, specimens plotted as representatives of the "middle" of the series necessarily vary as to their actual distances from the upper and lower contacts. Wherever possible the approximate distances from either of the contacts is given, such distance being determined by pacing, due consideration being given for the inclination of the strata.

Results of Chemical Treatment

From preliminary laboratory treatment described above, i.e., soaking in acid, it appeared that the specimens from the lower beds during such soaking effervesced considerably, and were decidedly easier to disintegrate after the treatment. The samples from the upper beds, however, as well as most of the middle bed samples, although they effervesced slightly, did not yeild to disintegration any more easily after such soaking, despite the fact that for many of them the concentration of the acid solution was increased, and the specimen was kept in it for a longer period of time.

This fact suggests that the lower beds are more calcareous than upper beds, the calcite evidently making up much of the cement, in contrast to the upper beds which are chiefly silica-cemented, the effervescence there probably being due to irregular and infrequent distribution of calcite amongst the quartz grains.

In outcrops from Strait Creek south to Monterey an intermittent cherty horizon made its appearance at the base of the sandstone. Samples at two locations were taken from this horizon but due to their high percentage of chert and iron, they were unable to be subjected to the sifting process, and although these did effervesce when put into a dilute acid solution indicating slight lime content, they were not noticeably softened by such soaking, indicating their essential composition to be that of silica.

As mentioned earlier in this paper, many geologists consider this layer to be Shriver chert, a lower bed of the larger Oriskany Series, underlying the Ridgely or Monterey Sandstone member. Since this report concerns itself mainly with the sandstone division, no further study was made on these cherty layers but their presence was necessarily considered in the discussion which follows, dealing with the conditions at the time of the deposition of these sediments. In relation to this problem it is of interest to note that this cherty horizon did not reappear south of Monterey.

Results of Mechanical Analysis

Histograms

The results of the mechanical analysis based upon sifting and sedimentation were first plotted by means of the histogram or rectangular plot (Plate 6). For convenience, the plots are arranged in three vertical columns as indicated, representing upper, middle, and lower beds, and ranging from Strait Creek vicinity at the top of the paper to Hot Springs at the lower end of the sheet. Here the reader is referred to the map at the front of this report (Plate 1) for more complete orientation. On this the dark dots represent the location of the outcrops and their relationship to the surrounding country may thus be seen.

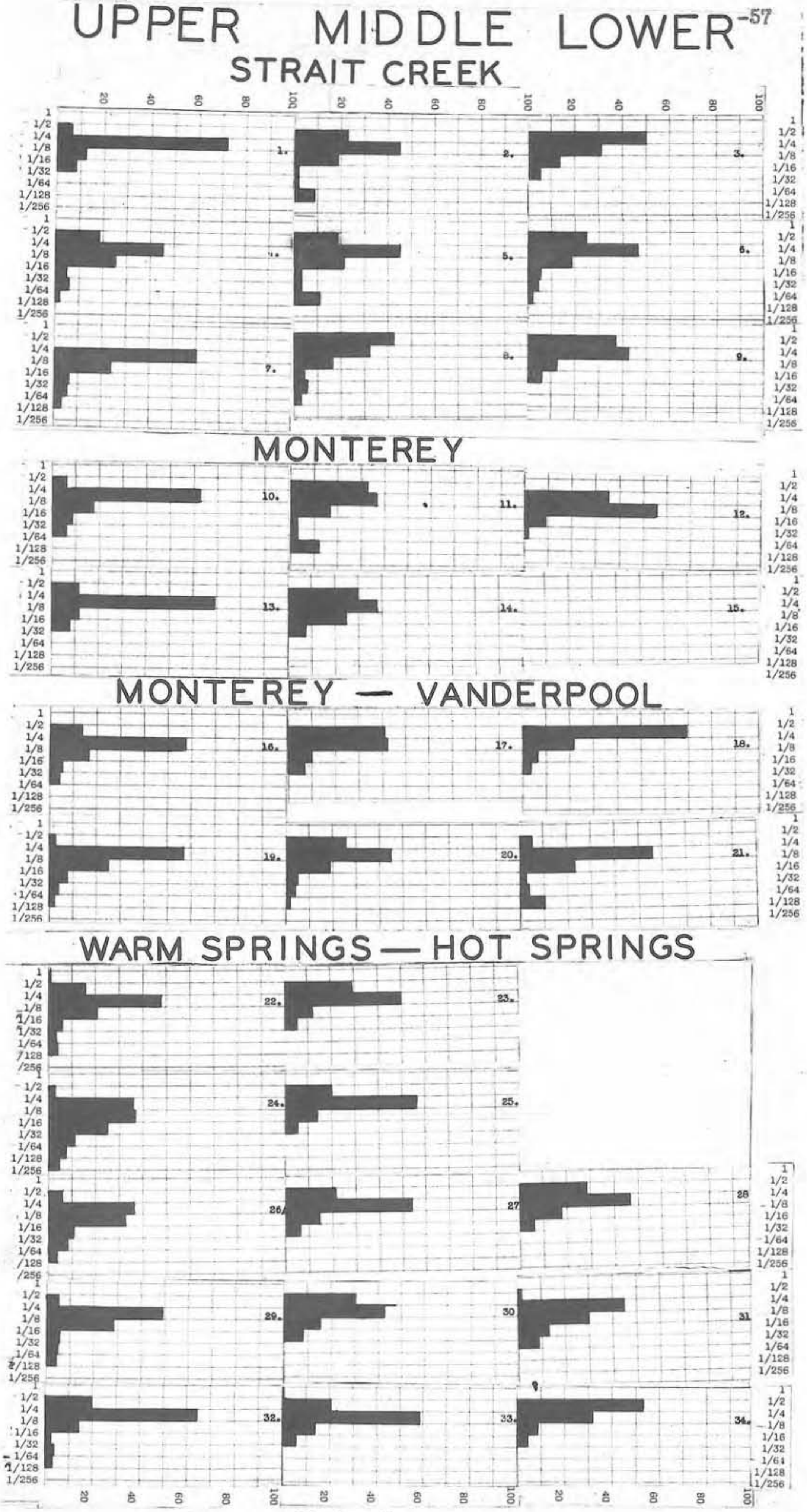
Accompanying the histograms an index has been arranged giving the exact location of the specimens according to the numbers that appear on each plot.

Index to Graphs

Index No.	Geographic Location	Stratigraphic Position
1	1 mile east of Strait Creek	Upper contact
2	" " " " " "	75 ft. below No. 1
3	" " " " " "	Lower contact
4	2 miles south of Strait Creek	Upper contact
5	" " " " " "	Approximately 100 ft. below No. 4
6	" " " " " "	50 ft. below No. 5
7	3 miles south of Strait Creek	Upper contact
8	" " " " " "	Middle of series (Approximate)
9	" " " " " "	Within 25 ft. of lower contact
10	1 mile east of Monterey	Upper contact
11	" " " " "	Middle of series
12	" " " " "	Lower contact
13	$\frac{1}{2}$ mile south of Monterey (east	Upper contact
14	" " " " " (limb of	30 ft. below No. 13
15	" " " " " (syncline)	10 ft. below No. 14
16	$2\frac{1}{4}$ miles south of Monterey (west	Upper contact
17	$2\frac{1}{2}$ " " " "(limb of	Approximately middle of series
18	" " " " "(syncline)	Lower contact
19	$3\frac{1}{2}$ miles south of Monterey (west	Upper contact
20	" " " " " (limb of	Middle of series
21	" " " " " (syncline)	Lower contact
22	Just south of Cobbler Mt. (top of anticline)	Upper contact
23	$3\frac{1}{2}$ miles south of Hot Springs along Cedar Creek (east limb of Collision Ridge anticline)	Approximately middle of series
24	East limb of Collision Ridge anticline	Upper contact
25	West limb of Collision Ridge anticline	Believed to be from middle beds
26	(East limb of Back Creek Mt., 4 miles)	Upper contact
27	(Northwest of Warm Springs)	Middle beds
28	" " " "	Lower contact

Index to Graphs (continued)

29	3 miles west of Warm Springs	(east limb	Upper contact
30	" " " " " "	(Bolar Mt.	Middle beds
31	" " " " " "	(Anticline)	Lower contact
32	6 miles west of Hot Springs	(southern	Upper contact
33	" " " " " "	(part of	Middle beds
34	" " " " " "	(Bolar Mt.)	Lower contact


UPPER
MIDDLE
LOWER
STRAIT CREEK
MONTEREY
MONTEREY — VANDERPOOL
WARM SPRINGS — HOT SPRINGS
20
40
60
80
100
1
1/2
1/4
1/8
1/16
1/32
1/64
1/128
1/256
1.
2.
3.
4.
5.
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8.
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34.

Plate 6

Keeping in mind, then, the fact that reading from left to right gives a vertical distribution and reading from top to bottom gives a north-south geographic distribution, a hasty study of the plots should reveal to the reader the following facts:

1. The lower beds are coarser than the upper beds. In all except plot No. 21 their graphs reveal as much as 50% of the grains from each specimen to be within the size group ranging from $\frac{1}{2} - \frac{1}{4}$ mm. which, according to the Wentworth scale, represents medium sand. By contrast, the upper beds have their maximum distribution between $\frac{1}{4}$ and 1/8 mm., which, according to Wentworth, may be classed as fine sand, and in these no one reveals more than 19% of the grains of each sample falling into coarser grade sizes.

2. The lower beds contain relatively small amounts of material less than 1/16 mm., silt and clay according to Wentworth. In all cases, except No. 21, less than 11% of the entire sample consists of silt and clay particles.

3. No definite conclusion can be derived from the histograms, as to the relative degree of sorting of the upper, middle and lower layers. Generally speaking, the samples from the middle layers are more poorly sorted in most cases. Also the middle beds tend toward a double or triple, and in plots 2, 5, and 11, a fourth maxima. The sediments are concentrated in medium, fine and very fine grades, and in the latter three specimens the fourth maxima occur in very fine silt or clay division. This may represent colloidal clay

developed during chemical treatment or possibly originating at the time of deposition.

4. Specimens taken from the limbs of the synclines seem finer than those from anticline structure. This is probably due to greater compression in the synclinal structure. This, therefore, cannot be considered indicative of the environment under which these sediments were originally deposited, since many of the quartz grains from the middle of the anticline revealed secondary growth of silica which would account for the larger size grains.

Frequency Curves and Measures

Although the histograms enable the reader to get a general survey as to the character of the sediment, the frequency curve presents a more complete picture in that it can describe for each sample by means of a mathematical figure or several figures, the average diameter of the grains, the degree of sorting, and the grade sizes containing the maximum degree of sorting.

The essential features, the derivation and advantages of such curves have already been treated at some length and will therefore not be discussed again. In the graphs that follow both the cumulative curve and its derived frequency curve were plotted for each specimen. As previously described, the ordinate of each plot consists of the percentage in terms of weight, and the abscissa represents the diameter of the sediments plotted logarithmically.[1]

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[1] See pages 40-42 of this report for relationship between direct and logarithmic plots.

Thus a semi-logarithmic curve is developed and each point on the cumulative curve represents the percentage of material greater than the particular size indicated.

For further description of each sediment, several measures were possible. Although every distribution curve reveals the <u>variation</u> in its distribution, another equally important feature of a frequency curve is its "central tendency"[1] or in these instances, a tendency of the grains to mass together at certain points in the curve. Thus it becomes important to know at what point in the curve this massing is greatest, how much deviation there is from this central concentration, and on which side of the point of concentration the greatest deviation occurs. These facts can be told from several different measures. According to Trask,[2] the median and the coefficients of sorting and skewness describe the sediment accurately. These will here be described briefly.

The "median" diameter marks the midpoint of the size distribution, i.e., 50% of the sediment has a diameter less than the median diameter, and 50% has one greater. It also shows the exact position in the Wentworth scale to which the sample belongs, i.e., if the median is 2.4 (phi unit) it is fine sand.

To determine the degree of sorting Trask has adopted an index of sorting that is very widely used today. This is based upon first

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[1] F. C. Mills, <u>Statistical Methods</u>, p. 107.

[2] P. D. Trask, <u>Origin and Environment of Source Sediments of Petroleum</u>, p. 67-83.

and third quartiles. These measures along with the median separate the entire distribution into four equal quarters so that one-fourth of the weight of the sediment is larger in diameter than the first quartile (Q_1) and three-fourths larger than the third quartile (Q_3). This then means that 50% of the weight of the sample lies between the Q_1 and Q_3. Thus the closer Q_1 is to Q_3 the better sorted will the sediment be, and Trask calculates this degree of sorting by the formula

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

where So = coefficient of sorting. He has further established a scale placing the sediment into classes according to their degree of sorting, and if So is less than 2.5 the sample is well-sorted, if it is greater than 4.5 it is poorly sorted, whereas if it is about 3.0 it is normally or moderately well-sorted. The above measure has been used with some modification, to be discussed below.

In addition to determining the degree of plentifulness of particles of approximately the same size as the median diameter (So), Trask also calculates the point of maximum sorting or the "mode" of the distribution by the coefficient of skewness. The formula by which this measure is calculated is as follows

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

where M = median diameter. While these measures are in their essance used almost universally by petrologists, they differ radically as to the method of computing them. Wentworth[1] advocates the use of moments

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[1] C. K. Wentworth, Method of Computing Mechanical Composition Types in Sediments, Bulletin of Geological Society of America, Vol. 40, p. 771-790, 1929.

rather than quartiles. Udden[1] has also devised an index of sorting based on average rate of decrease in weight-percentage for each subgrade on either side of the mode -- a method not well-adapted to an analysis in which complete size distribution is obtained rather than a series of subgroups.

Krumbein[2] also advocates the use of moments but here the determinations are made using the phi units instead of direct diameter that Trask utilized. On the basis of first, second, and third moments, Krumbein derives a series of measures corresponding to the "mean" or average diameter size, the standard deviation from this mean, and, again, the skewness. In the data that follow the arithmetic mean and standard deviation were calculated as follows: A tabular series of values were set up as shown in Plate 7. The data are arranged in Wentworth Classes (Column 1), corresponding phi units (Column 2), and the weight-percentage frequencies, (f), (Column 3). In Column 4, (d), the maximum grade, is chosen as zero and grades above and below are numbered in sequence as negative and positive integers respectively. Based upon thse two columns all necessary calculations are made. These may be followed without difficulty from the accompanying table, where formulas are given and calculations are made for standard deviation and mean size.

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[1] J. A. Udden, Mechanical Composition of Clastic Sediments, Bulletin of Geological Society of America, Vol. 25, p. 655-744, 1914.

[2] W. C. Krumbein, Application of Logarithmic Moments to Size Frequency Distribution of Sediments, Journal of Sedimentary Petrology, April, 1936, p. 35.

Krumbein also calculated skewness derived from n_3, the third moment, but its use could not be recommended for sediments of such a character as the Oriskany, i.e., features such as large amounts of poorly sorted clays and silts cause major fluctuations in its value, which caused the writer to discard it.

For this report it was originally intended to base the discussion of the curves upon Krumbein's moment measures since the moment method considers the entire range of the size distribution, while the quartile measures are based on the central 50% of the distribution. However, as previously mentioned, the peculiar character of several of the sediments, i.e., their "tail" of silt and clay, tended to throw off the moment measures to the degree where, although mathematically accurate, the picture of the sediment presented was not a true one. For this reason the writer found it necessary to calculate all measures including the skewness, on the quartile method. The mean and standard deviation values of Krumbein's, however, are also listed for the purpose of comparison.

Although the measures finally used represented in their essence the ones of Trask, some modification had to be made in their calculation since the plots are logarithmic ones and the values were determined in ϕ units. Krumbein[1] has made such an adaptation by modifying Trask's original formulas and [redacted] developing conversion

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[1] W. C. Krumbein, The Use of Quartile Measures in Describing and Comparing Sediments, American Journal of Science, 1936, p. 98-111.

Table Showing Computation of Moments of Size Distribution of Sediments

of

Sample 1 G

Grade Limits in mm.	Grades in ϕ units	Wt.-% (f)	d	fd	d^2	fd^2	d^3	fd^3
1 - 1/2	0-1	0	-	-	-	-	-	-
1/2 - 1/4	1-2	6.00	-1	-6	1	+6.0	-1	-6
1/4 - 1/8	2-3	62.70	0	0	0	0	0	0
1/8 - 1/16	3-4	18.00	+1	+18	1	+18.0	+1	18
1/16 - 1/32	4-5	7.50	+2	+15	4	+30.0	+8	60.0
1/32 - 1/64	5-6	5.8	+3	+17.4	9	+52.2	+27	157.0
Totals		100.00		+44.4		+106.2		+229

$$n_1 = \frac{44.4}{100} = .444$$

$$n_2 = \frac{106.2}{100} = 1.062$$

$$n_3 = \frac{229}{100} = 2.29$$

Mean $= M\phi = n_1 +$ midpoint of d scale

$$M_\phi = .44 + 2 = 2.44$$

Standard Deviation $= \sigma\phi = \sqrt{n_1 - (n_1)^2}$

$$\sigma\phi = \sqrt{1.06 - (.444)^2} = \sqrt{.863} = .928$$

Plate 7

charts whereby the results, though obtained in ϕ units, could be immediately converted into the more widely used measures of Trask and the latter's standard terms then applied. The major modifications will here be considered.

1. Since by the use of ϕ units the grade scale increases to the right, Q_3 will be the larger unit (although still representing the smaller grade). Also since in the logarithmic plot an arithmetic series rather than a geometric one must be dealt with, the original formula of Trask now takes the form

$$QD\phi = \frac{Q_3 - Q_1}{2}$$

where QD_ϕ represents half the spread between the quartiles. This value, QD_ϕ, may be converted[1] to So or Trask's sorting coefficient almost instantly, and the sample then classed according to Trask's index of sorting.

In skewness calculation, made upon this same basis, the value fluctuates around zero, for in a perfectly symmetrical curve the median corresponds exactly with the point half-way between Q_1 and Q_3, and the corresponding coefficient figure will be zero. However, if the curve is skewed, the arithmetic mean of the quartiles departs from this median and the degree to which the curve departs represents the skewness.

The skewness was therefore calculated by first determining the mean of the quartiles and then subtracting the median from it. This

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[1] Ibid., p. 102.

is expressed by the formula

$$Skq\phi = \frac{Q_1 + Q_3}{2} - Md\phi .$$

Skqϕ can then be converted to Sk, Trask's logarithmic measure to the base 10.[1] Thus if the value is a positive one, the curve is skewed to the right, toward the finer sediments, and if negative it is skewed to the left of the median, toward the coarser sediments.

Baker's Method

The author also considered using Baker's[2] factors to describe the frequency curves of the sediments. Baker attempts to express the mechanical composition of the sediments by two numbers representing Equivalent Grade and the Grading Factor for each sample.

In plotting his curves, Baker uses a direct plot rather than the logarithmic one, and plots his percentages, as the abscissae, and the grade sizes (after Wentworth's scale) as the ordinates. (See Plate 8). The figure representing the average diameter and known as the Equivalent Grade is obtained by dividing the area under the curve by the length of base line representing 100% weight, and interpreting the length so obtained, in terms of the scale of lengths used to represent diameters. The resulting figure is then taken as a representative diameter, and the fine sediments will therefore give a low figure and coarser sediments a larger figure.

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[1] Ibid., p. 109.

[2] H. A. Baker, On the Investigation of Mechanical Constituents of Loose Arenaceous Sediments, Geological Magazine, Vol. 57, 1920, p. 363 et seq.

Since it is possible for two different curves to give the same equivalent grade, a second figure must be found to completely and accurately catagorize a specimen. This is known as the Grading Factor and is based upon the respective proportions of size grades. The area enclosed between the first ordinate, the Equivalent Grade line and the curve, represents the measure of variation of the sediment below the grade of the ideally perfectly sorted sediment, and conversely the area enclosed between the last ordinate, the equivalent grade line, and the curve, represents the variation above the ideal grade.

Therefore the sum of the two variations gives the total variation from the hypothetically perfectly graded sediment, and also may be thought of as giving a measure of the tendency of the sediment toward constancy of grading, or restriction of the diameters to the one representing the equivalent grade size. Thus

$$\text{G.F.} = \frac{\text{Total area under curve} - \text{Total variation area}}{\text{Total area under curve}}$$

where G.F., or Grading Factor, represents actually the degree of sorting of the sediment. As the value approaches unity, grading is more perfect.

Although a description of a curve made on such a basis may have the advantage that the sediment may be quite completely described by two figures, for the purpose of geographic mapping, etc., the writer found that its use was not as universal as Trask's measures. It was also believed that since the purpose of such a description is to present data in a readily usable form, such figures would not serve as efficiently as the aforementioned measures, for they do not present a visual, graphic picture of the type of sediment as does the frequency curve, one which can more easily bring enlightenment to the inexperienced reader in such a study.

For purposes of comparison the same sample has been graphed both ways on Plate 8 on the following page. In the frequency curve the median is given in phi units but upon conversion corresponds almost exactly to the Equivalent Grade of Baker's. In both graphs the numerical figure indicating degree of sorting shows a well-sorted sediment.

Discussion of Curves

In the pages that follow each sediment is plotted in the form of a cumulative curve and its derived frequency curve. These are given the same index number as those used in the histograms and therefore the aforementioned index of locations is here introduced again for the sake of convenience. The three plots on each page represent in most cases, a sample from the upper, middle, and lower beds. The statistical measures are in two principal sets, i.e., those based on quartile measures and those based onmoments, and include the median (Md), first and third quartile (Q_1 and Q_3), the quartile derivation (QD_ϕ) and skewness ($Skq\phi$), arithmetic mean (M_ϕ) and standard deviation ($\sigma\phi$), each recorded below the plots, in ϕ units. In addition, Trask's coefficients of sorting (So) and of skewness ($\log Sk_{10}$) were derived for the sake of rapid classification in larger groups, i.e., "well-sorted," "poorly sorted," etc. Upon

No. 7

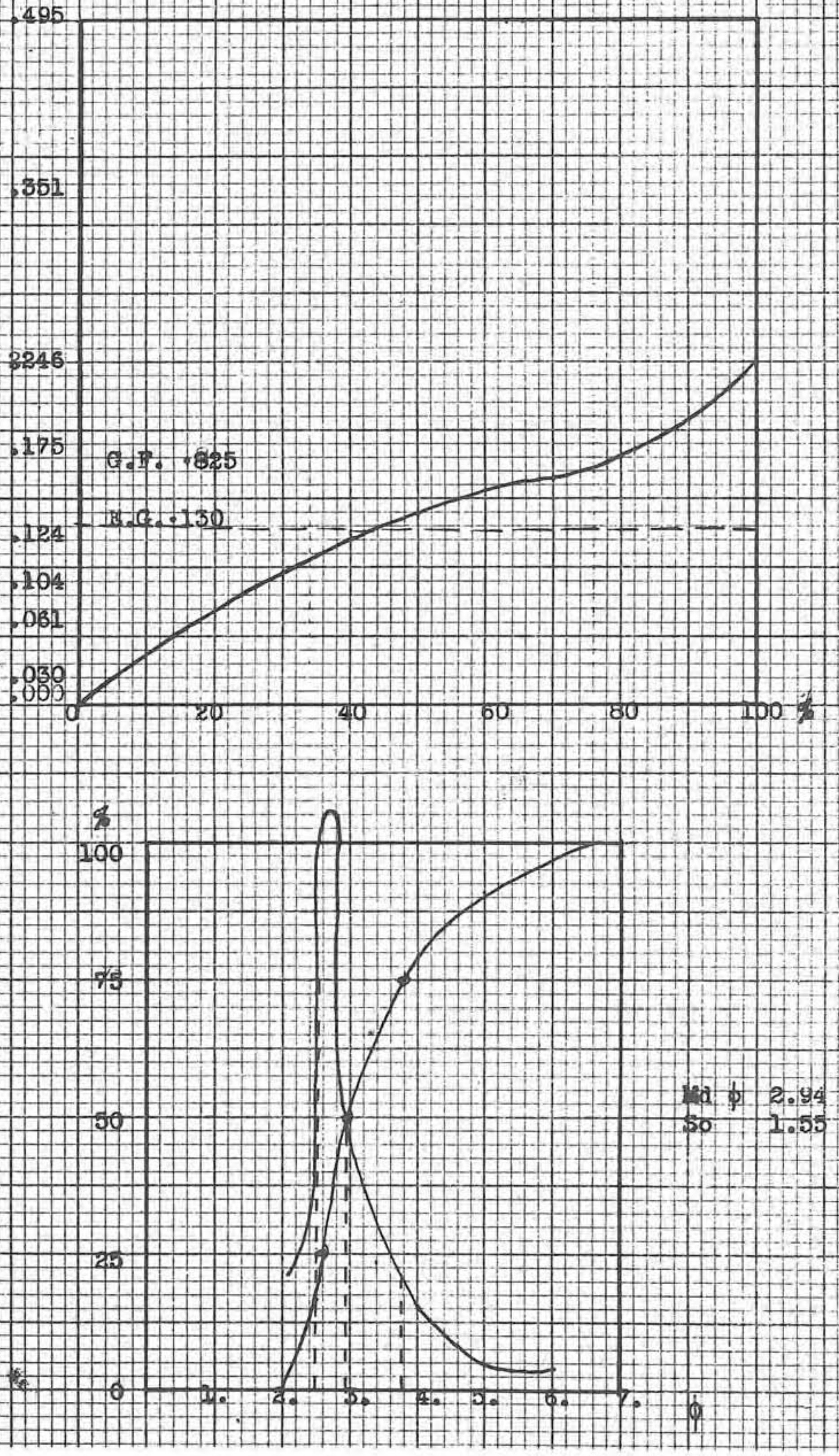

.495
.351
2246
.175
.124
.104
.061
.030
.000
G.F. .825
E.G. .130
0
20
40
60
80
100 %
%
100
75
50
25
0
1.
2.
3.
4.
5.
6.
7.
ϕ
Md ϕ 2.94
So 1.55

Plate 8

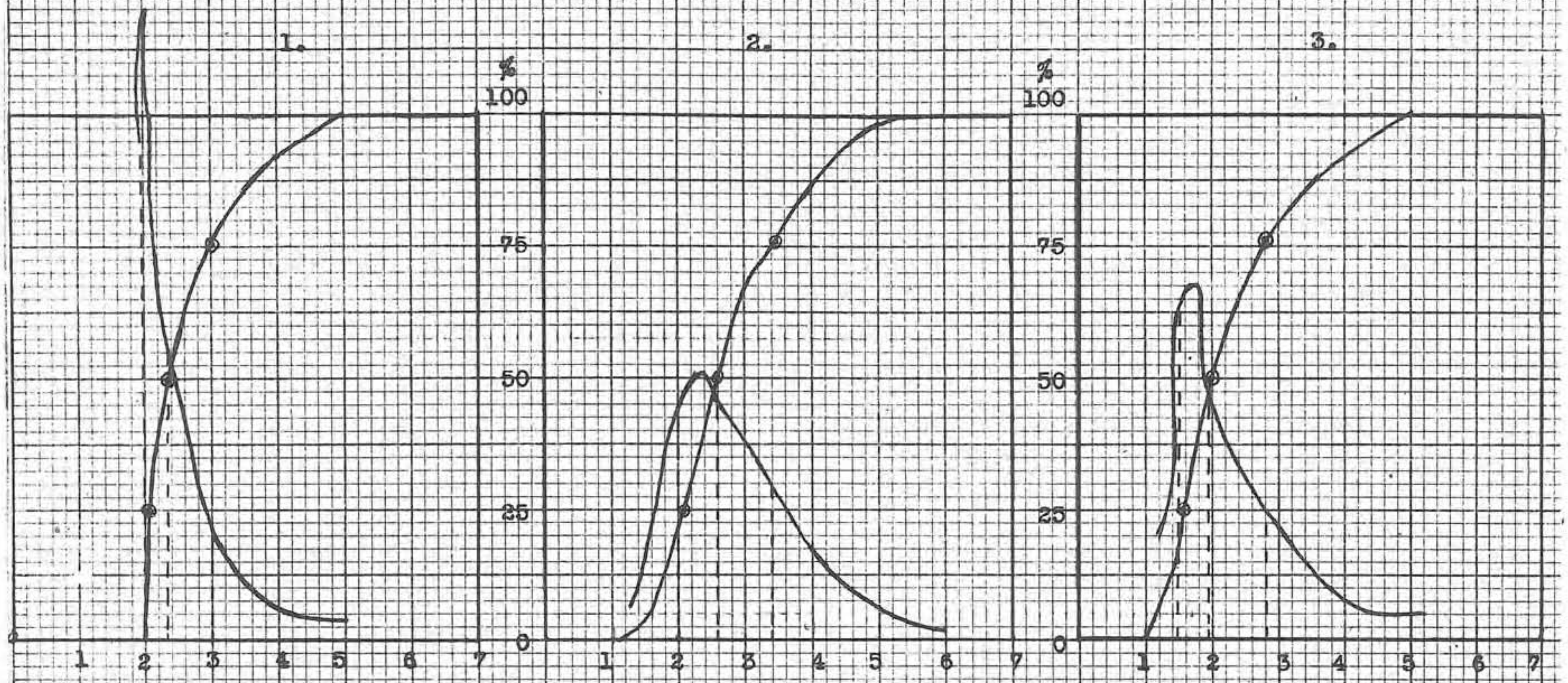
the cumulative curves heavy dots have been placed to mark the median, and first and third quartiles, and upon the derived frequency curve ordinates were erected representing the same measures. This enables the reader to tell at a glance in which phi unit 50% of the sediment is concentrated, and also what the median size diameter is. At the end of all the plots, the statistical data have been summarized in one complete table (Plate 21).

Index to Graphs

Index No.	Geographic Location	Stratigraphic Position
1	1 mile east of Strait Creek	Upper contact
2	" " " " " "	75 ft. below No. 1
3	" " " " " "	Lower contact
4	2 miles south of Strait Creek	Upper contact
5	" " " " " "	Approximately 100 ft. below No. 4
6	" " " " " "	50 ft. below No. 5
7	3 miles south of Strait Creek	Upper contact
8	" " " " " "	Approximately middle of series
9	" " " " " "	Within 25 ft. of lower contact
10	1 mile east of Monterey	Upper contact
11	" " " " "	Middle of series
12	" " " " "	Lower contact
13	½ mile south of Monterey (east limb	Upper contact
14	" " " " " (of syncline)	30 ft. below No. 13
15	" " " " "	10 ft. below No. 14
16	2¼ miles south of Monterey (west limb	Upper contact
17	2½ " " " " (of syn-	Approximately middle of series
18	" " " " " (cline)	Lower contact
19	3½ miles south of Monterey (west limb	Upper contact
20	" " " " " (of syn-	Middle of series
21	" " " " " (cline)	Lower contact
22	Just south of Cobbler Mt. (top of anticline)	Upper contact
23	3½ miles south of Hot Springs along Cedar Creek (east limb of Collision Ridge anticline)	Approximately middle of series
24	East limb of Collision Ridge anticline	Upper contact
25	West limb of Collision Ridge anticline	Believed to be from middle beds
26	(East limb of Back Creek Mt., 4 miles)	Upper contact
27	(Northwest of Warm Springs)	Middle beds
28	" " " "	Lower contact

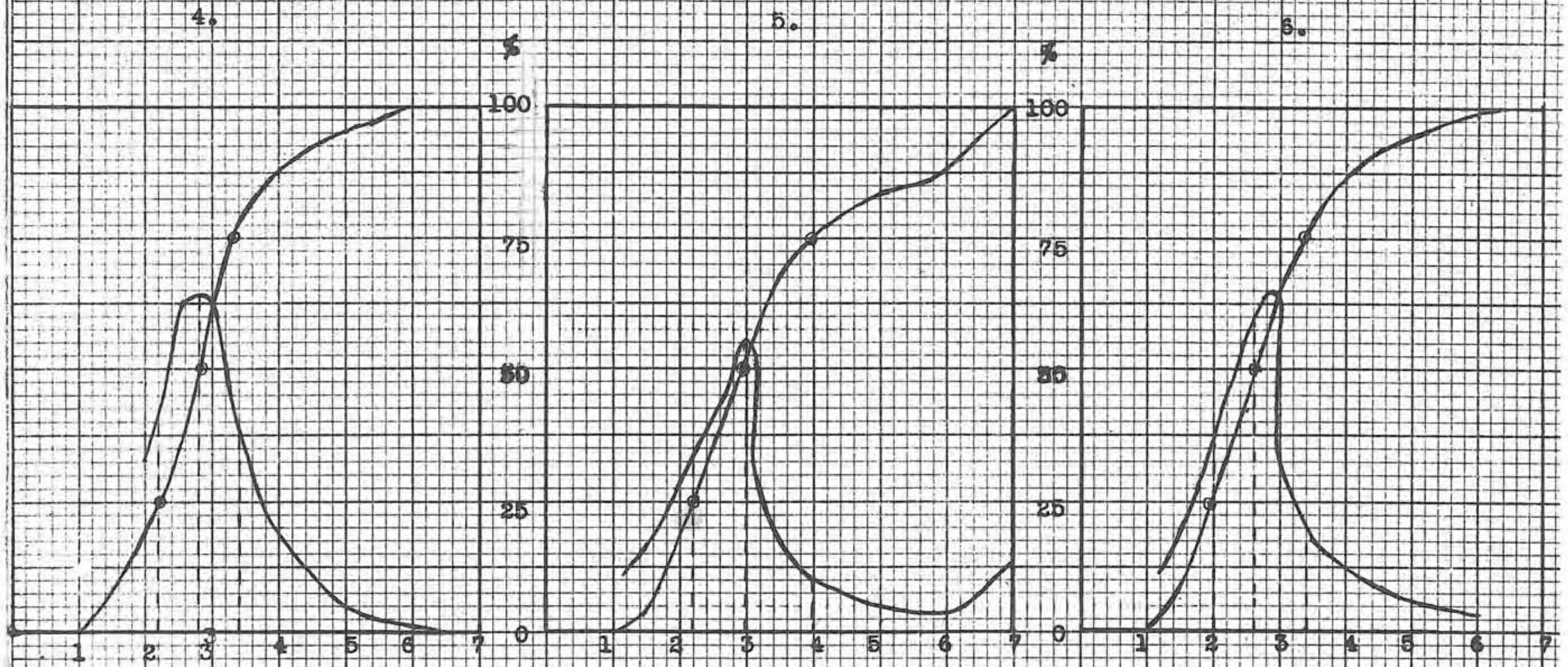
Index to Graphs (continued)

29	3 miles west of Warm Springs	(east	Upper contact
30	" " " " " "	(Bolar Mt.	Middle beds
31	" " " " " "	(anticline)	Lower contact
32	6 miles west of Hot Springs	(southern	Upper contact
33	" " " " " "	(part of	Middle beds
34	" " " " " "	(Bolar Mt.)	Lower contact



	Md	Q_1	Q_3	QD	So	Log_{10} Sk
1.	2.4	2.1	3.0	.45	1.35	-.09
2.	2.6	2.1	3.4	.65	1.55	-.09
3.	2.0	1.5	2.9	.70	1.65	—.12

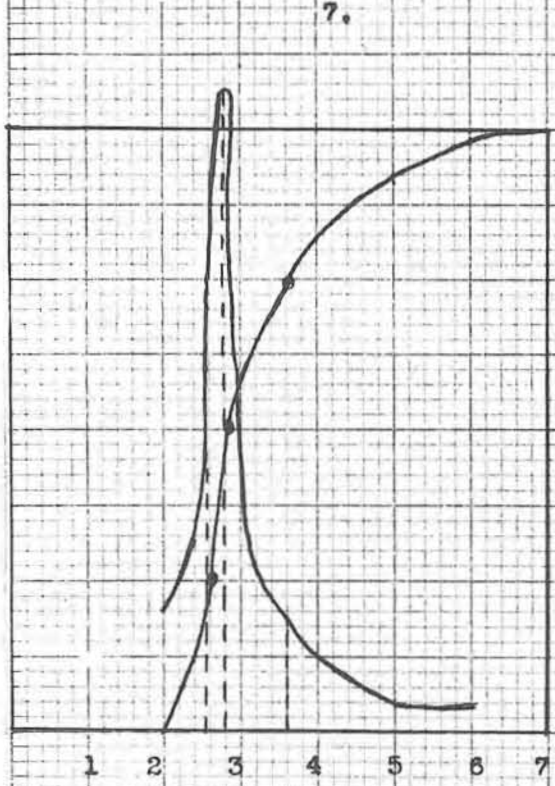
Plate 9



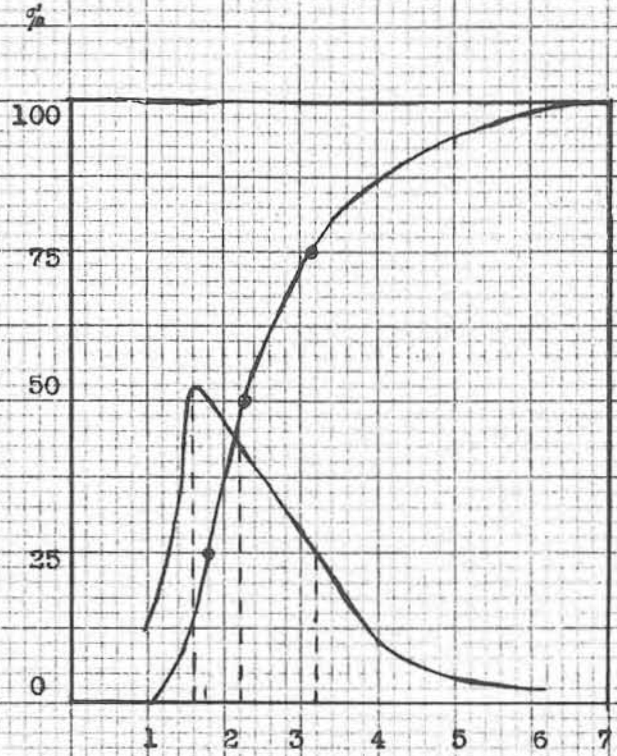
	Md	Q_1	Q_3	QD	So	$Log_{10}Sk$
4.	2.9	2.1	3.2	.55	1.45	.15
5.	2.9	2.2	4.0	.90	1.85	-.12
6.	2.6	2.0	3.3	.65	1.55	-.03

Plate 10

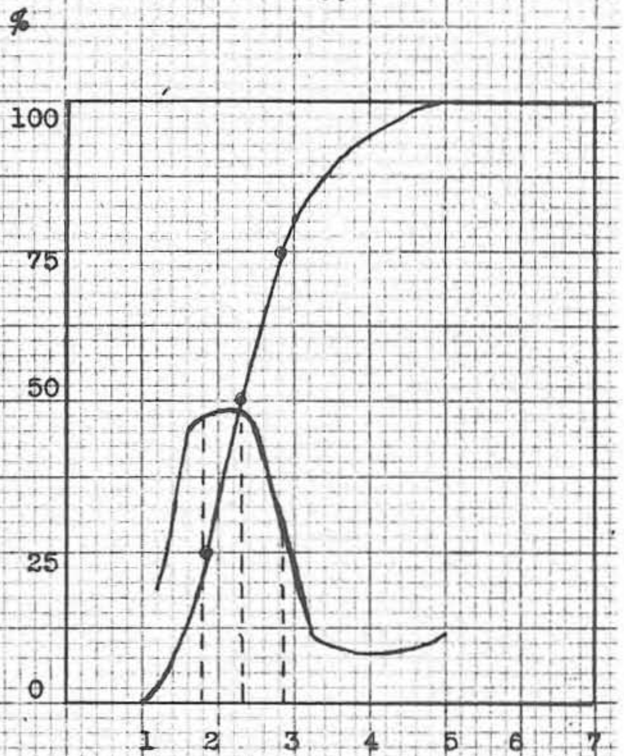
7.



8.

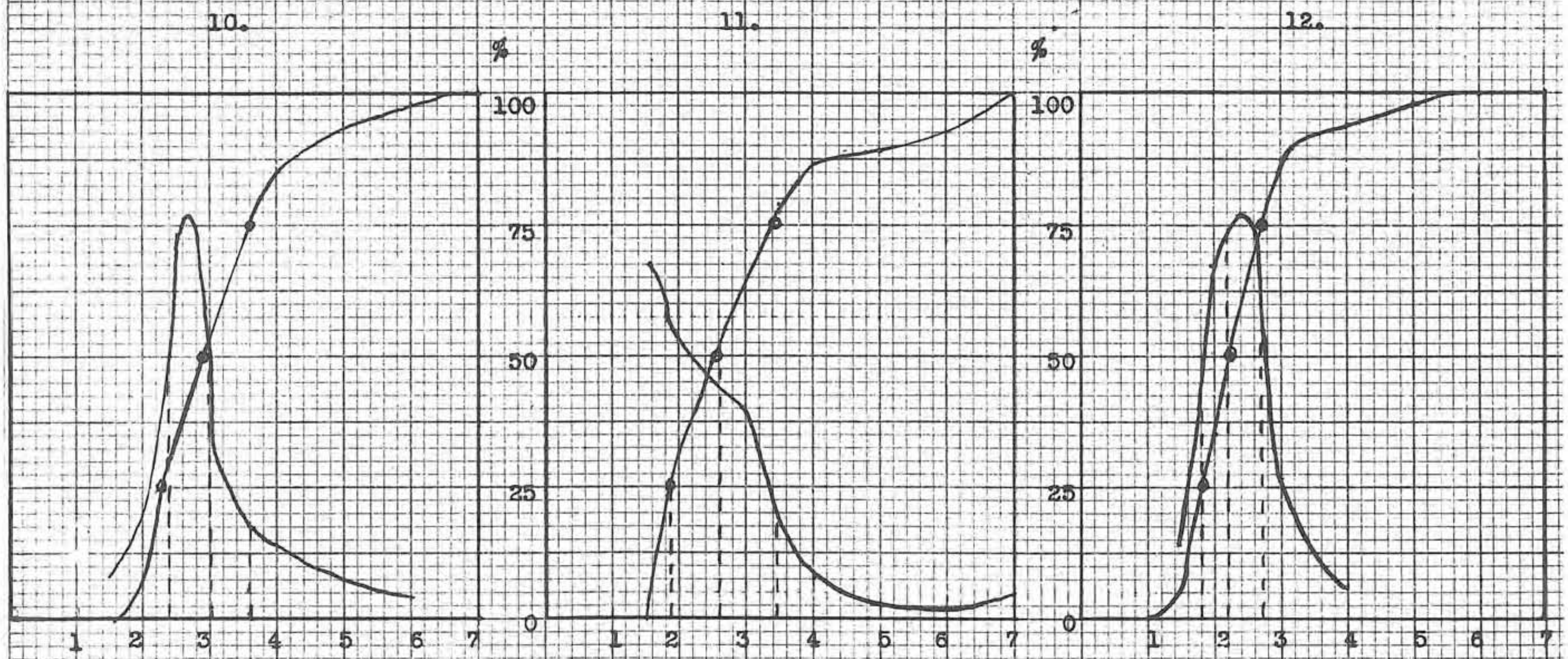


9.



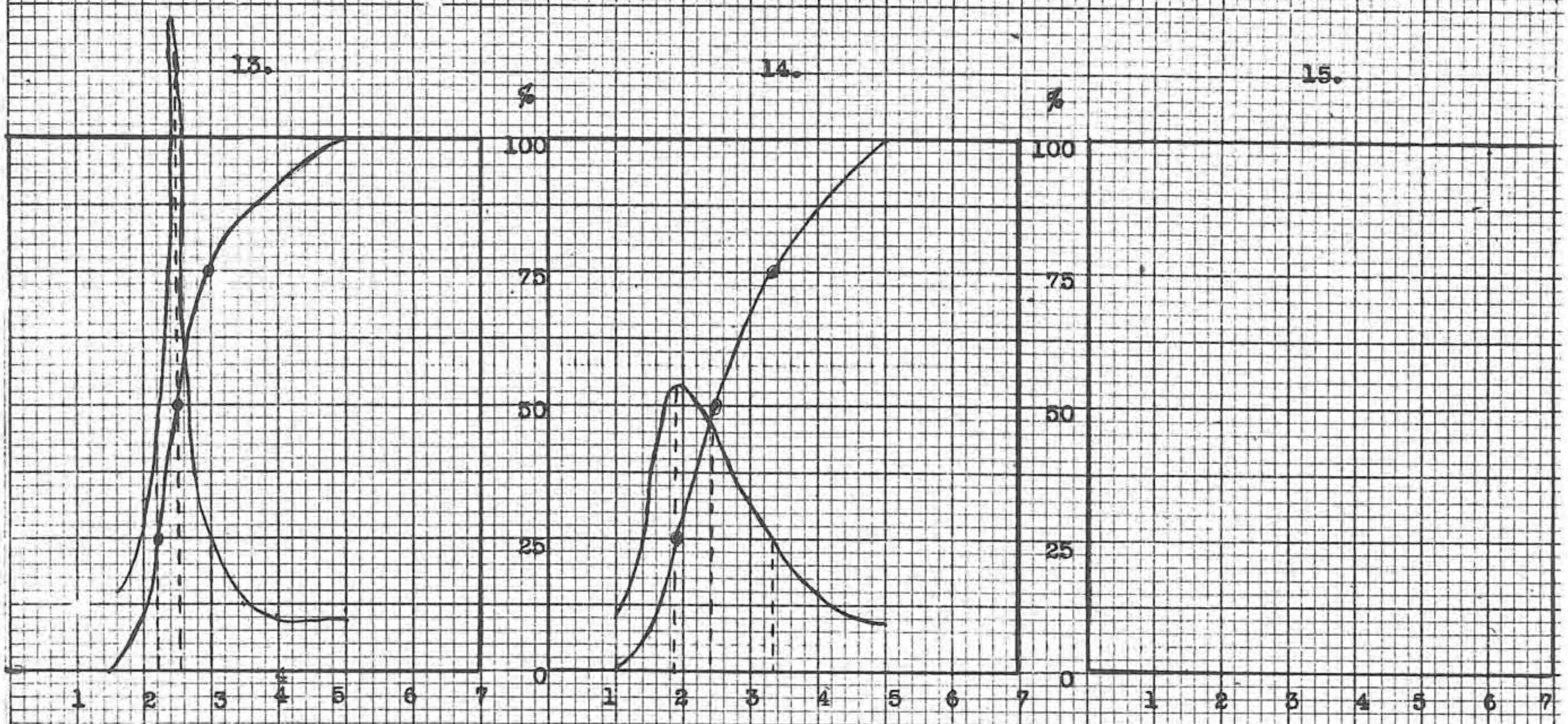
	Md	Q_1	Q_3	QD	So	Log_{10}Sk
7.	2.9	2.7	3.7	.50	1.4	-.18
8.	2.3	1.9	3.2	.65	1.55	-.15
9.	2.3	1.7	3.0	.65	1.55	-.06

Plate 11



	Md	Q_1	Q_3	QD	So	Log_{10}Sk
10.	2.9	2.4	3.7	.65	1.55	-.09
11.	2.6	1.9	3.5	.80	1.75	-.06
12.	2.2	1.9	2.8	.30	1.35	-.09

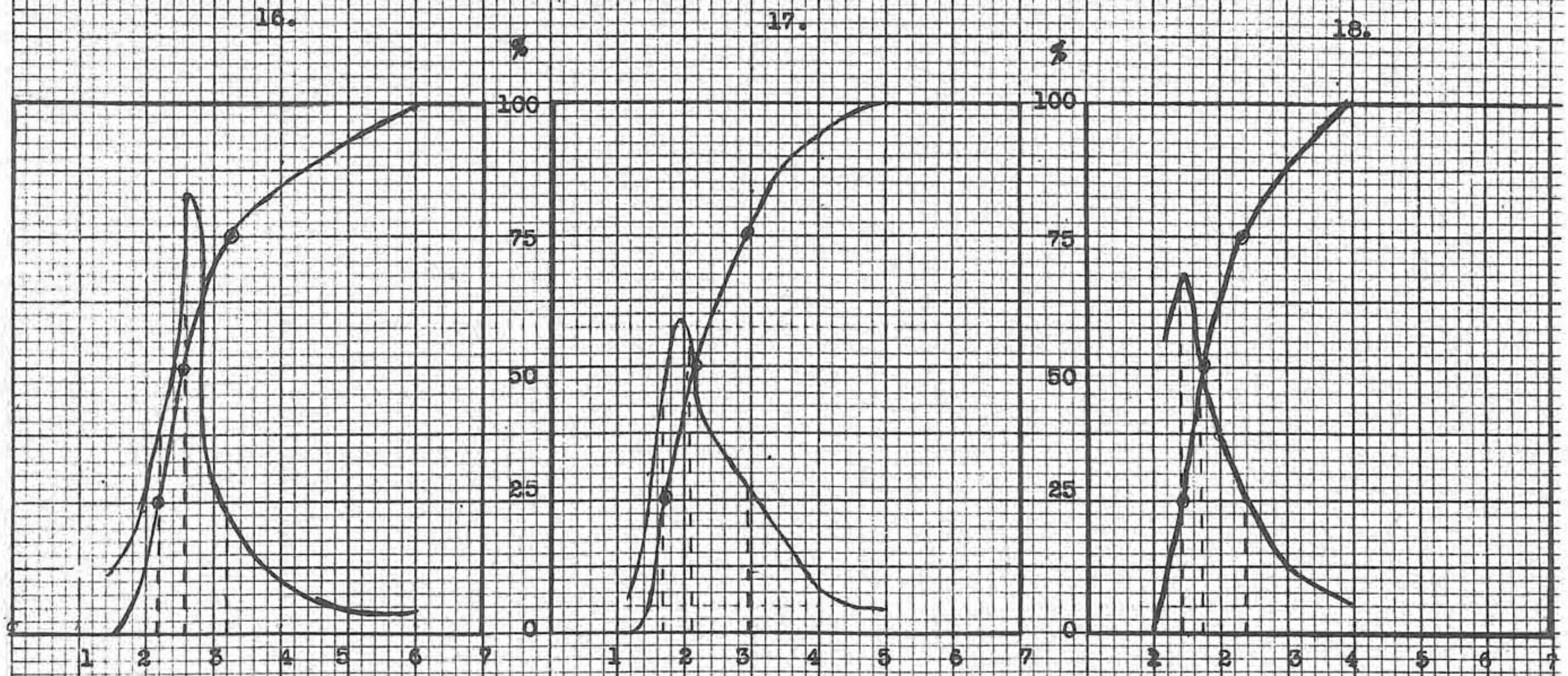
Plate 12



	Md	Q_1	Q_3	QD	So	Log_{10}Sk
13.	2.6	2.2	3.0	.40	1.35	.0
14.	2.5	1.9	3.2	.60	1.50	-.03

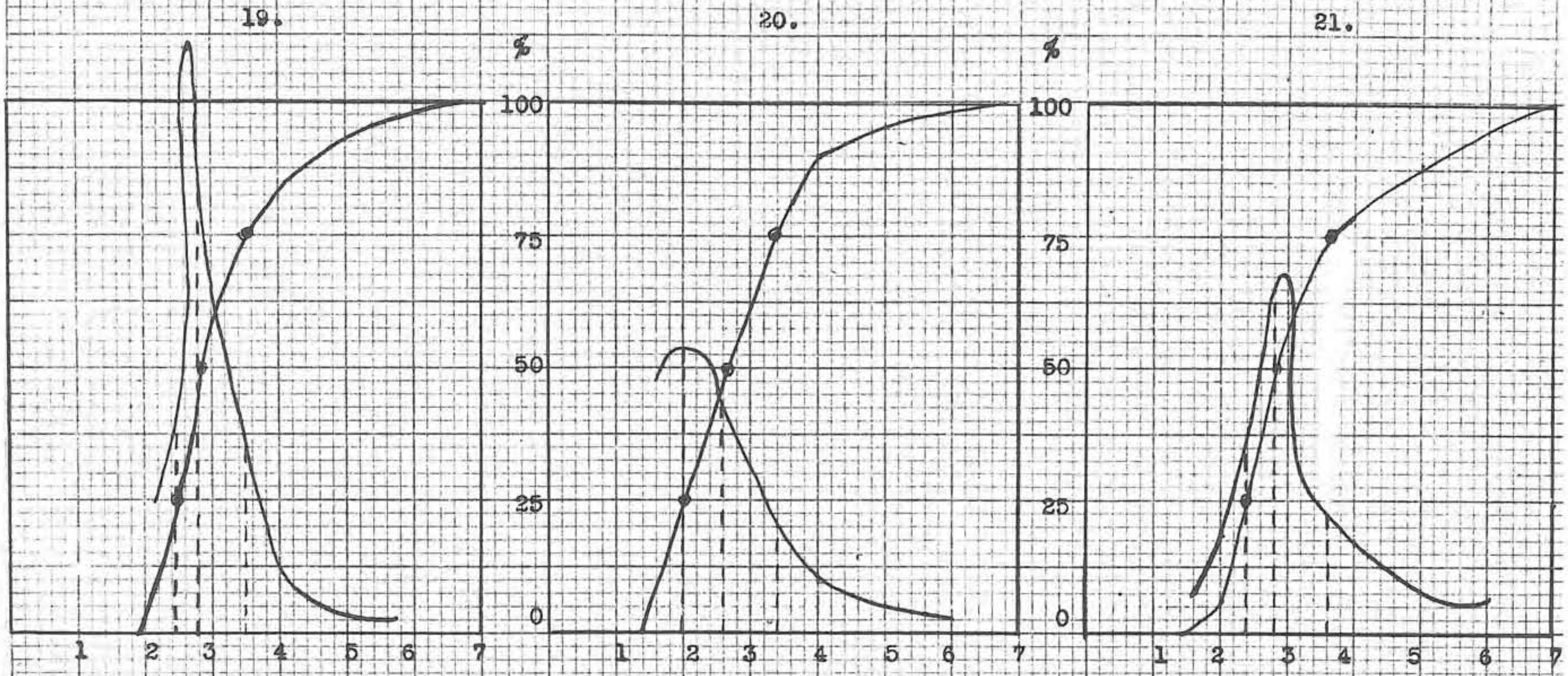
15. Highly conglomeratal ...no analysis

Plate 18



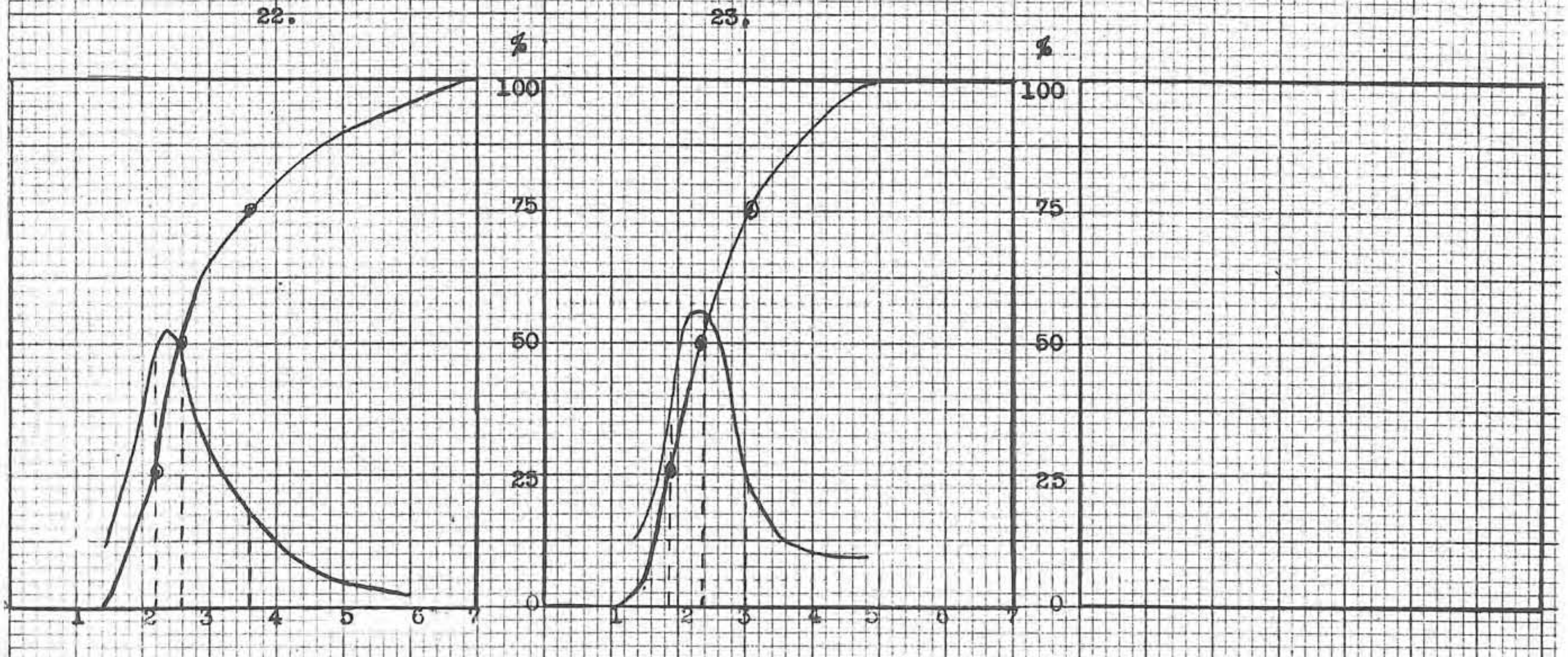
	Md	Q_1	Q_3	QD	So	Log_{10} Sk
16.	2.7	2.2	3.3	.55	1.45	-.03
17.	2.2	1.7	2.9	.60	1.50	-.06
18.	1.82	1.4	2.3	.45	1.35	.02

Plate 14



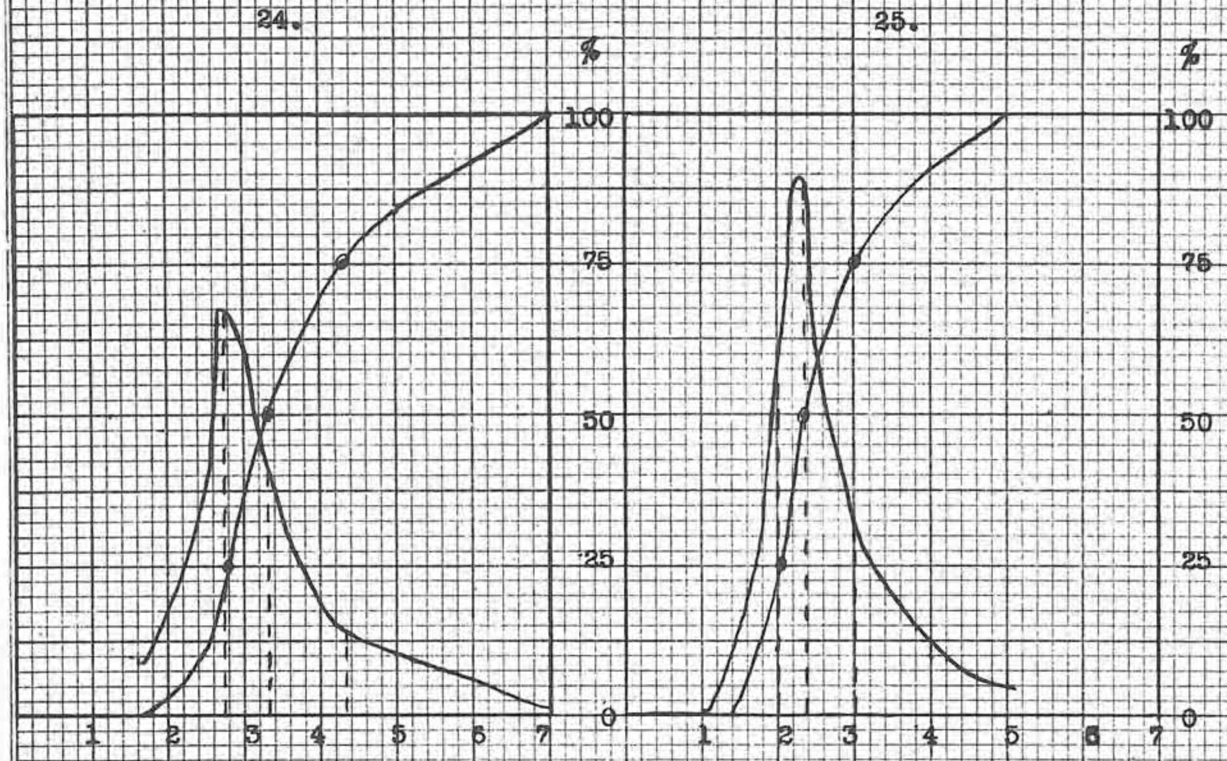
	Md	Q_1	Q_3	QD	So	$Log_{10}Sk$
19.	2.9	2.5	3.6	.55	1.45	-.09
20.	2.5	2.0	3.4	.70	1.65	-.12
21.	2.8	2.4	3.7	.65	1.55	-.16

Plate 15



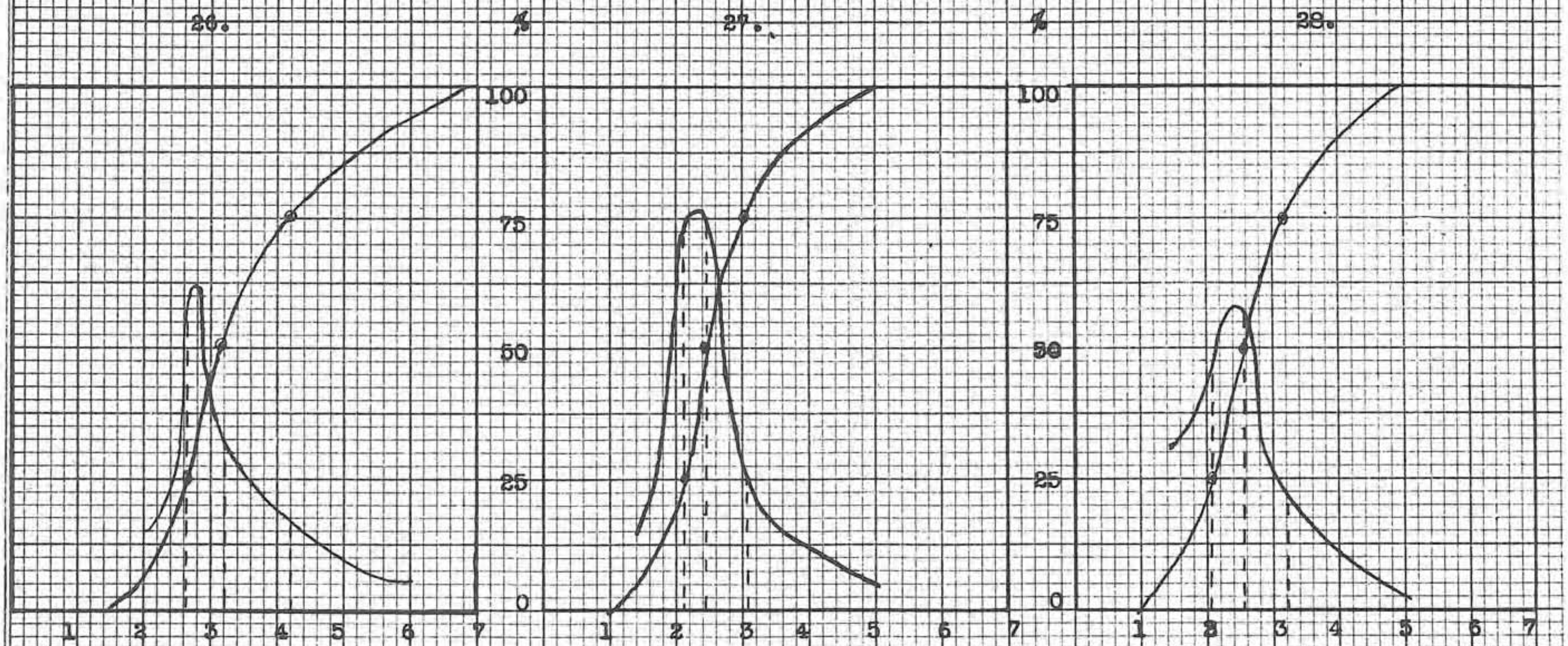
	Md	Q_1	Q_3	ΦD	So	Log_{10} Sk
22.	2.7	2.2	3.6	.70	1.65	-.12
23.	2.4	1.9	3.1	.60	1.50	-.06

Plate 16



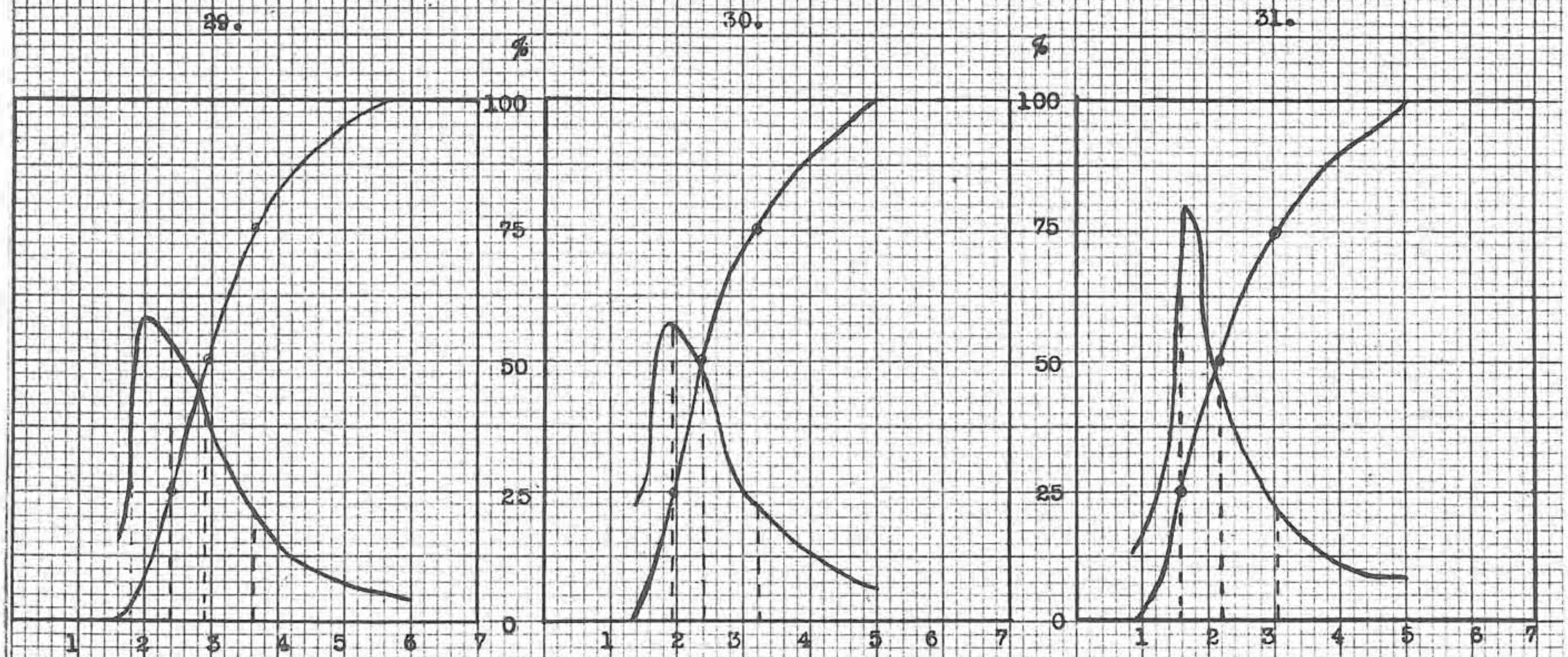
	Md	Q_1	Q_3	QD	So	$Log_{10}Sk$
24.	3.3	2.8	4.2	.70	1.65	-.12
25.	2.3	2.0	2.9	.45	1.35	-.09

Plate 17



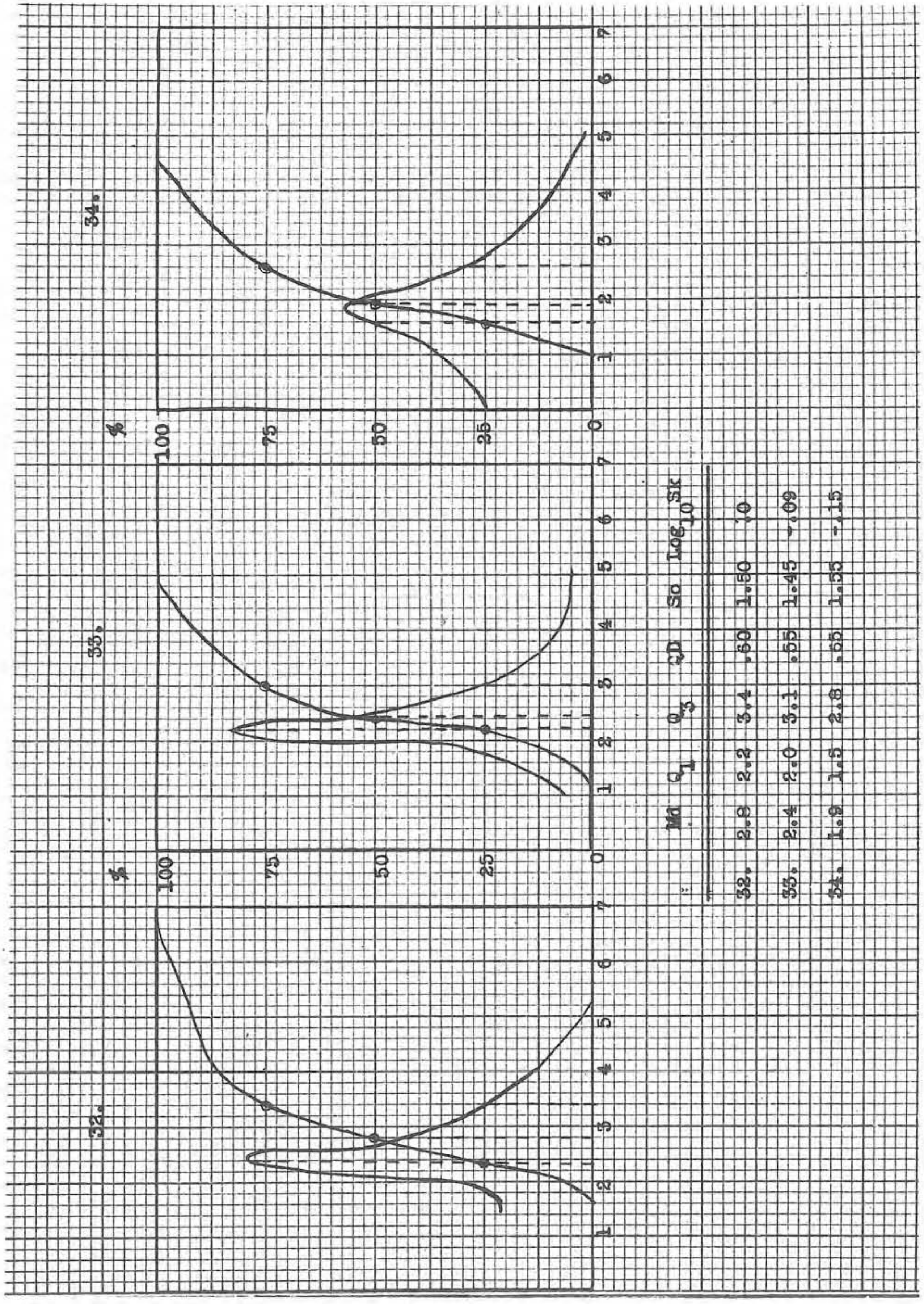
	Md	Q_1	Q_3	QD	So	Log_{10} Sk
26.	3.2	2.7	4.0	.65	1.55	-.09
27.	2.5	2.0	3.1	.55	1.45	-.03
28/	2.4	1.9	3.0	.55	1.45	-.03

Plate 18



	Md	Q_1	Q_3	QD	So	Log_{10} Sk
29.	3.0	2.5	3.7	.60	1.50	-.06
30.	2.4	1.9	3.2	.65	1.55	-.09
31.	2.1	1.7	3.0	.65	1.55	-.15

Plate 19



	Md	Q_1	Q_3	QD	So	Log_{10}Sk
32.	2.8	2.2	3.4	.60	1.50	.0
33.	2.4	2.0	3.1	.55	1.45	-.09
34.	1.9	1.5	2.8	.65	1.55	-.15

Plate 20

Table Showing Statistical Data as Expressed in Plates 9 - 20

Index No.	Sample	Md_ϕ	$Q_{1\phi}$	$Q_{3\phi}$	QD_ϕ	So	M_ϕ	$\sigma\phi$	Skq_ϕ	Log Sk_{10}
1	4D	2.4	2.1	3.0	.45	1.35	1.73	.705	+.15	-.09
2	2A	2.6	2.1	3.4	.65	1.55	2.25	.982	+.15	-.09
3	4A	2.0	1.5	2.9	.70	1.65	2.25	.895	+.29	-.12
4	2C	2.9	2.1	3.2	.55	1.45	1.75	.868	-.25	+.15
5	2B	2.9	2.2	4.0	.90	1.85	3.14	1.46	+.20	-.12
6	4C	2.6	2.0	3.3	.65	1.55	2.75	1.1	+.05	-.03
7	2L	2.9	2,7	3.7	.50	1.4	2.68	1.03	+.30	-.18
8	2E	2.3	1.9	3.2	.65	1.55	3.51	1.16	+.25	-.15
9	2H	2.25	1.7	3.0	.65	1.55	1.38	.877	+.10	-.06
10	1G	2.9	2.4	3.7	.65	1.55	2.44	.928	+.15	-.09
11	1F	2.6	1.9	3.5	.80	1.75	2.87	1.50	+.10	-.06
12	1D	2.2	1.9	2.8	.30	1.25	1.26	..65	+.15	-.09
13	5B	2.6	2.2	3.0	.4	1.35	1.66	.724	0	0
14	1H	2.5	1.9	3.2	.6	1.50	1.6	.921	+.05	-.03
15	1C	Conglomeritic - no analysis								
16.	3A	2.7	2.2	3.3	.55	1.45	2.31	.98	+.05	-.03
17	3C	2.2	1.7	2.9	.60	1.50	1.33	.869	+.10	-.06
18	2D	1.87	1.4	2.3	.45	1.35	2.47	.792	-.02	+.02
19	3D	2.9	2.5	3.6	.55	1.45	3.11	.961	+.15	-.09
20	2M	2.5	2.0	3.4	.70	1.65	2.69	.98	+.20	-.12
21	5A	2.8	2.4	3.7	.65	1.55	3.21	1.32	+.25	-.15
22	6D	2.7	2.2	3.6	.70	1.65	3.45	1.2	+.20	-.12
23	6A	2.4	1.9	3.1	.60	1.50	1.467	.822	+.10	-.06
24	6H	3.3	2.8	4.2	.70	1.65	2.535	1.17	+.20	-.12
25	6E	2.3	2.0	2.9	.45	1.35	1.589	.8	+.15	-.09

Plate 21

Table Showing Statistical Data as Expressed in
Plates 9 - 20 (continued)

Index No.	Sample	Md_ϕ	$Q_{1\phi}$	$Q_{3\phi}$	QD_ϕ	So	M_ϕ	$\sigma\phi$	Skq_ϕ	Log Sk_{10}
26	6Q	3.2	2.7	4.0	.65	1.55	3.37	1.18	+.15	-.09
27	6L	2.5	2.0	3.1	.55	1.45	1.58	.825	+.05	-.03
28	8	2.4	1.9	3.0	.55	1.45	1.5	.95	+.05	-.03
29	6G	3.0	2.5	3.7	.60	1.50	3.18	1.14	+.10	-.06
30	6P	2.4	1.9	3.2	.65	1.55	1.53	.925	+.15	-.09
31	6Z	2.1	1.7	3.0	.65	1.55	2.84	.99	+.25	-.15
32	6K	2.8	2.2	3.4	.60	1.50	2.87	1.07	0	0
33	6N	2.4	2.0	3.1	.55	1.45	2.07	.79	+.15	-.09
34	6M	1.9	1.5	2.8	.65	1.55	2.18	.79	+.25	-.15

Plate 21 (continued)

A study of the curves and data bears out the general conclusions made from the histograms. Specifically:

1. The medians of the upper beds range in phi units from 2.4 to 3.3 placing them, according to Wentworth's scale, into fine and very fine sand. The middle beds range from 2.2 to 2.6 with only one specimen showing a median of 2.9. These may be classed as fine sand but not as fine as the upper beds. The lower beds, with the phi units ranging from 1.87 to 2.5 and one specimen in 2.8 group, can be classed in the medium to fine sand groups. Thus it is again evident that the beds grade decidedly from medium to very fine grained sand from the bottom to the top of the series.

2. From the sorting factor, So, based upon Trask's index of sorting, all of the samples fall easily into the category of "well-sorted" sediments since all So values are well below 2.5, Trask's criterion for well-sorted sediments. From these same values, however, there appears to be no particular relationship between fineness or degree of sorting. In 50% of sediments the upper beds have the lower So value, indicating greater sorting and in the remaining 50% the lower or middle beds give the lower sorting value. Also there is no evidence of gradation according to geographic distribution. The same variation holds throughout from northernmost to southernmost samples. These values, however, are based only upon the middle 50% of the distribution.

3. From the skewness values, converted to Trask's measure calculated as log to the base of 10, it can be seen that all except two samples have their curves skewed in a negative direction, i.e., to the left of the

median, indicating that the maximum degree of sorting takes place between the first quartile and the median, or on the coarser side of the median. Since when the curve is perfectly symmetrical, the skewness values will be zero, it is evident that all the curves except two, both representing upper beds, and being perfectly symmetrical, i.e., having the median correspond with the point of maximum sorting, are skewed anywhere from -.25 to +.30. This means that the point of maximum sorting occurs from .25 of a Wentworth unit to the left of the median (toward coarser sediments), to .30 of a Wentworth unit to the right of the median (toward the finer sands).

4. The general shape of all the curves reveals the character of typical shallow water sands deposited possibly in the zone of breakers. All the curves are predominantly sandy, but some carry a "tail" of silt and clay rendering them asymmetrical. It is possible that these "tails" represent colloidal clay particles -- but as suggested by Krumbein[1] such a trend in the cumulative curve revealing poorly sorted clays and silts, might also be due to pronounced current action in water where the deposit was made. All of these factors will be discussed in greater detail at the end of this report.

Results of Studies in Roundness of Grains

The results of the roundness studies according to the method described in pages 47-50 are tabulated below. As was discussed in that section, the samples were assembled into three different size groups,

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[1] W. C. Krumbein and Esther Aberdeen, The Sediments of Barataria Bay, Journal of Sedimentary Petrology, April, 1937, p. 13.

i.e., $\frac{1}{2}$-$\frac{1}{4}$ mm. (in a few samples where sand grains larger than $\frac{1}{2}$ mm. were present, they were included in this group), $\frac{1}{4}$-1/8 mm., and 1/8-1/16 mm. In the tabulation that follows these size groups are called group 1, 2, and 3 for convenience, and the average roundness for each of these groups in each sample is recorded. In addition, the highest and lowest degrees of rounding for each group (representing actually, the deviation from the mean) was considered important enough to be tabulated. As heretofore mentioned, the author did not deem it necessary to determine the average roundness of the entire sample, but rather considered such a figure to be misleading. Comparisons were therefore made on the basis of size-fraction for size-fraction, rather than for the sample in its entirety.

According to Cox's classification,[1] it will be seen from the tabulated data that almost all specimens range from well-rounded to angular in shape, and a definite correlation may be made between size of the grain and the degree of roundness. It will be seen from the data that the larger grains are usually quite well rounded and the smaller grains decidedly angular. That this correlation does not depend upon the fact that the coarser grains are on the whole more plentiful than the finer ones, is shown by the fact that even in the upper beds, predominantly made up of very fine sands, this relationship still holds.

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[1] Op. cit., p. 181.

On the following page, plots are made taking samples from upper, middle, and lower beds -- each plot showing the relationship between average roundness of a given size fraction to the average roundness of other size fractions of the sample. The number in the right hand corner of each graph represents the index number of the sample, the same number used for previous plots. The abscissa of each graph represents grade-size expressed in phi units, and the ordinates, the roundness in terms of Cox's percentage values.

From the plots (Plate 22) it is evident that roundness is some function (not necessarily linear) of the size of the grain, the roundness falling off with surprising regularity with decrease in size of grains. However, it will be seen that no other correlation can be made, i.e., geographic distribution seems to have no important bearing on the roundness of the grains.

Plots also reveal no relation between roundness of each size fraction and the percentage of the whole which that size fraction makes up.

Possible Significance of Data on Roundness

Very little is known as to the rate at which quartz grains will become rounded. Anderson[1] has done experimental work on this problem and concludes that "rounding of sand grains is an exceedingly slow

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[1] G. E. Anderson, Experiments on the Rate of Wear of Sand Grains, Journal of Geology, Vol. 34, p. 144-158.

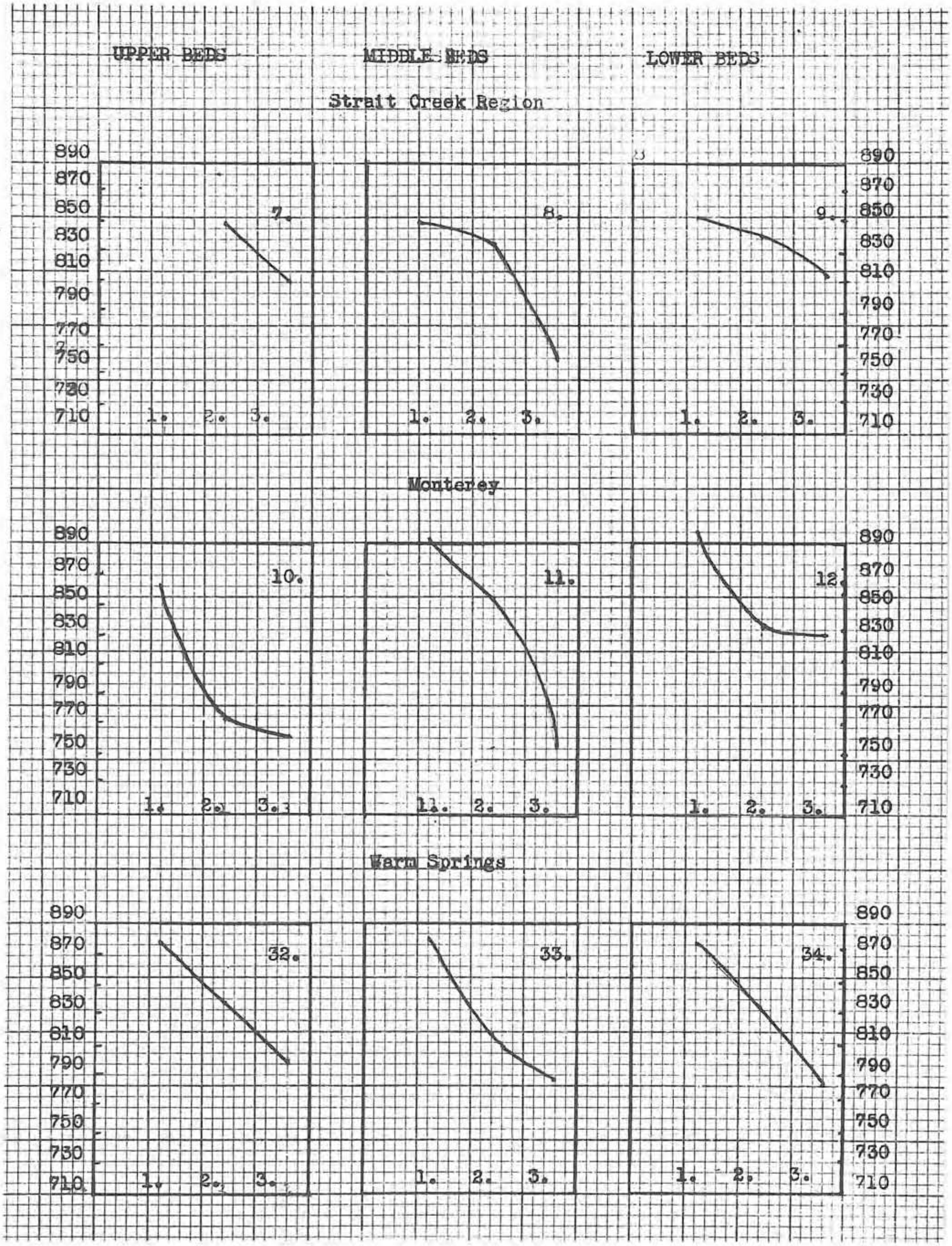
UPPER BEDS
MIDDLE BEDS
LOWER BEDS
Strait Creek Region
7.
8.
9.
Monterey
10.
11.
12
Warm Springs
32.
33.
34.
890
870
850
830
810
790
770
750
730
710
1.
2.
3.

Plate 22

Data Used for Plotting Roundness of Grains

Index No.	Sample No.	Size Group	Lowest degree of Roundness	Highest degree of Roundness	Average Roundness
1	4D	1	790	940	860-
		2	768	996	840
		3	796	946	842
2	2A	1	782	974	824
		2	670	954	824
		3	666	926	812
4	2C	1	825	980	884-
		2	646	942	814
		3	526	796	719
6	4C	1	762	946	849
		2	700	954	798
		3	600	900	790
7	2L	1	-	-	-
		2	755	950	849
		3	696	952	808
8	2E	1	750	960	850-
		2	652	946	835
		3	580	880	763
9	2H	1	720	979	852-
		2	724	964	839
		3	686	920	815
10	1G	1	790	978	861-
		2	642	896	772
		3	556	910	767
11	1F	1	760	978	895-
		2	786	946	854
		3	640	910	756
12	1D	1	826	947	896-
		2	700	946	836
		3	655	965	834
13	5B	1	776	940	849
		2	564	972	786
		3	600	964	756

Plate 23

Data Used for Plotting Roundness of Grains
(Continued)

Index No.	Sample No.	Size Group	Lowest degree of Roundness	Highest degree of Roundness	Average Roundness
14	1H	1	780	905	854-
		2	668	894	815
		3	600	924	780
16	3A	1	720	900	838
		2	700	924	824
		3	666	940	818
17	3C	1	776	962	860
		2	675	910	790
		3	660	960	839
18	2D	1	780	978	909-
		2	716	920	826
		3	600	890	776
19	3D	1	771	960	886
		2	725	945	821
		3	600	970	764
20	2M	1	782	955	880-
		2	762	956	836
		3	700	916	810
21	5A	1	830	967	890-
		2	664	924	820
		3	600	946	819
22	6D	1	826	956	881-
		2	786	964	846
		3	700	942	804
23	6A	1	810	975	888-
		2	775	956	830
		3	678	962	804
24	6H	1	702	900	810
		2	710	946	839
		3	730	868	810

Plate 23 (continued)

Data Used for Plotting Roundness of Grains
(Continued)

Index No.	Sample No.	Size Group	Lowest degree of Roundness	Highest degree of Roundness	Average Roundness
25	6E	1	800	951	875-
		2	634	942	826
		3	714	928	809
26	6Q	1	725	987	866-
		2	675	956	868
		3	642	954	824
29	6G	1	746	946	826
		2	684	942	802
		3	640	946	808
30	6P	1	774	964	876-
		2	684	946	790
		3	682	916	780
31	6Z	1	824	976	893-
		2	615	920	834
		3	634	925	769
32	6K	1	700	956	875-
		2	774	924	844
		3	710	966	804
33	6N	1	820	940	880-
		2	650	975	819
		3	606	882	780
34	6M	1	812	946	872-
		2	680	946	839
		3	670	886	786

Plate 23 (continued)

process," and other investigators conclude that the abrasion of quartz sand is a lengthier process than previously supposed. This fact suggests that quartz grains, or the larger ones at least, had as their immediate source other sediments, rather than crystalline rocks, for the degree of rounding manifested by them certainly suggests that the sediments have passed through more than one cycle of erosion. It is of interest to note here that some of the grains showed secondary growth of silica in microscopic study — but in many of these cases the secondary silica was seen to be an outgrowth of a previously rounded nucleus. It is therefore possible that much of the angularity of the second size group was due to such outgrowths. In the smaller particles, however, the writer sought deliberately for such evidence but here (1/8 - 1/16 mm.) the grains revealed great angularity and no evidence of secondary outgrowths as a possible cause.

The degree of correlation revealed between roundness and size grade MacCarthy[1] found to be typical of beach sands. He explained this by the fact that smaller particles are carried through suspension in the surf and are therefore not rounded as rapidly as the larger grains which may originally have been abraded by wind and reworked by water. Also, according to Galloway[2] if less than 50% of the grains

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[1] Gerald R. MacCarthy, The Rounding of Beach Sands, American Journal of Science, Vol. 225, 1933, p. 205; also, Eolian Sands - A Comparison, same publication, Vol. 230, 1935, p. 81.

[2] J. J. Galloway, Value of the Physical Character of Sands in the Interpretation of the Origin of the Sandstones, Bulletin of Geological Society of America, Vol. 33, 1922, p. 104.

are well-rounded, the sediment is of marine origin. MacCarthy in his treatise on Eolian sands also proved the greater efficiency of wind as an abrasive agent and explained the tendency of smaller grains to reveal greater angularity due to the fact that they are more effectively cushioned by air or water.

It may be pertinent to introduce here the fact that many of the larger grains especially, showed ground glass or "frosted" surfaces which according to Twenhofel[1] are evidences of wind abrasion. Some, however, have apparently been modified by solution and their surfaces are shiny and glassy. The degree of glassiness increases with decrease in size grade, again indicating the solution effect. In the smallest grade size the surfaces of the grains reveal no evidences of wind action.

Results of Heavy Mineral Separations

Although heavy mineral separation was made according to procedure discussed earlier in the paper, time did not permit a petrographic study and therefore no systematic identification of minerals was made.

According to Stow,[2] however, well rounded detrital grains of tourmaline with jagged secondary growths, are present. Dr. Stow has ascertained the secondary origin of these growths but has declared it to be more than a local phenomena.

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[1] Wm. H. Twenhofel, Treatise on Sedimentation, p. 57.

[2] Marcellus H. Stow, Authigenic Tourmaline in the Oriskany Sandstone, American Minerologist, Vol. 17, No. 4. Private communication, March, 1938.

During a hasty examination of a few heavy mineral slides the writer encountered such tourmaline growths in the form of splintery extensions of the parent grain, in the samples from Monterey locality. Zircon, leucoxene, and irregular lumps of limonite were also present.

The well-rounded appearance of many of these minerals and the fact that they are found among the very fine sands, again suggests that the round grains have gone through more than one erosional cycle. According to Rubey[1] such a concentration of heavy minerals within that grade-size (1/8 - 1/16 mm.) as contrasted with the paucity in remaining sizes, would be expected if the rock was derived from a previously sorted sedimentary source rock or if it had been subjected to considerable abrasion during transportation.

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[1] Wm. W. Rubey, Heavy Minerals Within Sandstone, Journal of Sedimentary Petrology, April, 1933, p. 22-24.

CHAPTER IV

CONCLUSIONS

From the foregoing field and laboratory data, an attempt will now be made to propose some explanation as to the conditions of sedimentation at the time of the deposition of the Oriskany sandstone. It should be remembered, however, that, since the aforementioned data are not complete enough to justify any final conclusion as to these conditions, all such interpretations are to be regarded as highly tentative ones subject to revision upon further study.

To date very little information on the sedimentation of Oriskany sandstone has been published, but material is available regarding the general paleography of the earlier Devonian sediments, and the writer did not hesitate to incorporate all such data as might seem pertinent in the following discussion.

History of the Oriskany Sandstone

General Environmental Conditions Previous to and Attendant upon Deposition of Oriskany Sediments

It is generally conceded that in the Early Devonian times the inland sea of the eastern section of the United States was restricted to the so-called Appalachian Basin, which actually represented an arm of the sea in the form of a long, narrow trough, extending in a directhe faunal evidences consisting of heavy shelled marine fossils, and from the frequent evidences of cross-bedding, the sediments may be considered as having been deposited in shallow marine waters, probably close to the margins or eastern shoreline of the aforementioned sea. This interpretation might explain some of the data on textural analysis of the stones. The fact that the coarser grades of sand, in the lower beds especially, are so strikingly devoid of finer clay and silts as contrasted to upper beds, can then be explained by agitation of the shallow waters, perhaps due to wave action.[1] Here the waves and currents would have to be strong enough to wash the coarser particles free of the finer ones but not strong enough to carry the coarser particles any great distance.

Thus moderate wave action in a shallow sea close to a shoreline might account for the high degree of sorting throughout all the lower beds from Strait Creek to Hot Springs, the lack of a north-south variation being explained by the fact that this entire region ran parallel to, and equally distant from the shoreline, and the character of the sediment is much more likely to change at a rapid rate in a direction normal to the shore than parallel to it. According to Twenhofel[2] uniformity parallel to the shoreline is to be expected.

The gradation in size of grain from lower to upper beds, however, becomes a little more difficult to explain. If sorting action of waves

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[1] Trask, op. cit., p. 84.

[2] Op. cit., p. 312.

and currents have carried off the finer particles, these should be deposited further west. No field or laboratory data from that region are available, but according to Schuchert[1] the material tends to get very much finer in the western section of the region "at times however an occasional interstratified layer of coarse material may be found." Evidently, then, the sediments were not all deposited at one time, difference in carrying or transporting power being the criterion. According to Twenhofel[2] such vertical gradation is common in shallow seas as contrasted to deeper water sediments which usually attain relatively uniform distribution over wide areas. Variable currents and storm waves may be influential in causing such stratification, since between storms the transporting power is lessened and finer material will readily be deposited upon the former coarser surface. Such tidal and wave effect might then explain the variation of the middle beds, the relative fineness of the upper beds, and the high degree of sorting throughout the entire series. In addition, it is probable that the westward transgression of the sea believed to have occurred in late Oriskany time, resulted in lower carrying capacity of water close to the shore, and the dropping of finer particles which later were to form the upper beds of the formation.

Source of Sediments

Such an explanation must be prefaced, however, by one explaining the source of these sediments. In early Devonian times the land mass

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[1] *Op. cit.*, p. 41

[2] *Op. cit.*, p. 312.

along the eastern margin of the Appalachian trough is believed to have been hardly above sea level.[1] Therefore, the supply of clastic sediments to this trough, as a result of stream erosion, was negligible, and it is possible that over this low land on the east, chemical rather than mechanical weathering was quite widespread. According to Fettke, there is no evidence of extensive vegetal covering in early Devonian, and the climate was probably sufficiently warm and moist to permit such weathering to go on to maturity, altering to the point of disintegration and pulverization all the softer minerals, leaving the more resistant insoluble quartz grains free. It is probable, then, that at this time these quartz grains and such of the minerals as escaped chemical disintegration were subjected to the action of wind which resulted in the accumulation of a sandy mantle over the lowland. In the laboratory, evidences of wind erosion were seen in the frosted surfaces of some of the larger grains and their greater degree of rounding.

During the latter part of Oriskany time the land mass on the east was uplifted[2] and stream erosion resulted in the shifting of these sands from the mainland to the trough, and the reworking of the previously wind-worn sands by streams and waves as heretofore explained, the highly pulverized and disintegrated materials being carried down by the streams to form the clay and silt deposits, laid down upon,

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[1] C. R. Fettke, op. cit., p. 243.

[2] Ibid.

and sometimes trapped among, the previously deposited coarser sediments. The subsequent action of the waves and water upon the sand grains was evidenced from laboratory study in the frequent pitted surfaces and the very glassy surfaces of some of the larger grains and all of the smaller ones as a result of the solution effect. The high degree of sorting is of course another result of wave action.

The fact that these sediments were derived from pre-existing sediments rather than crystalline rocks cannot here be conclusively proved due to lack of petrographic study on heavy minerals. However, a few facts gleaned from hasty laboratory study of the latter presents evidence that seems to point favorably toward such an explanation.

It will be recalled that all the heavy minerals examined appeared to be well-rounded and to be concentrated within the finer grades, i.e., 1/8 - 1/16 mm. Rubey[1] has found this concentration especially typical of sandstone source rock since the degree of abrasion of the heavy minerals as determined by their roundness and their concentration in the smaller size, is too great to have been evolved from only one cycle of erosion. According to Barrell,[2] although larger, heavier minerals clearly suffer more loss by abrasion than smaller, lighter ones in a unit distance of travel, that loss is due mainly, not to

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[1] Wm. W. Rubey, <u>Heavy Minerals Within Sandstone</u>, Journal of Sedimentary Petrology, April, 1933, p. 22-26.

[2] H. Sternberg, cited by Joseph Barrell, <u>Marine and Terrestrial Conglomerates</u>, Geological Society of America, Bulletin 36, p. 327.

their own movement which would be rather slow, but to the continuous blast of the rapidly moving lighter grains which are always sweeping past them. Thus small fragments would be broken off and carried away from the parent mineral, and the latter would then be subjected to further abrasion and sorting which eventually places them amongst the finer grades and makes them relatively scarce in the coarser grades. This again would seem to require more than one cycle of erosion to attain the degree of sorting evidenced in the Oriskany.

Degree of Transportation

Judging from the shapes of the coarser grains especially, one is apt to decide momentarily that the Oriskany sediments have been transported over long distances. In view of the foregoing discussion, however, and the fact that the sediments are found close to what is believed to be the former shoreline, being derived for the most part from the mainland immediately bordering the trough, it would seem as though actually they had travelled relatively short distances. Therefore, the explanation probably lies in the fact that the initial effect of a sedimentary source rock is likely to be similar to that of long continued transportation before deposition, and the Oriskany sediments were probably transported only a moderate distance.

Another question arises as to whether all the composing sediments of the Oriskany likely have the same source. Again a conclusive answer cannot be given. However, the fact that the smaller grains show glassy rather than frosted surfaces and are decidedly angular in shape raises the question as to whether or not they may have a more recent origin than the coarser sediments. While this is possible it does not seem probable, for MacCarthy[1] presents a plausible explanation of this in the statement that smaller particles are more effectively cushioned by air or water and are therefore not as easily abraded as larger ones. Thus it is probable that although the smaller grains do not show an abrasional history comparable to the larger ones, they are of the same age and origin.

Secondary Deposits

Evidences such as secondary enlargement of quartz and heavy mineral grains, and the formation of well-formed quartz crystals in the Hot Springs area, notably, suggest the work of underground water in interstices, fractures, and cavities of the sandstone. That such secondary deposition is also the cause of the iron and manganese nodules seems a likely conclusion. The fact that pockets or lens-like concentrations of iron oxide were especially numerous in the Hot Springs area in the same region that revealed much secondary mineral growth, bears out this fact. More recent investigations in the field of Oriskany iron ores[2] have brought forth indisputable evidence that such ores are replacement effects of meteoric waters descending down from rather ferruginous overlying shale, although it was originally

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[1] Gerald R. MacCarthy, Eolian Sands, American Journal of Science, Vol. 225, 1933. p.81

[2] Samuel E. Doak, Oriskany Iron Ores of Virginia, Engineer's Mining Journal, p. 386.

contended that long exposure to atmospheric agencies before consolidation of the sediments might, at that time, have caused iron oxide deposits to surround the grains. If such were the case, however, the lower layers especially should be universally brown in color and possess approximately equal amounts of the oxide. This is not so, but rather the presence of the manganese and iron deposits seems to be directly related to the degree of fracture of the containing rock.

Unsolved Problems

While the previous discussion has attempted to theorize and suggest possible interpretations of laboratory data, many problems still remain unsolved. Some of the latter remained so due to insufficient field study, i.e., a thorough study of the occurrence and textural trend of the Oriskany west of the present outcrops is necessary to describe adequately the irregular distribution and the gradation in size grain from the lower to upper beds. Until such an investigation can be carried on the writer has entertained the theory suggested originally by Suess and since elaborated upon by Schuchert[1] of oscillating shorelines as a possible explanation.

It is generally conceded that the uplift of the eastern boundary of the Appalachian Sea, had a tilting effect that pushed the Oriskany sea westward and caused the sediments to be laid down in a shallow transgressing sea. Such a basin would, of course, be constantly re-

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[1] C. Schuchert, op. cit. p. 511.

ceiving detrital materials and unequal loads in different areas would alter locally the depth of the sea and the width of the resulting deposits. Also such unequal loads and subsequent local subsidence would tend to cause the fluctuation of the shoreline and consequent gradations of sediment.

The cherty phase underlying the Oriskany sandstone, its occurrence in Monterey vicinity northward, and its absence in the Warm and Hot Springs area presents another problem. If, as Swartz[1] suggests, the Shriver Chert is a muddy bottom phase equivalent in time to Becraft of Helderbergian age, the writer has no explanation to offer. If, however, it may be considered the base of Oriskany sandstone, younger than Becraft, a possible explanation lies in the fact that during the latter part of the Helderbergian time, the sea was greatly reduced in size, and locally much of the Helderbergian upper strata was subjected to erosion. Simultaneously, local marsh lands and flats still remained in which muds were deposited which later may have consolidated to form what is now known as the Shriver Chert. Before consolidation, however, with the reflooding of the Appalachian trough and uplift of land mass on the east, the fauna which today characterizes Oriskany so typically, was introduced and in this manner perhaps became buried in the underlying muds. The Shriver is notably more closely related faunally to the Oriskany than to the Becraft.

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[1] Op. cit.

Summary

The present paper has attempted to evaluate the physical and environmental conditions under which the Oriskany sandstone was deposited, based upon a laboratory study of the textural characteristics of the sediments. The study included mechanical analysis by sifting and sedimentation methods and the plotting of the results on histograms and frequency curves. Additional studies were made on the roundness of the grains according to Cox's percentage determination, and although heavy mineral separations were completed for each sample, time did not permit identification of the separates.

The summary conclusions derived from data secured from the above investigations suggest that:

1. Oriskany sandstone represents shallow water deposits laid down in an inland transgressing sea, quite close to the shore.

2. The sediments were probably derived from pre-existent sands from land mass just east of Appalachian trough, rather than crystalline rocks.

3. Oriskany sands were transported only a moderate distance before deposition.

4. Subsequent to deposition and consolidation, the sandstone has been modified by ground water which has caused secondary crystallization, enlargement, and intergrowth of quartz grains and which is also responsible for pockets of iron oxide and manganese found especially in the Hot Springs area.

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