DIMENSIONAL GRAIN ORIENTATION STUDIES

OF

TURBIDITE GRAYWACKES

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ABSTRACT

This study describes the analysis of orientation measurements of elongated quartz grains in graywackes of turbidite nature of the Normanskill formation of New York and the Quebec Group of Quebec.

Definite relationships are demonstrated between the direction of flow, as indicated by the measurement of the flute casts, and the preferred orientation direction of the sand grains.

Dimensional orientation analysis of sand grains in thin section can be used to determine the transport direction of the turbidity current where this can not be determined by other means.

Size and shape analysis of quartz grains in thin section might be biased depending on how the thin section is cut with respect to the fabric of the rock.

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INTRODUCTION

(a) Preface.

The textural properties of sandstones can be thought to be a function of grain size, shape, orientation and packing (Griffiths, 1952). One of these fundamental properties, orientation of sand grains, has received relatively little attention, because of difficulties involved in its determination. Lack of agreement among workers on the relationships between the orientation pattern in the deposit and the direction of stream flow (Krumbein, 1940, 1942; Twenhofel, 1950), in turn did not encourage extensive studies in this field; furthermore, practical applications seemed limited.

Experimental work by Dapples and Rominger (1945), Schwarzacher (1951), and Rusnak (1957 a), has suggested that study of sand grain orientation is a possible means of determining transport direction.

In this study, the theory that the long axes of elongated quartz grains tend to align themselves parallel with the current direction, is tested in oriented graywacke samples of two different formations. The results of the grain orientation measurements are compared with the directional measurements of flute casts displayed on the bottom surface of the beds.

(b) Objectives of investigation.

The main objectives of this study are:

(1) To attempt to establish relationships between the orientation pattern of the quartz grains in graywackes and the azimuthal direction of the flute casts.

(2) To analyze the variations between samples and within samples of the same bed, and the operator error, to establish a practical standard procedure to investigate sand grain orientation in graywackes.

(3) To investigate the interdependency of the orientation pattern and the measurements of size and shape in thin section.

(c) Definitions of graywacke and turbidite.

The classification of sandstones must be based on fundamental petrographical properties, which are necessary and sufficient to define a rock specimen uniquely (Griffiths, 1952).

The term graywacke has been used in a wide variety of connotations, and it is not clear at the present day which properties of composition and texture are essential and adequate to define this rock term.

Recently several authors (Bokman, 1955; Dapples, Krumbein and Sloss, 1953; Folk, 1954; Kuenen, 1957; Packham, 1957; Pettijohn, 1954, etc.) have discussed the classification of this rock type, adding many characteristic features, which they consider to be diagnostic of graywackes, thereby only increasing the state of confusion.

Although the writer is primarily interested in the turbidite character of the rock studied, the use of this rock term in a more

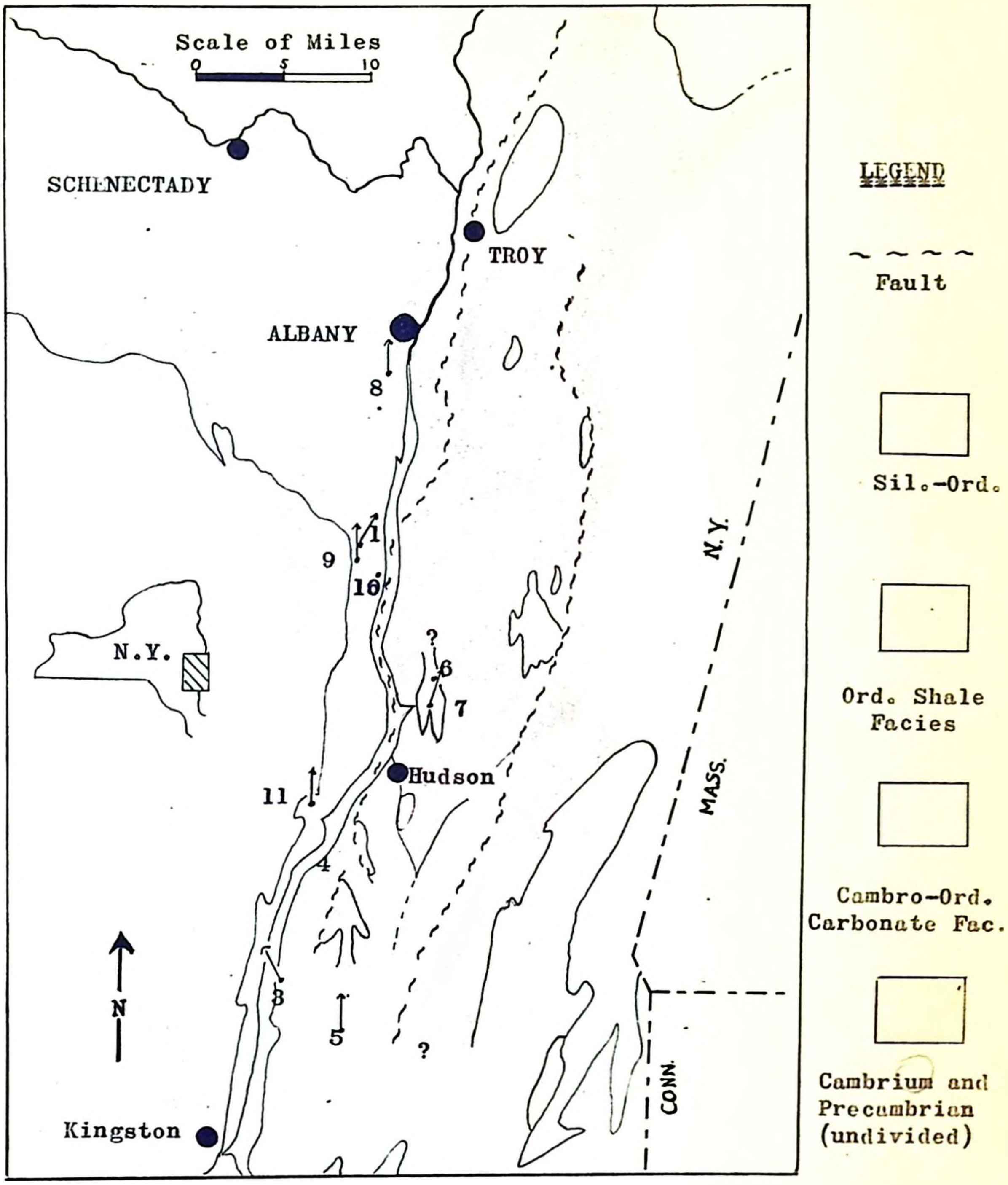

FIG. 1.- Geologic sketch map of the Hudson River Region between Kingston and the Capital District, N.Y.. Paleocurrent system in the Normanskill Graywackes is indicated by the arrows. Locality numbers are referred to in the text.

precise connotation is desirable. In this study Krynine's (1948) classification of sandstones has been employed, without, however, necessarily accepting its geotectonic implications.

The definition of turbidite, as a clastic rock deposited by a turbidity current, does no more than specify the agent of deposition.

(d) Geology and stratigraphy of the formations studied.

(i) The Normanskill Graywackes.

The Normanskill formation, of Ordovician age, outcropping in Eastern New York, lies within the Taconic Belt. The area of study is located approximately between Kingston, N.Y., and Albany, N.Y., in the Hudson Valley Region. (Fig. 1[1])

Ruedemann (1942) estimates the whole thickness of the Normanskill formation at approximately 2000 feet. He divides the Normanskill formation into two members; the lower Mt. Merino member, consisting of cherts and shales, and the upper Austin Glen member, consisting of graywackes and shales. Several controversial theories with regard to the stratigraphic and tectonic relationships have been proposed (Bucher, 1957; Craddock, 1957), but they are not discussed here.

Ruedemann further describes the presence of mud pellets, intraformational conglomerates, regular alternations of graywackes and shale (Fig. 2), ripple marks, cross bedding and "mud flow structures" at the underside of the graywacke beds.

[1] Locality numbers, which are referred to in the text, are given in an abreviated form; e.g. number 1 is PS-1-59.

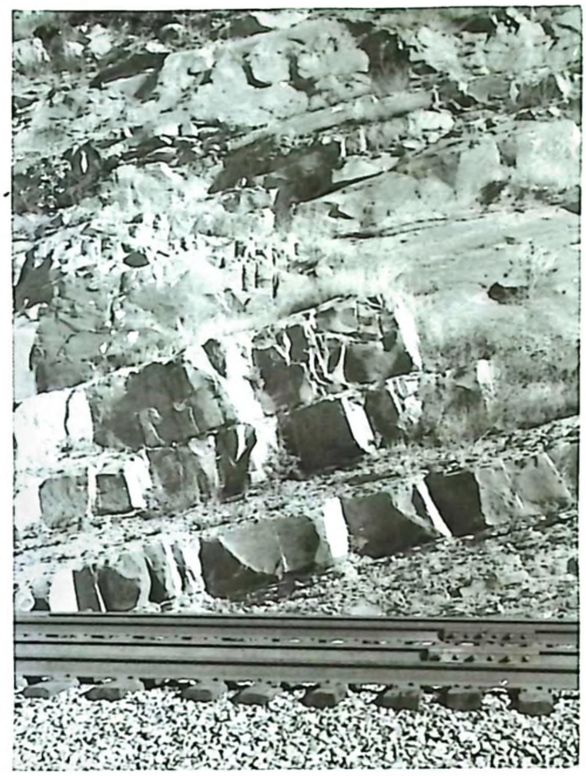

FIG. 2A.- Graywackes interbedded with shale; along New York Central Railroad, S. of North Germantown, N.Y..

FIG. 2B.- Graywackes interbedded with shale; tributary of Kinderhook Creek, S. of Stockport, N.Y..

These structures "give the impression that this formation was deposited in shallow water, probably near shore, where the velocity of the currents was frequently and rapidly changing". Fossils are scarce and include some graptolites, seaweed and euripterids. (Ruedemann, 1942)

Modern experimental investigations and field observations by various workers (notably Ph. H. Kuenen) offer~~s~~ a different point of view regarding the paleogeological and sedimentological interpretation of the formation. The hypothesis that the graywackes were deposited at such depth and distance from the source of detritus that turbidity currents could develop, is more acceptable than the alternative interpretation of a shallow water deposit.

A number of distinctive properties of turbidity current deposits, which have been described from several parts of the world, can be observed in the Normanskill graywackes.

(1) Graded Bedding.—Most of the beds show a sharp well defined contact with the underlying beds, indicating the intermittent character of the turbidity current activity. The upper surfaces frequently show a peculiar "ripple marking" (Figs. 3A and B). These structures have very likely been developed by the activity of currents on the finer "tail" after the main body of the turbidity current had passed (Middleton, unpublished) or by post depositional currents on the bottom of the ocean. Currents strong enough to rework even coarse sediments exist on the bottom of the present day oceans (Heezen et al., 1959).

(2) Oriented sole markings.— (a) Flute casts, roughly parallel oblong bulges, which are in fact casts of hollows in the

FIG. 3A.- Ripplemarks on the upper surface of a graywacke bed. Picture taken in the North direction. Scale is 6 inches long. Along New York Central Railroad, South of North Germantown.

FIG. 3B.- "Wavy" bedding on top of a graywacke bed. Along New York Central Railroad, South of North Germantown. Same scale as Figure 3A.

underlying shale, (Figs. 4A and B). The long axes of the flute casts are parallel or sub parallel to the turbidity current direction. (Kuenen, 1957).

(b) Drag marks (Fig. 4B)

(3) Absence of well developed current cross bedding.

(4) Scarcity of fossils.

No detailed study of the orientation of the sedimentary structures was made. However, measurements of the flute cast direction made at several different localities, show predominantly South West, South and South East derivations (Fig. 1). Observations by Dr. Middleton (unpublished) indicate deposition from currents which flowed from the South, South West or West. As most of the graywacke beds were tilted, the flow directions were obtained by reorientation of the bed in its original position, under the assumption that the tectonic rotation was about an axis parallel to the strike. It is notable that the direction of transport appears to be that of the original elongation of the sedimentary basin. The hypothesis of derivation of graywackes from the South West is supported by their regional occurrence. Graywackes are common, thick and coarse in the region around Catskill and Kingston but are much scarcer and finer grained in the New York - Vermont slate belt, further North, to judge from Ruedemann's descriptions.

The Normanskill graywackes are composed of seven major constituents: quartz, feldspar, clay matrix, "shale like" rock fragments, carbonate cement, carbonate rock fragments and heavy minerals. A typical average modal composition of the Normanskill graywackes is:

FIG. 4A.- Flute casts on the underside of a graywacke bed. Current direction presumably from lower right to upper left corner. Along New York Central Railroad, N. of Tivoli station, Madalin, N.Y.. (1 inch = 1 foot).

FIG. 4B.- Flute casts and dragmark. Current direction approximately from left (S) to right (N). Along Highway 9W, 5 miles S. of Ravena, N.Y.. (1 inch = 0.5 foot).

Quartz	20.0%
Feldspar	8.3%
Clay and rock fragments	48.0%
Carbonate	19.7%
Heavy minerals	0.9%

(Average of 23 samples of the Normanskill formation)

In Krynine's (1948) classification these rocks would be called low rank graywackes.

The Normanskill graywackes were presumably deposited in a "volcanic island arc" environment. The source area appears to be largely composed of sedimentary and low grade metamorphic rocks, with some basic and intermediate volcanic rocks.

(ii) The Quebec Group Graywackes.

The Quebec Group, a name proposed by Logan, for pre-Silurian Paleozoic rocks in the Appalachian Region of Quebec, consists of three formations near Quebec City (Melihercsik, 1956).

Quebec City formation
Levis formation
Charny (Sillery) formation

These formations extend in the North East direction along the South bank of the St. Lawrence River, forming a belt of rocks, of which the exact stratigraphic relationships are still unknown. Osborne (1956) describes heterogeneous, poorly sorted sandstone beds from 6 inches to 40 feet thick, containing mingled grains of diverse sizes and showing a tendency to have more of the larger grains toward the bottom of the bed.

"It is inferred that the materials were inshore accumulations which intermittently became unstable and slid, lubricated with water, down-slope to form the sandstones. The final deposits at depth have thick beds, in many places graded bedding, fluting of the underlying bed and other features suggesting rapid accumulation......" (Osborne, 1956).

A typical average modal composition of 17 graywacke samples from the Quebec group is:

Quartz	52.1%
Feldspar	12.9%
Clay and Rock fragments	25.7%
Heavy minerals	8.1%

This is also a low rank graywacke according to Krynine's (1948) classification.

The Quebec Group derived the bulk of its sediments from a crystalline gneiss area, largely acidic in composition, probably a shield area. Field observations suggest that the sediment was derived from the North, or North-North-West. This corresponds to a lateral rather than a longitudinal supply (Middleton, personal communication).

DIMENSIONAL ORIENTATION OF SAND GRAINS

(a) Historical Review.

The use of dimensional orientation analysis in sedimentary petrology is relatively new and has been primarily concerned with pebble fabric studies because of the easier techniques of investigation. (e.g. Wadell, 1936; Krumbein, 1939, 1940, 1942; Cailleux, 1945; de Waard, 1945; Kalterherberg, 1956; Schlee, 1957, etc.)

Only recently has dimensional orientation of sand size particles been applied as a workable geological tool to indicate the direction of transport (Helmbold, 1952; Kopstein, 1954; Nanz, 1955; Curray, 1956; Rusnak, 1957 b; Srimadas, 1957).

Experimental work by Dapples and Rominger (1945), Schwarzacher (1951) and recently Rusnak (1957) demonstrates that definite relationships exist between the orientation of sand grains and the direction of the depositing current. Results of these experimental investigations confirm the theory that the long axis of elongated grains tend, on a statistical basis, to align themselves parallel with the direction of flow of the transporting medium. Krumbein (1940, 1942) and Schlee (1957) found this also to be true in fluvial gravel deposits.

Schwarzacher (1951), later confirmed by Rusnak (1957), found that under certain experimental conditions, the sand grains not only displayed parallel alignment but also imbrication in the upcurrent direction, similar to that shown by pebble deposits in a stream bed. Rusnak also investigated the orientation pattern of experimental sand deposits of different size and shape distribution. Attempts by the two latter authors to make use of the larger end direction as an indicator for the current direction yielded inconclusive results.

The reliability of sand grain orientation as a means of determining transport direction has been tested in some situations with directional control. Nanz (1955) found the long axes of quartz grains of beach slope deposits along the Gulf Coast to be statistically aligned normal to the beach strike. Similar results were obtained by Curray (1956 b), who studied undisturbed samples of Recent Gulf Coast sands. Curray explains this by the tendency of the quartz grains to align themselves parallel with the back wash direction of the waves, which are generally normal to the coast line. This implies that in fossil beach deposits the preferred grain orientation can be expected to be normal to the long dimension of the sand body, which is in general parallel or subparallel to the former coast line. In fluvial deposits on the other hand, the trend of the sand body will be parallel to the preferred grain orientation.

Bonham (1953) observed preferred orientation of the quartz grains in both deformed and undeformed Tertiary sandstones of California. This could not be attributed to rolling and stretching after deposition and therefore must be the result of depositing processes.

Rusnak (1957 b) attempted to determine the sediment transport direction in channel deposits of the Pleasant View formation of Illinois by grain orientation analysis. The results of the cross bedding analysis in this typical Pennsylvanian cyclothem, however, were distinctly different from the preferred direction of the sand grains. Rusnak speculated that this might be due to the fact that different currents are represented in the non cross bedded parts of the formation.

Srimadas (1957) successfully applied the concept, that the elongate grains in a sandstone are aligned parallel to the depositing current, to Upper Jurassic sandstones of the East Godavari District, India.

The only examples of the geological application of sand grain orientation as a transport criterion in graywackes of turbidite nature, are the studies by Helmbold (1952) and Kopstein (1954). Dimensional orientation of sand grains was found and measured by Helmbold in the Tanner Graywackes of the Harz in Germany. Helmbold remarks, "that smaller grains (less than 0.1 mm.) show no recognizable orientation but the larger elongate grains have an orientation which is scarcely discernable in hand specimen". Kopstein (1954) reported long axes alignment in most specimens of the Cambrian turbidite graywackes of the Harlech Dome Area, Wales, and mapped these orientations together with other structures for the purpose of determining the direction of the current flow.

Most other investigations of dimensional orientation of sand grains, however, are restricted to isolated samples and were not primarily undertaken to trace relationships between the orientation of sand grains and the current direction (e.g. Griffiths, 1953; Griffiths and Rosenfeld, 1953; Dutta and Griffiths, 1955, etc.).

(b) Measurement of dimensional grain orientation.

(i) Introduction

The study of grain orientation in sandstone is subject to several limitations. It is necessary to make use of thin sections in order not to disturb the original fabric and we can therefore only study a two dimensional image of a three dimensional orientation. Elongate quartz grains may theoretically be considered to be three dimensional ellipsoids which possess a longest "a", an intermediate "b", and a shortest "c" axis, and the observer can not be certain that he sees any of these axes in thin-section. He must be content with the measurement of the apparent long "a" axis and the intermediate long "b" axis in the thin-section plane. Furthermore the observer can not determine unequivocally one end of the grain from the other; viz. he can only determine the lineation of the apparent long axis.

As the azimuth measurements generally range over 180 degrees, the problem arises that the physical mean preferred orientation can not in general readily be derived from the original measurement data. In order to determine whether preferred orientation of elongated quartz grains exist, it is necessary to demonstrate by accepted statistical methods that the arrangement of the grains exhibit a significant deviation from randomness. These problems are discussed in more detail in the section on the statistical treatment of the data.

(ii) Sampling Problem

Sampling of sand grains in thin-section for investigation of textural properties is still inadequately solved. This is especially true for orientation analysis. (Chayes, 1956).

Griffiths (Griffiths et al., 1955) emphasizes the fact that a random sample of measurements representing a homogeneous population is required as a basis of analysis. Sedimentary rocks are composed of sedimentation units (Otto, 1938), e.g. a set of quartz grains which is deposited under a limited range of conditions. This "sedimentation unit" is the theoretical homogeneous population which must be sampled randomly. There is no evidence, whether the assumption, that a homogeneous population of orientation is present in a single thin section, is correct. If sub-populations of grain orientations are present in the order of the dimensions of the thin section surface, this fact will have implications for the measurement of orientation. At this stage, however, it is not possible to define the subpopulation, if any, in graywacke thin sections sufficiently well to ascertain that (say) each point count traverse is a random sample of a homogeneous unit.

No specific sampling plan was designed in collecting the field samples. It was however, attempted to take samples representing the whole bed thickness. The direction of the flute casts was measured when the oriented samples were collected.

(iii) Techniques of measurement

The measurements in this study were made with the use of a binocular petrographic microscope, equipped with a mechanical point count stage. The microscope was also fitted with a cross hair ocular, to establish fixed reference lines and a micrometer ocular to measure grain dimensions.

The long "a" axis or axis of elongation of the grain image is operationally defined as the longest intercept across the grain. In ambiguous cases the most symmetrical axis was chosen (Fig. 5). Within the scope of this study the definition is equivalent to the one used by

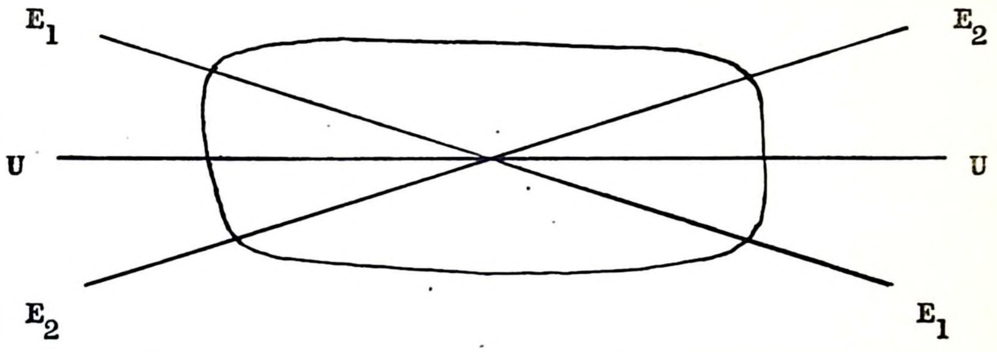

FIG. 5- Possible choices of long axes "a" in a grain.
E$_1$ and E$_2$: equivocal choices of long axis "a".
U: unequivocal choice of long axis "a".

(Modified after J.J. Hutta, 1956, Unpublished.)

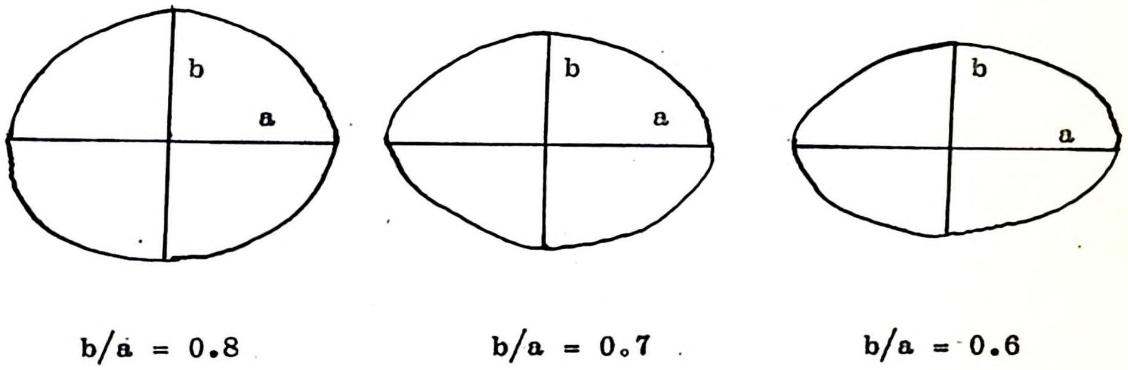

FIG. 6.- Visual estimation of the elongation class of a two-dimensional grain image.

Nutta (1956): "the axis which parallels the direction normal to the direction of minimum dimension." The longest intercept at right angles to the "a" axis is defined as the "b" axis.

In preliminary investigations selection of grains for measurement were made along linear traverses. However, selection of elongated grains will be biased depending on how the grains are oriented with respect to the direction of traverse. Unless it is attempted to measure all the grains, this method is impractical.

Selecting grains by point counting is a more objective method and has therefore been applied in this study. Point counting gives an area distribution approximating volume and weight distribution (Chayes, 1956). Volume distributions tend to give more weight to the larger grains; viz. larger grains which fall under the cross hairs more than once, are counted and measured more than once. To obtain the best estimate of the whole sample population, it is necessary to cover the whole thin section as adequately as possible.

It was decided to select only grains with a long axis "a" larger than 0.1 mm. ($a > 0.1$ mm.) and with an elongation ratio b/a smaller than or equal to 0.7 ($b/a \leq 0.7$). The elongation ratio limit was visually estimated with the aid of Fig. 6.

Size and shape limits were arbitrarily chosen. It was felt that these limits were justified, since measurements of very small grains and barely elongated grains gave rise to unnecessary technical problems. Furthermore this study was not primarily concerned with a systematic fabric, shape or size analysis of the graywackes.

Size and shape were estimated by measuring the long "a" axis and the intermediate "b" axis. A variety of thin section techniques for size measurements have been developed (Friedman, 1958). In this study, however, it was found practical to express the size the the logarithm to the base of two of (ab) in micrometer units[1] (1 Phi-Log$_2$ ab) in a modification of Krumbein's Phi-scale (Krumbein and Pettijohn, 1938). Shape is expressed by the elongation ratio b/a.

(c) Statistical treatment of the data.

The statistical analysis of grain orientation in thin-section involves a number of difficulties due to the cyclic nature of the angular data. It is generally not possible to determine one end of the quartz grain from the other. The problem arises that the orientation measurements in fact represent measurements of lineation ranging over 180°.

A quantitative study of directional properties must have as first objective the determination of the average direction. The expression of the mean and standard deviation of two-dimensional orientation data implies some degree of preferred orientation of the grains. Although a mean orientation may be calculated from a set of measurements in which an equal number of grains point in all direction, such a mean would not have any petrographical significance. Furthermore the linear mean and standard deviation are sensitive to the choice of origin (Jizba, 1953). A change of origin may make a considerable difference

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[1] 1 micrometer unit = 0.073 mm. under medium power

in the mean and standard deviation of the same distribution.

Reiche (1938), Krumbein (1939), and Curray (1956) presented a vector summation method of analyzing orientation data which is independent of origin. The orientation data can conveniently be grouped in arbitrary azimuth classes with a class interval over a 180° range. The midpoint of the first class is azimuth 0° (= 180°). The nine classes are therefore defined as 350° - 10° (170° - 190°) with midpoint 0° (180°), 10° - 30° (190° - 210°) with midpoint 20° (200°) etc. Each class of the observations is treated as a vector having direction and magnitude. This vector can be represented by an arrow, whose length represents the magnitude or the number of observations in each class (n). The direction of each vector is expressed by the midpoint value of each class. To maintain the periodic nature of the distributions the angle associated with each class midpoint is doubled (Krumbein, 1939). Each vector can be resolved in terms of components parallel to the axis of a Cartesian coordinate system. The components of a vector with direction $2\theta_i$ and magnitude n are respectively $n \sin 2\theta_i$ and $n \cos 2\theta_i$. The mean direction θ_m of the vectors representing all the classes can be determined from the relationship,

$$(1) \qquad \tan 2\theta_m = \frac{\sum n \sin 2\theta_i}{\sum n \cos 2\theta_i}$$

where n = number of observations in each class.

The mean vector direction is not synonimous with the mean in the linear statistical sense and we may therefore refer to it as the preferred orientation direction. The vector magnitude, r, of the preferred orientation direction can be derived from:

$$(2) \qquad r^2 = \left(\sum n \sin 2\,\theta_i\right)^2 + \left(\sum n \cos 2\,\theta_i\right)^2$$

(Curray, 1956)

The vector magnitude is usually expressed in percentages, L, of the total number of observations, n.

Reiche (1938) and Curray (1956) proposed that the vector magnitude be applied as a measure of dispersion comparable to the standard deviation.

Tukey's Chi-square test (Rusnak, 1957 b) can be used as a criterion to determine the degree of departure from random orientation. This test of the significance of orientation data is not only independent of origin but also more sensitive than the ordinary Chi-square test, because only the two degrees of freedom, most sensitive to orientation, are taken from the Chi-square for testing. The test is based on the departures of the observed data from an orientation distribution which is completely uniform. The measure of deviations in each class interval from an expected uniform distribution is given by the following:

$$(3) \qquad X = \frac{O - E}{\sqrt{E}}$$

where O = observed number of orientation measurements in each class

E = expected number of orientation measurements in each class.

Two factors S and C are the basis for this test:

$$(4) \quad S = \frac{\sum X \sin 2\theta}{(\sum \sin^2 2\theta)^{\frac{1}{2}}} \qquad \text{and} \qquad (5) \quad C = \frac{\sum X \cos 2\theta}{(\sum \cos^2 2\theta)^{\frac{1}{2}}}$$

Tukey then proposes that $C^2 + S^2$ be treated as Chi-square with only 2 degrees of freedom. The results of the test can be expressed as a probability value P. The actual Chi-square values are compared with the tables given in the standard texts. (e.g. Dixon and Massey, 1957, table A-6a, p. 385).

The orientation measurements can be represented as frequency histograms. The form of the histogram will depend on the reference line chosen. The statistical methods applied are independent of origin and therefore valid regardless of the exact shape of the histogram.

For details of these and other statistical tests employed in this study, the reader is referred to standard texts (e.g. Dixon and Massey, 1957) and to the geologic literature. (Krumbein and Miller, 1953, etc.).

DESCRIPTION OF THE EXPERIMENTS

(a) Preliminary experiment.

The orientation of the quartz grains of two thin sections PS - 11 - 59 - 1 - a and PS - 11 59 - 1 - b, cut from the same sample of the Normanskill section, was investigated with the objectives:

(1) To investigate whether preferred orientation was present in the thin sections.

(2) To investigate whether any relationship existed between the current direction, determined by measurement of the sole markings, and the preferred orientation of the elongated quartz grains.

To reduce sampling error to a minimum, it was decided to measure as many elongate grains in each thin sections as possible. Each thin section was very closely traversed and the azimuth of each eligible grain, falling under the intersection of the cross hairs, was measured. 400 grains were measured in each thin section, approximately covering the whole thin section. The circular mean preferred orientation θ_m and the measure of dispersion L, were computed after the measurement of every 50 grains. The results are summarized in table 1. The measurement data are grouped in 20° classes and are plotted as orientation frequency histograms in Figs. 7 and 8. The data in table 1 are graphically represented in Fig. 9A and B.

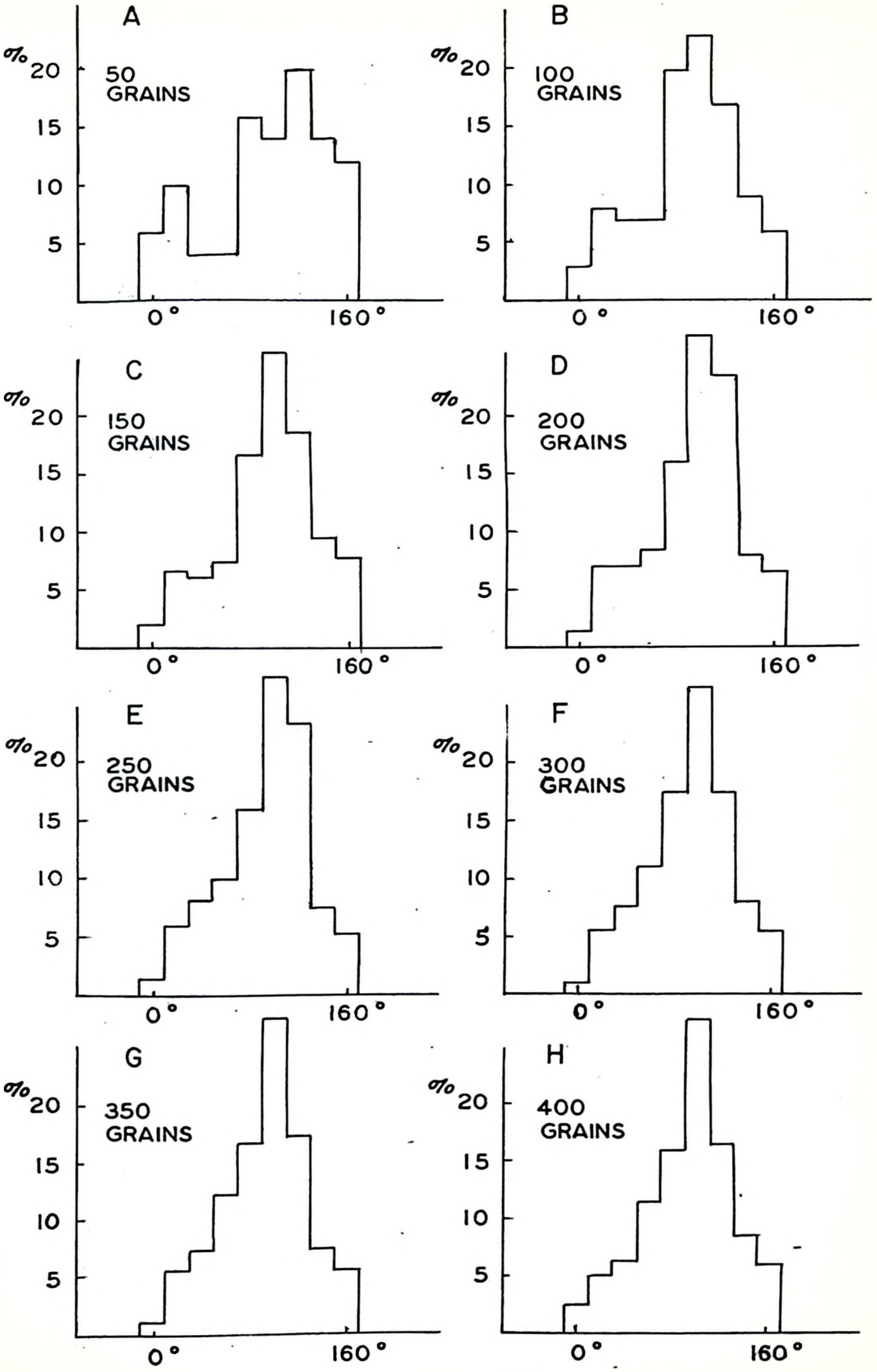

A
50 GRAINS
B
100 GRAINS
C
150 GRAINS
D
200 GRAINS
E
250 GRAINS
F
300 GRAINS
G
350 GRAINS
H
400 GRAINS
%
20
15
10
5
0°
160°

FIG. 7

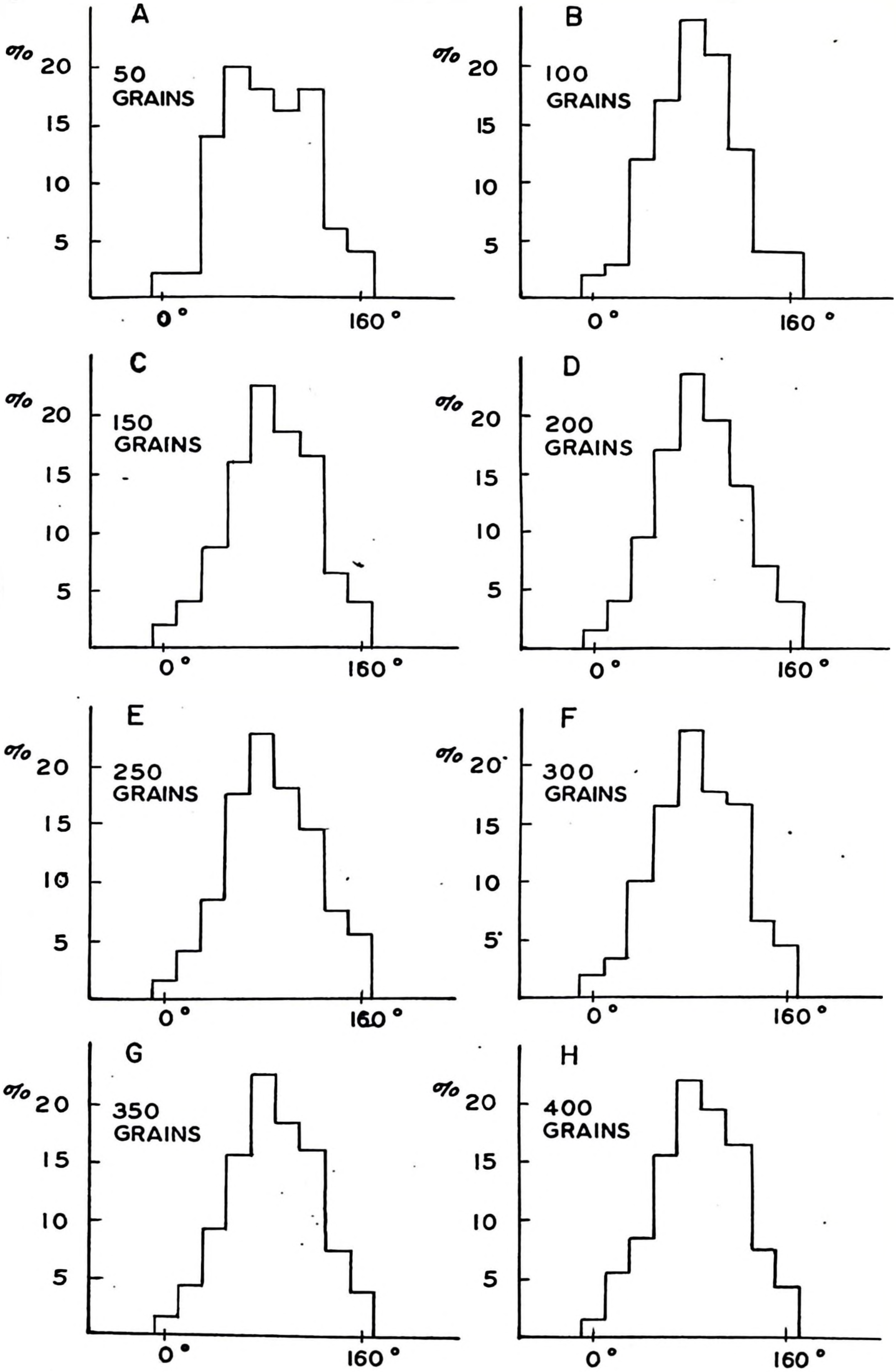

A
%
20
15
10
5
50 GRAINS
0°
160°
B
%
20
15
10
5
100 GRAINS
0°
160°
C
%
20
15
10
5
150 GRAINS
0°
160°
D
%
20
15
10
5
200 GRAINS
0°
160°
E
%
20
15
10
5
250 GRAINS
0°
160°
F
%
20
15
10
5
300 GRAINS
0°
160°
G
%
20
15
10
5
350 GRAINS
0°
160°
H
%
20
15
10
5
400 GRAINS
0°
160°

FIG. 8

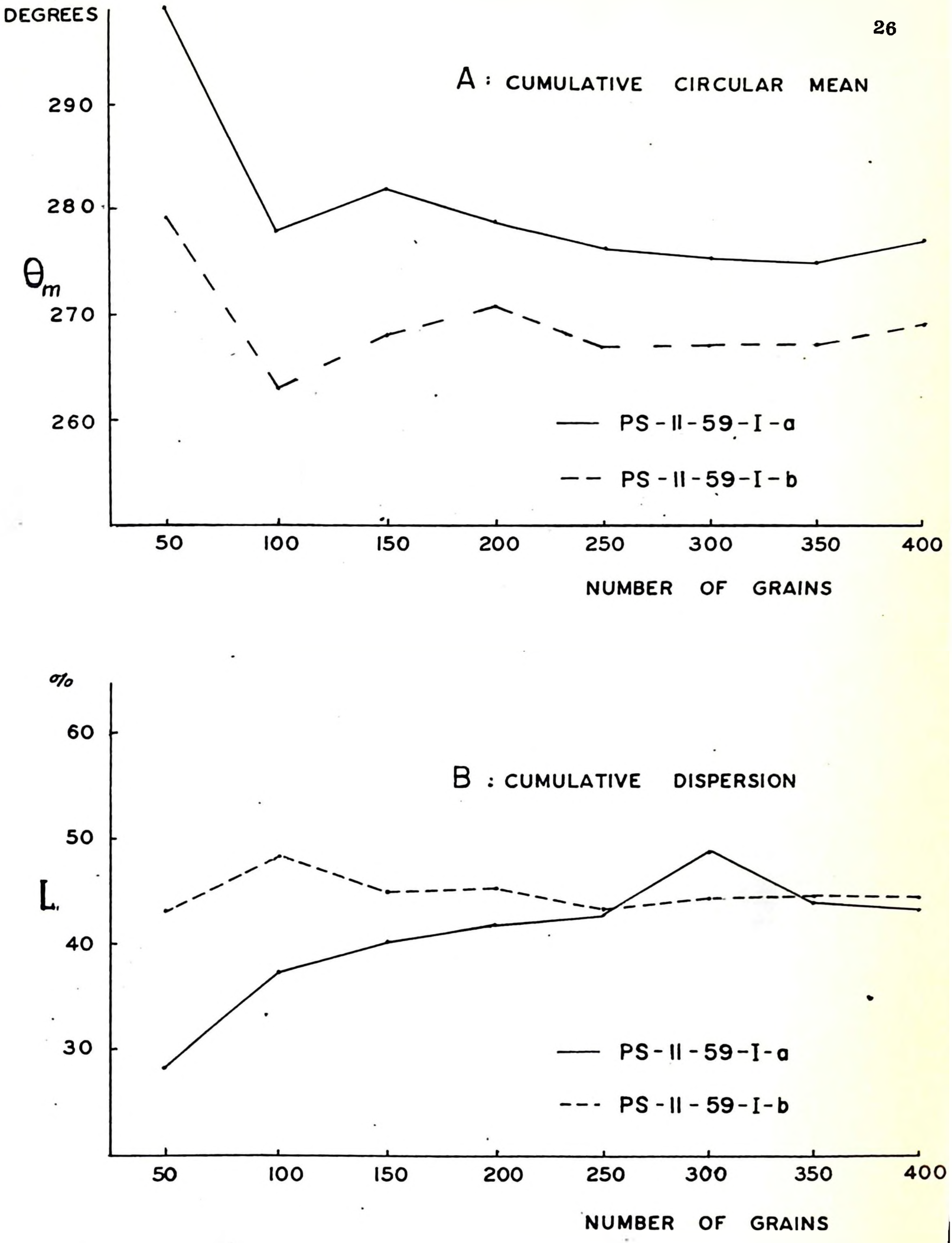

A : CUMULATIVE CIRCULAR MEAN
DEGREES
θ_m
290
280
270
260
PS - II - 59 - I - a
PS - II - 59 - I - b
50
100
150
200
250
300
350
400
NUMBER OF GRAINS
B : CUMULATIVE DISPERSION
%
L
60
50
40
30
PS - II - 59 - I - a
PS - II - 59 - I - b
50
100
150
200
250
300
350
400
NUMBER OF GRAINS

Fig. 9

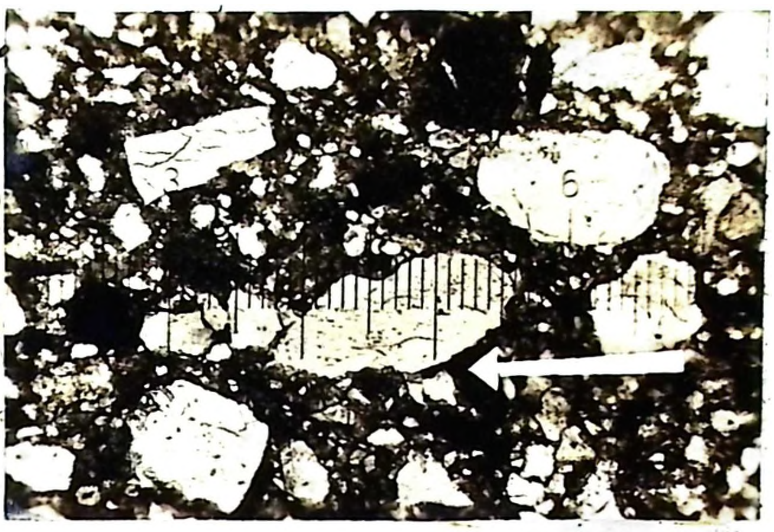


FIG. 10A.- PS-11-59-I-a

FIG. 10B.- PS-11-59-I-b

FIGS. 10A and B.- Photomicrographs of two thin sections of the Normanskill Graywackes. The arrow indicates the current direction as measured from the flute casts. (1 scale unit = 0.55 mm.)

Number of Grains	PS-11-59-1-a θ_m°	$L\%$	PS-11-59-1-b θ_m°	$L\%$
50	299.4	28.2	279.3	43.2
100	278.0	37.3	263.0	48.4
150	282.3	40.2	268.0	45.0
200	279.0	42.0	271.0	45.5
250	276.4	43.9	267.1	43.4
300	275.3	49.0	267.1	44.3
350	275.0	44.0	267.4	44.3
400	277.3	43.2	269.1	44.1

TABLE 1.

Tukey's Chi-square test indicates that significant (at 95% level) departures from random orientation occur even after only fifty measurements.

Measurements of flute casts indicate a current direction of 275°. We may conclude from table 1 that consistent preferred orientation within 10 % from the current direction is shown after 100 grains in thin section PS-11-59-1-a and after 150 grains in thin section PS-11-59-1-b. Fig. 9A indicates that differences between cumulative preferred orientations become very small after 200 grains; viz. the "flatness point" (Reiche, 1938) is reached.

Conclusions:

(1) The elongated quartz grains in both thin sections show a strong degree of preferred orientation (Figs. 10A and B).

(2) The preferred direction of orientation in both thin sections is parallel to the azimuthal direction of the flute casts, which presumably represent the current direction.

(b) Analysis of sampling design.

The object of this experiment is to examine the method of sampling for orientation measurements, in order to obtain significant results. Two aspects, the number of grains per thin section and the number of thin sections per sample will be examined.

For the purpose of this investigation two samples, PS-8-59-II and PS-8-59-b-III, were taken from the same bed, 15 cm. apart in lateral direction, and representing the whole thickness. Three thin section, 1, 2, and 3 were cut from each sample respectively from the bottom, the middle, and the top part of the bed, about 4 cm apart in the vertical direction. In each thin section the azimuths of 200 grains, selected by point counting, were measured. The circular mean $\bar{\theta}_m$ and the measure of dispersion L were computed after every 50 measurements. Standard deviation S was graphically estimated from Curray's empirical curve, which shows the relationships between vector magnitude and the linear standard deviation (Curray, 1956 a., Fig. 8, p. 123). These data are summarized in table 2. The original measurement data are plotted as histograms in Figs. 11 to 16.

Tukey's istropicity test, which was applied on the orientation data, indicates significant departure from random orientation, at the 95% level, in all thin sections after at least 50 measurements.

Cumulative curves of the circular mean vector directions are graphically represented in Fig. 17. It appears that larger samples do not necessarily provide estimates of greater precision.

In the discussion about sampling, it was pointed out, that a homogeneous population may not be represented in a single thin section.

Thin Section	θ_m^o	L%	S^o	θ_m^o	L%	S^o	θ_m^o	L%	S^o	θ_m^o	L%	S^o
PS-8-59-b-II-3	191.0	44.8	37.0	180.5	48.1	136.0	181.1	40.0	38.8	179.4	36.5	40.0
PS-8-59-b-II-2	133.8	36.6	40.0	138.0	20.6	45.3	143.3	17.7	47.2	144.4	13.3	47.8
PS-8-59-b-II-1	137.7	26.6	43.3	137.3	25.0	43.8	142.8	23.3	44.8	141.6	23.2	44.5
$\bar{X}$	154.1	36.0	40.1	151.8	31.2	41.7	155.5	27.0	43.6	155.1	24.3	44.1
PS-8-59-b-III-3	190.3	26.0	43.5	182.1	20.3	45.5	196.1	28.3	47.8	173.0	25.7	43.4
PS-8-59-b-III-2	131.3	25.8	43.4	123.1	30.2	42.0	125.2	22.4	44.8	148.0	17.6	46.2
PS-8-59-b-III-1	151.3	65.5	28.0	149.0	58.8	32.0	152.9	57.4	32.7	156.2	49.9	35.3
$\bar{X}$	157.6	39.1	38.3	151.4	36.5	39.8	158.0	36.0	41.7	159.0	31.0	41.6
$\bar{\bar{X}}$	155.8	37.5	39.2	151.6	33.8	40.7	156.7	31.5	42.6	157.0	27.7	42.8

Table 2

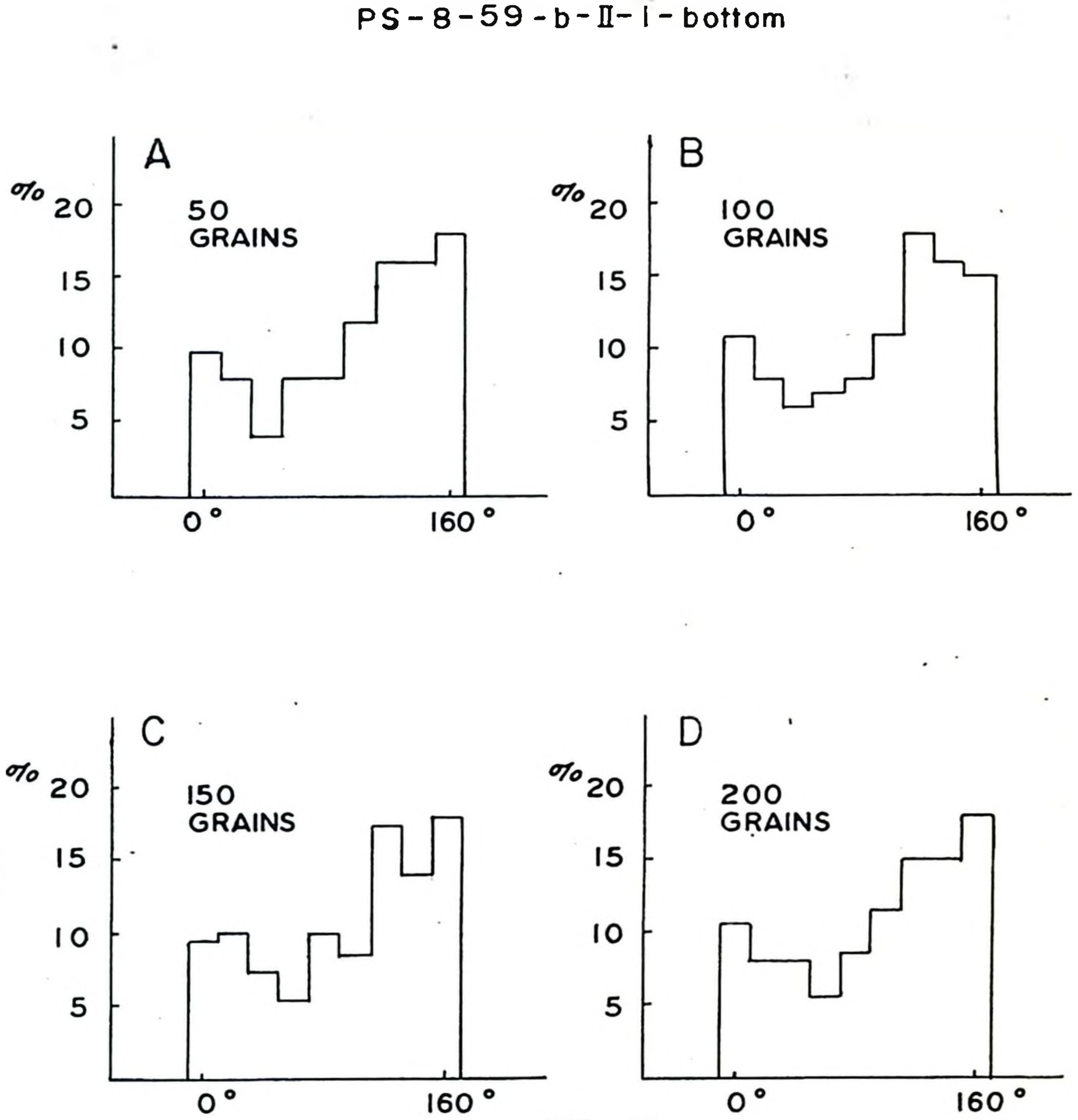


FIG. 11

FIGS. 11-16.- Histograms of the orientation distributions of the elongation of quartz grains, plotted after every 50 measurements. The ordinate is in terms of the percentage of the number of grains, and the class intervals along the abscissa are in steps of 20°, with mid points 0° to 160°. The original data of the orientation measurements have been used.

PS-8-59-b-II-2-middle

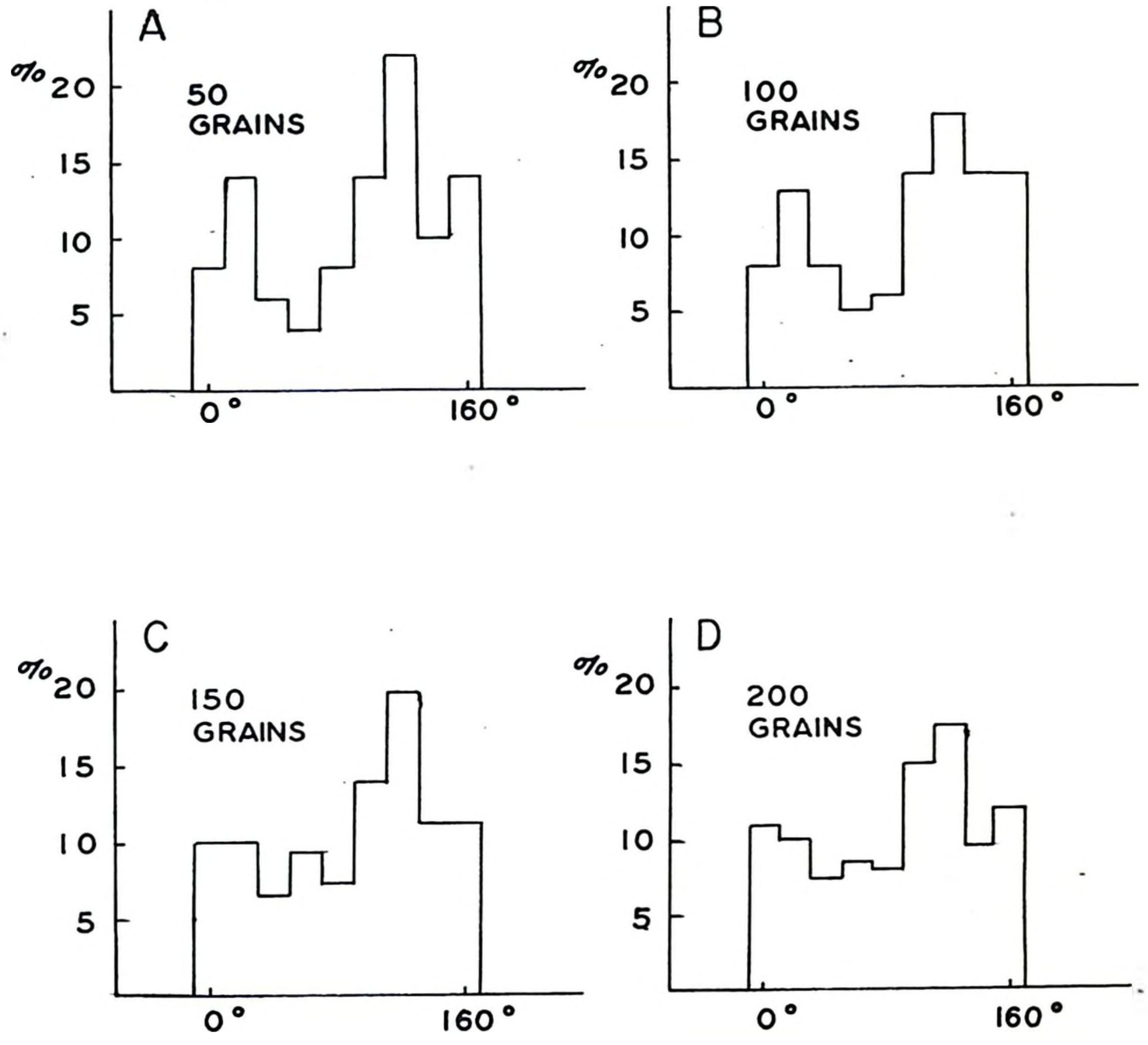
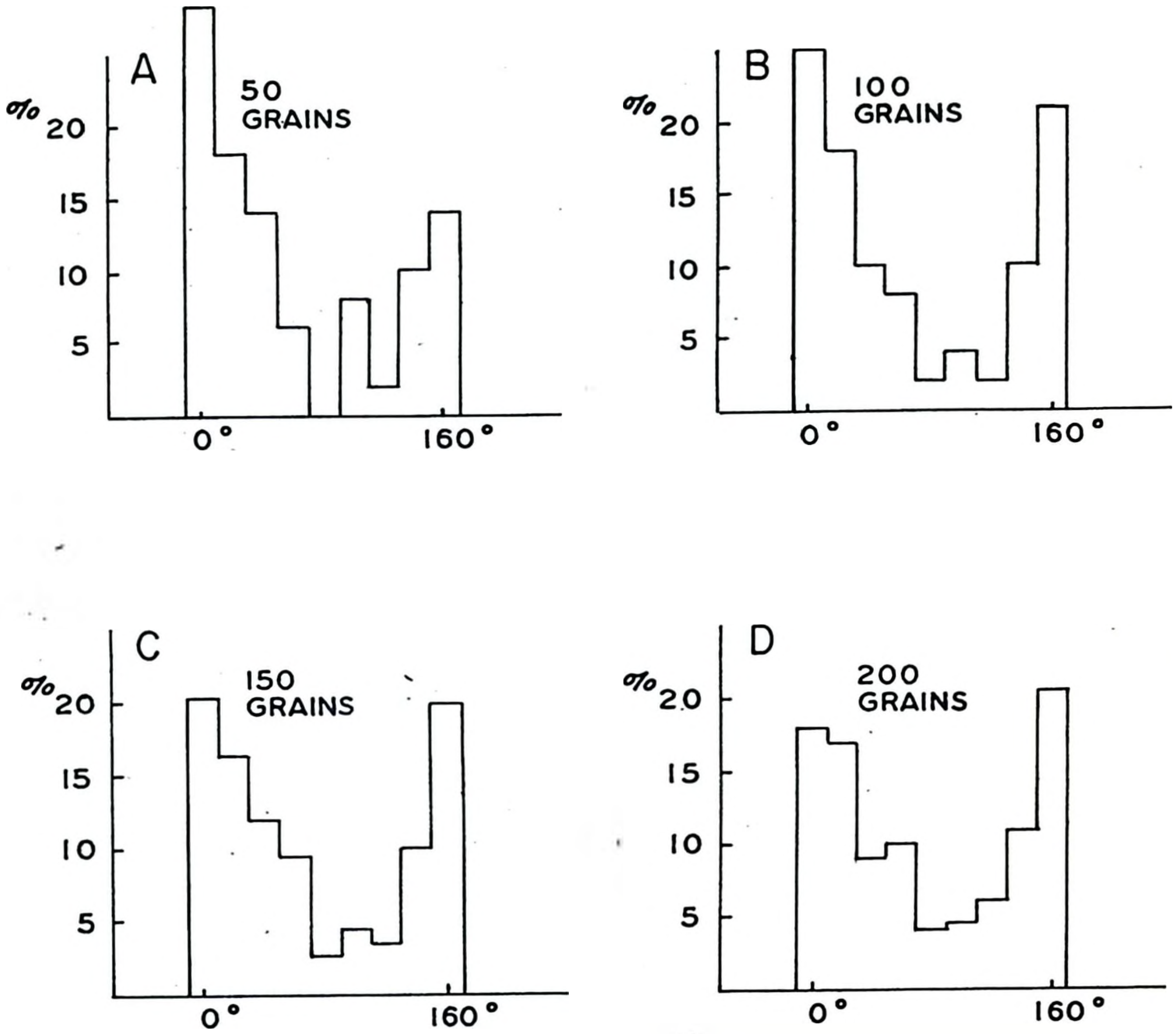


FIG. 12.



PS-8-59-b-II-3-top

FIG. 13

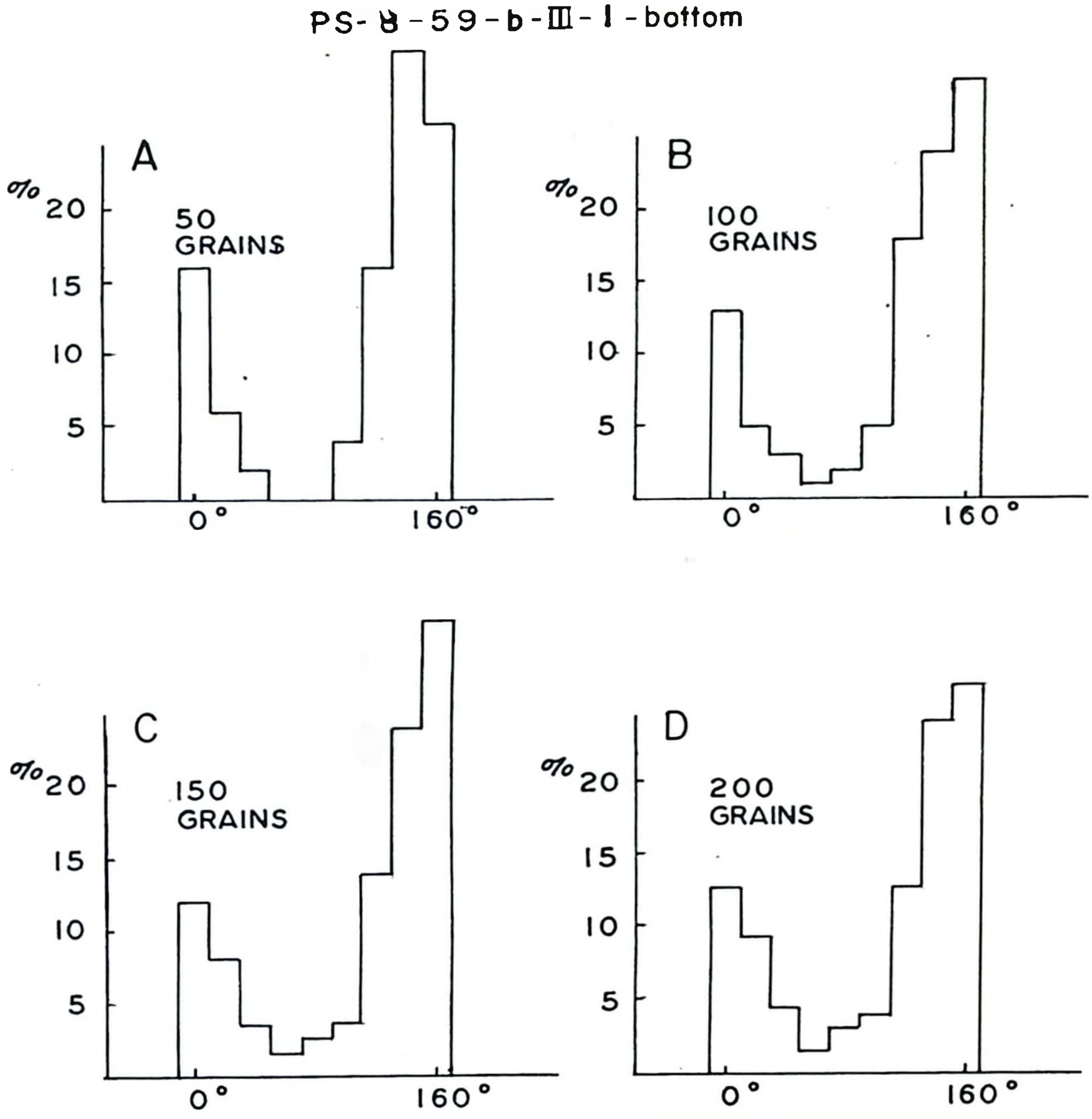

PS-8-59-b-III-1-bottom
A
%
20
15
10
5
50 GRAINS
0°
160°
B
%
20
15
10
5
100 GRAINS
0°
160°
C
%
20
15
10
5
150 GRAINS
0°
160°
D
%
20
15
10
5
200 GRAINS
0°
160°

FIG. 14

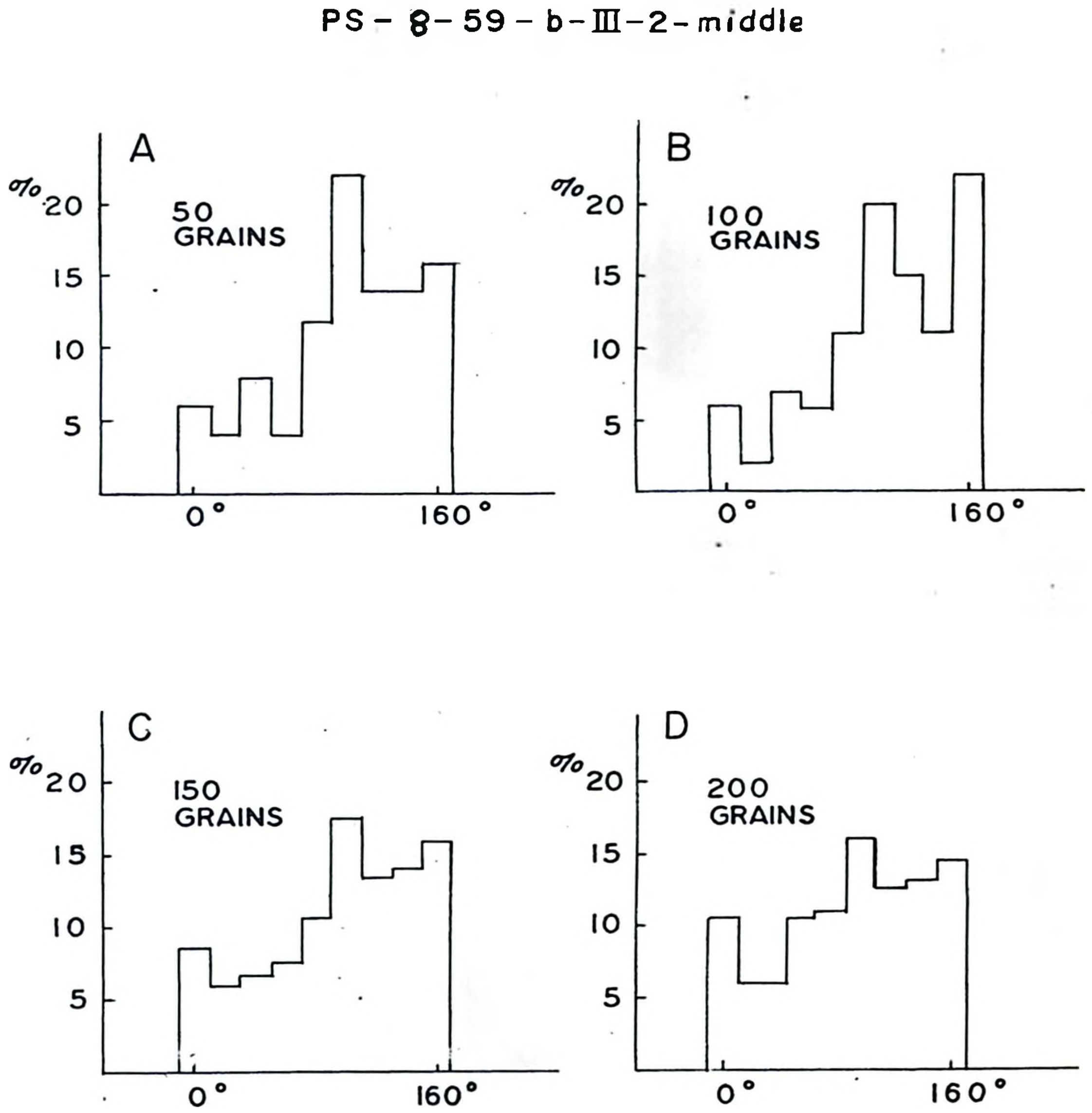

PS-8-59-b-III-2-middle
A
%
20
15
10
5
50 GRAINS
0°
160°
B
%
20
15
10
5
100 GRAINS
0°
160°
C
%
20
15
10
5
150 GRAINS
0°
160°
D
%
20
15
10
5
200 GRAINS
0°
160°

FIG. 15

PS - 8 - 59 - b - III - 3-top

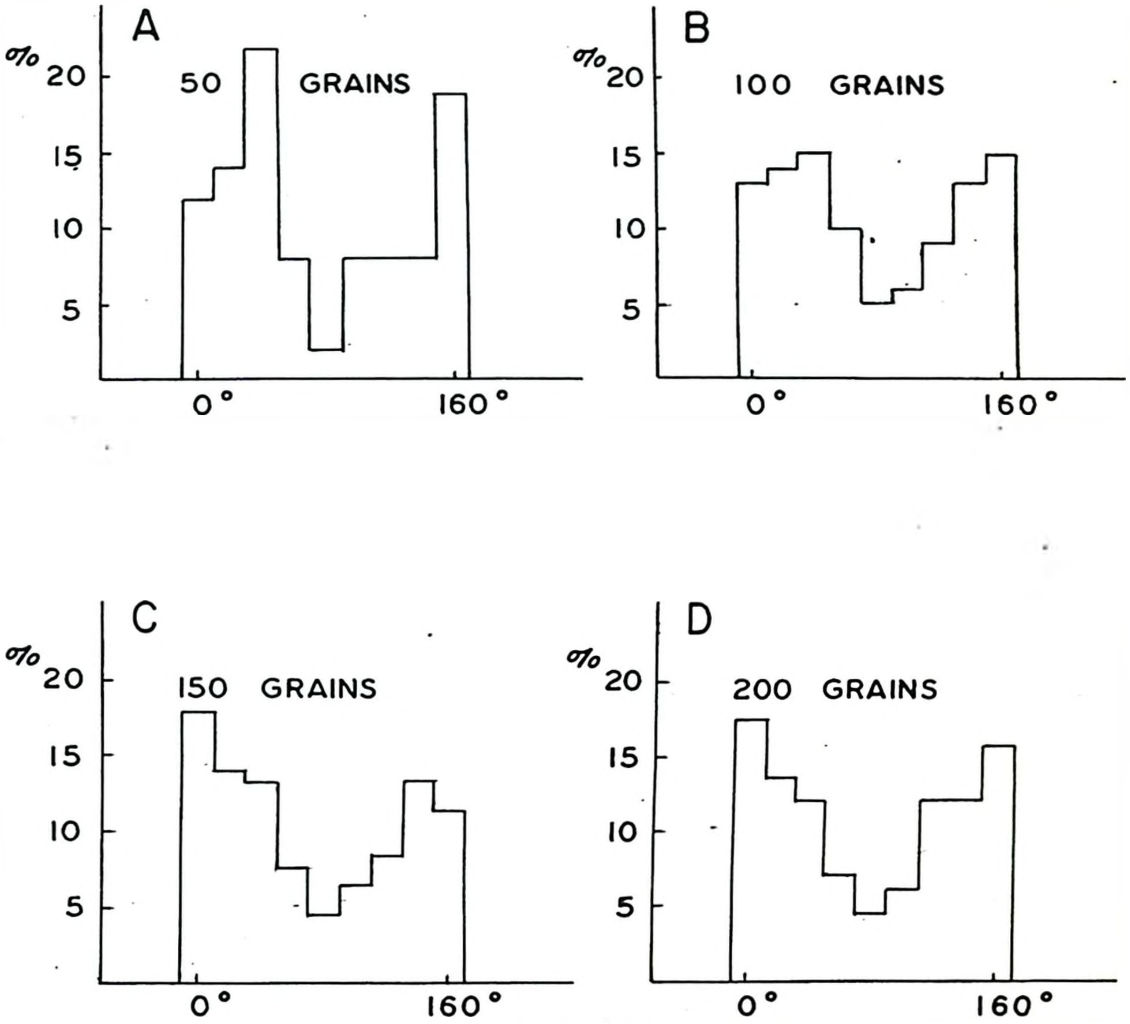


FIG. 16

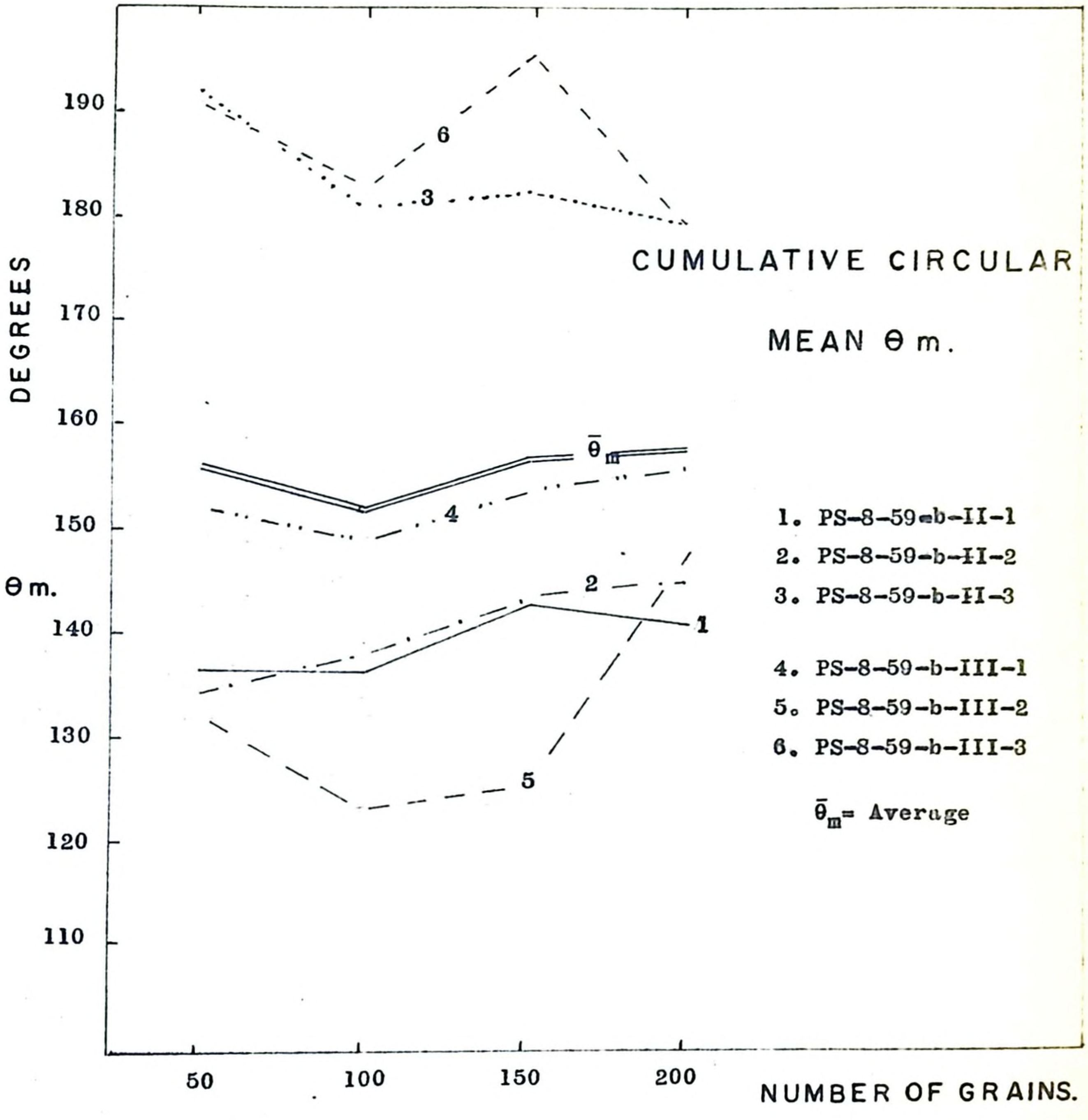


FIG. 17.- Cumulative circular mean orientation curves of 6 thin sections of bed PS-8-59-b of the Normanskill section. Data from table 2, page 30.

The problem with which we are dealing is to determine whether there are significant differences within a single thin section. In other words is it correct to assume that the grain azimuths are random samples from a homogeneous population.

Raup and Miesch (1957) have described a convenient method to determine the minimum number of directional measurements of cross bedding necessary in a certain area. This method can be applied directly to grain orientation measurements in thin section. Under the assumption that the grain orientation distribution is normal, the number of measurements needed to obtain a significant average direction is proportional to their variation. The estimated standard deviation of (say) the first 50 measurements is determined, from which the number of additional measurements can be computed. This number of additional measurements is required to obtain a circular mean of which one can be (say) 95% confident, that this mean falls within certain limits of precision. In other words, if this number is reached, one can be about 95% confident that the cumulative circular mean curve has reached its "flatness point" (Reiche, 1938). The number of additional measurements required beyond the first 50 to obtain a significant circular mean is given in table 3. For example in thin section PS-8-59-b-II-3 one can be 95% confident that the "true" average direction after 75 measurements lies within 200° and 182°.

The data in table 2 graphically represented in Fig. 17, however, seem to indicate that this is not the case in thin sections PS-8-b-111-2 and PS-8-59-b-1I1-3, indicating that these two thin sections probably do not represent homogeneous populations.

Thin section	2S	additional measurements required beyond 50.	total measurements	95% confidence limits of circular mean (degrees)
PS-8-59-b-11-3	74.0	25	75	±9°
PS-8-59-b-11-2	80.0	29	79	±9°
PS-8-59-b-11-1	86.6	34	84	±9°
PS-8-59-b-111-3	87.0	34	84	±9°
PS-8-59-b-111-2	86.0	34	84	±9°
PS-8-59-b-111-1	56.0	14	14	±7°

TABLE 3

In general an increase of measurements within the same thin section does not necessarily imply a decrease of the standard deviation. The circular means, however, appear to converge to the grand mean value of the circular means, approximating the value measured for the current direction (=155°). This might partly be due to the fact that after 200 measurements approximately the whole thin section was covered. Adequate thin section coverage and a large number of measurements will yield a more representative sample of the thin section population.

The number of grains and the number of thin sections required to obtain representative samples depend in general on:

(1) The texture of the sample: size and sorting, packing, orientation and possibly shape of the grains.

(2) The structural properties of the rock: presence of convolute lamination, slump structures, lensoid structures, load casting etc.

Large perturbations in the original orientation pattern can be expected if such structures are present in the graywacke bed. None of the samples collected showed any obvious major disturbances of this kind.

(c) Analysis of Operator Variation.

Besides the problem of sampling error, the question also arises how much variation is due to difference between operators. Griffiths and Rosenfeld (1953) point out that there are two possibilities involved in operator variation:

(1) Some operators tend to measure high values, other low values.

(2) Some operators are consistent, whereas others are inconsistent.

An analysis of variance includes the various possible sources of variation. Differences between thin sections, differences between operators and the inconsistency of the operators from thin section to thin section are the main effects (Griffiths and Rosenfeld, 1953). If the variation contributed by the inconsistency of operators from thin section to thin section, or by the interaction term of operators over thin sections, is high, the differences due to the other main effects must be large to be detected. The interaction term can therefore be used as an error term for thin sections and operators. Variations due to other unassigned errors, are a measure of error for the experiment as a whole.

Five operators designated as C, E, M, O and S examined the orientation of elongated quartz grains in two thin sections, PS-11-59-1-a(1) and PS-11-59-1-b(2). In an earlier experiment the presence of preferred orientation in both thin sections was demonstrated. Each operator selected 100 elongated grains per thin section by point counting, and measured the azimuth direction. The orientation data were rearranged around the grand mean value of the circular mean for each operator and each thin section (Table 6).

As the two thin sections were cut from two different levels of

SOURCE OF VARIATION	SUM OF SQUARES	D.F.	MEAN SQUARES	EXPECTED MEAN SQUARES	
				Type I	Type II
Thin sections (Rows)	$SSR=\sum_{1}^{r}(\sum_{1}^{cn} x)^2/cn-C.T.$	$(r-1)$	$MSR=\frac{SSR}{(r-1)}$	$\sigma^2+cn\sigma_r^2$	$\sigma^2+n\sigma_{rc}^2+rn\sigma_r^2$
Operators (Columns)	$SSC=\sum_{1}^{c}(\sum_{1}^{rn} x)^2/rn-C.T.$	$(c-1)$	$MSC=\frac{SSC}{(c-1)}$	$\sigma^2+rn\sigma_c^2$	$\sigma^2+n\sigma_{rc}^2+cn\sigma_c^2$
Interactions (Rows x Columns)	$SS(RC)=\sum_{1}^{rc}(\sum_{1}^{n} x)^2-C.T.-SSR-SSC$	$(r-1)(c-1)$	$MS(RC)=\frac{SS(RC)}{(r-1)(c-1)}$	$\sigma^2+n\sigma_{rc}^2$	$\sigma^2+n\sigma_{rc}^2$
Unassigned Errors	$SSE=SST-SSR-SSC-SS(RC)$	$(n-1)rc$	$MSE=\frac{SSE}{(n-1)rc}$	σ^2	σ^2
Total	$SST=\sum_{1}^{rcn} x^2-C.T.$				

Where $C.T.=(\sum_{1}^{rcn} x)^2/rcn$ and

r = number of thin sections (rows)
c = number of operators (columns)
n = number orientation measurements in each thin section

Error for the experiment is estimated by $\sqrt{EMS}$

Table 4.- Analysis of variance table of a two way crossed classification, type I and type II models.

SOURCE OF VARIATION	SUM OF SQUARES	D.F.	MEAN SQUARES	F	$F_{0.95}$	P
Thin sections (Rows)	287.2	1	287.2	0.121 NS	3.84	$0.50<P<0.75$
Operators (Columns)	15489	4	3872.25	1.635 NS	2.37	$0.75<P<0.90$
Interactions (Rows x Columns)	6333	4	1583.25	0.667 NS	2.37	$0.25<P<0.50$
Unassigned Errors	2347415.8	990	2371.12			
Total	2369525	999				

Pooled Error Mean Square = 236795 with 994 D.F.

Table 5. - Analysis of variance for the orientation of quartz grains in two thin sections, measured by 5 operators.

the same bed, the orientation measurements were arranged in a natural design at the intersection of rows (= thin sections) and columns (= operators). The orientation distributions are graphically represented by histograms in Fig. 18. The whole experiment can be summarized in the form of a mathematical model (Table 4), which indicates the steps to be taken in the analysis of variance. For details of the analysis of variance technique the reader is referred to one of the standard texts (e.g. Dixon and Massey, 1957, p. 139 - 152). The results of the computations in numerical form are given in Table 5.

The test of the analysis of variance consists of an attempt to disprove the following hypothesis:

H_1: There is no interaction, operators are consistent from thin section to thin section.

H_2: Thin section effects are zero.

H_3: Operator effects are zero.

In an analysis of variance of type I model, the interaction is tested against the error term, assuming that the contribution to variance from the inconsistency of operators does not exceed the contribution from the error term. The variance ratio yields an F-value of 0.667. The tabulated value of the F-distribution (Dixon and Massey, 1957, Rable A7 c, p. 390 - 403) list a value of 2.37 at the 95% level for (4,990) degrees of freedom. We expect the variance ratio exceeded in some 5 cases out of every 100 on average, even in random sampling from a homogeneous population. The observed value 0.667 is therefore likely to occur more frequently, in effect in more than 50, but in less than 75 cases out of one hundred ($0.50 < P < 0.75$).

On the basis of this test where we accept H_1, we may infer that the interaction term is an independent estimate of the error term; we may therefore pool the two terms to obtain a more efficient estimate. As the interaction term and the error term are estimates of the same population value, the pooled error becomes our basis for testing. Testing hypotheses H_2 and H_3, no significant differences between thin sections and between operators are found. In other words, the measurements of the thin sections by each of the 5 operators, represent in fact samples of the same population. One may therefore conclude from this experiment that the determination of orientation of elongated quartz grains in this example is not affected by the level from which the thin section was cut. Neither is it affected by the variations from operator to operator. It is, however, notable that this experiment suggests, that operator error is larger than thin section error.

If the operators are considered to be random samples of all possible operators, the type II model of the analysis of variance has to be used (Dixon and Massey, 1957, p. 174 - 177). Testing both hypotheses H_1 and H_2 in this model indicates that thin section and operator error are also non significant.

The error of the circular mean preferred orientation θ_m of the different operators is expressed by the confidence limits within which (say) 95% of all future determinations of θ_m made by the same operator on the same slide will be. The grand mean $\bar{\theta}_m$ of all operator means of the same thin section is the best possible estimate for the mean of the hypothetical population of 100 accurately measured azimuth directions in that thin section. The circular means and dispersions of each operator

FIG. 18

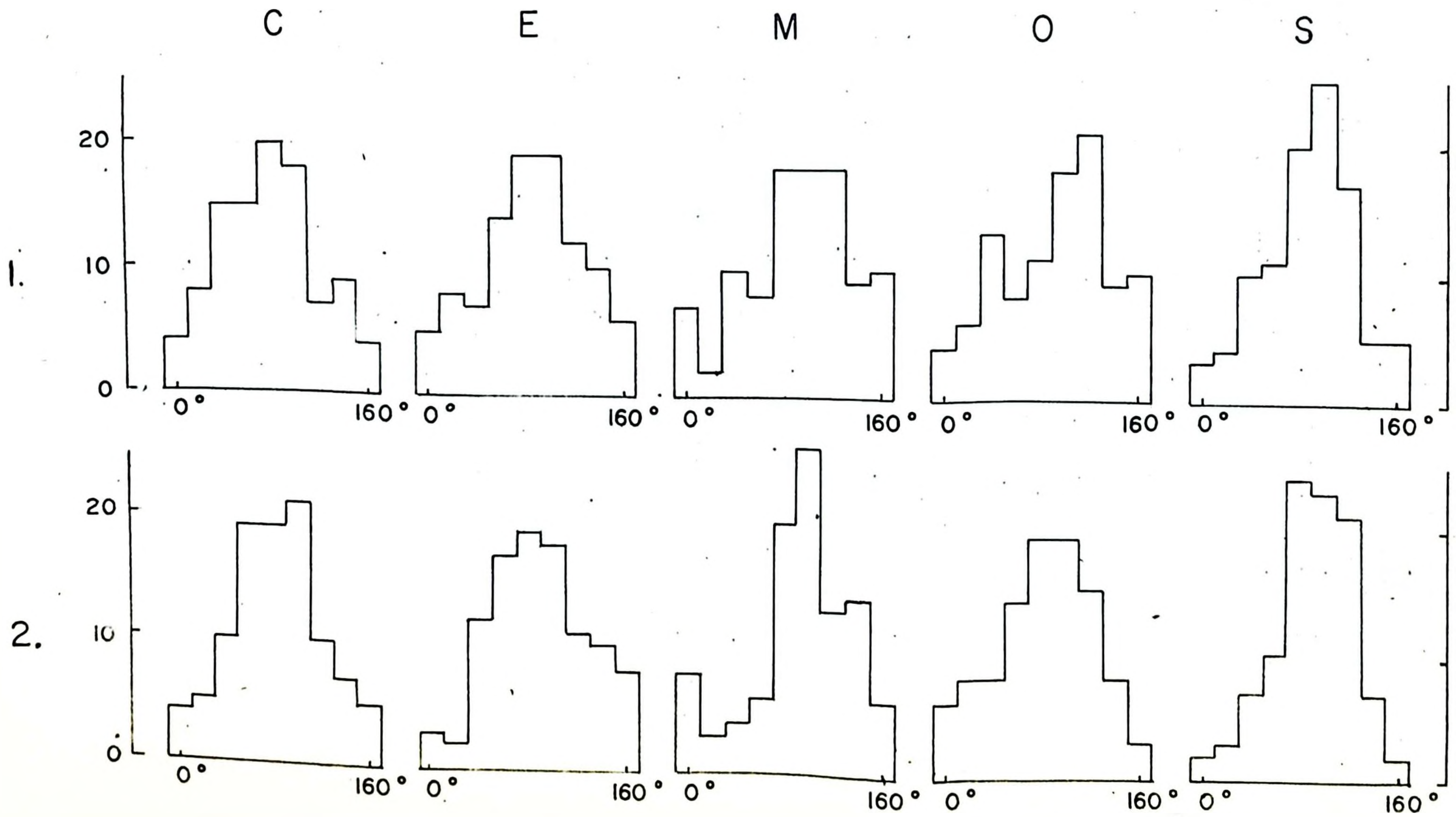


FIG. 18.- Orientation frequency histograms of two thin sections, PS-11-59-I-a, and PS-11-59-I-b, resp. (1) and (2), for 5 operators.

for each thin section is summarized in Table 6.

Operators	PS-11-59-1-a		PS-11-59-1-b	
	θ_m°	L%	θ_m°	L%
C	255.3	33.47	262.0	38.81
E	269.9	30.03	266.9	36.19
M	282.5	30.15	284.9	40.01
O	284.7	24.91	267.9	33.10
S	271.7	43.87	274.7	52.11
Average $\bar{\theta}_m$	272.8	32.49	271.3	40.04

Table 6

The confidence intervals of the overall mean, assuming only random errors, indicating how sure one can be that the true population mean θ_m is known from $\bar{\theta}_m$, are given by the formula:

$$(1) \qquad \bar{\theta}_m \pm \quad t_{N-1,\, 1-\alpha/2} \cdot \quad S/\sqrt{N}$$ (Dankier, unpub.)

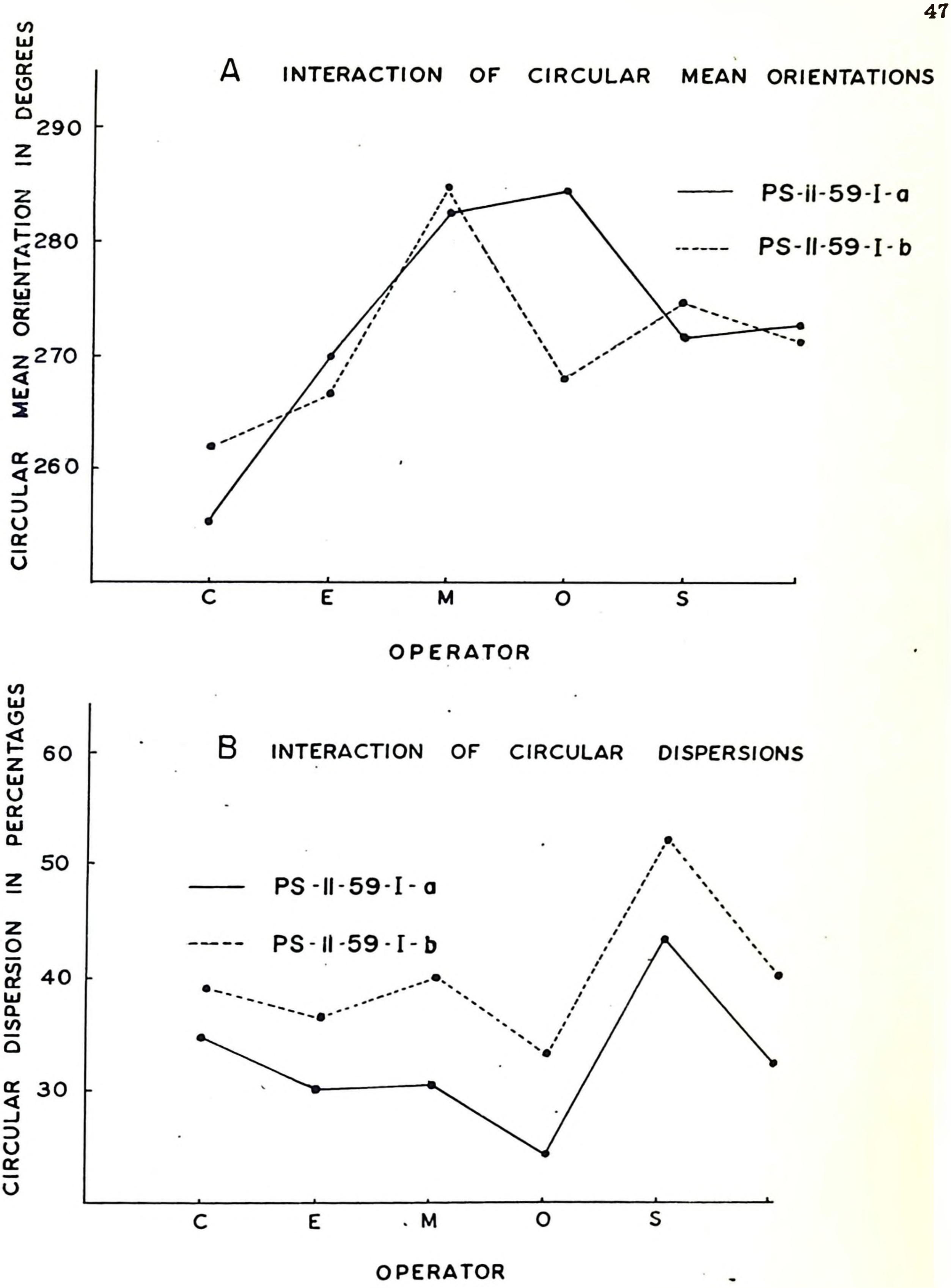
where N = number of operators

S = standard deviation

The t-distribution can be determined from tables in one of the statistics texts (e.g. Dixon and Massey, Table A-5, p. 384).

In thin sections PS-11-59-1-a and PS-11-59-1-b these intervals at the 95% level of probability are respectively 272.8° ± 14.6° and 271.3° ± 10.9°.

For the purpose of this investigation, however, one is more interested in the limits within which 95% (say) of all future determin-



FIGS. 19 A and B.- Interactions thin sections x operators, for circular mean orientations (A), and for circular dispersions (B).

ations of θ_m, made on the same thin sections by other operators, will fall. These confidence limits are given by the formula:

$$(2) \qquad \theta_m \pm t_{N-1,\ 1-\alpha/2} \cdot s\sqrt{\frac{N+1}{N}}$$

(Bankier, unpublished)

In thin sections PS-11-59-1-a and PS-11-59-1-b these limits are respectively 272.8° ± 32.6°, and 271.3° ± 26.8°.

The analysis of variance test indicated that the interaction term, operators over thin sections, was not significant in this experiment. In Figs. 19A and B the interaction is graphically represented by plotting the values of the circular means and the measures of dispersion against operators. Although only two thin sections were examined it is of interest to note that operators C and E remain consistently below the mean orientation value, whereas operator M remains consistently above the mean value. Operators C, E, M, and S have consistently lower values for thin section PS-11-59-1-a than PS-11-59-1-b, whereas operator O is inconsistent. Operator S shows remarkably less dispersion than the other 4 operators. It appears therefore that S was slightly biased in selecting the grains and measurement of the grains. All the operators appear to be consistent in dispersion.

(d) Duplication analysis.

In order to investigate the analytical error within one operator for the same thin section, the following experiment was designed.

Five thin sections were analyzed in duplicate by the same operator, the duplicate analyses being separated by a time interval

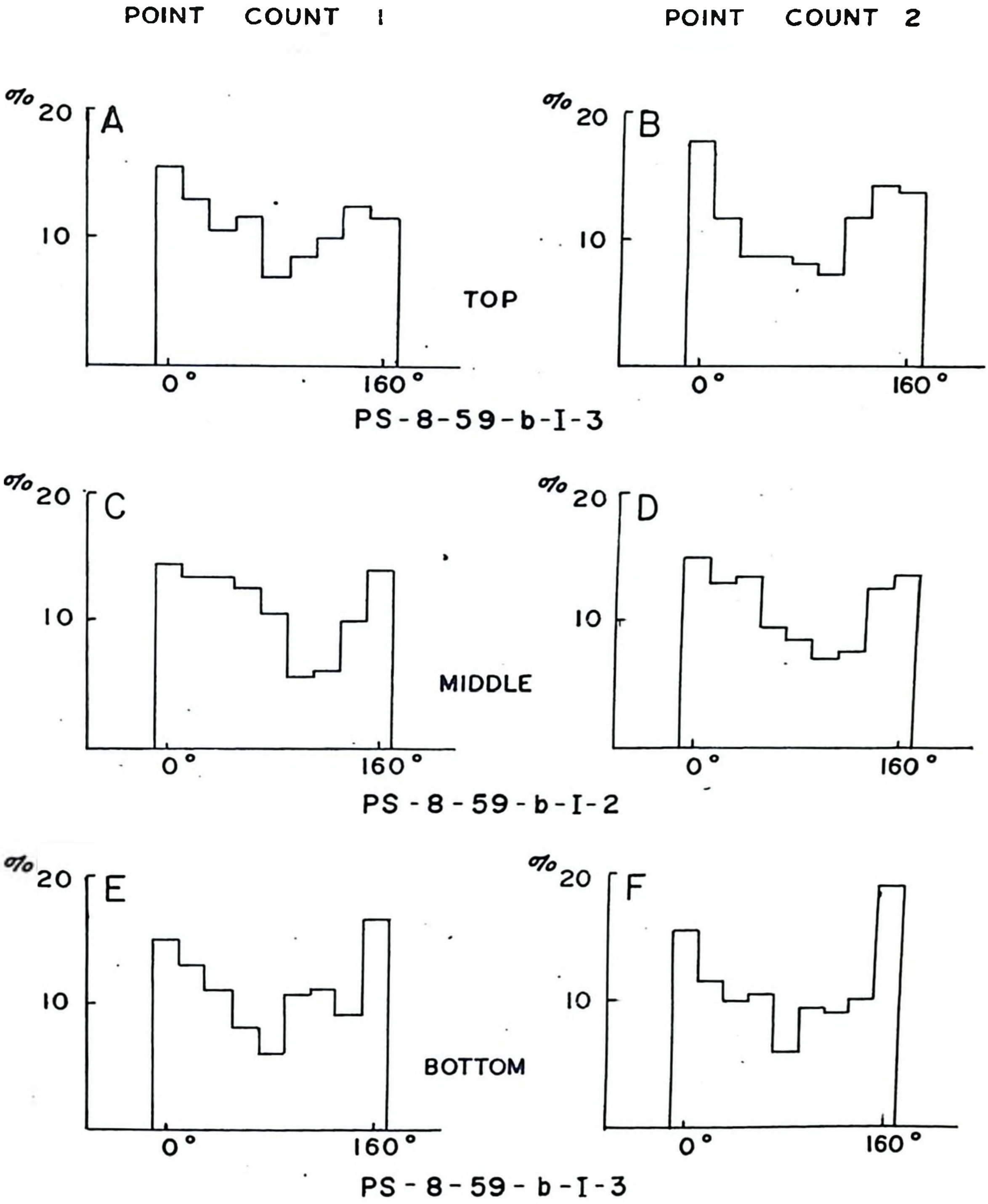


FIG. 20.- Frequency histograms of duplicate orientation analysis of three thin sections of bed PS-8-59 of the Normanskill section.

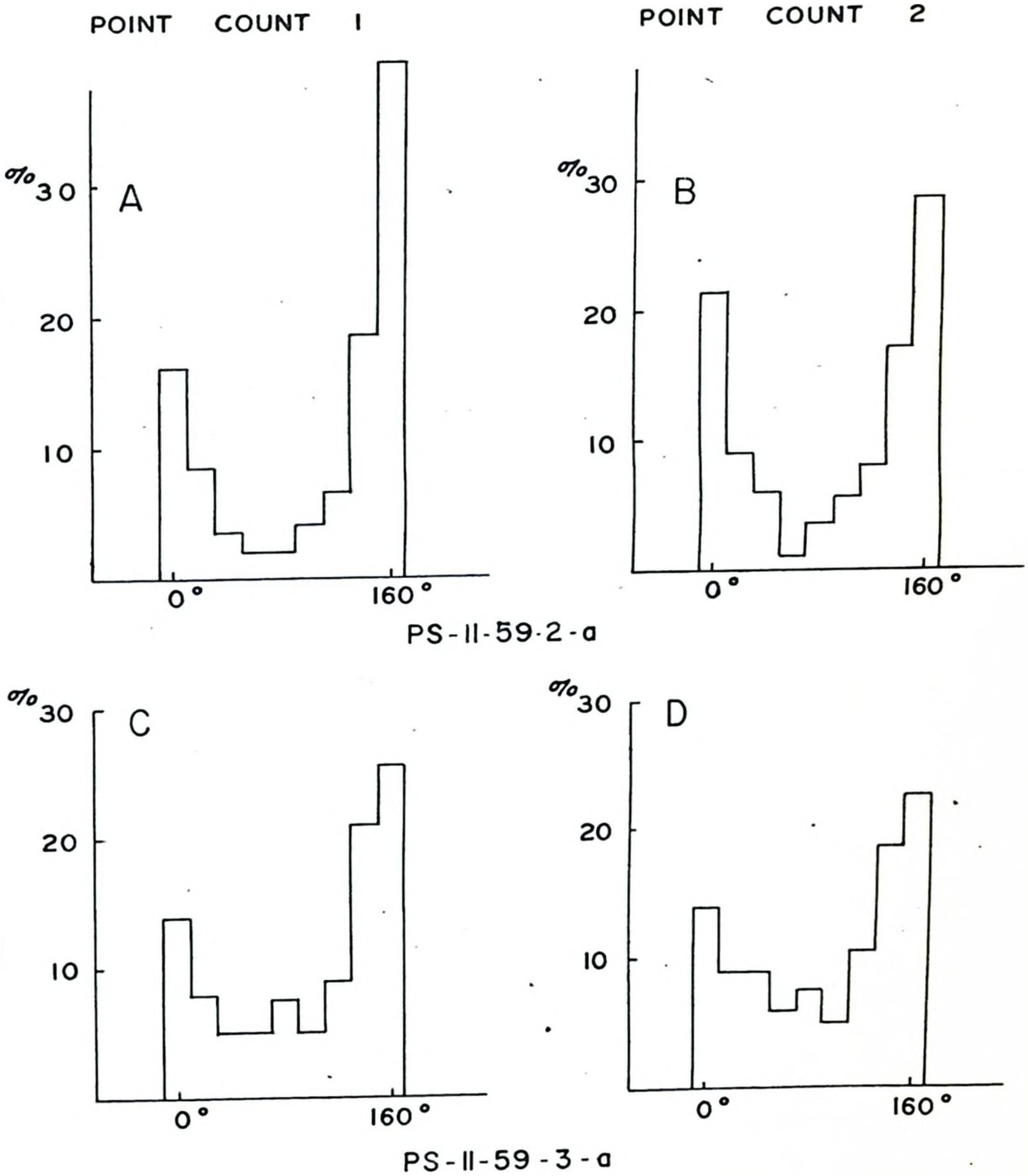
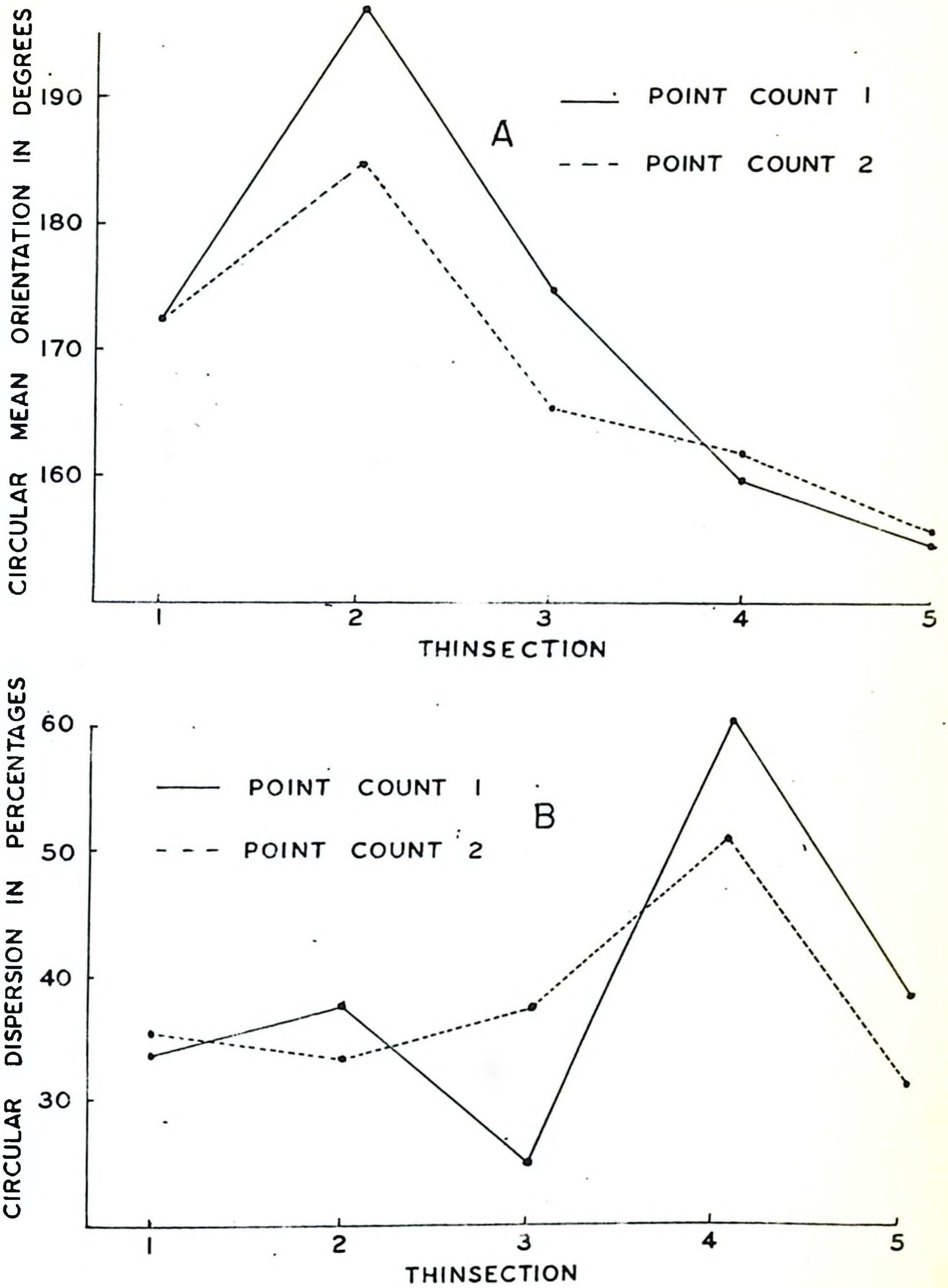


FIG. 21.- Frequency histograms of duplicate orientation analyses of two thin sections of bed PS-11-59 of the Austin Glen section.



FIGS. 22 A and B.- Cumulative circular means and dispersions of duplicate orientation analyses for 5 thin sections.

of several weeks.

(1) Three thin sections, PS-8-59-b-I-1, PS-8-59-b-I-2 and PS-8-59-b-I-3, respectively from the bottom, the middle and the top of the same bed of the Normanskill formation (fine grained rock).

(2) Two thin sections, PS-11-59-II-a and PS-11-59-III-a from a coarser grained bed of the Austin Glen section, both from the bottom of the same bed.

In each thin section the orientation of 200 grains, selected by point counting was measured. The orientation distributions of each thin section for each point count are graphically represented by histograms in Figs. 2~~2~~0 and 2~~3~~1. The computed circular means and dispersions are given in Table 7.

Thin section	Point Count (1)		Point Count (2)	
	θ_m	L	θ_m	L
1.PS-8-59-b-I-1	172.8	33.3	172.2	35.3
2.PS-8-59-b-I-2	197.1	37.5	185.0	33.4
3.PS-8-59-b-I-3	175.0	25.0	165.7	37.4
4.PS-11-59-II-a	159.9	60.5	161.9	51.1
5.PS-11-59-III-a	154.4	38.1	156.7	31.3

Table 7.

The data in Table 7 are plotted in Figs. 2~~3~~2A and B, and show that the circular means of both analyses are consistent within 15°. The 95% confidence intervals for the circular mean differences are respectively $^{+}11.85^{\circ}$ and -4.77°. The 95% confidence intervals for the mean differences between the dispersions of both analyses are respectively $+8.75^{\circ}$ and -7.54°. The measures of dispersion seem to be more inconsistent in the finer grained sample than in the coarser grained sample.

(e) Variation within beds.

The results in Table 2 (p. 30) suggested that the vertical variation within bed PS-8-59-b of the Normanskill section, especially differences between the top and the bottom part might be larger than the lateral variation.

The following bed samples of three different localities were investigated to analyze these variations within one bed sample.

(1) Q-I. A fine medium grained graywacke from the Sillery formation of the Quebec Group, St. Fabien $^{S}/_{M}$, P.Q.
(15 thin sections)

(2) PS-8-59-b. A fine grained sample of the Normanskill formation of the type section, Kenwood, S. of Albany, N.Y.
(6 thin sections)

(3) PS-11-59. A medium to coarse grained sample from the Normanskill formation, of the Austin Glen Section, Catskill, N.Y.
(6 thin sections)

200 grain orientations of grains selected by point counting were measured in each thin section. The thin sections were cut in a natural arrangement, designated as rows and columns. Differences between column data reflect lateral variations and differences between row data, vertical variations.

An analysis of variance of two way classification with single observation can be applied on the circular means of each thin section. This experiment can be summarized in a mathematical model of the analysis of variance Type I and II (Table 8).

SOURCE OF VARIATION	SUM OF SQUARES	D.F.	MEAN SQUARES	EXPECTED MEAN SQUARES (type I and II)
Row means	$SSR=\sum_{1}^{r}(\sum_{1}^{c}X)^{2}/c-C.T.$	$(r-1)$	$MSR=\frac{SSR}{(r-1)}$	$\sigma^{2}+r\sigma_{c}^{2}$
Column means	$SSC=\sum_{1}^{c}(\sum_{1}^{r}X)^{2}/r-C.T.$	$(c-1)$	$MSC=\frac{SSC}{(c-1)}$	$\sigma^{2}+c\sigma_{r}^{2}$
Residual error	$SSE=SST-SSR-SSC$	$(r-1)(c-1)$	$MSE=\frac{SSE}{(r-1)(c-1)}$	σ^{2}
Total	$SST=\sum_{1}^{rc}X^{2}-C.T.$	$(rc-1)$		

Where $C.T. = (\sum_{1}^{rc}X)^{2}/rc$ and r = rows

c = columns

Table 8.- Mathematical model of an analysis of variance table of two way classification with single observation.

The following two hypotheses will be tested:

H_1: The r rwo effects are zero; no vertical variation

H_2: The c column effects are zero; no lateral variation

(i) Quebec Group Bed Sample

15 thin sections were cut from 5 columns and three rows of the same bed, 6 cm apart in the horizontal and 6 cm apart in the vertical direction. The circular mean orientations of these thin sections are arranged at the intersections of rows and columns for statstical evaluation of differences between rows, and differences between columns (Table 9A). The analysis of variance of these data is given in Table 10A. Both lateral and vertical variations are insignificant in a type I and type II model test.

Tukey's isotropicity test showed that significant departure (at 95% level) from random orientation is present in all thin sections. This is also suggested by the shape of the histograms (Fig. 23). The current direction measured from the azimuth of the flute casts on the bottom surface of the bed is 155°. All the circular means orientations of the quartz grains, determined in the 15 thin sections of this sample are within 15% of this value. The dispersion data, which are also given in Table 9A, appear to be fairly consistent.

(ii) Normanskill Section Bed Sample

Similarly 6 thin sections were cut from two columns, 15 cm apart, of bed PS-3-59-b of the Normanskill Section. Of each column, 3 thin sections, approximately 4 cm apart in the vertical direction were cut, one from the bottom, one from the middle and one from the top part of the bed (rows). Analysis of variance of the circular mean orientations arranged at the intersections of tows and columns (Table 9B), indicates that

	Columns	Q-I-1		Q-I-2		Q-I-3		Q-I-4		Q-I-5			
	Rows	θ^o_m	I%	θ^o_m	I%	θ^o_m	I%	θ^o_m	I%	θ^o_m	I%	$T_{.j.}$	$\bar{\theta}^o_m$
	c	156.6	40.1	169.7	32.1	164.9	38.6	165.4	31.6	158.6	35.4	817.4	160.3
9A	b	160.5	40.2	162.8	29.5	158.6	40.5	173.4	31.0	159.0	31.9	814.3	162.8
	a	156.6	41.7	156.5	37.2	171.8	36.1	174.6	38.7	142.7	40.8	802.4	160.4
	$T_{i..}$	475.7		489.1		495.3		513.5		460.4		2434.1	
	$\bar{\theta}^o_m$	158.6		163.0		165.1		171.1		153.4			161.2

		PS-8-59-b-II		PS-8-59-b-III			
		θ^o_m	I%	θ^o_m	I%	$T_{.j.}$	$\bar{\theta}^o_m$
	3	179.4	36.5	173.0	25.7	372.4	176.2
9B	2	144.4	13.3	148.0	17.6	292.4	146.2
	1	141.7	23.2	156.4	49.9	298.1	149.0
	$T_{i..}$	465.5		477.4		942.9	
	$\bar{\theta}^o_m$	155.2		159.1			157.1

		PS-11-59-II		PS-11-59-III			
		θ^o_m	I%	θ^o_m	I%	$T_{.j.}$	θ^o_m
	c	141.7	41.7	156.2	40.9	318.6	159.3
9C	b	141.6	52.8	143.4	41.6	285.0	142.5
	a	161.9	51.1	156.7	31.3	298.0	149.0
	$T_{i..}$	445.3		456.4		901.7	
	$\bar{\theta}^o_m$	148.4		152.1			150.3

Tables 9A, 9B and 9C.–

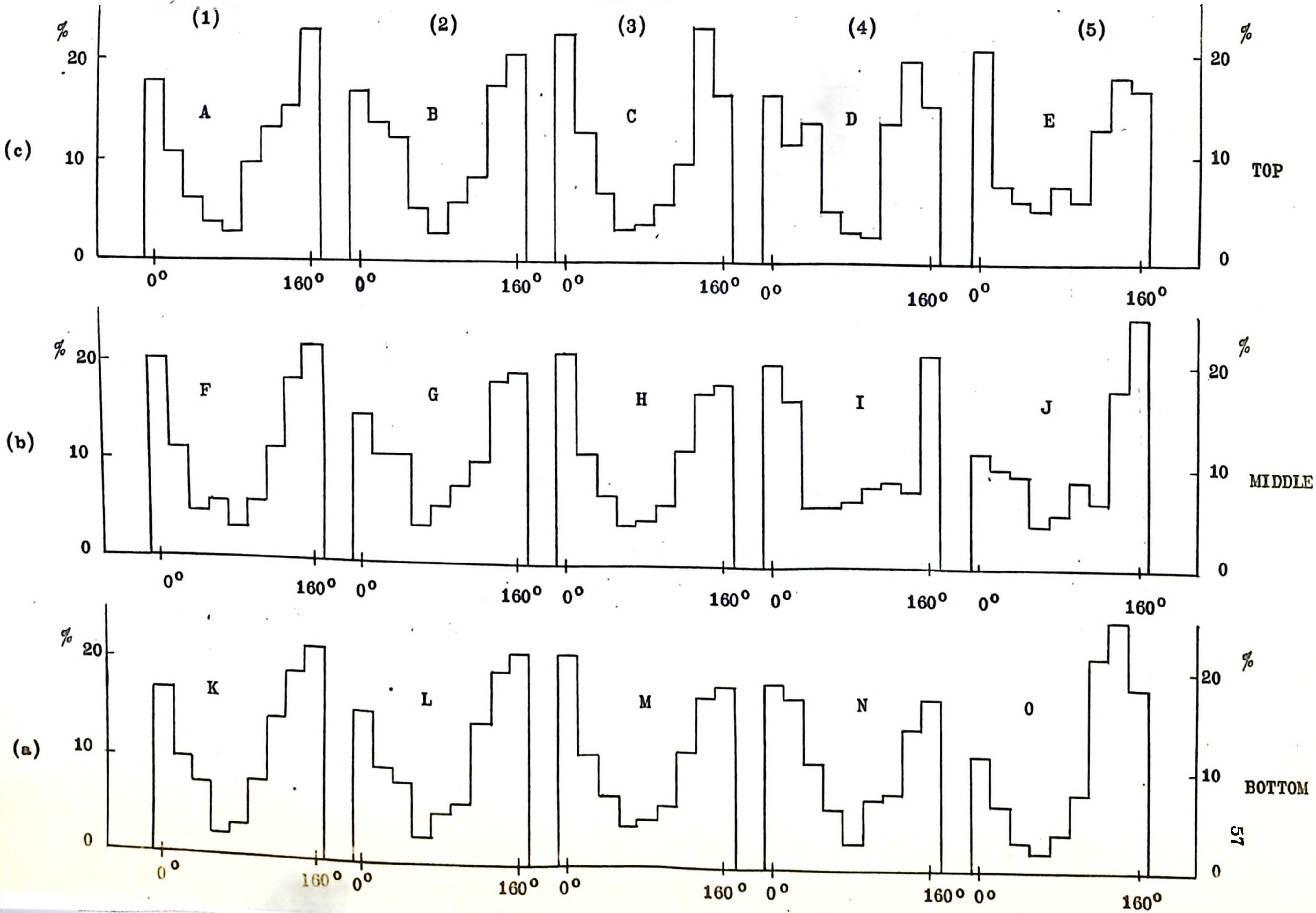
Circular mean preferred orientations and dispersions for each row, and each column of 15 thin sections from the Quebec Group (A), 6 thin sections from the Normanskill section(B), and 6 thin sections from the Austin Glen section (C).

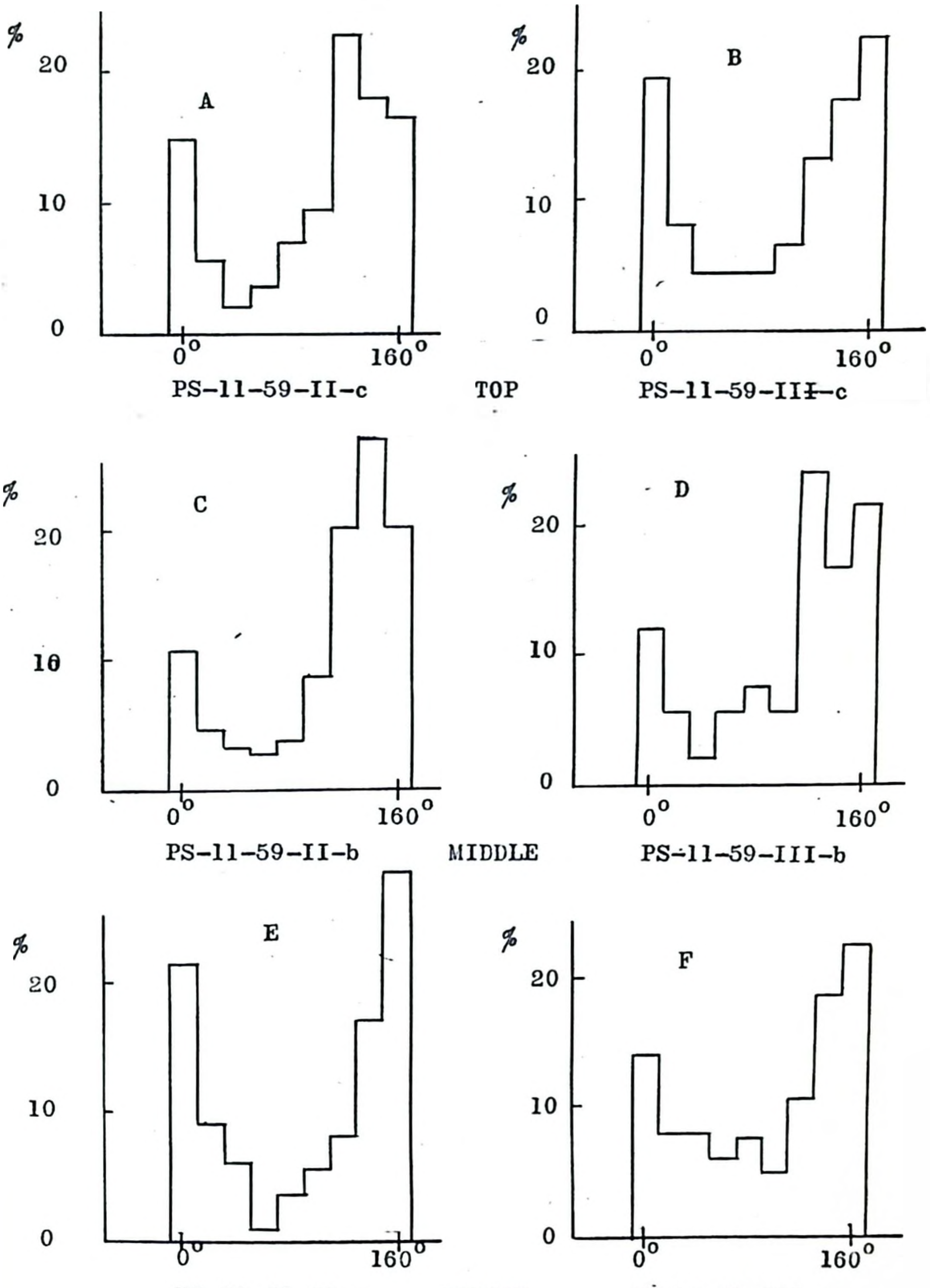
VARIATION WITHIN BEDS

FIG. 23.- Orientation frequency histograms for 15 thin sections of the same bed; Quebec Group, St. Fabien ^{s}/M., P.Q..

FIG. 24.-Orientation frequency histograms for 6 thin sections of the same bed; Normanskill formation, Austin Glen section.

FIG. 23





PS-11-59-II-c TOP PS-11-59-III-c

PS-11-59-II-b MIDDLE PS-11-59-III-b

PS-11-59-II-a BOTTOM PS-11-59-III-a

FIG. 24.- Orientation frequency histograms for 6 thin sections of the same bed; Austin Glen section.

	SOURCE OF VARIATION	SUM OF SQUARES	D.F.	MEAN SQUARES	F	$F_{0.05}$	P
	Row Means	15.36	2	7.68	0.139 NS	4.46	0.10<P<0.25
10A	Column Means	489.16	4	122.29	2.22 NS	3.84	0.75<P<0.90
	Residual	440.60	8	55.07			
	Total	945.60 945.12	14				
	Row Means	1096.83	2	584.41	14.769 S	9.55	0.95 < P < 0.95
10B	Column Means	23.6	1	23.6	0.635 NS	10.10	0.50 < P < 0.75
	Residual	111.41	3	37.13			
	Total	1231.84 ✓	5	246.36			
	Row Means	286.43	2	143.21	13.56 S	9.55	0.95 < P < 0.975
10C	Column Means	20.35	1	20.35	1.92 NS	10.10	0.50 < P < 0.75
	Residual	31.68	3	10.56			
	Total	338.46 ✓	5				

Table 10 A, B and C. – Analysis of variance tables of the circular mean preferred orientations of 15 thin sections of the Quebec Group sample (A),6 thin sections of the Normanskill section (B), and 6 thin sections of the Austin Glen section (C).

S = Significant
NS= Non Significant

vertical variation is significant at the 95% level(Table 10B). No lateral variation however, can be detected at the 95% level. The circular means of the bottom and the middle of the bed are all within 15% of the current direction measured from flute casts. The two thin sections of the upper part of the bed are respectively outside (179.4°) and barely within (173.0°) 20% from 155°. (see also Fig. 17). The differences between the mean preferred orientations of the quartz grains in the upper part of the bed and the middle and lower part suggest the possible existence of a separate "sedimentation unit" in the upper part of the bed. This might be explained by "resedimentation processes" in the upper part of the bed after deposition, or by deviating current directions in the "tail" of the turbidity current.

(iii) Austin Glen Section Bed Sample

6 thin sections of bed PS-11-59, ~~b~~cut in the same way as the Normanskill Section Bed Sample, were also analyzed. The statistical parameters Θ_m and L are summarized in Table 9C,. Analysis of variance of the circular means suggests significant vertical and no significant lateral variation (Table 10C). The circular mean orientations in all thin sections are within 15% of the current direction, measured from the flute cast measurements. No specific trends regarding the circular dispersions can be found in the two latter samples.

(f) Determination of transport direction by grain orientation analysis.

Sand grain orientation analysis to determine the direction of transport is useful where the paleocurrent system can not be determined by other means.

Thin section	Locality	Derivation (in degrees)		L%	Tukey's Chi-square	P
1. PS-4-59-1	N. Germantown*	199.16	SSW	36.0	51.75	0.001
2. PS-4-59-2	N. Germantown*	187.30	S	23.2	17.35	0.001
3. PS-6-59-2	Chittenden Falls*	201.25	SSW	13.3	7.38	$0.05 < P < 0.01$
4. PS-6-59-6	Chittenden Falls*	218.35	SW	26.2	29.04	0.001
5. PS-7-59-1	Stockport Falls	179.00	S	37.7	59.39	0.001
6. PS-8-59-c-6	Normanskill Cr.	233.00	SW	44.1	39.76	0.001
7. PS-9-59-a-9	Normanskill Cr.	210.00	SSW	32.7	19.05	0.001
8. PS-8-59-c-1	Normanskill Cr.	171.25	S	30.0	15.26	0.001
9. PS-8-59-c-2	Normanskill Cr.	175.25	S	40.4	33.31	0.001
10. PS-10-59-b-1	New Baltimore*	162.50	SSE	29.5	34.47	0.001
11. PS-10-59-b-2	New Baltimore*	148.80	SSE	22.1	9.14	$0.05 < P < 0.01$

Table 11.–Preferred grain orientation direction of 11 thin sections from different beds of the Normanskill graywackes. Asterisk indicates that no other current measurements were made.

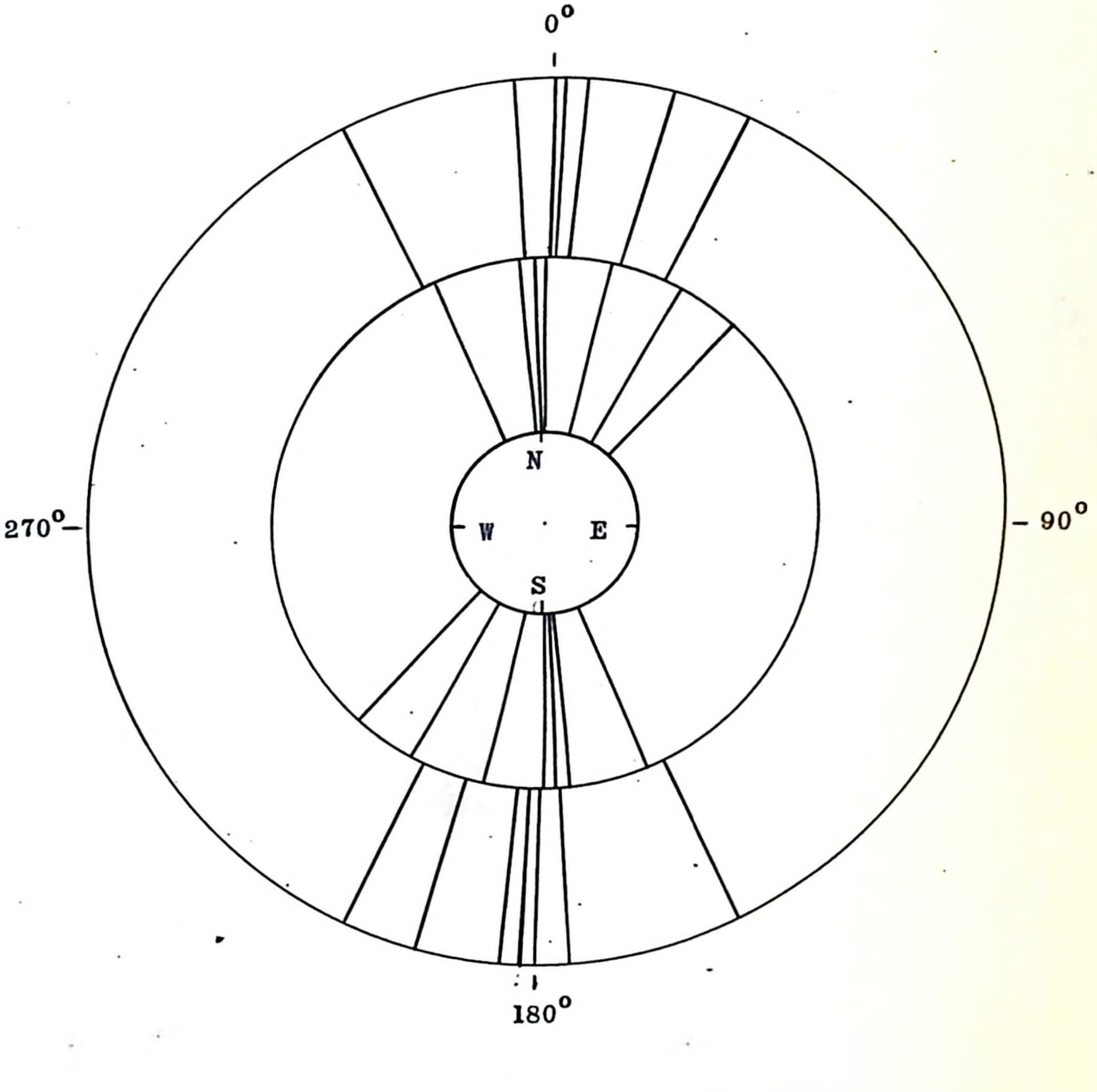


FIG. 25.- Current directions in the Normanskill graywackes as indicated by the flute casts (outer circle), and by the preferred orientation of the quartz grains in thin section (inner circle). Each line represents the average direction in one locality (flute casts), or in one bed (thin sections).

A number of thin sections from different localities have been analyzed to demonstrate the applicability of the depositing current. Only in two localities, Stockport Falls and the Normanskill section, were orientation measurements from other beds available.

The results of the orientation analysis of 200 grains, selected by point counting in each thin section, are summarized in Table 11. The orientation data are given in terms of the true azimuth with respect to the North direction (= 0°).

The current direction data of the Normanskill Graywackes as indicated by both the flute marks and the preferred orientation of the elongated quartz grains of all the thin sections investigated (Fig. 25), are remarkably uniform and show a predominant SSW direction of movement of the transporting current.

(g) Dimensional fabric analysis and its relationships to size and shape measurements in thin section.

Petrographic investigation of a number of thin sections of the Normanskill Graywackes has indicated that preferred orientation of elongated grains is very likely not only restricted to thin sections parallel to the bedding.

The analysis of grain orientation has shown that definite relationships can be established between the preferred lineation and the flow direction of the turbidity current. It is therefore not unlikely that preferred alignment of elongate grains is also present in thin sections cut in different directions with respect to the bedding plane.

Imbrication of pebbles of fluvial deposits in the upstream direction has been observed by Johnston (1922), Krumbein (1940, 1942), Cailleux (1945), Schlee (1957) and several other workers. Schwarzacher (1951) and Rusnak (1957 a) found imbrication, dipping towards the up-current direction, in experimental water-deposited sands. The direction of imbrication can be used as an indicator of the direction of transport for the sample. This method of determining transport direction may be more reliable than the position of the larger end of the elongate quartz grains (Lapples and Rominger, 1945). Attempts to make use of this latter criterion did not yield any satisfactory results.

It was therefore of interest to investigate whether imbrication can be detected in thin sections perpendicular to the bedding plane. Six thin sections, three from two different samples each, were analyzed with the following objectives:

(1) To investigate whether preferred orientation is present in thin sections cut in different directions with respect to the fabric.

(2) To investigate whether imbrication existed in thin sections perpendicular to the bedding plane and parallel to the current direction.

(3) To examine differences in preferred orientation and degree of orientation between thin sections cut in different directions with respect to the fabric.

(4) To compare the relationships between orientation, size and shape in thin sections cut in different directions with respect to the fabric.

(5) To investigate whether the existence of preferred orientation in the fabric will bias size and shape measurements of quartz grains in the same sample depending on how the thin section was

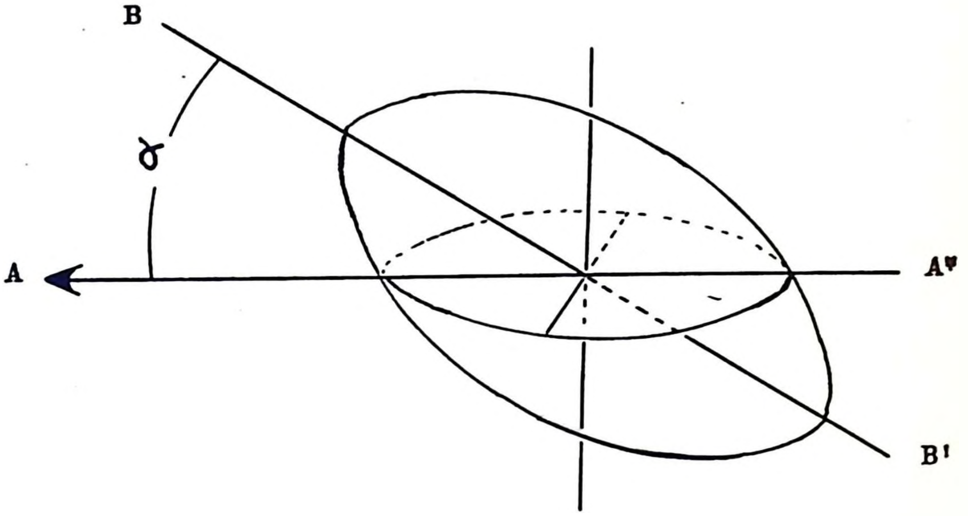


FIG. 26.- Schematic diagram showing the preferred direction of orientation, A-A', in the horizontal plane, and the preferred direction of orientation, B-B', in the vertical plane. The direction of flow is from A' to A, and the angle of imbrication is the angle α .

grain images will depend on the shape of the particles. Theoretically shingling of discoid sand grains will probably result in orientation of the elongate grain images parallel to the bedding; cross sections of rod shaped particles on the other hand might result in orientation normal to the bedding. As no three dimensional shape data are available, no explanation can be given for the angle value of 60° with the bedding plane (= 155°).

The fact that preferred orientation may occur in thin sections cut in different directions with respect to the fabric is schematically demonstrated for an elongate ellipsoidal particle (Fig. 26).

In addition to the orientation analysis, the size and shape of 200 grains selected by point counting were measured in each thin section. Therefore no size or shape limits were applied; only grains which were technically too small to be measured under the microscope (approximately 0.064 mm and smaller) were rejected. Size data were expressed in the modified Phi-scale and shape was expressed in terms of the elongation ratio b/a.

The results of the orientation, size and shape analysis are also given in Table 12A, and the measurement data are graphically represented by histograms in Fig. 27. The size and shape distributions are also plotted as cumulative curves in Figs. 28 and 29.

To test significant differences between the means of the size and shape distributions for the different thin sections, the "t" test (Dixon and Massey, 1957, p. 121 - 122) was applied. The test consits in an attempt to disprove the hypothesis that the sample means are representative of the same normal population, assuming that the sample standard deviation S is an efficient estimate of σ (Two-sided test H: $\mu_1=\mu_2$, where $\sigma_1^2 = \sigma_2^2 = \sigma^2$ is unknown).

The results of the "t" test, which is conducted at $\alpha = 0.05$ and with 398 degrees of freedom are given in Table 13. The region of rejecting the hypothesis that the two populations have the same means are $t < -1.966$ and $t > +1.966$.

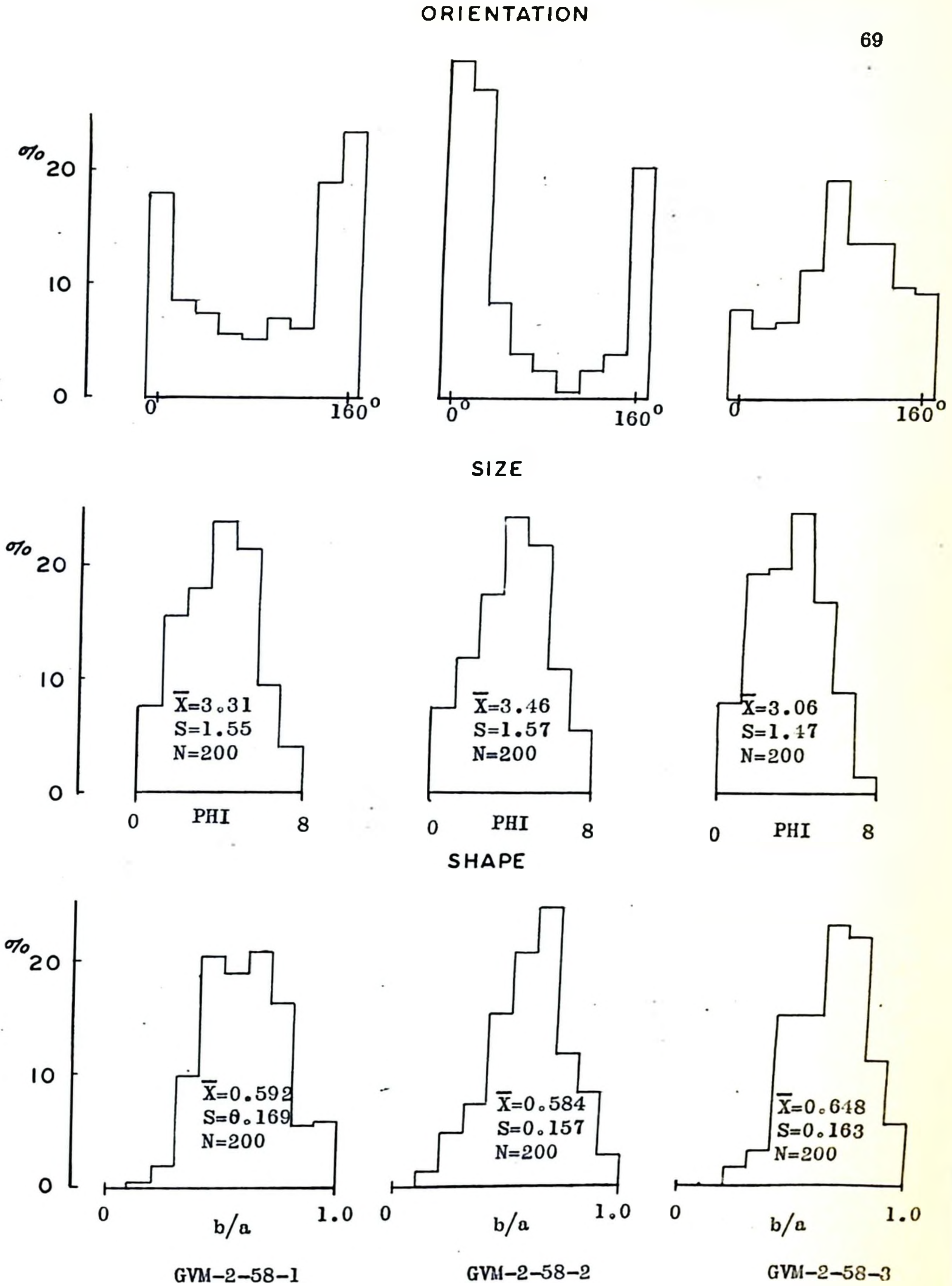
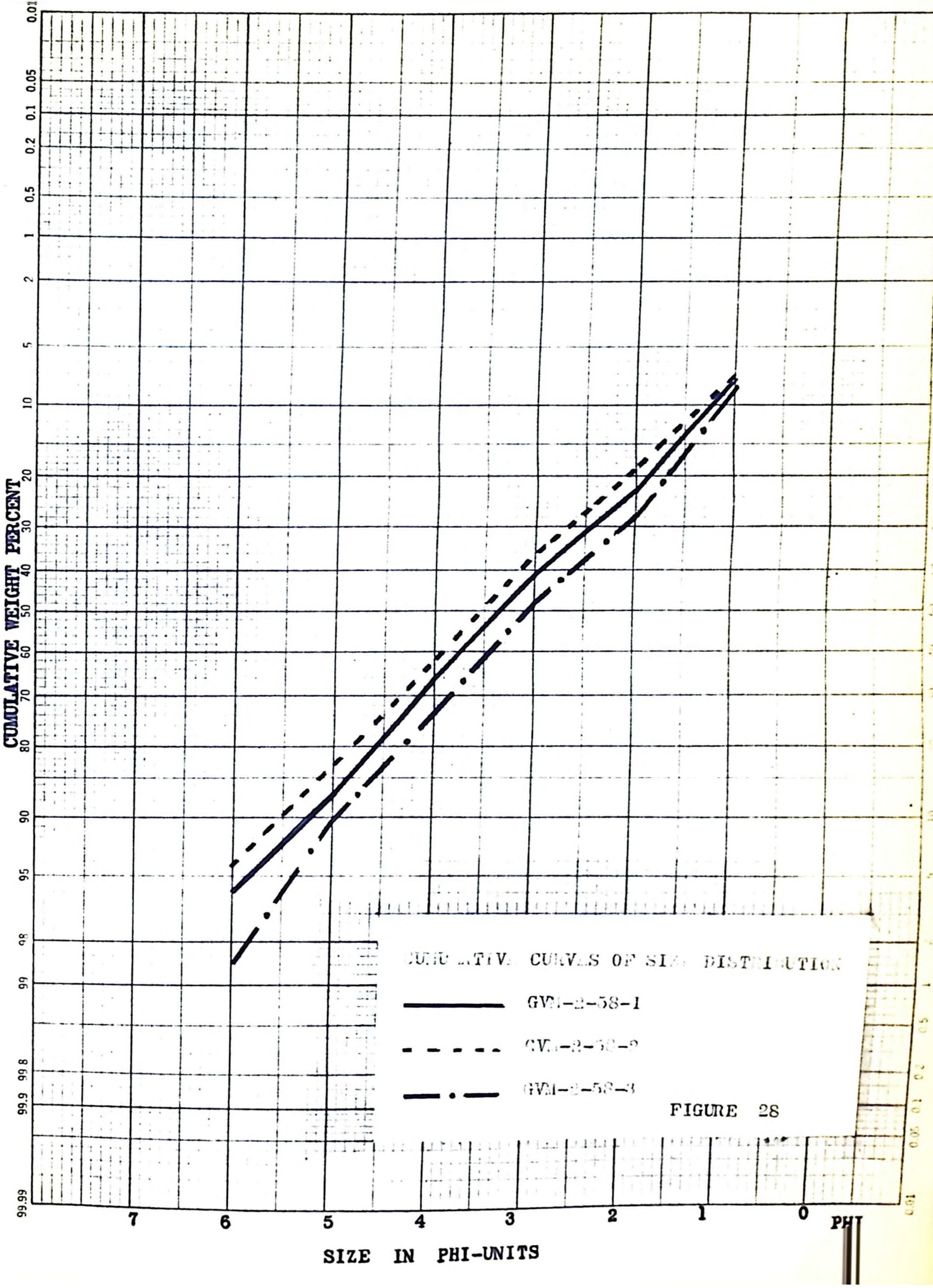


FIG. 27.- Histograms representing orientation, size and shape distributions of the quartz grains of three thin sections perpendicular to each other. Sample GVM-2-58.

FIG. 28


CUMULATIVE WEIGHT PERCENT
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PHI
SIZE IN PHI-UNITS
CUMULATIVE CURVES OF SIZE DISTRIBUTION
GVM-2-58-1
GVM-2-58-2
GVM-2-58-3
FIGURE 28

FIG. 29

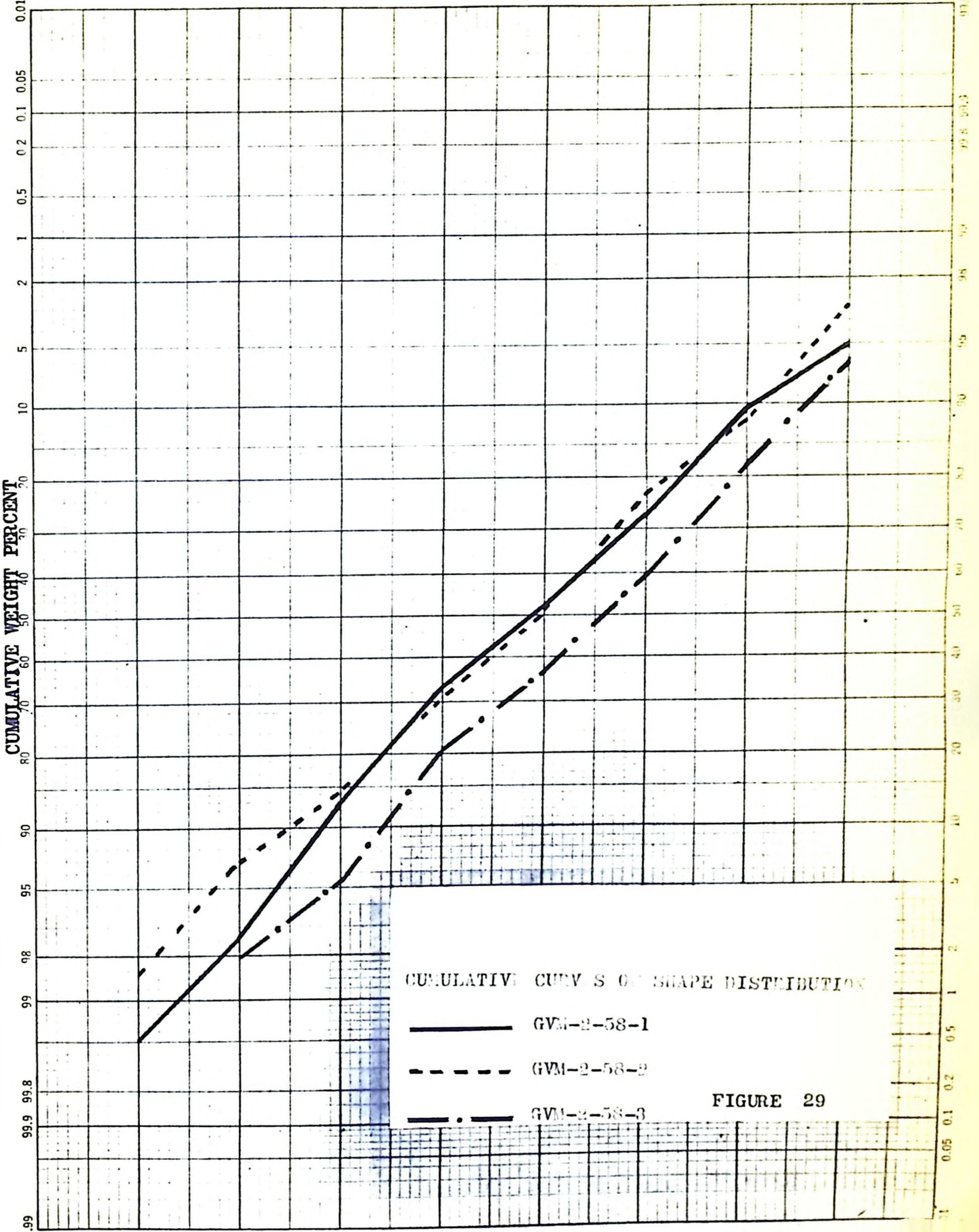


FIGURE 29

Hypothesis	t	Difference
SIZE		
$\mu_1 = \mu_2$	-0.961	No
$\mu_1 = \mu_3$	+1.655	No
$\mu_2 = \mu_3$	+2.616	Yes
SHAPE		
$\mu_1 = \mu_2$	+0.490	No
$\mu_1 = \mu_3$	-3.373	Yes
$\mu_2 = \mu_3$	-4.000	Yes

Table 13

Significant differences in size measurements at the 95% level can only be detected between thin sections GVM-2-58-2 and GVM-2-58-3, respectively with the highest and lowest degree of orientation. Differences between the means of the shape distributions is significant in two cases: between the thin section parallel to the bedding and the one perpendicular to the flow, and between the thin section parallel to the flow and the one perpendicular to the flow.

A finer grained sample of bed PS-8-59-a of the Normanskill section was examined in a similar way. As the direction of the flow marks on the bottom of the beds could not be determined, the thin sections were cut with reference to the strike:

(1) Perpendicular to the bedding plane and parallel with the strike (PS-8-59-a-1)

(2) Perpendicular to the bedding plane and perpendicular to the strike. (PS-8-59-a-2).

(3) Parallel to the bedding plane (PS-8-59-a-3).

The orientation of 100 grains, selected by point counting in each thin section, was measured, and afterwards each thin section was repoint counted for size and shape analysis. The results of these analyses are given in Table 1 . Orientation, size (in 0.1 micrometer units) and shape distributions are represented by histograms in Fig. 30 and cumulative size and shape curves are given respectively, in Figs. 31 and 32. Tukey's Chi-square test of isotropicity indicates significant departures from random orientation at the 95% level in all thin sections.

The mean preferred orientation in thin section PS-8-59-a-1, which is cut perpendicular to the bedding plane and parallel to the strike, is 72.8° with reference to the bedding plane. The direction of the bedding plane was taken as 155°. Thin section PS-8-59-a-2, cut perpendicular to the bedding plane, shows a preferred angle of dip of 14.6° with the bedding plane, which was also taken as 155°. From the results of the examination of sample GVM-2-58, we may conclude that thin section PS-8-59-a-2 is more likely to be parallel to the direction of flow than thin section PS-8-59-a-1. This is also confirmed by the high degree of orientation which we theoretically may expect in a thin section cut parallel to the flow direction.

The preferred orientation alignment in thin section PS-8-59-a-3, which is parallel to the bedding, is 159.3°-339.3°. The strike measured in the field was 125°, whereas under the microscope the strike, which was indicated on the thin section, was measured as 245°, approximately perpendicular to the mean grain lineation. Taking the direction of imbrication as a criterion for direction of transport, the mean preferred orientation of the quartz grains in terms of the true azimuth can easily be obtained. A simple calculation ($245^{\circ} - 159.3^{\circ} + 125^{\circ} = 210.7^{\circ}$) shows that the mean preferred orientation direction is 210.7°. Derivation from 210.7° (S.S.W.) is in reasonable agreement with the result of the field measurements at the same locality, which indicates a predominant derivation from the South.

The "t" test was applied to determine whether the size and shape distributions of the different thin sections had identical means (Table 14).

Hypothesis	t	Difference
SIZE		
$\mu_1 = \mu_2$	−0.414	No
$\mu_1 = \mu_{\cancel{2}}$ 3	−2.463	Yes
$\mu_2 = \mu_3$	−1.753	No
SHAPE		
$\mu_1 = \mu_2$	+5.053	Yes
$\mu_1 = \mu_3$	+2.528	Yes
$\mu_2 = \mu_3$	+2.588	Yes

Table 14

The critical regions of rejecting the hypothesis at $\alpha = 0.05$ and with 198 degrees of freedom are $t < -1.972$ and $t > +1.972$. The only significant difference in size measurements is between the thin section perpendicular to the bedding, PS-8-59-a-1, and PS-8-59-a-3, parallel to the bedding. The thin sections, however, which show a higher degree of

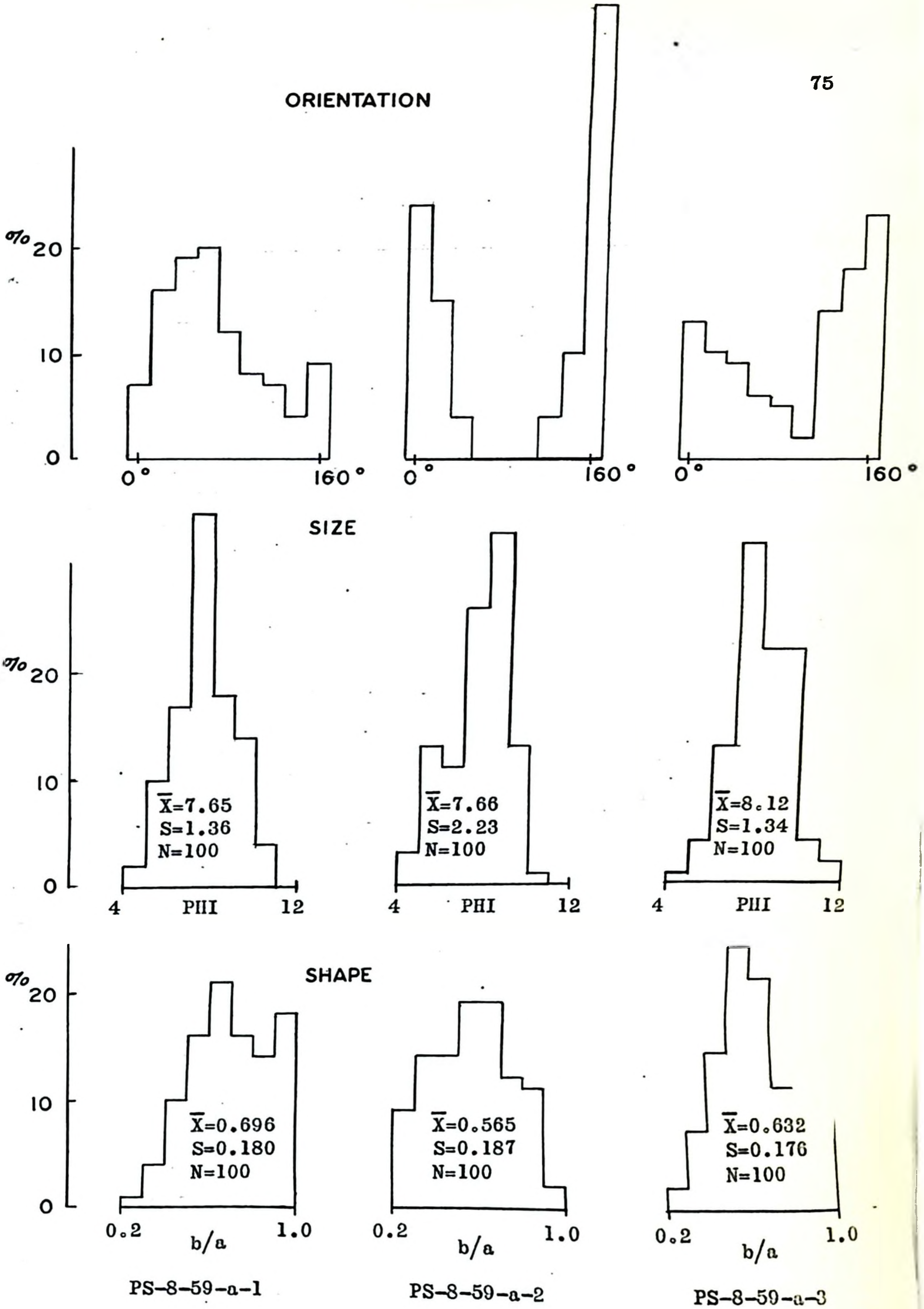
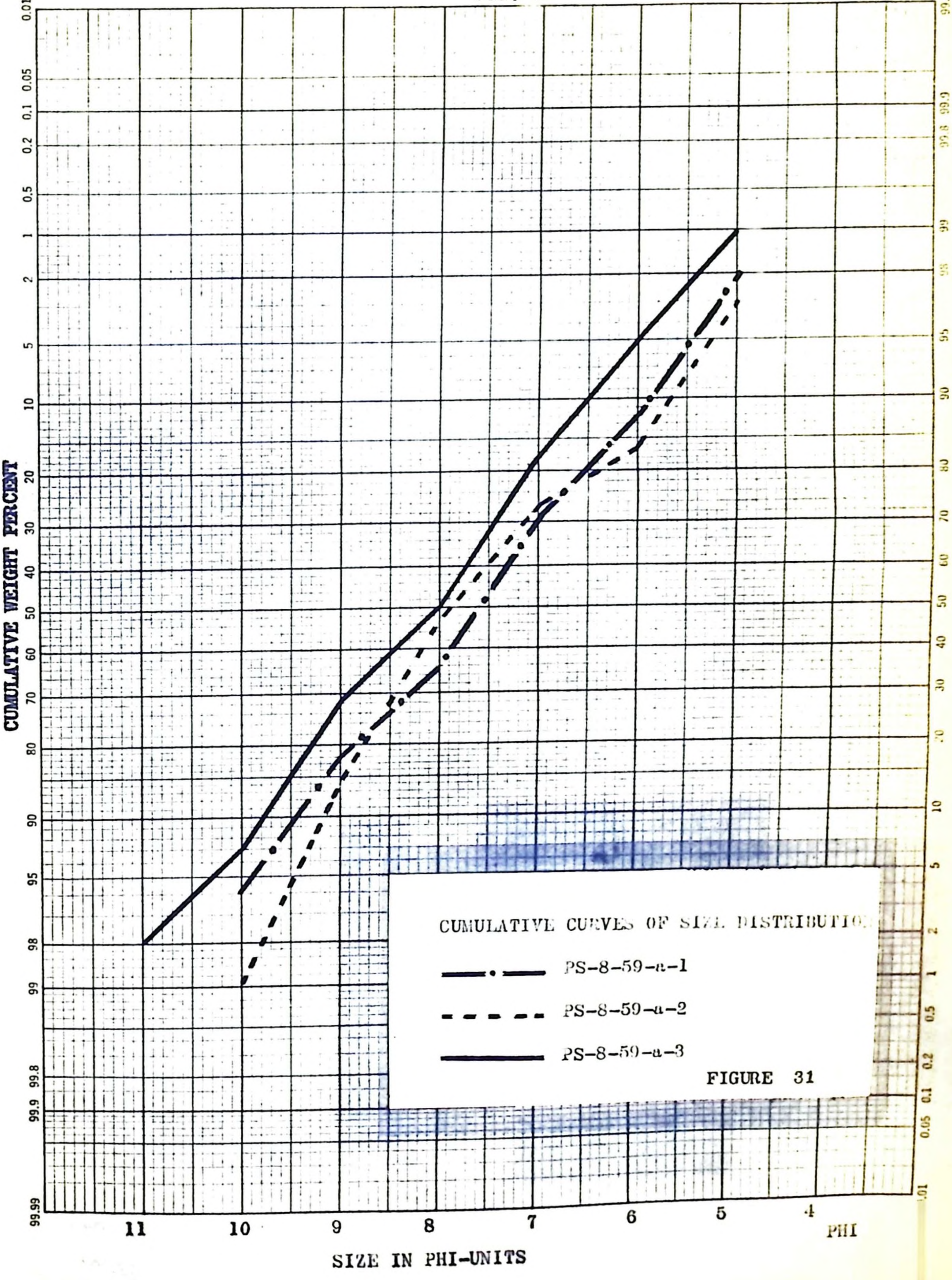


FIG. 30.- Histograms representing orientation, size and shape distributions of the quartz grains of three thin sections perpendicular to each other. Sample PS-8-59.

FIG. 31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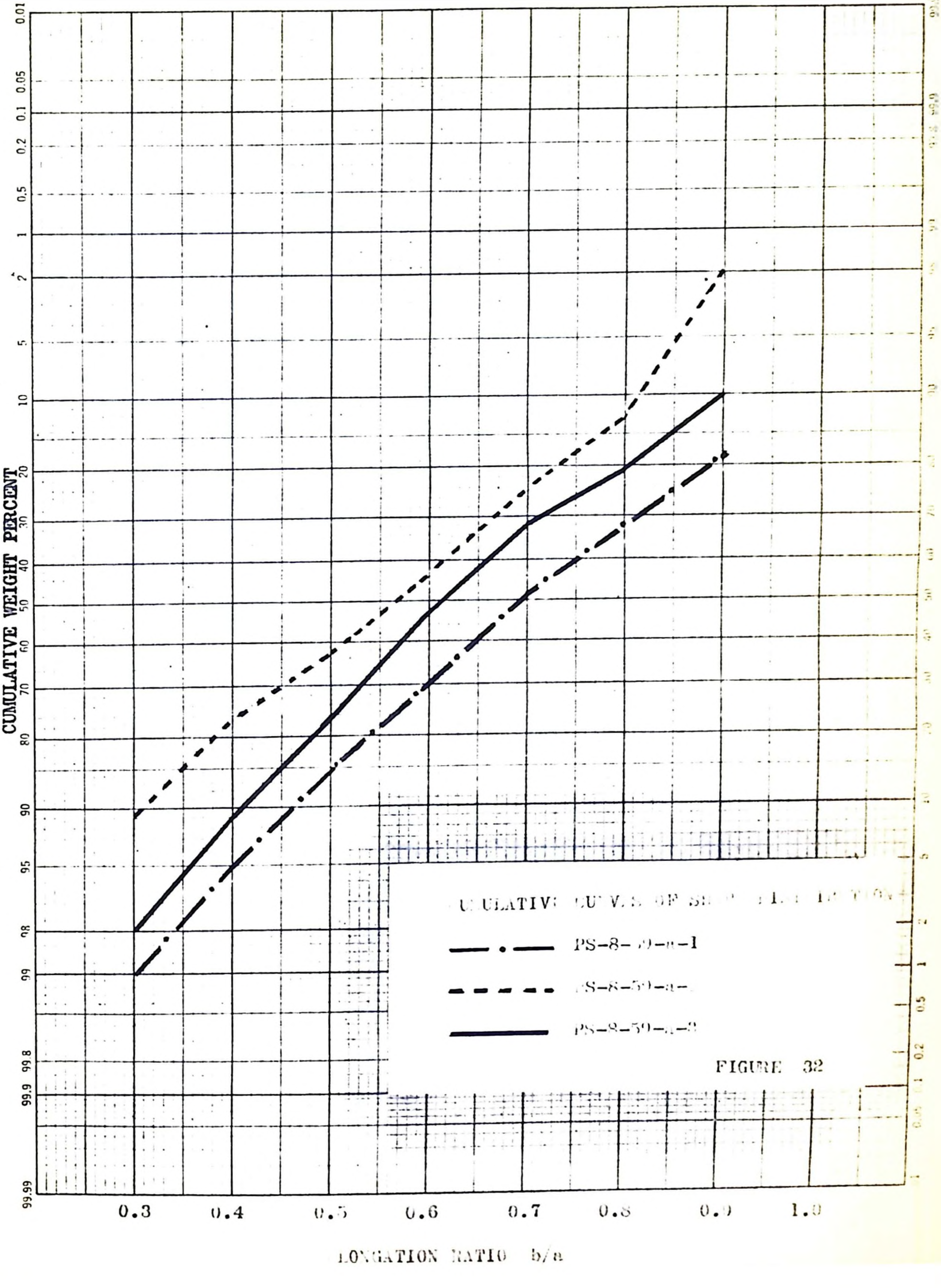
PHI
SIZE IN PHI-UNITS
CUMULATIVE CURVES OF SIZE DISTRIBUTIO
PS-8-59-a-1
PS-8-59-a-2
PS-8-59-a-3
FIGURE 31

FIG. 32


CUMULATIVE WEIGHT PERCENT
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0.3
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0.5
0.6
0.7
0.8
0.9
1.0
ELONGATION RATIO b/a
CUMULATIVE CURVES OF SHAPE ELONGATION
PS-8-59-a-1
PS-8-59-a-
PS-8-59-a-3
FIGURE 32

orientation have proportionally a larger number of more elongate grains. It appears therefore that the presence of preferred orientation in the fabric of a sample may bias size and shape measurements by means of thin section analysis, depending on how the thin section was cut with respect to the fabric. The presence of orientation probably affects shape measurements more than size measurements.

It may also be of interest to know how much variation in degree of orientation is due to the size and shape of the individual grains. The two main questions concerning this problem are:

(1) Is there a tendency for differences in preferred orientation between larger and smaller grains?

(2) Is there a tendency for differences in preferred orientation between better and less elongated grains?

The orientation, size and shape of 100 grains, selected by point counting in three thin sections was measured. Size and shape were therefore subject to the same limitations as applied to the measurement of orientation. The results of the orientation analysis in the three thin sections are given in Table 15:

Thin section	Locality	θ_m^o	L%
PS-11-59-I-a	Austin Glen	271.1	43.8
PS-11-59-I-b	Austin Glen	247.5	52.1
PS-8-58-b-I-1	Normanskill	172.8	33.3

Table 15

To investigate this problem the orientation measurements were divided into two categories:

(a) A category containing the 50% of the grain orientations having a higher degree of orientation with respect to the circular mean.

		SIZE						SHAPE					
Thin sections	Hypotheses	$\bar{X}_a$	S	$\bar{X}_b$	S	t	Diff.	$\bar{X}_a$	S	$\bar{X}_b$	S	t	Diff.
PS-11-59-I-a*	$u_a = u_b$	3.54	1.68	3.62	1.55	-0.246	No	0.504	0.135	0.560	0.100	-2.745	Yes
PS-11-59-I-b*	$u_a = u_b$	3.44	1.33	3.60	1.59	-0.769	No	0.510	0.103	0.563	0.092	-2.623	Yes
PS-8-59-b-I-1**	$u_a = u_b$	2.84	1.33	2.26	1.36	+3.321	Yes	0.520	0.117	0.539	0.112	-1.168	No

Table 16

* Region of rejection at $\alpha = 0.05$ and with 98 degrees of freedom, $t < -1.982$ and $t > +1.982$.

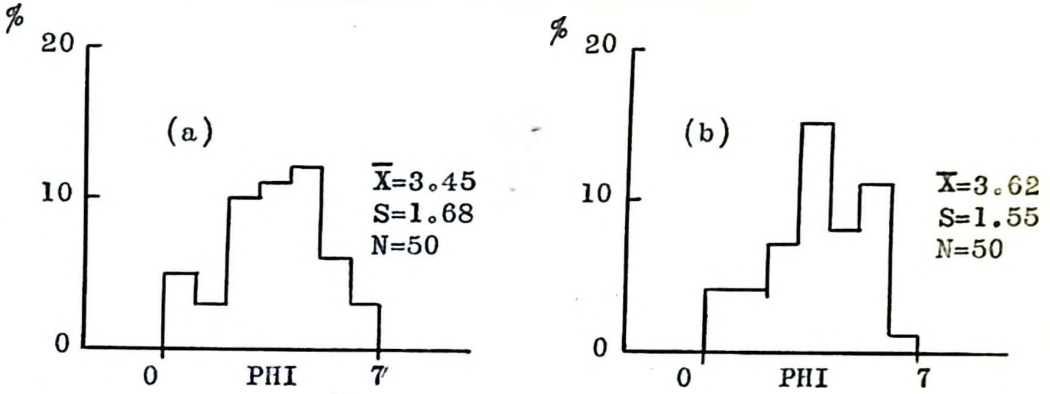
** Region of rejection at $\alpha = 0.05$ and with 198 degrees of freedom, $t < -1.972$ and $t > +1.972$.

(b) A category containing the 50% of the grains orientations having a lesser degree of orientation with respect to the circular mean.

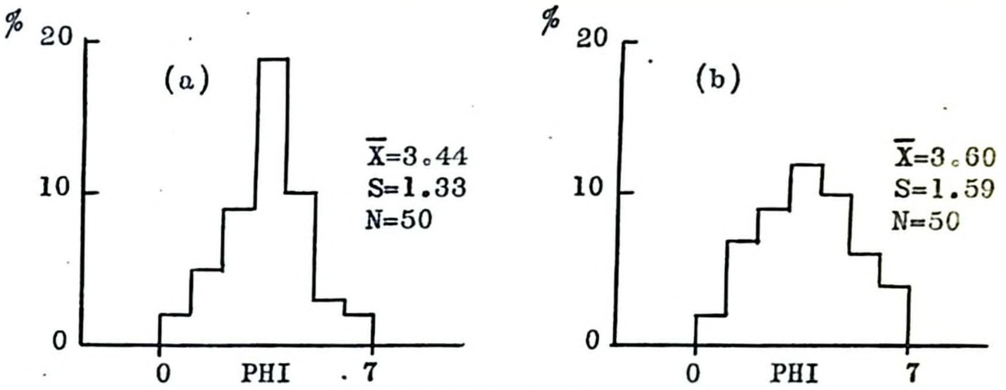
The size and shape distributions, differentiated in the two categories a and b are represented by histograms in Figs. 33 and 34 respectively, and by cumulative curves in Figs. 35 and 36.

The "t" test (Table 16) indicates that no significant differences between the size distributions at the 95% level can be detected in the two thin sections from the Austin Glen sample. However the larger grains in thin section PS-8-59-b-I-1 of the Normanskill sample tend to be better oriented than the smaller grains. The shape distributions of the better oriented categories of the two Austin Glen thin sections indicate that they are more biased towards smaller elongation ratios than the less oriented categories; whereas no significant differences in shape distributions could be detected in thin section PS-8-59-b-I-1.

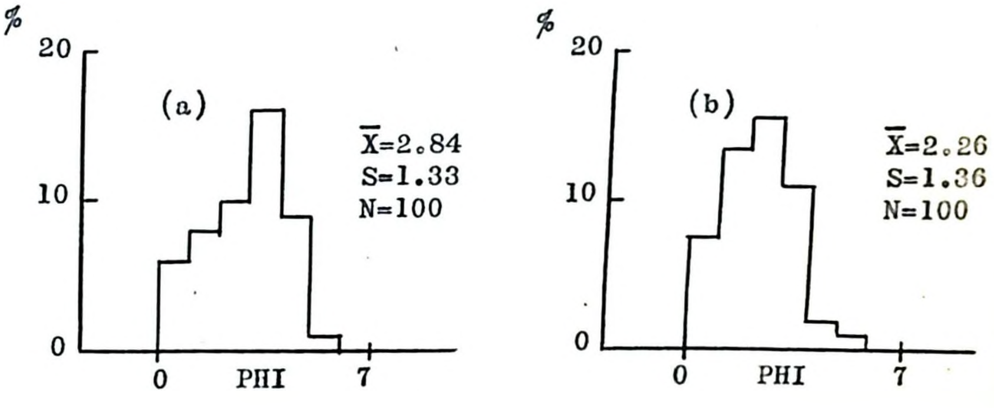
ORIENTATION AND GRAIN SIZE.



PS-11-59-I-a



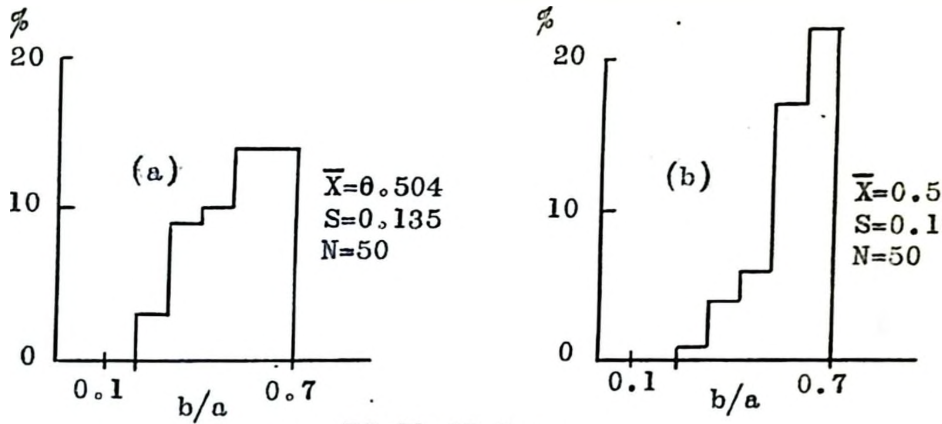
PS-11-59-I-b



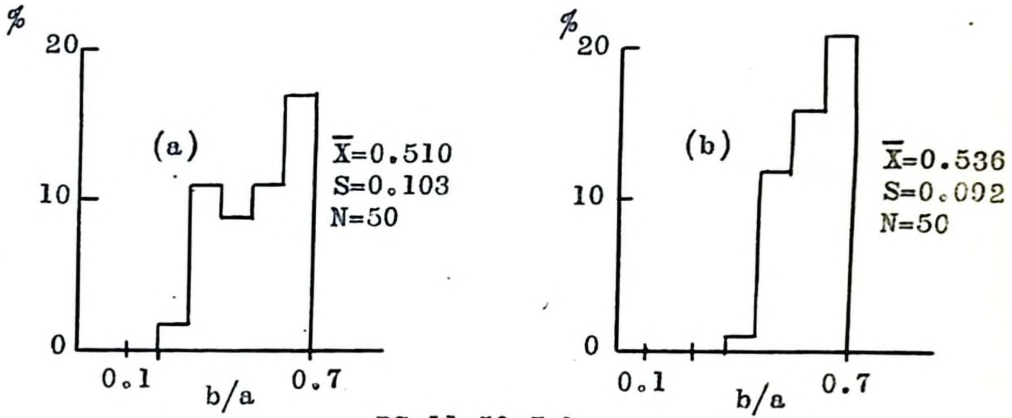
PS-8-59-b-I-1

FIG. 33.- Histograms representing size distributions of the category containing the 50 % of the grain orientations having a higher degree of orientation (a), and the category containing the 50 % of the grain orientations having a less degree of orientation (b), with respect to the circular mean.

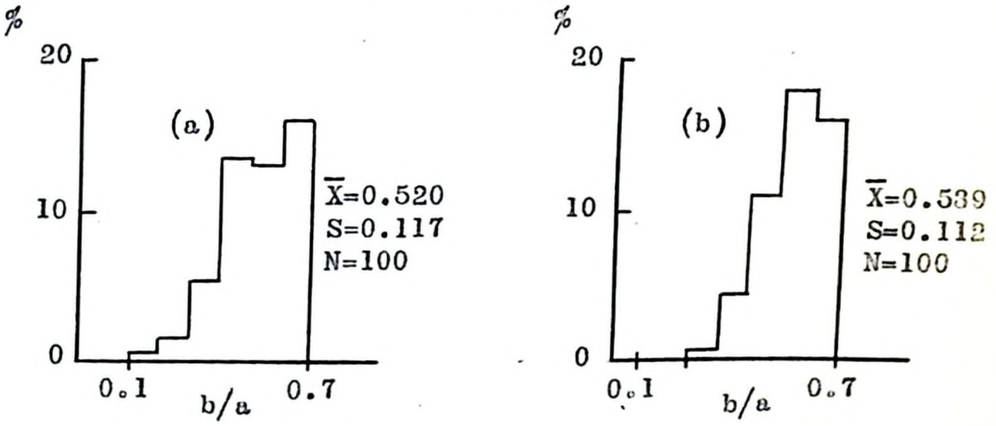
ORIENTATION AND GRAIN SHAPE



PS-11-59-I-a



PS-11-59-I-b



PS-8-59-b-I-1

FIG. 34.- Histograms representing shape distributions of the category containing the 50 % of the grain orientations having a higher degree of orientation (a), and the category containing the 50 % of the grain orientations having a less degree of orientation (b), with respect to the circular mean.

FIGS. 35 and 36.- The encircled points indicate the size, respectively shape data of the category having a higher degree of orientation.

FIG. 35

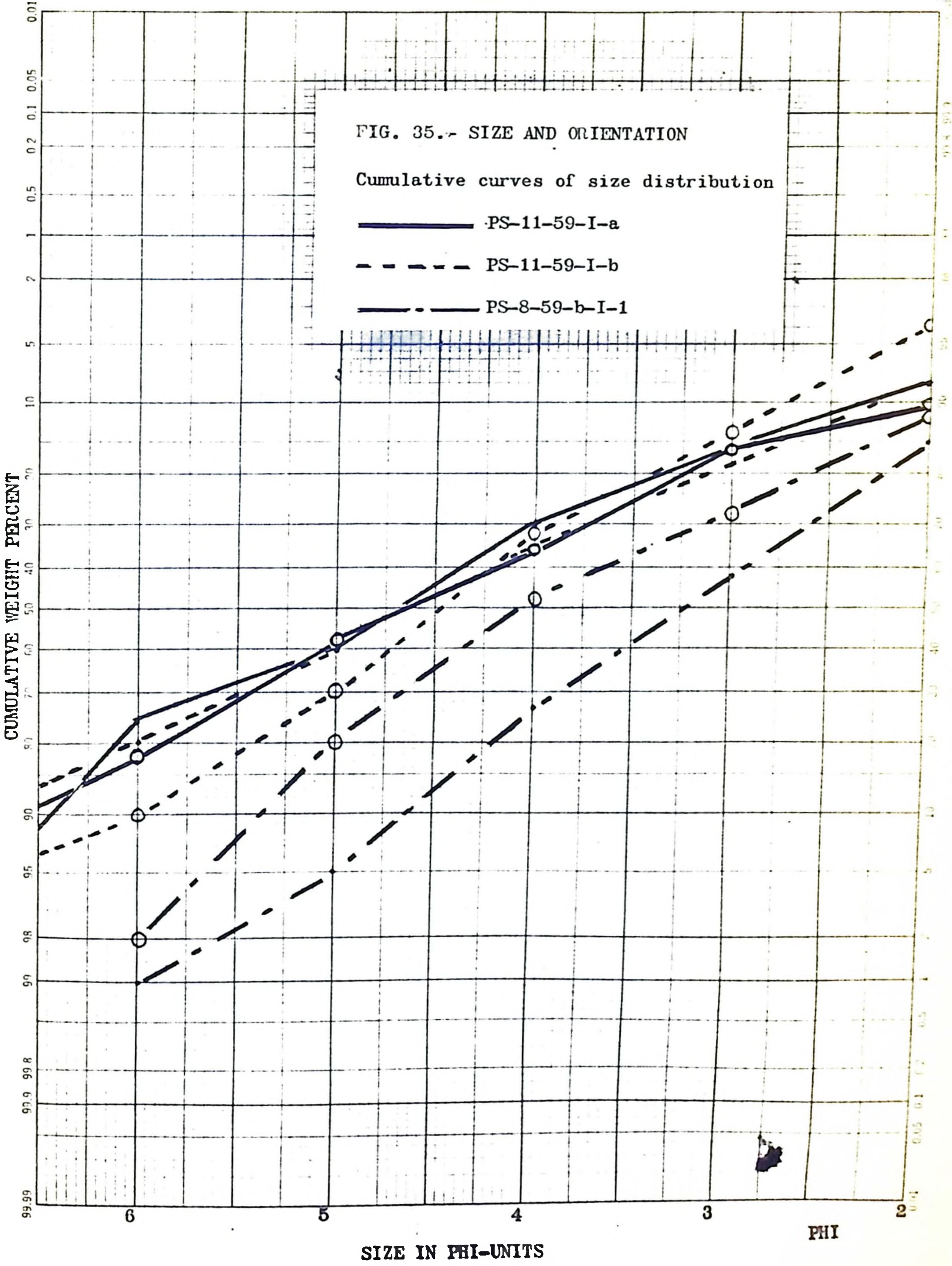


FIG. 35.- SIZE AND ORIENTATION

Cumulative curves of size distribution

FIG. 36

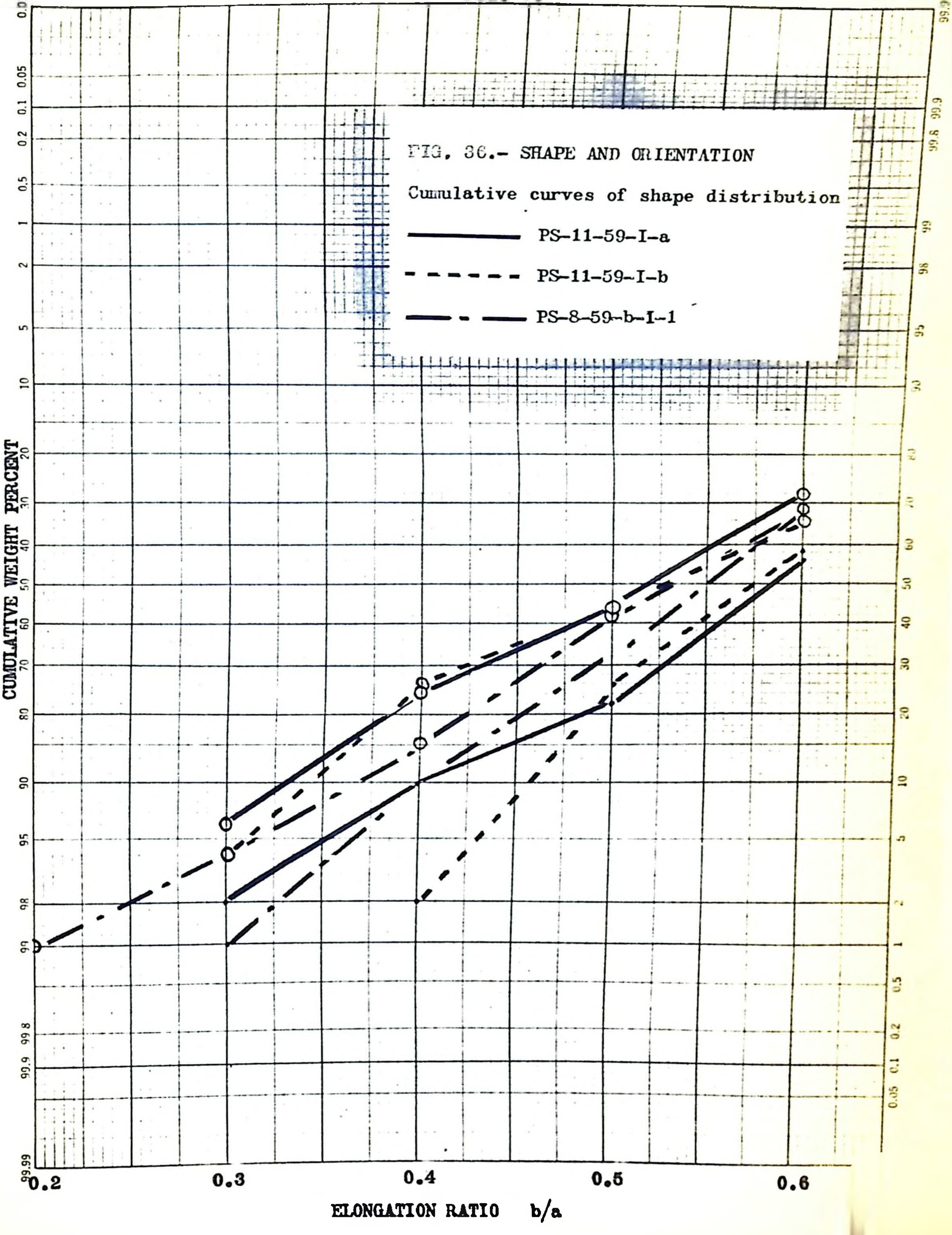


FIG. 36.- SHAPE AND ORIENTATION
Cumulative curves of shape distribution
PS-11-59-I-a
PS-11-59-I-b
PS-8-59-b-I-1
CUMULATIVE WEIGHT PERCENT
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
0.2
0.3
0.4
0.5
0.6
ELONGATION RATIO b/a

DISCUSSION

Sand grains are generally not perfect spheres, but are instead irregularly shaped elongate particles (Curray, 1956 b). Primary orientation of elongated particles can generally be associated with the transportation and deposition of grains in a fluid (Griffiths, 1953). Attempts to break this down to specific causes have not been very successful. Griffiths (1953) remarks that, "it is often believed that grains carried in suspension are aligned in parallel to the current direction, shereas in traction the long axes of such grains will be aligned perpendicularly to the current direction".

Theoretical considerations based on the laws of fluid mechanics indicate that elongate particles are deposited in a position of maximum stability relative to the forces acting upon them (Rusnak, 1957 a). Experiments under controlled hydrodynamic conditions by Schwarzacher (1951) and Rusnak (1957 a) indicate that the most stable position which elongate particles acquire in depositional transport is one, in which the long axes lie parallel to the direction of the fluid, dipping in the up-current direction. In the parallel position less resistance is offered to the depositing flow than if the long axes were aligned normal to the current direction.

Imbrication in the up-current direction also reflects a more stable position as the fluid forces will then help to keep the grain from moving. Fluid forces and gravitational forces will hold the particle both at the bottom and against the down current obstacle (Rusnak, 1957 a). According to Rusnak (1957 a) the velocity gradient in turbulent flows is relatively small and high angles of imbrication might therefore be anticipated.

As deposition takes place sand grains, therefore, tend to be oriented with the long axes parallel to the current direction either by being transported in this position or by rotation after striking the bottom at one end. Submarine turbidity currents produce structures and textures having preferred orientation: (1) by reaction with the bottom prior to deposition, (2) by the process of deposition and (3) by tractional reworking of the material they deposit (Sanders, 1956). More specifically the preferred orientation of the sand grains in turbidity current deposits might be influenced by the following factors:

(1) the shape and the size of the particles,
(2) influence of the adjacent particles,
(3) the occurrence of eddies within the turbidity current,
(4) the roughness factor of the bottom
(5) rate of sediment supply,
(6) post depositional changes.

The deposited grains often do not remain undistrubed as post depositional currents can realigne fabrics previously formed. The nature of turbidity current deposits however suggests that post depositional changes by current action are probably confined to the upper parts of the bed. Current ripple marks (Figs. 3A and 3B) testify that this process of realignment by post depositional current takes place. On ripple crests elongate particles tend to orient themselves with the long axes parallel to the current direction, and in troughs perpendicular to the current direction (Ingerson, 1940). Intricate internal structures as convolute lamination, slump structures etc., may account for large perturbations in the preferred elongation pattern.

SUMMARY AND CONCLUSIONS

Elongated sand grains in turbidity current graywackes tend to align themselves parallel to the fluid flow direction. Previous observations by Helmbold (1952) and Kopstein (1954) on similar rock types confirm this result, which is also in agreement with the theories and experimental data on the orientation of sand grains in water laid sand deposits (Rusnak, 1957 a).

The elongated sand grains are probably also imbricated with the direction of dip upstream.

Dimensional orientation analysis of sand grains in randomly selected thin sections is reasonably accurate to determine the direction of transport in turbidite graywackes. It is necessary to define orientation, size and shape parameters unambiguously to keep operator error to a minimum.

The presence of preferred orientation in the fabric may bias size and shape measurements in thin section, depending on how the thin section was cut with respect to the fabric.

It appears that the more elongated grains tend to be more nearly parallel to the fluid flow direction than the less elongate particles. Relationships between grain size and degree of orientation of the grain are less apparent.

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APPENDIX

List of localities and the results of the orientation measurements in the field and in thin sections.

Locality		Current Direction	Thin Section	N	Preferred Orientation of grains	Average Orientation
Ps-1-59	Along Hwy. 9W 5 mi. S. of Ravena	200°-210°				
PS-3-59	N. of Tivoli Station Madalin, N.Y.	153°				
PS-4-59	Along N.Y.C. Rail Rd. S. of North Germantown N.Y.	—	PS-4-59-1 PS-4-59-2	200 200	199.16° 187.30°	193.20°
PS-5-59	Along Hwy. 9 S. of Upper Red Hook, N.Y.	South				
PS-6-59	Kinderhook Cr., Chittenden Falls	—	PS-6-59-2 PS-6-59-6	200 200	201.25° 218.25°	209.75°
PS-7-59	Stockport Falls, tributary Kinderhook Creek	190°-195°	PS-7-59-1	200	179.00	179.00

Locality		Current Direction	Thin Section	N	Preferred Orientation of grains	Average Orientation
PS-8-59	Normanskill Cr., Kenwood, S. of Albany, N.Y.	175°	PS-8-59-a-1*	100	(perpendicular to the bedding)	
			PS-8-59-a-2*	100	(perpendicular to the bedding)	
			PS-8-59-a-3*	100	221.66	221.50
			PS-8-59-a-6	100	233.00	
			PS-8-59-a-9	100	210.00	
			PS-8-59-b-I-1	200	172.50	177.40
			PS-8-59-b-I-2	200	191.50	
			PS-8-59-b-I-3	200	170.30	
			PS-8-59-b-II-1	200	161.50	
			PS-8-59-b-II-2	200	164.33	
			PS-8-59-b-II-3	200	199.30	
			PS-8-59-b-III-1	200	176.30	
			PS-8-59-b-III-2	200	168.00	
			PS-8-59-b-III-3	200	193.00	
			PS-8-59-c-1	100	171.25	173.25
			PS-8-59-c-2	100	175.25	
PS-9-59	Hwy. cuts along 9W 1 mi. N. of jct. 144	—	—	—	—	—
PS-10-59	Matthew Point, 1½ mi. S. of New Baltimore, N.Y.	—	PS-10-59-b-1	200	161.50	155.65
			PS-10-59-b-2	200	149.80	
PS-11-59	Austin's Glen, Catskill Cr., Catskill, N.Y.	180-185°	PS-11-59-I-a	200	182.80	180.60
			PS-11-59-I-b	200	181.30	
			PS-11-59-II-a	200	171.75	
			PS-11-59-II-b	200	171.66	

Locality		Current Direction	Thin Section	N	Preferred Orientation of Grains	Average Orientation
Q-I	Quebec Group, St. Fabien S/M., P.Q.	155**	Q-I-1-a	200	158.65	161.21
			Q-I-1-b	200	160.51	
			Q-I-1-c	200	156.66	
			Q-I-2-a	200	169.75	
			Q-I-2-b	200	162.85	
			Q-I-2-c	200	156.51	
			Q-I-3-a	200	164.91	
			Q-I-3-b	200	158.60	
			Q-I-3-c	200	171.80	
			Q-I-4-a	200	165.46	
			Q-I-4-b	200	173.43	
			Q-I-4-c	200	174.63	
			Q-I-5-a	200	158.60	
			Q-I-5-b	200	158.98	
			Q-I-5-c	200	142.15	
GVM-2-58	Austin's Glen, Catskill Cr., Catskill, N.Y.	155**	GVM-2-58-1*	200	161.80	161.80
			GVM-2-58-2*	200	(perpendicular to the bedding)	
			GVM-2-58-3*	200	(perpendicular to the bedding)	

* Also size and shape measurements.
** Attitude of the beds unknown.