DIMENSIONAL GRAIN ORIENTATION

OF

ORDOVICIAN TURBIDITE

GREYWACKES

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by

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SCOPE AND CONTENTS: This study describes the analysis of orientation of elongate quartz grains in turbidite greywackes of the Normanskill Formation, (Ord.) New York.

No relationship is found between grain orientation and sole features of the beds. No relationship exists between grain orientations taken at different levels above the base of the beds.

Maximum grain size and maximum elongation decrease upwards in the beds. The most elongate grains are those which most clearly show preferred orientation.

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ABSTRACT

This study describes the analysis of orientation of elongate quartz grains in turbidite greywackes of the Normanskill Formation (Ordovician) in the Hudson Valley, Eastern New York, U.S.A.

Orientation in the bedding plane was examined in 44 beds, 85% of which showed a preferred orientation at the 90% level. Only 14% of these showed no significant deviation from the sole. No preferential departure from the sole existed; the grain-sole deviation is close to uniform; 40% demonstrating an anticlockwise deviation; 60% clockwise. There is a slight tendency for the maximum deviation to occur at the base of the beds.

There is no relationship between the deviation of the grain orientation from the sole with either percentage height above the base of the bed, at which the thin sections were cut, or with the measure of dispersion of the orientation. The latter bears no relationship with the height above the base of the bed.

Detailed studies of vertical relationships of orientation in the bedding plane were made in 19 beds; three of which were sampled both laterally and vertically. Although a local consistency of the mean grain orientation was found in some beds, the majority are highly inconsistent. No similar patterns of deviation occurred in the beds studied.

One bed that was studied showed divergent flute and groove casts on the base. Mean grain orientation within the flute was

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INTRODUCTION

1. PREFACE

Primary sedimentary structures which indicate palaeocurrent or palaeoslope directions have been widely studied because of their importance in determining dispersal patterns, provenance and palaeogeography. Preferred orientation of the long axis of sand grains is thought to indicate direction of transport of the sediment. Grain orientation in sand sized and smaller sediments was suggested as a means of determining transport by Dapples and Rominger (1945). Schwarzacher (1951) and Rusnak (1957,a) added further insight into the problem with experimental determinations.

Grains are thought to align themselves parallel to the transporting current and theoretically should have a mean orientation parallel to the mean orientation indicated by directional structures. Until recently the majority of workers have found this to be the case. Studies in turbidite sequences by Bouma (1963) and Spotts (1964) demonstrate that such a relationship does not always exist.

2. GRAIN ORIENTATION

Primary depositional fabric must be an equilibrium or near equilibrium response of clastic particles under the influence of forces of gravity, fluid flow and drag against other grains. A primary depositional fabric can be defined as the spatial arrangement of grains in a sediment, which by accepted statistical methods, can be shown to exhibit a significant deviation from uniform distribution.

a) Theoretical Rationale

Hydrodynamic and experimental results show that elongate grains should be deposited in a position of maximum stability with respect to the external forces. This has been demonstrated by Schwarzacher (1951) and Rusnak (1957,a) who found that most grains in a moderately sorted sediment lie with their long axes parallel to the direction of flow, with an upcurrent imbrication.

It has been theoretically demonstrated (Rusnak, 1957) that ellipsoidal grains in suspension are oriented with their long axes normal to the direction of flow; grains rolling along the bottom in traction also have their long axes normal to the flow. Inasmuch as sand grains are in suspension just prior to deposition and that they are lastly in traction one might predict that the long axes would be normal to the flow. This is, however, a position of instability for rough bottoms (Rusnak, 1957,a). An ellipsoidal grain will tend to advance by rolling around its short axis, that is, it will roll with its long axis normal to the flow. A streamlined shape will be stable only when all the forces are symmetrically disposed about the line which passes through the centre of the mass and the apex. Since the apex represents the farthest point from the centre of the mass, a stable position will only be obtained when the apex points in the direction of the relative fluid motion. (Kunkel, 1948) This applies to the flow of sediment over a rough bottom. For flow over smooth bottoms the grains will be normal to flow. As the size of the roughness elements on the bottom increase the ellipsoidal grains will act more erratically. The position of maximum stability depends on several other factors. The velocity of the flow near the bed must be at a critical value for particle movement; this value in turn is dependent on other parameters such as particle size and roughness elements. Rusnak found that the greatest departure of preferred orientation from the flow direction occurred in samples formed at low mean velocities.

An increase in the sphericity, that is a decrease in elongation, results in an increase in the degree of dispersion around the preferred direction of orientation (Rusnak, 1957).

Unfortunately no one of the factors can be singled out as being of the utmost importance and it is the various combinations and the degree of the combinations that are the determining factors in the orientation of the grains.

b) Practical status

Initial work on the grain orientation of sediments was done in the coarser materials, particularly those of glacial origin. With improvement in sampling and technique of measurement the study of sand sized and smaller particles has more recently come to the fore. Results from most studies of the fabric of sediments and sedimentary rocks have shown that the grains tend to be aligned parallel to the direction of flow as indicated by directional structures. A good review of the past studies in this field is given by Potter and Pettijohn (1963).

c) Turbidite case histories

Only a limited amount of work on the fabric of turbidites has been accomplished. Kopstein (1954) reported long axis alignment in most specimens of the Cambrian turbidites of North Wales. He interpreted this as a primary fabric despite the fact that other authorities (Woodland 1938), 1945; Shackleton 1953) had already pointed out that some of the grains had a preferred orientation determined apparently by cleavage. Bassett and Walton (1960) made investigations in three horizons of the Lower Cambrian turbidites of North Wales and found the distributions to be unimodal, bimodal and polymodal. When the distribution was unimodal it was subparallel to both the current marks and the cleavage, whereas in the bimodal distribution one mode was subparallel to the cleavage and the current and the other at right angles to this. As the cleavage and the current marks are parallel it is difficult to determine whether the orientation is due to primary deposition or due to metamorphism.

Smoor (1960) found parallel alignment of the grains with the sole features of the Normanskill greywackes. He also reported that there was no consistent lateral or vertical variation within a bed. Hand (1960) examined turbidites of Pliocene age in the Ventura basin of California. He found that in particular beds, several preferred directions may be apparent: (1) parallel to current flow, (2) between 20° and 40° to either side of the direction indicated by sole features, (3) at 90° to the current direction. He recognized that current normal orientation was frequently a secondary tendency, becoming more dominant with increase in grain size and decrease in the degree of sorting.

Bouma (1962) found that in general the preferred orientation was at right angles to the sole marks. Spotts (1964) working on the Miocene deposits of California, found the sole features to diverge 40 to 60 degrees from the mean direction of the preferred grain orientation. He attributed this to differences in direction between currents eroding the flutes and currents depositing the overlying beds. He demonstrated also that the grains of maximum elongation had a higher degree of preferred orientation.

3. OBJECTIVES OF THE STUDY

An attempt was made to test several hypotheses relating to grain orientation in the greywackes of the Normanskill Formation, (Ordovician), Eastern New York. Smoor (1960) attempted a similar study on the same strata; he demonstrated that a definite relationship existed between the direction of flow as indicated by the sole features and the preferred orientation direction of the elongate quartz grains, in that there was a parallelism of the grains with the sole marks. The present study was set up to test the validity of the following premises:-

(a) that the mean grain orientation is parallel to the mean orientation of the sole marks on the base of the greywacke beds.

(b) that if the above hypothesis is accepted, imbrication of elongate quartz grains can furnish the azimuth of transport of the sediment.

(c) that current direction, as indicated by grain orientation was persistent throughout particular beds in both a lateral and a vertical sense.

(d) that grain orientation is related to size and shape of the grains.

4. THE NORMANSKILL

a) Stratigraphy

The graded greywackes studied were collected from the Austin Glen Member of the Middle Ordovician, Normanskill Formation. The formation outcrops in a roughly linear belt between Saratoga and Poughkeepsie in the Hudson valley of Eastern New York State, U.S.A. (fig. 1) The formation has been correlated (fig. 2) with the Jacksonburg limestone of Eastern Pennsylvania and Northern New Jersey, and with the Kirkfield, Amsterdam, Rockland and Glens Falls limestone of the Mohawk valley. (Twenhofel et al. 1954).

The Normanskill was named by Ruedemann (1909) for the typical exposures in the Normanskill valley near Kenwood, south of Albany. Ruedemann (1930) estimated that the sequence had a minimum thickness of 1000 feet, but later estimates at various localities suggest that the thickness is probably nearer 2000 feet. Ruedemann divided it into two members; a lower, the Mount Merino Member consisting of cherts and shales, and an upper, the Austin Glen Member composed of greywackes and grey and black shales. The basis for this division was the presence of black chert pebbles in the greywackes. The Mount Merino beds also contain "the older faunal elements, as Nemograptus gracilis, indicative of the lower Normanskill beds, while those of the Austin Glen beds do not carry these forms." (Ruedemann 1930). Craddock (1957) renamed the basal portion of the Mount Merino Members as the Lower Red Shales Member. Berry (1962) further

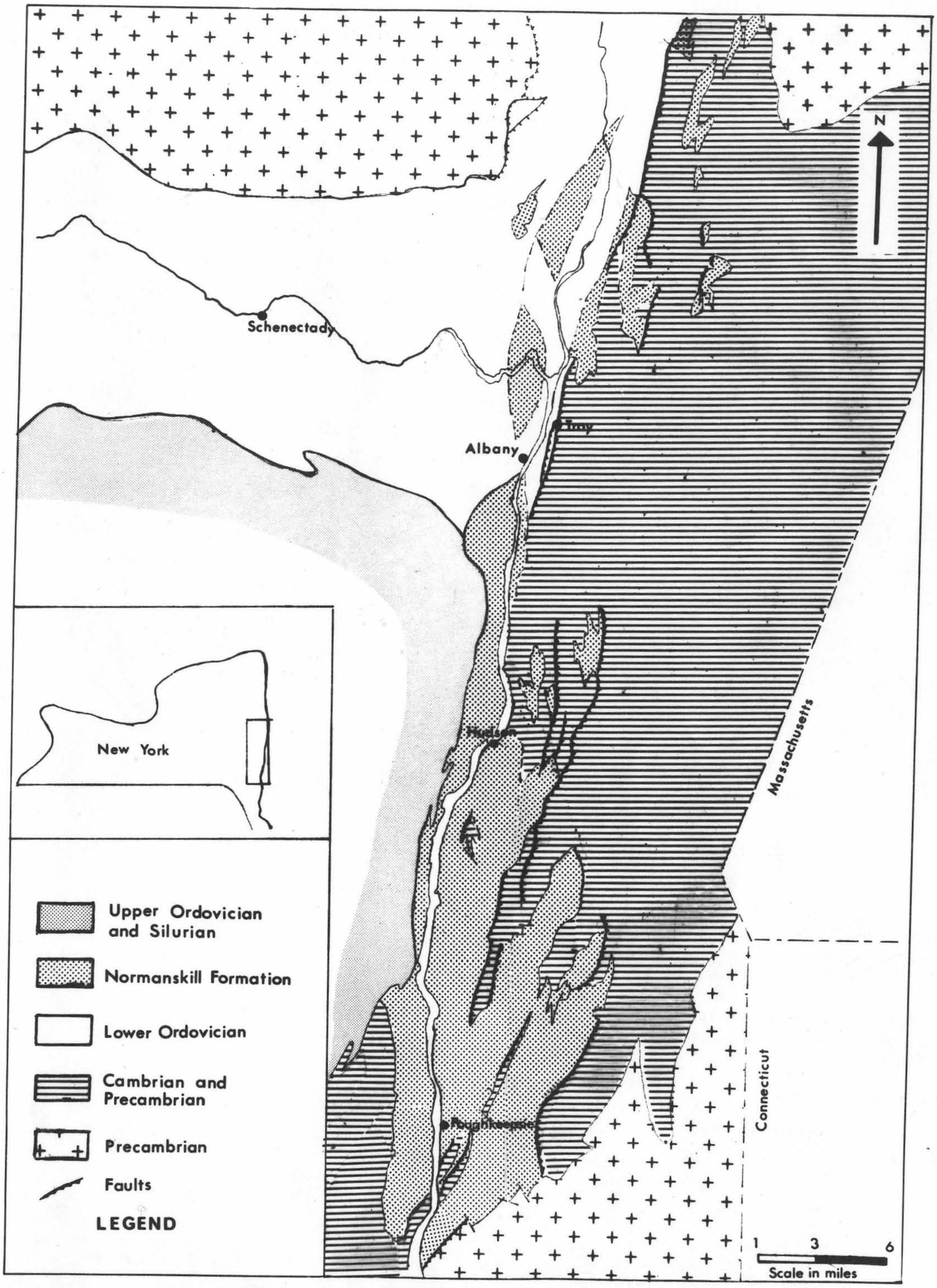


Fig. 1: Geological sketch map of the area under study.

(after N.Y. State Geological Survey map)

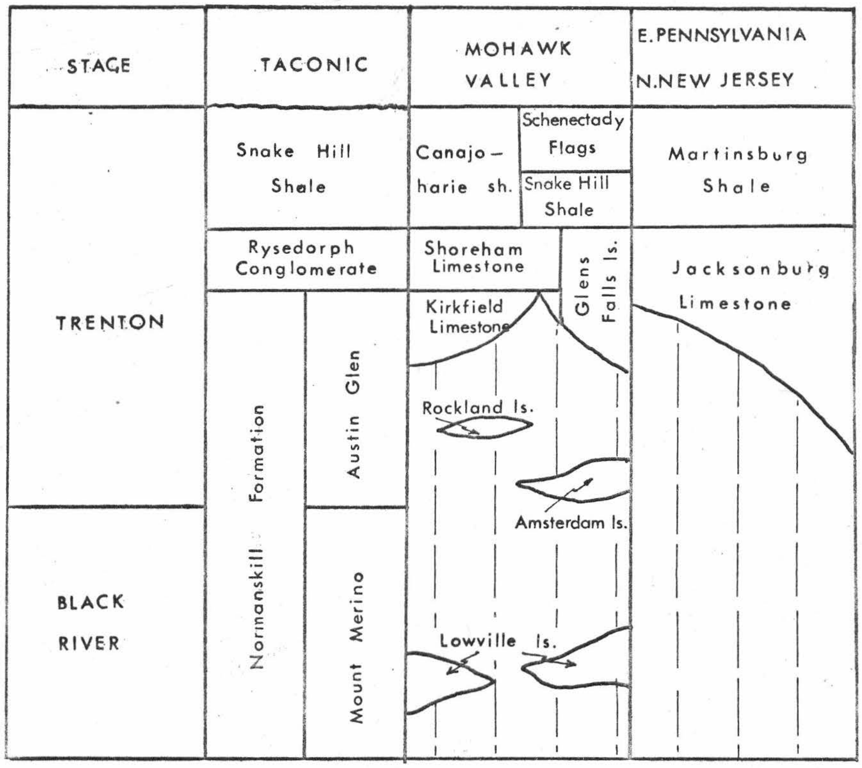


Fig. 2: Correlation of the Normanskill Formation with local Ordovician sequences. (After Twenhofel et al, 1954)

divides the Normanskill Formation into four members.

The greywackes of the Austin Glen are interbedded with grey and black fissile shales. Ruedemann (1901) noted features such as cross bedding, mud balls and graded bedding which led him to conclude that the sediments were shallow water in origin. He postulated that velocity fluctuations produced the greywacke shale couplets. It has since been satisfactorily proved to most geologists that the coarser sediments were transported by turbidity currents into deep water areas in which fine grained sediments were normally being deposited. Evidence of turbidity current origin is given by graded bedding and by the sole markings of the greywacke, the sharp basal contact and the gradational upper contact of the greywackes with the shales.

Underlying the Normanskill is the Deepkill Formation of Lower Ordovician age. This formation consists of an alternating succession of limestones, black graptolitic shales and greywackes.

The Rysedorf Conglomerate appears at the top of the Normanskill Formation and varies from three to 50 feet in thickness. (Ruedemann, 1942).

b) <u>Directional Features</u>

The primary directional features, assumed to indicate the direction of turbidity current flow and to which grain orientation was compared, were the sole features on the base of the greywacke beds.

The sole marks in the area of study fell into three major categories: a) flute marks; b) groove casts; c) chevron marks. (The reader is referred to descriptions of sole marks by Dzulynski and Sanders (1962).)

The groove casts are the most abundant type of sole mark in the

Normanskill. They are seldom found alone, but the flutes and the chevron marks are often found as isolated features.

a) Flute marks.

In the Normanskill several types of flutes are present:

(i) Simple conical types (Rucklin, 1938), blunt at one end and wider and flaring at the other occurred at widely scattered intervals. It was noted that where the flutes were close together they were parallel to each other. The length of these flutes varied from a few inches to two feet. In general the size of these flute marks was observed to be proportional to the thickness of the bed on which they occur.

(ii) Furrow flutes were observed locally. (Fig. 3A)

b) Groove casts in the sequence range in size from numerous faint ridges to smooth and patterned forms more than a foot wide and several inches in depth. They are generally found in association with flute marks. (fig. 3B.)

c) Chevron marks (fig. 4), were seen in two localities only; the process by which these were formed has not yet been determined. In the Austin Glen it may be noted that they were found in association with beds of finer grain than those of the flute and the groove casts. Pellet-like material, coarser grained than the main body of the sediment composing these features, was found in the chevron marks.

The flutes show the direction of the scouring current but it has also been questioned as to whether they represent the direction of transport of the sediment of the overlying bed. Dzulynski and Radomski (1955) are of the opinion that the sole markings were produced by a turbulent current, not a density current. The sediment filling the scours and

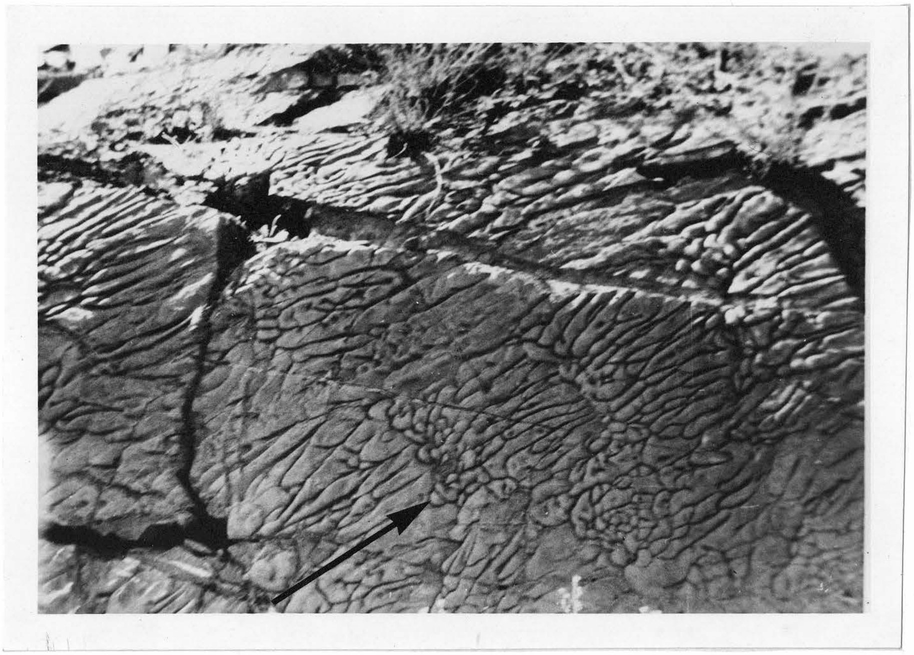


Fig. 3A: Flute casts; highway 9W, 5 miles south of Ravina.

Fig. 3B: Flute casts and groove marks. Locality as above.

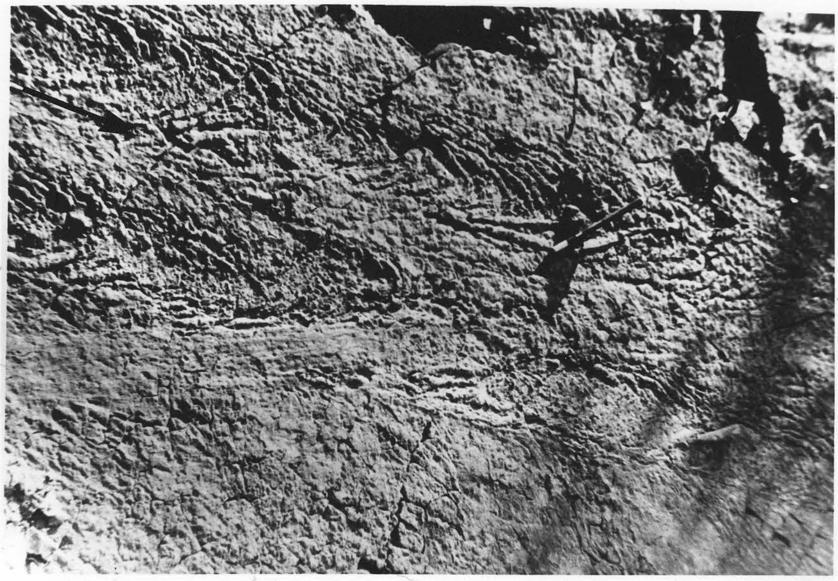


Fig. 4: Chevron marks; the direction of transport is from upper left to middle right.

forming the bed above was deposited by a later current which carried sediment in suspension. Crowell (1958) and Sanders (1963) also favour this view, but it has been contested by Keunen (1957a) and Keunen ten Haaf (1958) on the basis of field evidence. This must be discussed later for it may have important implications in explanation of the results obtained here.

Rucklin (1938) observed flutes to form slightly obliquely to the main current. McBride (1960) noted that some of the largest flutes have deviations of up to 60° from the general trend.

The groove casts do not indicate a specific azimuth of current flow as do the flute marks, rather, they indicate only an orientation. Only when inscribing tools are found do the grooves have a vector quality. Such tools have been found by some workers, but none were found in the Normanskill by the author or by previous workers. Dzulynski and Slacka (1958) noted a small log at the one end of one groove, but the usual agents are small fossils, pebbles and sand grains.

c) Palaeogeography

No detailed study of the structures indicative of current direction was made. However, measurements of flute and groove casts were recorded at several localities. As the greywacke beds are tilted, the flow directions of the turbidites were obtained by reorientation of the bed, under the assumptions that the tectonic rotation was about an axis parallel to the strike; and that folding was concentric. Results (fig. 5) south of Albany show a predominant derivation of sediment from the south. This is in agreement with the results of Smoor (1960) and Middleton (1965). At several localities in the south, for example

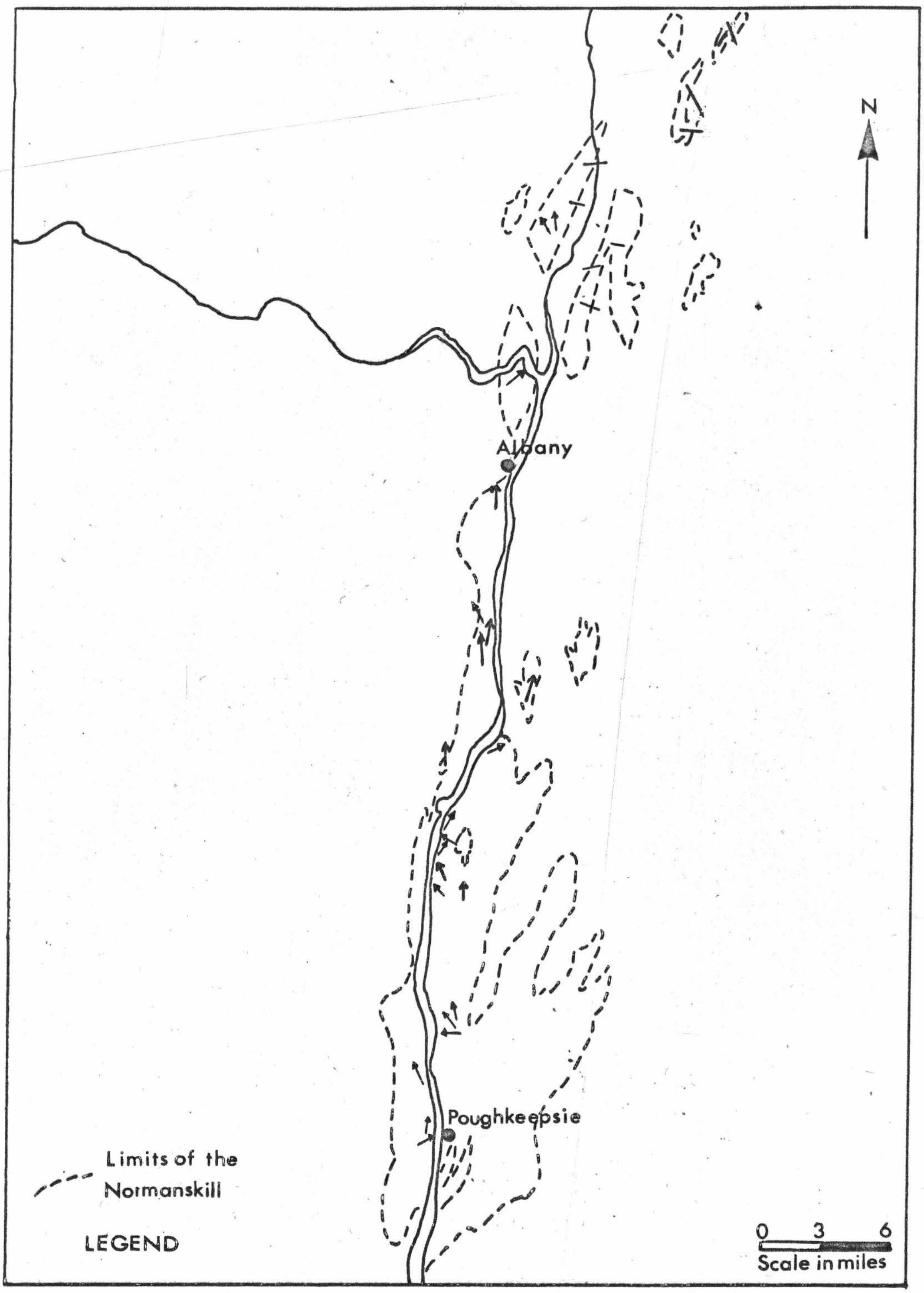


Fig. 5: Palaeocurrent map of the Normanskill Formation.

Rhine-cliff Bridge and Poughkeepsie, two current directions are prominent. This suggests currents both transverse and parallel to the axis of the basin of deposition. It is probable that the turbidity currents initially flowed transversely down the steeper side slopes of the basin, and then, on reaching the basin proper, turned and flowed parallel with the basin axis. The southerly derivation of the sediment is supported by the evidence (Ruedemann, 1942) that the greywackes are thicker and more abundant in the south than in the north.

North of Albany the pattern of the paleocurrents appears somewhat more complex. The sole features found in the area by the writer, afforded, in the majority of cases only an orientation, not a direction. One locality (fig. 6, no. 7) indicates a derivation of the greywackes from the south. Other outcrops in the area furnished an east-west orientation. Middleton (1965) found the flow directions at other outcrops in the area to indicate currents flowing to the north, northeast or east. On this basis one can make the assumption that the east-west groove marks were also formed by a current flowing towards the east.

One can conclude that the currents south of Albany flowed from the south; north of Albany they were deflected towards the northeast quadrant. The apparent easterly trend could possibly be produced by errors in the rotation of the strata about the strike, (Ramsey, 1961) as it has been suggested, (Zen. 1961, et al) that this northern area is allochthonous.

5. PETROGRAPHY

In thin section the Normanskill are seen to consist of poorly sorted quartz, feldspar, and rock fragments set in a microcrystalline matrix. Smoor (1960) found the sediment to be made of five major components; a typical modal analysis (from 23 samples) produced the following results:

Quartz	29.0%
Feldspar	3.3%
Clay and rock fragments	48.0%
Carbonate	19.7%
Heavy minerals	0.9%

The grain size of the quartz is generally less than one millimetre in length; it is angular and subangular and shows slight undulatory extinction on occasion. Interpenetration, of a small percentage of the grains, along mutual grain contacts results in low roundness values and irregular boundaries. The feldspar grains are angular to subangular and have an average grain size of 0.5 mm., that is, less than that of the quartz grains. The rock fragments consist chiefly of shale, schist and limestone; they are rounded to subrounded.

No evidence of the effects of metamorphism are visible in the thin sections, indicating that the preferred grain orientations calculated are of primary origin.

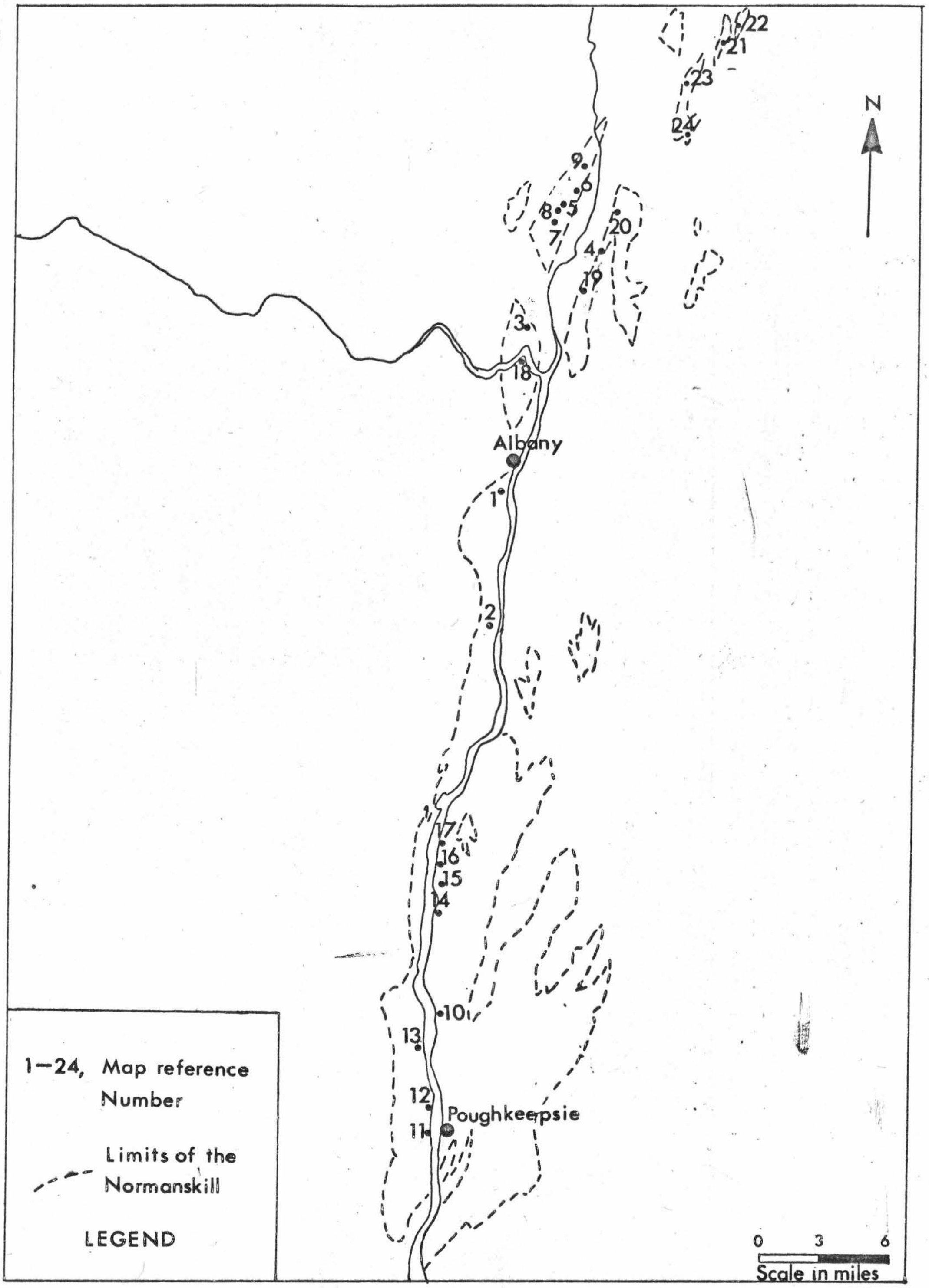


Fig. 6: Sample locations. Precise location and correlation of these numbers with the laboratory numbers is seen in Table 1.

EXPERIMENTAL DESIGN

1. FIELD SAMPLING

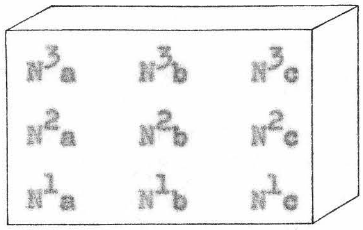
Samples were collected from the field from as wide an area as possible because the majority of similar studies have been somewhat limited in their geographic extent (fig. 6).

Measurements of dip, strike, thickness of bed, and directional features of individual turbidite deposits were taken in the field. The samples were labelled and measurements checked. In areas of good exposure, both lateral and vertical sampling of individual beds possessing recognizable sole features, was carried out. In areas of less good exposure or poor exhibition of sole features only single samples were taken. Not all of the samples were suitable for investigation of grain orientation; during the laboratory study it was found that particularly those samples collected from the tops of the beds possessed a grain size lower than the limits set for the study.

2. NOTE ON THE DIFFERENT NUMBERING SYSTEMS

As several different numbering systems (localities and thin sections) are involved, a short note will help to make their differences clear.

Samples with the prefix GVM or 62 were collected by Dr. G. V. Middleton, those with the prefix D64 were collected by the writer. The number following either of these prefixes is the locality number and the capital letter signifies the bed at that locality. The numbering indicating vertical and lateral sampling is best indicated by a figure.



The small letter indicates the lateral position, and the small number gives the relative vertical position of the sample with respect to those above and below it.

A list correlating the laboratory numbers with the map reference numbers is seen in Table 1.

TABLE 1.

LIST OF LOCALITIES AND CORRESPONDING LABORATORY REFERENCES NUMBERS.

MAP REFERENCE NUMBER	LOCATION	LABORATORY REFERENCE NUMBER
1.	S.W. side of Normanskill west of Old Bridge	D64 - 1 GVM 1
2.	Hwy. 9W, 6 miles south of Ravena.	D64 - 2
3.	Hwy. 146, 2 miles east of Clifton Park.	D64 - 3 GVM 4
4.	Hwy. 40, north of Schagticoke	D64 - 4 62-3
5.	Hwy. 32, 1/2 mile north of Quaker Springs.	D64 - 5 62-10
6.	North end of map reference 5.	D64 - 6
7.	Disused quarry, west of Quaker Springs.	D64 - 7 62-9
8.	Road cut outside above quarry.	D64 - 8
9.	1 - 1½ miles north of Quaker Springs.	D64 - 9 62-11
10.	Road to bridge at Kingston, east side of river.	D64 - 10
11.	Western approach to Poughkeepsie bridge.	D64 - 11.
12.	Hwy. 9W, 10 miles from Poughkeepsie.	D64 - 12
13.	Hussy Hill, hwy. 9W, north of Fort Ewen.	D64 - 13
14.	Tivoli Railway station.	D64 - 14
15.	Minor road between Tivoli and Cheviot.	D64 - 15

TABLE 1, (cont'd)

MAP REFERENCE NUMBER	LOCATION	LABORATORY REFERENCE NUMBER
16.	1/4 mile north of locality number 15.	D64 - 16
17.	Railway cut, south of North Germantown.	D64 - 17
18.	South bank of Mohawk River, west of hwy. 87 bridge.	62-1
19.	Hwy. 40, 0.7 miles south of 4.	62-2
20.	Hwy. 40, 1/2 mile south of North Easton.	62-4
21.	West Pawlett railway depot cut, Vermont.	62-5
22.	Hwy. 30, south of Poultney, south of bridge, Vermont.	62-6
23.	Side road east of South Poultney, Vermont.	62-7
24.	1 mile south of South Poultney, Vermont.	62-8

3. LABORATORY PREPARATION

The direction of strike and dip of the beds and the directional features were clearly drawn on the upper surface of each sample. The bedding of each was then set to the horizontal; samples which possessed an uneven base were set in plaster of Paris to retain the bedding always in the horizontal plane. Each sample was then cored vertically, the diameter of the core being 0.8 inches. The top and bottom of each core was clearly marked. Again, the strike and dip, and the directional measurements were transferred to the upper surface of the core. The base of the core was ground smooth and attached to thin section glass. Measurements on the upper surface were transferred to the glass, (fig. 7A). The core was sawn off near the base and the thin section completed, (fig. 7B). Errors that may have arisen in transferring measurements from the sample to the core, and from the core to the thin section were checked and were no more than $\pm$ 3 degrees. It is essential that the upper surface of the core always be kept up, and that the dip of the strata also be put on the thin section. The dip will give the best check that the thin section does not become inverted. If it does become inverted a mirror image of the grain orientation will result (fig. 7C).

When the direction of grain orientation had been determined, several thin sections were cut (from the core) in a vertical plane parallel to the preferred grain orientation. Care must again be taken to ensure that the thin section is adequately marked.

4. TECHNIQUES OF MEASUREMENTS.

Measurements were made on a petrographic microscope equipped with a cross hair ocular and a mechanical point count stage. The east-

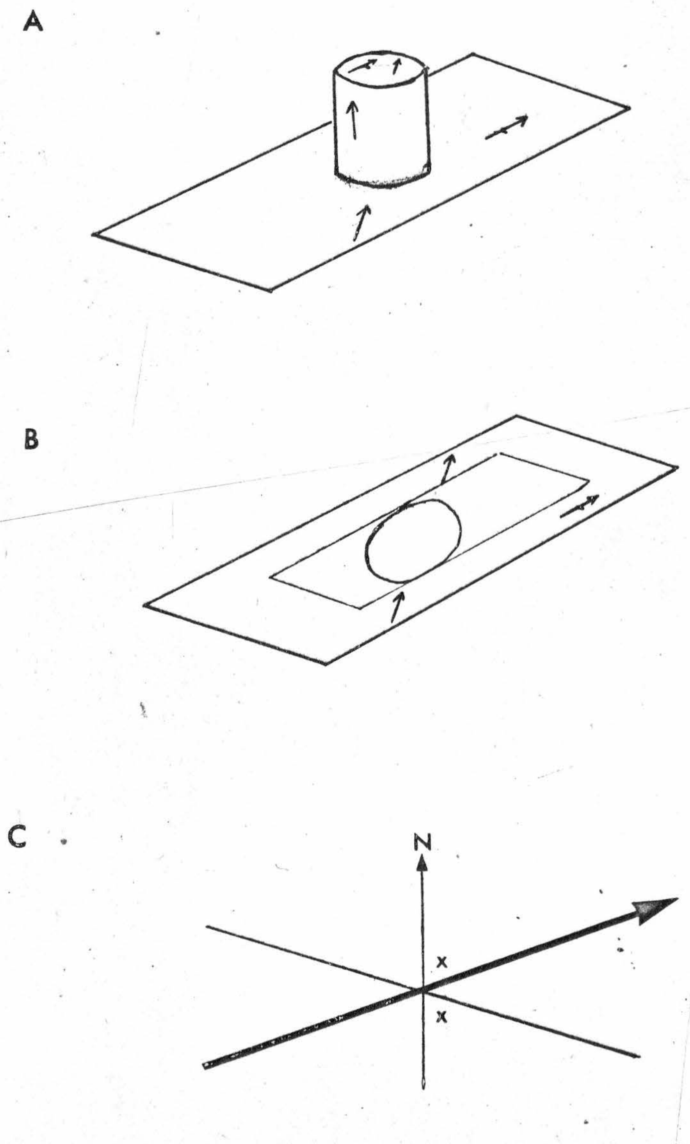


Fig. 7: A, core mounted on microglass; B, completed thin section; C, mirror image of the orientation obtained if the thin section or the core is inverted -- the true vector is x°, the wrong value is (180-x)°.

west cross hair ocular was used as a reference line for the measurements. Measurements were only taken on quartz grains; this conforms with the work done by Smoor, (1960), so that comparisons of the two studies could be made; further, it is important to measure only one mineral as hydrodynamic properties of all minerals vary and no meaningful correlation could be attempted if all the mineral types in a thin section were measured.

The orientation measured was that of the long "a" axis of the quartz grains. The shortest intercept at right angles to the "a" axis is defined as the "b" axis. Only those grains with an "a" axis greater than or equal to 0.1 millimetre, and with an elongation ratio b/a less than or equal to 0.7 were measured. The ratios were estimated visually (except where otherwise stated) with the aid of a figure (Smoor, 1960, p.17.).

Objective selection of the grains was made by point counter; only those grains falling under the cross hairs were measured. Grains under the cross hairs twice were measured twice, i.e., the resulting frequencies are volume frequences.

One hundred measurements were made per thin section; Smoor (1960) had calculated this to be sufficient. Raup and Miesch, (1957) describe a method that can be used in the field to determine the number of measurements of cross strata dip directions, necessary to obtain a significant average direction for an area. This is based on the fact that the number of measurements needed is approximately proportional to their standard deviation. They constructed a table for this purpose. The maximum standard deviation obtained in the present study is 49 degrees. Comparing this with the tables it indicates that the minimum number of grains required in order to obtain a good estimate of the grain orientation is 91. The confidence limits of the resultant vector are $\pm$ 10 degrees.

Size measurements were made on the Shadow Master micro-projector using a grid system for objective choice of grains. Only those grains falling on the intersection of the grid lines were measured. The finest measurement was 5 phi.

Quantitative shape analysis was made on six thin sections by measuring both the long "a" axis and the short "b" axis and determining the ratio b/a, for each grain.

5. GRAPHICAL METHODS

The orientations resulting from each thin section analysis are represented graphically by rose diagrams. The number of readings per 20 degree class interval is calculated and plotted at the centre of that class. The arrow on each diagram represents the direction of flow as indicated by the sole features; the small line represents the vector mean of the grain orientation. Rose diagrams of thin sections taken from the same bed are drawn in their natural relationship with the distance between the thin sections clearly marked.

6. OPERATOR ERROR

As a check on the subjectivity that may arise in such experiments tests were run to determine the magnitude, if any, of operator error in the grain orientation.

(a) Four different operators.

Two thin sections 62 3J2 and 62 3J4, cut from different intervals in the same bed, were examined by four operators -- "P", "D", "G" and "F". They selected and measured one hundred grains in each thin section by point counter. (Grains were measured in the manner described earlier.) After a period of four weeks the experiment was repeated on the same thin sections. The results are seen in Table 2. Orientation distributions are graphically represented in figures 8 and 9.

The data was subjected to an analysis of variance (Dixon and Massey, pp. 163-167). The test was designed to attempt to analyse the following hypotheses:

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

ii) H_2: Thin section effects are zero.

iii) H_3: Operator effects are zero.

The results of the analysis are seen in Table 3.

TABLE 3

Source of Variation	S.S.	df	M.S.	F	$F_{0.95}$
Thin Section	21170.5	1	21170.5	149.83	4.84
Operators	229.5	3	76.5	0.54	3.59
Interaction	82.0	3	27.3	0.24	4.07
Subtotal	21482.0	7			
Unassigned errors	1022.0	8	114.0		
Total	22494.0	15			

TABLE 2.

Operator	62 3J2					62 3J4				
	Trial 1		Trial 2			Trial 1		Trial 2		
	θ	L	θ	L	$\Delta\theta$	θ	L	θ	L	$\Delta\theta$
P	46	41.2	41	26.8	5	107	18.5	116	17.9	9
D	43	21.3	33	19.5	10	115	23.3	114	26.9	1
G	30	0.9	71	8.3	41	116	30.3	122	33.6	6
F	39	24.7	33	20.6	6	118	20.3	110	30.7	8
Average	37.7	22.0	46	18.8	15.5	114	23.3	113	27.7	6.0

ORIENTATION FREQUENCY DIAGRAMS ON SECTION

623J2 BY FOUR OPERATORS

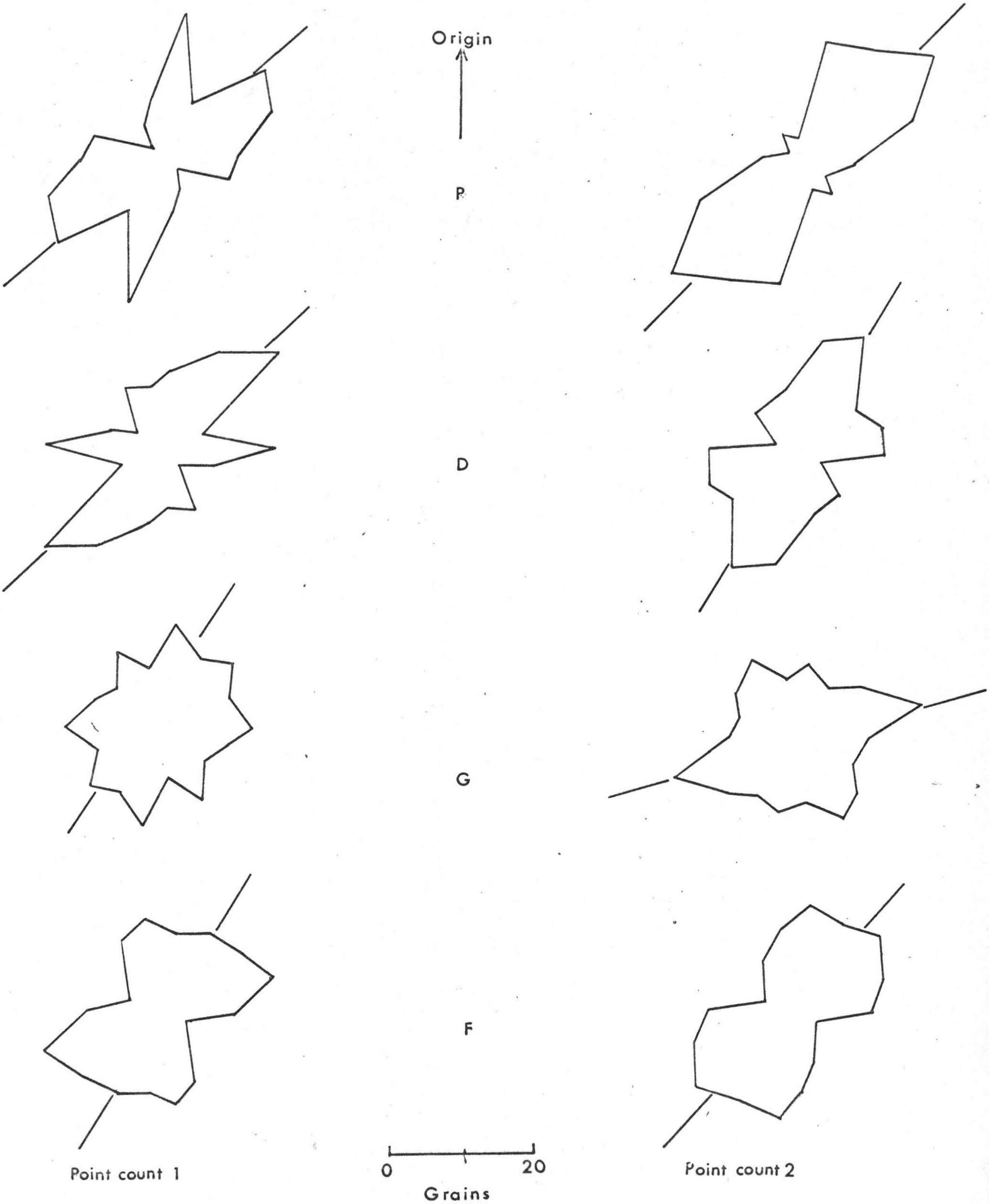


Figure 8

ORIENTATION FREQUENCY DIAGRAMS ON SECTION

623J4 BY FOUR OPERATORS

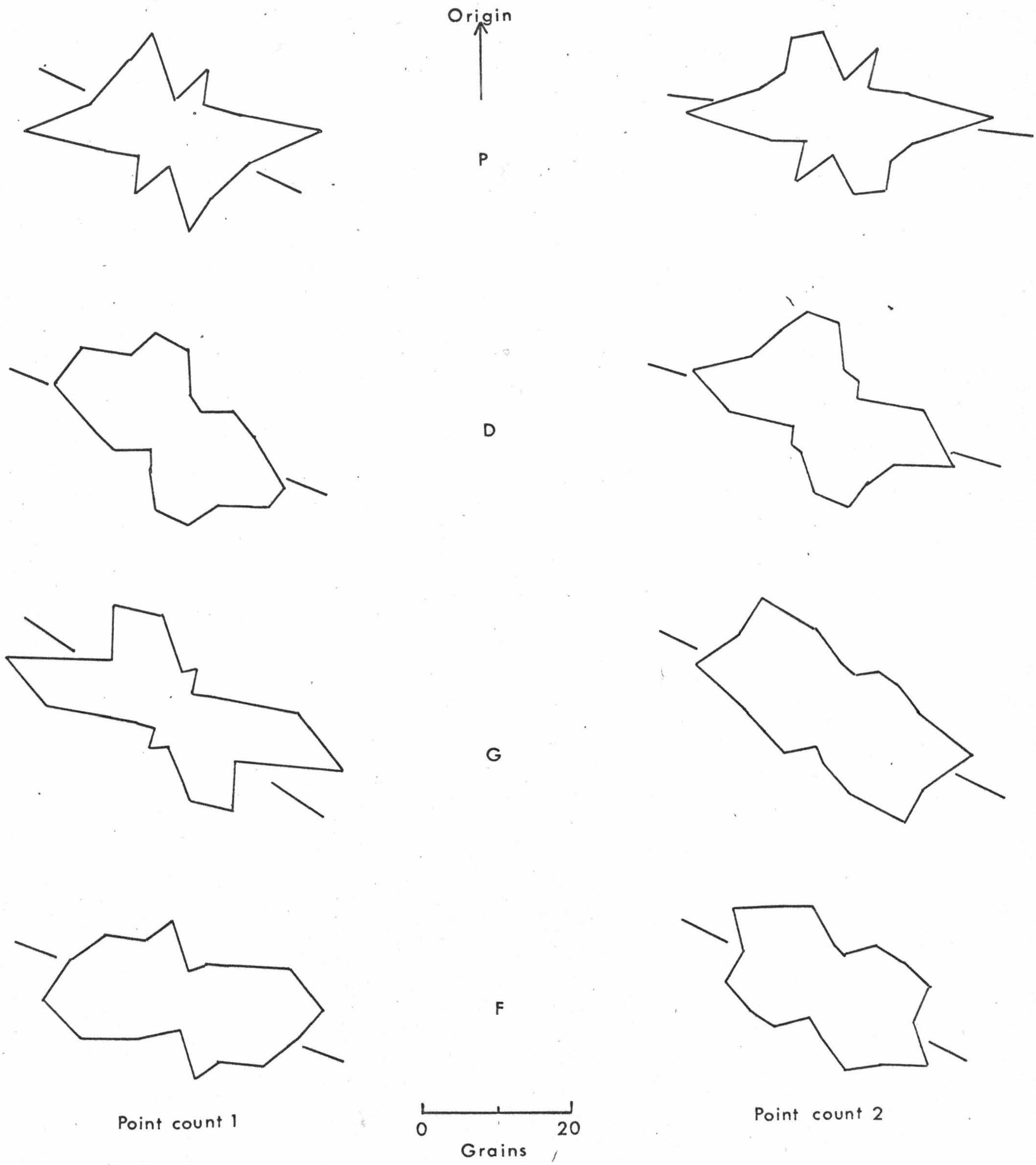


Figure 9.

The tests indicated that there was no interaction. This is graphically represented by plotting the circular means and the measures of dispersion against the operators. (figs. 10 and 11.) In section 62 3J2, operator P is consistently above the mean value of both the orientation and the dispersion. All results of operator D lie around the mean values. In section 62 3J2 operator G is inconsistent in his orientation measurements and also shows the maximum dispersion. In 62 3J4 his measurements are consistently above the average for both orientation and dispersion. Operator F shows dispersion values a little above the average; his orientation results are scattered around the average. Operators P and D had had previous experience in this type of experiment, while it was the first time that operators G and F had attempted such measurements.

On the basis of the analysis we may accept H_1. Testing H_2 indicates that the thin section effects are not zero; this was realized before the experiment was undertaken. The third hypothesis is accepted: there is no operator effect.

A further test was done on the consistency of the operators. Use was made of the statistic

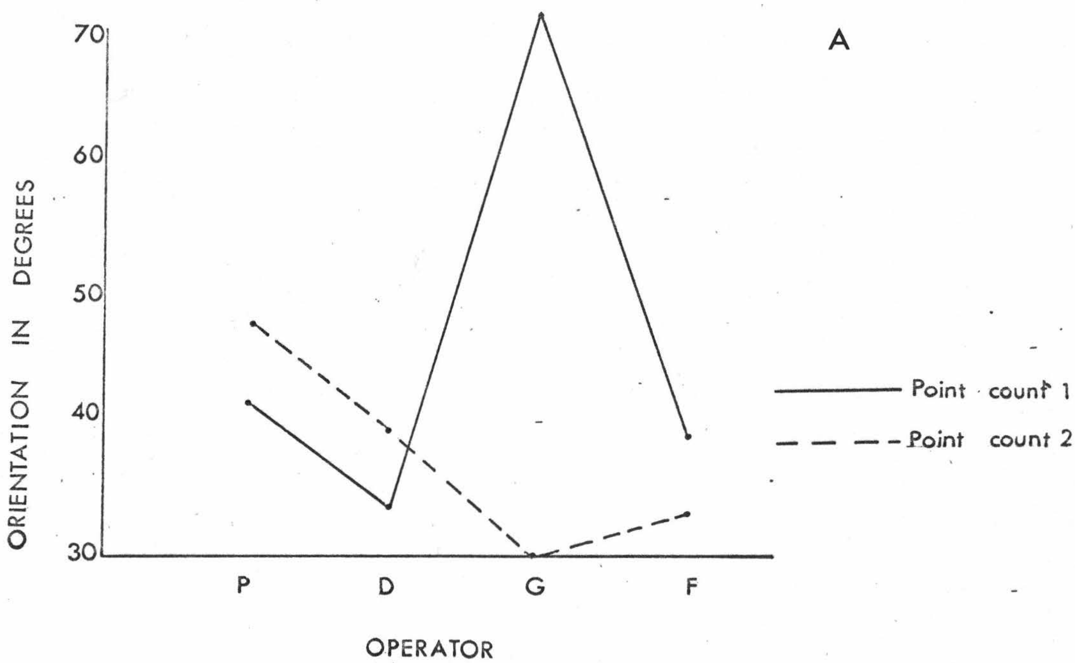
$$t = \frac{\bar{D}}{S_{\bar{D}}} \qquad \text{(Ostle, p. 121)}$$

Where $\bar{D}$ = the average difference of the two measurements made by the operators

$S_{\bar{D}}$ = the standard deviation of these differences.

This showed that there was no significant difference between the paired values at the 90 per cent level.

SECTION 623J2



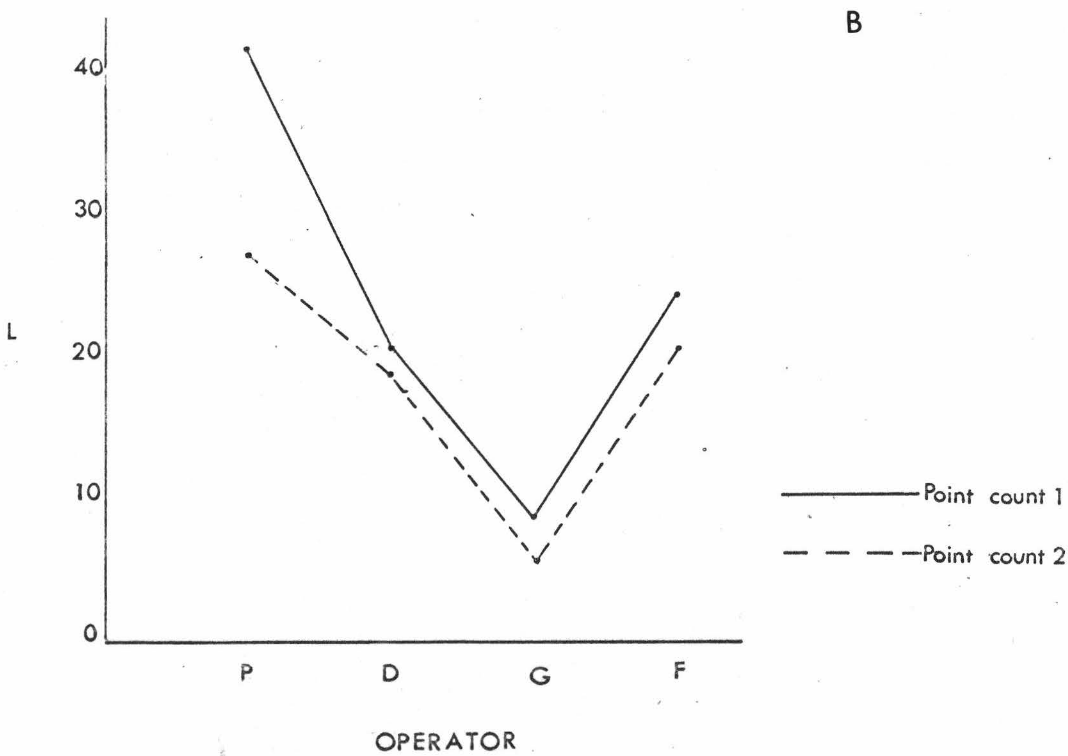
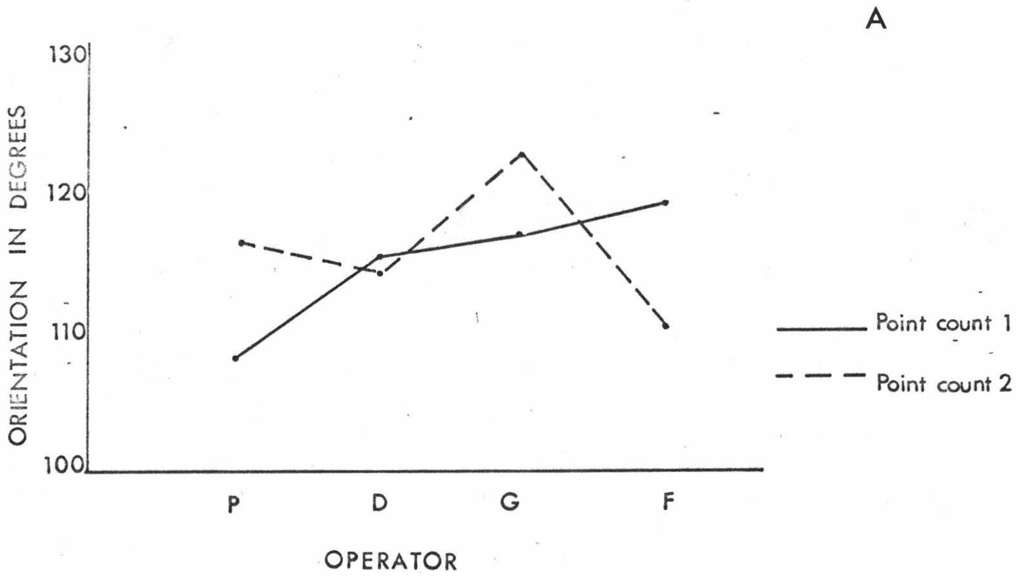


Fig. 10: Thin section X operators for circular mean orientation (upper graph) and for circular dispersion (lower graph).

SECTION 623J4



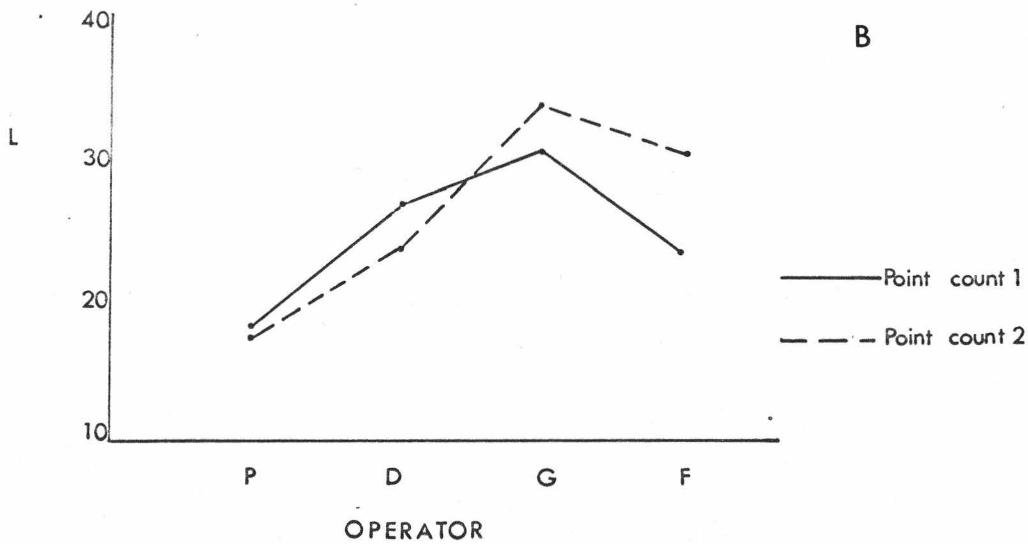


Fig. 11: Thin section X operators for circular mean orientation (upper graph) and for circular dispersion (lower graph).

The error of the circular mean preferred orientation $\bar{\theta}_m$ of all the different operators is expressed by the confidence limits within which 95% of all future determinations made on the same slide by the same operator will be. The grand mean $\bar{\theta}_m$ is the best possible estimate for the mean.

The confidence intervals for the overall mean were calculated; these indicate how sure one can be that the true population mean θ_m is known from $\bar{\bar{\theta}}_m$. They are calculated from the formula:

$$\bar{\bar{\theta}}_m \pm t_{(N-1)(1-\alpha/2)} \cdot \frac{S}{\sqrt{N}}$$

where N = the number of operators

S = the standard deviation.

In thin section 62 3J2, trial 1 shows these intervals at the 95% probability level to be $37.7° \pm 9.6°$, in trial 2, $46° \pm 9.2°$; section 62 3J4 trial 1 has confidence intervals of $114° \pm 8.8°$, trial 2, $113° \pm 8.8°$. Confidence limits for the experiment as a whole are $\bar{\theta}_m \pm 8.9°$.

(b) Duplication analysis on the same microscope

In order to evaluate the consistency of the writer in determining grain orientation five thin sections were analyzed in duplicate. The time interval between the first and last analysis was of the order of eight weeks. The orientation distributions are plotted in Figure 12. Figures 13A, 13B show the mean and dispersions plotted against the thin sections. The resulting data are shown in Table 4.

TABLE 4.

Thin Section	Point count 1		Point count 2		
	θ	L	θ	L	$\Delta\theta$
62 5A(3)	42	41.2	34	37.3	8
62 3J4	114	26.9	115	23.3	1
62 3J2	35	16.6	32	19.5	3
62 2B	179	16.3	163	15.2	16
D64 3C^{1}a	84	52.0	79	36.2	5
					6.8

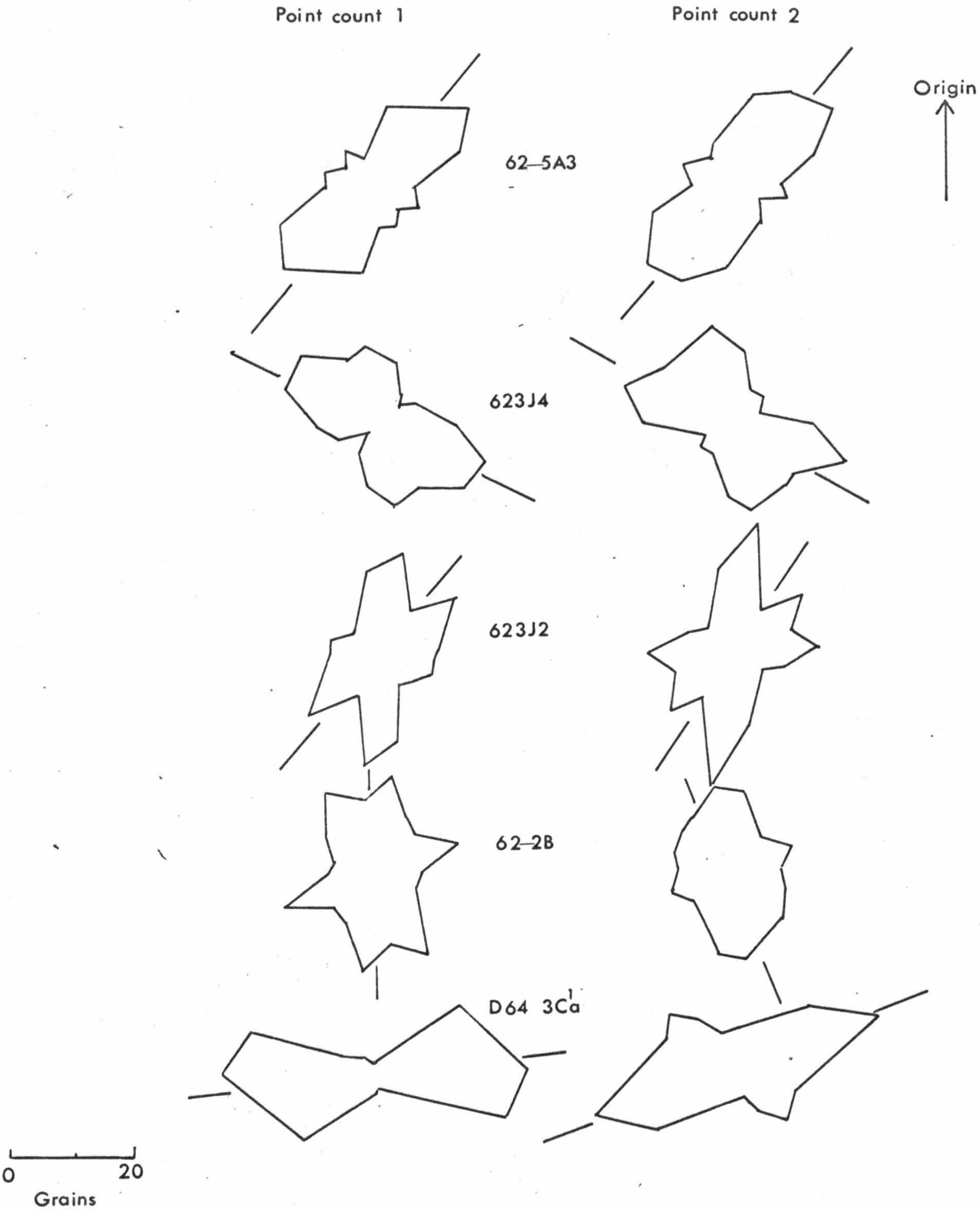
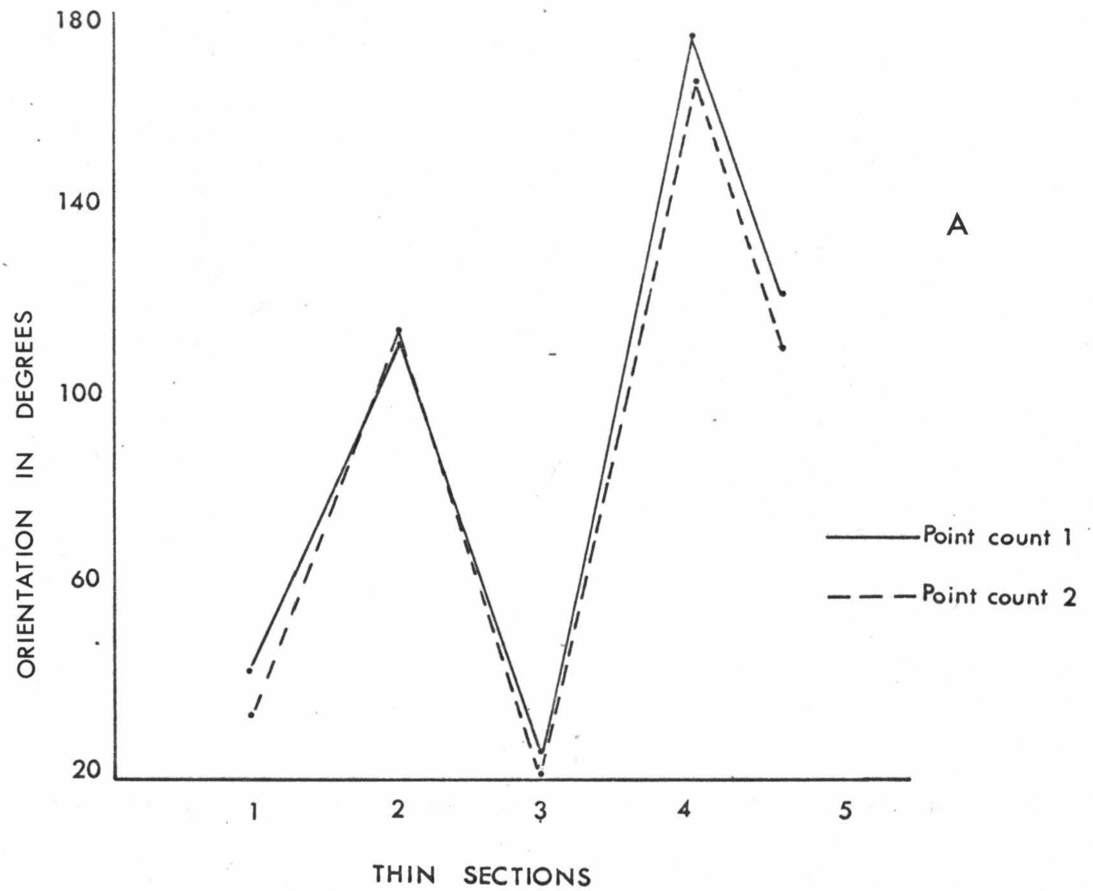
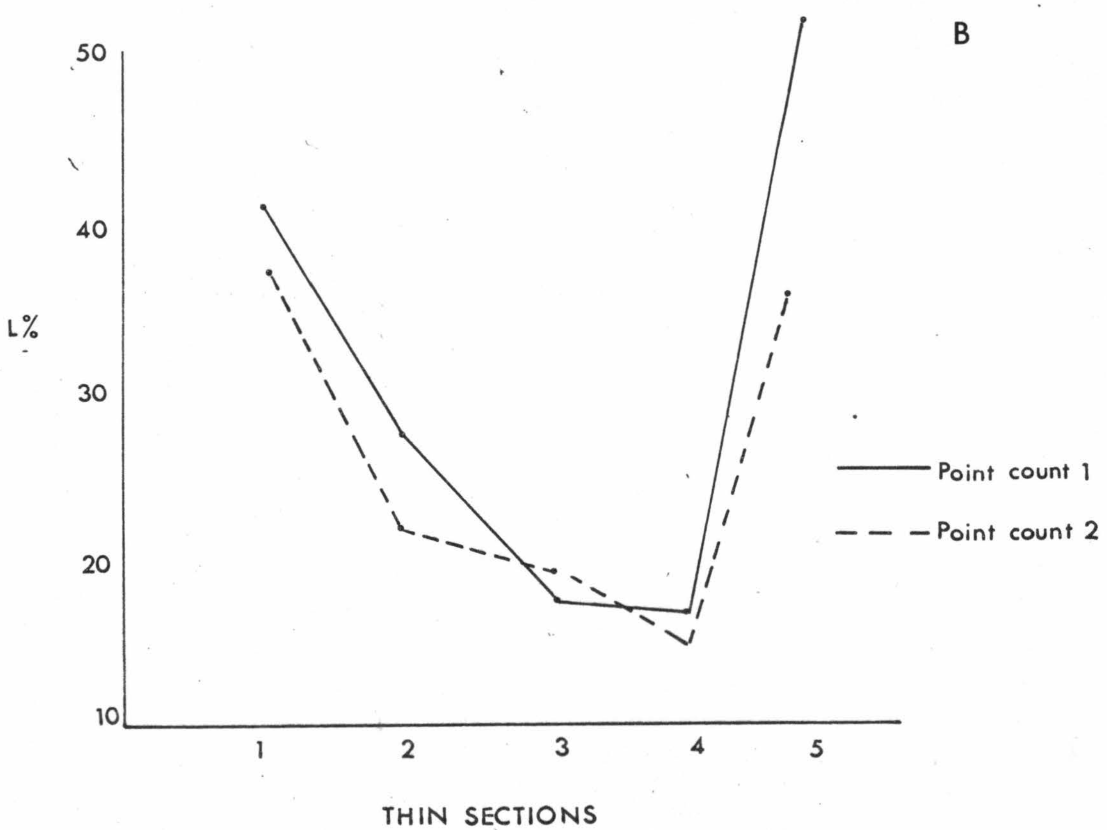


Fig. 12: Orientation frequency distributions for duplicate analysis on five thin sections.

Fig. 13: Circular means (upper graph) and dispersions (lower graph) for five thin sections.


180
140
100
60
20
ORIENTATION IN DEGREES
A
Point count 1
Point count 2
1
2
3
4
5
THIN SECTIONS


B
50
40
30
20
10
L%
Point count 1
Point count 2
1
2
3
4
5
THIN SECTIONS

A $\underline{t}$ - test for paired observations (Ostle p. 121) was run on the data. The value of $\underline{t}$ for the above data is 0.026. Therefore the hypothesis, that the means are equal, was accepted.

The data was also subjected to an analysis of variance. (Table 5).

TABLE 5.

	SS	df	MS	F	$F_{0.95}$
Between point counts	96.1	1	96.1	0.19	5.99
Between thin sections	26702.6	4	6676.6	83.2	4.53
Residual	481.4	6	80.2		
Total	26384.1	11			

This indicated that there was no difference between the vector means. This is in agreement with the results obtained from the $\underline{t}$ - test.

Confidence limits were calculated as before; these limits for the whole experiment are $\bar{\theta}_m \pm 8.6°$.

(c) <u>Duplidation analysis on different microscopes</u>.

A further duplication analysis was done on six thin sections taken from the same bed. The analysis was performed in duplicate on these sections, using two different microscopes, the first was that utilized throughout the study using a X50 magnification. The second was a binocular microscope with X125 magnification. The purpose behind the experiment was that it was thought that the smaller grains approaching 0.1 millimetres in length were perhaps being avoided on the first measurements. The results are tabulated in Table 6, and the distributions are graphically represented in Figure 14.

TABLE 6.

Thin section	Point count 1		Point count 2		
	θ	L	θ	L	$\Delta\theta$
$4N^1b$	128	8.5	99	27.9	29
$4N^2b$	144	34.7	122	13.9	22
$4N^3b$	136	33.9	138	36.9	2
$4N^1c$	140	13.8	99	10.7	41
$4N^2c$	167	37.9	182	30.8	15
$4N^3c$	60	32.5	90	26.5	30
					Av. 23

The results were subjected to a t - test as before. The hypothesis that the means are equal is accepted.

An analysis of variance was run on the data. The results are seen in Table 7.

TABLE 7.

Source of Error	SS	df	MS	F	$F_{0.95}$
Row means	12622.8	5	2525.5	4.1	5.05
Column means	50.4	1	50.4	0.8	6.61
Residual	3017.1	5	603.4		
Total	15690.3	11			

The hypothesis that the vector means are equal is accepted.

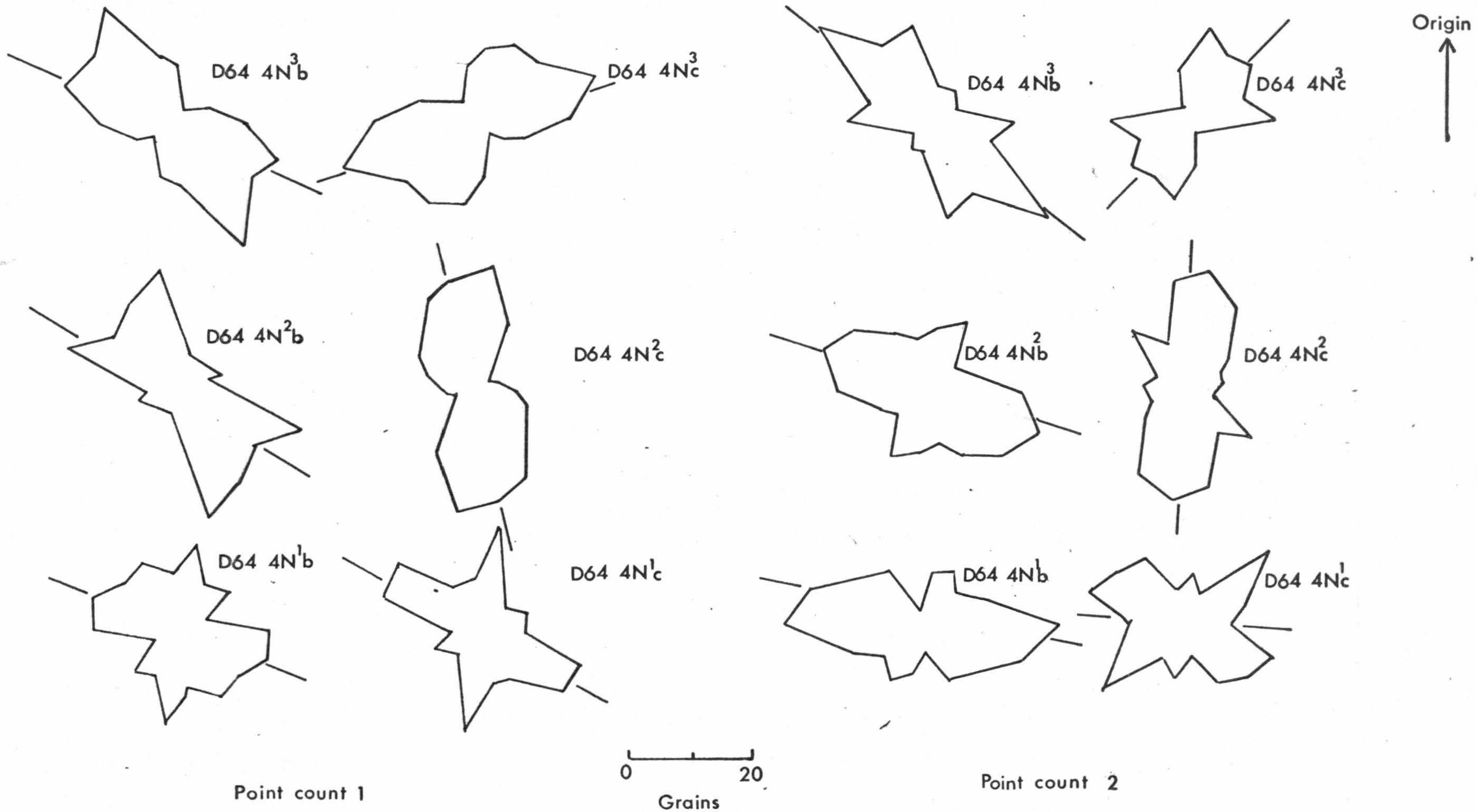


Fig. 14: Orientation frequency distributions measured in duplicate on six thin sections.

It can be seen that there is an increase in the degree of bimodality of the distributions on the second point count. (Fig. 14). It is possible that this represents the vector means of the smaller grains, which have possibly a different orientation than the larger grains. Confidence limits for this experiment were $\bar{\theta}_m \pm 8.6°$.

(d) Discussion.

The confidence limits for the three experiments fall close together, being respectively $\theta_m \pm 8.9°$, $\theta_m \pm 8.6°$, and $\theta_m \pm 8.6°$.

A measure of personal consistency can be qualitatively judged by comparing $\Delta\theta$ (that is, the differences between the two values of θ obtained for each thin section.) with the confidence limits. Only one thin section, (Table 4), out of five, has a vector mean whose difference is greater than the confidence limit. This particular thin section 62 2B has a non-significant orientation at the 90% level. The average $\Delta\theta$ for that whole experiment was 6.8°, well within the confidence limits of $\theta_m \pm 8.6°$.

The measure of consistency using two microscopes was poor, ($\Delta\theta$ = 23°) because a further variable had been brought in. The average confidence limits for this experiment are $\theta_m \pm 8.6°$. Table 6 indicates that only one thin section out of six fell within these limits. It is noticeable that the coarser sections, $4N^1b$ and $4N^1c$, taken at the base of the bed show very high values of $\Delta\theta$. This may be due to the fact that in point count 1, with a lower powered lense, the smaller fraction was not counted. Although the data indicates that the differences here are great, examination of figure 14, indicates that the pattern of orientation and the general vector direction does not vary as much as Table 6 suggests.

The average confidence limits for the first experiment are $\theta_m \pm 8.9°$, and $\Delta\theta = 10.7°$. The values of these obtained by the writer in the second experiment are lower. These indicate that the writer's measurements can be considered accurate as well as consistent. A further test of consistency and accuracy is furnished in the first experiment by comparing the author's values with those of the three other operators.

Smoor (1960) ran a similar experiment to the first one here described, using five operators instead of four. His value of average $\Delta\theta$ is 6.3°, and his average confidence limits $\bar{\theta}_m \pm 12.7°$. His duplication analysis resulted in average $\Delta\theta$ of 5.2° and the confidence interval, $\bar{\theta}_m \pm 7.6°$. The average $\Delta\theta$ is somewhat lower than that in the present experiments, but the measure of dispersion of the data in the present study is somewhat greater than that of Smoor's, which will account for the higher values of $\Delta\theta$.

In summary, any difference in vector means of less than 9° can be considered as non-significant, if the orientations being compared are statistically significant at the 90% level.

RESULTS

1. GENERAL STATEMENT OF ORDER

Initially, single thin sections, cut in the plane parallel to bedding, were studied in each bed. These showed no correlation with, or consistent deviation from the azimuth of the sole features. Beds were then examined both laterally and vertically in an attempt to explain the lack of correlation; but it was found that with this method of sampling too, the deviations of the grain orientation from the sole features were inconsistent both in a vertical and a lateral sense. Only a few beds show any consistent deviation of the grain orientation from the sole mark.

Where a good preferred orientation was found, a section was cut in the plane parallel to this and normal to bedding, in order to measure imbrication of the grains.

2. ORIENTATIONS IN THE BEDDING PLANE

a) Deviation from the sole.

Of eighty-five thin sections cut parallel with the bedding plane no constant relationship between the grain orientation and the sole features could be discerned. Only 14% showed no statistical deviation from the sole. Forty per cent of the thin sections demonstrated an anticlockwise deviation from the sole, sixty per cent were clockwise.

Figure 15 shows the deviation of each significantly preferred orientation from the sole mark near the point at which each section was made. There is an obvious absence of deviations in the -70° to -90° anticlockwise range. From -70° to +90° there is no obvious evidence of clustering, suggesting that there is no singularly preferred deviation. This is in disagreement with the work of Spotts (1964) who found the mean preferred orientation to deviate more or less constantly by 40 to 60 degrees from the sole marks.

Sections cut from different beds at the same locality generally show only one or other sense of deviation. Sections cut at locality 62 11 (Fig. 16) all show a definite anticlockwise movement from the sole, with the angular divergence being 25 to 75 degrees. Samples from outcrop GVM4 (Fig. 16) show less consistent deviations. All these sections were cut 4 centimetres above the base of each bed studied. The deviation of b, at this particular horizon in the bed can be considered zero, as it falls within the confidence limits stated in the test run for operator error. Other examples are shown in Figure 17. Sections from 62 11 and 62 2 both demonstrate an anticlockwise deviation; 62 9 has a clockwise sense of rotation; sections from localities GVM4 and 62 10 show both senses of deviation.

The results show that each locality has a tendency to possess only one sense of deviation of the grain orientation from the sole marks, but this may be due to the small sample size, as series of samples taken vertically from within a bed show both senses of deviation from the sole marks.

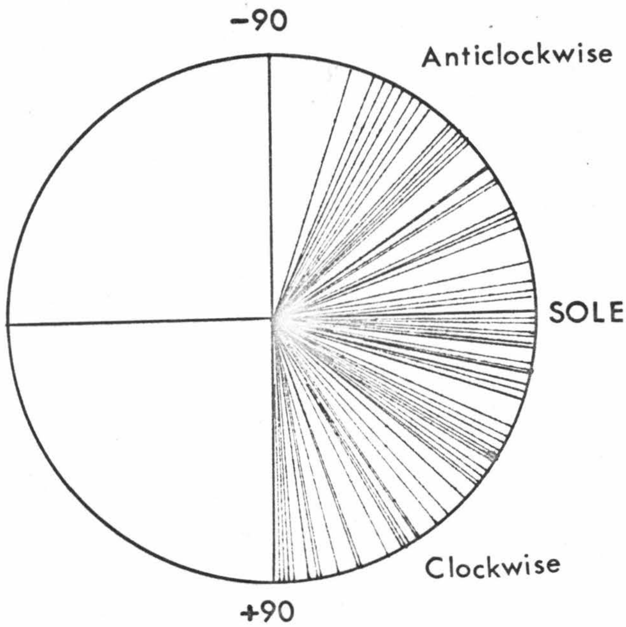
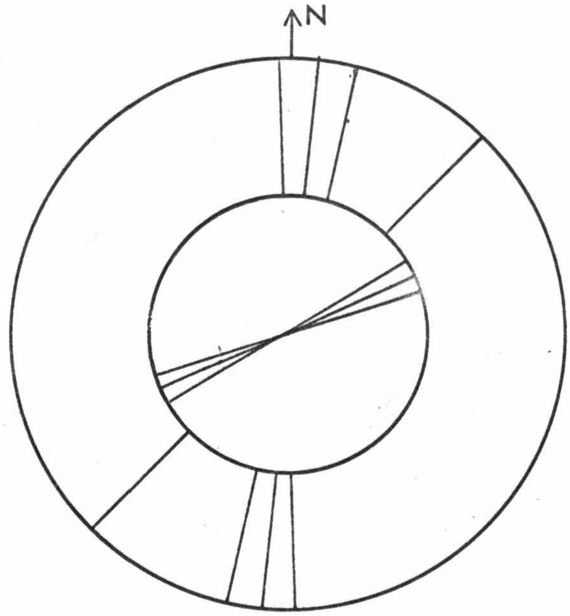
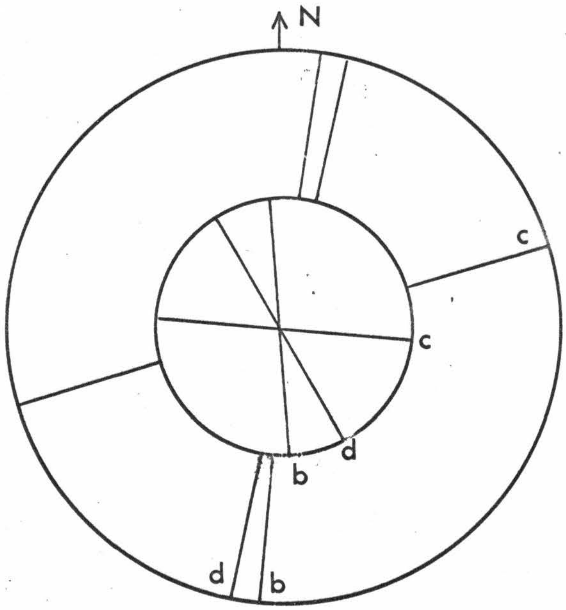


Fig. 15: Deviation of all significantly preferred grain orientations from the sole features.



62 11



GVM 4

Fig. 16: Current directions in the outcrops 62 11 and GVM 4, as indicated by the sole features (inner circle), and by the preferred orientation of quartz grains in thin section (outer circle). Each line represents measurements taken from different beds at each locality.

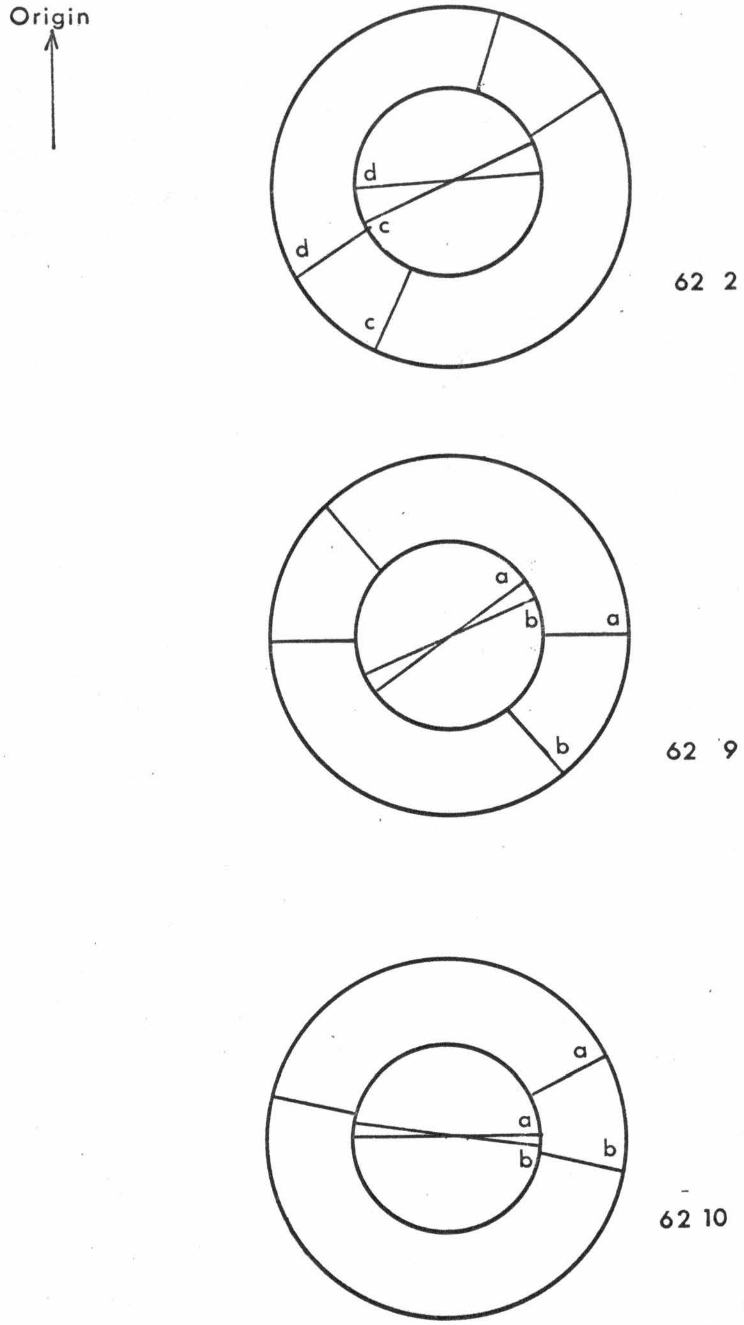


Fig. 17: Current directions in the outcrops 62-2, 62-9 and 62-10, as indicated by the sole features (inner circle) and the preferred orientation of quartz grains in thin section (outer circle). Each line represents measurements taken from different beds at each locality.

b) Deviation with relation to height above the bed.

The relationship of thin sections cut from individual beds at different vertical intervals showed no consistent pattern.

Inasmuch as orientation within different beds of different thickness had to be compared, the percentage height above the base of the bed was determined for each analyzed thin section. For all thin sections the deviation of the grain orientation from the sole features was plotted against the percentage height at which the thin section was cut. (Fig. 18). This tends to indicate that the maximum deviation generally occurred at the base of the bed. In the upper portions of the bed there is a greater tendency to clustering closer to the sole azimuth. This may be due to the lower sample size taken at this height; only seven thin sections above the 90% height were suitable for analysis, since others at this height possessed a grain size lower than the limits set for the study.

Figure 19 demonstrates that the deviations upward in a bed do not follow a single pattern. Each bed was found to have its own peculiar relationships at different heights above the base of the bed. Deviations with respect to the sole vary from clockwise to anticlockwise within individual beds. At the base of the bed, where maximum deviations tend to occur, the highest percentage of non-significantly preferred orientations is also found. This maximum deviation at the base could be explained by the interference of microrelief on the underlying beds or by the high intensity of turbulence in this portion of the history of the current.

The aforegoing considered only the sense of deviation of the grain orientation with respect to the sole marks. The sense of rotation

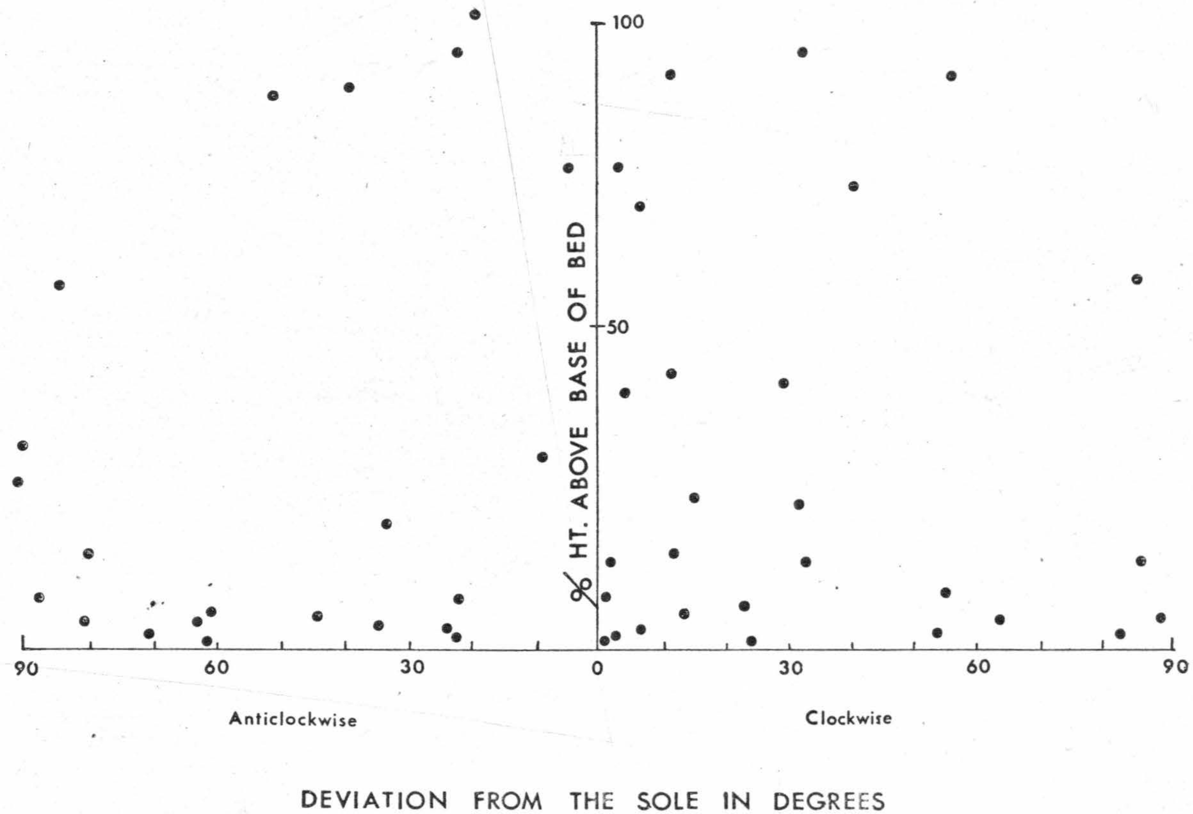


Fig. 18: Deviation of grain orientation from the sole with relation to height above the beds.

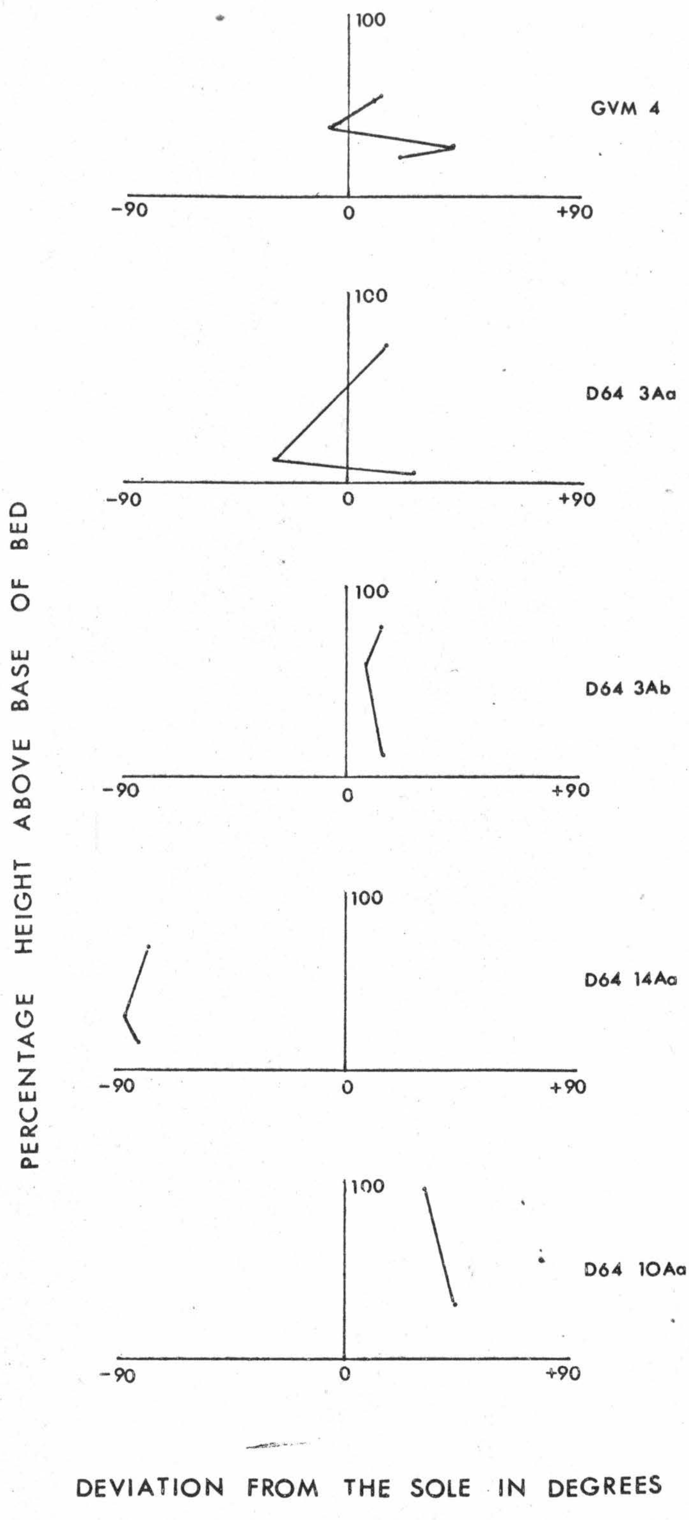


Fig. 19: Deviations of the grain orientation from the sole, in different beds, at different heights within the beds.

from one vector mean with respect to another can also be considered. An example is afforded by sections cut from bed 62 3J (Fig. 20), 27 cms. thick and having flow markings on the base at 67°. The first section, cut at two centimetres above the base, has a preferred orientation of 155°, giving a clockwise deviation of 88° from the sole marks. The second thin section at 10 centimetres above the base, resulted in a vector mean of 41°, which is an anticlockwise deviation of 26° from the sole, and 66° clockwise from the previous section. (Considering only a deviation of maximum 90°.) The third section cut at 18 centimetres above the base gave a value of 130°, clockwise from the sole by 73° and normal to the previous section. Finally the fourth section has a clockwise deviation of 43° from the sole but 20° from the third section.

These data suggest that single samples taken from a bed do not give a true representative orientation of the bed. In the present study one cannot even confidently interpolate the orientation between the heights at which the vector means have been calculated.

Another example is served by sections cut from bed D64 3A. (Fig. 21) The lowest thin section cut at 4 centimetres above the base of the bed, total thickness 180 centimetres, has a mean vector of $(89 \pm 8)°$ clockwise $(23 \pm 8)°$ from the sole. The second is at $(19 \pm 8)°$, anticlockwise from the sole and the previous section. The third is bimodal with a vector mean of $(72 \pm 9)°$, clockwise from the sole and the second section.

Similar examples were found throughout the study. Without giving further evidence, those illustrated here adequately indicate

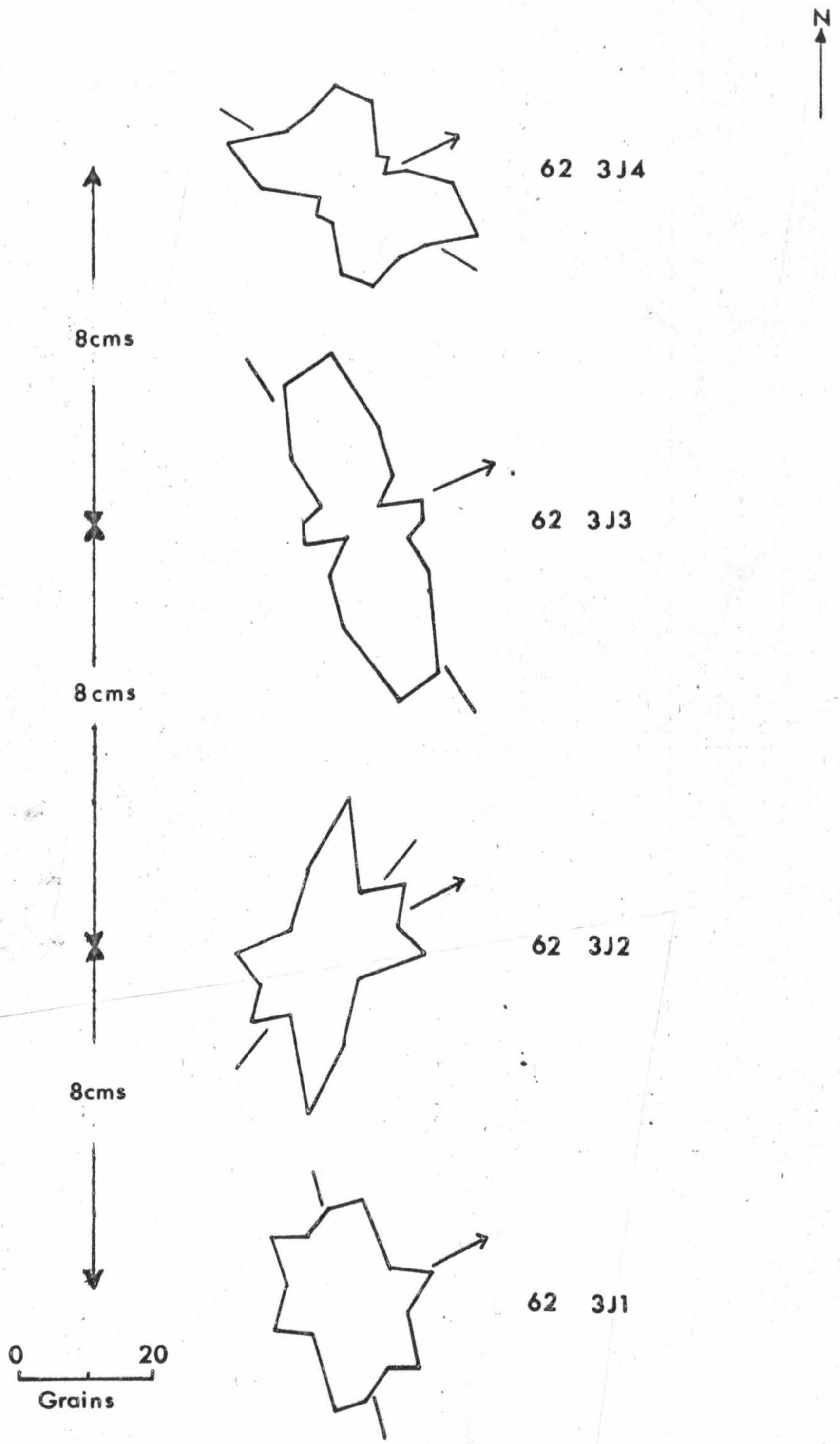


Fig. 20: Orientation frequency distributions in bed 62 3J.

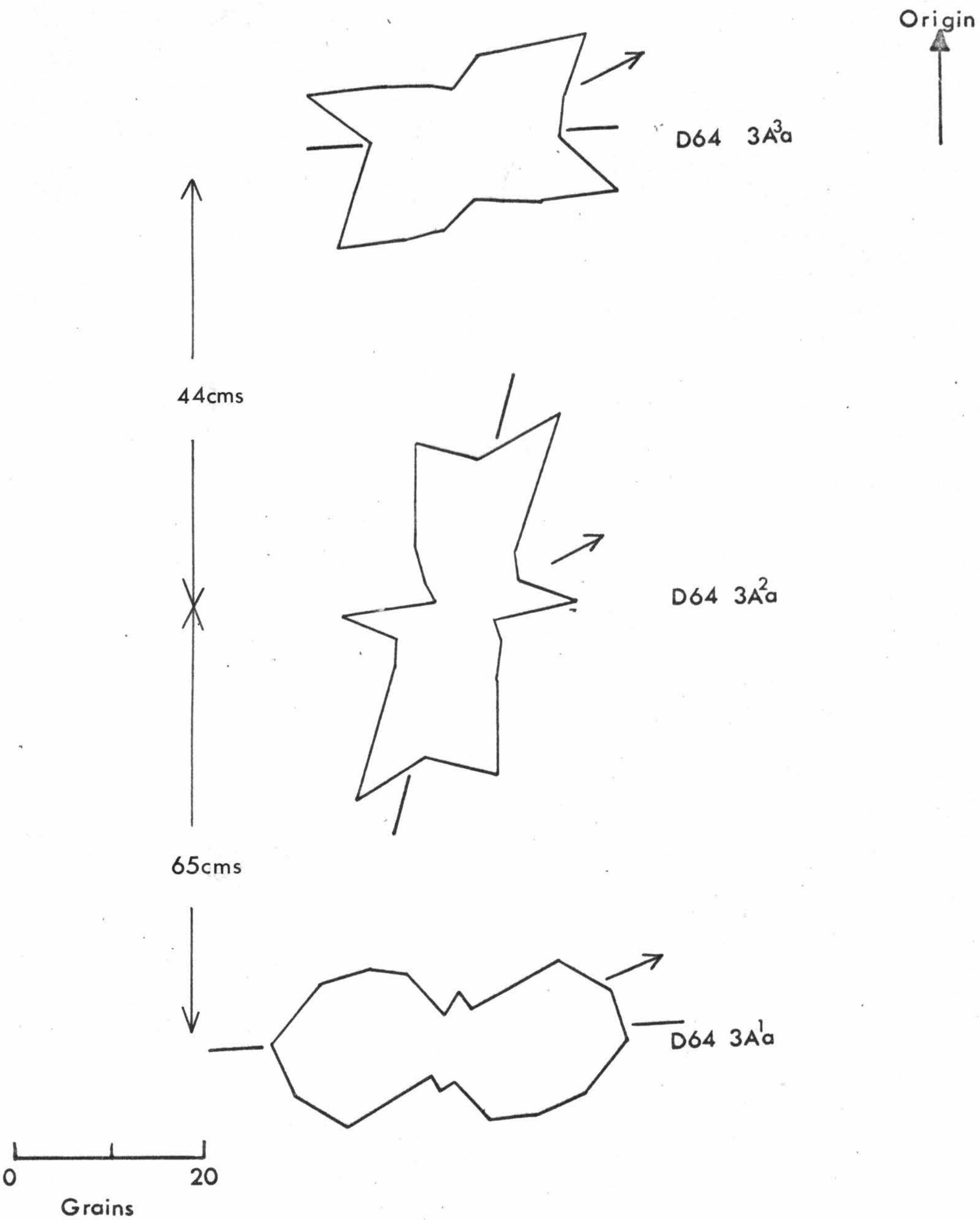


Fig. 21: Orientation frequency distributions for three sections cut from bed D64 3A.

lack of any relationship of grain orientation with the sole upwards through a turbidite bed.

c) Orientation of samples at closely spaced intervals.

Thin sections were cut from levels at only a few centimetres above each other within a bed. Sections from D64 14A, D64 15A and D64 16A serve as examples. The mean orientations cut from 15A are not significantly different from a uniform distribution at the 90° level; the vector mean of $15A^1b$ is $(131.9 \pm 9.6)°$, and of $15A^2b$, 3 centimetres above is $(148.5 \pm 9.6)°$, thus varying only by 17°. (Fig. 22). The lower section has a stronger bimodality than the upper, though they are both bimodal in the same direction. Sections from D64 16A both possess a significantly preferred orientation (Fig. 23). The vector means are $(186.1 \pm 7.8)°$ and $(201.3 \pm 7.8)°$, differing only by 15°. As found in the sections from D64 15Ab, sections from D64 14Aa also show a high degree of dispersion. Yet, comparable orientations are observed in the 3 sections cut at 3, 7 and 13 centimetres above the base of a bed, 19 centimetres thick. (Fig. 24).

From bed D64 17A (Fig. 25) four thin sections were cut at 3 centimetres above each other. The sample possessed two definite and different flow marks on the base; one, a large flute at 108°, and the other, groove casts at 333°. The first section was cut 2 centimetres above the deepest portion of the flute cast. This section had a vector mean of $(87 \pm 9.7)°$, also almost paralleling the direction of the same bottom mark. The first section taken above the flute and in the main body of the turbidite deposit, shows a sudden deviation from the lower fabrics, having a vector mean of $(342 \pm 9)°$, now approximating the orientation of the grooves. (333°). A^4a has a resultant vector of $(20 \pm 9)°$ which corresponds with

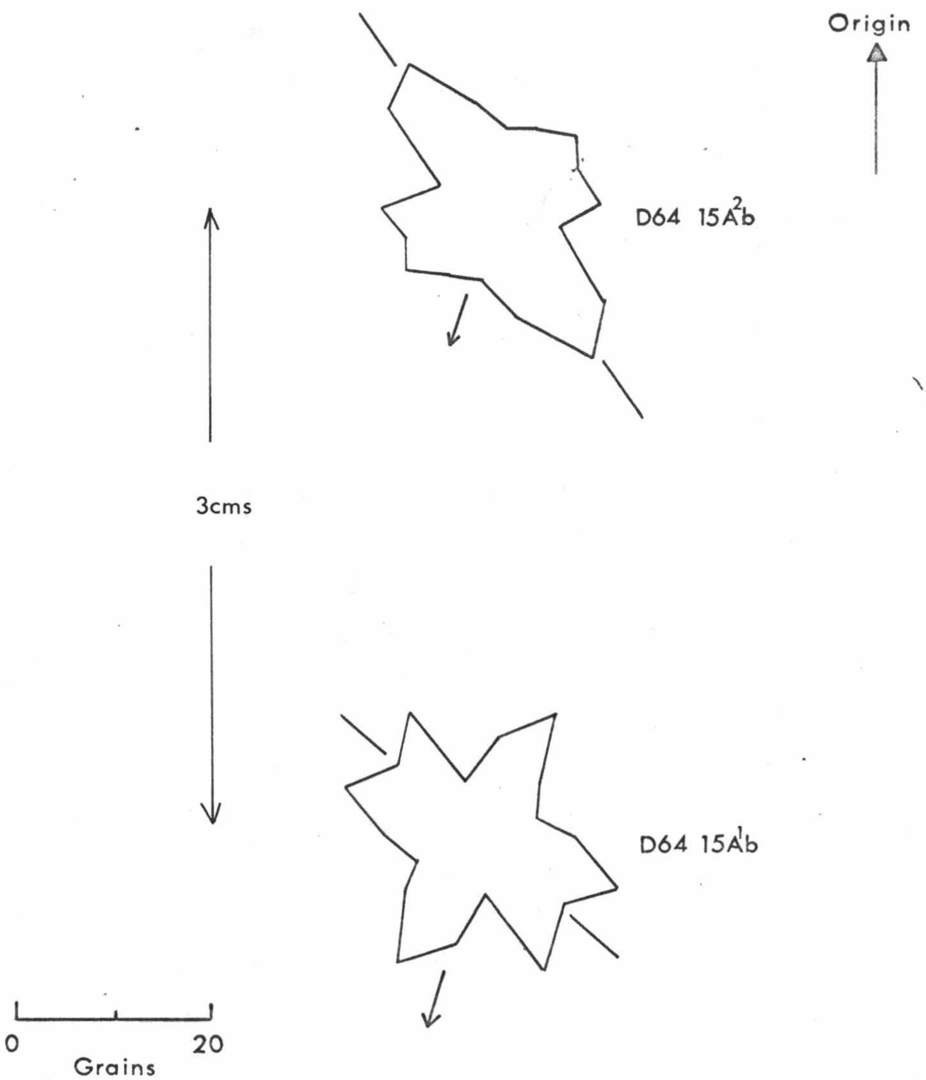


Fig. 22: Orientation frequency distributions of two thin sections from bed D64 15A.

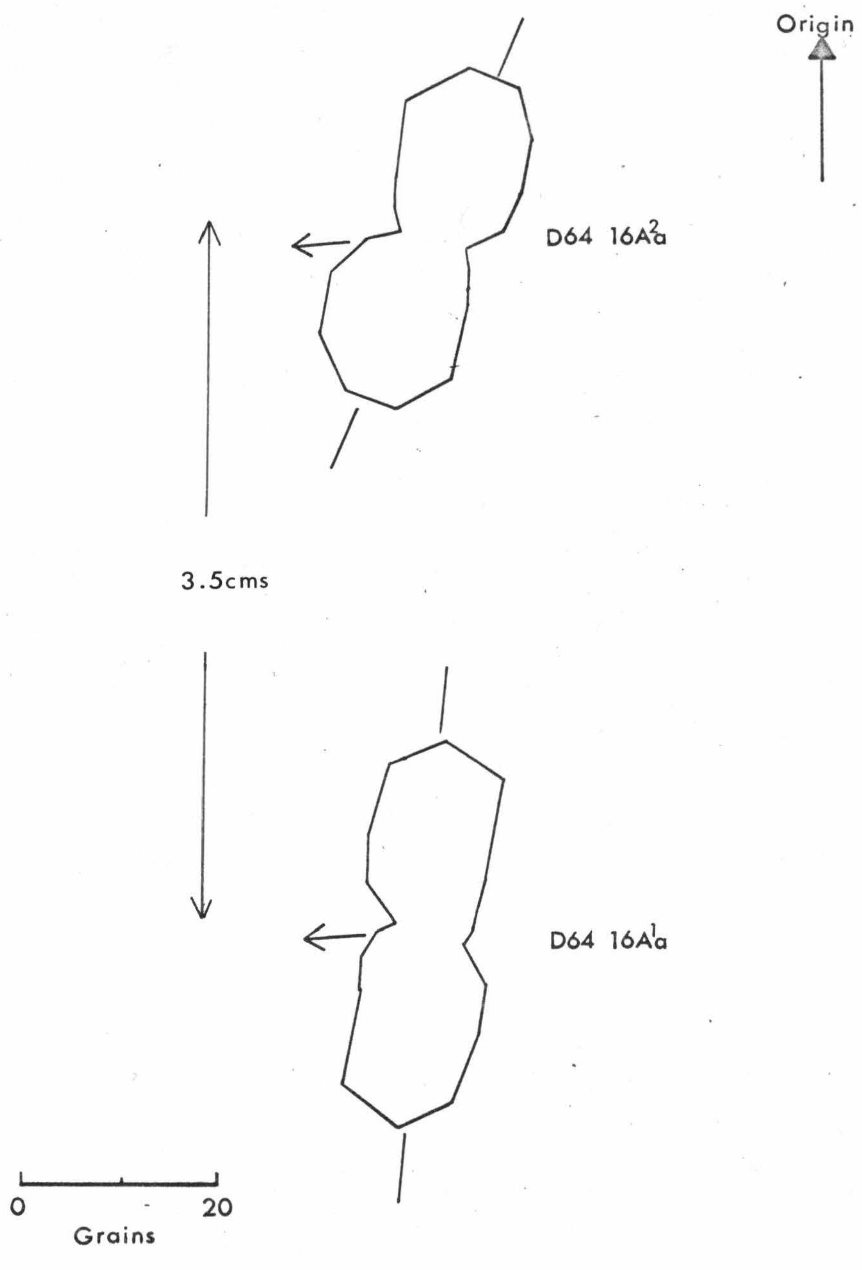


Fig. 23: Orientation frequency distributions of two sections cut from bed D64 16A.

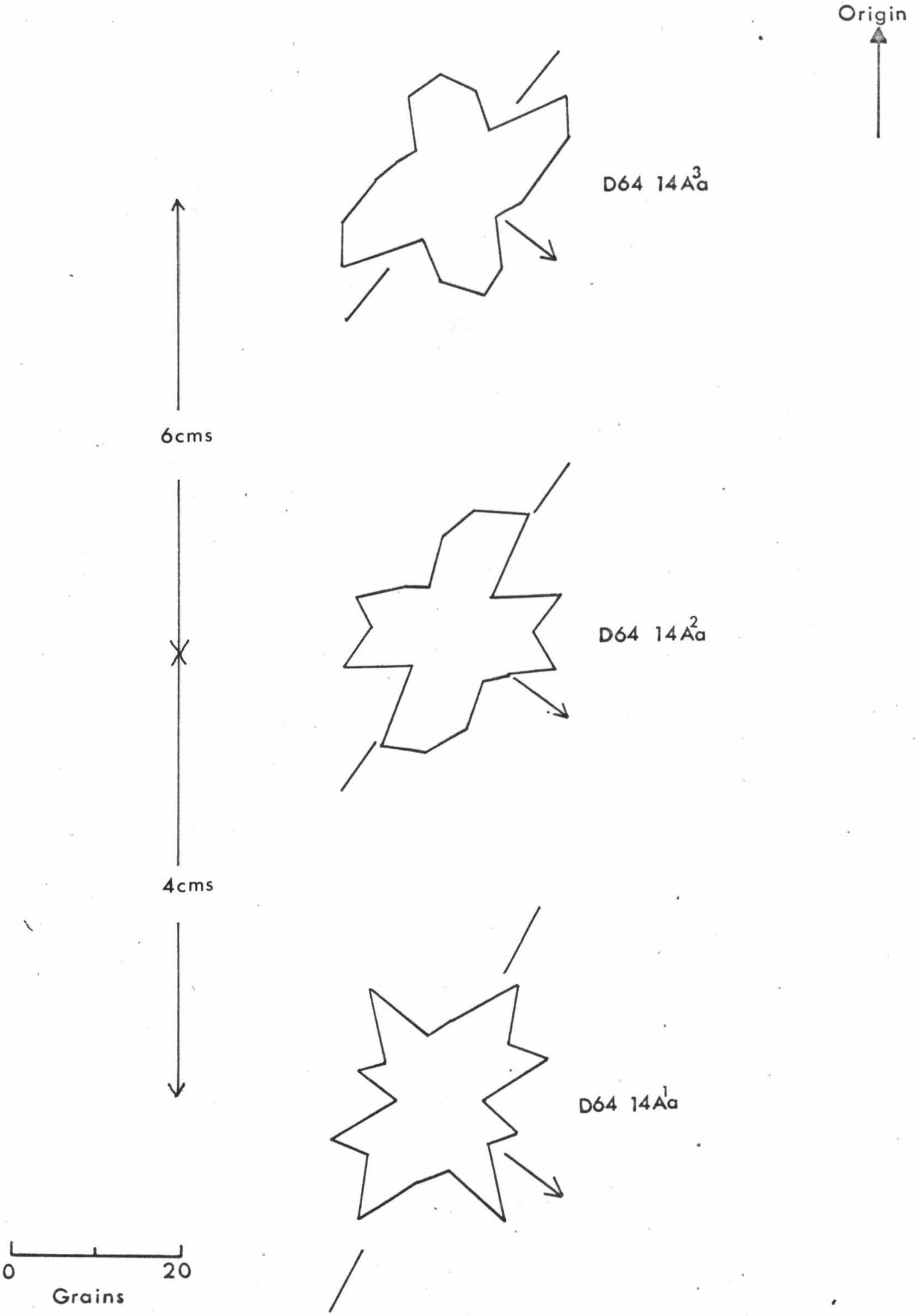


Fig. 24: Orientation frequency distribution of sections cut from bed D64 14A.

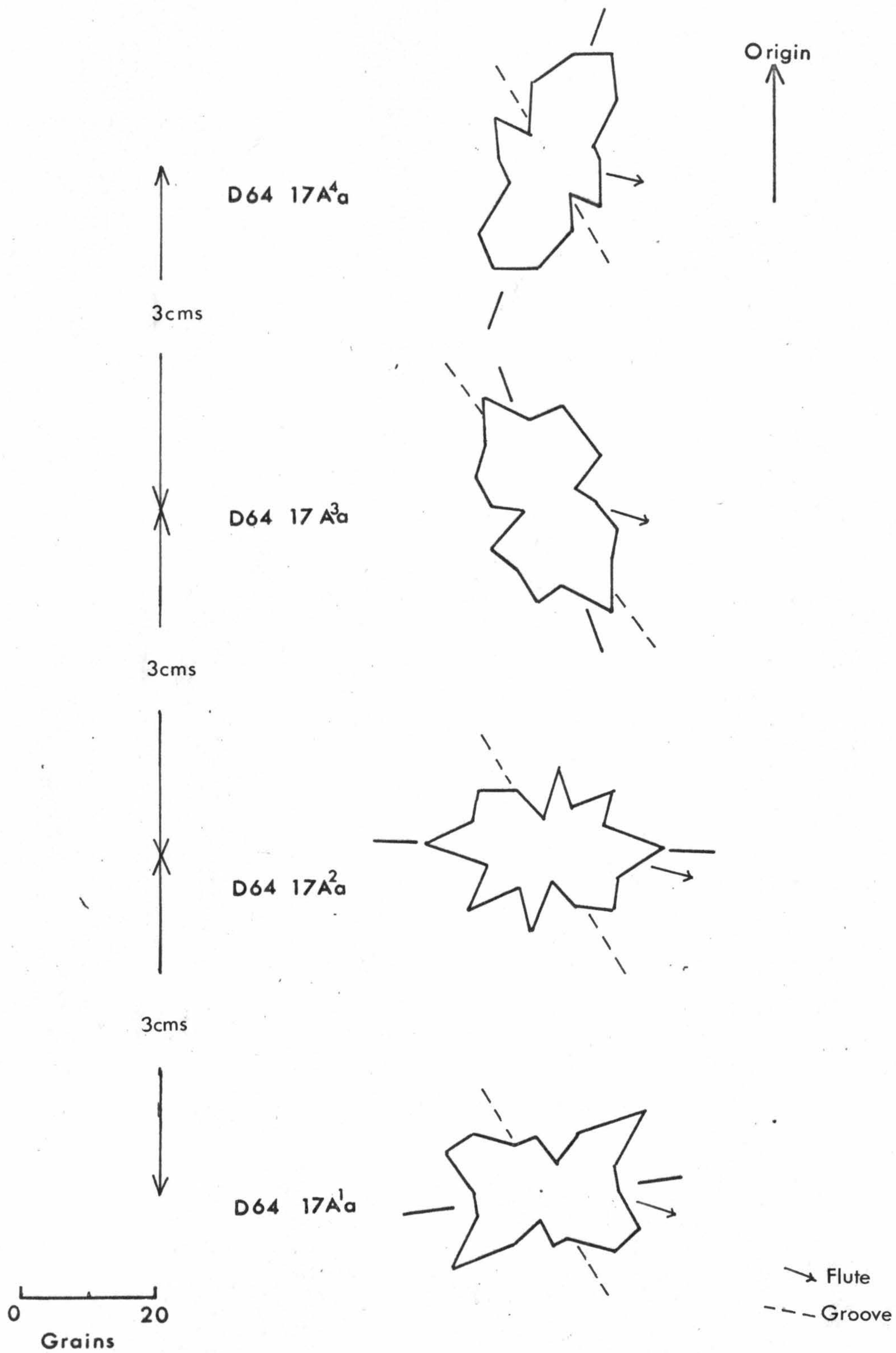


Fig. 25: Orientation frequency distribution for section cut from D64 17.

neither of the sole features, but it does have a secondary mode almost parallel to that of the grooves. The orientation above the flute has a lower degree of dispersion than those sections within the flutes. Yet, even in the lowest section there is a secondary mode again paralleling the groove marks.

The results suggest that the fabric is more closely related to the flow producing the groove casts than to that which scoured the flutes. Such results suggest that the flute casts were formed by an early eroding current which passed over the area prior to that one which produced the grooves and deposited the sediment. The flutes, linear hollows, imposed a certain restraint on the second current, producing a local orientation parallel to the flute itself.

Sample D64 2Ea was the subject of a similar study. Due to the small size of the sediment in this sample, only the two lower sections were adequate for examination. The sample possessed two large (3 inches wide, 1.5 inches deep) flute marks on the base whose direction was 110°, and smaller grooves with a direction of 140°. The lower section was cut from within the flute and the vector mean was $(10 \pm 7.8)°$. The second thin section was taken above the flute and a little above the groove casts; the vector mean was $(24 \pm 9.6)°$. Both these results then are different from the sole readings, and the results found in the above study may be fortuitous.

d) <u>Deviation with relation to dispersion of orientation</u>.

Figure 26 shows the lack of relationship of the angle of deviation from the sole with the measure of dispersion, L, in all sections. Nowhere is there any evidence of clustering which would indicate that particular deviations have a specific measure of dispersion. The higher the value of L, the lower is the scatter around the vector mean. There is a slight tendency for the maximum dispersion to be correlated with the greater deviation from the sole. The highest values of L show a lower deviation from the sole but the smaller deviations also demonstrate a low value of L.

Figure 27 represents plots of sections cut within individual beds. This illustrates that there is no consistent pattern within the beds.

e) <u>Relationship of dispersion with height above the base of the bed</u>.

Examples can be seen in Figure 28 which show the circular distributions of six thin sections. Sections from bed D64 9A demonstrate an increase in dispersion upwards through the bed, whereas those from D64 9C tend to decrease in dispersion upwards.

The vector magnitude plotted against the per cent height above the base of the bed again shows lack of any relationship. (Fig. 29).

The vector magnitude is plotted against the percentage height, for several different beds. (Fig. 30). These indicate that upwards in the bed there appears a slight tendency for decrease in dispersion value upwards. Sections from GVM4 and D64 9Ca both show a decrease in dispersion (i.e. an increase in the value of L) in the more central portions of the bed. This agrees with the supposition put forward previously.

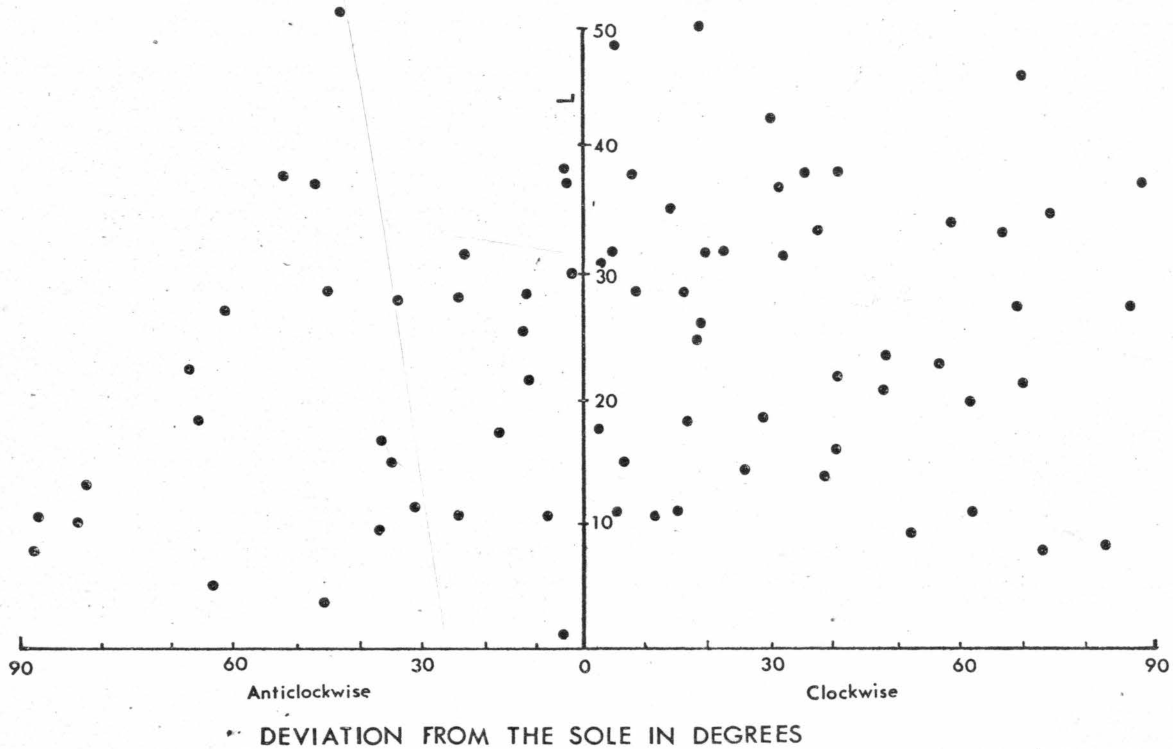


Fig. 26: Deviation from the sole marks plotted against the dispersion of each thin section.

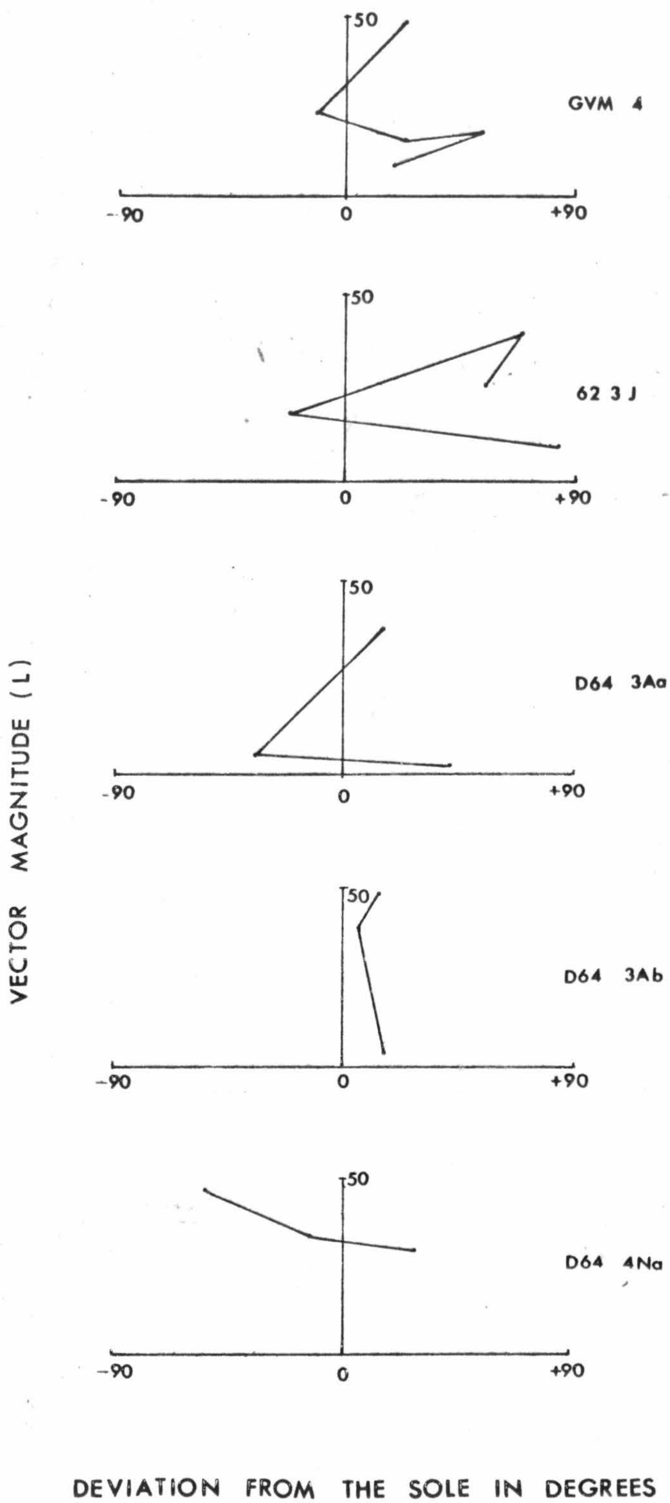


Fig. 27: Deviation from the sole against dispersion for five beds.

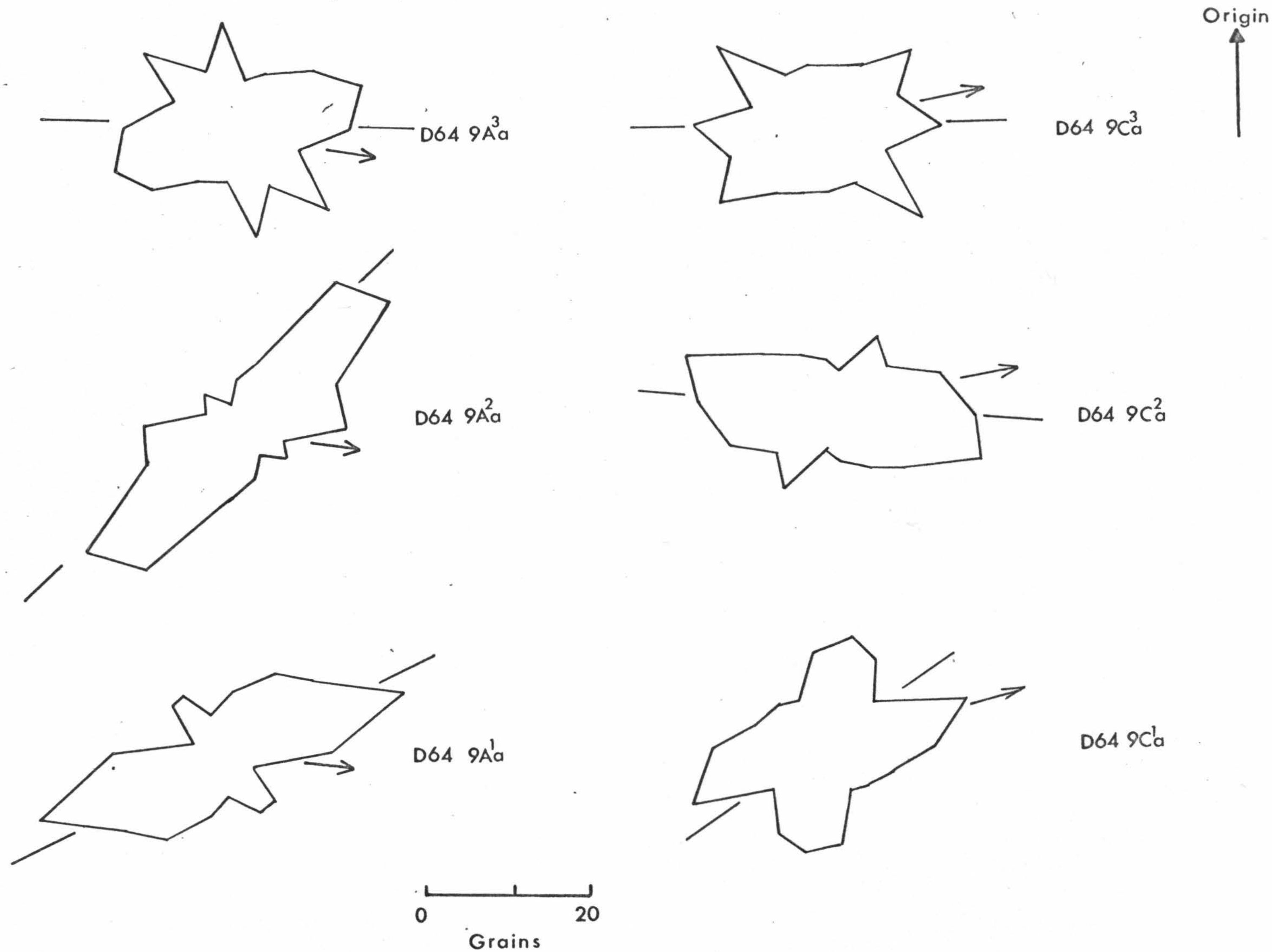


Fig. 28: Orientation frequency distributions for six thin sections from locality D64 9; three from bed A and three from C.

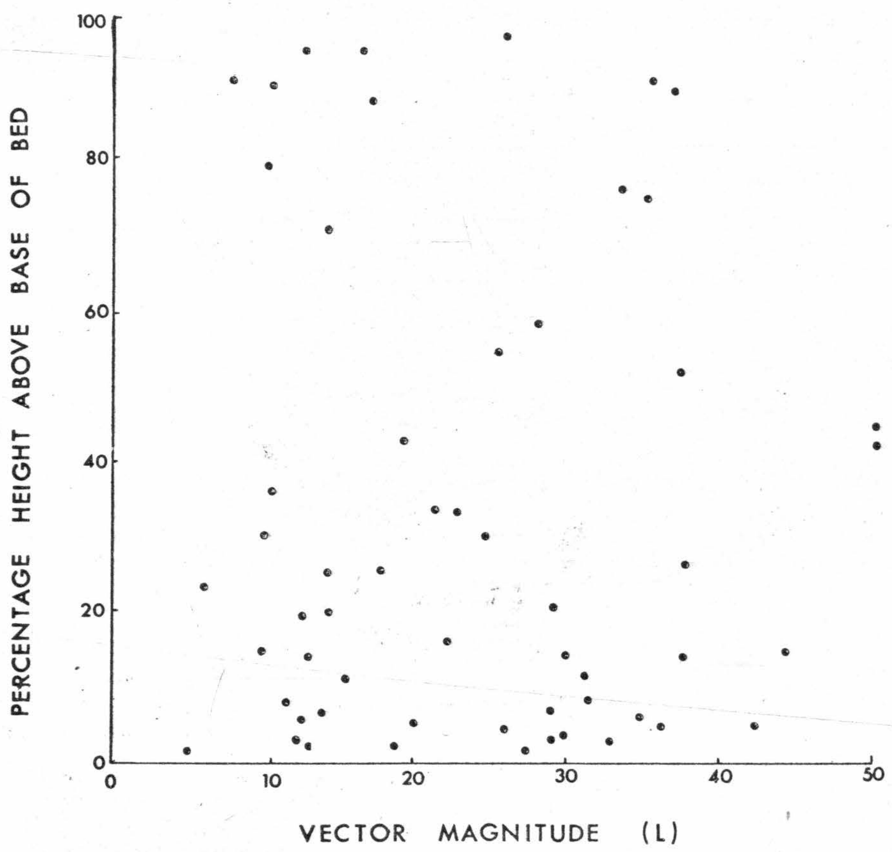


Fig. 29: Height above the base of the bed of each thin section against the respective measure of dispersion.

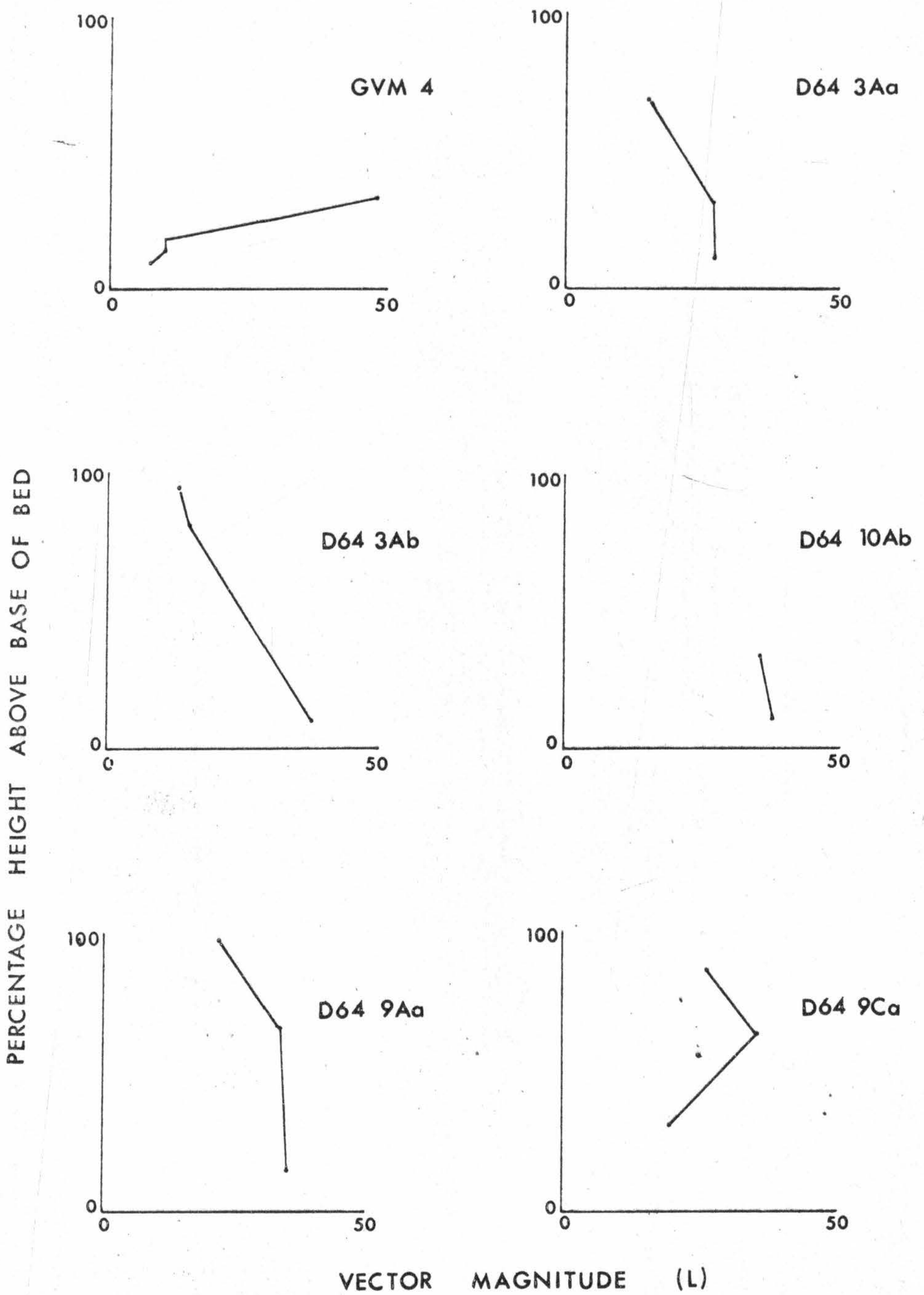


Fig. 30: Height above the base of the bed, at which thin sections were cut, against the measure of dispersion of each respective section, for six beds.

Yet example D64 3Ab shows an opposite trend.

It appears, in general, that the grain orientation has a maximum dispersion at the base of the bed. This may be due to the fact that sedimentation in the early stages of the depositional phase of the flow may be quicker and grains may not have time to orient themselves to a position of stability with respect to the flow before the next layer of the sediment is deposited.

During the deposition of the middle portion of the bed the velocity of the flow should have waned to some extent and the grains may remain at the depositional interface for a longer period allowing sufficient time for them to be oriented better.

In the higher portions of the bed the external conditions of the local environment may come into play. Thus if there is a small local current this will tend to reorientate the grains again with the possibility of increasing the dispersion.

f) Variation Laterally and Vertically within beds.

Several beds were studied in an attempt to determine if lateral relationships of grain orientation were closer than those observed in the vertical sense.

Nine sections were cut from bed D64 4N. Thin sections were cut in a natural arrangement of rows (horizontal) and columns (vertical). The columns were 300 centimetres apart and the rows 6 and 5 centimetres. (Fig. 31). The orientation direction of the sole was 80°. The orientation of 100 grains, selected by point counting, were measured in each of the 9 sections. The results are seen in Table 8, and their orientation distributions in Figure 31.

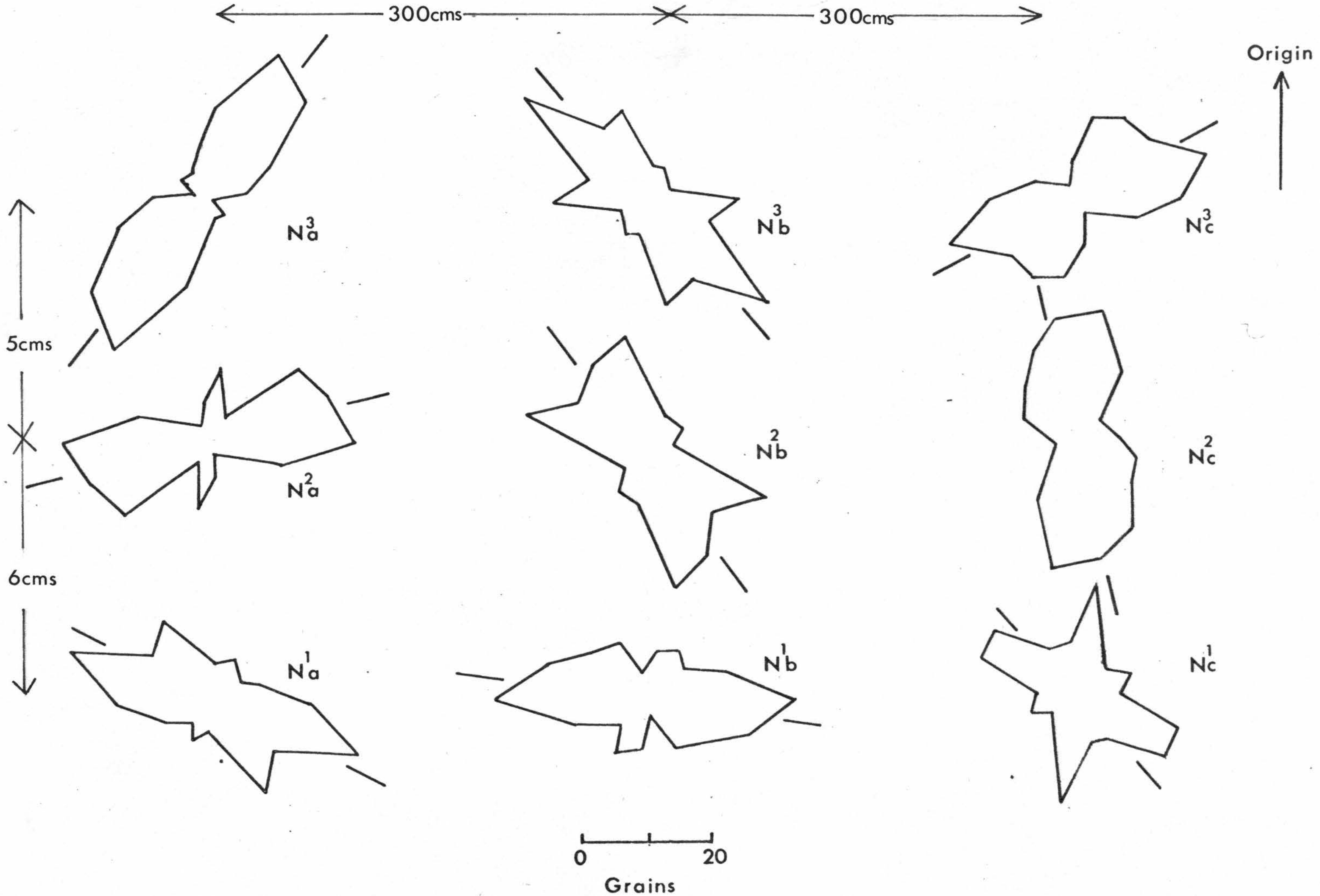


Fig. 31: Orientation frequency distributions for nine thin sections cut from bed D64 4N.

TABLE 8.

Thin section	θ°	Thin section	θ°	Thin section	θ°
$4N^3a$	38.7°	$4N^3b$	138.9°	$4N^3c$	60.0°
$4N^2a$	74.1°	$4N^2b$	144.2°	$4N^2c$	167.6°
$4N^1a$	114.3°	$4N^1b$	98.6°	$4N^1c$	140.0°
Sole	80°	Sole	80°	Sole	80°

The data was subjected to an analysis of variance; the results are summarized in table 1A of the Appendix (p. 93). They indicate that there is no difference between the columns or between the rows. This implies that there are no common trends to either the rows or the columns. To test for differences in the means of each adjacent pair the data was subjected to the <u>t</u> - test (Dixon and Massey, pp. 121-122). The results are tabulated in Table 2A of the appendix. This indicated that only thin sections $4N^2b$ and $4N^3b$ can be considered to have equal means.

The measure of dispersion were subjected to similar tests. The values of this measure are seen in Table 9.

TABLE 9.

Thin section	L	Thin section	L	Thin section	L
$4N^3a$	53.7	$4N^3b$	33.9	$4N^3c$	32.0
$4N^2a$	38.9	$4N^2b$	34.7	$4N^2c$	37.9
$4N^1a$	31.5	$4N^1b$	27.9	$4N^1c$	13.8

The results of the analysis of variance on these values (appendix, Table 3A, p. 94) indicate that there is no significant difference between the dispersion means, at the 95° probability level. It is noticeable, nevertheless, that the lowest values of L occur at the base of the beds suggesting that this is the position of maximum dispersion.

Similar studies were carried out on sample D64 3A. The columns were 180 centimetres apart and the rows, 51 centimetres. The values of the vector means are seen in Table 10.

TABLE 10.

Thin section	θ°	Thin section	θ°
$3A^3a$	72.0	$3A^3b$	76.3
$3A^2a$	19.3	$3A^2b$	68.4
$3A^1a$	89.0	$3A^1b$	80.0
Sole	66	Sole	66

The results of the analysis of variance are seen in Table 4A, (Appendix, p. 94). This again showed no significant difference between the row and column means. Results of the t - test on the data are seen in Table 5A, (Appendix, p. 94). These indicate that the only significant agreement between means is between sections $3A^3b$ and $3A^2b$, $3A^2b$ and $3A^1b$, $3A^3a$ and $3A^3b$, and $3A^1a$ and $3A^1b$. In other words, only thin section $3A^2a$ differs significantly from those adjacent to it. All others vary a maximum of 23° clockwise from the sole. In this bed there then appears a certain degree of consistency in the vector means and consequently in the deviation of the grain orientation from the sole marks.

Sections from bed D64 10A were treated in the same manner. The horizontal distance between the sections is 200 centimetres, and the vertical distance 3 centimetres. The values of the vector means are seen in Table 11 and the results are represented graphically in Fig. 32.

TABLE 11

Thin section	θ	Thin section	θ
$10A^2a$	333.8	$10A^2b$	330.1
$10A^1a$	339.0	$10A^1b$	328.8
Sole	300	Sole	300

From previous experiments one would expect the vertical sections to show the same or similar results, as it has already been noted that the change of vector means in a short vertical space is negligible. The somewhat unusual phenomenon is that the sections, considered in a horizontal sense, also show significant statistical agreement. It is also noted that the direction of the flutes on the base of this bed also coincide quite closely with the values of the vector means; the flutes differ from the grand vector mean by 332.9°. Results of the t - test on vector means are seen in Table 8A. Smoor (1960) cut six thin sections from two columns, 15 cms. apart. The vertical distance between the thin sections was 4 cm. Analysis of variance indicated that vertical variation was significant at the 95% level. No lateral variation however could be detected. (The circular means of the two lowest thin sections in each column were within 15% of the current direction as indicated by flute casts.) He explained this phenomenon by "resedimentation processes" in the upper part of the bed after deposition, or by deviating current directions in the "tail" of the turbidity current.

The results of bed D64 3A and D64 10A coincide more closely with those of Smoor's yet D64 4N shows no relationship, either laterally

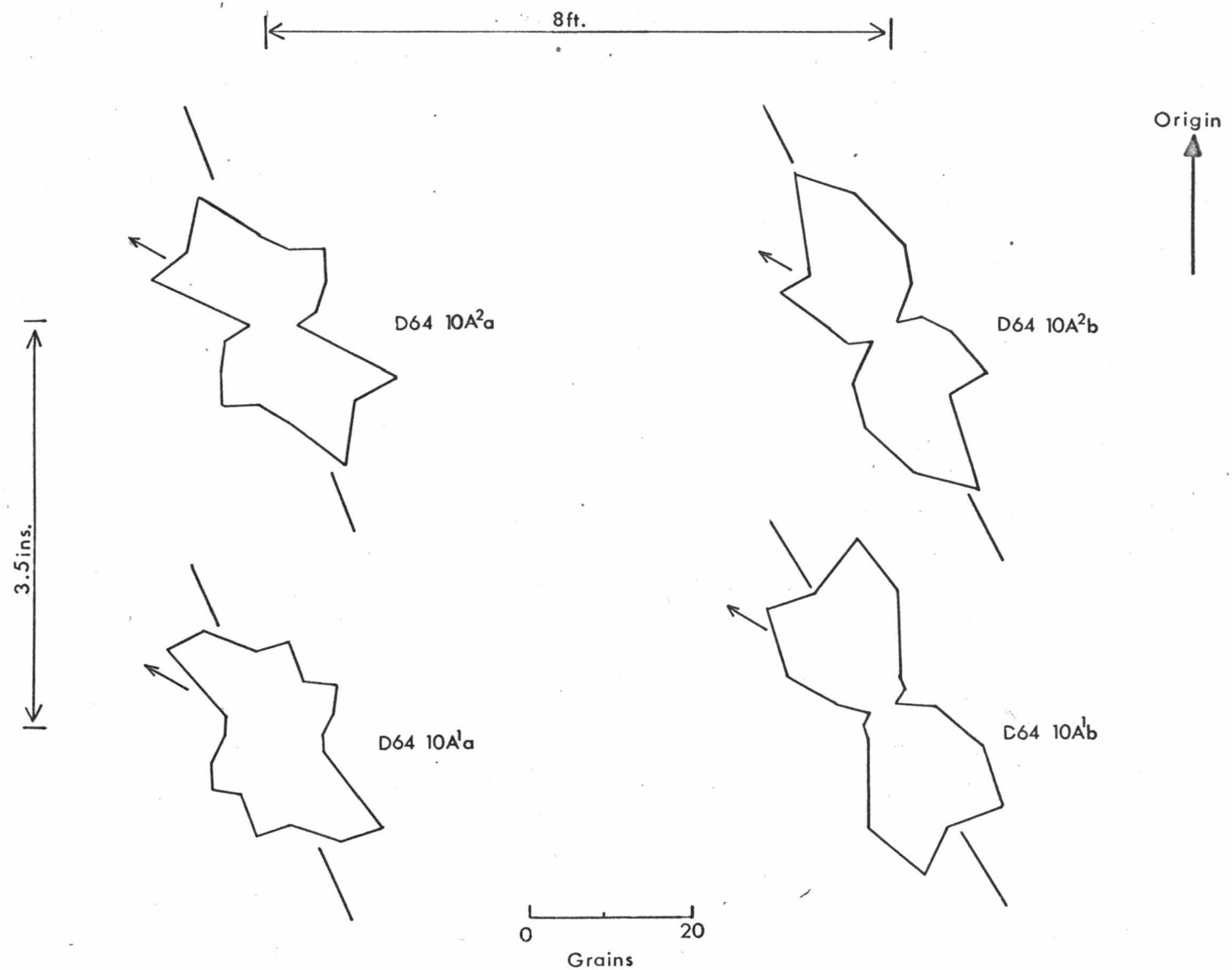


Fig. 32: Orientation frequency distributions for four sections cut from bed D64 10A.

or vertically.

g) Relation of grain size and shape to orientation.

Rusnak states that the orientation is influenced by the degree of elongation of the particles. In experimental studies he found there was an increase in the degree of dispersion around the preferred direction of orientation as sphericity increased. The correlation is low and is accounted for by the wide spread of sphericities in the sands with which he was experimenting. Smoor (1960) found that the more elongated grains tended to be nearly parallel to the fluid flow direction, which in his case was parallel to the sole marks. He found relationships between grain size and degree of orientation of the grain were less apparent.

To follow up these results, sections from D64 4N were chosen for a detailed study of the relation of grain size, elongation and orientation. Length, breadth and orientation were measured on one hundred grains in each thin section. Elongation, defined as breadth over length, was also calculated for each grain chosen; (it must be remembered that the greater the elongation, the smaller the ratio value will be). The orientation distributions are represented in Figs. 33B - 38B.

There is no significant difference in the mean grain size at different points in the same bed. (Table 7A, appendix p. 95). The only grading of statistical significance is that of maximum grain size which decreases from the bottom to the top of the bed. Cumulative curves of the grain size (Figs. 39, 40) do not plot as straight lines on probability paper but as slightly convex up curves. This indicates that the sediments are slightly positively skewed. These results agree with those of Middleton (1962).

Fig. 33 - 38

A. represents the circular plot of maximum length (outer polygon) and breadth (black polygon) for each 20° class interval.

B. represents the circular plot for maximum elongation per 20° class interval.

C. Grain orientation

D. Average length (outer polygon) and breadth (black polygon) per 20° class interval.

E. Average elongation per 20° class interval.

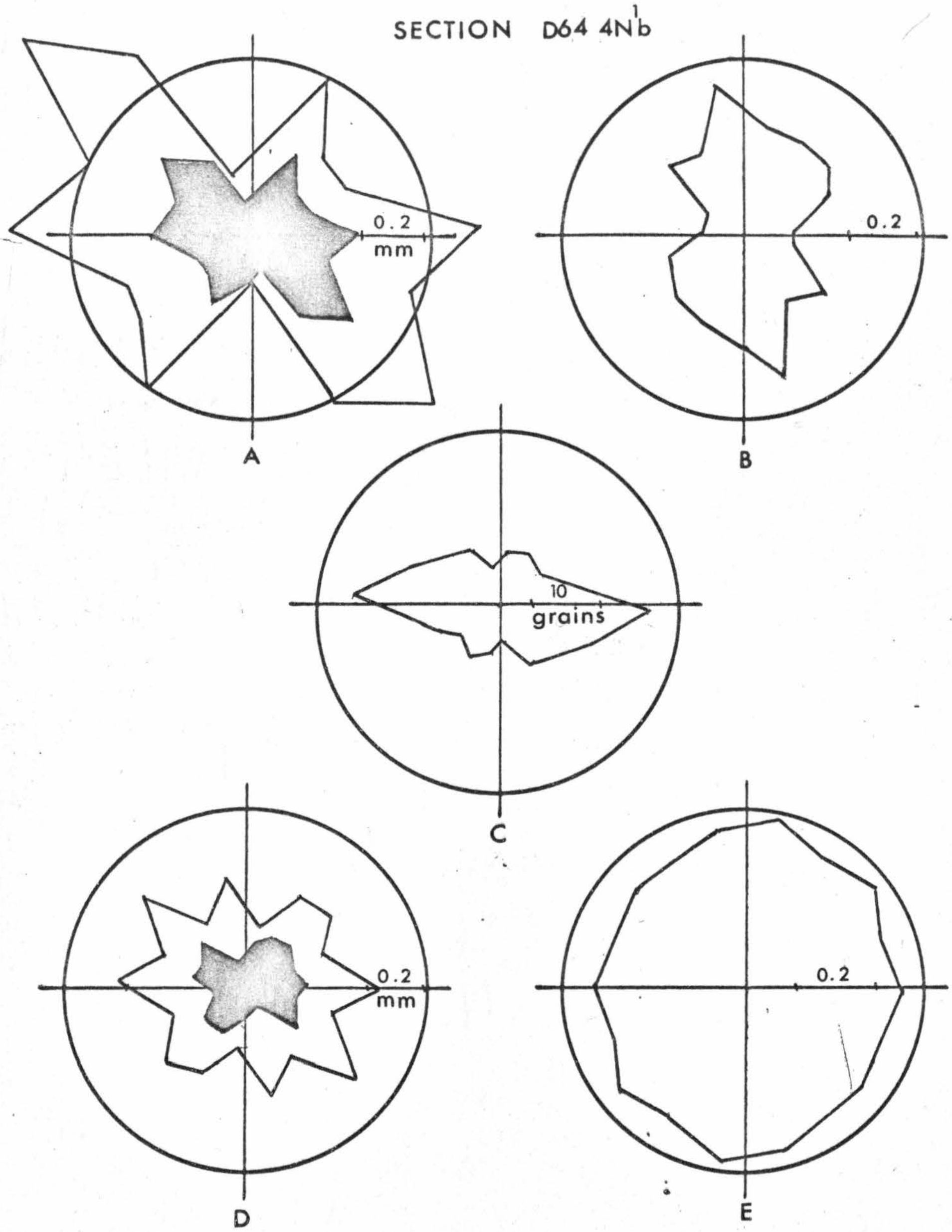


Fig. 33:

SECTION D64 $4N^2b$

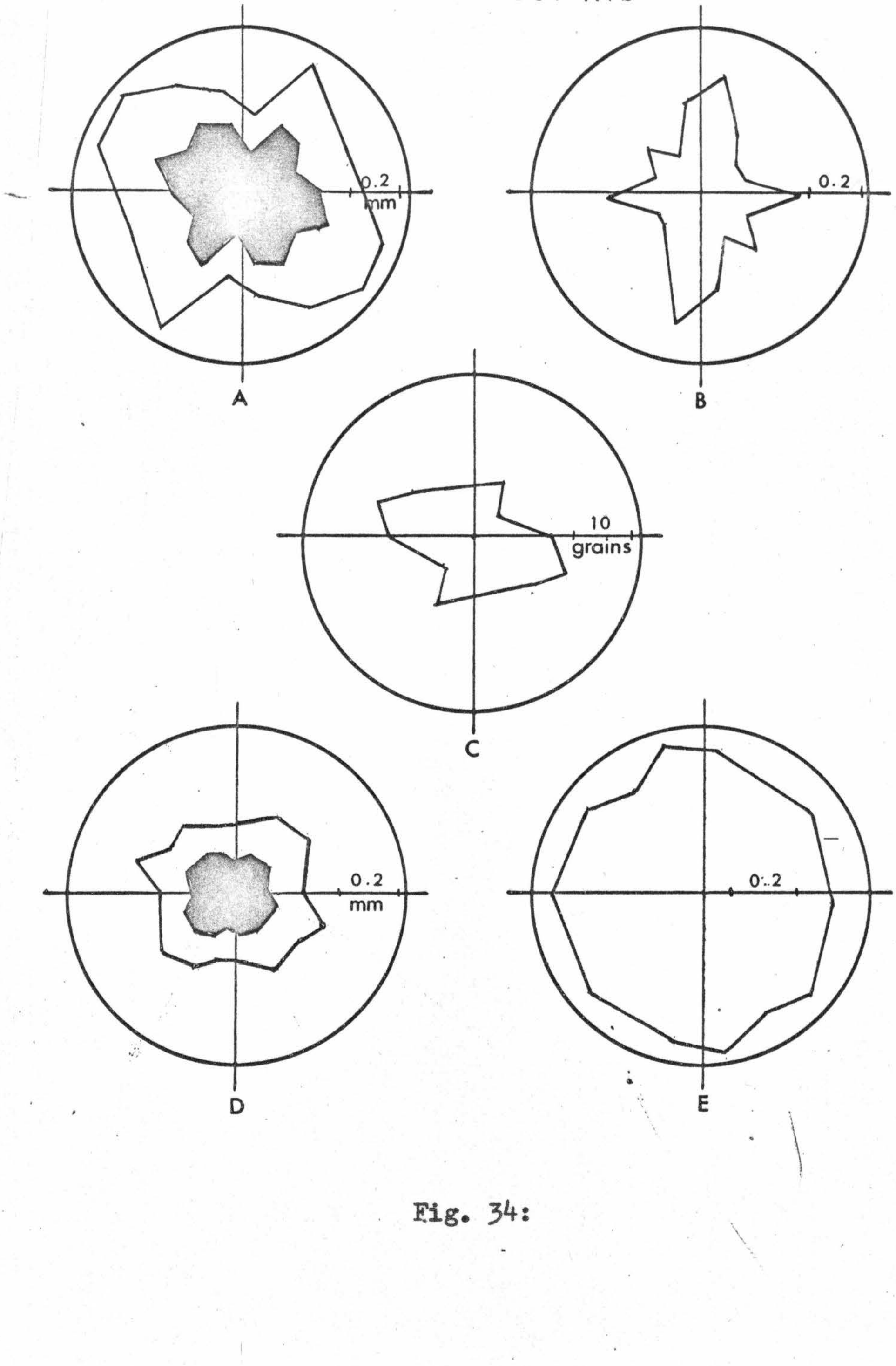


Fig. 34:

SECTION D64 $4N^3b$

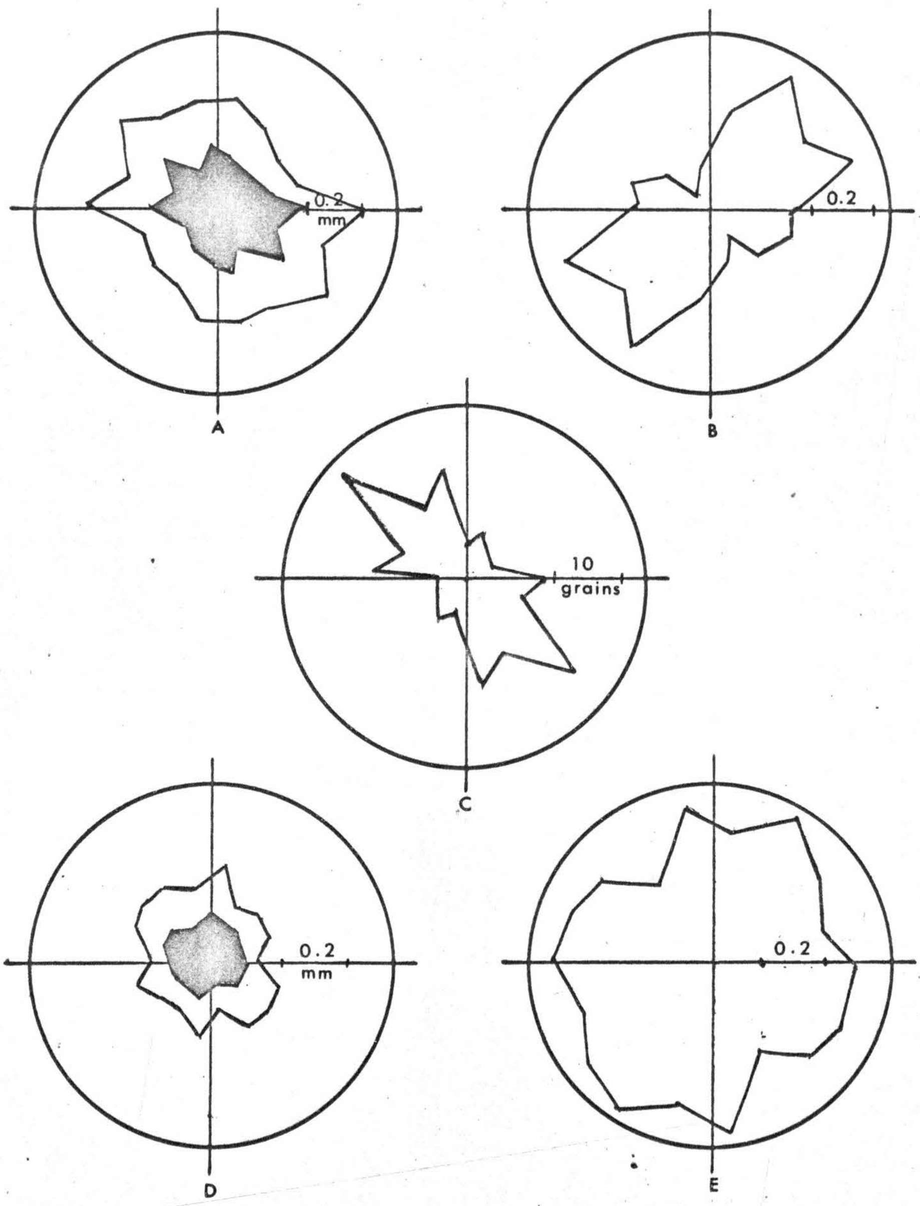


Fig. 35:

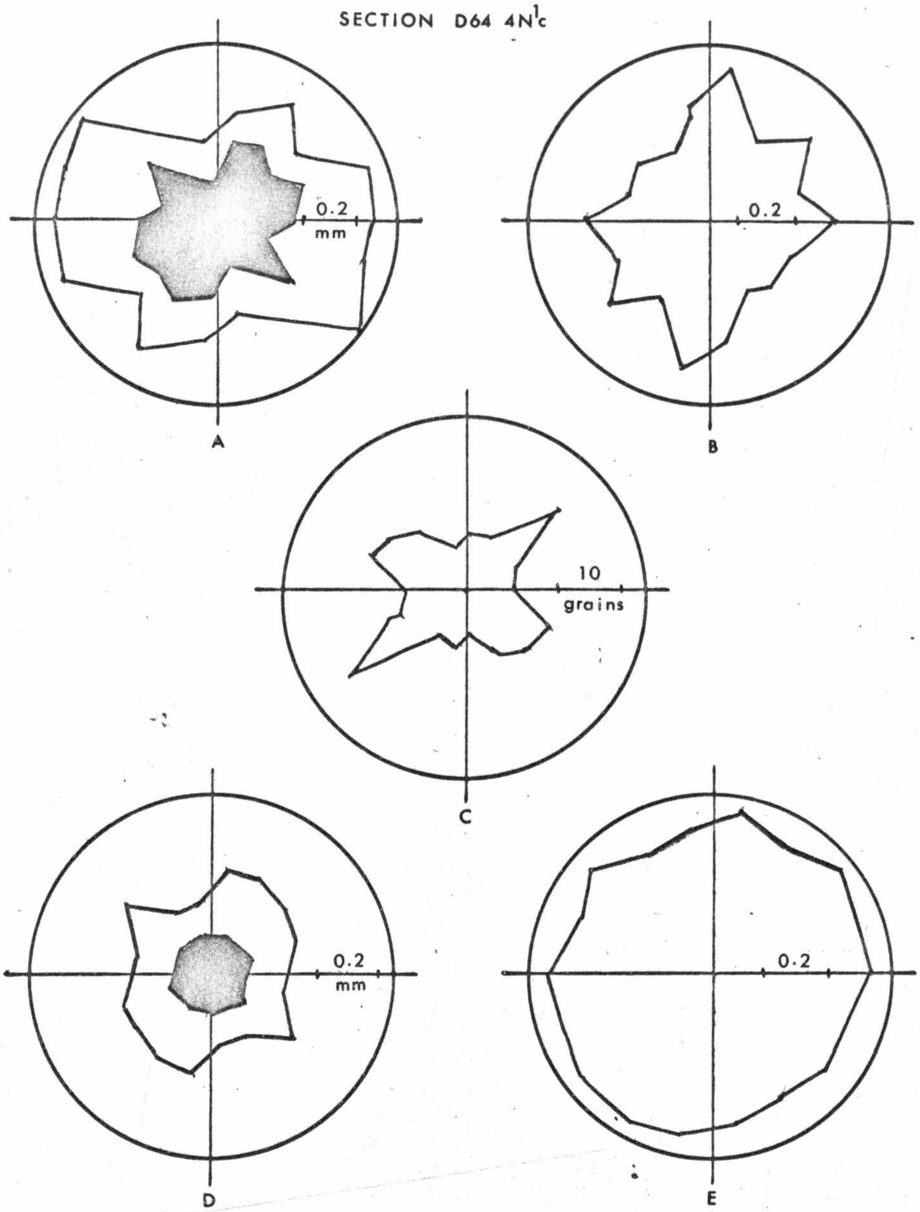


Fig. 36:

SECTION D64 $4N_c^2$

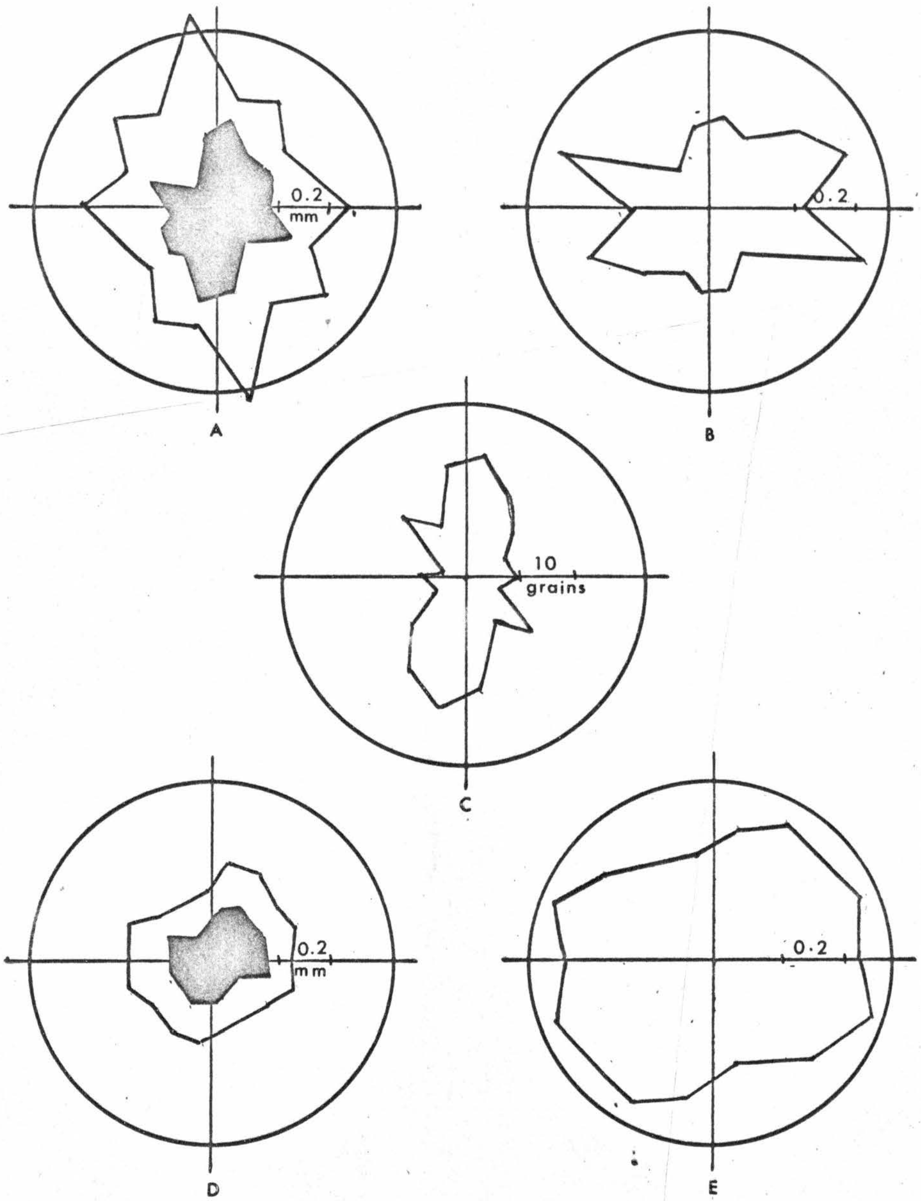


Fig. 37:

SECTION D64 $4N^3_c$

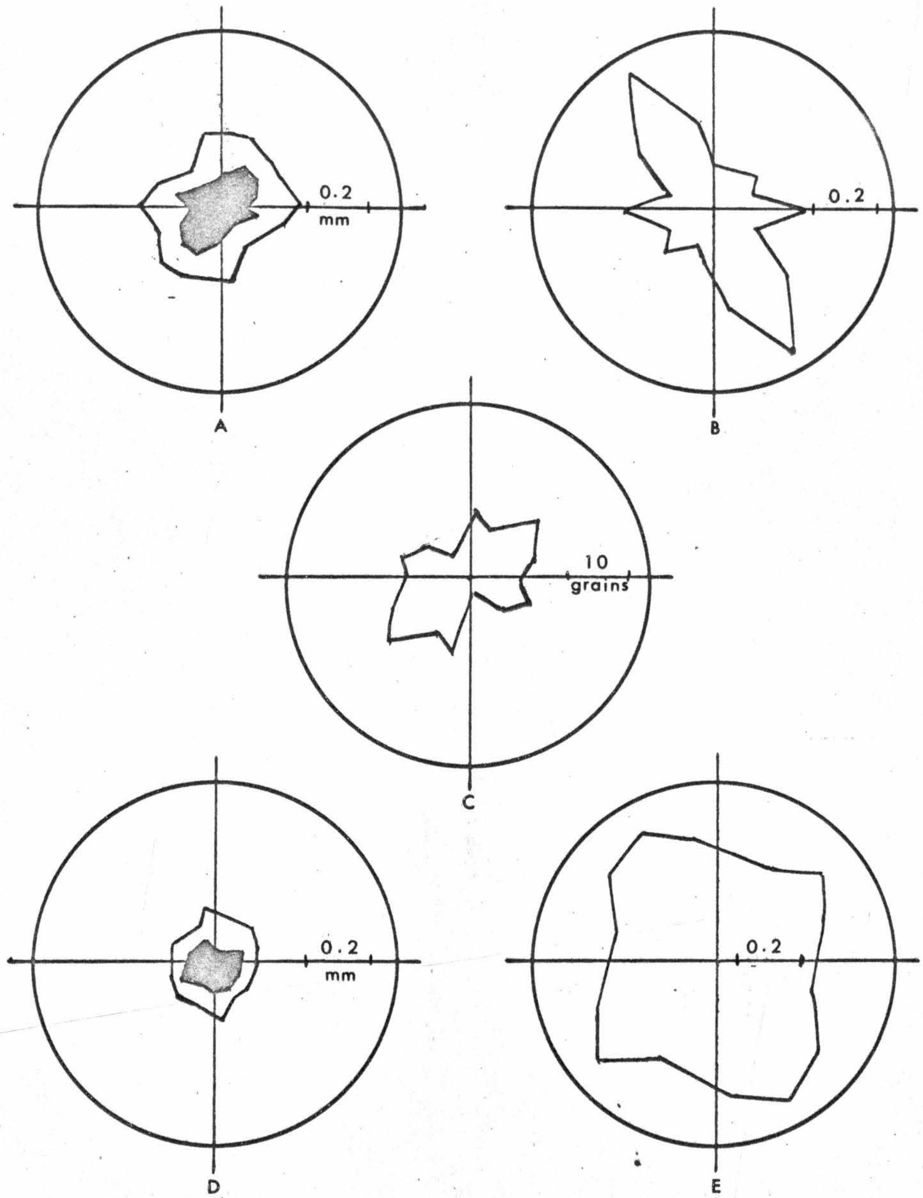


Fig. 38:

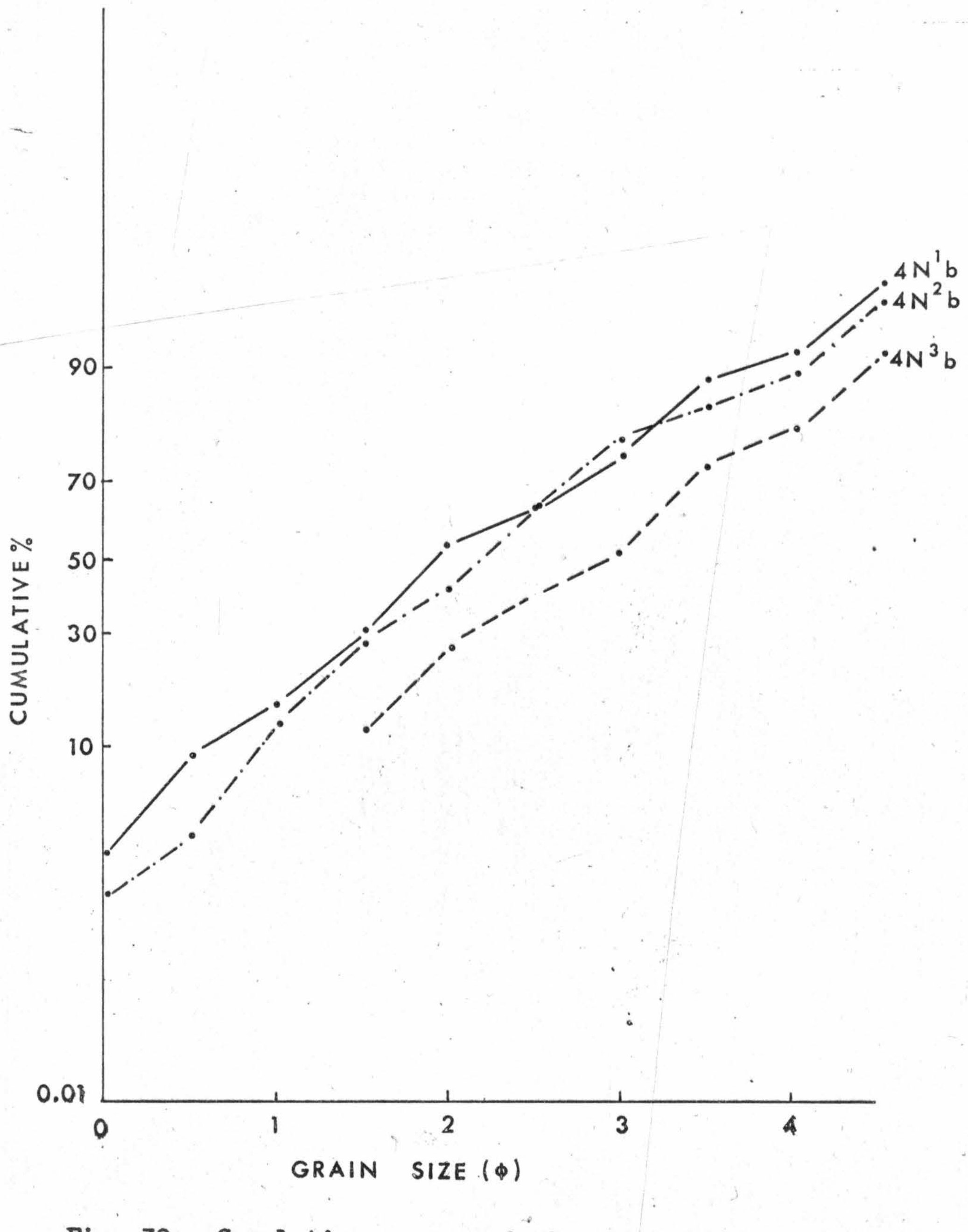


Fig. 39: Cumulative curves of size distribution.

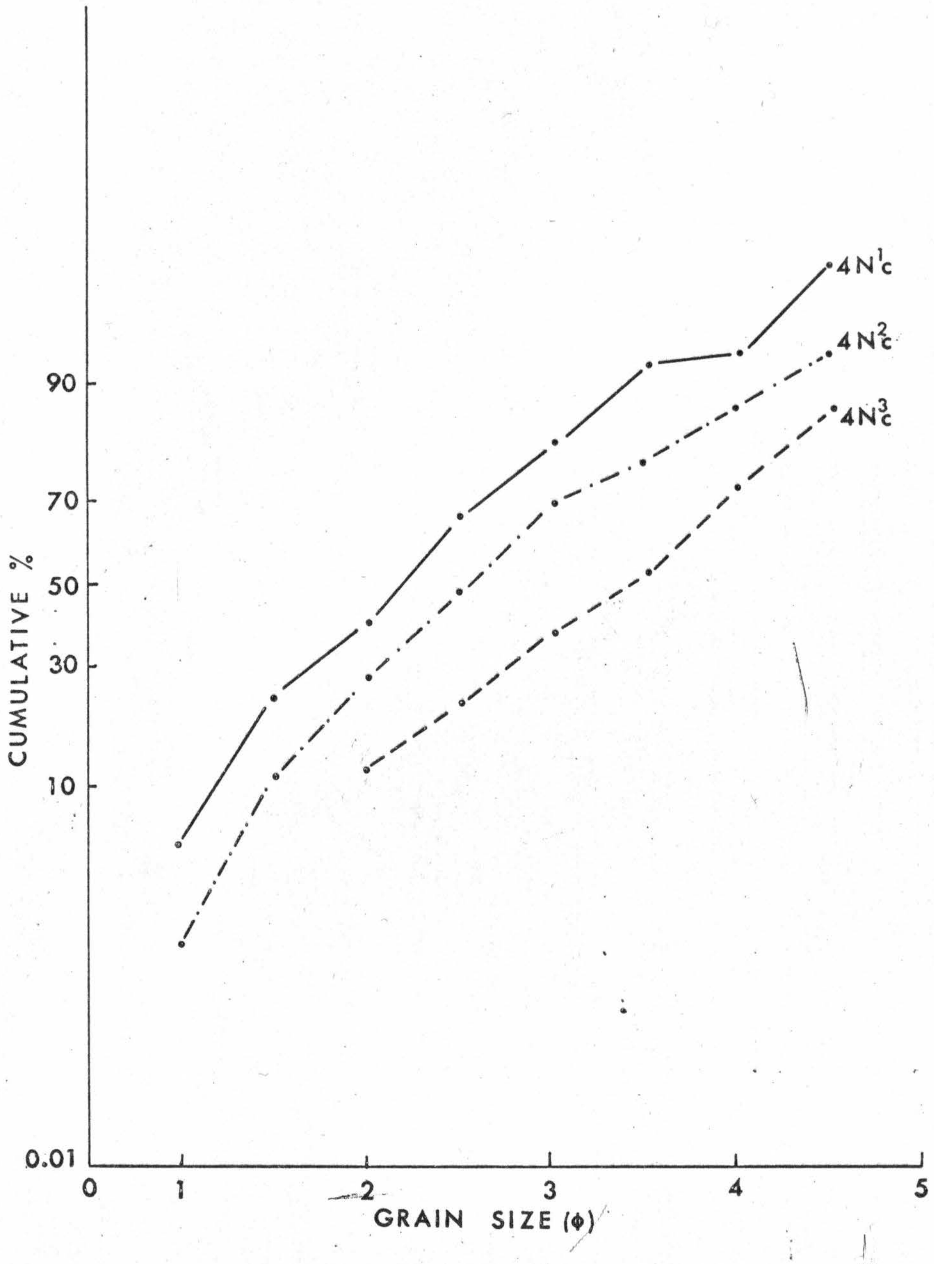


Fig. 40: Cumulative curves of size distribution.

Similarly there is no significant difference between the average elongation upwards in the bed, yet the maximum elongation increases towards the top of the bed.

For each 20 degree class interval the maximum length was determined and plotted against the midpoint of that class interval. (The outer polygon of Figs. 33A - 38A). Similarly the average length, maximum and average breadth were plotted. Maximum elongation (i.e. the minimum value for b/a) and average elongation were also calculated for each class and plotted in a similar fashion. (Figs. 33 - 38, B and E)

From the graphs it can be seen that the only outstanding correlation existing with that of the orientation distributions (C) is that of maximum elongation, (B). Section $4N^1c$ which shows a strong bimodality, suggests the same correlation.

The plots of maximum length and breadth have a slight tendency to correlation with the grain orientation, in that plots of maximum length and breadth coincide with the preferred orientation. This indicates that there is a correlation between the maximum length and maximum elongation, that is, the grains of maximum length at each level are the most elongate.

The maximum elongation occurs in the higher portions of the bed. Pettijohn (1957) noted that the most spherical grains, all other things being equal, will settle out before those of lower sphericity so that the less spherical lend to be transported in suspension a greater distance. If traction is the mode of transport the opposite will prevail because grains of high sphericity have a tendency to roll more readily, and will outdistance the more angular grains in the sediment load. These observations, therefore, indicate that in all probability even the tops of the beds were transported in suspension.

The plots of average length and breadth (D) show roughtly circular polygons indicating no correlation with the elongation or with the orientation.

These results correlate closely with those of Spotts (1964), i.e. that the grains of maximum elongation correspond to the classes of the maximum preferred orientation.

Further attempts to correlate the parameters are seen in figures 41 and 42. Both sets suggest a decrease in average grain size upwards but this is not significant statistically. (Table 7A, appendix p. 95). The standard deviation of the ratio b/a for both sets of sections shows a decrease towards the centre of the bed. This indicates that the dispersion of the elongation diminishes towards the centre of the bed; suggested better sorting with respect to elongation at the centre of the bed.

The deviation of the vector mean from the sole increases in Nb towards the top of the bed; in Nc it increases to the midpoint and then reverts back.

In figure 42 the parameters are plotted against L. No consistency is seen in relation to the grain size. There is an overall tendency for the value of L to increase up the bed. The centre of Nb shows divergence from this pattern where the value of L decreases from 28 to 14 percent. The results of Nc are in agreement with those suggested before, i.e. that minimum dispersion is towards the centre of the bed; those of Nb disagree.

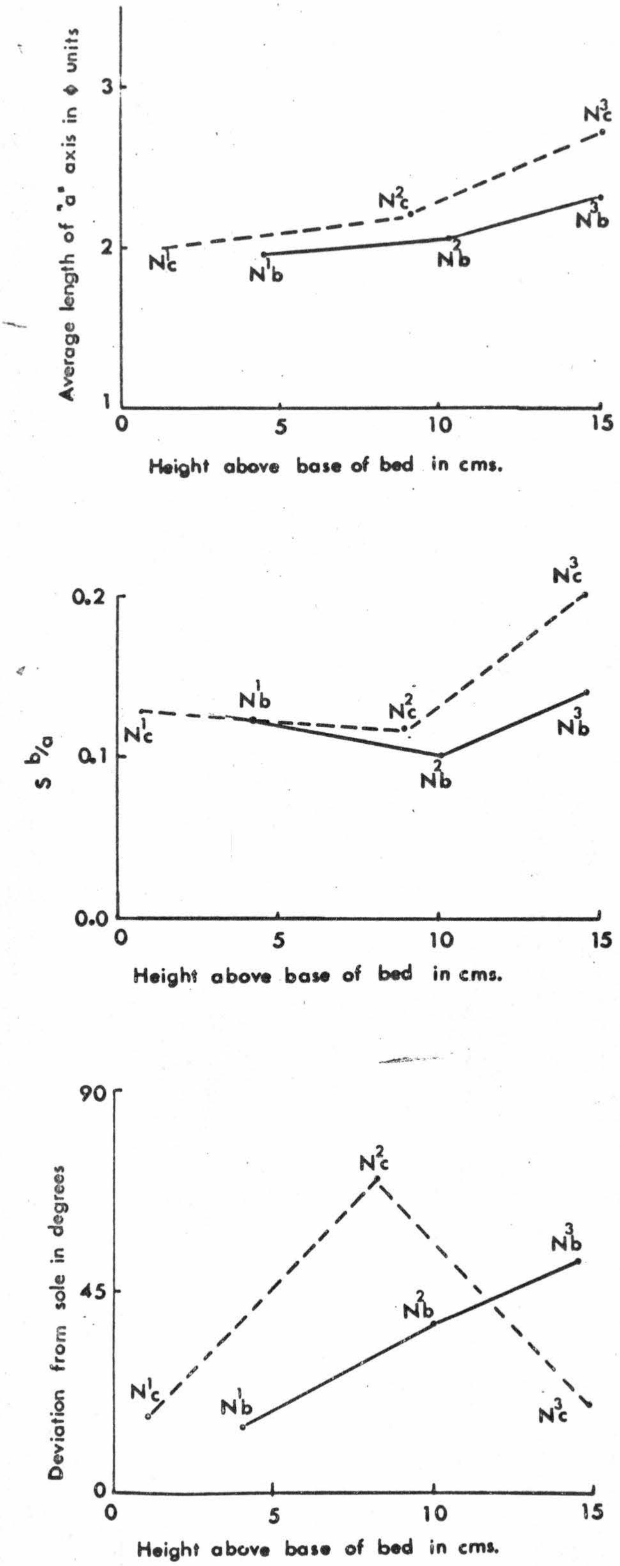
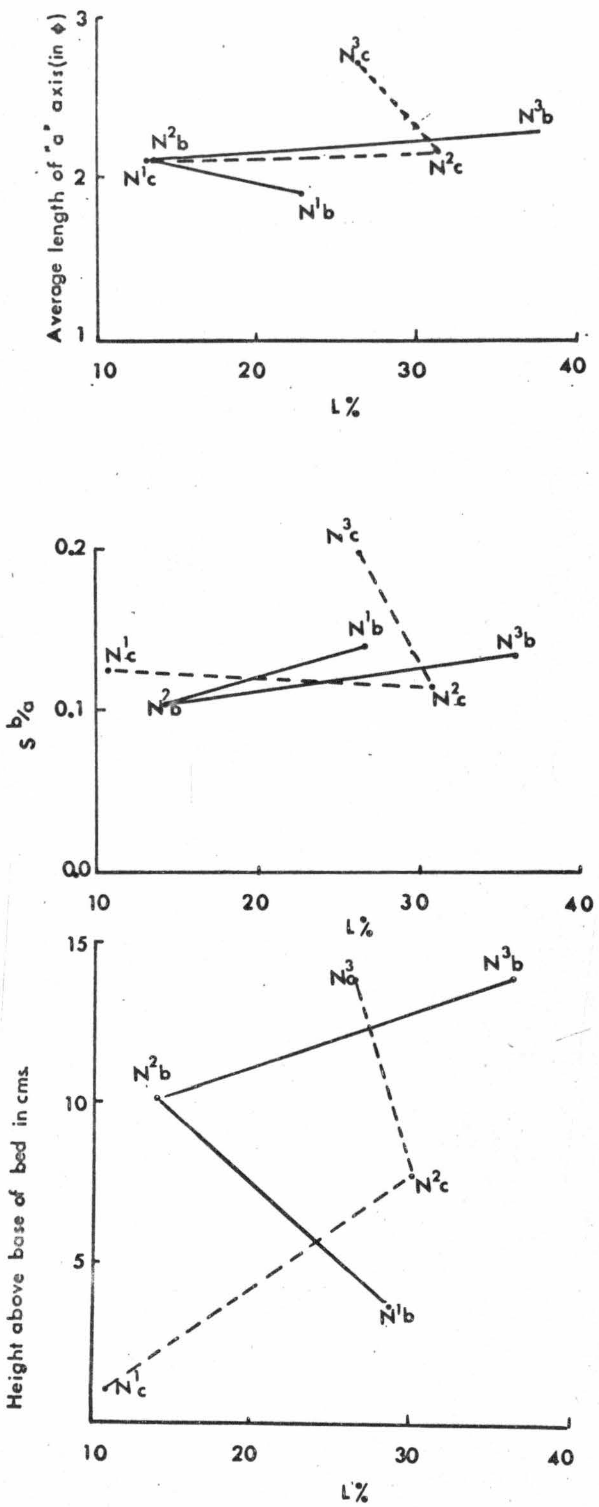

Average length of "a" axis in φ units
Height above base of bed in cms.
S b/a
Height above base of bed in cms.
Deviation from sole in degrees
Height above base of bed in cms.

Fig. 41:



Average length of "a" axis (in φ)
3
2
1
10
20
30
40
L%
N²b
N¹c
N¹b
N³c
N³b
N²c
0.2
0.1
0.0
$S_{b/a}$
N¹c
N²b
N¹b
N³c
N³b
N²c
15
10
5
Height above base of bed in cms.
N²b
N³b
N²c
N¹b
N¹c

Fig. 42

3. GRAIN IMBRICATION

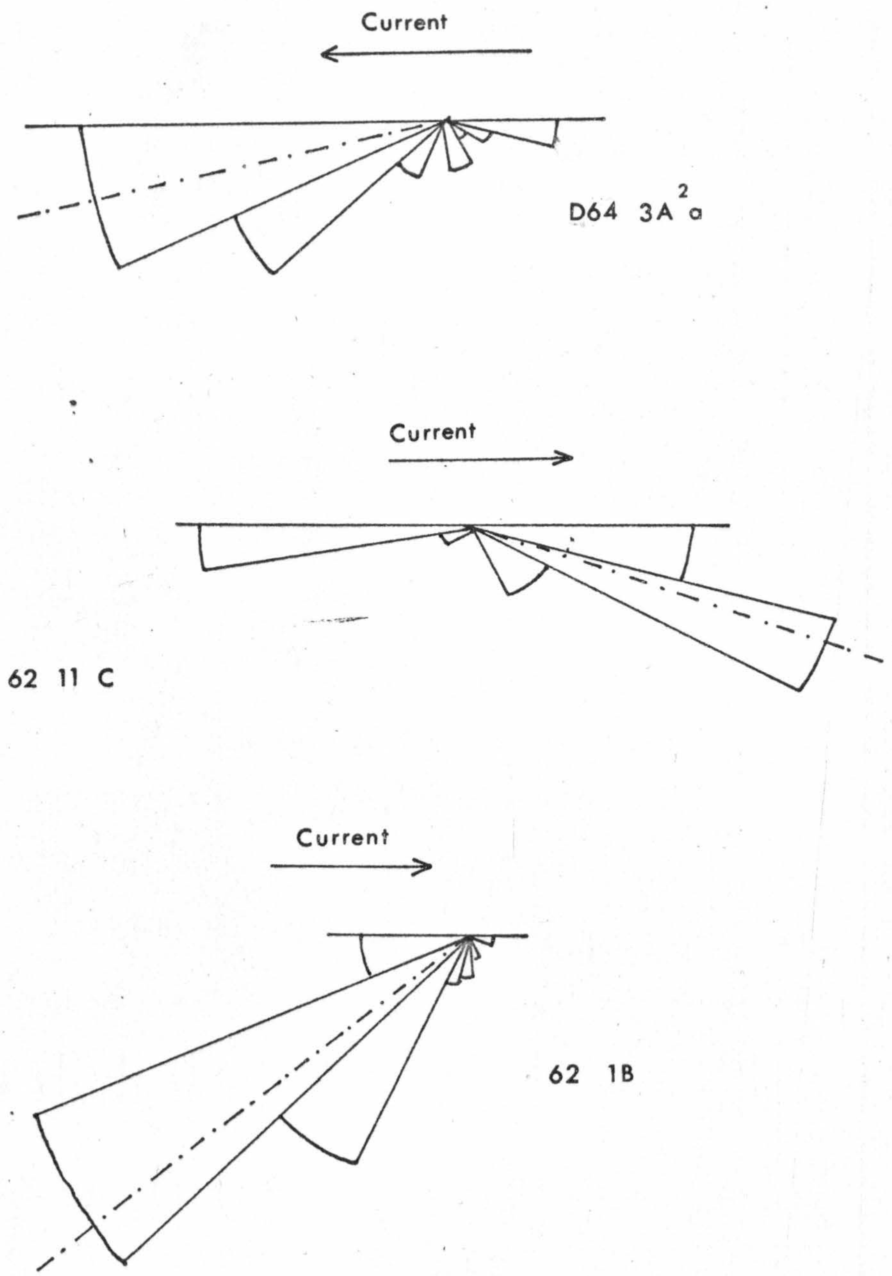
Several thin sections were cut in the plane perpendicular to the bedding and parallel to the direction of flow as indicated by the preferred orientation. The purpose of this was to determine if any imbrication existed and if so, whether it had a positive or a negative angle of attack to the direction of flow indicated by the sole marks. The positive denotes an upward inclination into the direction of fluid motion, and the negative indicates a downward inclination into the direction of flow. If the particles have a positive angle of attack, there will be a lift force, resulting from a high pressure under the particle, and a low pressure above and behind it; this will tend to flip the particle over. Thus the most stable position is the negative angle of attack.

Schwazacher (1951) noted that imbrication existed in several experimentally deposited sands. He found that the angle of imbrication is greater, with a higher velocity, and in water lain deposits compared with aeolian sands. Rusnak (1957) found an average upcurrent imbrication of 14.2° for twelve samples.

Field data give varying results but upstream imbrication is predominant. Kopstein (1954) working on the Harlech Dome deposits describes predominantly downcurrent imbrication for coarser materials. In the finer materials he found no distinctly preferred direction. Smoor (1960) found a predominant upcurrent imbrication of 30°. Potter and Mast (1963) found that a total of 89 per cent of their samples showed an upcurrent imbrication, 58 per cent of them with average dips between 11° and 20°. Only 11 per cent were imbricate downstream. Spotts (1964) also found a distinct upcurrent imbrication in the Altamira Sandstone of California.

All samples chosen for the study of imbrication showed a distinct departure from uniform grain orientation (at the 95 per cent level), in the plane parallel to bedding. The angle of imbrication ranges from 36° to 2.6° (Fig. 43). Because of the possible uncertainty of determining the bedding planes, and considering confidence limits of ± 7°, it was considered best not to put much weight on those samples with an angle of imbrication of less than 7°.

Eighty per cent of the sections studied showed average imbrication dips of 15° to 25° from the horizontal. As the mean orientations in the bedding plane were not coincident with the sole marks on the base of the bed from which the thin sections were taken, the determination of up and downcurrent direction was somewhat subjective. The direction of grain orientation nearest to the direction of the flow mark for each section was chosen. Eighty per cent of the sections indicated an upcurrent direction of imbrication, in agreement with the results reported by Smoor (1960).



43: Grain imbrication in three beds.

DISCUSSION

Primary orientation of elongate particles can generally be associated with the transportation and deposition of grains in a fluid (Griffiths, 1953). Rusnak (1957) theoretically demonstrated that ellipsoidal particles are deposited in a position of maximum stability with respect to the forces acting upon them. Schwarzacher (1951) and Rusnak (1957) experimentally demonstrated that this position is such that particles lie with their long axes parallel to the direction of flow, dipping in an upcurrent direction.

In 86% of the sections studied, in the plane parallel to bedding, there was no significant parallelism with the sole features. Spotts (1964) found an average departure of 47° from the sole marks and interprets his results as being due to different directions of flow of "erosional and depositional turbidity currents". In the present study, no singular deviation is prominent. Hand (1961) found two directions to be prominent; one parallel to the flow and the other, normal. He attributes this to the rate of deposition on the basis that poor sorting indicates rapid deposition. He found that the current-normal orientations predominated in the most poorly sorted parts of the sediment body. This suggests that the sediment, which in suspension is current normal, (Rusnak 1957) was immediately deposited and no further forces were capable of acting on it in order to orient it to a position of stability with the long axis parallel to flow. In the present study the degree of sorting increases upwards in the bed, but not significantly so. The rate of sedimentation is unlikely to be exactly the same in any of the beds sampled; if sedimentation is slower than that which produces current-normal orientation, the forces acting on the particle will cause the particle to obtain a position of maximum stability, i.e. parallel to the flow. Yet the rate of sedimentation may not be slow enough to accomplish this; it is noted that there is a slight tendency for the uppermost portions of the bed to be oriented more parallel to the current.

Schwarzacher (1951) noted that the depositional velocity of the sediment is more important than the velocity of the flow. The term depositional velocity is taken to mean that proportion of the material deposited per unit time. He attempted to prove this by experimental determinations, assuming that the fabric is a function of the feeding velocity. Schwarzacher states that his results varied widely, though he does not state how or why. As the feed velocity in turbidity currents is not the same from current to current, then on this basis one would not expect the same orientation pattern in all the beds.

The probability that two currents are involved in the formation of turbidite deposits is indicated only by one bed; thin sections cut within the flute of this possess an orientation parallel to that of the flute; yet thin sections cut in the main body of the bed are parallel to groove casts which have a different orientation to that of the flutes. This may indicate that the flute marks were formed by a scouring current and the turbidite itself flowed in from a different direction at a later time. The fabric within the flute demonstrates a secondary mode parallel to that of the grooves, indicating that although the depositing current was parallel to the grooves, the linear hollow of the flutes locally guided a certain amount of the sediment.

Bouma (1962) expected to find a certain set of sequences of varying orientations; he suspected that orientation in the graded interval would be parallel to the current, normal to the current in the ripple interval and somewhat variable in the laminated layers. However, nowhere could he observe this arrangement. Almost all of his grain orientation determinations were a little more than 90° to the right of the flow, as indicated by sole features. Only two beds, with Bouma's structural sequence were found, but were not collected in the present study. Otherwise only graded bedding and parallel lamination were observed and collected. It is difficult, then, to interpret the grain orientation here found in the light of Bouma's sequences.

CONCLUSION

The initial objective of the study was to determine whether the mean grain orientation, in the plane of bedding, coincided with that of the sole marks on the base of turbidite beds of the Normanskill Formation, New York. Of thin sections from 44 beds, 85% showed a preferred orientation at the 90% level, of which only 14% did not deviate significantly from the sole marks. No preferential departure from the sole existed; 40% of the thin sections demonstrated an anticlockwise deviation; 60% were clockwise. The deviation varies up to 90° either side of the sole. There is a slight tendency for the maximum deviation to occur at the base of the beds and to be at a minimum towards the top.

Imbrication of the grains exists in the plane normal to bedding and parallel to the direction of flow, as indicated by the grain orientation parallel to bedding. Eighty per cent of the thin sections studied showed average dips of 15% to 25% from the horizontal. As the mean grain orientation in the bedding plane is not coincident with the sole marks on the base of the bed from which the thin sections were cut, the determination of up and down current directions of dip is somewhat subjective. The direction of grain orientation nearest to the direction of the flow mark for each section was chosen. From this, 80 per cent of the determinations had an upcurrent direction of imbrication.

There is no constant relationship between the deviation of the grain orientation, in the plane parallel to bedding, and the height above the base of the bed from which the thin sections were studied, other than a tendency for maximum deviation at the base of the bed. No two beds exhibited the same pattern of deviations upwards. Significant agreement of the vector means was found within one bed; a second -- sampled laterally and vertically demonstrated agreement of the vector means in one vertical section, yet a second section cut from the same bed, 180 centimetres away showed lack of correlation at the centre. Yet another bed, demonstrated no significant agreement of the mean grain orientation anywhere within the bed.

One bed, possessing divergent flute and groove casts on the base was sampled vertically at 3 cms. intervals. Mean grain orientation within the flute was parallel to that structure. Higher up the mean grain orientation became aligned parallel to the orientation of the grooves. Another bed showing similar sole features did not show the above relationships.

Maximum grain size and maximum sphericity decrease upwards in the beds. The more elongate grains were more closely related to the grain orientation.

A P P E N D I X

APPENDIX

1) STATISTICAL TREATMENT OF THE DATA.

The statistical analysis of grain orientation in thin section, involves a number of difficulties in that the data is cyclic in nature; it has a period of 180 degrees.

The primary objective is the determination of the average direction of the grains measured. The linear mean and the standard deviation are sensitive to the choice of origin, (Jizba, 1953), i.e. a change of origin will make a difference in the mean and the standard deviation of the same population. Therefore the vectors must not be treated as scalars.

To work on 180 degree data it is necessary to operate on 2θ rather than on θ, where θ is the angle of each grain from some arbitrary origin. The vector mean can be calculated from the equation:

$$\tan 2\theta = \frac{\Sigma \sin 2\theta_i}{\Sigma \cos 2\theta_i}$$

A measure of the dispersion of the data is given by the vector magnitude:

$$r = \sqrt{(\Sigma \sin 2\theta_i)^2 + (\Sigma \cos 2\theta_i)^2} \qquad \text{(Curray, 1956)}$$

The vector magnitude is usually expressed as a percentage, L, of the total number of observations, N. The higher the value of L the higher the degree of preferred orientation.

To test for the degree of departure from uniform distribution Tukey's Chi Square test was used. (Rusnak, 1957; Harrison 1957) This test is independent of the choice of origin. It is not a straightforward application of the Chi Square test; it is designed to test for the presence of a single maximum and minimum frequency in a unimodal distribution.

As in the usual Chi Square test the data is grouped into classes, in this case from 0 to 19 degrees, from 20 to 39 degrees etcetera, and then compared with the uniform "expected" distribution. The measure of deviation for each class interval is given by:

$$X = \frac{O-E}{\sqrt{E}}$$

where O is the ...rved number of orientation measurements in each class, and E is the "expected" number of measurements for uniform distribution.

Two factors S and C are the basis for this test, where

$$S = \frac{\Sigma x\sin 2\theta}{(\Sigma \sin^2 2\theta)^{1/2}}$$

$$C = \frac{\Sigma x\cos 2\theta}{(\Sigma \cos^2 2\theta)^{1/2}}$$

Tukey then proposes that these be treated as Chi Square with two degrees of freedom. Chi Square values are compared with the tables given in the standard texts. The level of probability taken in this study was 90 percent.

2. TABLES OF STATISTICAL RESULTS

TABLE 1A

Source of error	SS	df	MS	F	$F_{0.95}$
Row means	4114.35	2	2057.18	1.33	6.94
Column means	4954.36	2	2477.18	1.60	6.94
Residual	6183.69	4	1545.92		
Total	15252.40	8			

Analysis of variance results for vector means on nine thin sections in bed D64 4N.

TABLE 2A

Hypothesis	t	accept	reject	t	accept	reject	Hypothesis
$\mu N^3a = \mu N^3b$	-16.6		x	-5.9		x	$\mu N^3a = \mu N^2a$
$\mu N^3b = \mu N^3c$	+13.1		x	-6.6		x	$\mu N^2a = \mu N^1a$
$\mu N^2a = \mu N^2b$	-11.5		x	-0.88	x		$\mu N^3b = \mu N^2b$
$\mu N^2b = \mu N^2c$	-3.8		x	+7.6		x	$\mu N^2b = \mu N^1b$
$\mu N^1a = \mu N^1b$	+4.3		x	-17.9		x	$\mu N^3c = \mu N^2c$
$\mu N^1b = \mu N^1c$	-8.8		x	-4.5		x	$\mu N^2c = \mu N^1c$

The rejection region that the two populations have the same mean is

$$-1.996 \geqslant t \leqslant +1.996$$

$\underline{t}$ - test on the vector means of nine thin sections in bed D64 4N.

TABLE 3A

Source of error	SS	df	MS	F	$F_{0.95}$
Row means	712.16	2	356.08	0.21	6.94
Column means	875.52	2	437.76	00.26	6.94
Residual	6755.24	4	1677.81		
Total	8342.92	8			

Analysis of variance for dispersion of nine thin sections in bed D64 4N.

TABLE 4A

Source of error	SS	df	MS	F	$F_{0.95}$
Row means	1785.08	2	892.54	1.9	19.0
Column means	328.54	1	328.54	0.71	200.0
Residual	962.62	2	463.31		
Total	3040.24	5			

Analysis of variance for vector means in bed D64 3A.

TABLE 5A

Hypothesis	t	accept	reject	Hypothesis	t	accept	reject
$\mu A^3a = \mu A^2a$	8.56		x	$\mu A^3a = \mu A^3b$	-0.68	x	
$\mu A^2a = \mu A^1a$	-12.16		x	$\mu A^2a = \mu A^2b$	-7.69		x
$\mu A^3b = \mu A^2b$	1.21	x		$\mu A^1a = \mu A^1b$	1.81	x	
$\mu A^2b = \mu A^1b$	1.9	x					

$\underline{t}$ - test on vector means in bed D64 3A.

TABLE 6A

Hypothesis	t	accept	reject
$\mu A^2a = \mu A^2b$	-0.67	x	
$\mu A^1a = \mu A^1b$	-1.98	x	
$\mu A^2a = \mu A^1a$	0.99	x	
$\mu A^2b = \mu A^1b$	-0.24	x	

$\underline{t}$ - test on vector means in bed D 64 10A.

TABLE 7A

Source of error	SS	df	MS	F	$F_{0.95}$
Row means	0.282	2	0.141	8.29	19.0
Column means	0.085	1	0.085	5.00	18.5
Residual	0.035	2	0.017		
Total	0.402	5			

Analysis of variance results on grain size (average) in nine sections from bed D64 4N.

3. LIST OF THIN SECTIONS AND RESULTS OF ANALYSIS

TABLE 8A

Thin section	θ	Deviation from the sole	L	χ^2		Ht. above base of bed in cms.	Bed thickness (cms.)
G.V.M.4 Bed B	171.3	1.3 c	31.9	17.1	**	4.0	46.8
G.V.M.4 Bed C	72.1	22.9 a	11.7	2.7	N.S.	4.5	60.0
G.V.M.4 Bed D1	163.1	13.1 c	11.9	3.6	N.S.	3.5	21.0
Bed D2	207.1	57.1 c	14.27	3.4	N.S.	4.5	21.0
Bed D3	188.9	38.9 c	14.6	5.1	*	5.5	21.0
Bed D4	139.1	10.9 a	25.1	12.9	**	6.5	21.0
Bed D5	165.6	15.6 c	50.3	46.9	**	9.0	21.0
62 1 B	60.4	28.0 c	35.78	25.89	**	3.7	--
62 2B	163.5	55.2 c	16.2	5.73	*	4.5	--
62 3 J1	165.4	82.0 a	21.1	6.18	**	2.0	27.0
62 3 J2	35.9	31.1 a	16.6	6.9	**	10.0	27.0
62 3 J3	140.0	73.0 c	35.3	25.1	**	18.0	27.0
62 3 J4	115.0	48.0 c	23.5	12.3	**	26.0	27.0
62 3 K	126.7	66.7 c	22.93	11.04	**	--	--
62 3 L	123.3	28.3 c	18.18	6.94	**	2.5	5.5
62 3 U1	79.3	35.62 a	11.57	1.86	N.S.	4.0	17.0
62 3 U2	173.2	58.2 c	21.9	8.92	**	6.0	17.0
62 4 B	63.8	46.2 a	21.0	8.2	**	--	--
62 5 A3	39.5	40.5 a	39.6	28.8	**	--	17.5
62 5 B	10.1	5.1 a	49.1	39.9	**	2.0	5.0
62 5 D1	30.2	5.2 a	38.0	26.5	**	--	12.5

TABLE 8A (cont'd)

Thin section	θ	Deviation from the sole	L	χ^2		Ht. above base of bed in cms.	Bed thickness (cms.)
62 5 D2	22.5	12.5 a	22.4	10.8	**	--	12.5
62 6 A	34.6	6.4 a	2.06	0.02	N.S.	--	--
62 7	176.7	26.7 c	13.87	3.93	N.S.	--	--
62 8 B	151.6	6.6 a	31.7	18.9	**	--	--
62 9 A	90.9	35.9 c	38.4	31.4	**	2.5	4.0
62 9 B	139.05	79.05 c	28.5	13.8	**	--	--
62 10 A	154.8	64.8 c	23.3	11.4	**	--	40.0
62 10 B	112.3	2.3 c	33.18	20.84	**	2.0	60.0
62 11 A	126.0	51.0 c	11.9	3.4	N.S.	1.0	30.0
62 11 B	37.8	42.8 a	5.29	0.98	N.S.	--	45.0
62 11 C	175.5	85.5 c	29.717	17.4	**	2.0	60.0
62 11 D	3.2	66.8 a	26.8	14.5	**	2.0	32.0
62 11 F	45.6	24.3 a	19.7	7.4	**	1.0	27.0
62 11 G	12.83	62.13 a	28.4	14.5	**	4.0	45.0
62 11 J	34.48	35.52 a	11.57	1.86	N.S.	3.0	42.5
D64 2 C^3a	202.7	64.3 a	18.5	6.5	**	55.0	60.0
D64 2 C^1b	155.	90.0	9.01	2.07	N.S.	18.0	60.0
D64 2 C^1c	219.3	34.62 a	18.76	7.65	**	14.0	60.0
D64 2 D^1a	22.2	60.8 a	5.669	0.69	N.S.	1.5	75.0
D64 2 D^2a	62.4	20.6 a	29.23	11.62	**	5.0	75.0
D64 2 D^3a	Too fine for the experiment.					22.5	75.0
D64 3 A^1a	89.0	23.0 c	34.2	22.9	**	4.0	180.0
D64 3 A^3a	19.3	46.7 a	30.9	19.8	**	73.0	180.0

TABLE 8A (cont'd)

Thin section	θ	Deviation from the sole	L	χ^2		Ht. above base of bed in cms.	Bed thickness (cms.)
D64 3 A^3a	72.0	6.0 c	15.7	4.76	*	124.0	180.0
D64 3 A^1b	79.0	14.0 c	36.0	24.1	**	3.0	180.0
D64 3 A^2b	68.4	3.4 c	13.69	3.46	N.S.	59.0	180.0
D64 3 A^3b	76.3	11.3 c	20.3	11.59	**	110.0	180.0
D64 4 N^1a	114.3	26.3 c	31.49	22.08	**	3.5	15.0
D64 4 N^1a	23.7	56.3 a	23.6	11.45	**	5.0	15.0
D64 4 N^2a	74.1	5.9 a	38.8	30.35	**	9.5	15.0
D64 4 N^3a	38.7	42.7 a	53.7	59.52	**	13.5	15.0
D64 4 N^1b	98.6	18.6 c	27.89	15.40	**	3.0	15.0
D64 4 N^2b	144.2	64.2 c	34.7	24.75	**	9.0	15.0
D64 4 N^3b	138.9	58.9 c	36.89	24.4	**	14.0	15.0
D64 4 N^1c	140.0	60.0 c	13.8	4.07	N.S.	2.0	15.0
D64 4 N^2c	167.1	86.9 c	37.9	25.4	**	8.5	15.0
D64 4 N^3c	60.2	19.8 a	32.0	22.7	**	14.0	15.0
D64 7 A^1a	113.3	7.3 c	29.3	16.6	**	1.0	--
D64 7 A^1b	32.4	71.6 a	10.6	2.2	N.S.	1.0	--
D64 8 A^1a	186.9	1.9 c	18.49	4.85	*	2.5	--
D64 9 A^1a	63.7	31.3 a	28.9	16.5	**	4.5	22.0
D64 9 A^2a	47.3	48.7 a	33.8	28.8	**	12.0	22.0
D64 9 A^3a	88.6	6.4 a	11.86	2.7	N.S.	20.0	22.0
D64 9 C^1a	45.3	29.7 a	12.0	3.4	N.S.	19.0	25.0
D64 9 C^2a	92.6	17.6 c	25.6	13.6	**	4.0	25.0
D64 9 C^3a	88.1	13.1 c	11.42	3.4	N.S.	12.0	25.0

TABLE 8A (cont'd)

Thin section	θ	Deviation from the sole	L	χ^2		Ht. above base of bed in cms.	Bed thickness (cms.)
D64 10 A^1a	339.3	39.3 c	17.7	5.4	*	4.0	14.0
D64 10 A^2a	333.8	33.8 c	24.01	10.5	**	13.0	14.0
D64 10 A^1b	328.8	28.8 c	43.5	36.7	**	4.5	14.0
D64 10 A^2b	330.1	30.1 c	37.0	26.9	**	13.0	14.0
D64 12 A^1a	157.1	71.1 a	28.0	13.7	**	1.0	--
D64 12 A^2a	329.5	63.4 c	4.6	0.78	N.S.	4.0	--
D64 13 A^1a	28.2	38.2 c	8.02	1.294	N.S.	--	--
D64 14 A^1a	203.2	80.2 a	10.42	2.08	N.S.	3.0	19.0
D64 14 A^2a	35.9	87.1 a	10.52	1.98	N.S.	7.0	19.0
D64 14 A^3a	39.7	83.3 a	13.03	2.64	N.S.	13.0	19.0
D64 15 A^1a)) D64 15 A^2a)	Too fine for the experiment						--
D64 15 A^1b	131.9	64.1 a	6.92	0.82	N.S.	2.5	--
D64 15 A^2b	148.5	47.5 a	9.346	2.337	N.S.	5.5	--
D64 16 A^1a	186.1	78.9 a	34.9	25.9	**	4.0	--
D64 16 A^2a	201.3	63.7 a	23.0	34.9	**	7.5	--
D64 17 A^1a	87.1	--	18.1	6.59	**	1.0	12.0
D64 17 A^2a	90.3	--	15.5	4.669	**	4.00	12.0
D64 17 A^3a	342.6	--	25.3	11.11	**	7.00	12.0
D64 17 A^4a	220.2	--	22.1	10.4	**	10.00	12.0

* indicates significance at the 90% level.

** indicates significance at the 95% level.

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