OPERATOR VARIANCE IN ORIENTATION MEASUREMENTS IN TILL MACROFABRIC ANALYSES

An Experimental Study

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Abstract. The present study discusses some aspects of measurement errors in till-macrofabric analyses. An attempt is made to throw light on the operator variance in orientation measurements, owing to the influence of the long-axis dip and the axis ratio of pebbles. Furthermore, the effect of the above-mentioned sources of error on till-fabric analyses is discussed.

To recognize these sources of error and to estimate their effect quantitatively, they have been segregated from natural till by experimental designs.

It is concluded that under the present conditions operator variance has arisen from difficulties in measuring accurately the orientation of stakes with dips of 50° or more. However, these errors do not affect the characteristic of the artificial till fabric seriously, even though the orientation differences often amount to 10—30° for the same stake. Furthermore, the study shows that operator variance arising from the above-mentioned errors has been reduced considerably by using an orientation goniometer instead of a compass.

INTRODUCTION

In using quantitative analyses for the estimation of the variance in the properties of glacial till or any other material, it is necessary to make sure that differences due to technique do not interfere with the natural differences which are to be investigated. Therefore, in estimating till-fabric analyses, one should take into account the facts that both the dip, the direction, and the intensity of the preferred orientation are affected by errors in the measurements and the choice of statistical methods for summarizing the data. In addition, they depend on the consistency of the till fabric in relation to the number of pebbles making up each sample.

The reliability of orientation and dip analyses in relation to the consistency of the till fabric has been investigated by Kauranne (1960), Norris (1962), Young (1969), and Krüger (1970). The problem of finding suitable statistical methods for analyses has been discussed, *inter alia* by Krumbein (1939), Curray (1956), Andrews and Shimizu (1966), and Krüger (1970). The importance of measurement errors has been studied by both Griffiths and Rosenfeld (1954) and Hill (1968), and some aspects of this problem are the subject of discussion in the present paper.

By way of introductions, Hill points out (p. 93) that measurement errors comprise both errors in the measurement of the orientation and dip of pebbles and variations resulting from differences in the initial selection of pebbles for measurement, and possible errors arising from the removal of the pebbles for examination before measuring. Hill ascribes these sources of error to inconsistency in the operator or to differences between operators. Hill has demonstrated experimentally (p. 104) that operator variance induced by the sources of error mentioned above does not affect the original fabric seriously, even though the differences due to measurement error often amounted to 30° or 40° for the same pebble.

In addition, Hill inspected the data of the experiment, in order to see if pebbles with steep dips had larger variances in orientation measurement, but he had too small a number of steeply dipping pebbles for conclusive results (written communication, 1971). Certainly, that problem comes into the picture in seeking the sources of inconsistency in the performance of orientation measurement, both in the operator and as between operators.

The present study is therefore an attempt (1) to throw light on the operator variance in orientation measurements owing to the influence of the long-axis dip and the axis ratio of pebbles, and (2) to estimate the effect of the above-mentioned sources of error on till-fabric analyses.

To recognize these sources of errors and to estimate their effect quantitatively, they have been segregated from natural till by experimental designs.

Fig. 1. Artificial till fabric representing pebbles with an *a:b* axis ratio of 6:2.

DESIGN OF ARTIFICIAL TILL FABRICS

The experiment was carried out on four artificial till fabrics representing pebbles with *a:b* axis ratios of 3:2, 4:2, 5:2, and 6:2. Each design consisted of a plaster slab, 30 x 30 cm, on which 25 identical stakes with a diameter of 5 mm were carefully fixed with an interspace of 5 cm (Fig. 1). The stakes were randomly oriented, seeing that a preferred orientation might affect the performance of measurements (Johansson, 1960, p. 142). Five of the stakes had dips of 0°, 10°, 20°, 30° and 85°, respectively, while the dips of 35°, 40°, 45°,... 75° and 80° were represented by two stakes each. In this way, the dips that might be expected to increase the variance in the orientation measurements were particularly taken into account. Furthermore, brown plaster of Paris was placed in between the stakes, giving the design an undulating surface, in order to create the most realistic field situation with pebbles carefully exposed for measuring. In order to avoid shadows, the lighting in the laboratory was subdued and diffused.

MEASURING INSTRUMENTS

Two series of experiments were carried out, using different instruments. The measuring instruments were a Silva compass graduated in 2° intervals and an orientation goniometer. The goniometer had been recently constructed as a research tool intended for the solution of till-fabric problems. Similar equipment for orientation studies is illustrated in papers by Karlstrom (1952) and Harrison (1957).

The orientation goniometer used in the present case has a revolving stage with a diameter of 60 cm and is graduated in 1° intervals from 0° to 360° (Fig. 2). The revolving stage carries two small stages, movable at right angles to each other. After a "till cube" has been re-oriented on the upper stage, the orientation of long axis of pebbles which are accepted for analysis is measured using threads of sight.

PROCEDURE OF EXPERIMENT

Four operators took part in the experiment. Operators I and II were two students of physical geography, who were experienced in handling a compass, having previously taken part in research projects. Operator III was the present writer, who is considerably experienced in till-fabric analyses, and operator IV was a laboratory worker, who is usually occupied with the reading of measuring instruments and who had been trained to handle a compass.

In the first series of the experiment, analyses of the four artificial till fabrics were carried out, 100 stakes being measured by each of the four operators on each of four occasions, using the Silva compass. Furthermore, the procedure was repeated by operator III at an interval of a month. The second series of the experiment was carried out by operators III and IV, using the orientation goniometer. The whole experiment produced 2,800 orientation values. All the values were rounded to the nearest 5° interval.

For each operator, the analyses of the four designed till fabrics were completed within six days. The order in which the fabrics were analysed was changed, as was

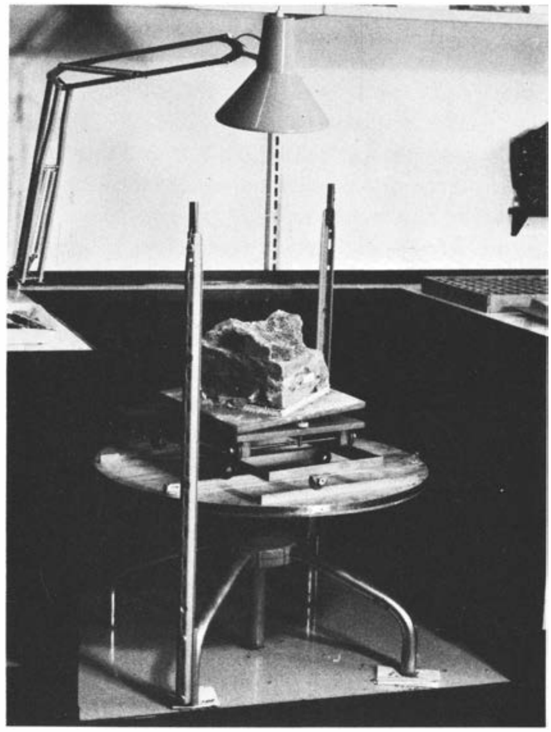

Fig. 2. Orientation goniometer used in the experiment.

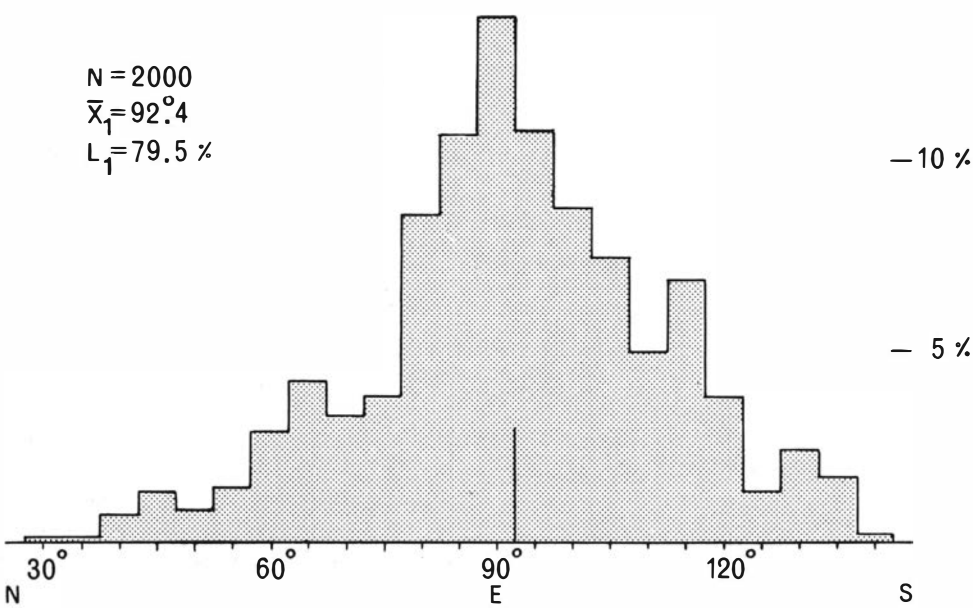

Fig. 3. Histogram of transformed orientation data measured by using a compass.

not the case with the stakes. The time allowed to complete the measuring of the 25 stakes on each occasion was unlimited but amounted to 12 and 28 minutes, on the average, using the compass and the goniometer, respectively.

On going through the data, it appeared that in nine cases the orientation values showed an incredible deviation. The nine measurements were repeated to avoid errors due to mistakes in reading the compass or booking the results.

TRANSFORMATION OF DATA

As was mentioned above, the stakes of the artificial till fabrics were randomly oriented. However, the handling of the data is facilitated if the orientation values have a normal frequency distribution. Therefore, the random distribution has been transformed into an approximately normal frequency distribution to within a $\pm 50°$ range.

Fig. 3 shows the frequency distribution of 2,000 transformed orientation data measured by the compass. The mean ($X_1 = 92.°4$) has been calculated by using two-dimensional vector analysis, and the dispersion around this value is expressed by the vector magnitude ($L_1 = 79.5$ %). Using the orientation goniometer, the mean (X_2) and the vector magnitude (L_2) of 800 measurements are 93.°8 and 80.1 % respectively.

ANALYSIS OF COMPASS MEASUREMENTS

The original data are too extensive to be published, but the relative range of distribution of the orientation measurements in relation to operators, axis ratio, and long-axis dip are listed in Table I. In the operators the range of distribution is only 0–5° for stakes dipping less than 45–75° but increases to some extent with increasing dip values. The difference between the operators is well marked between operators II and III, while the other two operators takes up an intermediate position. Furthermore, it appears that an increasing axis ratio gradually increases the range of distribution in operators I and III *a*. The other operators are more variable, but it is obvious that in the case of the axis ratio 6:2 the range of distribution decreases considerably.

Fig. 4 shows the orientation measurements from stake to stake on the fourth occasion of the axis ratio 3:2, compared with the mean for all operators for each stake for the whole experiment. The consistency in both operators is clear. Thus, operator II's measurements are above the mean, with the exception of the 1st (dip of 40°) and the 23rd (dip of 20°) stakes. On the other hand, operator IV's measurements are below the mean, except for the 12th (dip of 70°), 13th (dip of 0°), and 17th (dip of 65°) stakes. But it must be pointed out that inconsistency in operators from stake to stake, i.e. variations above and below the mean, as demonstrated by Hill (1968, p. 101), appears from an examination of the other operators.

Furthermore, Fig. 4 shows that both operators very often estimate the orientation of stakes dipping less than 45° as identical with or close to the mean (for example, the 1st, 7th, 13th, 16th, 22nd, and 23rd stakes), while stakes with steep dips deviate seriously (for example, the 3rd, 4th, and 18th stakes). The other operators follow the same rule.

Fig. 5 serves to illustrate graphically the result of different kinds of operator variance. The mean (X_1) for the whole experiment is inserted on the graph, and each point represents the mean for each occasion. Operator I shows both a gradual increase of the mean value and an increasing control, and a gradual approach to a constant decision throughout the experiment. The case with operator IV is almost the opposite, as she has a relatively large magnitude variation in mean values throughout the analyses. Operator II takes up an intermediate position, as the axis ratio 3:2 corresponds with that of operator I, while the axis ratio 6:2 mostly corresponds with the trend of operator IV. Operator III is stable, as he makes the same decisions with great consistency. Furthermore, it can be seen that operator II estimates consistently high values for all occasions, while operator III and IV mostly tend to record low values (cf. Fig. 4). Finally it must be emphasized that the influence of the axis ratio which appears from Table I does not affect the preferred orientation seriously but is masked by differences between operators, owing to the measurement of stakes with steep dips.

Similarly, the analysis of the vector magnitude (Table II) shows inconsistency in operators I and II, as well as an increase of the vector magnitude from axis ratio 3:2 to 6:2. On the other hand, operators III and IV show great consistency and no significant differences, either between the operators or owing to different axis ratios.

The two effects of dip and axis ratio are listed in Table III. In accordance with the foregoing analysis, it is clear that a combination of the operators will increase the relative range of distribution for steeply dipping stakes seriously, since the operators yield different results. On the basis of an axis ratio characteristic of

Table I. Relative range of distribution of orientation measurements in degrees (compass).

No. of obser-vations	Long-axis dip	Operator I Axis ratio *a:b* 3:2	4:2	5:2	6:2	Operator II Axis ratio *a:b* 3:2	4:2	5:2	6:2	Operator III *a* Axis ratio *a:b* 3:2	4:2	5:2	6:2	Operator III *b* Axis ratio *a:b* 3:2	4:2	5:2	6:2	Operator IV Axis ratio *a:b* 3:2	4:2	5:2	6:2
	0°	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
4	10°	5	0	0	5	5	5	0	5	0	5	0	0	0	0	5	0	5	5	0	0
	20°	0	5	0	5	5	0	5	5	0	0	0	0	0	0	0	0	0	5	5	5
	30°	0	0	0	5	5	5	5	5	0	0	0	0	0	0	0	0	5	0	5	5
	35°	5	5	5	0	5	5	0	5	5	5	5	0	5	0	5	5	5	5	5	0
	40°	5	5	5	0	5	5	5	5	5	0	5	0	0	5	5	0	5	5	5	5
	45°	5	5	5	0	5	5	10	0	5	5	5	5	5	5	5	5	5	5	10	5
	50°	5	5	5	5	5	5	10	10	5	5	0	5	5	5	5	0	10	5	5	0
8	55°	5	5	5	5	5	10	10	5	5	5	0	5	5	5	5	5	5	10	5	5
	60°	0	5	5	5	10	5	10	5	5	5	0	5	5	10	5	0	5	5	10	5
	65°	10	5	5	5	15	10	5	5	5	5	5	5	5	5	0	5	10	5	10	5
	70°	15	10	5	5	5	10	15	10	5	5	5	5	5	5	5	5	5	5	5	10
	75°	15	10	5	10	20	10	15	15	5	10	5	5	5	10	5	10	10	10	10	5
	80°	15	5	15	10	15	15	25	15	15	10	5	10	10	10	10	10	10	10	15	5
4	85°	10	20	10	10	25	15	10	15	20	15	15	10	20	15	20	0	20	20	15	15
Sum of relative ranges		95	85	70	70	130	105	125	105	80	75	55	55	70	75	75	45	100	95	105	70

Table II. Analysis of the vector magnitude (L %).

Axis ratio	Operator I Occasion 1	2	3	4	Operator II Occasion 1	2	3	4	Operator III *a* Occasion 1	2	3	4	Operator III *b* Occasion 1	2	3	4	Operator IV Occasion 1	2	3	4
3:2	72	77	80	78	83	74	78	82	81	80	81	83	78	80	79	82	80	76	78	76
6:2	81	83	84	82	80	82	79	86	81	79	80	80	78	77	79	80	79	78	78	79

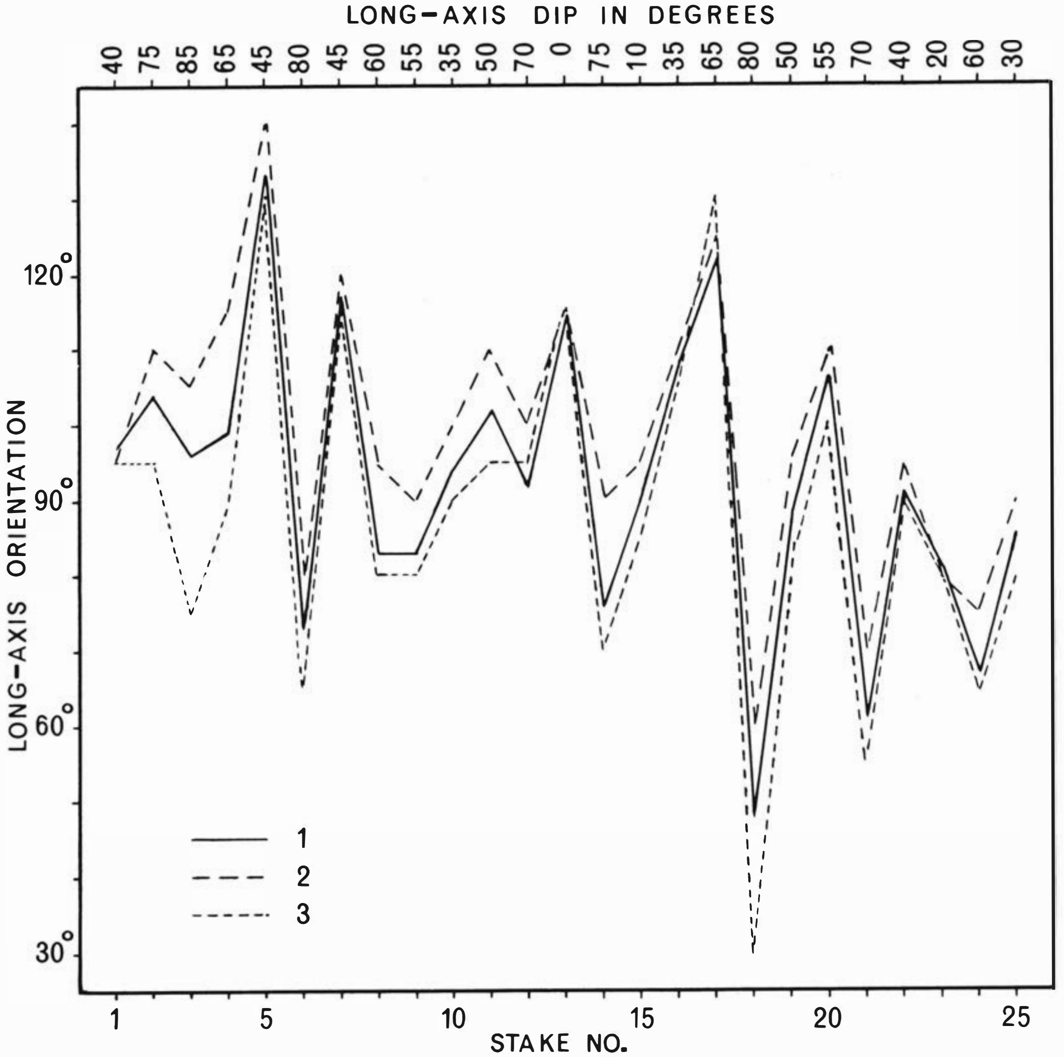

Fig. 4. Consistency in operators II and IV from stake to stake on the fourth occasion for the axis ratio 3:2. (1) Mean for all operators for each stake for the whole experiment, (2) operator II, and (3) operator IV.

natural till (Fig. 6), the range of distribution has been weighted and the mean calculated for each dip value, as shown in Fig. 7 A. Furthermore, three times the weighted standard deviation has been inserted in the graph. The smooth curves so obtained show the operator variance that might be expected in the orientation measurement of each stake. The potential error increases seriously for stakes dipping more than 45°, as this part of the curve is logarithmic. It should be noted that in the present experiment the conditions are optimal, while in field work the analyses are subject to some difficulties, for example, those resulting from an inconvenient position.

ANALYSIS OF GONIOMETER MEASUREMENTS

The bracketed figures in Table III show the influence of the long-axis dip and the axis ratio on the relative range of distribution of the orientation measurements. It appears that the range is considerably reduced throughout the grades of dip and only increase somewhat for the most steeply dipping stakes (dips of 80–85°). Obviously, the relative range of distribution decreases with increasing axis ratio. The range has been weighted and the mean values are shown in Fig. 7 B. Operator variance in orientation measurements due

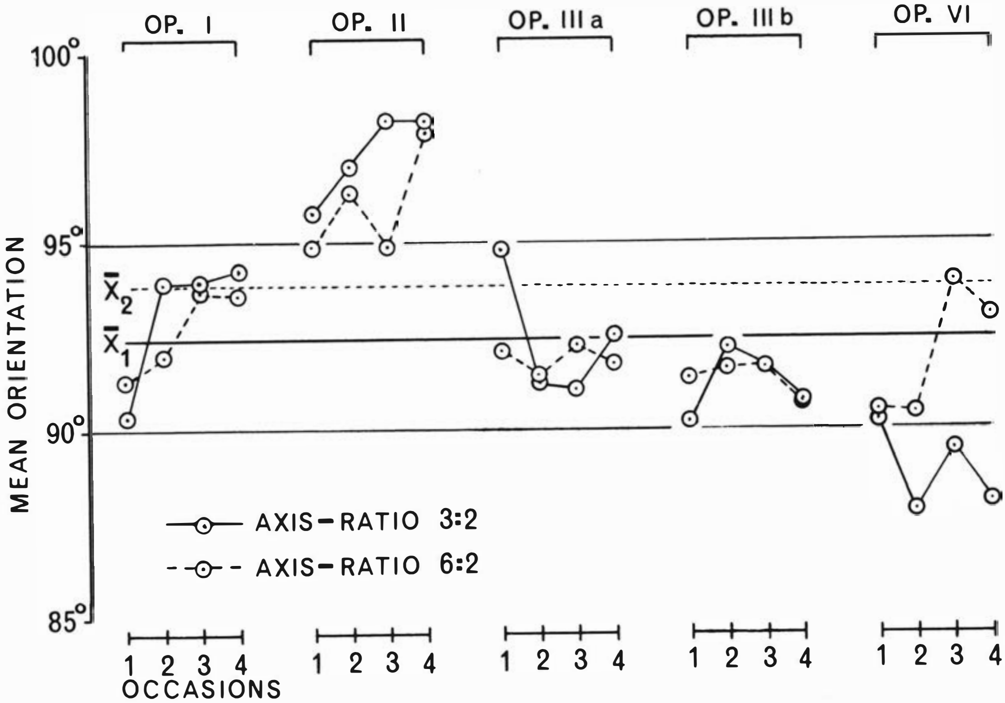

Fig. 5. Different kinds of operator variance. X_1 is the mean for the whole experiment, using the compass. $\bar{X}_2$ is the mean for the whole experiment, using the goniometer.

Table III. Relative range of distribution of compass-orientation measurements in degrees. Bracketed figures indicate the range of goniometer measurements.

Long-axis dip	Axis ratio 3:2		4:2		5:2		6:2	
0°	0	(5)	5	(5)	5	(0)	5	(0)
10°	10	(5)	10	(0)	5	(0)	5	(0)
20°	5	(0)	10	(5)	5	(0)	10	(0)
30°	10	(5)	5	(5)	5	(0)	5	(0)
35°	10	(5)	10	(5)	5	(0)	5	(0)
40°	10	(5)	10	(5)	15	(0)	5	(0)
45°	10	(0)	10	(5)	15	(0)	10	(0)
50°	20	(5)	5	(0)	10	(0)	10	(0)
55°	15	(5)	20	(5)	15	(0)	10	(0)
60°	15	(5)	10	(5)	25	(5)	15	(5)
65°	25	(5)	15	(5)	15	(5)	15	(5)
70°	20	(5)	20	(5)	15	(5)	25	(5)
75°	25	(5)	25	(5)	30	(5)	25	(5)
80°	35	(10)	25	(10)	25	(10)	25	(5)
85°	45	(10)	35	(10)	25	(10)	30	(10)
Sum of relative ranges	225	(75)	215	(75)	215	(40)	200	(35)

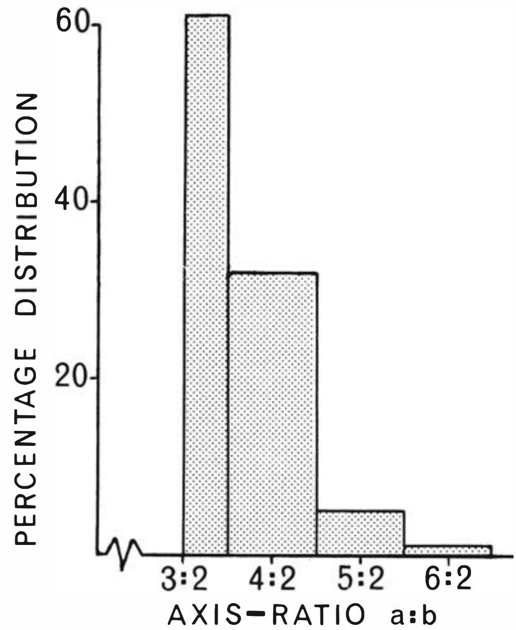

Fig. 6. Histogram of frequency distribution of the axis ratio of 700 pebbles from natural till, Fakse Banke, Denmark. The axis ratio of pebbles selected for orientation measurement in till-fabric analyses has been defined as at least 3:2.

to both long-axis dip and axis ratio is seen to be insignificant.

DISCUSSION

The foregoing analysis of data has shown that, in using a compass, the operators yield different orientation values, and not only different values but values which show inconsistency from occasion to occasion. Seeing that differences in axis ratio do not affect the orientation measurements of horizontal stakes, it is concluded that in the present study the operator variance arose principally from errors in measuring stakes with steep dips. In the present case, the potential error in orientation measurements increases seriously for stakes dipping more than 45°. Certainly, this might have been expected, but nevertheless the problem has only occasionally received attention. Thus, in a detailed study of the internal composition and structure of drumlins in Northern Ireland, Hill (1971, p. 22) eliminated pebbles with dips of 70° or more from fabric analyses because of difficulties in measuring their orientation accurately, and in a till-fabric study from Zealand, Denmark, pebbles dipping more than 40° were eliminated (Krüger, 1970, p. 137).

However, the above-mentioned errors are random, not cumulative, and therefore in sufficiently large samples they do not affect the results of the analyses seriously. The present experiment shows a total error restricted to within a ±6° range of the mean orientation, and the vector magnitude is vitiated by an error of ± 6 %. It is important to mention that these limits are related to artificial till fabric with a mean dip of about 50°. In natural till, pebbles dipping more than 50° are usually rare, even in ablation till and thrust till, as pointed out by Niewiarowski (1969, p. 146). Thus, only 8 % of 1180 pebbles from lodgement till in the central part of New York State had dip values of more than 40° (Holmes, 1941, p. 1316), and 9 % of 769 pebbles from lodgement till in southern Zealand dipped more than 40° (Krüger, 1970, p. 137). Exceptionally, the average amount of dip for pebbles in the Wadena drumlin field was 23° (Wright, 1957, p. 27). Certainly, these circumstances reduce the possibility of measurement errors owing to long-axis dip. Furthermore, attention is called to the fact that

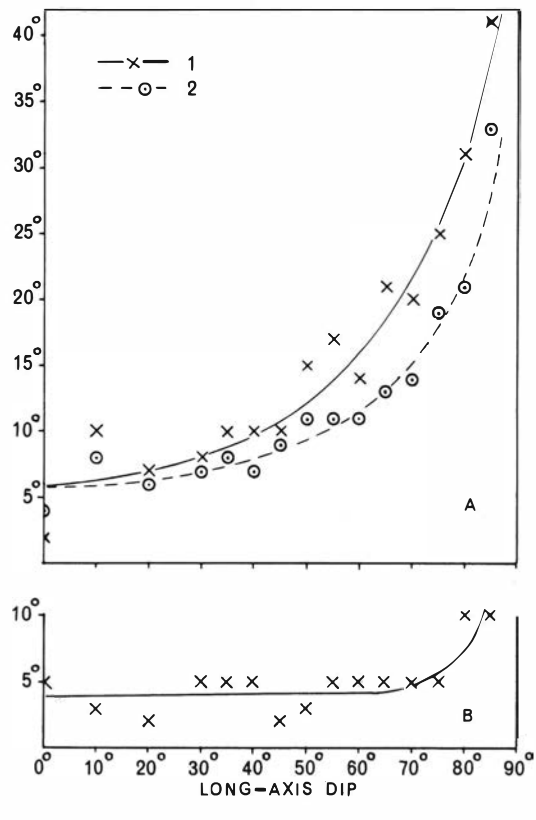

Fig. 7. Potential error in orientation measurement in relation to long-axis dip (A), using a compass or (B) using a goniometer. (1) Weighted mean range of distribution for the whole experiment. (2) Three times the weighted standard deviation.

operator variance arising from errors of measurement is masked by inconsistency of the till. Thus, the preferred orientation of 50 pebbles may deviate within a $\pm 18°$ range of the mean over very short horizontal distances (2–26 m), and even if the analyses are combined two by two, there is no appreciable reduction of this range (Krüger, 1970, p. 143).

On the other hand, the errors of measurements are accentuated if subgroups are established according to the amounts of long-axis dip, in order to investigate the influence of this till-pebble property on the long-axis direction during the time of deposition (cf. Holmes, 1941, p. 1323).

The examination of the data has shown that operator variance owing to orientation measurements in field technique could be reduced if pebbles with dips of 50° or more were eliminated from fabric analyses.

By using an orientation goniometer, the possibility of operator variance is reduced considerably, even when a long-axis dip of 85° is used as an upper limit and when other errors arising from the goniometer technique are added. Harrison (1957, p. 102) has determined the sources of error in using the goniometer technique, and indicates the maximum expectable errors under careful working conditions. From the original position in the field to the position on the goniometer stage, the average error in the orientation of the "till cube" is estimated at only 3° and the error in measuring the orientation of the long-axis of the pebble is about 5°. In the present study, the error in measuring pebble orientation is shown to be about 4°. Thus, under the worst conditions, the total error in an orientation measurement, using a goniometer, is about 7°.

CONCLUSION

It is concluded that, in the present experiment, operator variance due to the orientation measurements being made with a compass arose principally from difficulties in measuring accurately the orientation of stakes with dips of 50° or more. However, these errors do not affect the characteristic of the artificial till fabric seriously, even though the orientation differences often amount to 10–30° for the same stake.

Furthermore, the study shows that operator variance arising from these errors has been reduced considerably by using the goniometer technique. In addition, errors due to a restricted space in which to manipulate the compass and resulting from a cramped position might be reduced, since the goniometer permits more pleasant working conditions.

ACKNOWLEDGEMENTS

The experimental study was made during the winter of 1971–72. The author wishes to thank Winnie Eberhardt, Ole Humlum, and Jesper Ratjen for their willingness to take part in the experiment. He is also grateful to Villy P. Jensen for undertaking the task of constructing the orientation goniometer used in the experiment. All the drawings have been made by the author.

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KEY WORDS

Till. Macrofabric. Till macrofabric. Operator variance. Measurement errors. Goniometer. Experiment.