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ORIGIN OF SHAPES OF QUARTZ SAND GRAINS

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ABSTRACT

The quartz grains in many metamorphic rocks tend to be elongate parallel to the c-axis. Recently a similar elongation has been observed in the quartz grains of unmetamorphosed sandstones; also another elongation parallel to the unit rhombohedron. Current explanations ascribe these elongations to fractures parallel to these directions and differential abrasion during transport. To check these explanations three sets of experiments were carried out, with the following results: (1) There was a decided tendency for some samples of quartz to fracture parallel to the unit rhombohedron, but no sample showed a pronounced fracture parallel to the c-axis. (2) Quartz grains from weathered (but undisturbed) quartzose igneous and metamorphic rocks show a tendency to be elongate parallel to prism and unit rhombohedral faces. (3) Abrasion tests on oriented prisms show that quartz is harder on prism faces than normal thereto. It is concluded that the elongation of quartz sand grains is due to original shape rather than to fracture and differential abrasion during transport.

It has long been observed that the quartz grains in many metamorphic rocks show a tendency to be elongate parallel to the c-axis. More recently a similar elongation has been observed in the quartz grains of unmetamorphosed sandstones.

From a study of the St. Peter and Jordan sandstones Wayland[1] concluded that, "It is probable that clastic quartz grains are longer and harder in the direction of the optic axis."

Rowland[2] found this elongation of quartz grains to obtain in three channel sandstones and a shale of lower Pennsylvanian age. He found a similar elongation parallel to the unit rhombohedron and concluded that, "These positions can be correlated with differential hardness of quartz and are similar to positions obtained in pressure experiments."

Krynine[3] describes quartz grains elongate parallel to the c-axis in the Third Bradford Sand of Pennsylvania. These grains he calls schistose

[1] Wayland, Russell G., Optical orientation in elongate clastic quartz: *Am. Jour. Sci.*, **237,** 99–109 (1939).

[2] Rowland, Richards A., Petrofabric determination of quartz grain orientation in sediments: Abstract. *Bull. Geol. Soc. Am.*, **51,** 1941–1942 (1940).

[3] Krynine, P. D., Petrology and genesis of the Third Bradford Sand: *Penn. St. Coll. Bull.*, **29,** p. 19 and Figs. 9 and 10 (1940).

quartz, i.e., quartz derived from schist, and the elongation is ascribed to original grain shape in the schist.

Krynine has noted this elongation also in many other Paleozoic sandstones of the Appalachian Region, in the Siwalik Series of India, the Triassic of the Connecticut Valley, and in many other sedimentary rocks from various parts of the world. He offers the following summary of his observations:[4]

"(1) Quartz grains in sediment coming from igneous and metamorphic rocks have *different shapes*, but *similar* elongations (parallel to the c-axis).

"(2) Although the elongation remains constant the igneous quartz grains have a tendency to have their less elongated shape reduced still farther (form a prolate ellipsoid to a slightly prolate sphere) by differential abrasion re-inforced by selective transport.

"(3) A secondary elongation parallel to the c-axis may be produced by secondary enlargement due to deposition of secondary silica.

"(4) It is a fact that not less than 75% (and possibly much more) of the quartz in sediments come either from metamorphic rocks or from re-worked sediments which frequently have been subjected to low rank metamorphism and hence suffered elongation of quartz. Obviously then most of the quartz in sediments will have a definite shape and elongation parallel to the c-axis—which it does."

The explanations advanced by Wayland and by Rowland for the elongation of quartz grains in the sandstones appear to involve three assumptions: (1) that the grains of quartz in a sandstone are mostly fragments of larger original crystals or grains, (2) that the grains tend to break parallel to the c-axis, and (3) that the grains wear down faster in the prism zone than normal thereto.

An attempt to check these three assumptions was made by performing three sets of experiments: (1) a statistical study was made of the angles between c-axes and long axes of the grains of freshly crushed quartz, (2) abrasion tests were performed on oriented prisms cut from a single large crystal of quartz to determine the relative resistance to abrasion in three different crystallographic orientations, and (3) relation of elongation to optic axis was determined for quartz grains from badly weathered (but undisturbed) quartzose rocks.

(1) It has been assumed by various workers that quartz has a tendency to fracture parallel to the c-axis, but if there is a cleavage in that direction it is completely overshadowed by the more prominent rhombohedral cleavage. Griggs and Bell[5] found that when a cylinder of quartz with its long axis parallel to the c-axis was splintered by compression parallel to the cylinder axis, the splinters were dominantly parallel to the crystallographic c-axis, but with cylinders of other orientations there was

[4] Personal letter Feb. 27, 1942.

[5] Griggs, David, and Bell, James F., Experiments bearing on the orientation of quartz in deformed rocks: *Bull. Geol. Soc. Am.*, **49**, 1723–1746 (1938).

no more tendency for the splinters to be parallel to the c-axis than normal thereto.

The case of "clastic" quartz sand can probably be more closely approached by breaking quartz grains in random orientation by crushing in a mortar. This was done for pegmatite quartz, and for fragments of a single large quartz crystal. The measurements were made by means of a universal stage from grains mounted in balsam on a microscope slide. For each grain the position of the c-axis and the longest dimension of the grain were measured and plotted on a piece of tracing paper over a stereographic net. The paper was then turned until the points representing the axis and the elongation were on the same great circle, in which position the angle between them could be read from the net. Figure 1 is

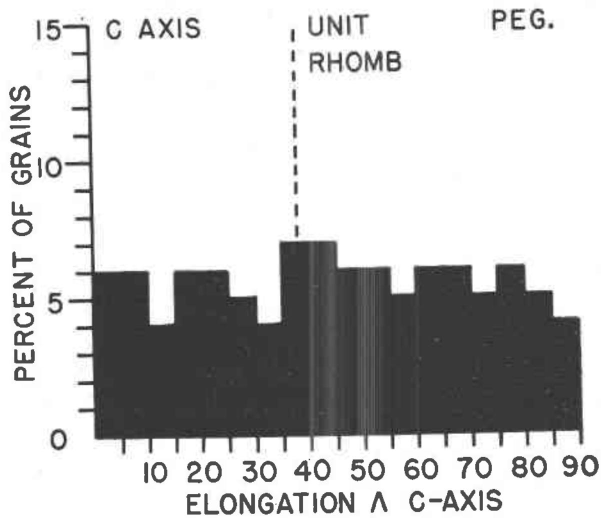

FIG. 1. Histogram showing relation of c-axis and elongation of fragments in pegmatite quartz that has been crushed in a mortar.

a histogram showing the relation of the optic axes of the grains from the pegmatite quartz to the long dimensions of the grains. There is no significant preferred orientation. Figure 2 is a histogram of the grains from the single quartz crystal from Hot Springs, Arkansas.[6] There is a strong maximum representing the rhombohedral cleavage, but only one grain out of 100 measured is elongate parallel to the c-axis—fewer than are elongate normal thereto.

Pegmatite and vein quartz make up but a small part of sandstones,

[6] Kindly furnished by Dr. H. D. Miser of the U. S. Geological Survey. Oriented prisms were cut from this same crystal for the abrasion tests described below (2).

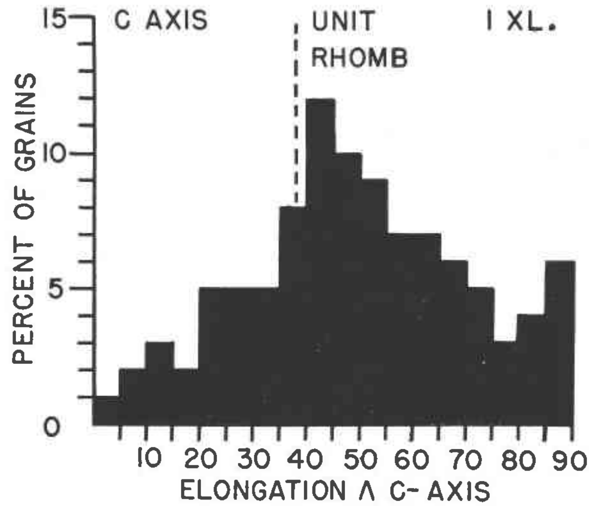

FIG. 2. Histogram showing relation of c-axis and elongation of crushed fragments of a single Hot Springs quartz crystal.

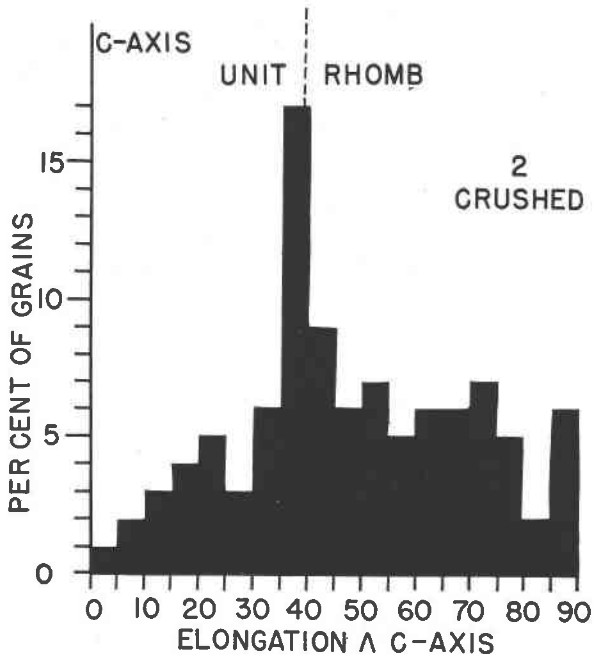

FIG. 3. Histogram showing relation of c-axis and elongation of fragments in crushed quartz from a granite gneiss. Compare Fig. 6.

most of the quartz being derived from quartzose igneous and metamorphic rocks. Therefore, quartz grains from such rocks in which an elongation of the original quartz grains parallel to the c-axis had been demonstrated [see (3), below] were crushed in a mortar, mounted, and measured as described above. Figure 3 is a histogram of the crushed grains from a granite-gneiss, and Fig. 4 is from a chlorite schist. In each there is a maximum determined by the rhombohedral cleavage. In each there are only a few grains in which the c-axis and elongation are sub-parallel, and the angular intervals between 40° and 90° average a little higher than normal. These histograms should be compared with those of un-

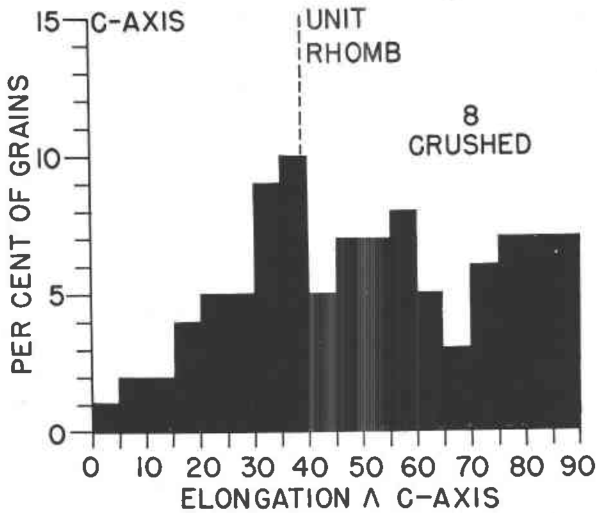

FIG. 4. Histogram showing relation of c-axis and elongation of fragments in crushed quartz from a chlorite schist. Compare Fig. 10.

crushed quartz grains from the same rocks, Figs. 6 and 10. The lack of grains elongate parallel to the c-axis in the crushed material may be due in part to the fact that many of the original grains were elongate parallel to the c-axis, hence the blows of the pestle were directed at a high angle to the c-axis. According to the work of Griggs and Bell this should produce more fractures at a high angle to the c-axes than at a low angle thereto.

(2) If quartz does not break parallel to the prism zone there must be some other explanation of the observed elongation of the quartz grains in sandstones. There are two possibilities: (a) If the quartz grains were softer in the prism zone, then differential abrasion during transport might develop grains elongate parallel to the optic axis; (b) the original grains may have been elongate parallel to the optic axis.

Ichikawa[7] says that the experience of Japanese quartz workers shows that the artificial basal plane is much softer than the natural crystal faces, and that the "prismatic faces are harder than others." The rhombohedral faces are not mentioned specifically.

Milligan[8] determined the impact abrasion hardness of a quartz crystal in five different directions, using a Zeiss sandblast machine. His results were as follows:

Plus prism faces	5.1
Minus prism faces	4.5
Plus rhombohedral faces	5.7
Cleavage face parallel to minus rhombohedron	4.3
Artificial basal plane	4.9

These tests indicated that the positive rhombohedral and the corresponding prismatic faces are more resitant to abrasion than is the basal plane, while the negative rhombohedral and prismatic faces are less so. If these values are valid for quartz grains on which there are few, or no definite faces, then the shapes developed by differential abrasion cannot be predicted, but will depend upon the shapes and development of faces, or surfaces approximately parallel to faces, of the original grains.

An independent test of the relative abrasion hardness of the positive prismatic and rhombohedral faces, and of the artificial basal plane was made by cutting square prisms normal to these respective faces and subjecting them to abrasion on a carborundum cup wheel, kept wet with a stream of water. The set-up is shown in Fig. 5. The upper plate has six square holes above the face of the carborundum wheel. These holes are in brass discs, each of which is graduated with 19 equally spaced divisions. The square holes in the prism holders permit the prisms to be ground in four different positions while the holders are in a given orientation.

The procedure used during abrasion was to put a prism in each hole, with pairs having a common crystallographic orientation diametrically opposed to each other. The prisms were ground for ten minutes and then each was turned 90 degrees in its holder. This was repeated until the prisms were ground in four positions. The prism holder was then turned one division and the above repeated. Each prism remained in a given hole until the holder had been turned through all 19 divisions. The prisms were then shifted clockwise to the next holder and the grinding cycle was repeated. This was continued until each prism had had a

[7] Ichikawa, S., Studies on the etched figures of Japanese quartz: *Am. Jour. Sci.*, **39**, 455–473 (1915).

[8] Milligan, Lowell H., The impact abrasion hardness of certain minerals and ceramic products: *Jour. Am. Ceram. Soc.*, **19**, 187–191 (1936).

grinding cycle in each holder. It is believed that this procedure effectively eliminated any differences in rate of abrasion that might have been due to position, or direction of motion of the abrasive across the faces. The prisms were made of equal cross-section and were weighted to 50 g. each during the runs.

The artificial basal plane proved to be the softest, and the rhombohedron most resistant. Another experiment was run in which the prismatic and rhombohedral faces were turned against each other with no abrasive between, until the difference in the amount of abrasion could be measured. It was in the same direction. These results are in accord with those of Milligan, obtained by dry impact abrasion tests. The faces of the negative rhombohedron on the crystal used were too small for the tests to be applied to them, and the negative prism faces were not tried.

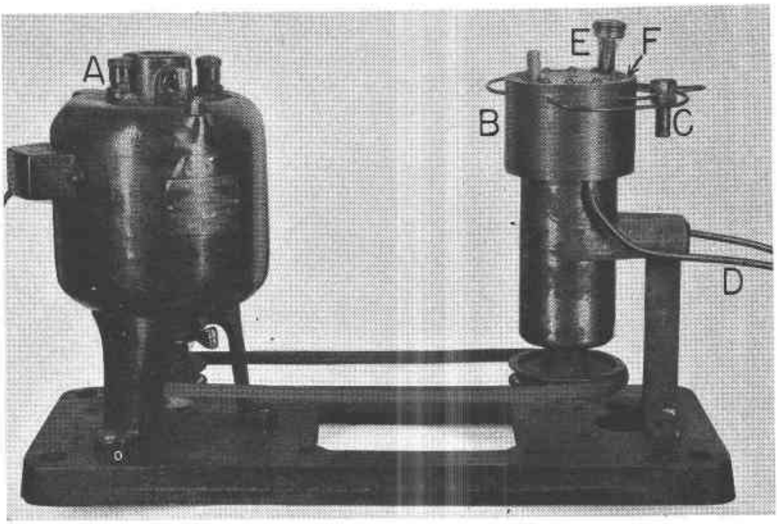

FIG. 5. Set-up for determining relative resistance to abrasion of different crystallographic directions in quartz. A, motor; B, housing for carborundum cup wheel; C, tubes for water jets; D, tubes to carry waste water away; E, quartz prism with pan for weights; F, plate carrying prism holders.

If the average hardness of the prismatic faces is the greatest of any, as Ichikawa reports, then differential abrasion could not develop an elongation parallel to the optic axis. If the average hardness of the rhombohedral faces is greatest and if the original grains had only prismatic and rhombohedral faces, the elongation might be emphasized, but it would have been there all the time.

If the grains were more or less irregular and without definite crystal faces, as appears more probable from a study of quartz grains from a granite, then elongation parallel to the c-axis would probably not be developed in any case.

(3) The remaining possibility is that the quartz grains were originally elongate parallel to the c-axis. In order to check this possibility several specimens of badly weathered granites, gneisses, and schists were collected. The material was still in place, but was so badly weathered that

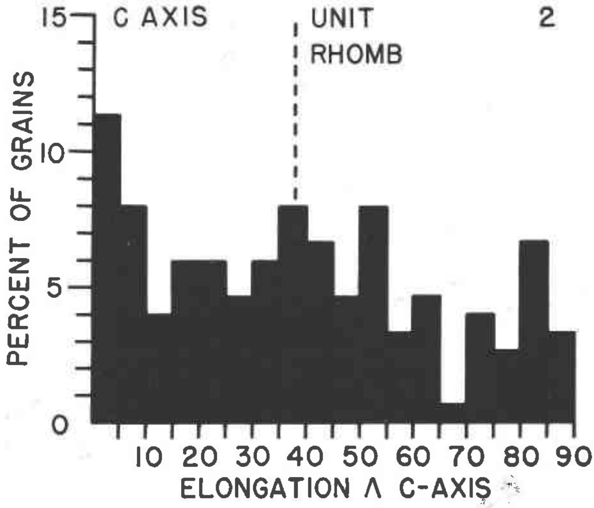

FIG. 6. Histogram showing relation of elongation and crystallographic directions in original quartz grains from a granite gneiss. Compare Fig. 3.

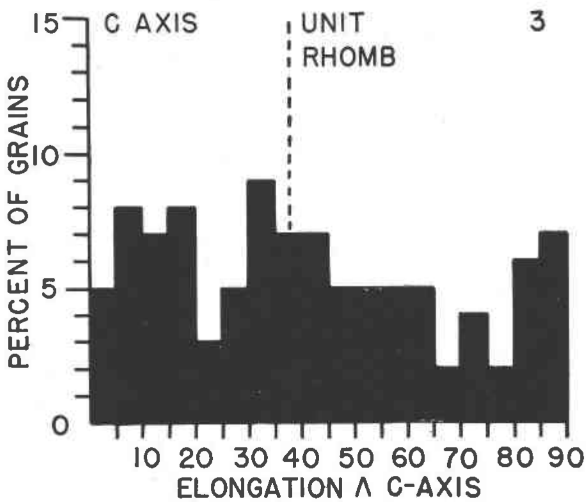

FIG. 7. Histogram showing relation of elongation and crystallographic directions in original quartz grains from a massive granite.

it could be raked out by hand. Each sample was washed free of very fine material, dried, and sieved to the approximate size of the grains in sandstones studies by Wayland. The quartz was then freed from the other minerals with mixtures of bromoform and acetone, and mounted in balsam on slides for universal stage work.

Figures 6 to 10 are histograms showing the relation of elongation of

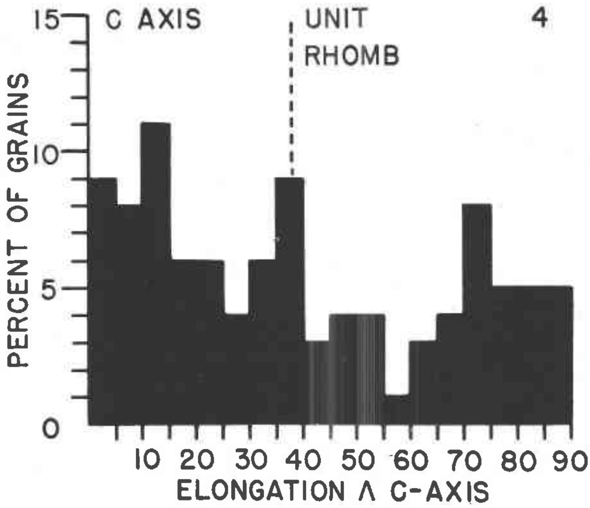

FIG. 8. Histogram showing relation of elongation and crystallographic directions in original quartz grains from a para-gneiss.

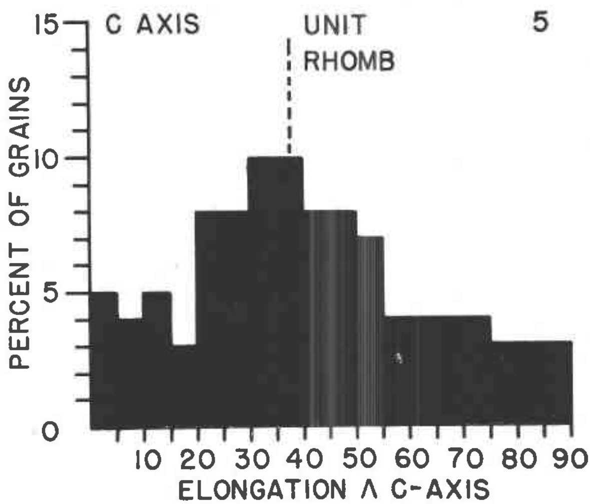

FIG. 9. Histogram showing relation of elongation and crystallographic directions in original quartz grains from a slightly gneissic granite.

original grains to the c-axis. The diagrams are by no means identical, but there is one generalization that holds good for all of them,—in each there is one maximum at or near the c-axis, and another at or near the rhombohedron.

If we assume, with Wayland, that elongate grains will roll along a bedding plane with the long axis normal to the current, then we can draw a generalized theoretical diagram representing what we should expect to find with regard to the orientation of the axes of these quartz grains if they were deposited in such a manner in a sandstone.

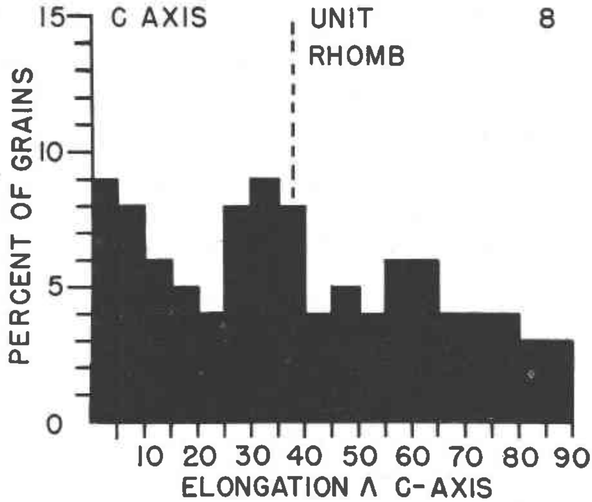

Fig. 10. Histogram showing relation of elongation and crystallographic directions in original quartz grains from a chlorite schist. Compare Fig. 4.

By taking the number of axes that fall into a given zone on the projection sphere and dividing by the area of that zone, we obtain the average density for that zone. Thus, for the zone 0–20° from the B-axis the average density is 4.25. The average density for the corresponding area on Wayland's diagram is only 2.04. This difference is to be expected, because we have assumed a perfect orientation of the longest axes of the grains, which would never be realized in nature.

The density of the zone 30–40° is higher than the 20–30° zone, because of the elongation parallel to rhombohedral faces. Therefore, we should expect sub-maxima around 35–40° from the B-axis. Such a generalized diagram is shown in Fig. 11. There is a maximum concentration at B, with sub-maxima between 30° and 40° therefrom. Wayland's diagram from the St. Peter sandstone is reproduced as Fig. 12. The sub-maxima of the theoretical diagram are present on Wayland's diagram, but he did not consider them in his explanation of the elongate grains.

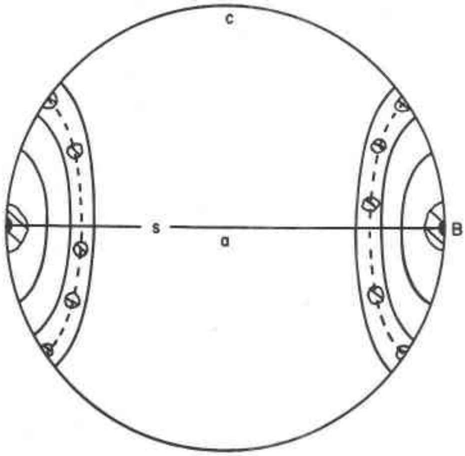

FIG. 11. Theoretical diagram showing quartz orientation in a sandstone formed of quartz grains having elongations like those shown in Figs. 6–10. It is assumed that the grains roll along and are deposited with their longest dimension parallel to the B fabric axis.

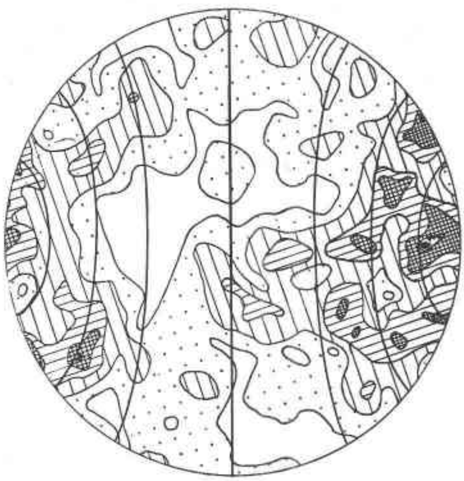

FIG. 12. Wayland's diagram of 155 quartz axes from the St. Peter sandstone. Small circles drawn in for comparison with the theoretical diagram of Fig. 11.

The maxima and sub-maxima of Wayland's diagram are somewhat displaced from their theoretical positions. This may be due to an error of a few degrees in cutting the thin section[9], or to a slight drag during deposition.

[9] The thin section was not cut exactly parallel to the *bc* plane. Personal communication from Wayland while this paper was in press.

Summary and Conclusion

These experiments show: (1) that quartz has no pronounced tendency to fracture parallel to the c-axis; (2) that elongation parallel to the c-axis is not likely to be developed by differential abrasion; (3) that unbroken and unworn quartz grains show elongations parallel to the c-axis and parallel to rhombohedral faces. These elongations are adequate to explain the shapes of quartz sand grains observed by Wayland and by Rowland and the maxima and sub-maxima of Wayland's diagram of c-axes of quartz in the St. Peter sandstone.