X-ray studies of natural fabrics. I. *Growth-fabrics in hematite kidney ore and in fibrous calcite*

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[Read 17 September 1964]

Summary. Fibres of hematite in kidney ore are elongated at right angles to the *c*-axis. The fibre axis, which may be normal to a face of either of the hexagonal prisms $\{10\bar{1}0\}$ or $\{11\bar{2}0\}$, may show an abrupt change of orientation along the length of a fibre. There is little preferred orientation around the length of the fibres.

It is confirmed that in some calcite satin spar the fibres are elongated parallel to an edge of the cleavage rhombohedron; in other fibrous growths the elongation is either parallel to or perpendicular to *c*.

X-RAY techniques have offered to structural petrologists an opportunity to study fabrics that are too fine-grained for optical measurement. They also make possible the complete determination of the 'lattice orientation' of a uniaxial mineral without the additional requirement of a measurable morphological feature (such as the cleavage planes or twin planes in calcite) to supplement the determination of the orientation of the optic axis.

The earliest methods involved transmission through a flat specimen and photographic recording, as in the pioneer studies of slates by Sander and Sachs (1930) and Sander (1934). In place of the flat plate of the simple Debye-Scherrer procedure other arrangements have been evolved, such as the conical camera used by Braitsch (1957) when studying the mode of aggregation of fibrous forms of silica. These methods, with stationary specimen and film, provide useful information concerning the symmetry of the fabric about the direction of the transmitted beam, but a rather large number of sections at different angles is necessary to obtain a complete orientation-picture. In polymineralic fabrics confusion may arise as a result of superimposition of reflections from different mineral components. Metallurgists, faced with just this problem of determining a complete orientation-pattern ('pole figure') for a crystalline aggregate, turned to the development of special texture goniometers, in which a moving film was translated synchronously with rotation of the specimen. In instruments based on the principles of

Weissenberg (1924) and Kratky (1930), the film is enclosed in a cylindrical camera and a coaxial slotted screen permits reflections from one selected family of planes only to reach it. This type of goniometer was first used to study rock fabrics by Ho (1947), who prepared his specimen in the form of thin cylindrical rods which could be rotated about their length. Wooster (1948) described an instrument of modified Kratky type in which the X-rays were reflected from a flat specimen making a small (adjustable) angle with the beam, and Starkey (1964, 1964*a*) has described a further development along these lines, using a thin section and combining reflection and transmission in one photograph.

Photographic records provide only broadly qualitative information unless one is prepared to enter the difficult field of densitometry, and metallurgists have found in the diffractometer an easier approach to quantitative measurements. In the method due to Schulz (1949) a flat specimen is rotated about its normal and also tilted about an axis in its own plane. (As in most instruments of this kind, the specimen is also translated in its own plane in order to pass a larger number of grains through the beam.) The sphere of projection is thus scanned spirally, and the results can be plotted directly on a net to within about 15° of the perimeter; foreshortening at high angles of tilt causes a loss of intensity (von Gehlen, 1960). A texture goniometer for the Schulz method is available commercially from Philips and from Siemens & Halske. By using a spherical specimen, Jetter and Borie (1953) were able to avoid all changes in the diffraction geometry throughout a complete set of measurements, and this procedure has been applied in petrofabric work by Higgs, Friedman, and Gebhart (1960).

Growth fabric of fibrous hematite in kidney ore. More than half a century ago Pelikan (1894) noticed, when examining very thin sections of fibrous hematite by transmitted light, that vibrations parallel to the length of the fibres were the more strongly absorbed, corresponding to the ordinary ray; the fibres must therefore be elongated at right angles to the optic axis. Mügge (1928) pointed out that the strong tendency towards platy habits often shown by hematite implied that the directions of maximum velocity of growth lay in the basal pinacoid {0001}.

Hematite affords strong X-ray reflections from planes of the rhombohedron[1] $\{10\bar{1}4\}$, prism $\{11\bar{2}0\}$, and rhombohedron $\{01\bar{1}2\}$ with relative intensities 100 : 80 : 70. Fig. 1*a* shows in equal-area projection the pattern of $\{11\bar{2}0\}$ reflections obtained on a Philips texture goniometer from a specimen of kidney ore cut approximately parallel to the length

[1] Indices for X-ray setting, c/a 2·730.

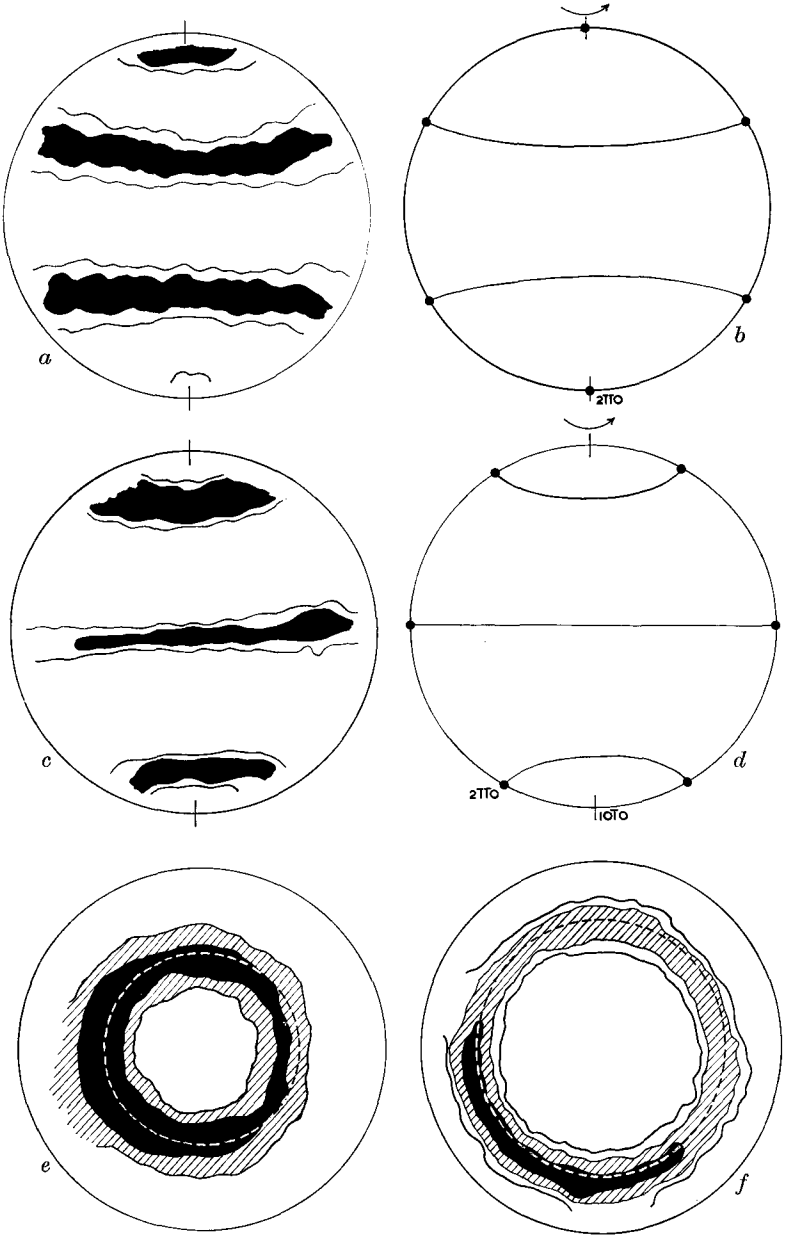


FIG. 1. (*a*) Kidney ore, section (nearly) parallel to fibres. Equal area projection of $\{11\bar{2}0\}$ reflections. Intensities >20, 10, <10 in terms of an arbitrary unit. (*b*) Equal area projection in explanation of fig. 1*a*. The fibre axis, which is the rotation

of the fibres. The fibre axis is parallel to the north–south line on the projection; the concentrations towards the poles and along small circles of 60° radius show that the fibres must be sharply aligned at right angles to a plane of the prism $\{11\bar{2}0\}$, see fig. 1*b*. Other specimens of kidney ore, however, cut and measured in similar fashion, give a strongly contrasted diagram, as in fig. 1*c*, which corresponds to the fibre axis being at right angles to a plane of the prism $\{10\bar{1}0\}$, see fig. 1*d*.

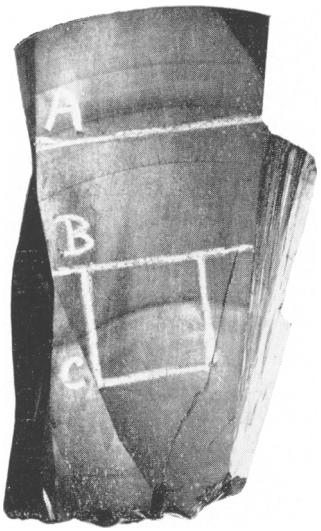
In yet other examples of massive kidney ore, with fibres of the order of 10 cm in length, an abrupt change from the one orientation to the other has been found part way along the fibres; the change may occur at a layer of more coarsely crystalline specular hematite, though there is not necessarily any such change on passing across any particular layer. The areas *A* and *B* of the specimen shown in fig. 2 gave identical diagrams of the type shown in fig 1*a*, corresponding to a fibre axis at right angles to a plane of the prism $\{11\bar{2}0\}$. In part of the area *C* the fibre axis is oriented at right angles to the other prism but, by traversing the whole of the area within the marked square, the two patterns are obtained superimposed in the projection (fig. 3).

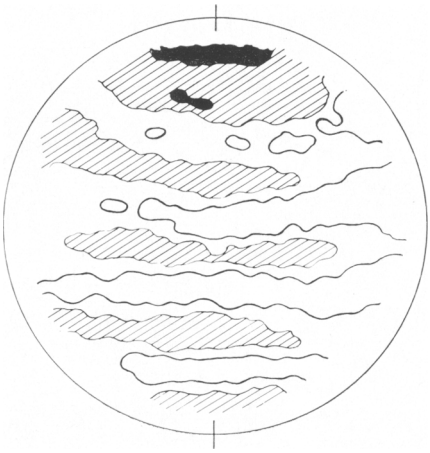
The distribution of intensities in most of the diagrams obtained from sections parallel to the length of the fibres suggests that there is little preferred orientation around the length of the fibres. This conclusion is confirmed by measurements made on sections cut at right angles to the length of the fibres, figs. 1*e* and 1*f*. It is also supported by the appearance of specimens in which plates of specular hematite have grown on the surface of the kidney ore, fig. 4. The plates, flattened parallel to (0001), stand on edge, in an attitude determined by the fibre axis of the kidney ore, but show little sign of any preferred orientation around this axis.

Growth fabric of fibrous calcite. In an optical study of calcite satin spar from Alston Moor, Spencer (1897) showed that the fibres of calcite were elongated parallel to an edge of the cleavage rhombohedron, and this has been confirmed by an X-ray study. Strong reflections are

FIG. 1 (*cont.*)

axis, is normal to $(2\bar{1}\bar{1}0)$. The small circles mark the loci of four of the prism planes on rotation. (*c*) Projection of $\{11\bar{2}0\}$ reflections from another specimen. Intensities > 20, 15, < 15. (*d*) Equal area projection, with fibre axis as rotation axis normal to $(10\bar{1}0)$. (*e*) $\{01\bar{1}2\}$ reflections (measured as $02\bar{2}4$) from a section (nearly) at right angles to the fibres. Intensities > 10, 5, < 5. The radius of the pecked circle = 43° 6′ = $(11\bar{2}0) \wedge (01\bar{1}2)$. (*f*) $\{10\bar{1}4\}$ reflections from same specimen as fig. 1*e*. Intensities > 20, 15, 10, < 10. The radius of the pecked circle = 57° 35′ = $(11\bar{2}0) \wedge (10\bar{1}4)$.





FIGS. 2 and 3: FIG. 2 (left). Kidney ore, cut parallel to the fibres, showing growth zones. For explanation see text. Length of specimen 10 cm. FIG. 3 (right). $\{11\bar{2}0\}$ reflections from the area C of the specimen illustated in fig. 2. Intensities > 20, 10, 5, < 5.

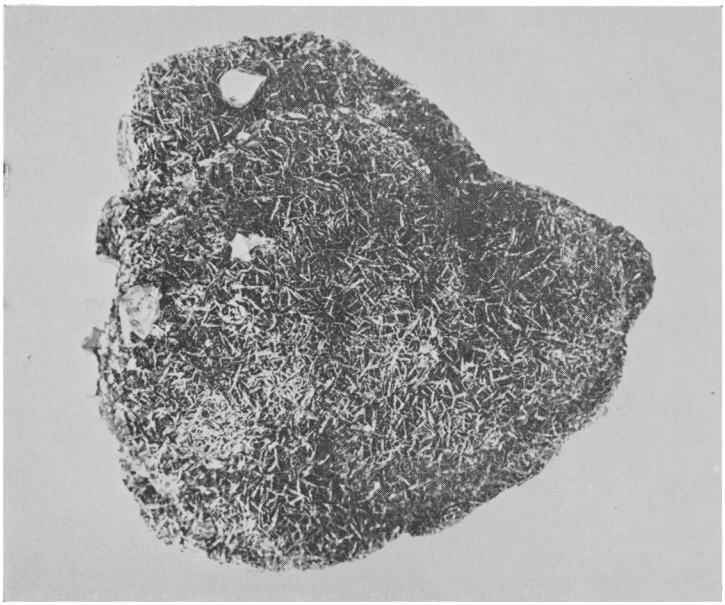
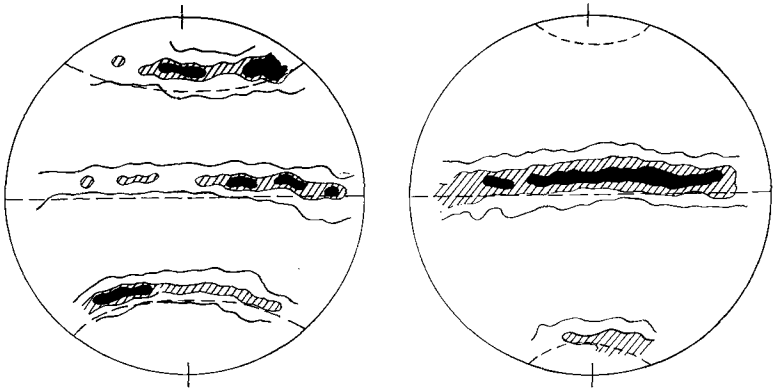
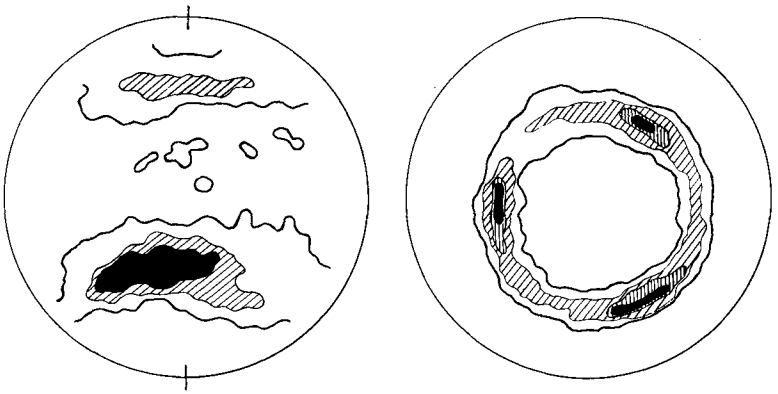


FIG. 4. Specular hematite growing on the surface of kidney ore. Diameter of specimen 7·0 cm approximately.



a *b*

FIG. 5. (*a*) {11$\bar{2}$0} reflections from satin spar cut parallel to the fibres. Intensities > 20, 15, 5, < 5. For explanation see text. (*b*) {10$\bar{1}$4} reflections from the same specimen as in fig. 5*a*. Intensities > 40, 25, 5, < 5.



a *b*

FIG. 6. (*a*) {10$\bar{1}$4} reflections from a section of calcite beef cut normal to the fibres. Intensities > 30, 20, 10, < 10. (*b*) {10$\bar{1}$4} reflections from a section of the same calcite beef, cut (nearly) parallel to the fibres. Intensities > 30, 20, 10, < 10.

afforded by planes of the rhombohedron[1] {10$\bar{1}$4} and the prism {11$\bar{2}$0}, with relative intensities 100 : 14. Fig. 5*a* shows the distribution of intensities of reflections from {11$\bar{2}$0} planes given by a specimen cut parallel to the fibre axis. The pecked lines show the loci of poles of these planes if the fibre-axis, parallel to the N–S diameter of the projection,

[1] Indices for X-ray setting, c/a 3·42.

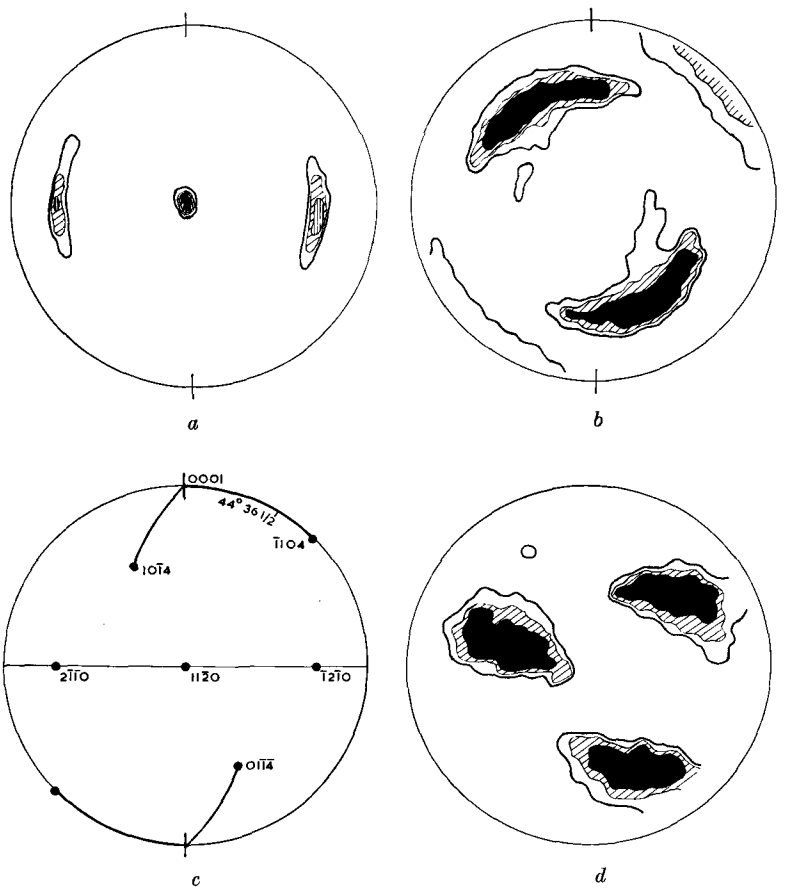


FIG. 7. (*a*) $\{11\bar{2}0\}$ reflections from a section of nodular vein calcite cut normal to the fibres. Intensities $> 100, 75, 50, 25, < 25$. (*b*) $\{10\bar{1}4\}$ reflections from the same section as in fig. 7*a*. Intensities $> 50, 25, 10, < 10$. (*c*) Equal area projection of calcite on $(11\bar{2}0)$, in explanation of the positions of concentrations in figs. 7*a* and *b*. (*d*) $\{10\bar{1}4\}$ reflections from a section of the same material as in figs. 7*a* and *b*, cut nearly parallel to the fibres. Intensities $> 50, 25, 10, < 10$.

is parallel to an edge of the rhombohedron $\{10\bar{1}4\}$. It is also clear from the pattern that there is little preferred orientation around the length of the fibre. Fig. 5*b* shows in similar manner the results obtained by measurement of reflections from planes of the rhombohedron $\{10\bar{1}4\}$.

It is interesting to note that one implication of this orientation of the fibres is that cleavage parallel to the length of a fibrous $CaCO_3$ mineral

is not necessarily diagnostic of aragonite, as is sometimes asserted (e.g. Winchell, 1951).

Finely fibrous 'beef' from the Inferior Oolite at Mells Quarry, near Frome, Somerset, and a more coarsely crystalline nodular growth of calcite associated with a hematite vein in the Carboniferous Limestone in the same quarry were also studied.

Fig. 6*a* shows the intensities of reflections from $\{10\bar{1}4\}$ planes from a specimen cut perpendicular to the fibres of the beef. It is clear that the fibre axis is *c* and that there is a high degree of preferred orientation around the fibre axis. This is confirmed by measuring the intensities of similar reflections from a specimen cut (nearly) parallel to the fibre axis (fig. 6*b*).

The vein calcite also was examined in sections cut perpendicular and parallel to the fibres. The results plotted in fig. 7*a–d* show that the fibres are elongated at right angles to the prism zone, i.e. at right angles to the *c*-axis, and that there is again a high degree of preferred orientation, both of the fibres and around the fibre axis. This elongation at right angles to *c* is readily confirmed optically; separated fibres tend to lie on a cleavage and give an oblique interference figure with a principal plane at right angles to the fibre axis.

Acknowledgement. The texture goniometer used in this work was obtained through a grant from the Royal Society, which is gratefully acknowledged. Many of the X-ray measurements were made by Mr. G. Day.

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[*Manuscript received 17 November 1966*]