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THE MEASUREMENT OF FLOW-STRUCTURES

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Abstract

The problem of measuring and representing the orientation of biaxial minerals in rocks is considered. Orientation diagrams of feldspar and augite in a lava are presented. The feldspar shows a constant orientation pattern throughout the flow examined.

Introduction

In a previous paper[1] the writer discussed the problem of measuring and representing the orientations of uniaxial minerals in rocks. It was pointed out that a more precise optical determination of the orientation of the crystal lattice is possible in the case of biaxial minerals. Three crystal classes only are of importance in this connection, the holohedral classes of the orthorhombic, monoclinic and triclinic systems.

In measurement with the universal stage the orientation of at least two of the axes of the optical indicatrix may be determined directly and the third can then be obtained graphically. Thus it is always possible to fix the orientation of the indicatrix. In the case of the orthorhombic system this also fixes the orientation of the crystallographic axes. Not so in the case of the monoclinic holohedral class, here two possible orientations of the crystallographic axes may correspond to one recognizable orientation of the indicatrix, and in the holohedral class of the triclinic system there are even four possible crystal orientations for each determined orientation of the indicatrix. If dispersion could be recognized in observations of this kind it might be an aid in establishing the situation of the crystallographic axes. As it is one must resort to the measurement of morphologic features, cleavage, crystal boundaries, twinning. If a single known crystal direction can be established and the orientation of the principal optical directions has been determined, the problem of fixing the crystal axes is solved for the classes here considered.

[1] "Pressure-shadows" and the measurement of the orientation of minerals in rocks, *Am. Mineral.*, **16**, pp. 55–70, 1931.

Schmidt[2] has discussed the representation of orientations of biaxial minerals. He selected some two of the principal optical directions and drew separate orientation diagrams for each. This procedure is satisfactory in the case of orthorhombic minerals but may obscure the results if used for monoclinic or triclinic minerals.

Let us suppose that all the *c* axes of the hornblende in a certain rock are oriented nearly parallel to a certain direction, and that also the *b* axes are nearly parallel. Let us further suppose that orientations measurements are represented by plotting optical directions. Then there will be two maxima for X and two maxima for Z but both pairs of maxima will correspond to a common maximum in the orientation of the *c* axes.

In triclinic minerals there also correspond several possible orientations of X, Y, and Z to a given orientation of certain crystallographic directions. The case of the plagioclase feldspars is of particular interest. Suppose the feldspars in a certain rock to be oriented with the *c* axes nearly vertical and the (010) faces about parallel. To such an orientation there correspond four positions of the indicatrix. If measurements on such a rock were shown in diagrams for any pair of X, Y, and Z, there would correspond four maxima of each of these to the single maximum that would be obtained by plotting the *c* axes or other suitable crystal elements. In this way the plotting of optical directions to represent the orientation of monoclinic or triclinic minerals may fail entirely to show the characteristic features of orientation.

So far studies in petrotectonics[3] have dealt largely with uniaxial minerals and such biaxial minerals, micas, as conveniently could be treated in a similar fashion. The purpose of this paper is twofold, to treat an example of the orientation of biaxial minerals and to establish a type case of measured orientation due entirely to magmatic flow.

Material

The latite of Tuolumne Table Mountain, California, was selected for study. Both the geology and petrography of this flow are discussed in numerous publications of the U. S. Geological Survey. The most detailed description is given by Ransome.[4]

[2] Schmidt, W., Zur Regelung zweiachsiger Mineralien in kristallinen Schiefern, *Neues Jahrb.*, Beilb. **57A,** pp. 203–222, 1928.

[3] Knopf, E. B., Petrotectonics, *Am. J. Sci.*, **25,** pp. 433–470, 1933.

[4] Ransome, F. L., Some lava flows of the western slope of the Sierra Nevada, California, *Bull.* **89,** *U.S.G.S.*, 1898.

Specimens, oriented in the field, were collected at six points along a fifteen-mile section of the middle course of the flow. Two or more thin sections of each were prepared affording a sufficient number of feldspar phenocrysts for statistical treatment.

The rock differs little from place to place, a fact also attested by earlier observers. The feldspar phenocrysts vary greatly in size, a few attaining maximum dimensions of half an inch or more. They are mostly euhedral tabular to (010). Other prominent forms are (001), (110) and ($1\bar{1}0$). All crystals show many times repeated

FIG. 1. Thin section of latite about 2 miles east of Vallecito, Big Trees Quadrangle, California. This section served for part of the measurements used in figures 2, 7 and 8. ×2.4.

oscillatory zoning, but the range of composition is exceedingly narrow. Numerous determinations indicate that the feldspar throughout is a labradorite of about 52–53% An. This agrees well with the statement of Ransome that the composition is Ab_3An_4 or Ab_1An_1.

The flow structure of the rock is not particularly conspicuous (fig. 1) but measurement showed it to be so uniform that only a selection of the results, representing however the entire length of the flow examined, will be reported here.

Method

Most of the feldspar phenocrysts show albite, Carlsbad and La Roc Tourné twinning. Pericline twinning was observed occasionally. All four parts of a feldspar crystal twinned according to these three principal laws have two directions in common, the *c* axis and the normal to (010). Accordingly these two directions were chosen for representation in the diagrams.

The (010) poles can sometimes be fixed by direct observation. The *c* axes must be obtained indirectly. These directions are most easily determined graphically and one or both were so determined for each feldspar crystal measured. This was a most laborious task. It was facilitated somewhat by using a ground glass fitted with divided circle mounted to rotate over a Wulff net as suggested by Schmidt.[5]

It is desirable to plot a large number of poles for each diagram. To this end it was necessary to combine the observations from several thin sections of the same specimen for some of the diagrams, though a few of the larger sections afforded over a hundred measurements each. Where the sections were not cut parallel this involved another operation, the rotation of the plane of projection, carried out separately for each pole plotted.

All of the diagrams in this paper are on a vertical plane and the upward direction is at the top of the figure in each case. The letter S on each diagram denotes south. This fully fixes the orientation. No attempt is made to relate the results to direction of flow or other external vectors, except gravity, concerning the direction of which there might be some doubt. The legend adopted is the same for all diagrams and one convenient for the results obtained. The greatest concentration of poles observed was about 6 or 7% of the total within one per cent of the area.

Results

Figure 2 shows the orientation diagram of (010) poles in a specimen at the head of the section examined. Figures 3 and 4 show patterns for (010) poles and *c* axes in a specimen about 10 miles downstream. Figure 5 shows the pattern of (010) poles at the lowest point examined. Figure 6 shows the distribution of poles which form the basis for figure 5.

[5] *Op. cit.*, p. 205.

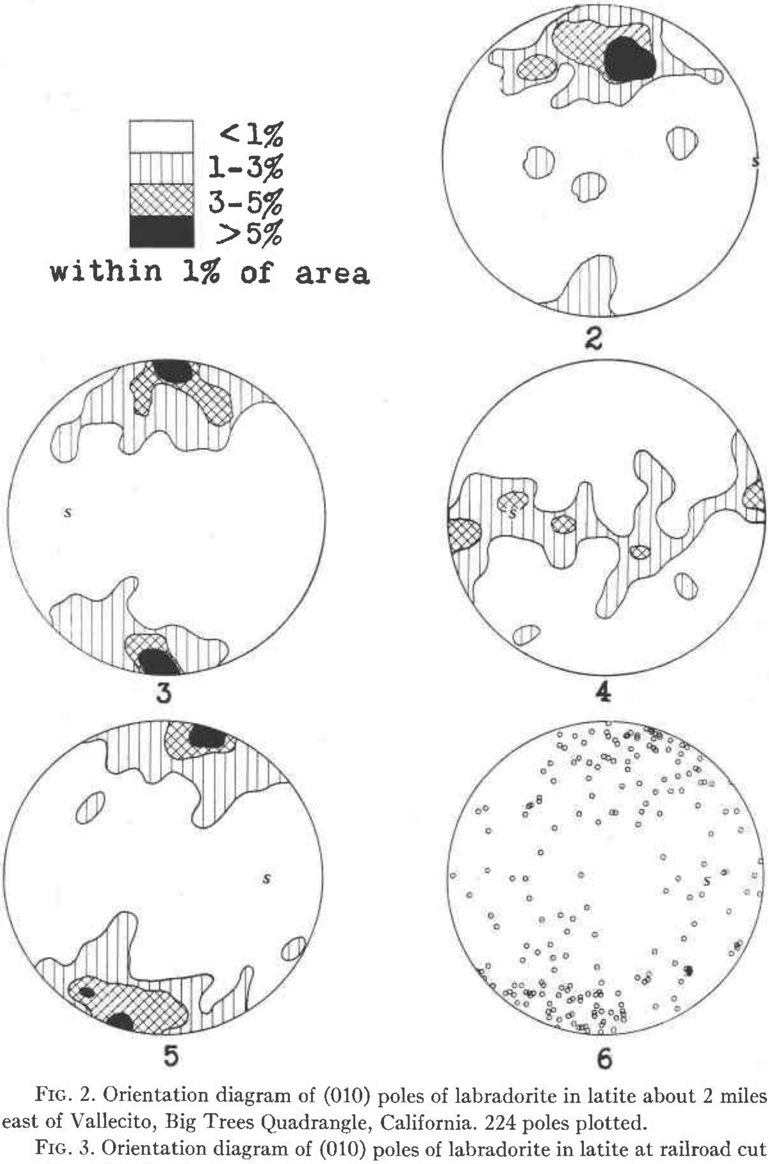


FIG. 2. Orientation diagram of (010) poles of labradorite in latite about 2 miles east of Vallecito, Big Trees Quadrangle, California. 224 poles plotted.

FIG. 3. Orientation diagram of (010) poles of labradorite in latite at railroad cut near Rawhide, Sonora Quadrangle. 99 poles plotted.

FIG. 4. Orientation diagram of *c* axes corresponding to fig. 3.

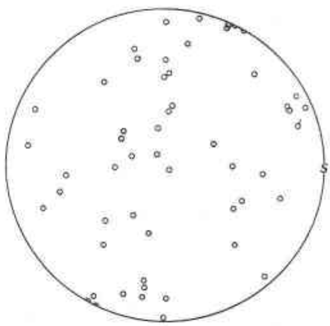
FIG. 5. Orientation diagram of (010) poles of labradorite in latite near Mountain Pass, Sonora Quadrangle. 207 poles plotted.

FIG. 6. (010) poles of labradorite corresponding to fig. 5.

It appears from these diagrams that the (010) poles have a subparallel nearly vertical orientation. The c axes cannot then have a completely random orientation since they must show a minimum where the (010) poles show a maximum, the angle between these directions, being 90°. The orientation of the c axes is not so pronounced. They are arranged in a belt containing no single prominent maximum. In other words, the tabular feldspar crystals seem, on the average, to lie horizontally with no common orientation of directions within the tabular faces.

The groundmass, of course, also shows a certain amount of flow structure, but the microlites are much too small for measurement.

Augite phenocrysts are not so plentiful as feldspar so that the requisite numbers for orientation measurements are not easily available. Nevertheless, an attempt was made to measure them in



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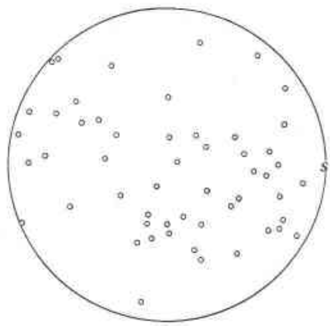

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FIG. 7. 53 b axes of augite in latite about 2 miles east of Vallecito.
FIG. 8. 53 c axes of the same crystals whose b axes are shown in fig. 7.

that specimen where they were found to be most numerous. Because of the aforementioned disadvantages of plotting optical directions, the b and c axes were determined for the augites from a measurement of some two axes of the indicatrix and either the (100) twinning plane or the (110) cleavage or both. The forms (100), (010) and (110) could be observed on most of the short prismatic crystals. Some of the augite is intergrown with orthorhombic pyroxene and some is corroded or in aggregates. This was not included in the observations. Only single, mostly euhedral, crystals were measured. They too are very uniform, $2V=47\text{–}50°$ and $Z \wedge c=43°$.

The results are shown in figures 7 and 8. Because of the small number of observations, contouring and shading of the diagrams were not attempted. The orientation is not nearly so pronounced as for the feldspars, but the *c* axes do seem to fall very largely in a horizontal band. In other words, the short prismatic augite crystals tend to be roughly parallel to the tabular feldspars.

TRANSFER OF GRAINS FROM ONE LIQUID TO ANOTHER*

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Introduction

In the course of the potash investigations of the U. S. Geological Survey, several thousand samples of drill cuttings from saline deposits have been examined by the immersion method. The first mount of the powder representing a sample is ordinarily made with an oil whose refractive index is near that of halite (1.544), because in such a medium the halite, which is the chief constituent of most samples, is "flattened out," so that the other constituents are clearly visible. The appearance of the common minerals under these conditions becomes familiar with practice, and they are usually recognized at sight in the initial mount. When a mineral that is not thus easily recognized occurs, it can, as a rule, be identified with certainty and with economy of both labor and material by means of the procedure that forms the subject of the present article. This procedure consists essentially of transferring individual grains from the initial immersion medium to one or more other liquids—usually to other immersion media with whose refractive indices the indices of the grain are compared. The grains are washed in xylol prior to accurate measurement of indices or to microchemical tests. It is hoped that this technique may occasionally be useful to other persons who study mixtures of minerals or artificial compounds by the immersion method.

Instruments Used

All of the instruments depicted in Fig. 1 may be employed in transferring grains, and they will be considered here with reference

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