PHOTOMETRIC DETERMINATION OF PREFERRED ORIENTATION OF FELDSPARS IN FINE-GRAINED IGNEOUS ROCKS

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CONTENTS

I. Abstract

The crystal habit and optical orientation of many feldspars combine to provide a convenient means for determining shape orientation from optical data. Results from photometric determinations of five different units show that it is possible to deduce, within narrow limits, major flow patterns producing planar orientation in certain fine-grained igneous rocks. It may be possible to determine the direction of flow from such a technique.

II. Introduction

Feldspars are commonly tabular enabling them to align with the flow in a fluid magma. The optical orientation, being fixed for a given composition, reflects this alignment and may be detected by the procedure described in this paper. Balk (1937, p. 14) has indicated the tendency of feldspar phenocrysts to show a platy parallelism. Also, Waters (1960, p. 365) has reported a parallelism of the (010) plane of microphenocrysts of plagioclase with the base of some flows of Columbia River basalt in the zone near the base. In an igneous rock, therefore, in which there is preferred orientation of the tabular feldspars they appear optically in agreement when viewed parallel to the direction of planar orientation.

A strong preferred orientation of such grains in thin section can be detected by eye under crossed nicols with the aid of the gypsum plate. A weak orientation may be detected by a photometer technique, which has been used for studying quartz fabrics (Martinez, 1958). This method involves

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measuring by means of a photometer the variation in the intensity of light with a wave length dominantly of 750 millimicrons passed through a standard thin section on the stage of a petrographic microscope with a gypsum plate inserted and nicols crossed during a 360° rotation of the stage. Maximum intensity of light occurs when the trend of the directions of vibration of the fast rays lies parallel with the slow direction of vibration of light in the gypsum plate.

The method described here functions for albite, oligoclase, andesine and labradorite. Z is not normal to (010) but is more nearly so than parallel with it in these plagioclases (Emmons, 1943, figs. 53-56; Muir, 1955, figs. 1, 2). It follows that the average relation of Z to (010) for a number of grains rotated about *b* will be Z normal to (010). Albite twinning in the plagioclases should not affect this statistical relationship. Crystals of plagioclase tabular parallel to (010), a common habit (Winchell, 1951, p. 312), should appear statistically length-fast when viewed from any direction normal to *b*. Thus, preferentially oriented tabular plagioclases in a section of an igneous rock should be length-fast, when viewed parallel to a planar orientation.

According to Winchell (1951, pp. 265, 312) plagioclase crystals are also sometimes elongated parallel to *a* and feldspar microlites are usually of this habit, except that when larger, they may be tabular parallel to (010). Other habits listed by Winchell are elongation parallel to *b* and, rarely, elongation parallel to *c*. Brinkman (1957) in discussing mineral orientation in basalts, stated that the plagioclase laths were elongate parallel to *c*.

The optical orientations shown by Muir (1955, figs. 1, 2) suggest that plagioclase crystals as calcic as about An_{50} and elongated parallel to *a* favor a length-fast aggregate orientation when viewed in any direction normal to *a*. Plagioclase crystals more calcic than An_{50} should average out to be length-fast if elongated parallel to *c* when viewed in any direction normal to *c*. Laths of highly calcic plagioclase elongated parallel to *a* and the more sodic plagioclases elongated parallel to *c* may appear statistically length-slow when viewed in a direction normal to a planar orientation containing a lineation. Plagioclase less calcic than An_{70}, elongated parallel to *b*, should be statistically length-slow viewed normal to *b*. *Tabular* plagioclase less calcic than An_{70}, however, would be statistically length-fast when viewed parallel to a planar orientation and also for a considerable range diverging from this direction if not for most directions.[1] The length-fast length-slow relations for other habits discussed above also hold true for quite a range of directions and for probably a greater range of compositions than those indicated as limits.

III. Photometric Technique

Comparison of trends of fast-ray vibration directions obtained from photometric measurements with long-axis determinations of feldspar laths have been made for a number of fine-grained igneous rocks. The photometric technique employed was essentially that described by Martinez (1958) except that the output of the photocell was measured directly by an ohmmeter. Figure 3, Plate 1 shows the equipment employed. The photocell (Clairex Corporation number CL503AL), shown in Figure 2, Plate 1, peaks at 733 millimicrons. It is shown mounted in Figure 1, Plate 1. It was adapted to fit over the vertical tube of an L2300TP-QR American Optical polarstar trinocular petrographic microscope. The image was focused on the sensitive element of the photocell by a 5X eyepiece placed in the vertical tube. The two positions of the stage for both minimum and maximum light intensity were recorded. Because an ohmmeter was used directly rather than using a galvanometer in a more sensitive circuit some imprecision resulted in these determinations. The limits of error were minimized by averaging the data. The two positions for minimum intensity were equally adjusted to differ by 180 degrees. The same adjustment was made for the positions of maximum intensity. If these adjusted positions of maximum and minimum intensity did not differ from each other by 90 degrees they were equally adjusted to so differ. The position of maximum intensity thus determined is considered to represent that position at which the trend of the directions of vibration of the fast rays is parallel or very nearly parallel with the slow direction of vibration of light in the gypsum plate. No

[1] This generalization is supported by the empirical data given in section IV.

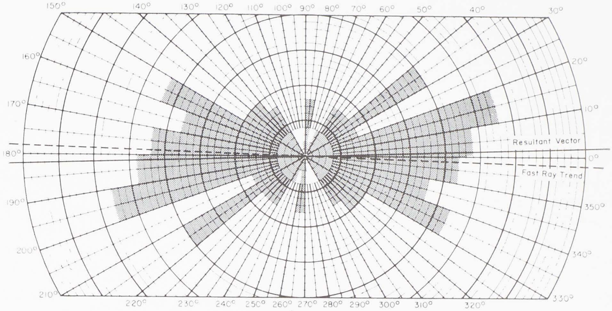

Figure 1. Comparison of the fast ray trend with 101 long axis determinations of feldspar laths longer than .057 mm in section CH577A-2 of a basalt from the Big Bend National Park.

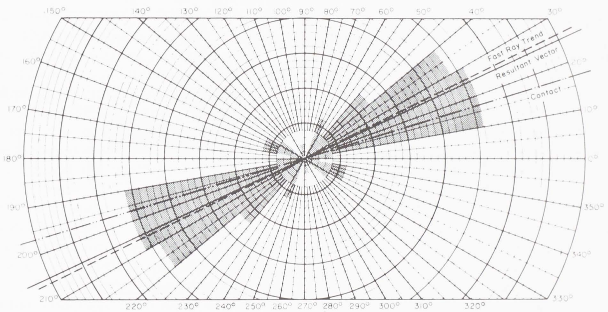

Figure 2. Comparison of the fast ray trend with 68 long axis determinations of feldspar phenocrysts in a thin section from the Higganum dike.

attempt was made in this work to correct for possible errors due to directional effects of the photocell. Three to six 9.5 mm square areas of each section were measured. The direction of preferred orientation in each section was obtained by using a vector method for averaging the individual measurements made for each section (Curray, 1956, p. 118-120). For these computations, each individual observation was considered to be of the same magnitude.

IV. Discussion of Results

A thin section of the Ash Spring basalt from the Big Bend National Park (Lonsdale, *et al.,* 1955) was used for a comparison. This rock is fine grained, composed predominantly of oligoclase laths in an intergranular texture. Figure 1 is a polar histogram showing the results of 101 long axis determinations of feldspar laths longer than .057 mm in an unoriented section of this basalt. These data were plotted in 10° class intervals. To obtain a resultant vector for this distribution, a procedure similar to that described by Curray (1956, p. 118-120) was employed. Each 10° class interval was considered to represent an observation vector passing through the center of the class interval and having the magnitude of the class interval. The angles of these observation vectors from the zero position on the plot were doubled and a vector average was determined graphically. The angle thus

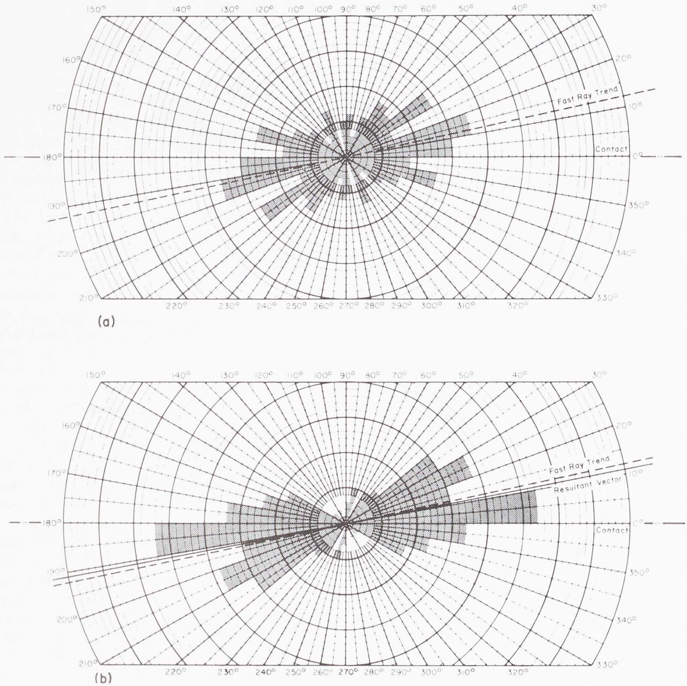

Figure 3. Comparisons of the fast ray trend with 143 long axis determinations of feldspar laths longer than .057 mm in section 36 of the Bridgeport dike. (a) long axis determinations along traverses parallel to contact; (b) long axis determinations along traverses normal to contact.

obtained was divided by two to get the resultant vector direction. The resultant vector magnitude, expressed in percent, is obtained by dividing the vector sum by the total number of measurements. The resultant vectors shown on other figures in this paper were computed in the same manner. This computed resultant vector lies only 4° from the fast-ray trend of the feldspars which was determined photometrically. The long-axis determinations were obtained along traverses normal to the 0°-180° line on Figure 1. This has the effect of enhancing the apparent preferential orientation but should not introduce too large an error in the computed direction. Traverses at right angles to this direction would have the opposite effect of attenuating the true preferential orientation. For some of the other sections described, I have made determinations in both ways. The photometric technique overcomes to some extent this real dilemma in measuring trends of such elongate grains.

Figure 2 gives a comparison of the photometrically determined fast-dry trend with 68 long-axis determinations of labradorite phenocrysts in a thin-section of a basalt dike in Higganum, Connecticut. Figure 3, Plate 2, is a photomicrograph of this section. The diameter of the field is approximately 5.5 mm. This section is porphyritic and holocrystalline. Feldspar phenocrysts range from

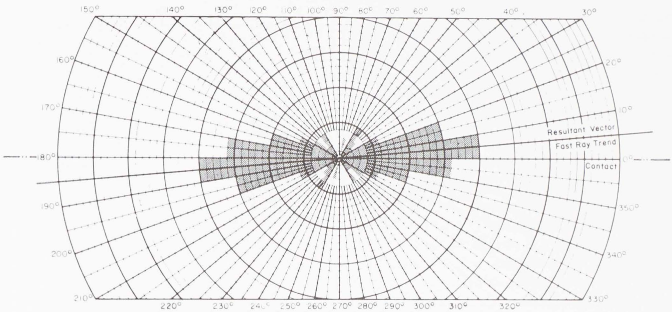

Figure 4. Comparison of the fast ray trend with 99 long axis determinations of feldspar laths longer than 0.3 mm in section 35 of the Bridgeport dike. The determinations were made along traverses normal to the contact.

slightly over 0.1 mm to nearly 2 mm in length. The groundmass consists of pyroxene and feldspar grains approximately .02 mm in diameter. Visual examination under crossed nicols with the gypsum plate inserted shows the optical orientation of the phenocrysts and the plagioclase crystals in the matrix to be almost identical. The contact of the dike and the country rock is included in the section. The fast-ray trend differs from the resultant vector of long axis determinations by only 1 degree. Both trends approach parallelism with the contact, but there is an appreciable angular difference. This may be of genetic significance.

Comparisons have been made in two mutually perpendicular sections cut adjacent and normal to the contact of a basalt dike in Bridgeport, Connecticut. The groundmass ranges from cryptocrystalline at the contact to very finely crystalline at the other side of the section. Phenocrysts include labradorite, clinopyroxene, and altered olivine, ranging from less than .1 mm to as much as 1.3 mm in their maximum dimension. Figure 3a shows a comparison of the inferred photometrically determined fast-ray trend with 143 long-axis determinations of feldspar laths longer than .057 mm in section 36. These long-axis determinations were made along traverses parallel to the contact. Figure 3b is similar to 3a except that the traverses were normal to the contact. The fast-ray trend differs from the resultant vector by only 2 degrees. Figure 4 gives a comparison of the inferred (010) trend with 99 long axis determinations of feldspar laths longer than 0.3 mm in section 35. These determinations were made along traverses normal to the contact. In this section the fast-ray trend is coincident with the resultant vector. As in the section of the Higganum dike, the fast-ray trend and the resultant vector were not exactly parallel with the contact.

Figures 5a thru 5c show results obtained from a vertical thin-section of the Hampden basalt on the campus of Trinity College in Hartford, Connecticut from about 6 inches above the base of this Triassic lava flow. This sample of the basalt is fine-grained with a porphyritic and intersertal texture. Most of the groundmass feldspars range in length from about 0.1 mm to 0.2 mm. The phenocrysts range from about 0.3 to nearly 2.0 mm. The plagioclase is andesine which shows sericitization and partial replacement by calcite. Figure 5a gives a comparison of the fast-ray trend with 139 long-axis determinations along vertical traverses of laths longer than 0.32 mm. In this instance the fast-ray trend differs from the resultant vector by 10 degrees. The apparent dip of the flow in this plane is also indicated on the plot. Figure 5b is a plot showing the comparison of the fast-ray trend with 188 long-axis determinations along traverses normal to the horizontal of laths longer than .057 mm. Results are similar to 5c. The fast-ray trend differs by 8 degrees from the resultant vector. Figure 5c represents a comparison of the fast-ray trend with 257 long-axis deter-

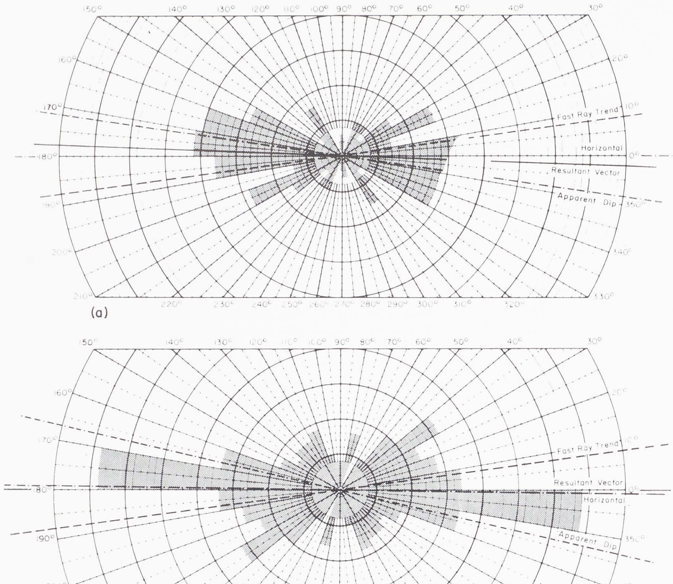

Figure 5. Comparison of the fast ray trend with long axis determinations of feldspar laths in section 40 (vertical) of the Hampden basalt. (a) 139 determinations along traverses normal to the horizontal of laths longer than 0.32 mm; (b) 188 determinations along traverses normal to the horizontal of laths longer than .057 mm; (c) 257 determinations along traverses parallel to the horizontal plane of laths longer than .057 mm.

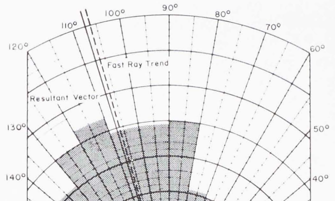

Figure 6. Comparison of the fast ray trend with 604 long axis determinations of feldspar laths in a section of an Oregon basalt.

minations of laths longer than .057 mm along traverses parallel to the horizontal plane. This plot, as would be expected, is much less significant than those of 5a and 5b.

A comparison is given in Figure 6 of the photometrically determined fast-ray trend with 604 long-axis determinations of feldspar (labradorite) laths in an unoriented section of an unidentified Oregon basalt. This basalt is fine-grained having a texture that is in part intergranular and in part intersertal. The long-axis determinations were made along traverses parallel to the 0°-180° line on the plot. Figures 1 and 2, Plate 2, photomicrographs of this basalt in plain light, show that the shape orientation is not obvious. The approximate size of the field included in each photometric determination is indicated in Figure 1, Plate 2. The fast-ray trend in this instance is only 1° from parallelism with the resultant vector.

V. Degree of Orientation

Table 1 lists the magnitude of the orientation[2] for all of the individual measurements expressed in percent of the maximum value. The percent orientation of the resultant vector of the long-axis determinations is also given for each thin-section. Variations in thickness should cause appreciable differences in intensity measurements (Martinez, 1958, p. 602). For this reason these magnitudes were not used in vector determinations.

VI. Conclusions

The data show that for a variety of fine-grained igneous rocks the plagioclases are length-fast in a statistical sense in the measured planes.[3] The angular difference between the fast-ray trend and the resultant vector of the long-axis determinations for

[2] The difference between minimum and maximum intensity.

[3] It has already been indicated that for certain crystallographic habits the plagioclase laths may be statistically length-slow in sections normal to those measured.

Table 1

Degree of Orientation Expressed in Percent

Section No.	Unit	Individual Photometric Determinations							Resultant Vector Magnitude Long-axis Determinations
		Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6	Ave.	
CH577A2	Ash Spring basalt No. 2	44	25	36				35	47.0
3.5	Higganum dike	28	18	30				25	67.5
36	Bridgeport dike	23	12	19	20	6	14	16	58.6
35	Bridgeport dike	19	6	12	11	19	17	14	66.1
40	Hampden basalt	11	6	19	5	10	17	11	37.4 & 48.5*
366	Oregon basalt	17	6	7	9	15	16	12	23.1

* Resultant vector magnitude of distribution shown in Figures 5a and 5b.

the various sections was: 1°, 1°, 2°, 4°, and 8° to 10°. Only for the Hampden basalt was the angular difference (8° to 10°) appreciable. Only in the section of Ash Spring basalt were most of the individual grains length-fast. In the other sections the relationship was only statistical.

It seems reasonable to conclude from the data that the feldspar in the Ash Spring basalt is either flattened parallel to (010) or elongated parallel to *a*. For the basalts in which the plagioclase is labradorite, it is considered most likely that the feldspar is tabular on (010).

The results from this representative group of sections also indicate that major flow patterns which produce a planar orientation, readily can be deduced.[4] The oriented sections are all cut normal to and very near or adjacent to contacts. The large change in flow velocity normal to the contact in this zone would be expected to produce a strong preferential orientation (Balk, 1937). The section from the Big Bend National Park probably is also cut normal to the contact. The orientation of the Oregon basalt is not known. The preferential orientation in sections normal to contacts is often so strong that it can be detected by eye. Even for such sections, however, the use of the photometer is advisable as it provides objective and possibly semi-quantitative data. A small angular difference was consistently found to exist between the contact and the preferential orientation, either as directly measured or inferred from photometer measurements. If this can be demonstrated from further studies to be a general condition, somewhat analogous to imbrication in sediments, it might be possible to deduce the direction of flow from sections cut normal to the contact. It is also possible that sections parallel[5] to the contact may be useful for such a purpose. If the feldspars are tabular parallel to (010) many of the (010) planes should be aligned parallel to the contact but those that are not may be rotated by changes in the flow velocity parallel to the contact. This lineation or alignment (possibly in a plane of foliation) should indicate current direction. It seems most likely that this lineation would be identical with a fast-ray trend. Such a lineation, however, can be detected by photometric measurements of the type described whether it is parallel to a fast or slow-ray trend. A study is under way in which flow directions inferred from photometric data will be compared to flow directions inferred from bent pipe amygdules. One of the units being examined is the Hampden basalt.

The principal conclusion derived from this study is that rational and consistent relations exist between the fast-ray trend and shape orientation in certain feldspars. This fast-ray trend can be determined by photometric means. Major flow patterns can thereby be deduced. It is possible that minor flow patterns reflecting flow direction can also be derived.

[4] From universal stage measurements of the orientation of (100) and (010) planes of plagioclase laths, Brinkman (1957) concluded that the microstructure of basalts gives a picture of flow in the melt.

[5] It is not necessary for such sections to be taken near the contact. Better results may be obtained for sections far from the contact.

VII. Acknowledgments

The section of the Higganum dike used in this study was supplied by Mr. Barre Alan Seibert, who had studied this unit as an undergraduate at Wesleyan University. Dr. Ross Maxwell of the Bureau of Economic Geology of the University of Texas made available the section of lava from the Big Bend National Park. Dr. Joe Webb Peoples and Dr. J. R. Balsley of Wesleyan University were of assistance in allowing the writer use of certain facilities there. Dr. Randolph W. Chapman of Trinity College very kindly pointed out appropriate outcrops of the Hampden basalt containing bent pipe amygdules. He was also very helpful in outlining the geology and petrography of this unit. Special thanks are given to Mr. J. G. Rabinowitz of the Clairex Corporation for suggesting and providing the photocell used in this study. Some years ago, Dr. A. E. Sandberg of Louisiana State University suggested that the author might extend his photometric studies to an investigation of igneous rocks. Special thanks are due for this suggestion and other help and inspiration from Dr. Sandberg.

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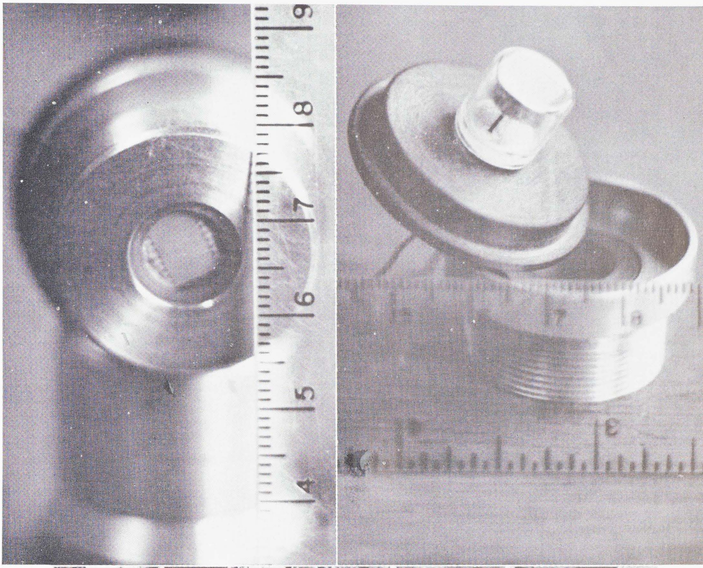

PLATE 1

1. (upper left) Photocell mounted in its adapter.
2. Clairex Corporation number CL503AL photocell.
3. Equipment used for photometric determinations: voltage regulator at left center, ohmmeter at bottom center, adapter for photocell surmounting microscope, and light filter in substage.

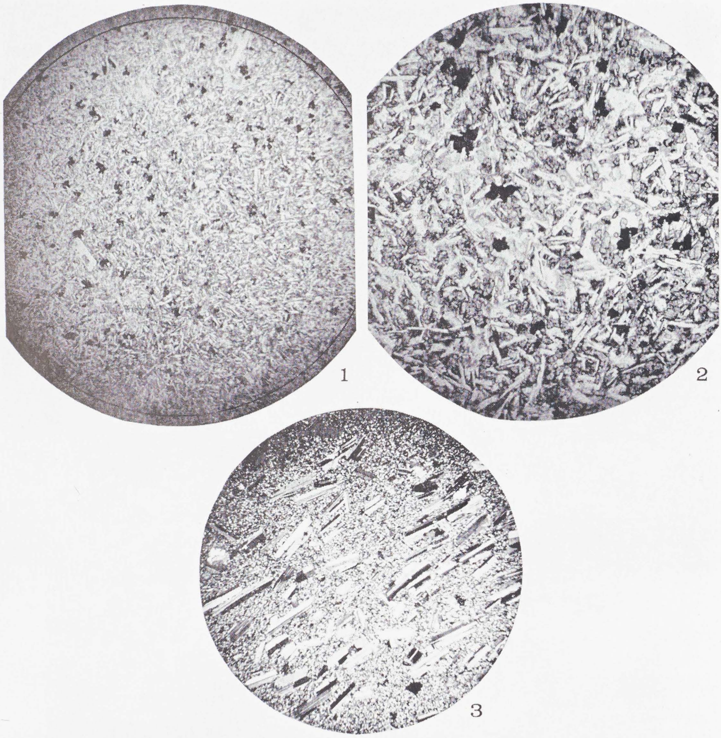

PLATE 2

1. Photomicrograph of thin-section from the unidentified Oregon basalt in plain light, X14. Circle indicates approximate size of field included in a photometric determination.
2. Photomicrograph of thin-section from the unidentified Oregon basalt in plain light, X39.
3. Photomicrograph of thin-section from the Higganum dike. X-Nicols. Diameter of field is approximately 5.5 mm.

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