The Optical Analysis of Volcanic Rocks as a Means of studying their Genetical Relationship.

By

Seitarô TSUBOI.

火山岩成因上の關係を研究する一手段としての光學分析

所員　坪　井　誠　太　郎

先づ岩漿中に於ける結晶作用に就きて考究し同一成因系統の火山岩中に斑晶をなす斜長石と有色鑛物との成分の間に一定の共存關係の存すべきことを論じたり。而して實際の場合に就きて此の關係を求むるには有色鑛物の成分を決定するに困難あるが故に其の光學恒數を以て之を代表せしむることを提案せり。次に是に依りて得られたる諸火山岩の關係を例示しかゝる方法が火山岩成因系統の研究に有利なることを說けり。

Introduction.

The object of the present paper is to suggest a means of studying the genetical relationship of volcanic rocks. Its essential procedure is the optical determination of the porphyritic minerals that constitute the rocks; hence it may be called an "optical analysis" of volcanic rocks. It is based on the current view on the crystallization and differentiation of rock-magmas.

In the following pages, the basic principle will be first described, then the procedure necessary for the practical application of the principle, and finally, some actual examples of the results obtained by means of the optical analysis will be cited as illustrations of its utility in the genetical study of volcanic rocks.

Ideal Paragenic Relation of Felsic and Mafic Minerals in Volcanic Rocks.

Most of the important pyrogenic minerals are solid solutions with a wide range of chemical composition. In the course of crystallization of these minerals from a rock-magma, they react continually with the liquid in which they are immersed, whereby they suffer a continual change of composition, with a corresponding and reciprocal modification of the composition of the liquid.

When a calc-alkali magma cools, it is usual that the minerals of two distinct solid solution series—plagioclase and mafic mineral—undergo a parallel separation from the magma. The early separated plagioclase is a calcic one, i. e. one comparatively rich in *An*, the higher-melting component; and as the crystallization proceeds it reacts with the residual liquid to become richer and richer in *Ab*, the lower-melting component. The early mafic mineral is also rich in the higher-melting component; but upon crystallization, it is continually modified in composition and becomes gradually enriched in the lower-melting component.(1)

The processes as outlined in the above are regarded as going on in magma-reservoirs. The igneous material in a reservoir is extruded intermittently at various stages of crystallization of the magma, and by its consolidation a volcanic rock comes into existence. The liquid portion of the igneous material solidifies as the groundmass of the rock; while the crystals formerly suspended in the liquid form the phenocrysts embedded in the groundmass. Then, the mutual correspondence in composition of the crystals of plagioclase and mafic mineral separating in the reservoir must be represented by the paragenic relation of the phenocrysts of these minerals in a series of volcanic rocks from that source. In the ideal case, where the effects of the above-mentioned processes are not disturbed, it is expected that an earlier mafic mineral associates with the more calcic plagioclase, and a later mafic mineral with the more sodic plagioclase.

This ideal paragenic relation may be shown by means of a graph. In Fig. 1, the compositions of porphyritic minerals of the plagioclase and mafic series are denoted respectively by the abscissae and the ordinates, the earlier members of each series being represented by the points closer to the origin, and the later members by those farther apart from the origin. Then, to each volcanic rock a point is assigned, indicating the compositions of the plagioclase and the mafic mineral that constitute the phenocrysts of the rock. In the ideal case, the points representing a series of volcanic rocks of one and the same genetical lineage are to be arranged along a certain ascending curve as shown in the figure. A

A diagram, as that in Fig. 1, which shows the paragenic relation of the minerals in rocks will be referred to, for simplicity, as a "paragenesis diagram."

The ideal relation represented by Fig. 1 is to be exhibited most typically when the cooling of the magma proceeds uniformly with perfect equilibrium and the sinking of the crystals is prevented. Such condition, however, may

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(1) N. L. Bowen, Jour. Geol., Vol. XXX, 1922, pp. 177-198.

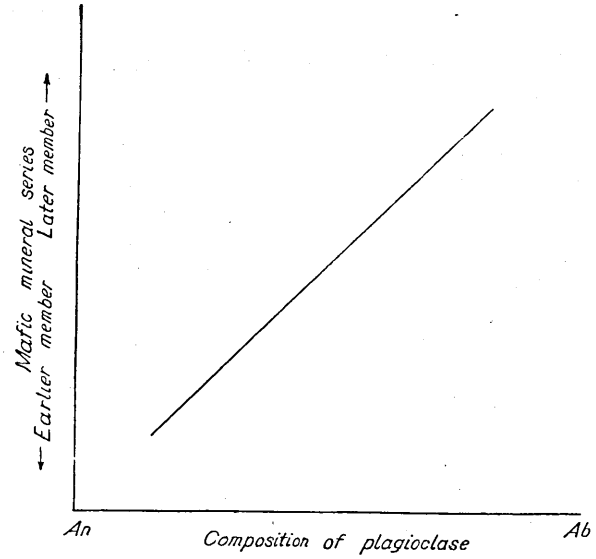

Fig. 1.—The ideal paragenic relation of porphyritic minerals in cognate volcanic rocks.

never be realized in the actual cases of the volcanic rock formation. There are a number of possible factors that may cause the disturbance in the ideal relation. But, in many cases, the effect of those disturbing factors may be slight, or at least not so great as to obliterate entirely the relation. Then, the relation may be utilized for tracing the genetical lineages of volcanic rocks.

On the basis of the principle detailed in the above, we are now to proceed to examine the actual paragenic relations between the two series of porphyritic minerals.

Use of the Optical Constants of Mafic Minerals for representing their Composition-Variation.

In order to make a paragenesis diagram for actual volcanic rocks, it is necessary to determine the compositions of plagioclase and mafic mineral that occur in association as phenocrysts in each of those rocks, and to fix the position of the point representing the rock.

In determining the compositions of the minerals for this purpose, chemical methods are not applicable in most cases, since the minerals in rocks are usually small in size and are not suitable in their quality for chemical analyses. Other methods must therefore be preferred.

Fortunately, the relation between the chemical compositions and the optical constants of plagioclases is well established; and the optical methods, such as the dispersion method,(1) are applicable in determining their compositions. Therefore, the abscissa of the point for any rock in the paragenesis diagram can be found without difficulty.

On the other hand, the difficulty in determining the compositions of the mafic minerals arises from the fact that the data for most of these minerals are not sufficient to enable us to establish their compositions from their optical constants or any other properties that are readily determinable. Moreover, there is still another difficulty, even if their compositions were determinable. It is due to a lack of knowledge of the constitutional characters of the mafic minerals. For determining the ordinates of the point for each rock in the diagram, it is prerequisite to know, with regard to the mafic minerals, what components they consist of, and how the proportion of these components varies in the course of their crystallization. Unfortunately, however, little is known at present of these constitutional characters.

In order to eliminate the above-mentioned difficulties, it is proposed here to use the optical constants, instead of the chemical compositions, of the mafic

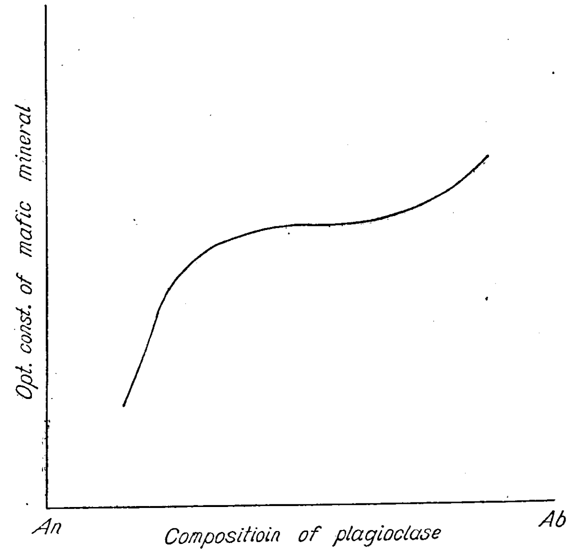

Fig. 2.—A paragenesis diagram, transformed from Fig. 1 by taking the optical constants of the mafic minerals as ordinates. Here the line has been drawn distorted, for it may differ in curvature from that in Fig. 1.

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(1) S. Tsuboi, Miner. Mag. (London), Vol. XX, 1923, pp. 93-107.
S. Tsuboi, Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. II, Vol. I, Pt. 5, 1926 p. 146-152.

minerals in connection with the attempt to find the actual paragenic relations of porphyritic minerals. It is to be noted that what is essential for the purpose now in view is to trace, in whatever way (not necessarily in terms of chemical composition), the composition-variation of the mafic minerals. This can be effected by the use of their optical constants, since these vary continuously as their chemical compositions. Moreover, while there are difficulties in determining the chemical compositions, the optical constants are easily and accurately determinable even with such small crystals as occur commonly in rocks. It is for these reasons that the optical constants are preferably taken for the present purpose.

By the use of the optical constants of mafic minerals for representing their composition-variation the paragenesis diagram in Fig. 1 will be transformed into such one as in Fig. 2.

Actual Paragenic Relations of Porphyritic Minerals in some Volcanic Rocks.

We may now examine the actual paragenic relations of the porphyritic minerals in some volcanic rocks. As examples of such, the relations between plagioclases and monoclinic pyroxenes in the volcanic rocks of Idzu Islands, Fuji, Amagi, and Tokachi are given below in tabular form. Here, for representing the composition-variation of monoclinic pyroxenes the smaller refractive indices (for sodium light) in their cleavage-flakes, $n_{1D\,(110)}$, are taken.(1)

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(1) S. Tsuboi, Jap. Jour. Geol. & Geogr., Vol. III, 1924, p. 24; Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. II, Vol. I, Pt. 5, 1926, p. 156.

The refractive indices ($n_1 < n_2$) in a cleavage-flake parallel to (110) of a monoclinic pyroxene are:

$$\left.\begin{aligned} n_1^2 &= \frac{2\gamma^2\alpha^2}{(\gamma^2+\alpha^2)+(\gamma^2-\alpha^2)\cos(\psi-\psi')} \\ n_2^2 &= \frac{2\gamma^2\alpha^2}{(\gamma^2+\alpha^2)+(\gamma^2-\alpha^2)\cos(\psi+\psi')} \end{aligned}\right\}$$

in which

$$\left.\begin{aligned} \cos\psi &= -\sin(\Omega-\delta)\sin K \\ \cos\psi' &= \sin(\Omega+\delta)\sin K \end{aligned}\right\}$$

where Ω is the angle between Z and one of the optic binormals, δ is the angle $Z \wedge c$, and K is the angle between the normals to (110) and to the optical plane (010).

The refractive indices in the cleavage-flakes can be found more easily than the principal refractive indices, and are just as characteristic of each member of the mineral series.

TABLE I.(1)

Rocks		Plagioclases	Monoclinic pyroxenes $n_1\nu_{(110)}$
Idzu Islands and Fuji	No. 1	Ab_{15} An_{85}	1.686(5)
	No. 2	Ab_{21} An_{79}	1.689
	No. 3	Ab_{25} An_{75}	1.691(5)
	No. 4	Ab_{25} An_{75}	1.691(5)
	No. 5	Ab_{25} An_{75}	1.691
	No. 6	Ab_{25} An_{75}	1.692
	No. 7	Ab_{27} An_{73}	1.691(5)
	No. 8	Ab_{27} An_{73}	1.692
	No. 9	Ab_{30} An_{70}	1.692(5)
Amagi	No. 10	Ab_{28} An_{72}	1.689
	No. 11	Ab_{48} An_{52}	1.690
	No. 12	Ab_{56} An_{44}	1.691
Tokachi(2)	No. 13	Ab_{16} An_{84}	1.688
	No. 14	Ab_{42} An_{58}	1.692
	No. 15	Ab_{42} An_{58}	1.693
	No. 16	Ab_{53} An_{47}	1.693
	No. 17	Ab_{39} An_{61}	1.690
	No. 18	Ab_{42} An_{58}	1.693
	No. 19	Ab_{44} An_{56}	1.693
	No. 20	Ab_{44} An_{56}	1.692

No. 1....Ôshima(3) (Somma lava)
No. 2....Miyakejima(4) (Dyke at Ôkubohama)(5)
No. 3....Ditto (Lava at Benkene)(6)
No. 4....Ditto (Central cone lava)
No. 5....Mikurashima(7) (Lava)
No. 6....Hachijôjima(8) (Lava)
No. 7....Kôdzushima(9) (Basaltic block in liparite tuff bed)
No. 8....Niijima(10) (Basaltic block in liparite tuff bed)
No. 9....Fuji(11) (Enkyô(12) lava)
No. 10....Amagi(13) (Asamayama(14) lava)
No. 11....Ditto (Tôgasayama(15) lava)
No. 12....Ditto (Ioyama(16) lava)
No. 13
No. 14 ..Tokachi,(17) Hokkaidô (Lower lava)
No. 15
No. 16 ..Ditto (Upper lava)
No. 17
No. 18 ..Ditto (Mae-Tokachi(18) lava)
No. 19....Dittto (Parastic cone lava)
No. 20....Ditto (Bomb ejected in 1926)

From the data given in Table I the paragenesis diagram of Fig. 3 is constructed. As is seen in the figure, the points representing the rocks closely related in geological occurrence are arranged along one and the same curve, while those representing the rocks remote in geological relation along different curves. Thus the rocks under consideration are of three distinct genetical

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(1) For the data of Table I the writer is indebted to Mr. H. Tsuya of this Institute.

(2) F. Tada & H. Tsuya, Bull. Earthq. Research Inst. Tokyo Imp. Univ., Vol. II, 1927, p. 84.

(3) 大島 (4) 三宅島 (5) 大久保濱 (6) ベンケ根 (7) 御藏島 (8) 八丈島 (9) 神津島 (10) 新島 (11) 富士 (12) 猿橋 (13) 天城 (14) 淺間山 (15) 遠笠山 (16) 伊尾山 (17) 十勝 (18) 前十勝

lineages, I, II, and III. All of these rocks are pyroxene-andesites, or closely allied thereto, and are not easily distinguishable from each other without applying the optical analysis. It is one of the advantages of the optical analysis that by its means petrographically similar rocks, such as those here exemplified, can be differentiated into genetically distinct groups.

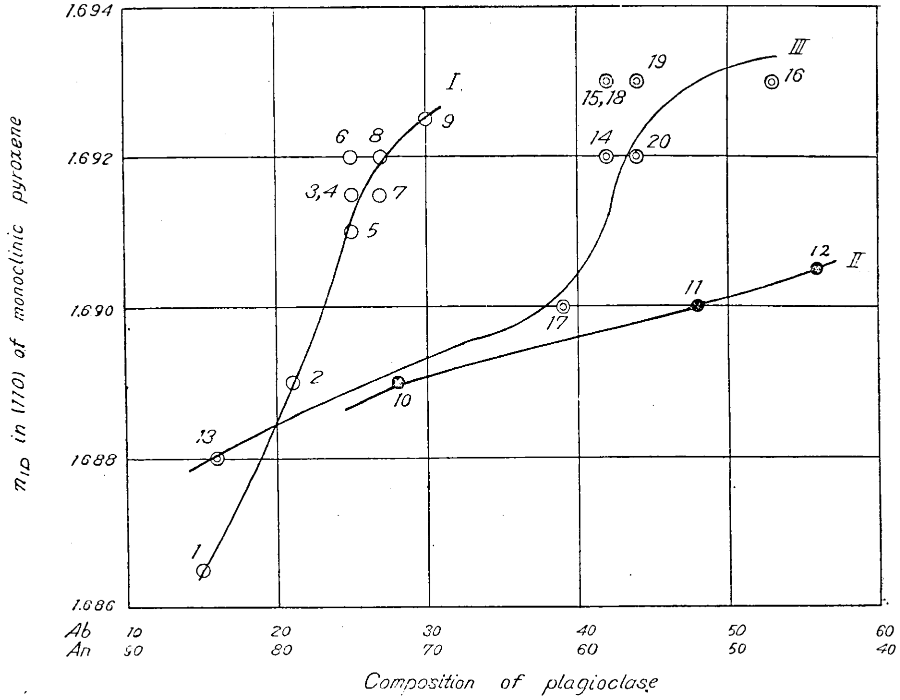

Fig. 3. |—| The actual paragenic relations of plagioclases and monoclinic pyroxenes in the volcanic rocks of Idzu Islands (1–8), Fuji (9), Amagi (10–12), and Tokachi (13–20).

Concluding Remarks.

In the foregoing pages, the principle and the procedure of the optical analysis have been described, and its utility for the genetical study of volcanic rocks has been illustrated.

In the examples cited in the above, the smaller refractives index $n_{1D\,(110)}$ of monoclinic pyroxene was taken for representing its variation in composition, but any other optical constants may be used for the same purpose. In some cases, more than one optical constant of a mafic mineral may be needed for determining the genetical lineage of volcanic rocks.

In the application of optical analysis, it must be borne in mind that ther egular paragenic relation of the minerals as represented in Fig. 1 is expected only for those that have been reacting with the surrounding liquid in a magma-reservoir, but not for the relict minerals which have not been participating in the reaction. Therefore, if there are present more than one kind of the felsic or mafic minerals as phenocrysts in a series of volcanic rocks, it is safe to take the latest one of those porphyritic minerals for the purpose of tracing the genetical lineages of the rocks.

A fuller and more general account of the optical analysis, which is of wider scope, will be given in another paper now under preparation. The present one is to be regarded as introductory to it.