The distinction of analcime from leucite in rocks by X-ray methods.

By F. A. Bannister, M.A.
Assistant-Keeper in the Mineral Department of the British Museum of Natural History.

[Read January 13, 1931.]

SINCE W. Lindgren[1] first detected the presence of microphenocrysts of analcime in basalt, many observers have recorded this mineral as a constituent of igneous rocks, but there is some difficulty in distinguishing between analcime and glass and between analcime and leucite in thin rock-sections. For instance, H. Rosenbusch[2] identified the interstitial colourless isotropic material in monchiquites as glass, whereas L. V. Pirsson[3] showed it to be analcime. H. S. Washington[4] showed that basalts from Sardinia, previously thought to be leucitic, contain phenocrysts of analcime. A. Lacroix[5] also found, in his study of north African basaltic lavas, that in many cases so-called leucite-lavas actually contain analcime and not leucite. More recently, Dr. F. Dixey and Mr. W. Campbell Smith[6] have described, associated with phonolites and kenytes from the Lupata Gorge, Zambezi River, Portuguese East Africa, lavas containing phenocrysts of analcime up to 1½ cm. in diameter. These lavas are compared with blairmorite, a volcanic rock from Alberta 'characterized by dominant phenocrysts of analcite in a matrix composed of analcite, alkali feldspar, and alkali-pyroxene, with titanite, melanite, and nephelite. . . .'[7] The analcime in the lavas from the Lupata Gorge

[1] W. Lindgren, Proc. California Acad. Sci., 1890, ser. 2, vol. 3, p. 52.

[2] H. Rosenbusch, Mikroskopische Physiographie der massigen Gesteine, 3rd edition, 1896, vol. 2, p. 539.

[3] L. V. Pirsson, Journ. Geol. Chicago, 1896, vol. 4, p. 679.

[4] H. S. Washington, Journ. Geol. Chicago, 1914, vol. 22, p. 742.

[5] A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1924, vol. 178, pp. 529–535. [Min. Abstr., vol. 2, p. 309.]

[6] F. Dixey and W. Campbell Smith, Geol. Mag. London, 1919, vol. 66, p. 256. [Min. Abstr., vol. 4, p. 224.]

[7] J. D. MacKenzie, The Crowsnest volcanics. Canada Geol. Survey, Mus. Bull. no. 4, Geol. Ser. no. 20, 1914, p. 27.

is described as 'quite isotropic and pale-yellow in thin section, and shows traces of twin-lamellae often seen in leucite, but determination of its density (2·2–2·3), refractive index (about 1·48), and chemical constituents proves it to consist wholly of analcite'. From the area immediately south of the district described by Dr. F. Dixey, near the Fidzi River, F. P. Mennell [1] has recorded as pseudomorphous after leucite 'porphyritic crystals 2–5 mm. across of a rather yellowish greasy-looking appearance', which, from his description, seem to correspond to the phenocrysts in the blairmorite recorded by Mr. W. Campbell Smith as analcime. Whether these phenocrysts represent original leucite or primary analcime, it is important to place their identification beyond doubt.

X-ray methods afford a ready and certain means for mineral determination, and it is now proposed to apply them to confirm Mr. W. Campbell Smith's identification of the analcime phenocrysts. It is interesting to note here that X-ray methods would also decide the problem of interstitial analcime referred to above. Not only could the two other possible interstitial minerals, sodalite and leucite, be distinguished from analcime, but a direct proof would also be given of the crystalline or glassy nature of the material. Laue photographs have already been used by the author in distinguishing small nepheline phenocrysts of low refractive index from felspar in thin rock-sections.[2] Apart from identification, the Laue photographs in this case yielded values of the axial ratio and also the relative orientation of phenocrysts in the same section. A Laue photograph of a substance possessing cubic symmetry would constitute identification only as regards the distribution and intensities of the spots.

In applying X-ray methods to the supposed analcime phenocrysts of the blairmorites from the Lupata Gorge, the possibility of twinning and the cubic symmetry of analcime suggested the powder method rather than any other. A fragment of a phenocryst, previously studied by Mr. W. Campbell Smith, was finely powdered after a preliminary density determination by the flotation method (*d* 2·29). The measurements of the lines of the powder photograph are given in table I, together with data from powder photographs of analcime from the Cyclopean Islands, Sicily, published in a paper on the

[1] F. P. Mennell, Geol. Mag. London, 1929, vol. 66, p. 536. [Min. Abstr., vol. 4, p. 225.]

[2] F. A. Bannister, Abstr. Proc. Geol. Soc. London, 1929–1930, 1930, p. 104.

structure of analcime by Mr. W. H. Taylor.[1] The data are in complete agreement, not only as regards the position of the lines, but also their approximate relative intensity. A further powder photograph of analcime from the Cyclopean Islands was taken for direct comparison, and it was found that the lines of the analcime phenocryst photograph coincided exactly. Also, as table I shows, there are no visible lines present other than those to be expected from analcime.

Corresponding data for leucite do not appear to have been published. To complete the work, therefore, a small clear crystal of leucite from Monte Somma, Mt. Vesuvius, Italy, was powdered and a photograph taken. The leucite and analcime photographs are readily distinguishable. The measurements of the leucite powder photograph are given in table II. An attempt has been made to assign indices to the diffracting planes. For this purpose a small platy fragment of a leucite crystal was selected from the same specimen used for the powder photograph and a Laue photograph taken perpendicular to the plate. The pseudo-cubic pattern obtained suggests that the plane of the plate is parallel to the face (100). Between crossed nicols the plate shows the characteristic twin-lamellae parallel to the (110) faces, crossing each other approximately at right angles. Rotation photographs were then taken about the [100], [010], [001], [011], and [111] axes. The fragment appears to possess orthorhombic symmetry and the photographs indicate a unit body-centred cell whose edges are $a = 12{\cdot}95$, $b = 13{\cdot}12$, $c = 13{\cdot}74$ Å., the limits of error in each case being $\pm 0{\cdot}04$ Å. The density of the fragment is 2·47, and the unit cell contains 16 molecules of the type $KAlSi_2O_6$. The indices assigned to the lines of the leucite powder photograph are derived on the basis of the data from the rotation photographs. It has not, however, been possible to assign indices to all the lines. This, coupled with the fact that the fragment used for the rotation photographs shows twin-lamellae, leaves open the possibility of lower symmetry or different cell-edges for the unit cell of untwinned leucite. The data given in tables I and II do, however, show that powder photographs of leucite and analcime constitute a certain and ready means of distinction between the two minerals. There is no doubt, therefore, that the blairmorite phenocryst studied is analcime and is sensibly free from other components.

[1] W. H. Taylor, Zeits. Krist., 1930, vol. 74, pp. 1–19. [Min. Abstr., vol. 4, p. 369.]

TABLE I.

Data from powder photographs of analcime.

(*a*) Analcime phenocryst in blairmorite from Lupata Gorge, Zambezi River, Portuguese East Africa. (N724 = B.M. 1929,173,72.) $d = 2{\cdot}29$, unit cell-edge $a = 13{\cdot}70 \pm 0{\cdot}05$ Å.

(*b*) Analcime crystal from Cyclopean Islands, Sicily. (B.M. 1914,332). $d = 2{\cdot}27$, unit cell-edge $a = 13{\cdot}70 \pm 0{\cdot}05$ Å.

(*c*) Analcime crystal from Cyclopean Islands, Sicily. W. H. Taylor's data. Unit cell-edge $a = 13{\cdot}68 \pm 0{\cdot}04$ Å.

Observed diameters of the Debye-Scherrer rings. cm.		sin θ.			Observed intensities.		Indices of planes.
(*a*)	(*b*)	(*a*)	(*b*)	(*c*)	(*a*)	(*c*)	
1·70	—	0·140	—	0·138	*vs*	*vs*	(211)
1·93	—	0·159	—	0·159	*ms*	*m*	(220)
2·28*	—	0·188	—	—	*m*	—	(400)
2·48*	—	0·203	—	—	*m*	—	(400)
not observed	—	—	—	0·211	—	*vw*	(213)
2·735	—	0·224	—	0·226	*vvs*	*vvs*	(400)
3·10	—	0·254	—	0·253	*vw*	*vvw*	(420)
3·23	3·23	0·264	0·264	0·264	*vs*	*vs*	(233)
not observed	—	—	—	0·276	*w*	*w*	(422)
3·50	3·50	0·286	0·286	0·286	*m*	*ms*	(413)
3·78	3·79	0·307	0·309	0·308	*ms*	*ms*	(215)
3·90	—	0·317	—	0·320	*w*	*mw*	(440)
4.27	—	0·346	—	0·346	*ms*	*m*	(235)
4.48	—	0·362	—	0·365	*vw*	nil	(415)
4·70	—	0·379	—	0·382	*w*	nil	(613)
4·94	—	0·398	—	0·397	*w*	nil	(435)
5·03	5·04	0·404	0·405	0·406	*ms*	*m*	(640)
5·14	—	0·413	—	0·414	*m*	*m*	(633)
5·53	5·53	0·442	0·442	0·443	*ms*	*ms*	(237)
5·62	—	0·449	—	—	*m*	—	(800)
5·70	—	0·435	—	—	*m*	—	(417)
6·07	—	0·482	—	—	*m*	—	(831)
6·60	—	0·519	—	—	*w*	—	(219)
6·92	—	0·542	—	—	*m*	—	(239)
7·28	7·29	0·567	0·568	—	*ms*	—	(277)
7·56	—	0·586	—	—	*w*	—	(10.3.1)
7·71	—	0·596	—	—	*m*	—	(817)
7·90	—	0·608	—	—	*vw*	—	(10.4.0)?
8·23	8·23	0·630	0·630	—	*m*	—	(639)
8·60	—	0·653	—	—	*w*	—	(866)
9·11	—	0·685	—	—	*w*	—	(10.5.5)
9·68	—	0·718	—	—	*w*	—	(10.8.0)

The diameter of the cylindrical camera = 6·04 cm. θ = glancing angle corresponding to Cu$-K_\alpha$ radiation, $\lambda = 1{\cdot}539$ Å., *s* = strong, *m* = medium, *w* = weak, *vs* = very strong, &c.

* These two lines are due to Cu$-K_\beta$ and W$-L_\beta$ radiation.

TABLE II.

Data from powder photograph of leucite, $d = 2{\cdot}49$, from Monte Somma, Mt. Vesuvius, Italy. (B.M. 53690.)

Diameters of Debye-Scherrer rings. cm.	sin θ.	Observed intensities.	Indices of planes.
1·40	0·115	*s*	(112)
1·75	0·145	*vs*	(211)
2·31*	0·190	*m*	(004)
2·49*	0·204	*m*	(004)
2·60	0·214	*w*	(123)
2·75	0·226	*vs*	(004)
2·90	0·237	*vs*	(400)
3·00	0·246	*w*	(303) ?
3·15	0·258	*w*	(042)
3·29	0·268	*s*	(420)
3·35	0·273	*s*	(233)
3·50	0·286	*vvw*	(242)
3·60	0·294	*s*	(215)
4·01	0·326	*s*	(404)
4·10	0·334	*w*	(440)
4·35	0·352	*w*	(235)
4·41	0·357	*w*	(253)
4·47	0·362	*m*	(532)
5·00	0·402	*vw*	(631)
5·19	0·417	*w*	(064)
5·34	0·428	*w*	(246)
5·40	0·432	*m*	(426)
5·60	0·447	*m*	(008) ?
5.80	0·462	*ms*	(417)
5·91	0·470	*w*	—
6·11	0·485	*m*	(280)
6·35	0·502	*m*	(660)
6·60	0·519	*m*	—
7·20	0·560	*m*	—
7·64	0·591	*w*	—
8·05	0·618	*ms*	—

The diameter of the cylindrical camera = 6·04 cm. θ = glancing angle corresponding to Cu$-K_\alpha$ radiation, $\lambda = 1{\cdot}539$ Å.

* These two lines are due to Cu$-K_\beta$ and W$-L_\beta$ radiation.

Chemical analyses of the zeolites show that the silicon to aluminium ratio in general varies considerably, and it is also known that the alkalis can be readily replaced without alteration of crystal form. Taylor has correlated the fairly constant silicon to aluminium ratio in analcime with the crystal structure obtained by X-ray methods.

He has also shown by powder photographs that substitution of the sodium by silver atoms does not alter the cell-size, but does affect the relative intensities of the X-ray diffractions. It has been possible owing to his work to note carefully in the X-ray photograph of the analcime phenocryst those lines which would be most affected by any replacement of the sodium atoms, and there is no indication of any apparent departure from the relative line-intensities of the normal analcime photograph. Primarily, the photographs now taken constitute a method of identification, and the most accurate measurements of intensity of X-ray diffractions do not compete in accuracy with chemical analysis. However, the present work, in conjunction with the refractive index value, indicates that the analcime phenocryst is probably of normal composition.

The interest in applying X-ray methods to the study of rocks lies not only in the identification of difficult cases, but in the possibility of studying any given mineral in rock-sections. With the object of seeing whether in the above case the Laue method or the oscillation method applied to a thin section of the analcime phenocrysts would yield satisfactory results, a Laue photograph of a small fragment of Lupata Gorge analcime was taken, using monochromatic radiation. The spots produced are large and rather diffuse; their elongated shape indicates that they all correspond to monochromatic radiation and not to white radiation. Table III gives the measurements on this photograph and shows the presence of important analcime lines of table I. The phenocryst is not, therefore, a single crystal, but is made up of smaller individuals in sub-parallel position. Those individuals correctly oriented diffract the copper radiation and produce the relatively strong lines already noted. In addition, each individual produces its Laue pattern due to white radiation. These spots are very faint and small, and a background of these superposed Laue patterns can actually be observed on the plate. The powder photograph obtained when a crystalline substance is not sufficiently finely pulverized shows flecked Debye-Scherrer rings, and when the powder is yet coarser the rings are no longer continuous, but broken. The photograph of the phenocryst fragment under consideration is an extreme case of this latter type. In order to describe the photograph, not only the glancing angle θ is given for each spot, but also the angle of azimuth ϕ measured from a line through the centre of the plate arbitrarily chosen as horizontal. Table III shows the number of spots on any one ring and their corresponding ϕ values. There are several equal ϕ value intervals of

TABLE III.

Data from Laue photograph, using monochromatic radiation, of a fragment of analcime phenocryst in blairmorite from Lupata Gorge, Zambezi River, Portuguese East Africa (N724 = B.M. 1929,173,72).

Indices of planes observed.	sin θ.	θ.	Angles of azimuth ϕ.				
(211)	0·140	8°	79°	131°	—	—	—
(220)	0·159	9° 10′	0	131	—	—	—
(400)	0·224	13 3	0	19	38°	106°	270°
(233)	0·264	15 19	0	19	38	157	—
(413)	0·286	16 36	38	64	79	284	—
(215)	0·307	17 58½	79	106	122	140	157
(440)	0·317	18 30	64	79	—	—	—
(235)	0·346	20 15	190	205	229	350	—
(444)	0·395	23 16	44	166	339	—	—
(640)	0·404	23 49	222	232	270	339	—
(237)	0·442	26 14	42	160	—	—	—

θ = glancing angle corresponding to Cu$-K_{\alpha}$ radiation, $\lambda = 1{\cdot}539$ Å.

Spots were also observed for the strongly reflecting planes (400), (233), (413), and (215), corresponding to W$-L_{\alpha_1}$ radiation, $\lambda = 1{\cdot}473$ Å.

about 19° repeated on the plate. If the values of θ and ϕ be plotted stereographically, it is found that the strongly diffracting planes, e.g. (400) or (233), for these neighbouring ϕ values have an angular separation of 4° to 5°. It is probable, therefore, that the maximum tilt between neighbouring particles of the phenocryst is of the same order.

The analcime in blairmorites from the Lupata Gorge forms large icositetrahedra. Although the external form suggests a regular internal crystalline formation, the X-ray investigations have shown that the phenocryst is broken into coarse particles which are no longer perfectly alined, but show only a sub-parallel arrangement. Since the molecular weights of analcime and leucite are approximately equal, the molecular volumes are inversely as the ratio of the densities, namely, 2·5 : 2·3 respectively. If the analcime phenocrysts are pseudomorphs after leucite, the expansion of 1·09 by volume might not be sufficient to affect seriously the external form of the icositetrahedra.

The present work, therefore, is consistent either with the view that the phenocrysts are primary or that the analcime is pseudomorphous after leucite or a hypothetical soda-leucite. If the phenocrysts are primary, their sub-parallel arrangement may be due to irregularities of growth or to stresses imposed after crystallization.

Summarizing the above results, powder photographs have satisfactorily confirmed the identity of the analcime phenocrysts in blairmorites from the Lupata Gorge. A Laue photograph of a fragment of the phenocryst using monochromatic radiation has also yielded information on the crystalline aggregation of the phenocrysts.

In conclusion, I should like to thank Mr. W. Campbell Smith for suggesting this problem and for his continued help.