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Objektyp: **Article**

Zeitschrift: **Schweizerische mineralogische und petrographische Mitteilungen  
= Bulletin suisse de minéralogie et pétrographie**

Band (Jahr): **47 (1967)**

Heft 1: **Feldspäte**

PDF erstellt am: **21.09.2024**

Persistenter Link: <https://doi.org/10.5169/seals-36935>

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# Unmixing in the Sanidines of the "Pietra Verde" of the Dolomites (Italy)

By *Ezio Callegari* and *Renzo De Pieri* (Padova)

With 5 figures in the text

*Riassunto.* Viene descritto un nuovo tipo di criptopertite caratterizzato dalla presenza di tre fasi monocline. I riflessi del sanidino originario sono accompagnati da quelli dovuti a due fasi monocline smistate, l'una ricca di potassio, l'altra ricca di sodio.

*Abstract.* A new type of cryptoperthite is described which is characterised by the presence of three monoclinic phases, the still unexsolved sanidine being accompanied by two exsolved monoclinic alkali feldspars, respectively Na-rich and K-rich.

## Introduction

Recent petrographic investigations have shown K-feldspar (sanidine and orthoclase) to be among the major volcanoclastic components of the green tuffs and tuffites known as "pietra verde" (CALLEGARI, 1964; CALLEGARI and MONESE, 1964; BACELLE and SACERDOTI, 1965; CALLEGARI and DE PIERI, 1966).

These tuffaceous rocks of the lower Ladinian mark the first appearance of the triassic volcanism into the Dolomitic Region (LEONARDI, 1955; ACCORDI, 1959). In thin sections many crystals and fragments of volcanic rocks are seen embedded in an abundant matrix, formed by very fine volcanic ashes. Zoned plagioclases ("high"-andesine) predominate among the crystal fragments, followed in order of importance by quartz, K-feldspar (mainly sanidine) and biotite.

Under the microscope the sanidine crystals appear slightly turbid. Zoning is absent. A slight mottled extinction is observed in many crystals, which is probably due to different degrees of unmixing. Perthite-like

associations between sanidine and chess-board albite ("patch-perthites") have frequently resulted from the partial replacement of the K-feldspars, which took place during diagenesis (CALLEGARI and DE PIERI, 1966).

The sanidine crystals are elongated according to [100]; the optic axial plane is perpendicular to (010). Baveno, Manebach and Karlsbad twinings are frequently observed. The  $2V_{\alpha}$  angle commonly ranges from  $15^{\circ}$  to  $33^{\circ}$  (conoscopic measurements on the U-stage), but values up to  $40^{\circ}$  have sometimes been measured. There is a marked dispersion  $r > v$ ; the maximum dispersion measured was as follows:  $2V_{\alpha} = 19^{\circ}$  (495  $m\mu$ ),  $2V_{\alpha} = 24^{\circ}$  (670  $m\mu$ ).

For the present study three sanidine-rich samples of "pietra verde" were selected. They are as follows:

*Sample M.* Green crystal tuff from the Buchenstein strata near the Dosso di Uomo (Marmolada's southern side). It contains many water-clear sanidine crystals, without traces of unmixing. Their optical properties are as follows:  $2V_{\alpha} = 15^{\circ}$ — $22^{\circ}$ ,  $\alpha' \wedge (001)$  in (010) =  $6^{\circ}$ . Baveno and Manebach twinings are often observed.

*Sample 23 c.* Green crystal tuff from the outcrops of "pietra verde" near Brusè (on the road to Col di Lana, Alta Valle Cordevole). It contains abundant slightly turbid sanidine crystals, whose optical properties are as follows:  $2V_{\alpha} = 22^{\circ}$ — $33^{\circ}$ ;  $\alpha' \wedge (001)$  in (010) =  $6^{\circ}$ ;  $n_{\beta} = 1.525$  (at  $23^{\circ}$  C). Many crystals exhibit a slightly mottled extinction. Baveno and Manebach twinings are of common occurrence.

*Sample 2082.* Grey tuffaceous sandstone from the Buchenstein strata at Passo del Feodo (Val di Fiemme). It contains abundant sanidine crystals with a slightly turbid appearance. The  $2V_{\alpha}$  angle varies from  $25^{\circ}$  to  $40^{\circ}$ , with a mean value of  $33^{\circ}$  (average of 11 measurements). The crystals commonly exhibit a mottled extinction. Baveno and Manebach twinings are frequently present.

#### X-ray study

From a concentrate of sanidine crystals, obtained by means of heavy-liquids treatment of the powdered rock samples, fresh cleavage flakes (ca. 0.1—0.2 mm) were hand-picked under the binocular for the X-ray study with single-crystal methods. All the selected crystals appeared perfectly homogeneous under the polarizing microscope.

For each of the studied crystals precession photographs were taken with the *a*-, *b*-, and *c*-axis as the precession axes. The X-ray patterns revealed the crystals from sample M to be single-phase sanidines, whereas

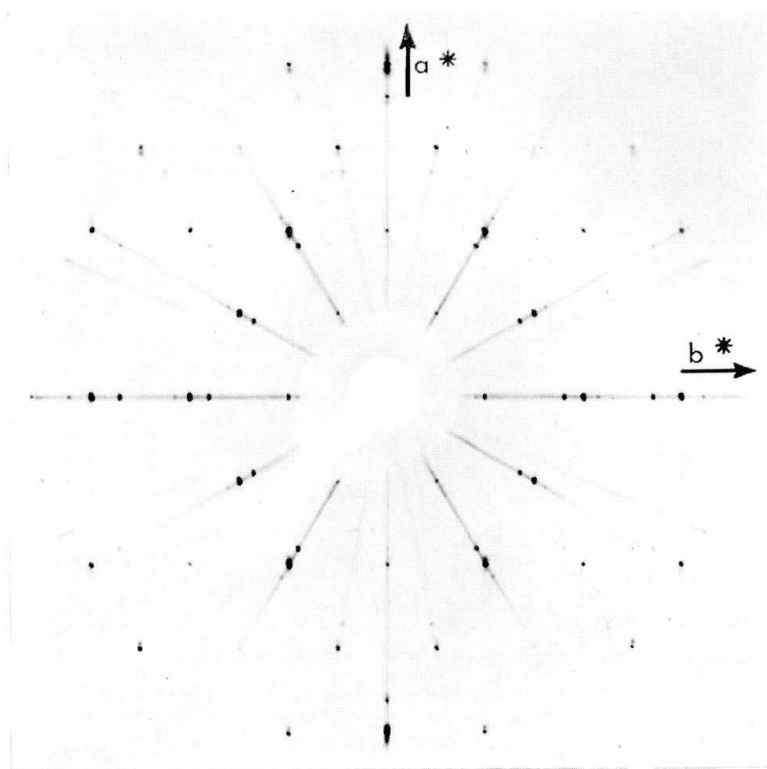


Fig. 1. Unmixed sanidine 23 c.  $a^* b^*$  precession photograph, unfiltered Cu radiation. Three distinct phases are seen in the  $a^*$ -axis direction. The strongest reflections belong to the still unexsolved sanidine.

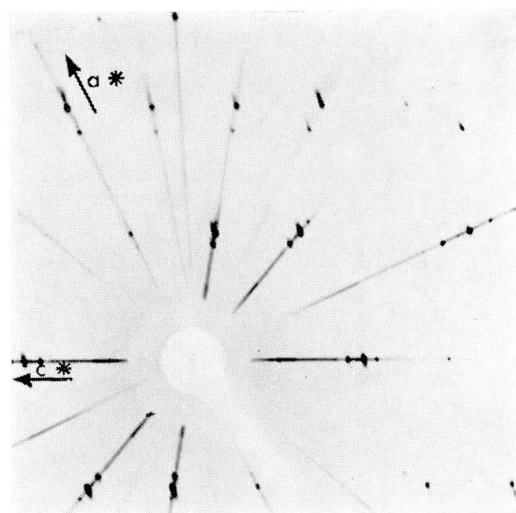


Fig. 2. Unmixed sanidine 2082.  $a^* c^*$  precession photograph, unfiltered Cu radiation. The reflections of the exsolved feldspars are seen in addition to the strong reflections of the still unexsolved sanidine. Note the elongation of the reflections for the Na-rich feldspar nearly in the direction of the  $a^*$ -axis.

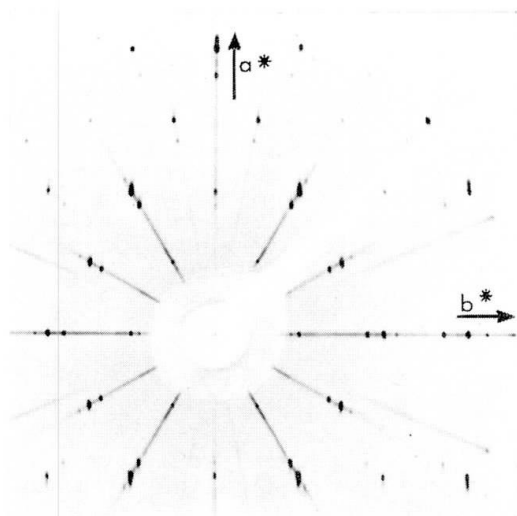


Fig. 3. Unmixed sanidine 2082.  $a^* b^*$  precession photograph, unfiltered Cu radiation. The reflections of the two monoclinic exsolved phases are seen in the direction of the  $a^*$ -axis. The reflections of the K-rich exsolved material are very close to those of the still unexsolved sanidine.

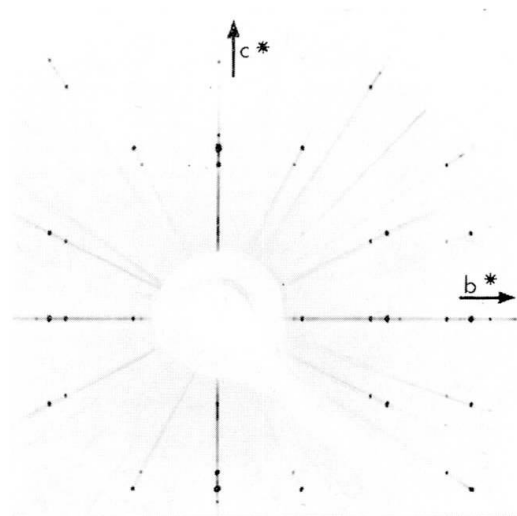


Fig. 4. Unmixed sanidine 2082.  $b^* c^*$  precession photograph, unfiltered Cu radiation. No splitting of the sanidine reflections is observed.



Fig. 5. Unmixed sanidine 2082.  $b$ -axis zero level Weissenberg photograph, calibrated according to PABST (1957). Unfiltered Cu radiation. The three monoclinic phases of this cryptoperthite are clearly visible. Three  $\beta^*$  values can be measured for each of the three distinct  $c^*$ -axes. The inset diagram shows an enlargement of the (002) reflection.

three distinct phases were found in the sanidine crystals 23c and 2082. In fact the precession pictures of these latter crystals showed a marked splitting of the reflections in the direction of the  $a^*$ -axis (Fig. 1, 2 and 3), the sharp and strong reflections of sanidine being accompanied by two weak spots. No splitting was observed in the direction of the  $b^*$ - and  $c^*$ -axes (Fig. 4). This indicates that the three phases have nearly identical values of the  $b$  and  $c$  lattice parameters but differ from each other for the values of the  $a$  lattice parameter and for the intensities of their reflections. It is interesting to note that *all the three phases are monoclinic* ( $\alpha^* = \gamma^* = 90^\circ$ ).

The lattice parameters for each phase are reported in Tab. 1. For the sanidine 2082 three distinct  $\beta$  and  $c$  values are given, because three distinct  $c^*$  axes are clearly recognizable in the  $b$ -axis zero level Weissenberg photograph. As seen in Fig. 5, the presence of three well resolved spots has enabled us to measure  $\beta$  and  $c$  values for each phase. This was not possible with the sanidine 23c because in the Weissenberg photographs the reflections appeared only elongated without being resolved.

Table 1. *Lattice constants of selected sanidines from the "pietra verde" of the Dolomites<sup>1)</sup>*

Sample		$a$ Å	$b$ Å	$c$ Å	$\alpha$	$\beta$	$\gamma$
23 c	Na-rich phase	8.32	12.998	7.174	90°	116.0°	90°
	Sanidine	8.49	12.998	7.174	90°	116.0°	90°
	K-rich phase	8.64	12.998	7.174	90°	116.0°	90°
2082	Na-rich phase	8.25	13.000	7.192	90°	117.4°	90°
	Sanidine	8.49	13.000	7.176	90°	116.5°	90°
	K-rich phase	8.65	13.000	7.154	90°	115.6°	90°
M	Sanidine	8.486	13.007	7.185	90°	116.0°	90°
Cryptoperthite <sup>2)</sup>	Sanidine	8.47	12.94	7.16	90°	116.1°	90°
	Na-rich phase	8.12	12.94	7.16	90°	116.6°	90°
Cryptoperthite <sup>3)</sup>	Exsolved Na-feldspar	8.14	12.99	7.16	90°	116.6°	90°
Monalbite <sup>4)</sup>		8.38	12.94	7.14	90°	116.1°	90°

<sup>1)</sup> The estimated error for the lattice constants is  $\pm 0.1^\circ$  for the  $\beta$  angles;  $\pm 0.3\%$  for the  $a$  parameters ( $\pm 0.07\%$  for the sample M) and  $\pm 0.07\%$  for the  $b$  and  $c$  parameters.

<sup>2)</sup> After JUNG D. (1965).

<sup>3)</sup> After SOLDATOS K. (1965).

<sup>4)</sup> After BROWN W. L. (1960), quoted in JUNG D. (1965).

The features of the X-ray patterns suggest the sanidines 23 c and 2082 to be cryptoperthites with two monoclinic exsolved phases.

From the data reported in Tab. 1 the  $(\bar{2}01)$  spacings were calculated for both the sanidine and the exsolved phases. The values obtained in this way were found to be in good agreement with the values of  $(\bar{2}01)$  spacings measured on *b*-axis zero-level Weissenberg photographs calibrated with NaCl according to PABST (1957). Assuming the possibility to use the determinative curve of BOWEN and TUTTLE (1950), average compositions were deduced for each phase, which are reported in Tab. 2.

Table 2. *Calculated and measured values for  $d_{(\bar{2}01)}$  and composition of each phase as deduced from the mean values of  $d_{(\bar{2}01)}$*

Sample		$d_{(\bar{2}01)}$ calc. Å	$d_{(\bar{2}01)}$ meas.	Average Ab content (% by weight)
23 c	Na-rich phase	4.11	n. d.	62 %
	Sanidine	4.18	4.16	32 %
	K-rich phase	4.25	4.21	2 %
2082	Na-rich phase	4.09	4.08	72 %
	Sanidine	4.19	4.17	27 %
	K-rich phase	4.25	4.25	0 %
M	Sanidine	4.18	n. d.	27 %

From the data of Tab. 2 it appears that the two exsolved phases correspond respectively to an almost pure K-feldspar<sup>1)</sup> and to a Na-rich feldspar. The composition of this latter, as referred to the centre of the spots, ranges from  $Or_{38}Ab_{62}$  to  $Or_{28}Ab_{72}$ . It should be noted, however, that the spots of the Na-rich phase are often elongated in the direction of the  $a^*$ -axis (Fig. 2, 3 and 5): this may mean that a larger variation in composition actually occurs in the exsolved Na-rich feldspar than is expressed by the reported mean values.

<sup>1)</sup> It must be noted that according to the  $d_{(\bar{2}01)}$  values found for the exsolved K-rich feldspar the determinative curve of BOWEN and TUTTLE (1950), lead to an impossible Or content of more than 100 %. The same composition is obtained from the determinative curve of LAVES (1952) based on the *a* lattice parameter. This fact is similar to that observed by LAVES (1952, p. 562) for the "exsolved albite" from some cryptoperthites. According to LAVES this may be due to the initial stage of unmixing in the cryptoperthites, which "may be expected to produce 'phases' structurally modified from those of the stable series" (LAVES, 1952, p. 562).

It is probable that the same effect may act upon the exsolved Na-rich feldspar.

It is interesting to note that the unexsolved sanidine phase, which constitutes the essential part of the studied cryptoperthites, exhibits the same composition as the single-phase sanidine M, which contains about 27% Ab (by weight).

Also noteworthy is the good agreement between the composition of the sanidine phase of the crystal 23 c as deduced from the measurement of the  $(\bar{2}01)$  spacing and the total composition of the same crystal as determined by means of the electron-probe analysis. Quantitative determinations made by R. GUBSER (E.T.H., Zürich) gave the following composition (by weight):  $\text{Or}_{71}\text{Ab}_{28}\text{An}_1$ .

As deduced from visual comparison of the relative intensities of the reflections, the "exsolved phases" should not exceed together about 10% of the total composition<sup>2)</sup>. The K-rich exsolved phase predominates over the Na-rich exsolved material. Both of the exsolved phases seems to be untwinned.

A tendency has been observed for the elongated reflections of the exsolved Na-rich feldspar to depart from the direction of the  $a^*$ -axis of both the sanidine and the K-rich phase (Fig. 2 and 5). An angle of about 20' was measured between the  $a^*$ -axis of the sanidine phase and the  $a^*$ -axis of the Na-rich phase as measured at the extremity of the elongated spots. This feature is similar to that described by LAVES (1952) for the orthoclase-albite-cryptoperthites and to that recently found by JUNG (1965) for a sanidine-monalbite-cryptoperthite.

#### Concluding remarks

The X-ray behaviour of the selected K-feldspars from the so called "pietra verde" of the Dolomites indicates that either single-phase or unmixed sanidines may exist, whose composition as a whole seems to be fairly constant (ca.  $\text{Or}_{70}\text{Ab}_{30}$ ). The An content is low (0.88% An, by weight).

The sanidine-cryptoperthites are composed of three phases, the most predominant of which is represented by the original unexsolved sanidine. Of the two exsolved phases one is an almost pure monoclinic K-feldspar (with the restrictions discussed in the footnote of p. 116); the other one

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<sup>2)</sup> Moreover, it is hard to make a suitable estimate for the following reason: the ratio of the intensity of the "exsolved" material to the intensity of the main spots depends strongly on  $\vartheta$  (see fig. 1). This fact may be connected with a "quasi-homogeneous" character of this cryptoperthite (cfr. LAVES, 1952, p. 563).



is a monoclinic Na-rich feldspar (about 62 to 72% Ab), whose X-ray behaviour very much resembles that of the exsolved Na-rich phase (monalbite?) found by JUNG (1965) and that of the exsolved monoclinic Na-feldspar found by SOLDATOS (1965).

As seen from the data reported in Tab. 1, the  $a$  lattice parameter of the exsolved Na-rich material in the studied sanidines was found either to be intermediate between the  $a$  values of BROWN's monalbite and those of JUNG's and SOLDATO's exsolved monoclinic Na-feldspar, or to approximate to the  $a$  value of BROWN's monalbite.

On the ground of its composition and monoclinic symmetry the exsolved Na-rich feldspar may be defined as K-monalbite according to LAVES (1960). Therefore the sanidines 23 c and 2082 are monoclinic three-phase cryptoperthites.

The existence of unexolved sanidines and the very small amount of the exsolved material found in the sanidine-cryptoperthites seem to indicate that the unmixing is in an initial stage. The presence of three phases suggests that it occurred at low temperatures, but failed to reach final equilibrium.

It may be noted that in the sanidine 2082 the exsolution of the K-monalbite seems to have occurred as a "continuous" process as proved by the marked elongation of the reflections in a direction close to the  $a^*$ -axis. A similar effect was observed by SOLDATOS (1965).

Owing to the fairly constant composition of the studied sanidines, it is interesting to compare their X-ray behaviour and their optical properties (as deduced from the study of thin sections of the selected rock specimens). It appears that when unmixing occurs a large variation is observed in the  $2V$  angle, which tends to become larger and larger as the amount of the exsolved phases increases. In addition  $2V$  may have been affected by a higher degree of Al/Si order prevailing as the exsolution process increases.

#### *Acknowledgements*

We are greatly indebted to Prof. F. LAVES (Zürich) for helpful discussions and for his kind hospitality. We wish to thank Dr. R. GUBSER (Zürich) for the analysis by means of the electron-probe and Prof. W. S. MACKENZIE for useful discussions on the subject. The Authors express their gratitude to Prof. F. LAVES for his critical reading of the manuscript. The present work was carried out with the aid of contributions from the Centro di Studio per la petrografia e la geologia del Consiglio Nazionale delle Ricerche.

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Manuscript received May 8th, 1966.