

# Morphology, twinning, and optical orientation of gismondine

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**SUMMARY.** Gismondine is a monoclinic mineral but prior to X-ray determination of its unit cell it was variously regarded as orthorhombic, monoclinic, or triclinic on account of its intricate twinning. A study of gismondine crystals from Osa Quarry, near Rome, indicates that the morphologically dominant form is  $\{232\}$  which by twinning about the normal to  $\{100\}$  produces penetration-twinned octahedral crystals united on  $(100)$  and  $(001)$ . Gismondine has poor cleavage on  $\{232\}$ ; optic plane is  $(010)$  and  $\gamma: [001] = 42.5^\circ$  (in obtuse  $\beta$ ).

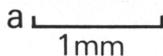
GISMONDINE is a monoclinic zeolite mineral, which on account of its penetration twinning (fig. 1a, b) shows tetragonal or orthorhombic pseudosymmetry. It was named by K. C. von Leonhard (1817) after Professor Gismondi who had previously (1816, 1817) discovered an apparently similar mineral, zeagonite, which, being a mixture of gismondine and phillipsite, was not accepted as a species. The morphological cell of gismondine was considered to be monoclinic, orthorhombic, or triclinic (see Dana, 1892). Kalb (1932) deduced an orthorhombic morphological cell, axial ratio, 0.9657:1:0.7491. The first single crystal X-ray diffraction study by Kraus (1939) showed it to be orthorhombic,  $a = 13.68$ ,  $b = 14.28$ ,  $c = 10.60$  Å, axial ratio similar to that of

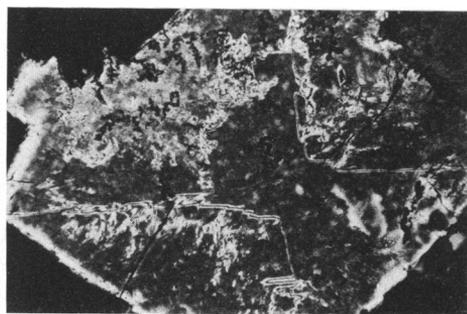
Kalb and space group  $Cmmm$  or  $Ccca$ . Fischer and Kuzel (1958) and Fischer (1963) have deduced the correct monoclinic cell and crystal structure of gismondine, space group  $P2_1/c$ . The new monoclinic cell,  $a = 10.02$ ,  $b = 10.62$ ,  $c = 9.84$  Å, and  $\beta = 92^\circ 25'$  is related to the Kraus cell by the transformation matrices: orthorhombic to monoclinic  $\frac{1}{2}0/001/\frac{1}{2}\bar{1}0$ ; monoclinic to orthorhombic  $101/10\bar{1}/010$  (fig. 2).

The morphology, twinning, cleavage, and optical orientation of gismondine are still ambiguous (see Winchell and Winchell, 1964) and form the basis of this study.

*Specimen and method of study.* The specimen examined was from Osa Quarry, near Rome, Italy. The crystals of gismondine, up to 0.5 cm across, occur as isolated or intertwined octahedra on a volcanic rock matrix. The associated mineral natrolite occurs in the form of balls. Occasionally prismatic natrolite crystals penetrate and project out from the gismondine crystals. The crystallographic  $c$ -axis of gismondine was located on a cleavage fragment by means of a rotation pattern. It was subsequently found to be inclined both to the  $\gamma$  vibration direction and the line of cleavage intersection by means of the universal stage on the same crystal fragment. Oriented thin sections



a  1mm



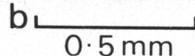
b  0.5 mm

FIG. 1. a (left). Branching, fern-like and interpenetrating twinned, length-fast aggregates of gismondine from Iceland. Plane polarized light.

b (right). Gismondine section normal to the  $b$ -axis showing four segments twinned on  $\perp \{100\}$  and united on  $(100)$  and  $(001)$ . Specimen from Osa Quarry, Rome, Italy. Plane polarized light.

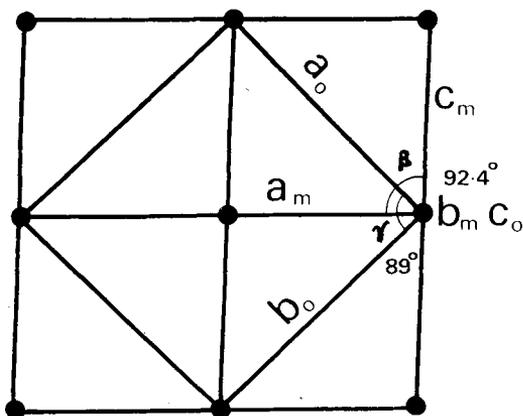


FIG. 2. The relationship between the Kraus's pseudo-orthorhombic (*o*) C-faced-centred cell and the primitive monoclinic (*m*) unit cell of Fischer and Kuzel.

parallel to (001) and (010) were examined by the universal stage to locate the cleavage and composition planes, twin axis, and optical orientations of the individuals in the twinned crystals.

**Morphology.** Marignac (1845) interpreted the crystals as tetragonal bipyramids, with angles 'sur les arêtes de la base  $92^{\circ} 30'$ , sur les arêtes culminantes  $118^{\circ} 30'$ ', but notes that these angles are very variable— $89^{\circ}$  to  $93\frac{1}{2}^{\circ}$  and  $117^{\circ}$  to  $122^{\circ}$  (these are, of course, the supplements of the face-normal angles).

Lasaulx (1879), Des Cloizeaux (1883), and Rinne (1889) examined sections made both perpendicular and parallel to the pseudo-tetragonal axis in polarized light. Rinne showed that sections normal to the pseudo-tetragonal axis are divided into four sections, presenting the same optical properties as are found in the present study for sections normal to the *b*-axis established by the X-ray data (fig. 4); Rinne took the pseudo-tetragonal axis as [001], the crystals being interpenetration twins on the near-rectangular prism {110}. He presumed the faces developed to belong to the form {011}, and found  $2V_{\alpha} 82^{\circ}$  for Na-light. Calculations show Rinne's form {011} to be {043} and his (043) equivalent to  $(\bar{2}32)$  of this study.

The present study shows that the pseudo-tetragonal octahedron consists of four faces of the form  $\{232\}$  and four of its twin  $\{\bar{2}\bar{3}\bar{2}\}$  around the normal to (100). The calculated angles  $(232):(232)$ ,  $88^{\circ} 18'$ , and  $(\bar{2}\bar{3}\bar{2}):(\bar{2}\bar{3}\bar{2})$ ,  $90^{\circ} 42'$ , are clearly Marignac's  $86\frac{1}{2}^{\circ}$  to  $91^{\circ}$ , while the calculated angles  $(232):(\bar{2}\bar{3}\bar{2})$ ,  $61^{\circ} 35'$ , and  $(232):(\bar{2}\bar{3}\bar{2})$ ,  $57^{\circ} 34'$ , are Marignac's  $63^{\circ}$  to  $58^{\circ}$  (fig. 3). The calculated angle  $(232):(\bar{2}\bar{3}\bar{2})$ ,  $2^{\circ} 6'$  corresponds with  $1^{\circ}$  to  $3^{\circ}$  observed by Streng (1874) and  $3^{\circ} 19'$  observed by Seligmann

(1877). The transformation from the Marignac/Rinne setting to the present setting is  $\frac{1}{2}0/001/\frac{1}{2}10$ , and the reverse is  $202/202/020$ , i.e.  $101/101/010$ .

**Cleavage.** The gismondine cleavage is reported to be parallel to the general crystal form {111} (Kalb, 1932) or {101} (Winchell and Winchell, 1964). It is not clear how Kalb arrived at the form {111} since his axial ratios imply the prismatic form. Winchell and Winchell give properties of both monoclinic and orthorhombic systems and it is impossible to say whether one or the other is implied. In the present study two nearly orthogonal cleavages were noted. Both are poor and their intersection line makes an angle of about  $5^{\circ}$  with the  $\gamma$  vibration direction which lies in the obtuse angle  $\beta$ ,  $\gamma:[001] = 42.5^{\circ}$ . On the gismondine stereogram the poles of these cleavages correspond with the poles of the  $(\bar{2}32)$  and  $(\bar{2}\bar{3}\bar{2})$  planes, therefore the cleavage is parallel to the general crystal form  $\{232\}$ .

**Twinning.** Gismondine has interpenetrant twinning, which is best seen in sections parallel to (010) (fig. 1b). These sections show four segments united along two discontinuous, zig zag planes at  $92.5^{\circ}$  to each other. The diagonally opposite segments are optically alike and the two segment pairs extinguish about  $5^{\circ}$  apart. Both pairs are bisected by the  $\alpha$  vibration directions, which in quadrants A and B' (fig. 4) are at  $85^{\circ}$  to each other since in quadrant A  $\alpha:[001] = 47.5^{\circ}$ . The  $\beta$  vibration direction, common to all the segments, is normal to the

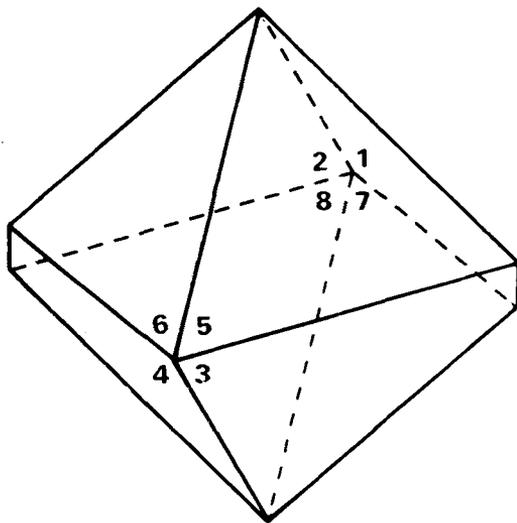


FIG. 3. Idealized drawing of a crystal of gismondine showing the form  $\{232\}$  (faces 1, 2, 3, 4) and its twinned equivalent form  $\{\bar{2}\bar{3}\bar{2}\}$  (faces 5, 6, 7, 8).

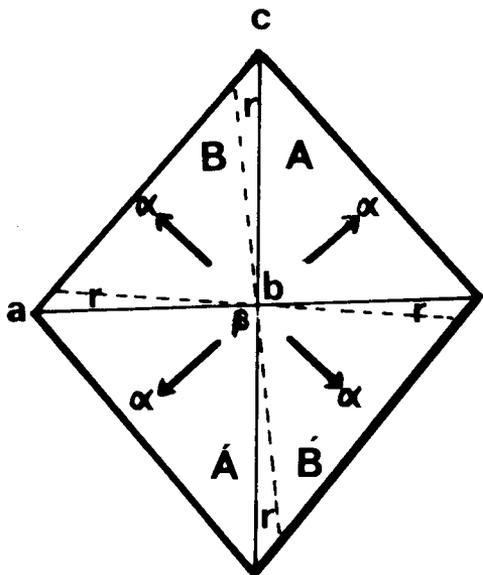


FIG. 4. Orientation in an (010) section of twinned gismondine. The segment pairs  $A-A'$  and  $B-B'$  extinguish  $5^\circ$  away because  $\alpha:[001]$  in the two pairs is  $47.5^\circ$  so that  $\alpha_A:\gamma_B = 5^\circ$ . The small segments ' $r$ ' have the same orientation as  $B-B'$  except for extinction at a small angle.  $\beta$ , common to all segments, is normal to the section.

section (fig. 4). With composition planes vertical, rotation on the outer E.-W. axis of the universal stage produces the same polarization colours in all the segments therefore twins are normal. The segment pair ( $A-A'$ ) occupying the acute angle has uniform extinction but the other pair ( $B-B'$ ) contains two other segment pairs ( $r$  in fig. 4) and has an over-all patchy extinction. Twinning occurs on the normal to  $\{100\}$  and composition planes are approximately parallel to  $(100)$  and  $(001)$ .

**Mechanism of twinning.** The penetration twinning of gismondine is similar to that of gypsum and albite (Donnelly, 1967), which form fourlings seen respectively on  $(010)$  and  $(100)$ . The gismondine twinning is related to its growth characteristics. It has been observed (fig. 1a) that gismondine grows preferentially along the  $[101]$  direction, which is also the direction of the acute bisectrix  $\alpha$ . This explains the length-fast character of the gismondine radiating aggregates (Walker, 1962, p. 190). It has already been stated that the faces developed in this direction belong to the form  $\{232\}$  (fig. 5). Growth in the other two quadrants starts around nuclei that are in twinned orientation with respect to the untwinned crystal and which subsequently coalesce into optically and crystallographically continuous twinned quadrants.

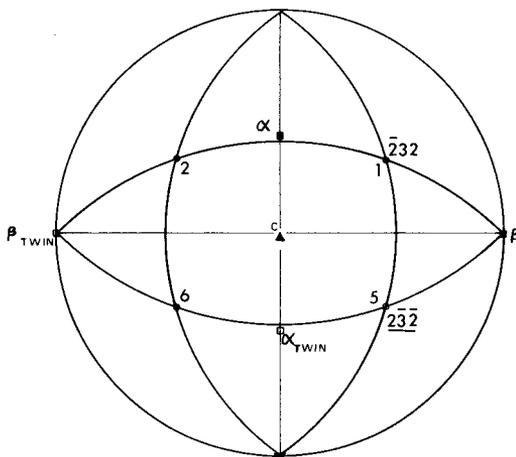


FIG. 5. Stereographic projection showing morphology, cleavage, twinning, and optical orientation of the twinned crystals of gismondine. Numbers 1, 2, 5, 6 represent poles of faces (fig. 3) and poles of cleavages (upper hemisphere only). Outer triangle is twin axis and central triangle marks the location of the pole to  $(001)$ .

The reason for this twinning may be seen from the structure of gismondine (Fisher, 1963) projected on  $(010)$  (fig. 6). Penetration twinning on the normal to  $\{100\}$  introduces a mirror plane parallel to  $(100)$  and a glide plane parallel to  $(001)$ . Across the mirror plane the adjacent segments may therefore be considered as reflection twins. Some adjustment of the structure must take place during uniting along the composition planes and during coalescence of the twinned nuclei, hence the patchy extinction of the twinned quadrants and development of segments ( $r$ ).

The optical orientation of gismondine is:  $\beta||[010]$ ,  $\gamma:[001] = 42.5^\circ$  in the obtuse angle  $\beta$ ;  $2V_x = 86^\circ$ .

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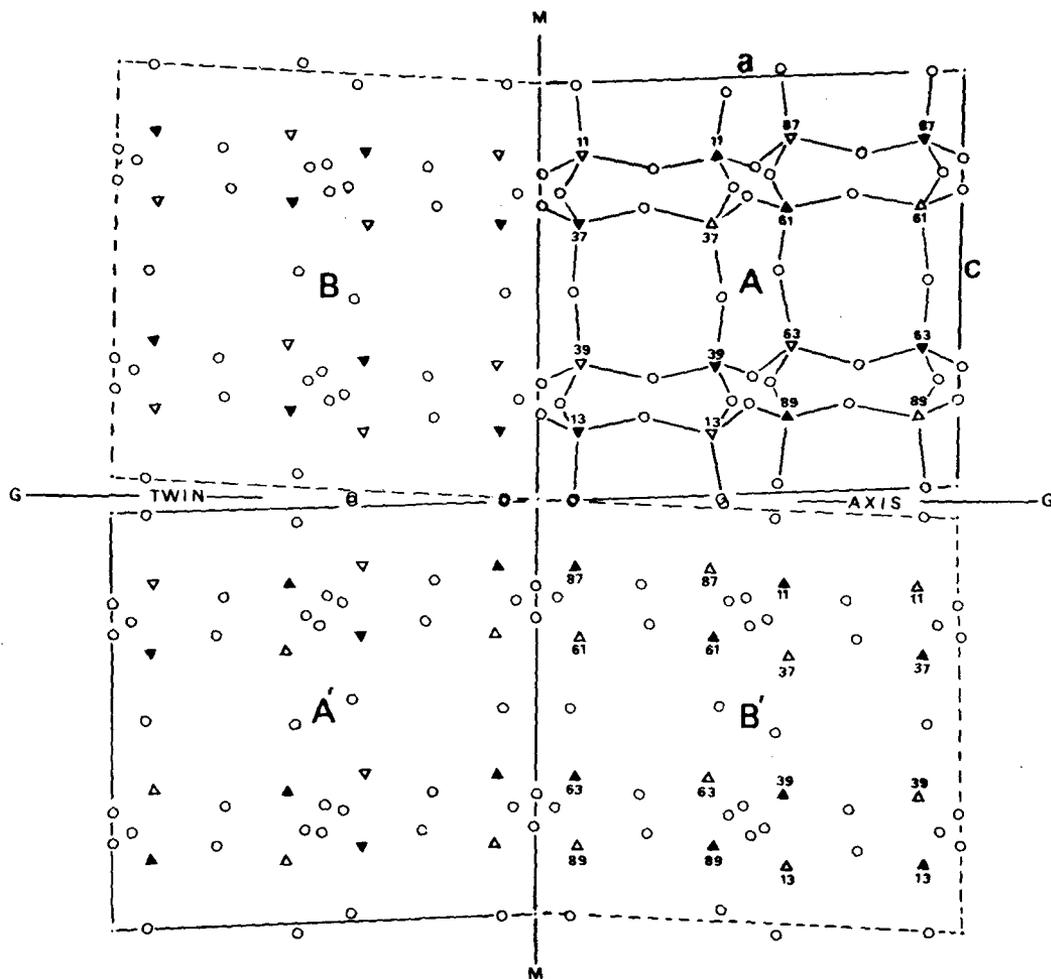


FIG. 6. The (010) projection of the gismondine structure ( $A-A'$ ) after Fischer (1963). Twinning on  $\{100\}$ , twin axis  $[\perp(100)]$ , produces twinned structure  $B-B'$ , united to  $A-A'$  along (100) and (001) planes—which respectively become mirror ( $MM$ ) and  $b$ -glide ( $GG$ ) planes of the twinned crystals. Silicon, solid triangles; aluminium, open triangles; oxygen, open circles. Heights along the  $b$ -axis of silicon and aluminium atoms across the two  $c$ -glide planes at heights 25 and 75 in the plane of the page are shown as percentage of the  $b$ -axis repeat period.

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