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TWINNED HAMBERGITE FROM THE GILGIT DISTRICT, NORTHERN PAKISTAN

R. PETER RICHARDS

Water Quality Laboratory, Heidelberg College, 310 East Market Street, Tiffin, Ohio 44883, U.S.A.

ABSTRACT

Hambergite crystals from a locality in northern Pakistan occur attached to elbaite, and show two different habits on the same specimen. Neither habit has been previously described. Crystals of the first habit are twinned by reflection on {110} and consist of plates flattened parallel to the twin plane, and bounded by {001}, {100}, {010}, {210}, {110}, and {341}. Crystals of the second habit, including the main crystal on the specimen, are also twinned and have a conspicuously hemimorphic habit. They are double twins by reflection on {110}, composed of a large central crystal in twinned relationship to two platy crystals, one on each side. Twin boundaries are marked by re-entrant grooves, and by optical discontinuities observable even in unpolarized light at low magnification under a binocular microscope. The forms present include those on the platy twins, plus {241}. The difference between the two habits results from differences in the effect of twinning on crystal growth in the presence of one or two twin planes. The observed hemimorphy is a property of the twinned aggregate, and does not call into question the holohedral symmetry of untwinned hambergite.

Keywords: hambergite, twinning, crystal morphology, Gilgit, Pakistan.

SOMMAIRE

Des cristaux de hambergite provenant d'un gisement du nord du Pakistan, près de Gilgit, se trouve attaché à l'elbaïte, et montre deux morphologies distinctes sur le même échantillon. Ni l'une, ni l'autre de ces morphologies n'avait été décrite auparavant. Les cristaux dans le premier cas sont maclés par réflexion sur {110} et sont faits de plaquettes parallèles au plan de macle, delimitées par les formes {001}, {100}, {010}, {210}, {110}, et {341}. Les cristaux ayant le second habitus, y compris le cristal le plus imposant de l'échantillon, sont aussi maclés, et possèdent une morphologie hémimorphique évidente. Ils sont doublement maclés par réflexion sur {110}, et comportent un gros cristal central en relation de macle avec deux cristaux en plaquette, un de chaque côté. Les interfaces entre les macles se manifestent par des rayures rentrantes, et par des discontinuités optiques observables même en lumière non polarisée à faible grossissement, avec un microscope binoculaire. Les formes présentes sont celles qui figurent sur les macles en plaquettes et, en plus, {241}. La différence entre les deux habitus résulte des différences dans l'influence du maclage sur la croissance cristalline, soit qu'il y ait un ou deux plans de macle. L'hémimorphie observée serait une propriété des agrégats maclés, et ne remet aucunement en question la symétrie holoédrique de la hambergite non maclée.

(Traduit par la Rédaction)

Mots-clés: hambergite, maclage, morphologie, cristaux, Gilgit, Pakistan.

INTRODUCTION

Hambergite is a rare beryllium borate, $Be_2(BO_3)(OH,F)$, found in syenitic and granitic pegmatites. It is orthorhombic, with space-group symmetry *Pbca* (Zachariasen 1931, Zachariasen *et al.* 1963) and unit-cell parameters *a* 9.776, *b* 12.194, *c* 4.430 Å for nearly pure OH end-member crystals (Himalaya mine, San Diego County, California: Burns *et al.* 1995). Although it may show hemimorphic development, several independent studies indicate holohedral symmetry (point group 2/*m* 2/*m* 2/*m*). According to Palache *et al.* (1951), hambergite crystals are usually prismatic, with longest dimensions parallel to the *c* axis, and its {100} faces are typically striated parallel to the *c* axis. Hambergite has perfect cleavage on {010} and good cleavage on {100}. Crystals may be twinned on {110} (Drugman & Goldschmidt 1912, Switzer *et al.* 1965).

Recently, twinned crystals of hambergite with two unusual habits were found in northern Pakistan, reportedly at Stak Nala along the Skardu Road in the Gilgit District. These twins of hambergite are attached to prisms of tricolored elbaite. Both minerals are partially coated with white fine-grained borian muscovite in vermiform crystals and anhedral masses. This assemblage is consistent with formation in a pocket environment in a granitic pegmatite.

The morphology of these hambergite twins is not similar to any shown in Goldschmidt (1918) or described in the more recent literature, nor is it similar to other Pakistani specimens that dealers have seen. The purpose of this note is to describe these new habits of twinned hambergite.

MATERIALS

One specimen was available for study; on it, a large hambergite crystal (25 mm long) is attached to an elbaite crystal (Figs. 1, 2). This crystal is hemimorphic and prismatic with pyramidal modifications. Much of the surface is coated with an aggregate of white vermiform mica crystals, which partly encrust both the tourmaline and the hambergite. Some of the mica has been scraped away to show the major minerals to better advantage, but differences in surface luster indicate that some portions of the major crystals were never covered. About a dozen additional small hambergite crystals, not exceeding 2 mm in maximum dimension, were discovered during examination of the specimen under low magnification (20×). These are mostly or completely embedded in mica. Several of these have the same morphology as the large hambergite crystal (hereafter called H1 for "Habit 1"), but the rest have a different, platy morphology (H2, see Fig. 3). All crystals of both habits appear to be twinned.

METHODS

The hambergite crystals were examined under low magnification using a binocular microscope. Selected small crystals were removed from the specimen and examined with a petrographic microscope under crossed polarizers to identify the presence of twinning. The identity of crystals of both habits was confirmed by X-ray examination. A small quantity of the mica also was removed and submitted for X-ray identification. X-ray analysis was done with a Guinier–Hägg focusing camera and Cu$K\alpha_1$ radiation with synthetic spinel as an internal standard. Cell parameters were refined using the program of Appleman & Evans (1973), as modified by Garvey (1986).

Twinning was initially assumed to be on {110}, as reported in the literature. This assumption was validated by comparisons of calculated and measured interfacial angles across twin boundaries.

The small H1 crystal was mounted with its end face parallel to the stage of the petrographic microscope, and the presence of two twin planes was revealed by examination under crossed polarizers. The angles between extinction directions across the twin planes were measured, as were angles between twin planes, crystal faces perpendicular to the microscope stage, and internal cleavage cracks. The same crystal

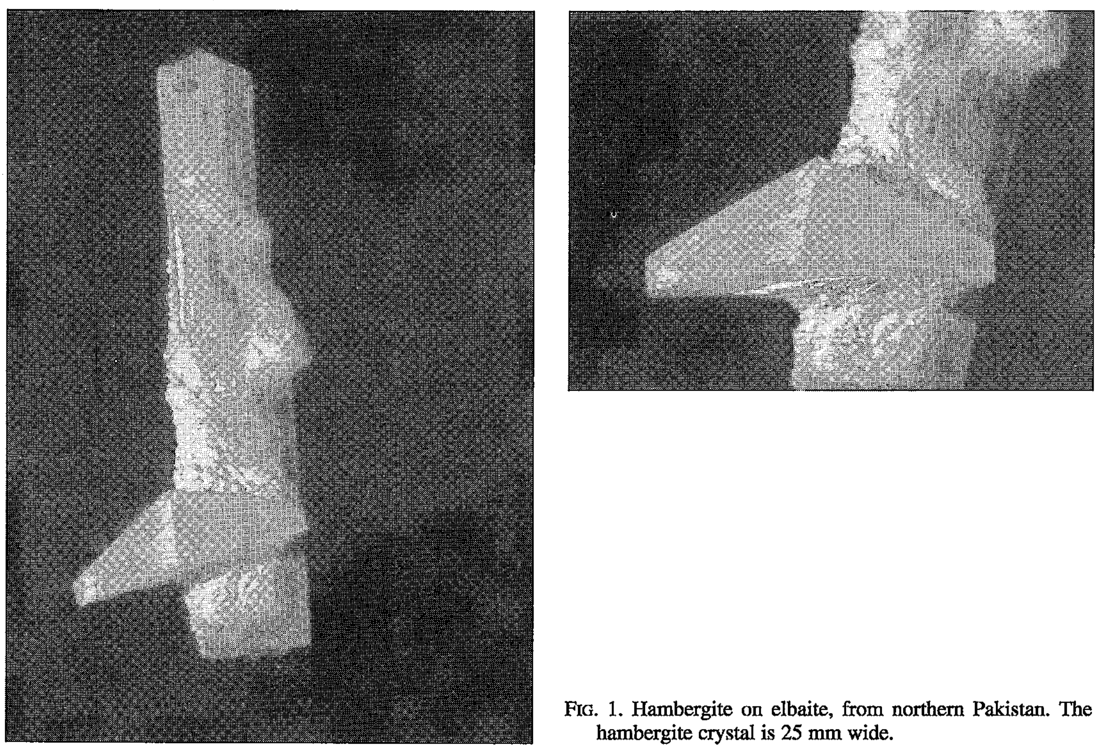


FIG. 1. Hambergite on elbaite, from northern Pakistan. The hambergite crystal is 25 mm wide.

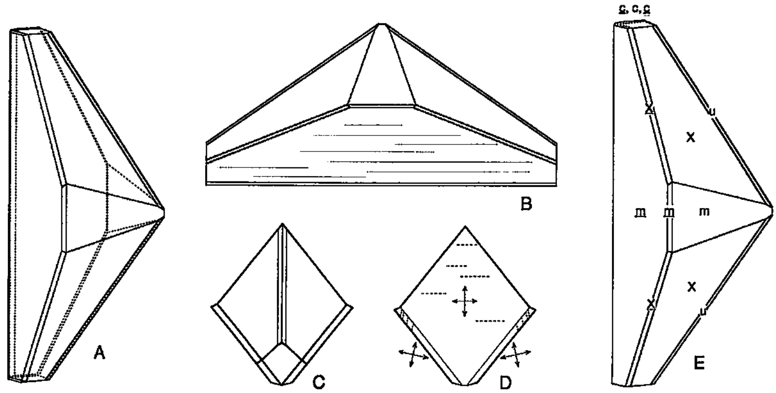


FIG. 2. Doubly twinned hambergite (H1). A. Clinographic projection in standard orientation. B. Orthographic projection with {010} of the large central individual parallel to page and [001] horizontal, indicating the orientation of striations. C. Orthographic projection, rotated 90° about the vertical axis of the page relative to B, showing the morphology of the end of the crystal and the shape of the cross-section. D. Cross section in same orientation as C, showing location of twin planes and orientation of extinction directions and cleavages. E. Forms shown are c {001}, m {110}, and u {241}.

was measured with a two-circle optical goniometer, and the faces present were determined by comparing the stereographic projections of the measured crystal with those of morphological interpretations constructed using SHAPE (Dowty 1980).

No H2 (platy) crystals appropriate for goniometric study were available, so an initial morphological interpretation was based on comparisons with the measured H1 crystal. An incomplete H1 crystal was mounted with one of the large faces parallel to the stage of the petrographic microscope, and angles defined by edges of the face were measured to help

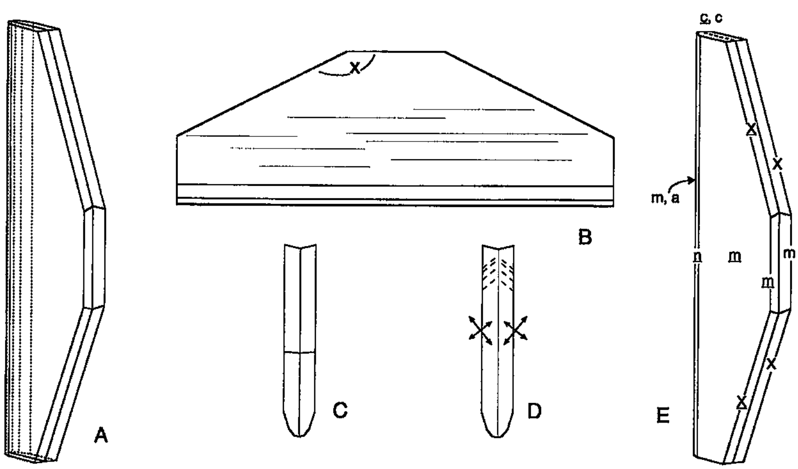


FIG. 3. Singly twinned hambergite (H2). A. Clinographic projection in standard orientation. B. Orthographic projection with twin plane parallel to page and [001] horizontal, indicating the orientation of striations. C. Orthographic projection, rotated 90° about the vertical axis of the page relative to Fig. 2B, showing the morphology of the end of the crystal and the shape of the cross-section. D. Cross-section in same orientation as C, showing location of twin plane and orientation of extinction directions and cleavages. E. Forms shown are a {100}, c {001}, m {110}, n {210}, and X {341}.

establish the identity of the faces involved in the angle. The same crystal was mounted on its end face, perpendicular to the twin plane, and the angle between extinction directions in each sector of the twin was measured to confirm the twinning relationship. The angle between internal cleavage cracks and the large face also was measured. These angles were compared with corresponding angles calculated from the morphological interpretation using SHAPE, to confirm the validity of the interpretation.

Results

X-ray examination shows that crystals of both habits are hambergite. Refined cell parameters based on 16 indexed powder-diffraction lines are *a* 9.7343(53), *b* 12.1837(74), *c* 4.4350(13) Å (Robert F. Martin, pers. comm., 1995). The cell parameters *a* and *c* are consistent with the replacement of about 20% of the OH with F, using the relationships determined by Burns *et al.* (1995). For reasons that are not clear, the *b* parameter is indicative of no F substitution for OH.

A successful unit-cell refinement of the mica based on 18 indexed lines shows that it is a borian muscovite, $2M_1$ polytype, with cell parameters *a* 5.1218(11), *b* 8.8652(22), *c* 20.0125(24) Å, and β 94.460(47)°. A small amount of the *1M* polytype also may be present.

All hambergite crystals of both habits examined under crossed polarizers are reflection twins, and have one or more clearly visible contact planes. The strong similarity in habits between these and the crystals remaining on the specimen, together with features observable under the binocular microscope, such as re-entrant angles, internal cleavage cracks, and internal optical discontinuities across twin boundaries, demonstrate that all crystals on this specimen are twinned.

All twins have a pair of well-formed large faces that are oriented parallel to a twin plane and are striated parallel to the longest dimension of the twin. All crystals of both habits have small faces (the "end faces" referred to above) that are perpendicular to the striated faces, the twin plane(s) and the perfect {010} cleavage. Assuming that the twin plane(s) belong to {110}, they intersect the perfect cleavage along [001]. Since the small end faces are perpendicular to all these planes, they are also perpendicular to their intersection; therefore, the end faces belong to {001}. The striated faces belong to {110}, and the striations are parallel to [001], as reported in the literature.

All twins are hemimorphic, but the hemimorphy is much more conspicuous in H1 twins than in H2 twins. Hemimorphy is strictly a consequence of twinning, and does not call into doubt published studies indicating that single crystals of hambergite have holohedral orthorhombic symmetry.

Crystals of habit H1

The small H1 twin, mounted on a {001} face and examined under a petrographic microscope with crossed polarization, is clearly a double twin. The twin consists of three individuals, a relatively blocky central individual flanked by two platy individuals, with different directions of extinction (Fig. 2). The angles between extinction directions in the central and side crystals measure 76° and 80°. The angle between the twin planes measures 76.5°. In addition to internal traces of the {010} cleavage, a few traces of the poor {100} cleavage are present. Both twin planes and all internal traces of both cleavages in all three individuals are perpendicular to the stage. Thus both twin planes must be in the [001] zone. The angles between extinction directions across the twin planes compare well with the calculated angle across (110), 77.2°. The angle between the twin planes compares well with the calculated angle between (110) and ($\bar{1}$10), 77.2°, but not with that between (110) and (1$\bar{1}$0) (102.8°), and indicates that the twin planes are symmetrical about (100) rather than about (010). This observation is consistent with the orientation of the {010} cleavage relative to the twin planes (Fig. 2D).

H1 twins show pronounced hemimorphic symmetry. The left half (as drawn in Fig. 2A) is composed of a pair of {110} faces that belong to the platy individuals and are parallel to the respective twin planes. These faces converge at the left edge of the twin, making an angle less than 90° with each other, and are lightly striated parallel to [001]. The right half of the crystal consists of four symmetrically equivalent, somewhat curved faces of a dipyramid, and two smaller triangular faces that belong to an {*hk*0} prism. All of these faces belong to the central individual. The top and bottom ends of the twin are truncated by small, flat faces of {001} shared by all three individuals.

Narrow re-entrant grooves occur along the edges where the platy individuals meet the central individual (Fig. 2C). The bottom of each groove is the intersection of the twin plane with the surface (Fig. 2D). The twin planes, conspicuous under crossed polarizers, are faintly visible in unpolarized light under the binocular microscope as optical discontinuities, if one looks into the crystal through the {001} end faces.

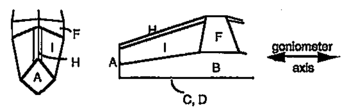
Along the left edge of the twin (Fig. 2A) are a few small flat-bottomed chips that reflect the perfect (010) cleavage of hambergite. Planar cracks in the interior of the aggregate are parallel to the cleavage surfaces present in the chips, and show that the chipped portion belongs to the central individual.

The same twin was measured on a Stoe two-circle optical goniometer. Because of its small size, many faces on this twin do not give a reflected light figure; these faces were brought into position for measurement by direct observation of the light reflected from the

TABLE 1. GONIOMETRIC MEASUREMENTS ON DOUBLY-TWINNED HAMBERGITE*

Face type	rho	phi	Quality of reflected light figure
A	0°	—	Centered at rho=0° ± 8'; very faint reflected light figure
B	90°	230°	Faint reflected light figure smeared out along phi
B	90°	130°	No reflected light figure
C	90°	145°	No reflected light figure
C	90°	213°	No reflected light figure
D	90°	166°	No reflected light figure; not in sketch
E	90°	358°	No reflected light figure; not in sketch
F	90°	50°	Reflected light figure very faint but of good quality
F	90°	307°	Good reflected light figure
G	90°	332°	No reflected light figure. Reflections from re-entrant groove by F
G	90°	25°	No reflected light figure. Reflections from re-entrant groove by F
H	60°	31°	Very faint reflected light figure
H	60°	326°	No reflected light figure
I	63°30'	42°20'	Moderately blurred reflected light figure from near top of this curved face
I	63°20'	314°40'	Moderately blurred reflected light figure from near top of this curved face

sketches of the crystal for identification of faces:



*Phi corrected to align center individual so that faces of f, i, and h are approximately symmetric about phi=0. Letters assigned to faces are for bookkeeping during goniometry only, and are not intended to imply Miller indices.

face into the viewing telescope. This method leads to measurements that are reproducible only to about ±1°, as opposed to the ±4′ accuracy provided by the reflected light figure. Many of the more important faces yielded reflected light figures, and could be measured more accurately (Table 1).

The forms present on the twin were established by comparing the stereographic projection of the measurements with stereographic projections of forms chosen using the observations above, forms reported in the literature, and experimentation using SHAPE in which proposed Miller indices were adjusted iteratively to bring the stereographic projections more nearly into coincidence. The results are listed in Table 2 and shown in Figure 2E.

In Figure 4, the stereographic projection of the measured twin is shown using filled circles to mark the poles of the faces. The poles of the faces of the final model for the twin are marked with larger open circles. The two projections are very similar, and agree sufficiently closely that the model can be accepted as valid.

TABLE 2. MILLER INDICES FOR FORMS ON DOUBLY-TWINNED HAMBERGITE *

Form letter	Miller indices	Face designation for goniometry (Table 1)
a	1 0 0	D
b	0 1 0	E
c	0 0 1	A
m	1 1 0	F, B, G
n	2 1 0	C
u	2 4 1	H
X	3 4 1	I

* Underlined forms were measured on the platy side crystals; the rest were measured on the large central crystal. Form letters follow the usage in Palache *et al.* (1951) and Switzer *et al.* (1965).

Crystals of platy habit H2

Twinning is easily detected by petrographic examination of these crystals under crossed polarizers. A single twin-plane is parallel to the large striated {110} faces. No evidence of polysynthetic twinning or of complex composition-surfaces was seen. On a fragment of a platy twin oriented with {110} parallel to the stage, extinction directions are parallel and perpendicular to the striations, and the angle x (Fig. 3B) measures 155°. With the same fragment oriented with {001} parallel to the stage, extinction in each member of the twin is inclined 38° to the twin plane (Fig. 3D).

Twinning is revealed on the surface of the crystal by the presence of a re-entrant groove (along the right edge of the crystal in Fig. 3A). The interfacial angle between the faces in the re-entrant groove was estimated at 30° by examination using a binocular microscope. Facets of the {010} cleavage occur in chips along the sharp edges between the large flat faces and the re-entrant groove; they have the orientation shown in Figure 3D.

Assuming that the twin plane is {110}, these observations are sufficient to establish the forms shown in Figure 3E. The secondary faces belonging to {110}, {210}, {010}, and {341} were identified by comparison with corresponding faces on the indexed double twin, and checked for reasonableness against the observations above. The angle between the {010} cleavage and the {110} twin plane is calculated to be 38.6°, the re-entrant angle is calculated to be 25.6°. The angle x, measured on a SHAPE drawing with the twin plane parallel to the plane of the paper, is 153.3°. These results are all in good agreement with the observations.

Discussion

Both of the habits of hambergite described in this paper are hemimorphic, which is inconsistent with the reported symmetry of hambergite. The presence of twinning on {110} is sufficient to explain the hemimorphy of the twinned aggregates. A contact twin on {110} has aggregate symmetry $2mm$, and only the mirror plane perpendicular to the c axis coincides with

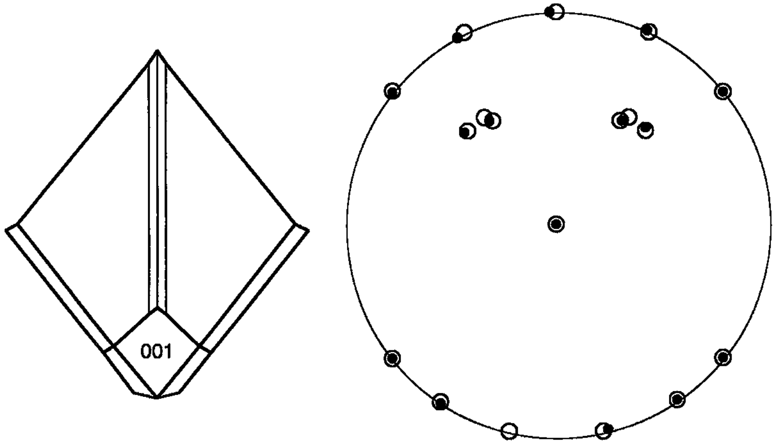


FIG. 4. Goniometric projections of a measured crystal and a morphological interpretation generated using SHAPE. The crystal at left is in the same orientation as the stereographic projection: both the viewing axis and the projection axis are normal to the pinacoidal face {001}. Plotting positions of measured faces are shown using small filled circles, and those of faces on the model crystal are shown using larger open circles.

a symmetry element of the untwinned crystal. Thus the hemimorphic nature of these twins does not contradict the holohedral symmetry of untwinned hambergite.

The two habits of twinned hambergite are strikingly different from each other. This might be explained as a consequence of two generations of growth, but the paragenesis suggests that twins of both habits grew simultaneously. Furthermore, twins of each habit share a common element of identical morphology: the platy crystals, which flank the prismatic twin and comprise the platy twin.

The different habit of single and double twins on this specimen attests to the power of twinning to affect crystal morphology. It is well known that new layers of growth are nucleated in the re-entrant angles created by twinning (Henderson 1983, Hartman 1955), causing the faces in the notch to grow faster than those elsewhere, even faster than other faces of the same form. This growth advantage conferred by twinning often results in twins being larger than untwinned crystals on the same specimen. It also accounts for the distortion in habit that accompanies twinning, of which typical Japan law twins of quartz and butterfly twins of calcite (contact twins on $\{01\bar{1}2\}$) are well-known examples.

In the case of the platy twins of hambergite, the effect of this differential nucleation of growth layers is to accelerate growth on faces that intersect the twin plane, leading to the platy habit. In the prismatic double twins, the same process accounts for the platy flanking individuals. However, the individual in the middle gains a symmetrical growth-advantage from twin planes on each side, and the geometry of the configuration allows this central individual to capture most of the mass of deposited material.

Comparisons with hambergite crystals from other localities

Kazmi *et al.* (1985) described hambergite from Stak Nala, Gilgit District, Pakistan as occurring in two habits: tabular with the pinacoids {100}, {010}, and {001} dominant, and dipyramidal with {111} dominant and with common twinning. A photograph shows the tabular crystals to be quite platy but provides no details; no photographic documentation was given for the dipyramidal habit. No measurements or drawings were given to document the morphology, and the twin law was not described. It is possible that the two habits referred to are the same as those described above, but only if their morphological analyses are entirely wrong. In the absence of more complete information, it must be assumed that the habits described in Kazmi *et al.* are different from those described in this paper.

Goldschmidt (1918) illustrated hambergite crystals from Norway and from several localities in Madagascar. The crystals are all prismatic, and most are elongate along [001]. No habit illustrated resembles those described here. One twin on {110} is illustrated, but no pronounced distortion due to twinning is apparent.

Świtzer *et al.* (1965) illustrated crystals from the Little Three mine, Ramona, and from the Himalaya mine, Mesa Grande, both in San Diego County, California. All illustrated crystals are prismatic and show no similarity to the habits described here, although the form {341} is present on some of their crystals from both localities. Contact twins on {110} were reported but not described.

Marcusson (1985) illustrated a hambergite crystal from the Himalaya mine as a drawing traced from a photograph. No morphological information is given, but the drawing shows portions of prism and dipyramid faces and possible traces of {010} cleavage on the surface of the dipyramid faces. If the long direction of the crystal is taken to be parallel to the *c* axis, it bears some similarity to the prismatic habit described above, but has a somewhat steeper dipyramid (approximately {561}) and lacks the twinning that characterizes the material described in the current paper.

Hambergite is not a common mineral, published morphological descriptions are uncommon, and some are quite incomplete or qualitative. This makes morphological comparisons difficult. Given the descriptions available in the literature, however, the habits of twinned hambergite described here from northern Pakistan appear to be different from any previously described.

Conclusions

Hambergite from the Gilgit District, Pakistan, occurs as twinned crystals with two different hemimorphic habits that have not been previously described. Both habits involve contact twinning on {110}. The hemimorphy is a consequence of the contact twinning, and does not contradict the holohedral symmetry previously determined for hambergite. Platy H2 twins are composed of two individuals, whereas twins of the more prismatic H1 habit are composed of three individuals: a large central individual twinned to platy individuals on each side, by reflection on (110) and ($\bar{1}10$) or, equivalently, ($1\bar{1}0$) and ($\bar{1}\bar{1}0$). The habits differ from each other because of the different influence of the twin plane on crystal growth, depending on whether one or two twin planes are present.

Acknowledgements

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