MAKING CRYSTAL MODELS

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Abstract

Simplified directions are given based on the gnomonic projection for preparing a net to make hollow models of crystals from Bristol board, etc. The procedure is illustrated by detailed descriptions for making chrysolite and orthoclase models. It could be adapted easily to the making of mine or structure models.

In the study of morphological *crystal*lography (as contrasted to "*model*lography") it is customary for the student to prepare plan and perspective drawings, as well as to calculate the various crystal constants. In some cases this work is further supplemented by cutting a solid model.[1] The necessary apparatus to carry out this operation is rather costly. The writer has found that the preparation of a model made of Bristol board is not only a satisfactory substitute as regards the final result, but no expensive machinery is required and the process is valuable from the pedagogic point of view in clarifying in the student's mind the principles of crystal drawing. Moreover a collection of such models whose greatest dimension is 8 to 10 inches is a valuable asset for teaching purposes.

The plan neeeded to prepare a hollow model made of paper, cardboard, glass, cellulose acetate, etc., can be obtained easily from the face-poles of the standard equator gnomonic projection of the crystal. In what follows it is assumed that the reader is familiar with this projection and the method of making ordinary crystal drawings from it.[2] In this projection, planes (faces) are represented by points (face-poles) where lines normal to them from the center of the sphere (which coincides with the point of intersection of the crystal axes) pierce the projection plane. A crystal face might also be represented in this projection plane as a line formed by the intersection of the two planes, providing the face is considered to be moved parallel to itself until it intersects the center of the

[1] Goldschmidt, V., *Kursus der Kristallometrie*, 38–45 (1934).

Palache, C., and Lewis, L. W., A saw attachment: *Am. Mineral.*, **12,** 154–156 (1927).

Chace, A., and Kersten, H., Crystal models made on a milling machine: *Am. Physics Teacher*, **6,** 215 (1938).

[2] The method is very simply explained in the writer's article in the *Journal of Geology*, **32,** 538–542 (1924). Other elementary presentations in English include:

Porter, M. W., *Practical Crystal Drawing: Am. Mineral.*, **5,** 89–95 (1920) (reprinted in The Goldschmidt Two-Circle Method, 1921).

Barker, T. V., *Graphical and Tabular Methods in Crystallography*, 55–58 (1922).

Walker, T. L., *Crystallography*, 160–164 (1914).

McNabb, W. M., and J. W., Guide for crystal drawing: *Jour. Franklin Inst.*, **221,** 539–546 (1936).

sphere. Such a projection is called the euthygraphic projection.[3] It has advantages over the gnomonic projection where it is desirable to show direction,[4] since a line may be represented in the euthygraphic projection by a point made where the line (moved parallel to itself till it goes through the center of the sphere) cuts the projection plane. A gnomonic projection is easily converted to a euthygraphic projection; from any given face-pole (of known ρ-angle) drop a line through the center of the projection and locate a point on this line, the other side of the center at a distance from the center corresponding to an angle of $(90°-\rho)$. The gnomonic scales of the projection protractor[5] greatly facilitate the plotting of these distances. A perpendicular to this line through this point is the required euthygraphic projection of the face in question.

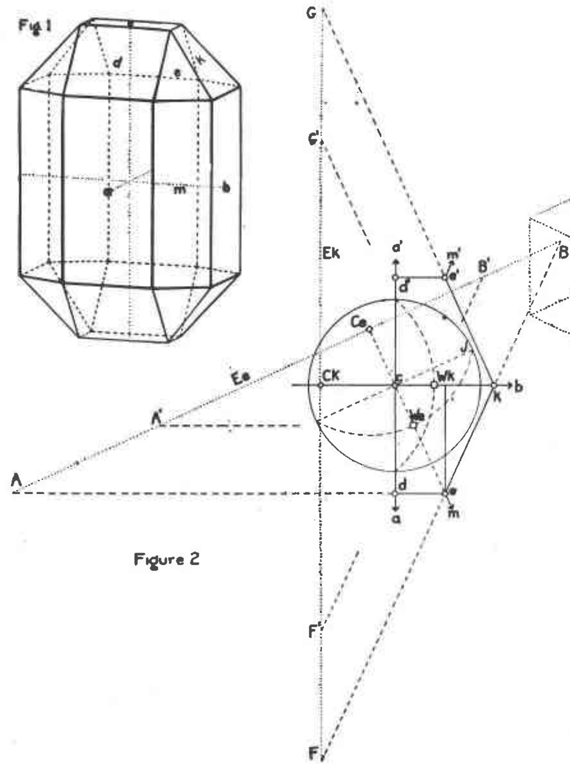
Suppose one wishes to prepare a model of the simple chrysolite crystal of Fig. 1 which has all the forms of the orthorhombic dipyramidal class. The gnomonic projection (gnomonogram) of a part of this crystal is shown by continuous lines in Fig. 2. The plan drawing on *c* of this crystal is given in Fig. 3 by dotted lines. The continuous lines of this figure depict the appearance of one face of each form assuming the crystal to be "unfolded" so that each face lies in the plane of the paper [(001) plane of the crystal]. To prepare this it is only necessary to remember that the guide line represents the trace of the picture plane in the gnomonic projection and that the line of sight is assumed to be perpendicular to the picture plane; that is, the perspective drawing made from the gnomonic projection is orthogonal, not clinographic. The object is to picture each face as it appears looking normal to it; in short, the plane of the crystal face is to coincide with (be parallel to) the picture plane in each case. Thus the guide line used in drawing any given face is the euthygraphic projection of that face.

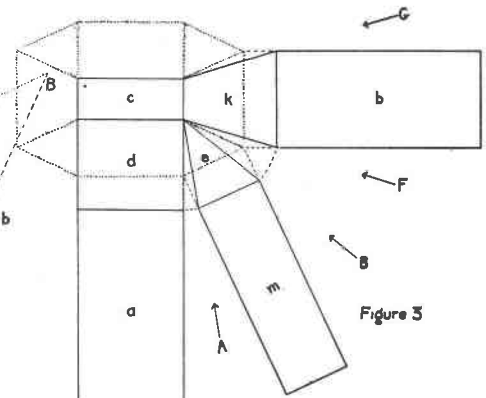
For drawing the *c* face then, since its pole is at the center of the primi-

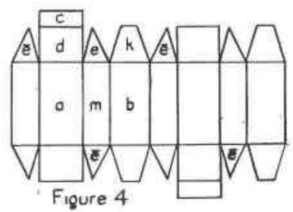
[3] This is the same as the linear projection of Fedorow. It is not to be confused with the linear projection of Quenstedt, in which the projection plane is likewise normal to the *c*-axis, but at a point equal to minus unity on this axis if the crystal face is supposed to cut the center of the axial cross (or the projection plane may be considered to lie at the axial intersection normal to the *c*-axis while the crystal face cuts plus unity on the *c*-axis).

[4] Of course a direction may be shown in the gnomonic projection as a point, but then one must distinguish between two kinds of points: one derived as a face-normal, the other as in the euthygraphic projection. The stereographic and cyclographic projections are analogous, and their uses in solving geologic problems have recently been described by the writer in *Bull. Am. Assn. Petr. Geol.*, **22** (9), 1261–1271 (1938). Also see "Drillhole Problems in the Stereographic Projection," *Econ. Geol.*, **36**, 551–560 (1941) and the reference of footnote 5.

[5] Fisher, D. Jerome, A new projection protractor: *Jour. Geol.* **49**, 292–323 (1941) and 419–442 (see especially 317–318). See note at end of this article.







FIGS. 1–4. Chrysolite
1. Perspective
2. Gnomonogram
3. Plan
4. Net

tive circle in Fig. 2, the picture plane is horizontal (normal to the *c*-axis), the guide line becomes a circle of infinite radius whose angle point (center of the fundamental sphere rotated about the guide line as an axis into the plane of the gnomonic projection) lies at *c*. In short, the *d* edge of face *c* (that edge on face *c* made by the intersection of the *d* and the *c* faces, Fig. 3) is obtained by extending *dc* of Fig. 2 to the guide line at *a* and joining the point thus located with the angle point at *c*. Then a normal to *ca* gives the desired direction. Thus the boundaries of the face are simply normals to *cd* and *ck* of Fig. 2, drawn as in Fig. 3 with edges of lengths proportionate to those on the crystal at any desired scale of enlargement. Where the plane of projection is parallel to the *c*-face (which it is not in the monoclinic and triclinic) the ordinary plan drawing and the net drawing coincide for the *c*(001) face.

To draw face *e* of Fig. 3, go 90° from face-pole *e* of Fig. 2 along the dashed line in the direction *ec* and establish the point *Ce*, the center of the dotted zone-line *Ee*. Then *Ce* is out from *c* by $r \tan(90° - \rho)$ of face-pole *e;* thus *Ce* is quickly located with the projection protractor.[6] *Ee*, the euthygraphic projection of *e*, is normal to *ce* and serves as the guide line in drawing face *e*. Establish its angle point *We* on the central *ce* by using the stereographic scale of the projection protractor, remembering that *c* to *We* in stereographic degrees equals *ce* in gnomonic degrees.[7] The direction of *A* of Fig. 3 is the *d* boundary of face *e* and is normal to a line (not drawn in Fig. 2) joining *A* and *We*. *A* of Fig. 2 is on *Ee* where a line through *de* cuts *Ee*.[8] Similarly *B* of Fig. 3, the direction of the *k* edge of face *e*, is normal to the line *B* to *We* of Fig. 2, in which *B* is on *Ee* where cut by *ek* extended. The other edge of *e* (Fig. 3) is normal the central *Ce* to *e* of Fig. 2, since *em* extended cuts *Ee* at *Ce* and *We* lies on this line. It is drawn at such a distance from the top vertex of the face *e* as to preserve the average dimensions of the crystal being reproduced, on the same scale of enlargment as already used in drawing face *c*. This means that it is of the same length as the corresponding edge shown by a dotted line in the plan drawing on (001).

The general rule for drawing the net plan of any crystal face is to find its guide line taken as its euthygraphic projection *E*. Considering this line as a zone line, determine its angle point *W*. Find the point where a

[6] Since *J* is the angle point for the line *ce*, if one has no projection protractor the point *Ce* may be located by laying off a normal to the line *eJ* at *J* (not drawn in Fig. 2).

[7] In the absence of a projection protractor, *We* may be located by striking a circular arc with center at *Ce* and radius *Ce* to *J;* note *J* is where a line through *c* parallel to *Ee* cuts the primitive circle.

[8] Where no faces parallel to the *c*-axis are involved, paper may be saved by establishing a point *A′* on *Ee* where a line parallel *de* through *We* cuts *Ee*, and taking for the required direction a line normal to *A′ c*.

line joining the gnomonic projection (face-poles) of the two crystal faces which make the edge in question cuts the guide line E. Lay a straightedge on this point and W and using a right-angle triangle obtain the normal which is the direction desired.

For face m the guide line runs through c normal to the m-arrow (e.g., it is cJ) and the angle point Wm (not indicated in Fig. 2) lies where this arrow cuts the fundamental circle. To get the e edge of m, note that a line through the e and m face-poles cuts this guide line at c; thus a normal to the m-arrow gives the desired direction, while lines parallel this arrow give the a and b boundaries of this face (this latter direction is normal to the guide line for the m face). The length of this face is made proportionate to the size of the face on the crystal as already outlined.

The a, b, d, and k faces are prepared in similar fashion, but the e length of the d face is made equal to the d length of the e face, and the length of the e edge of the k face is analogously determined, as shown by the two dashed-line circular arcs of Fig. 3 with centers at the top vertex of e.

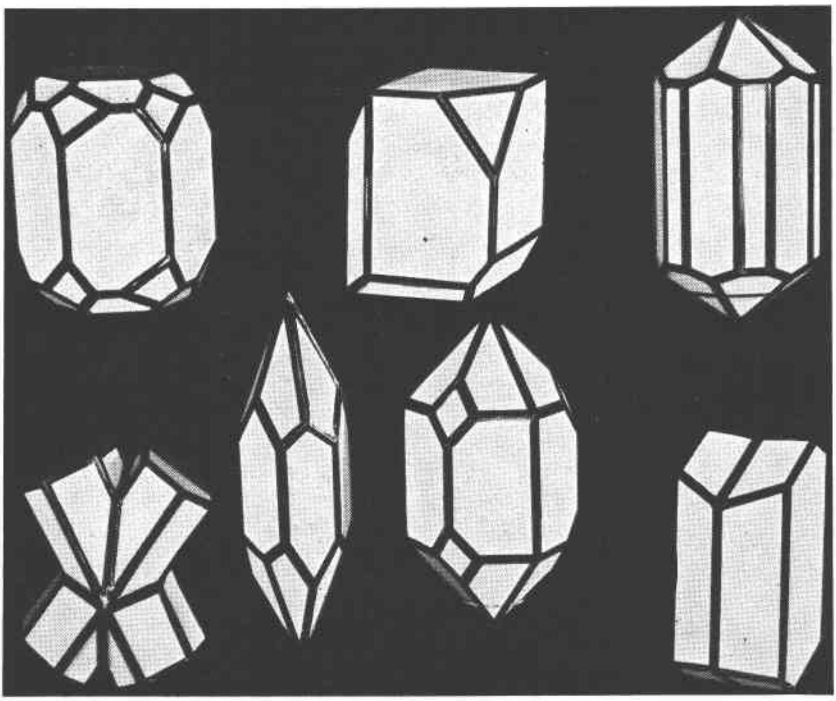


Fig. 9. Crystal Models. Vanadinite (C. G. Johnson), Kyanite (P. Herbert), Apatite (G. W. Sandberg), Staurolite (N. A. Riley), Calcite (A. Swineford), Quartz (G. Botero), and Albite (K. L. Cook).

The dashed lines continuing the edges of the [001]-zone (*m* and *b* faces in Fig. 3) make clear the relation between the plan drawing on *c* and the method of drawing here described.

To prepare the idealized model net shown in Fig. 4 a drawing is needed (in Fig. 3) for but one face of each crystal form present. This part of the task is relatively simple for a model of high symmetry consisting of but a single (closed) form. Place tracing paper over (or a sheet of wrapping paper under) Fig. 3 and with a needle prick through the corners of faces *c*, *d*, and *a*. Then move the tracing paper so that its *m* edge of *a* lies above the *a* edge of *m* of Fig. 3 and prick the corners for *e* and *m*. Proceed in similar fashion till all the crystal faces are outlined on the tracing paper. Note that the latter must be turned upside down in locating the vertex of the four faces marked $\bar{e}$ in Fig. 4. Now very carefully check the whole net for accuracy, using a T-square, right-angle triangle, and dividers or compass. Finally, place this over a sheet of Bristol board and prick all the corners through it and outline the net on the Bristol board with a sharp hard pencil as shown in Fig. 4.

The next four paragraphs are devoted to the technique of preparing a similar net for a monoclinic crystal. Following this, the method of fabricating a model from a net is described.

For the benefit of beginning workers the same method is applied to a slightly more complex case as is illustrated in Figs. 6, 7, and 8. The crystal is orthoclase from near Ontario, Oregon, collected by W. R. Lowell, perspective of which is given in Fig. 5, with forms $b\{010\}$, $c\{001\}$, $m\{110\}$, $y\{\bar{2}01\}$, and $o\{\bar{1}11\}$. The plan drawing on a normal to [001] is shown by dotted lines in Fig. 7; gnomonic and euthygraphic projections of one face of each form appear in Fig. 6. What follows is according to the rules given five paragraphs back. Let D of Fig. 7 which represents the highest point of the crystal (*c*-axis vertical) be common to the plan on the normal to [001] and the analogous point of the net pattern. Draw DA (the *o* edge of face *c*) of Fig. 7 normal to the line from A to Wc of Fig. 6. Ordinarily the *c*-face would be completed at this stage, as the general rule of finishing one face at a time is a good one. But since the length of AB [which $=AC=A'C'=A'B'/\cos(90°-\beta)=A'B'/\sin\ \beta$] is easily determined graphically from the length of AC, one side of the *b*-face, this latter face is completed first. From A' of the plan drawing of Fig. 7 draw $A'C'$ and $A'F'$ normal to the lines Wb to *c* and Wb to F respectively of Fig. 6, locating C' and F' of Fig. 7 by lines through B' and E normal to Eb of Fig. 6. Then in Fig. 7 draw AC and AF parallel and equal in length to $A'C'$ and $A'F'$, respectively. Draw lines normal to Eb of Fig. 6 through C and F of Fig. 7, making CG of length appropriate to the crystal, and complete face *b* by lines parallel and equal to AC and AF. Locate B by making AB equal in length to AC. Draw BH normal to the line H to Wc of Fig. 6 locating H directly below D (in a direction parallel the a-axis trace of Fig. 6), and complete face c of the net pattern of Fig. 7 by parallel and equal lines to the three already drawn.

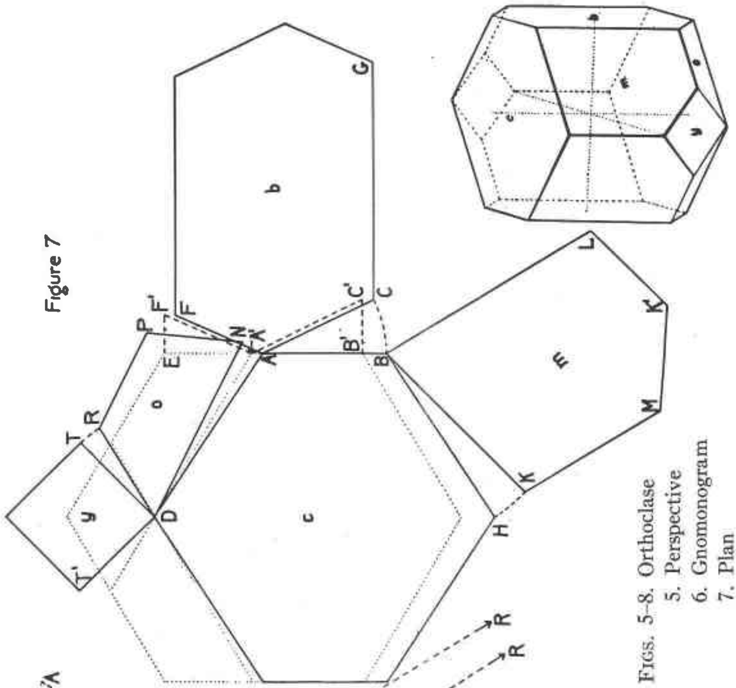
Face o of Fig. 7 is begun at D, making DN equal to DA and normal to the line N to Wo of Fig. 6. NP of Fig. 7 is made equal to AF and is normal to the line P to Wo of Fig. 6. PR of Fig. 7 is parallel to DN, and DR is normal to the line R to Wo of Fig. 6 (R is off the paper here; the direction R to Wo marked on Fig. 6 is obtained by placing the paper on a large sheet and extending the lines Eo and yo). DT and DT' of the y face of Fig. 7 (which is a rhombus only 43′ off a square) are made equal to DR and are drawn as normals to the lines Wy to T and Wy to T', respectively, of Fig. 6.

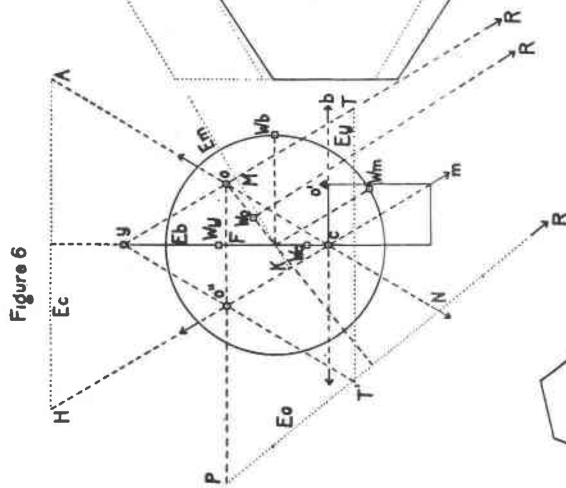
Draw face m of Fig. 7 beginning at B and making BK of length equal BH and normal to the line K to Wm of Fig. 6. BL of Fig. 7 is made equal to CG and (like KM) is drawn normal to Em of Fig. 6. LK' of Fig. 7 is made equal to RP and is drawn normal to the line K to Wm of Fig. 6. This is because it is an edge between m and a *lower* face whose face-pole is marked by the dot in a tiny triangle[9] labelled o' in Fig. 6; but when one wants a lower edge like this, one uses the opposite face-pole represented by a dot in a tiny circle (marked o'' in Fig. 6) as if the face-pole in question were operated on by an inversion (center of symmetry).[10] Similarly $K'M$ of Fig. 7 is found to be equal to DT and is made normal to the line M to Wm of Fig. 6 (M is where the m-arrow through y cuts Em).

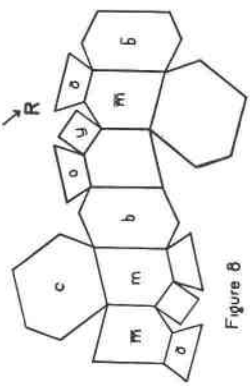
A net may now be prepared from Fig. 7 as was done from Fig. 3. The result is shown in Fig. 8. Specific rules that will apply to all crystals can hardly be stated. In general, the net is "strung along" some pronouncedly prismatic zone involving maximum face areas and edge lengths. The $mb=[001]$ zone used in Fig. 8 could nearly as well be replaced by a $cmo=[\bar{1}10]$ zone. In any case great care must be exercised to keep corresponding edges of equal lengths. It will be noted that the tracing paper must be turned upside down on Fig. 7 in taking off the faces of Fig. 8, indicated with a bar over the letter. Faces such as c and y of Fig. 7, or a, b, c, d, and m of Fig. 3, which have a two-dimensional symmetry of two mutually-perpendicular planes plus inversion or a 2-fold axis, can be traced off in four ways (tracing paper either side up, and at 180°-azimuth

[9] Symbolism and method of projection used here are as described in Fisher, *op. cit.*, *Jour. Geol.* **49**, 313–319 (1941).

[10] These principles are important in preparing a net for a hemimorphic crystal, such as tourmaline, where the lower half (faces designated by face-poles placed in tiny triangles) will be different from the upper half. Here follow these rules, using a tiny circle face-pole diametrically opposite the given tiny triangle one, and then remember that the directions obtained will be those of the face opposite to the one desired; thus the face in question will appear to be upside down.







FIGS. 5–8. Orthoclase
5. Perspective
6. Gnomonogram
7. Plan
8. Net

positions in either case). Those as *k* of Fig. 3 with only one plane of symmetry can be traced off in but two ways (tracing paper either side up). Those with but inversion or a 2-fold axis, such as *b* of Fig. 7, can also be traced in but two ways (tracing paper at two azimuths 180° apart, but only one side up). Finally, those with no symmetry, such as *e* of Fig. 3 and *m* or *o* of Fig. 7, can be taken off in only one position of the tracing paper.

When ready to make the model, carefully trim off the net drawn on Bristol board (Figs. 4 or 8) along the outside lines, using a safety razor blade mounted in a convenient handle, either freehand or running against a steel straight-edge. Then lightly cut along all other lines and fold the Bristol board along these cuts. With the aid of a roll of $\frac{3}{8}$ or $\frac{1}{2}''$-wide red Scotch cellulose tape (like that used for binding lantern slides) the proper edges may now be joined together. It is important that the tape be bisected lengthwise by the crystal edge it joins. The faces may be labelled or lettered as desired. Colored or white tape, or Bristol board, may be used to give different effects as is common in model making. Two coats of colorless hard varnish improve the final product. Or shellac may be sprayed on; but do not use this as a first coat if any material in colored India ink is on the model; the ink will run.

In Fig. 9 appears a few of the 19 models made by the writer's students during the past three years. The interfacial angles are in most cases accurate to within 1°, which is far better than is true for the ordinary wooden model. At present a model is being made to show the seven type forms for each crystal class of not-too-high symmetry.

Nets of the type here described have been printed on paper to be pasted on cardboard and made by students into small models.[11] Jordan recommends washing with a weak solution of isinglass before varnishing. This is not satisfactory on Bristol board since it causes warping.

The method of model making herein described is very direct and involves no new theory.[12] The stereographic-cyclographic projections[13] may be used for the same purpose with economy of paper; the time saved in most cases seems to justify the preference for the gnomonic, however.

Note

The projection protractor mentioned in footnotes 5 to 7 can be obtained from the University of Chicago Bookstore, which also sells reprints of the article describing its use, as well as Penfield protractor paper.

[11] Jordan, J. B., *Crystallography: a Series of Nets* (**1921**).

Smithson, F., *Patterns for the Construction of Crystal Models,* D. Van Nostrand Co. (**1928**).

Barker, T. V., *The Study of Crystals,* 41–47 (**1930**).

[12] That is, it follows from the general theory of crystal drawing from the gnomonic projection. This is given in brief by Professor Charles Palache (*Am. Mineral.*, **5,** 96–99, 1920) who kindly made several suggestions which are incorporated into this paper.

[13] Tertsch, H., *Das Kristallzeichnen auf Grundlage der stereographischen Projektion,* 18–20 (1935). Here the angles of the (010) face are wrong.