The production of wooden replicas of natural crystals.

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Summary. A cutting technique, based on the use of carefully prepared plan projections, has been evolved for the making of unlimited numbers of accurate wooden replicas of natural crystals.

WOODEN or plaster models, although poor substitutes for natural crystals, constitute an essential part of the equipment of any elementary course in crystallography due to the fragility, the small dimensions, and the scarcity of good quality natural crystals, and, perhaps most of all, to the differences, commonly great, in external appearance between natural individuals of a single species. Although most introductory demonstrations are based on the ideal, geometrically perfect, type of model, elementary students in this Department are introduced to the study of crystals via specimens characterized by natural morphology, i.e. via good but irregularly developed crystals which, externally, are apparently devoid of symmetry.

It is clear, however, that each individual in classes of some fifty students (the number is likely to be considerably increased in the near future) cannot simultaneously have continuous access to the details of the morphology of the single natural crystal, only a few millimetres in size, on display at each practical demonstration. There thus arises the problem of providing, for each student, an accurate wooden replica, of manageable dimensions, of every such crystal. The problem is rendered more difficult by the necessity that this high degree of accuracy and reproducibility be attainable at the hands of a technician unfamiliar with the details of crystal morphology—a condition that renders unsatisfactory the model-making appliance of Parker and Strebel (1954) on account of the continual need therewith for accurate identification of reference planes, which may change several times during the making of a single model.

The apparatus and the cutting technique employed are basically similar to those of Palache and Lewis (1927). Double-ended models, however, are cut without reversing the work-piece. This means that throughout the cutting of each complete model only two reference directions, the horizontal and vertical circle zeros, are used. To achieve the necessary accuracy in the resulting models, very careful adjustment of the cutting machine, using, as necessary, a micrometer and dial gauge, is essential: at all times the slides, the two axes of rotation, and the plane of the saw blade must bear the correct relationships to each other. Moreover, before cutting each face, the horizontal and vertical circles must be accurately set to the nearest $\frac{1}{4}°$. Failure to make the above preliminary adjustments and the successive settings with the necessary accuracy will inevitably result in non-parallelism of the zone edges—a defect that, when appearing in the longer, narrower faces, is embarrassingly obvious.

Given correct adjustment of the cutting machine, the production of smooth plane faces and sharp rectilinear edges on the models depends largely on three factors: the type of wood and the type and maintenance of the saw blade. The wood should be hard and durable and as free as possible from hardness and colour variations due to grain: strongly developed grain sub-parallel to the long edges of narrow faces can almost completely mask the latter. Woods found suitable are Nigerian abura and yellow cypress but, even with these, careful selection is still very important. The saw blade must be maintained in a sharp condition, always ensuring perfect uniformity of set and circularity. The type found most satisfactory is the Black and Decker planer saw blade (U. 1901).

The accurate reproduction of any type of model is achieved by the use of photostat copies of a series of cutting plans. Each cutting plan shows the lines of intersection between the various faces involved in the cutting plan on the one hand, and a chosen reference face, usually the basal face or a prism, on the other.

An accurate plan view (fig. 1*A*) of the crystal is first drawn from a stereographic or gnomonic projection to show the desired relative dimensions, in plan, of all edges. The lines of the plan perimeter, drawn in the order of cutting the prism faces concerned, and produced as necessary to show the extent of each cut, constitute, in systems other than monoclinic and triclinic, the final prism cutting plan (fig. 2*A*). This is best prepared on a fixed piece of tracing paper and traced direct from the plan view.

The cutting plan for the first termination shows the lines of intersection of the various terminal faces with the basal plane. The positions of these lines are easily deduced with the aid of a series of silhouettes, drawn by projection from the plan view and distributed radially with respect to it on the same sheet of paper (figs. 1*B* to 1*E*). Each silhouette is constructed as viewed along the axis of a zone defined by the basal plane and by one or more of the terminal faces. On each silhouette the traces of all constituent faces are produced to cut the trace of the basal plane. These intersections (figs. 2*B* to 2*E*) are then projected on the

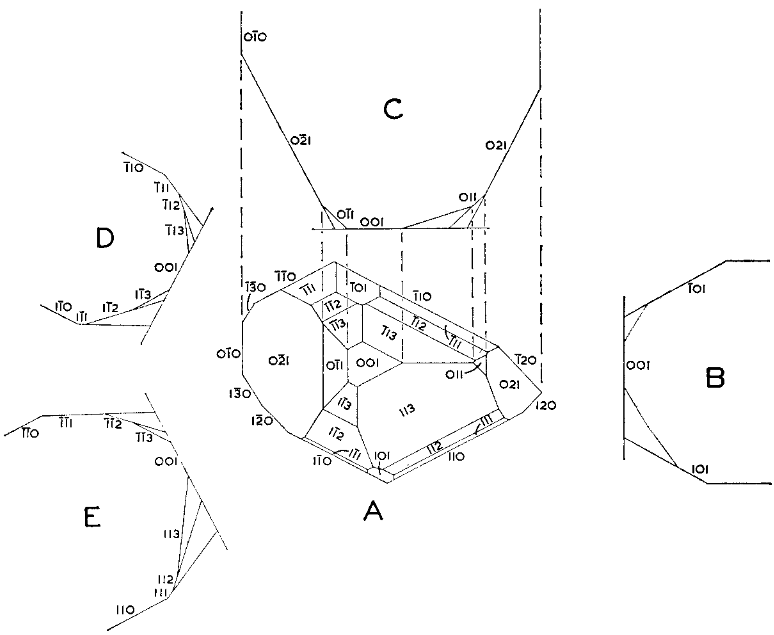

FIG. 1. Plan view of a topaz crystal (*A*) surrounded by four silhouettes (*B*, *C*, *D*, *E*), each constructed as viewed along the axis of a zone defined by the basal plane and by one or more of the terminal faces. Each terminal face is incorporated in one or other of the silhouettes. On each silhouette the trace of each constituent terminal face is produced to cut the trace of the basal plane.

prism cutting plan, which, although remaining superimposed on the plan view, is now separated from it by a piece of plain paper to avoid confusion between face outlines on one drawing and cutting lines on the other. Again, the cutting lines are drawn on the cutting plan in the sequence of cutting of the faces concerned and show the extent of each cut (fig. 2*A*). In general, terminal faces are best cut in order of increasing departure from the prism zone.

In monoclinic and triclinic cases also the above procedure is followed, keeping in mind that the set of lines so produced is the required cutting plan as viewed along the vertical axis and not, in general, perpendicular to the basal plane. The final cutting plan is produced by projection of the above vertical-axis view on the basal plane.

After listing, in order of cutting, the face-symbol and two-circle angles for each face involved in the cutting plan, the cutting procedure

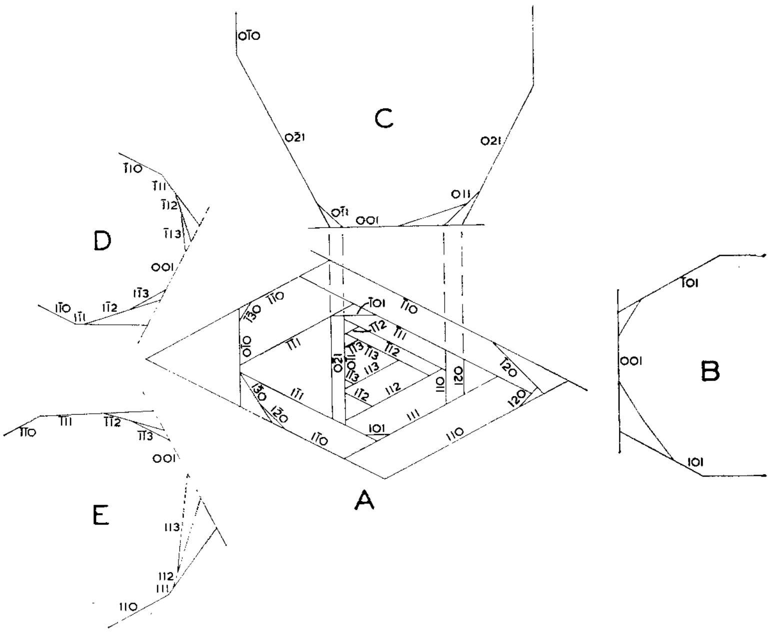

FIG. 2. Cutting plan (*A*) for prism and first termination of the topaz crystal of fig. 1*A*. The prism cutting plan, incorporating all (*hk*0) faces, is traced direct from the perimeter of the plan view (fig. 1*A*). The cutting plan for the first termination is constructed by projection from the basal plane of each silhouette (*B*, *C*, *D*, *E*—identical with *B*, *C*, *D*, *E* of fig. 1).

is comparatively simple. First, cut the basal plane, whether or not it is to appear on the final model, and the prism chosen as first in the cutting sequence. A photostat copy of the cutting plan is then fixed on the basal plane, carefully ensuring coincidence of the appropriate cutting line and the newly cut edge. With the saw face passing accurately through each cutting line in turn, all remaining faces are then cut in the order indicated in the cutting list. It is, of course, obvious that the above method may also be employed in cutting any second termination by the technique of Palache and Lewis (1927).

A second termination may also be cut with the aid of a few similar cutting plans without the necessity for cutting off and reversing the partially finished model, thereby overcoming the attendant risk of misorientation, however slight. The cutting plans, of necessity several in number since one is denied access to the second basal plane, are projected this time on the minimum number of carefully chosen prism faces, preferably the largest if they are in favourable orientations. Each cutting plan shows the lines of intersection of the prism face concerned and the group of adjacent terminal faces, including in each case the terminal plane, i.e. the plane, through the model termination, perpendicular to the prism axis (= basal plane in the higher symmetry cases). Some faces may, obviously, be equally conveniently included in either of at least two adjacent cutting plans but in general each face, except the terminal plane, which appears in all, need appear in only one of the several cutting plans. The method of constructing these cutting plans is exactly as for the first termination, with the chosen prism in each case as the plane common to all associated silhouettes and as the final plane of projection. A relatively simple example of this is the cutting plan, projected on $(1\bar{1}0)$, for faces $(10\bar{1})$ and $(20\bar{1})$ of the second termination of an irregular orthoclase model (fig. 3).

As a preliminary to cutting, the terminal plane, whose exact position must be determined by measurement along the prism, is represented by a line scribed around the model at right angles to the prism edges. The various cutting plans are then pasted on the corresponding prism faces with, in each case, the lines representing the terminal plane and the prism edges accurately coinciding with the corresponding line and edges on the prism face.

Cutting may now proceed, bearing in mind that, as for the first termination, faces are best cut in order of increasing departure from the prism zone. However, in view of the now reversed saw : cutting-plan relationship, and on account of the width of the saw cut, it may not always be possible to follow this ideal sequence without, while cutting one face, destroying the cutting line for a subsequent face. In such cases, either the order must be reversed or a new cutting plan must be affixed to make good the deficiency.

In practice it is found that cutting of the largest face, which need not be the basal face, is best left until the end, provided that this can be done without undue disturbance of the cutting scheme outlined. In fact, in difficult cases the model may be plotted and cut in an unconventional attitude so that the largest face, a prism, for example, is more or less perpendicular to the vertical circle axis. A simple example of this is the cutting of a set of identical irregular flattened octahedra. The cutting

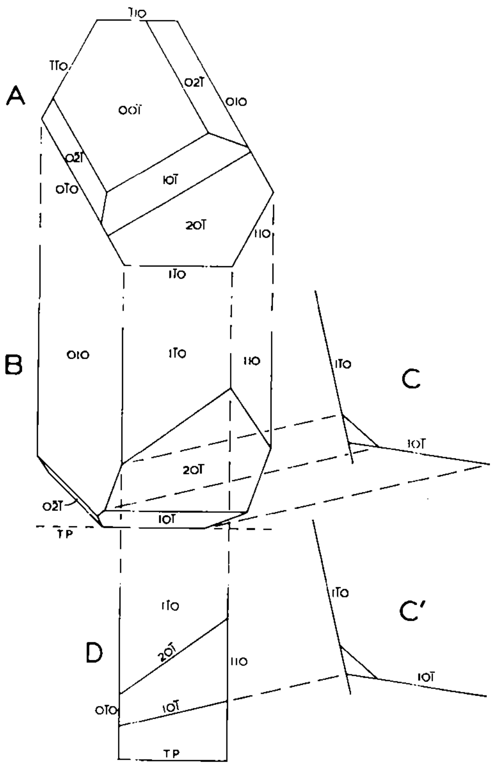

FIG. 3. Preparation of the cutting plan, as projected on (1̄10), for (10$\bar{1}$) and (20$\bar{1}$) of the second termination of an orthoclase crystal. *A*, plan view of the second termination of the orthoclase crystal. *B*, projection of same on (1$\bar{1}$0), showing the terminal plane, *TP*. *C*, *C′*, silhouette, projected from *B*, as viewed along the axis of zone [(1$\bar{1}$0) (10$\bar{1}$)]. *D*, cutting plan, projected on (1$\bar{1}$0), showing, to facilitate correct orientation on the model, its lines of intersection with (110), (0$\bar{1}$0), and the terminal plane, *TP*. The cutting line for (20$\bar{1}$) is its line of intersection with (1$\bar{1}$0) as in *B*. The cutting line for (10$\bar{1}$) is projected from *C′*.

plan was prepared with the two dominant faces, say (111) and ($\bar{1}\bar{1}\bar{1}$), as the first and second terminal faces respectively. Cutting was then easily carried out in the following sequence: the first terminal face, on which the cutting plan was subsequently stuck; the three faces of the first termination; the three faces of the second termination (these are easily projected on the only cutting plan); and the second terminal face, the cutting of which detached the model. The cutting position for the final face is determined by the desired degree of flattening. Other simple models, like the rhombic dodecahedron, may be treated in a similar fashion.

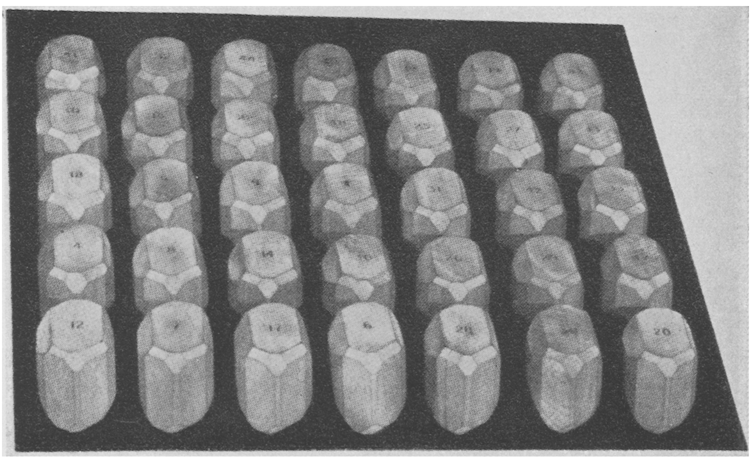

FIG. 4. Double-ended wooden models of anorthite.

In conclusion, it is clear that this technique not only permits the production of any number of identical irregular crystal models (fig. 4), but also facilitates the cutting of multi-form regular models to show any desired habit and any degree of relative importance of the several forms depicted.

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