CONSTRUCTION AND STUDY OF FLOW STRUCTURE MODELS FROM FIELD DATA

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ABSTRACT

Transparent models based on field data are helpful laboratory and training aids for the three-dimensional study of flow structures in igneous rocks. Field procedure is discussed and details of construction and assembly of models are given. An illustrative example involves the Storm King granite of the Hudson Highlands of New York.

INTRODUCTION

While investigating the Storm King granite in the Hudson Highlands of New York, the writer frequently encountered difficulties in determining the regional flow structures with sufficient accuracy in the field. Strong weathering effects limit reliable structural measurements to occasional road cuts exhibiting reasonably fresh rock surfaces. Hornblende crystals and crystal aggregates of rather stout prismatic habit, perhaps comparable to the shape of a matchbox, provide the visible linear elements arranged in both linear and planar flow structures. The resulting mineral parallelism has a streaky rather than banded appearance on the various exposure surfaces. But the streaks generally show insufficient variation in elongation, width and continuity to permit a clear distinction between lineation patterns representing traces of flow lines, flow layers and a combination of both. Also critical outcrop surfaces, e.g. perpendicular to flow lines or parallel to flow layers, are often absent or else poorly developed in the predominantly two-dimensional road cut exposures.

Consequently a method of constructing simple models based on all available field data was employed, to study the three-dimensional orientation of the flow structures in such doubtful localities.

FIELD PROCEDURE

A preliminary investigation is made to ascertain the reasonably constant orientation of visible mineral parallelism on exposure surfaces having similar strike and dip. This being the case, it can be assumed that the flow structures have sufficiently uniform orientation throughout the outcrop to permit study by the model method.

Measurements are then taken on as many different exposure surfaces as possible. A minimum of 8 to 10 is recommended. In road cuts much of the desired information must be obtained by careful study of relatively small re-entrant surfaces produced by blasting and quarrying. In addition to the strike and dip of each surface, the pitch[1] of lineation is determined.

The universal clinometer as described by Ingerson (1942) and Fairbairn (1942, p. 107) is a most useful instrument for this purpose. Otherwise pitch may be measured with the Brunton compass as follows: On high-angle surfaces the apparent pitch of lineation is found by sighting along the edge of the compass with the clinometer in a vertical plane striking parallel to the strike of the surface. On low-angle surfaces the bearing[2] of the lineation is measured by sighting with the compass held in the horizontal position. In both cases subsequent corrections have to be made, in order to find the pitch either stereographically (Bucher, 1944) or by adaptation of the diagram for computing apparent dip (Billings, 1942, p. 422).

Appearance of each surface should be noted in detail with the help of field sketches to indicate whether the mineral streaks are narrow or wide, short or long, continuous or discontinuous, linear or wavy, etc. Under favorable conditions actual scaling of these features may be useful. Finally fracture systems are measured with particular attention to presence and attitude of slickensides, frequency and spacing of joints within a system, mineralization of fractures and similar features.

Construction of Model

Select a suitable vertical dimension for the model ($1\frac{1}{2}$ inches used by the writer) and prepare auxiliary construction scales as indicated in Fig. 1.

Construction of the model is greatly simplified by starting from a top horizontal plane whether or not field data for such a surface are available. The lines bounding this plane represent both the top edges of the model and the strike lines of the inclined surfaces. A preliminary layout of the ground plan is made on a Penfield protractor circle[3] as shown in Fig. 2. The strikes of the outcrop surfaces are plotted in their correct orientation and numbered in consecutive order. Dips are indicated by map symbols. A ground plan layout of suitable proportions is obtained by proper grouping and parallel translation of the strike lines bounding the top horizontal plane. Surfaces inclined less than 90° are always represented as outside positive slopes, i.e. overhangs are avoided. This procedure of shifting surfaces parallel to themselves is proper, since field observations have indicated essential uniformity of mineral orientation.

[1] "The pitch is the angle that a line in a plane makes with a horizontal line in that plane." (Billings, 1942, p. 135.)

[2] "The bearing of a line in space is its projection onto the horizontal plane, measured from the geographical north." (Bucher, 1944, p. 195.)

[3] Copies may be obtained from the University of Chicago Bookstore.

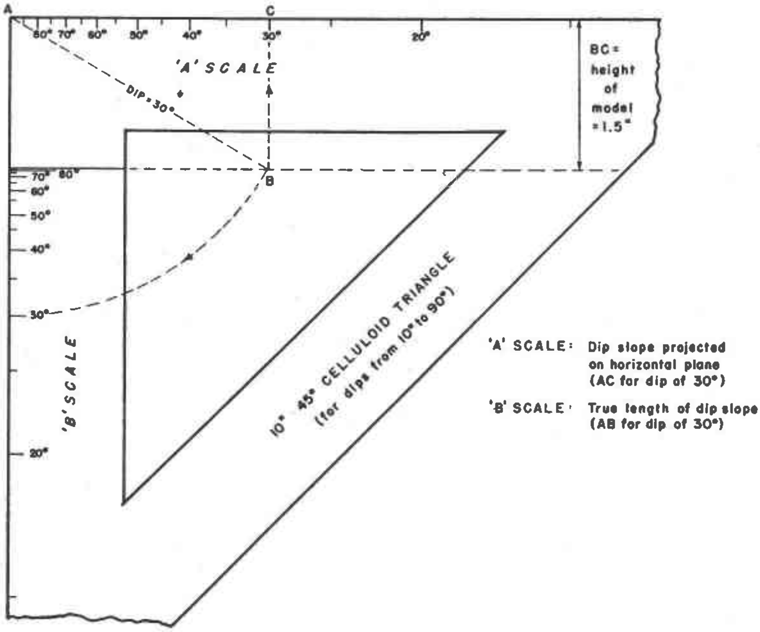

FIG. 1. Construction of auxiliary scales.

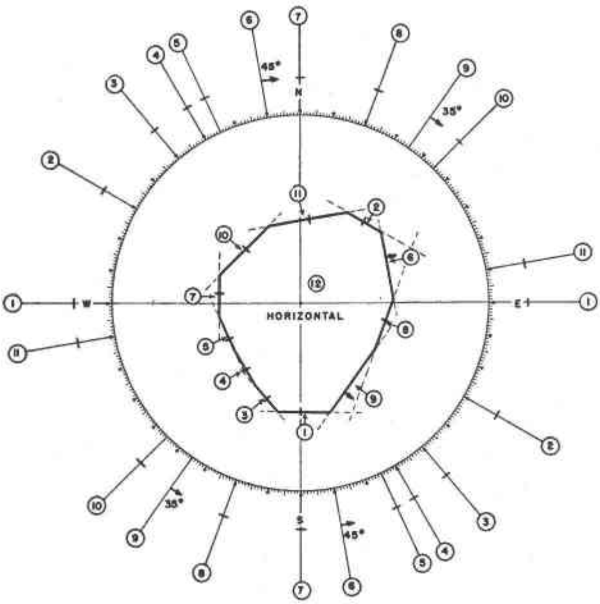

FIG. 2. Preliminary layout of ground plan for model shown in Figs. 5 and 7.

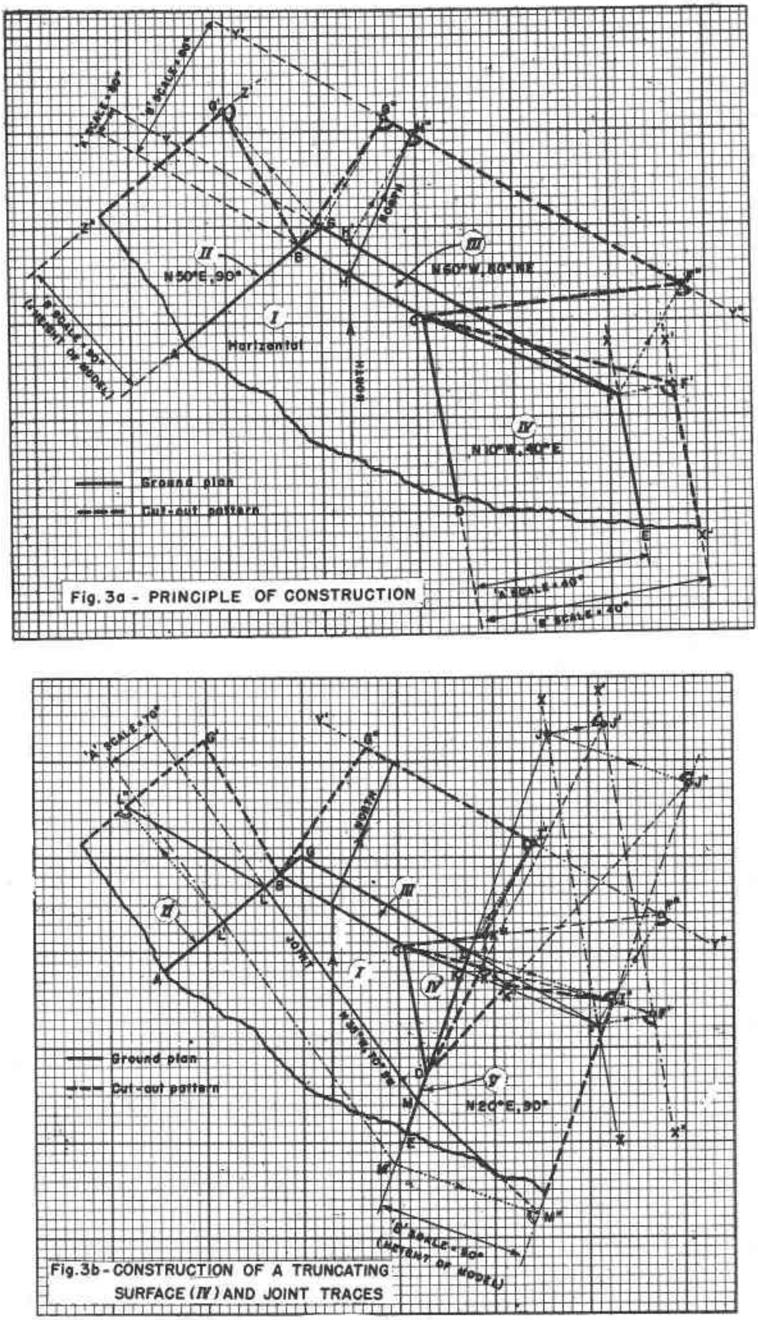

FIG. 3. Construction of model cut-out pattern. Modified portion of model shown in Fig. 5.

The actual construction of the model plan and net is made on a large sheet of 1/10 inch graph paper. Drafting operations may be speeded by the use of a parallel ruler and an aircraft plotter.[4] Figures 3 and 4 illustrate successive steps of construction for a portion of the model shown in Figs. 5 and 7, with modifications designed to increase the instructive value.

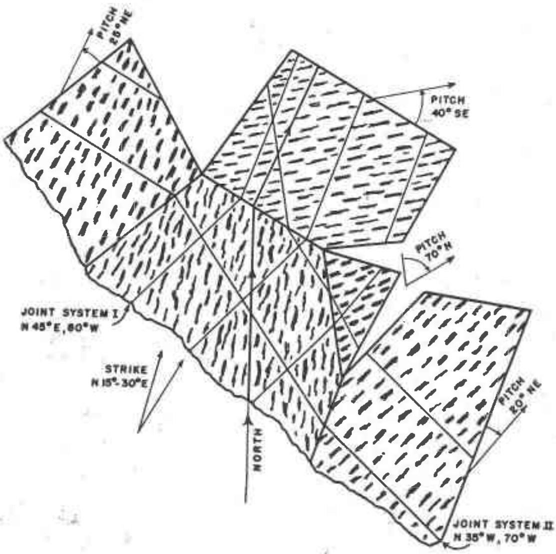

FIG. 4. Addition of surface lineations to tracing of cut-out pattern of Fig. 3*b*.

The top edges of the model are plotted first, maintaining the approximate proportions of the preliminary layout (Fig. 2). The ground plan is then completed by plotting the projected dips of the inclined surfaces from the auxiliary 'A' scale (Fig. 1) and by drawing the lines of intersection of these surfaces with each other and with the horizontal base plane of the model. Referring to Fig. 3*a*, lines AB, BC and CD are the top edges of surfaces II, III and IV respectively. The projection of surface III, dipping 80° NE, is obtained by drawing YF parallel to BC at a distance corresponding to 80° on the 'A' scale; likewise XE parallel to CD at a distance corresponding to the dip of 40° for surface IV. BG and CF are the vertical projections of the inclined edges formed by surfaces II–III and III–IV respectively.

[4] Also known as Weems plotter, a combination protractor scale and straight edge permitting rapid and accurate plotting of bearings from a north reference line in a single operation (Weems, 1938, p. 52).

The next step involves rotation of each inclined surface about its strike axis (top edge) into the top horizontal plane, in order to obtain the net or cut-out pattern of the model (Fig. 3*a*). Using the auxiliary 'B' scale (Fig. 1) for the true lengths of the inclined model surfaces after rotation, draw another set of lines parallel to the top edges at distances corresponding to the surface dips, viz. Z′Z″//AB, Y′Y″//BC, X′X″ //CD. The inclined edges are then rotated to complete the cut-out pattern. Each edge, appearing in vertical projection on the ground plan, is resolved into two cutting lines, because it is common to two adjoining surfaces each of which must be rotated about a different strike axis. Edge CF, formed by surfaces III and IV, is first rotated about BC and then about CD. Point C lies in the top horizontal plane and therefore remains in position during rotation. Point F, the intersection of edge CF with the horizontal base plane of the model, is rotated about BC by erecting a perpendicular to Y′Y″ (base line of surface III and parallel to BC) and finding the point of intersection F″. Similarly F′ is determined by rotation of F about CD. CF′ and CF″ are the desired cutting lines of edge CF and must be of equal length. This provides a useful check on the accuracy of construction. Lines BG′ and BG″ are constructed in the same manner by rotating point G about AB and BC.

To provide a means of orienting the model, the traces of a vertical NS plane approximately bisecting the ground plan should be plotted. HH′ (Fig. 3*a*), for instance, is the trace of this reference plane on surface III as it appears on the ground plan. HH″ is the actual trace on the cut-out pattern.

When field data are obtained from a road cut, vertical or high-angle surfaces will predominate with the effect of reducing the size of model surfaces with medium to low dips to triangular facets truncating the top corners of the model. Although the basic principle of construction has been demonstrated above, it might be appropriate to discuss its application to the specific case involving a truncating surface of this type (Fig. 3*b*).

By adding the vertical surface V (Fig. 3*b*) to the layout of Fig. 3*a*, surface IV becomes a small triangular truncation of the corner formed by surfaces I, III and V. DJ (edge between IV and V) and its intersection K with edge CF are found by the same method of construction used in Fig. 3*a*. The revised ground plan, then, shows three new edges, viz. CK (truncated portion of CF), DK (truncated portion of DJ) and KI (edge between III and V). DJ is rotated about CD and DE to obtain the cutting lines DJ′ and DJ″. CF′ and DJ′, both the result of rotation about CD, intersect in K′ thus defining CDK′ as the true outlines of surface IV. Describe an arc of radius CK′ about C to intersect CF″ in point K‴. Then CK′ = CK‴ = two cutting lines of edge CK. Likewise DK′ = DK″ = cutting lines of edge DK. Finally locate I′ by rotation of I (terminus of edge KI in base plane of model) about BC and I″ by rotating about DE. Connect K‴ with I′ and K″ with I″ to complete the revised cut-out pattern.

Fracture systems, dikes, etc., may now be added by finding their traces or lines of intersection with the surfaces involved. Fig. *3b* shows the construction of a joint cutting surfaces I, II and V. LM is the trace on surface I and L′M′//LM the vertical projection of the dip slope ('A' scale =70°) toward the SW. Consequently LL′ and MM′ are the ground plan projections of the joint traces on surfaces II and V respectively. L′ is rotated about AB to L″, and LL″ is drawn to show the actual trace on the cut-out pattern. MM″ is the corresponding trace on surface V.

Mineral lineation is the last structural feature placed on the construction net by plotting its pitch on each surface of the cut-out pattern, and by indicating its orientation with a series of parallel guide lines (not shown in Figs. *3b* and 4).

The outlines of the cut-out pattern together with north reference line, joint traces, dikes, etc., are now traced in India ink on an overlay of 15-point (.015 inch thick) transparent cellulose acetate, the material used to fashion the model. It is advisable to dull the glossy acetate surface by vigorous rubbing with talcum powder, Fuller's earth or a similar mild abrasive, in order to improve its ink-adhesion quality. Tracing paper or tracing cloth are suitable substitutes for the acetate, but must subsequently be mounted on thin cardboard to lend adequate rigidity. The obvious drawback of this procedure is the lack of transparency of the resulting model.

The actual appearance of mineral lineation on the original outcrop surfaces is reproduced in ink directly on the acetate overlay by referring to the field sketches and by following the guide lines of pitch (Fig. 4). India ink, black or colored, is preferable to special acetate inks, because corrections and changes can be made readily on the completed overlay. India ink does not form a permanent bond with the acetate and can be removed with a little absorbent cotton wrapped tightly around the tapering end of a brush or pen holder and moistened with water containing a small amount of ammonia.

Upon cutting out and folding of the acetate model pattern, the cut edges of the inclined surfaces will join properly, if reasonable care has been exercised in its construction. Folding of the model pattern is facilitated by making shallow scratches on the *inside* surface of the acetate along the folding lines. The rather brittle material also has a tendency to crack or split along sharp bends no matter how carefully the operation is performed. This drawback is overcome by the bonding procedure shown in Fig. 6.

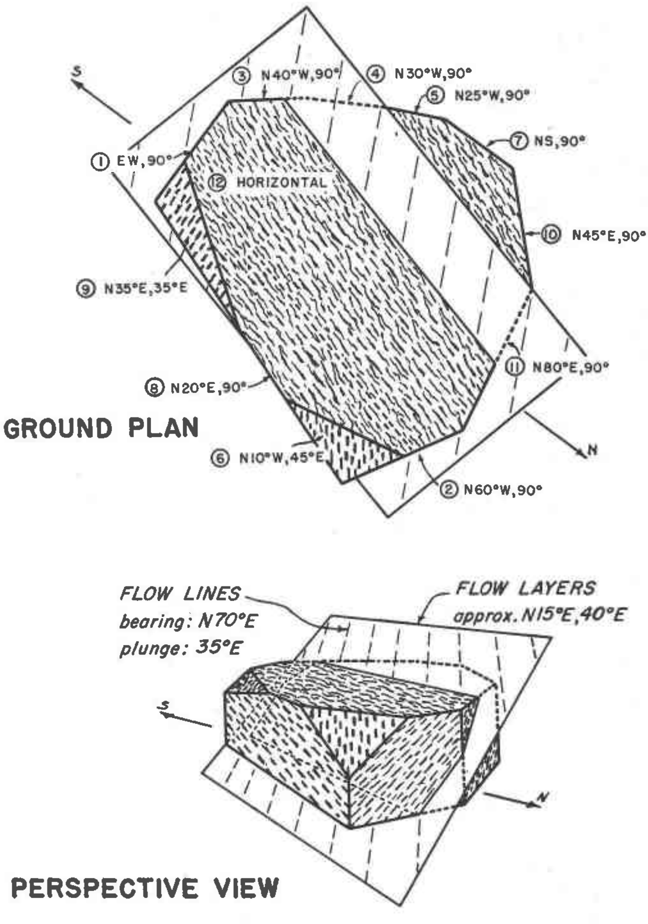

FIG. 5. Model showing flow structures in road cut of Storm King granite at Lake Askoti, 7 miles SW. of Bear Mountain, N. Y. Joint traces and pegmatite dike are omitted. Numbers of outcrop surfaces correspond to Fig. 2.

Hold the free or split edges of the model firmly together and place a dry, L-shaped strip of acetate across the juncture on the inside of the model. Dip a brush into ethyl acetate (or acetone) and apply to the free edges of the strip. Capillary action will draw the liquid into the space between the strip and the model surface where it will dry in a matter of seconds. The resultant bond is durable and transparent serving at the same time as reinforcement of the model edge. Transparent scotch tape is not recommended for this purpose, because it will become wrinkled and discolored with time.

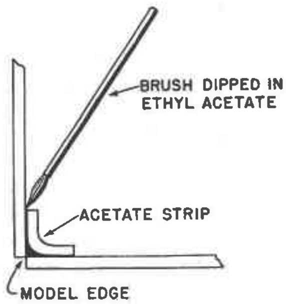

FIG. 6. Method of bonding and reinforcing the model edges.

Study of the Model

Orientation of the transparent model on a baseboard containing suitable directional markings (Fig. 7) reveals the three-dimensional attitude of the flow structures and permits their measurement with a degree of accuracy comparable to that inherent in the original field measurements.

When both flow layers and flow lines are present, surfaces exhibiting traces of the flow planes are selected (all surfaces of Fig. 5 except numbers 6 and 9). The dip and strike of the flow layers can then be determined geometrically by reversing the construction procedure on the graph paper layout thus finding the plane responsible for the attitude of mineral lineations on the selected model surfaces.

The coordinates of flow lines within a flow layer are determined from lineations on model surfaces more or less parallel to the plane of flow, e.g. triangular surfaces 6 and 9 of Fig. 5. Under certain conditions a graphic solution (Lowe, 1945) may be employed by finding the line of intersection (representing the flow line) between the flow layer and a plane containing the lineation direction on the particular surface and being perpendicular to the latter. Application of this construction to all surfaces showing flow line trend usually results in several possible answers.

The median of the bearings and plunges[5] is taken as the acceptable solution.

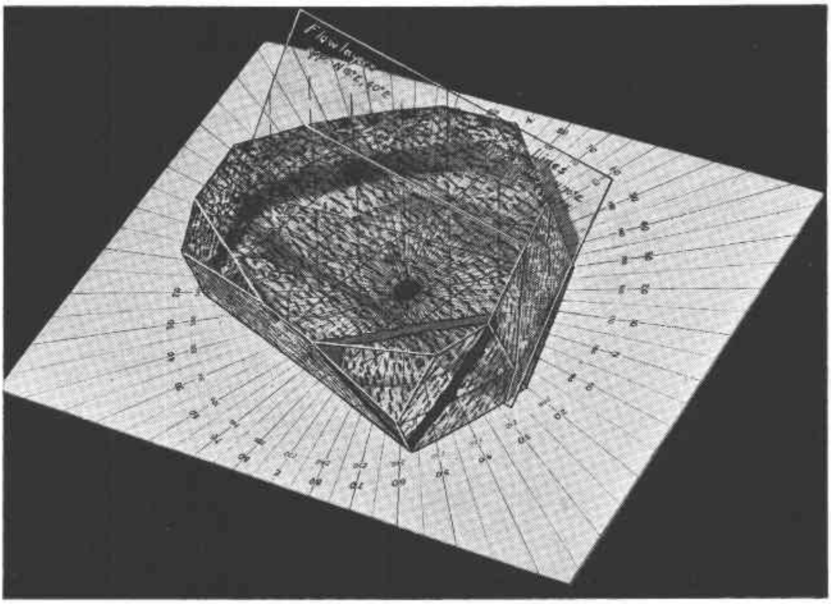

FIG. 7. Transparent acetate model of outcrop illustrated in Fig. 5 showing flow structures, joint systems and granite pegmatite dike.

Unusual cases where the linear elements do not lie in the plane of flow cannot be detected by study of the model.

Inspection of the model also facilitates the recognition and classification of joint systems in relation to the flow structures (Balk, 1937, part I.).

CONCLUSION

The construction of transparent models based on field data is a simple and helpful aid in the study of flow structures under adverse field conditions or when petrofabric analysis is not feasible due to lack of time or equipment. Once a certain facility of operation has been acquired, even relatively complex models can be constructed in 8 hours or less.[6] Another advantage lies in the fact that the results obtained represent the average

[5] Plunge may be defined as the angle which a line in space makes with the horizontal, measured in a vertical plane (Billings, 1942, p. 44).

[6] Six hours were spent on the construction of the model shown in Fig. 7.

for an entire outcrop, a feature which is particularly desirable in regional and reconnaissance investigations. The degree of accuracy falls within the usual limits of error inherent in the original field measurements.

This method is also valuable as a training aid by giving students of structural petrology a means of visualizing the three-dimensional aspect of internal flow structures. The writer has found that the student's ability to recognize the more obscure and complex flow structures in the field was greatly improved after construction and study of a few models.

References

Balk, R. (1937), Structural behavior of the igneous rocks: *Geol. Soc. Am.*, Memoir **5,** part I.

Billings, M. P. (1942), Structural Geology. Prentice-Hall, N. Y., 44, 135, 422.

Bucher, W. H. (1944), The stereographic projection, a handy tool for the practical geologist: *Jour. Geol.*, **52,** 191–212.

Fairbairn, H. W. (1942), Structural Petrology of Deformed Rocks. Addison-Wesley Press, Cambridge, Mass., 107.

Ingerson, E. (1942), Apparatus for direct measurement of linear structure: *Am. Mineral.*, **27,** 721–725.

Lowe, K. E. (1945), A graphic solution for certain lineation problems: (Abstract) *Bull. Geol. Soc. Am.*, **56,** 1179.

Weems, P. V. H. (1938), Air Navigation. 2nd Ed., McGraw-Hill, N. Y., 52.