Procedures and Studies in Photogeology

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Photogeologic Procedures in Geologic Interpretation and Mapping

By RICHARD G. RAY

PROCEDURES AND STUDIES IN PHOTOGEOLOGY

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A discussion of the general categories of photogeologic procedures and photogrammetric instruments

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Fred A. Seaton, *Secretary*

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ILLUSTRATIONS

PHOTOGEOLOGIC PROCEDURES IN GEOLOGIC INTERPRETATION AND MAPPING

By Richard G. Ray

ABSTRACT

Many photogeologic procedures are used in geologic interpretation and mapping. These procedures are grouped into four general categories: interpretation and annotation of geologic data on photographs, quantitative determination of geologic data from photographs, planimetric base-map compilation, and transfer of geologic data from photographs to base maps. The procedures described pertain largely to vertical aerial photography.

INTRODUCTION AND ACKNOWLEDGMENTS

During the past few years increasing use has been made of aerial photographs for geologic interpretation and mapping within the U. S. Geological Survey, although Survey geologists to some extent have used photographs in geologic mapping for more than three decades. However, photogeologic procedures were first used extensively as a specialized technique in interpretation and mapping in the Survey's geologic mapping of Naval Petroleum Reserve No. 4 in northern Alaska (1947–53). More recently photogeologic procedures have been extensively applied in geologic studies of Utah and Alaska. It is primarily the purpose of this paper to bring together and discuss briefly these procedures.

The many procedures of photogeology are potent tools in geologic interpretation and mapping, but these procedures in most mapping projects are supplemental to the field study itself. Because the term "photogeology" is sometimes misinterpreted to mean a substitute for "field geology" it is a poorly chosen term, and it is perhaps unfortunate that it has come into common use in the literature during the last several years. As here used, photogeology is defined as "the study and interpretation of photographs, normally aerial, for the purpose of obtaining geologic information; it also normally includes presentation of information from photographs in appropriate form, such as on mosaics, areal geologic maps, or geologic cross sections." Stereoscopic examination of photographs is usually involved in such study and interpretation, but this is not always necessary.

Procedures currently used in photogeologic study of an area may be grouped into four general categories: (1) interpretation and annotation of geologic data on photographs, whether these data are interpreted entirely in the office by stereoscopic examination of photographs, or whether they are observed in the field and transferred to photographs as part of the field mapping project; (2) quantitative determination of geologic data from photographs by use of appropriate photogrammetric measuring instruments; (3) planimetric base-map compilation from photographs; and (4) transfer of geologic data from photographs to base maps. Whether photogeology is employed as a primary mapping method, as in some reconnaissance projects, or whether it is used as a secondary mapping method in conjunction with more detailed field mapping, the procedures practiced are generally the same.

Present usage of photographs is confined largely to the so-called vertical aerial photography, although there has been and may well be in the future a significant place for oblique aerial photographs as well as terrestrial photographs in photogeologic work. The procedures described below consequently pertain almost entirely to use with vertical aerial photographs.

The writer is indebted to William A. Fischer for his description of the multiplex and Kelsh plotters.

INTERPRETATION AND ANNOTATION OF GEOLOGIC DATA ON PHOTOGRAPHS

VALUE OF STEREOSCOPIC VIEWING AND CHOICE OF STEREOSCOPE

Whereas conspicuous geologic features are commonly visible on single aerial photographs and the casual user of aerial photographs may employ single prints, the wealth of information as shown in stereoscopic view is many times greater inasmuch as the stereoscopic model gives a three-dimensional impression of the terrain. Details, such as fine lines or textural differences, not readily seen on single photographs—or even on the ground—are commonly shown clearly in the stereoscopic model. Such clarity is in many places a direct result of the common association of fine lines and textures with relief changes, which are exaggerated in most stereoscopic models. Vertical exaggeration (also called relief exaggeration), which is an exaggeration of the vertical scale with respect to the horizontal scale, is a potent aid in making geologic interpretations from aerial photographs; most stereoscopic models exhibit marked vertical exaggeration.

The most important instrument used in photogeologic study is the stereoscope. Choice of the particular stereoscope used may differ widely, but for efficient study in concentrated or prolonged photogeologic interpretation, certain fundamental features should be present in the instrument. Also, for most effective stereoscopic viewing the photographs must be properly oriented as described on pages 9–11. Ideally, the stereoscope should be designed to permit comfortable viewing of the photographs without fatiguing the back and neck muscles; it should permit viewing the entire stereoscopic model at one time for rapid scanning or cursory study of the area; it should have a magnifying device so that detailed study may be made of specific features on the photographs; it should be designed to allow freedom of hand movement for annotation; the lens system should be relatively free from distortion to permit estimating quantitative geologic data; and the lines of sight from the eyes to the photographs preferably should be contained in an apparent vertical plane—this permits most interpreters to visualize the horizontal datum of the stereoscopic model more readily and results in more reliable estimates of quantitative data that must be referred to this datum. It would also assist the interpreter materially in certain studies if the stereoscope assembly were adjustable to correct for the small amounts of tilt that might be present in the photographs. At present no one stereoscope meets all the above requirements.

Several makes of stereoscopes exist, but basically there are three types—the lens, the mirror, and the prism; stereoscopes that employ combinations of these basic optical elements are also made. All have certain advantages and disadvantages. Use of the simple lens pocket stereoscope (fig. 1) demands a large overlap of the steroscopic portion of the two photographs being viewed. In order to view the overlapped area it is necessary to bend up or "flip" one edge of one photo-

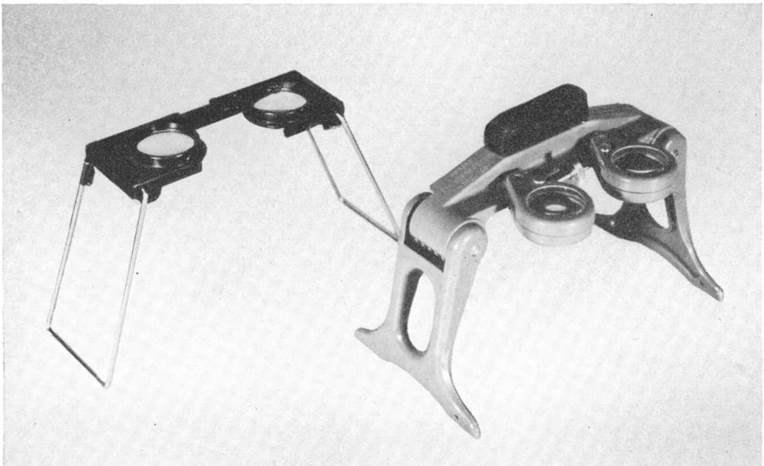

FIGURE 1.—Pocket stereoscopes commonly used.

FIGURE 2.—Mirror stereoscope with binocular attachment.

graph. Also, it is awkward to annotate photographs under the pocket stereoscope owing to the close spacing of the stereoscope supports; there is little or no freedom of movement in using a pencil or pen. An advantage of the simple lens pocket stereoscope is its magnification, but for estimating quantitative data, such as the strike and dip of a sedimentary bed, the pocket stereoscope must be used with great care because of the lens distortion. However, for rapid qualitative checking of a geologic feature this instrument is especially helpful and is used frequently in the office in conjunction with the mirror and prism-mirror stereoscopes. The portability of the pocket stereoscope recommends it as a field instrument.

Many mirror stereoscopes (fig. 2) are so designed that an observer must look vertically down at the photographs. This is not as comfortable a viewing position for prolonged working as a stereoscope with tilted viewing assembly, but it fixes the line of sight from the eyes to the photographs in a vertical plane, thus permitting easier visualizing of the horizontal datum of the stereoscopic model and consequently more reliable estimating of quantitative data. A special mounting arm allows complete freedom of movement for annotation of the photographs. Mirror stereoscopes of the type shown in figure 2 permit full separation of the aerial photographs. This allows the entire sterescopic model to be seen when low-power magnification (normal viewing arrangement) is used; a binocular attachment may be present for detailed work. The binoculars used for high-power magnification reduce the field of view considerably; a slight repositioning of photographs may be necessary for comfortable stereoscopic viewing when changing from one magnification to the other. The loss of illumination by virtue of the greater number of glass surfaces and distances a light ray has to pass through in the binoculars of the mirror stereoscope is not a serious objection or limitation to the use of this stereoscope.

A relatively new prism-mirror stereoscope of foreign design is shown in figure 3. Its tilted viewing assembly permits easy operation without undue strain of the back and neck muscles, but this arrangement so designed for comfortable viewing causes the image plane to appear tilted and thus for most interpreters the instrument is difficult to use in making quantitative estimates of geologic data that must be referred to the horizontal datum of the stereoscopic model. One unique feature of this stereoscope is that the photographs are placed a considerable distance away from the observer. This permits two stereoscopes to be arranged back to back so that two individuals may view the same stereoscopic model simultaneously. The largest field of view includes about one-half the stereoscopic model. Scanning of the stereoscopic model is accomplished by movement of prisms in the optical system, rather than by physical movement of the photo-

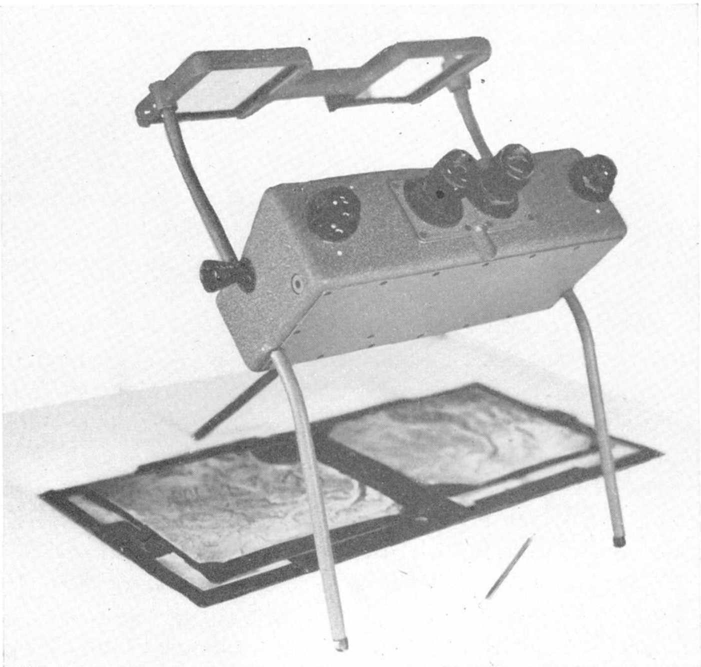

FIGURE 3.—Stereoscope with tilted viewing assembly.

graphs. After the photographs are properly oriented they need not be reoriented or moved during study of that stereoscopic model. A simple knob adjustment permits rapid change of magnification from 1.5× to 4.5×; no shifting of photographs is necessary when changing from one magnification to the other. Design of the supporting legs does not permit complete freedom for annotation, but this is not a serious objection. The instrument is not easily portable and is thus primarily used in the office.

RECOGNITION OF GEOLOGIC FEATURES ON PHOTOGRAPHS

Inasmuch as recognition of geologic features on photographs is basic to carrying out many of the procedures described, a description of recognition criteria seems appropriate. The most significant recognition elements for geologic interpretation are photographic tone, texture, pattern, and relation of associated features. Size and shape may also be very important in certain geologic problems. Recognition of geologic features based on the combined use of the fundamental recognition elements is the first step in a two-step process of geologic interpretation of an area from aerial photographs. The second step is the deduction of the geologic significance or history of an area, insofar as possible, based on observations of the distribution and relationship of the geologic features recognized.

Photographic tone.—Photographic tone is a measure of the relative amount of reflected light that is actually recorded on a photograph. On conventional photographs these tones are usually shades of gray, but may be black or white. The ability of the human eye to differentiate subtle tone changes is a significant asset in geologic interpretation of aerial photographs.

In areas of good exposures bedding is characteristically recorded on the aerial photograph by differences of photographic tone. These differences may be abrupt as illustrated by white-weathering marlstone beds in a sandstone sequence, or they may be subtle as shown by two successive similarly colored sandstone units. Faults may be indicated by a change in photographic tone as shown on opposite sides of a straight or gently curving line; and alluvial fans, pediments, lava flows, and intrusive rocks are usually identified, at least in part, by tone differences.

Texture.—Texture may be defined as the composite appearance of a combination of features too small to be clearly seen individually. The scale of the photographs thus has an important bearing on texture. For example, a network of fine lines referred to as a texture on high-altitude photographs may well be recognizable as a network of joints on low-altitude photographs. Likewise on high-altitude photographs a mottled texture resulting from small amoebalike outlines may be clearly the result of kettle holes that are distinctly discernible on low-altitude photographs. The explanation for a particular texture is not always necessary to make that texture of importance in geologic recognition. Textures of gravel deposits mantled by vegetation may be distinctive, or textures of surfaces of lava flows may differ sufficiently to permit differentiation of the flows. Intrusive igneous rocks commonly have a distinctive texture owing to a crisscrossing of many joints almost universally present in such rocks.

Pattern.—Pattern as used herein, refers to the orderly spatial arrangement of geologic or other features and thus in a sense may result in a particular texture, such as a crisscrossing of lines due to joints. A common example of the use of this recognition element is the analysis of stream pattern, which may be a significant aid in interpreting the underlying geologic terrane. Patterns of joints may suggest certain rock types, or a knowledge of fault patterns of an area may be helpful in locating faults in a similar nearby terrane.

Patterns resulting from particular distributions of lines are common, but a single line, or lineation, may be a special illustration of pattern. For example, a lineation may result from an orderly arrangement of stream segments, trees, depressions, or other features. This arrangement may be a continuous alinement of geologic, topographic, or vegetation features, but more commonly it is a discontinuous alinement. Lineations are especially important as expressions of faults, but they may also represent a variety of other geologic phenomena.

Relation of associated features.—The relation of associated features is commonly important because a single feature may not be distinctive enough to permit its identification. Thus identification of depressions in surficial deposits as kettle holes may be possible because of associated glacial ice nearby. However, of greater significance is the overall association of several geologic features that permit further interpretation and deductions regarding the general geologic environment and geologic history of that environment.

Size.—The term "size," used as a general recognition element covering all interpretation fields, is more appropriately considered in geologic interpretation in relation to thicknesses of strata, amounts of offset along faults, or other finite measurements. These measurements may be directly related to topographic expression. If the thickness of a formation is known it may aid in identification, and determining the range in thicknesses may be essential to understanding the regional geology.

Shape.—Shape as a recognition element in geologic interpretation is of significance primarily insofar as relief or topographic expression is concerned. In this regard it may be critical in the final geologic interpretation of certain features. Rectilinear depressions are expressions of faults in many areas. Dome-shaped weathering surfaces are characteristic of certain sandstone formations. The convex surface of alluvial fans is diagnostic in many places. Hummocky relief on lava flows together with lobate termini aid in identification of such flows.

Combinations of recognition elements.—Most geologic interpretations are based on a combination of recognition elements. Bedding may be recognized, even in areas of sparse outcrops, by an association of photographic tone, topographic expression, and texture. Lava flows may be distinguished because of surface relief and texture as well as association with nearby volcanic cones. Faults are commonly expressed on photographs as straight lines and may be further identified by an abrupt photographic tone change on opposite sides of these lines, as well as a pronounced offset of recognizable rock types. The combined use of all recognition elements cannot be overstressed in interpreting specific geologic features; the overall geologic history is deduced from these specific interpretations. Where more than one plausible explanation of recognition data is possible the fundamental geologic ability of the interpreter will largely determine the appropropriateness of the final conclusions.

METHODS OF ANNOTATING

The importance of careful annotation of geologic and related data ranks high among photogeologic procedures. Just as photointerpretation is limited by the quality of the photographs, so too are results of many compilations from photographs limited by the quality of the annotations. Much has been said and written regarding the use of transparent overlays for annotating, but several disadvantages have been pointed out by Desjardins (1950, p. 2288) who prefers to annotate directly on the photographs. The common practice of placing photographs directly in the so-called paper-print plotters, which are used frequently for transferring detail in map compilation, is also a compelling factor for annotating directly on the photographs.

Annotations may be made in several ways. Grease pencils, semigrease pencils, or colored lead pencils have been used for marking photographs, but these are not too satisfactory. Most grease pencils make lines that are too wide (consider that 0.01 inch on a 1:20,000-scale photograph represents about 16½ feet on the ground); exact plotting of fine detail is difficult. Colored lead pencils do not "take" well to most print surfaces and furthermore tend to damage the surface of the photograph because of pressure exerted to make even a poorly legible mark.

Ink is the best medium for annotating. Many inks have been tried and two types, tempera and india, have been found to be satisfactory, although there are distinct advantages and disadvantages with each. Tempera, which comes in a wide variety of colors, shows up clearly on the face of a photograph and is easily erased with a water-damp cloth or cotton. Its brightness is an advantage on photographs that are to be used in different projector-type machines for transfer purposes. However, tempera dries rapidly, gums up the pen point, and makes wider lines than are desirable for some purposes. If a person is proficient in using a crowquill or other fine-point pen, india ink can be controlled better than tempera and makes finer lines if applied properly. The need for fine lines is very aptly put by Desjardins (1950, p. 2290) who says—

> In the first place, these fine lines are appropriate for the order of magnitude of many of the features noted, and for the desirable habit of drawing precisely upon the outcrops or other features. This extreme care with the positions of the lines is insurance against jumping of beds, and it keeps the eyes alert for small important details. In the second place, the finer the line, the less it covers up. Thicker lines or misplaced lines are a sure way to cover up and prevent recognition of small features. In the third place a fine line located with precision gives the eyes a valuable geometric tool. If the line follows an outcrop, for instance, the eyes are provided something they can grasp visibly standing out in the three-dimensional picture to facilitate its spatial projection and discovery elsewhere in the surrounding topography.

Although india ink will give the desired fine lines, some colors erase with difficulty, even in the solvent ammonia, and some colors, especially red, cannot be erased completely. However, if fine lines are essential to a particular study and a variety of colors is not needed, black india ink is highly recommended for annotating purposes.

DETERMINATION OF QUANTITATIVE GEOLOGIC DATA FROM PHOTOGRAPHS

ORIENTATION OF PHOTOGRAPHS FOR STEREOSCOPIC VIEWING

Proper orientation of photographs for steroscopic viewing is necessary in any work where quantitative measurements or reliable estimates of structural data are required. A three-dimensional impression of the terrain can often be obtained in haphazard arrangement of photographs under the steroscope owing to the ability of the human eye to compensate small areas for misorientation of the photo-pair, but such misorientation may cause significant errors, especially in the quantitative evaluation of low-dipping planar structures, such as bedding in sedimentary rocks. Also, as mentioned previously, the field of view preferably should appear to be horizontal for estimating quantitative geologic data inasmuch as planar and linear structures in the steroscopic model are generally referred mentally by most interpreters to the horizontal plane of the desk top. Proper orientation of photographs is also to be encouraged to avoid eye strain.

Regardless of the type of stereoscope used, proper orientation of photographs demands that they be alined along the flight lines. This requires alining the principal points and transferred principal points, and can be accomplished in different ways. (The principal point is located at the intersection of lines drawn between opposite fiducial marks located on the four sides of the photographs. It is transferred to the other photograph of the stereo-pair by steroscopic inspection.) One photograph is fastened to the table by a straight pin through the principal point, allowing for rotation of the print around this axis. The second photograph is fastened to the table in the same manner, the distance of image separation of the photographs ranging from about 2 inches if a pocket stereoscope is used to more than 10 inches if a mirror or prism-mirror stereoscope is used. With the two photographs free to rotate around the respective pins, a straight edge is laid against the two pins. Each photograph is then rotated until the transferred principal points also lie along the straight edge (equivalent to the line of flight). (See figure 4.) This places all

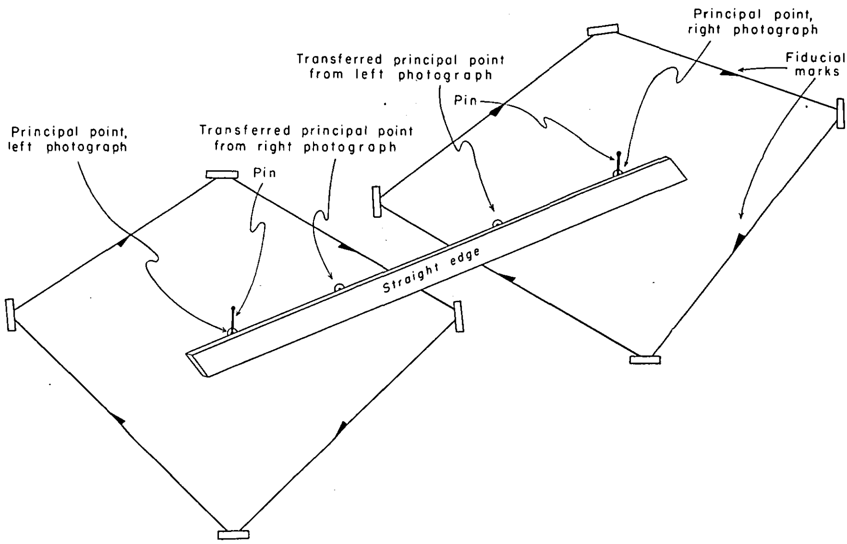

FIGURE 4.—Diagram showing correct orientation for photographs for stereoscopic viewing.

four points—two principal points and two transferred principal points—along the same line, and the photographs are then taped down in their correct positions for stereoscopic viewing (Nowicki, 1952, p. 529–533). In placing the stereoscope into position for viewing, care should be taken that the stereoscope axis—the horizontal line through the centers of the eye lenses—is parallel to the line connecting the principal and transferred principal points of the photo-pair. Although the discussion of proper orientation technique appears to be long, orientation procedure takes but a short time and is essential in work where quantitative measurements or reliable estimates are to be made.

Correct orientation may also be made in a somewhat simpler manner. A thread or fine string is stretched in the plane of the photographs parallel to the stereoscope axis (the horizontal line through the centers of the eye lenses) and attached to the table with thumb tacks. Each photograph, with its principal and transferred principal points marked, is then slipped underneath the thread or string. The principal points and transferred principal points are merely lined up under the string, taking care to separate the prints for comfortable viewing, and photographs are taped to the table. In practice, some photogeologists have the thread and photo-holding assembly on a separate movable cardboard mount. This allows movement of the stereoscopic model if the Ryker stereoscope, which is most conveniently mounted in a fixed position, is used.

PHOTOGRAMMETRIC MEASUREMENTS OF GEOLOGIC DATA

An integral part of most photogeologic studies is the quantitative determination of geologic data by use of appropriate photogrammetric instruments. These instruments are measuring devices that afford reliable objective data concerning structural attitudes, stratigraphic thicknesses, and relative altitude differences. Such measuring devices aid in photogeologic interpretation of an area in much the same way as the Brunton compass or planetable and alidade do in field interpretation. The procedures followed in making these quantitative measurements are varied and depend on the particular photogrammetric instruments used.

Several instruments have been or are currently being used for determining relative altitudes of points in a stereoscopic model (fig. 5).

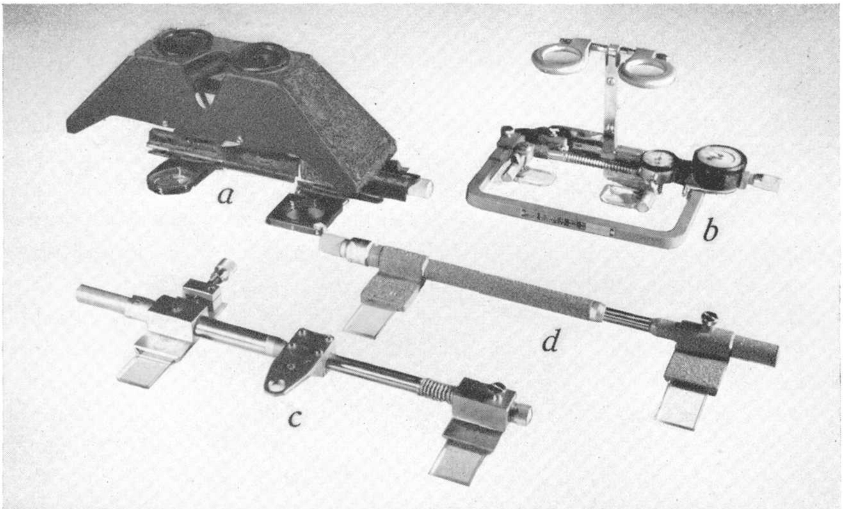

FIGURE 5.—Height-finding instruments commonly used. *a,* Stereocomparagraph; *b,* Height-finder with dial reading scale; *c,* Stereometer with drum reading scale and parallel-motion arm attachment; *d,* Stereometer with drum reading scale.

All are based on the "floating-dot" principle, where two dots, one seen with each eye, are fused stereoscopically into a single dot that appears to float in space. The apparent height of the single fused dot is related to the horizontal separation of the individual dots being viewed. Thus by measuring the horizontal separation between individual dots when the fused dot in the stereoscopic model is placed at the top of an object (such as a hill or a cliff) whose height is to be determined, and subtracting from it the measurement of the horizontal separation between individual dots when the fused dot is placed at the bottom of that object, the so-called parallax difference is obtained, and this is directly related to the height of the object.

One of the most commonly used height-finding instruments is shown in figure 5*d*. The measuring device, or parallax bar, is attached to a drum-type scale reading directly to hundredths of millimeters. In practice the horizontal separation of individual dots is measured to the closest hundredth of millimeter. In order to obtain the object's height in feet the resulting parallax difference must then be multiplied by a conversion factor determined by the flying height of the plane at the time of exposure of the photo-pair and by the photo base of that photo-pair.

Computing relative altitudes using the stereocomparagraph or other stereometers follows the same general procedure as that just described. Some stereometers have no mechanism for attaching the instrument to a parallel motion arm, but this is not a serious deterrent to their use as proper orientation is achieved optically. Parallax may be recorded on a drum-type scale or dial-type scale, depending on the instrument used (fig. 5).

Another height-finding instrument, of particular use to the field geologist because of its portability and design for use with the pocket stereoscope, is shown in figure 6. This instrument has also been designed for use with mirror stereoscopes. This new parallax ladder is advantageous for field use as it is designed to read relative heights directly in feet. Like the above-mentioned instruments, it is based on the floating-dot principle. The instrument consists of two rows of dots on separate plastic arms, and a device for introducing factors of photo base and flying height of the plane (fig. 6). Introducing the photo base and flying height gives a slight divergence to the arms on which the dots are scribed. Thus a series of pairs of dots each with different horizontal separations exist. The difference in separation of any two pairs of dots for different flying heights and photo bases has been predetermined and set to represent 5 feet of relative elevation. The instrument, oriented at right angles to the flight line, is used by sliding it over the stereoscopic model until a pair of dots—seen stereoscopically as a single dot in space—appears to fall on the base of the object whose height is to be determined. A relative reading in feet is then

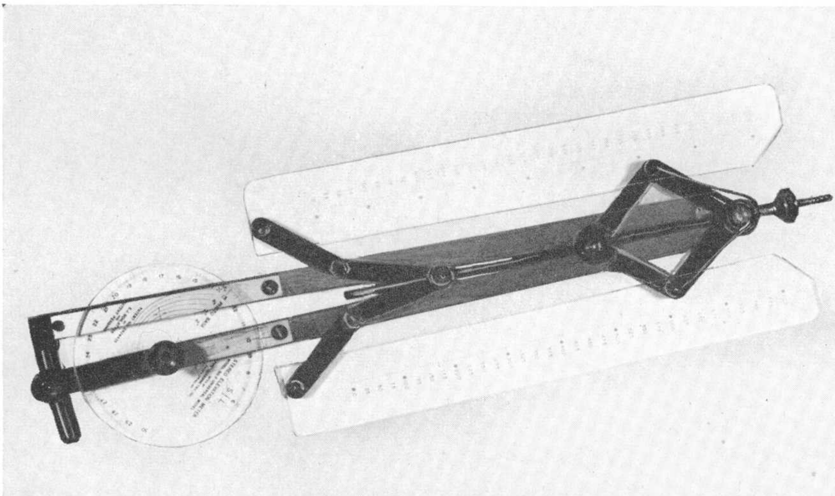

FIGURE 6.—Direct-reading parallax ladder.

made directly from the instrument. The elevation meter is then moved until a different pair of dots—also seen stereoscopically as a single dot in space—appears to fall on the top of the object whose height is to be determined. Again the relative reading in feet is made directly from the instrument. The difference of these two relative readings is the height of the object in question.

An instrument designed primarily for slope determinations has recently become available. It consists of two transparent disks with eccentric circles of specific diameters scribed thereon (fig. 7). These disks are mounted in a frame so as to be movable horizontally in a fashion similar to the dots of the stereocomparagraph or stereometer. In stereoscopic view the two sets of eccentric circles appear as a cone that is divided into several zones. By proper horizontal spacing of the

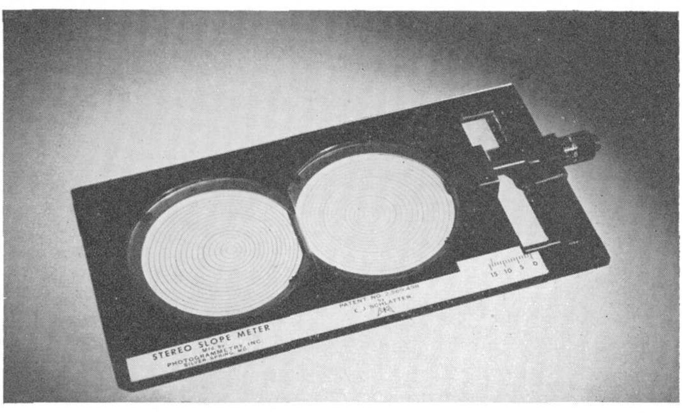

FIGURE 7.—Slope-measuring instrument. (Courtesy of Photogrammetry, Inc.)

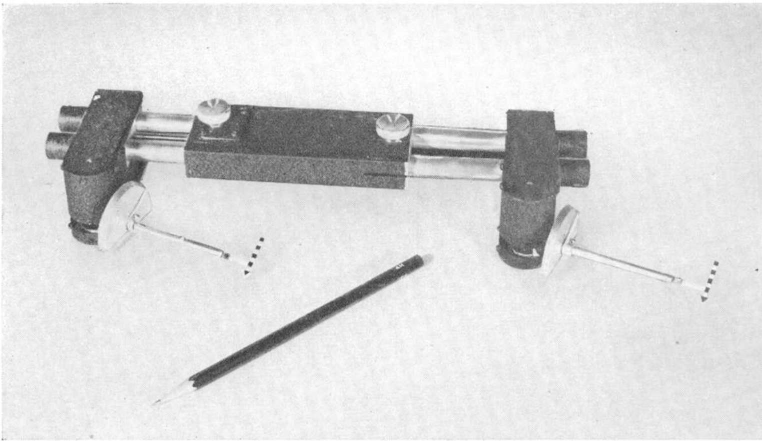

FIGURE 8.—Stereo Slope Comparator.

two disks, the resulting cone seen stereoscopically can be raised or lowered so that some two circles will rest on the slope or grade to be determined. By appropriate simple calculations the slope can now be determined. Center dots present on each of the transparent disks also permit relative altitudes to be determined from the stereoscopic model.

An instrument that promises to be of particular use to interpreters is the Stereo Slope Comparator [1] (fig. 8), now being tested and evaluated. The instrument is designed specifically for determining strikes and dips of planar structures but differs somewhat in operation from the stereometer-type instruments for slope determinations. It uses two small targets that may be fused stereoscopically into a single target. Like the fused dot in the stereometer-type instrument, the fused target is raised or lowered with respect to the stereoscopic model by varying the horizontal separation between individual targets. However, the dip is determined by actual physical tilting of the target in space. Because of the vertical exaggeration inherent in most stereoscopic models, the dip determined is an exaggerated dip that must be reduced to a true dip. This is done by reference to a supplementary slope chart and slope-conversion graph. The Stereo Slope Comparator has the particular advantage of allowing strikes and dips of planar structures to be determined rapidly.

PLANIMETRIC BASE-MAP COMPILATION

Where no base maps exist planimetric bases may be compiled using control derived from radial- or stereo-templet triangulation nets. Radial-templet methods of control, based on single templets constructed for each photograph, have been used for many years, but stereo-templet methods, using a double templet construction based on

[1] This instrument is also familiarly known as the Super Duper Dipper.

the stereoscopic model, is relatively new (Scher, 1955). The map positions of selected points on the photographs are determined by this aerial triangulation network. These points then serve as control for transfer of planimetric data from the photographs to the base. Although the base-map compilation is primarily an office technique, horizontal control based on field survey is necessary for checking accuracy and for determining the scale. Completion of the base map requires transfer of planimetric data, primarily streams and culture, to the point-control manuscript. The transfer of planimetric data is usually accomplished at the same time as transfer of geologic data from photographs to the base manuscript. These transfer procedures are described below.

TRANSFER OF GEOLOGIC DATA FROM PHOTOGRAPHS TO BASE MAPS

REFLECTING PROJECTORS

Transfer instruments of this type involve direct projection of a single photograph to the base map or base control. In practice the photograph is projected so that control points on the photograph coincide insofar as possible with the control points on the base manuscript, and planimetric detail is then sketched directly. All photograph control points and base manuscript control points will rarely coincide, however, because of ground relief, which results in radial displacement of images on all single aerial photographs. This is especially true if relief of the area being studied is high. Therefore, this transfer technique works best on photographs of areas of low relief. Adjustments in scale of different parts of a photograph may be made to compensate for excessive relief displacement, but map accuracy is generally lost under these conditions. If fairly dense stream control already exists on a base map, it may be feasible, provided relief of the area is low, to transfer data by direct projection based on this control, and thus obtain more reliable positioning of geologic data than by point control alone. Errors due to tilt inherent in aerial photographs cannot be corrected with most direct-projection instruments. However, in present commercial photography, the small amounts of tilt do not pose serious positioning errors of planimetric detail, especially if the map is only semidetailed or is of reconnaissance nature.

SKETCHMASTER

The sketchmaster is an instrument that uses the camera lucida principle in transferring data from the photographs to the base map. Both vertical and oblique sketchmasters exist, but most geologic interpretation and annotation is done on vertical aerial photographs, and use for this type instrument would be confined largely to the vertical sketchmaster. In brief, the sketchmaster allows the operator to view a single photograph image superposed on the base map. Adjustments for scale changes permit coincidence or near coincidence of photograph control points and base-map control points. Geologic detail is sketched directly on the base map. This instrument can be adjusted to remove small amounts of tilt inherent in some vertical photographs, but like the direct-reflecting projector large amounts of radial displacement due to relief exaggeration cannot be effectively removed.

MULTISCOPE

The multiscope is a combination of mirror stereoscope and camera lucida. Photographs are mounted on movable photograph plates that permit small adjustments for tilt. The viewing assembly is constructed to allow the insertion of one or two semitransparent mirrors in the eyepiece, so that in operation either a single photograph image or the stereoscopic model may be superposed on the map base. Although the stereoscopic model may be seen at all times, use of only one semitransparent mirror permits the eye to see only one photograph image superposed on the map base; the resulting plot is similar to that from the sketchmaster—no errors due to relief displacement are removed. If, however, two semitransparent mirrors are used, appropriate manipulations permit true orthographic plotting of detail from the stereoscopic model. Scale adjustments between photographs and map base are made by interchanging special lenses in the viewing assembly together with changing manually the distance of the viewing assembly above the map base.

RADIAL PLANIMETRIC PLOTTER

The radial planimetric plotter consists of a mirror sterescope mounted above two photograph tables (fig. 9). A transparent plastic arm with a centrally scribed line extends from and pivots around the center of each table. These arms are linked to a pantograph attachment. In operation, a pair of vertical photographs is oriented on the photograph tables for proper stereoscopic viewing, and control points on the photographs are oriented to control points on the base manuscript. As the plastic arms radiate from different centers they cross each other and form the so-called plotting cross. Movement of the pantograph attachment moves the plotting cross over the stereoscopic model and permits tracing of photograph detail on the base manuscript. Inasmuch as the radial arms that intersect an object on each photograph represent azimuth lines from known points on the base manuscript, the intersection of these two arms will represent the true map position of that object. Thus the displacement of an object on a photograph resulting from high relief of the terrain is effectively removed; this is one of the chief advantages in using the radial plani-

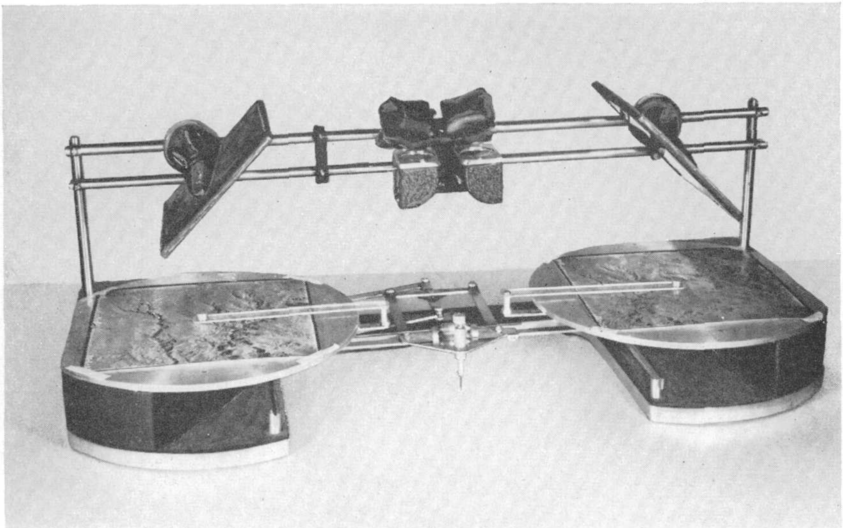

FIGURE 9.—Radial planimetric plotter.

metric plotter. Unfortunately the radial lines do not intersect along the principal line between photographs, and the photograph tables must be shifted to their alternate centers before the central area of a stereoscopic model can be delineated. However, the radial planimetric plotter is easily set up and takes no great skill in operation. It is highly recommended for transfer of data from photographs to base maps especially where semidetailed maps are concerned. However, this instrument does not permit removal of tilt that may be present in the photograph, and thus cannot be used in precision large-scale mapping.

THE KEK PLOTTER

The KEK plotter consists of a stereoscope, two photograph tables, floating-dot assembly, and drawing attachment (fig. 10). Its operation is based on the floating-dot principle and it may therefore be more difficult for some persons to use than the radial planimetric plotter. The plotting cross of the radial planimetric plotter is replaced in the KEK by the fused dot floating in space. By raising or lowering the photograph plates the fused dot is positioned on the ground in the stereoscopic model. Vertical motion of the photograph plates is linked to a drum scale on which relative altitudes can be read directly in feet. Movement of the pantograph drawing attachment allows geologic detail to be sketched directly on the map base, but during this sketching the fused dot must be held on the ground in the stereoscopic model by simultaneous movement of the photograph plates. Because the photograph plates may be tilted to make an approximate correc-

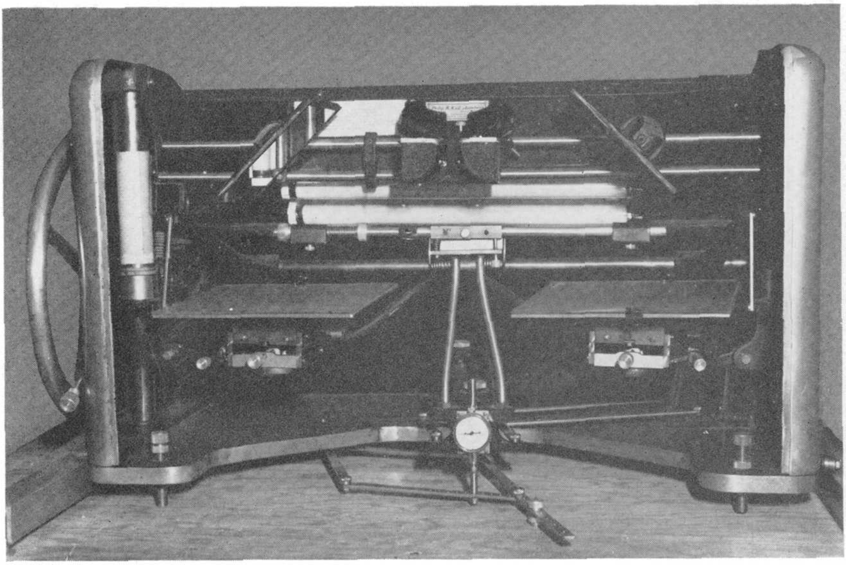

FIGURE 10.—KEK plotter.

tion for tilt that may be present in the photographs, the instrument is a more precise instrument than the radial planimetric plotter. It also permits contouring. However, for many geologic map compilations, the somewhat less accurate, but simpler radial planimetric plotter is preferred.

WERNSTEDT–MAHAN-TYPE PLOTTER

The Wernstedt-Mahan-type plotter is generally similar in principle to the KEK plotter but differs slightly in operation. The floating dot is positioned on the ground in the stereoscopic model by vertical motion of the disks on which the dots are scribed, whereas in the KEK plotter the position of the disks containing the scribed dots is fixed and the photograph plates are moved vertically in order to position the floating dot at a particular level in the stereoscopic model. The stereoscope of the Wernstedt-Mahan-type plotter is adjustable, permitting very nearly the recovery of the perspective of photographs from photography ranging in focal length from about 8¼ inches to 12 inches.

MULTIPLEX

The multiplex (fig. 11) is a precision stereoplotting instrument in which photographic images on 2-by 2-inch glass-plate diapositives are projected directly to a viewing surface beneath the projectors. The anaglyph principle is used to create the third dimension, two or more photograph images being projected through colored filters, alternately red and blue. The stereoscopic model is viewed through glasses similar in color to the filters used in the projectors, that is, red over one eye and blue over the other. In multiplex projection all features of the terrain are optically re-created in the stereoscopic model in essentially true relationship. The model is usually viewed on a small white-surfaced table called a platen, which may be raised and lowered so that a small illuminated dot in its center is kept in contact with the surface of the ground as seen in stereoscopic view. Vertical motion of the platen is transmitted to a scale reading in millimeters of parallax or, on some instruments, to a scale reading heights directly in feet. Features are traced orthographically on the base map by a pencil located directly beneath the illuminated dot on the platen. In multiplex projection the entire model area is illuminated, and if the terrain being viewed has only low or moderate relief the stereoscopic model may be observed in its entirety by subsituting a large white surface for the platen. This overall view of the stereoscopic model is often of considerable use in geologic interpretation.

In geologic work the multiplex has many advantages over simpler photogrammetric instruments. The model scale about 2.5× that of the original photography generally results in greater ease of interpretation and measuring of geologic data as well as closer positioning of detail on the map. Where field control is available any tilt inherent in the photography can be removed so that true orthographic positioning of detail is obtained. The multiplex is especially advantageous in

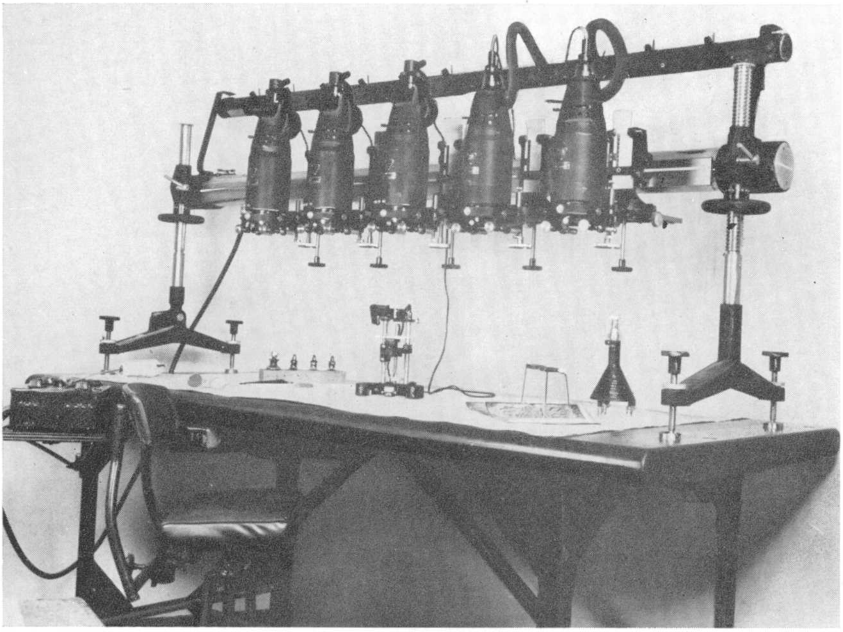

FIGURE 11.—Multiplex.

that interpretation, measuring, and plotting of geologic data can be carried out in one continuous operation.

KELSH PLOTTER

The Kelsh plotter (fig. 12), like the multiplex, projects an image from glass-plate diapositives to a viewing surface below the projectors; measuring and plotting are done with attachments to a small movable carriage mounting a platen on which the stereoscopic model is viewed. As in the multiplex the anaglyph principle is used to create the third dimension.

The Kelsh plotter differs from the multiplex in that it uses 9- by 9-inch glass-plate diapositives on which the photograph image is the same scale as the original photography. The projected model scale is about 5× that of the original photography, or about 2× the scale of

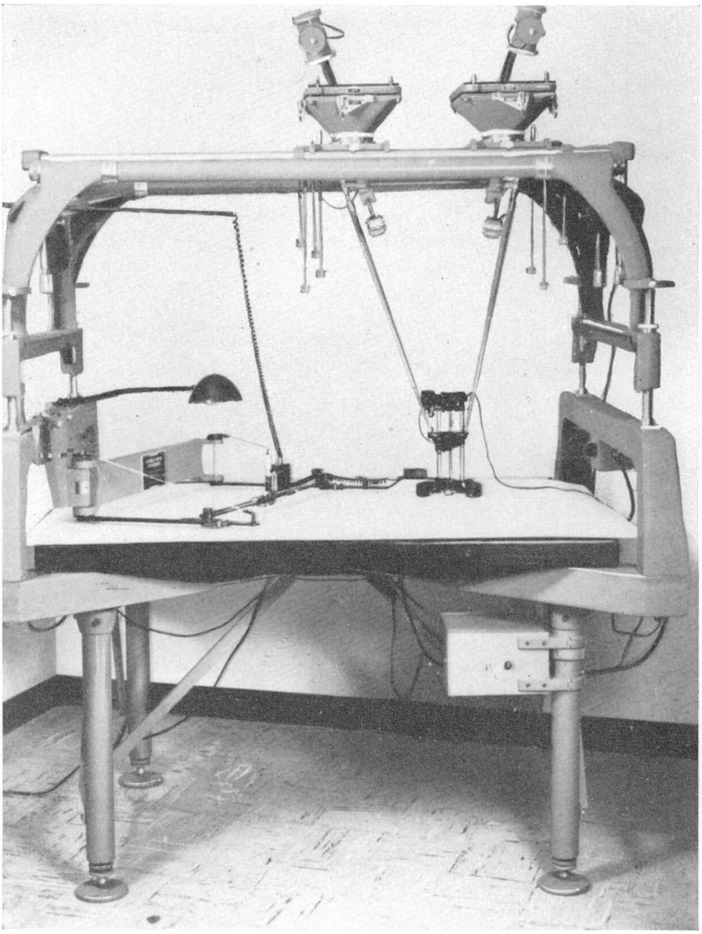

FIGURE 12.—Kelsh plotter.

the multiplex model. Only that part of the Kelsh model appearing on the platen is illuminated; this results in a greater concentration of light and a more brightly illuminated model. However, this concentration of light prevents viewing of the entire model at any one time.

Because of the 5× enlargement of the original photography scale plus the use of diapositives the same size and scale as the original photographs, thus preserving a high degree of resolution in the projected model, high-altitude photography at scales of 1:60,000 to 1:70,000 can be used in the Kelsh plotter in routine photogeologic compilation where 1:20,000-scale photographs are normally employed with simpler photogrammetric instruments. This may reduce by as much as 90 percent the number of stereoscopic models that would normally be oriented for interpretation and plotting using 1:20,000-scale photographs. In detailed studies the use of 1:20,000-scale photography, enlarged to 1:4,000 in the Kelsh plotter, gives the interpreter a great advantage in interpreting geologic data as well as positioning such data on the base map. As with the multiplex, interpreting, measuring, and plotting geologic data can be done in one continuous operation with the Kelsh plotter.

THE ER–55 PROJECTOR

The ER–55 projector, now being manufactured, holds great promise for geologic interpretation and measuring quantitative geologic data. This projector, used on a multiplex bar, combines the high degree of illumination now found in the Kelsh plotter with the ability to view the entire stereoscopic model, an advantage of the multiplex. Resolution in the smaller diapositives (4- by 4-inch) does not differ significantly from that in Kelsh plates. Convergent and divergent photography can also be accommodated with the ER–55 projector.

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