STRUCTURAL CONTOURING FOR THE PHOTOGEOLOGIST

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PERHAPS the most useful single product of the work of the photogeologist, especially when engaged in petroleum exploration, is the preparation of structural contours. These contours furnish the best means for visualizing and evaluating potential oil producing structures. They are the usual exploration product of other survey methods, as field work, gravity surveys, seismograph surveys, etc. Likewise they are the desirable outcome of photogeology, which can often give this result completely unassisted by field work or supplied elevation data.

A photogeologist's dependence on supplementary data decreases, of course, progressively as his training and experience increase. When rigorous methods of insuring accuracy are mastered, field work becomes unnecessary for purposes of correcting mistakes. When the proper photogrammetric techniques are acquired, the need for supplied elevations is eliminated for the usual tasks of contouring structure and measuring stratigraphic columns. When sufficient interpretational skill is attained, supplementary field work to fill geologic gaps is made unnecessary at least in a large number of petroliferous regions, insofar as the usual detailed areal, structural, and stratigraphic mapping are concerned. Not only does this realize a great saving in terms of speed and economy, but in many areas where no other methods can succeed—due to lack of exposures or lack of distinguishing characters in the lithology—photogeology is the only available means of gaining a detailed surface geologic picture.

The present article gives several successful methods for structural contouring by photogeology, with the emphasis mainly upon those that do not require the attainment of the greatest amount of the various special skills. It also emphasizes methods for the situations where no elevation control is available. It is hoped that the article will fill a need, not only for photogeologists in training, but also for many professionals who have not yet mastered the problem of photo structural contouring without ground control, especially in areas of gentle to flat structural dip. All the methods, however, require considerable practice for efficient use, even when the operation is essentially mechanical rather than interpretational.

THE OUTCROP PATTERN

The preparation of structural contours to a measured interval presupposes the completion of the basic geologic interpretation as regards the delineation of the outcrop and fault pattern. The present article does not discuss the criteria of interpretation yielding this, nor does it make any difference in what is to follow, whether this was derived with or without the help of field work or other externally supplied information. To prepare the contours satisfactorily, however, requires that the outcrop pattern be presented according to certain specifications, which are as follows:

a) Scattered fragmentary outcrop lines with little or no continuity or correlation are unsatisfactory. These may be good as a basis for placing locally applicable dip and strike symbols, and estimating the degree of dip, or even the local contour spacing for structural contours, but hardly for continuous measured contours of any extent.

b) Even if the photo expression of bedding is poor or discontinuous, the best interpretational effort must be made to carry selected stratigraphic horizons as continuously as possible. These should be at fairly close stratigraphic intervals, more numerous, usually, than the number of formational contacts intended for the compilation. The outcrop pattern should include published or to-be-published contacts.

c) The outcrop pattern should be drawn on alternate photos of a flight series, and should cover these photos completely. The lines should be drawn on the photos themselves, and not on overlays. They should be very fine ink lines in various colors, and not pencil or crayon lines.

d) The lines should be drawn with the maximum care and precision as to their correct positions on the photograph, even with reference to finer details of vegetation, etc., as seen under the stereoscope. Particularly they must lie in the correct positions at all places, with respect to the third dimension as closely as the eye can tell. This means in practice that where an outcrop is either actually seen or confidently interpreted, the line is placed exactly upon it, and where not seen or so indicated, the line is placed by careful extension, conforming to the topography so as to lie exactly in the plane produced by the portions of the line first established.

TOPOGRAPHIC CONTOURS

Several of the methods of structural contouring utilize in a preliminary step, topographic contours as a means of deriving the necessary elevations of points along the selected outcropping beds, or of points through which the structural contours must pass. For this purpose, topographic contours, no matter how accurate, cannot be used if merely present on a separate topographic map. Contours are usable only when drawn neatly and carefully upon the visible stereoscopic model on which the outcrop pattern is also seen. The outcrops and contours are separated on the two photos which are combined under the stereoscope.

The writer has previously published the instructions for training in accurate contour sketching on the stereo photos guided by such an available topographic map.* This training is invaluable, not only for the specific objective of elevation determinations, but for the mastery of refinement and skill that also improve accuracy of geologic annotations. As more precision is attained, the topographic map used as a guide may be on a smaller scale, or be less accurate, and yet serve adequately. With further practice a few supplied field elevations or bench marks may replace the topographic map, and even these may be finally dispensed with. While the original article recommends that the contours not be drawn upon the set of photos on which the geology is drawn, but on the alternate photos of a second set, this duplication of photo sets is now recommended only for beginners. A professional photogeologist should require only one set, and experience no confusion in drawing contours of elevation on a model which already has geologic outcrops drawn upon it. Of these two types of annotations, the geology should by all means be drawn first.

To facilitate certain preferred methods of structural contouring, the topographic interval should be double that of the intended structural contours. If the relief is very small, they may be drawn at the same interval, and at times some other simple multiple than these is indicated. This relation is of no importance when the topographic contours are used merely to get spot elevations on

* Desjardins, Louis, and Hower, S. G., "Geologic mapping from the air," *Oil and Gas Jour.*, Vol. 37, No. 52, May 11, 1939, pp. 44–46, 59. Or:

Desjardins, Louis, and Hower, S. G., "Geologic, topographic and structural mapping from aerial photographs," *Am. Petr. Inst.*, Finding and producing oil, 1st ed., 1939, pp. 29–33. Also:

Desjardins, Louis, "The contouring problem," PHOTOGRAMMETRIC ENGINEERING, Vol. 6, No. 4, Oct.–Dec. 1940, pp. 163–165.

beds, but is useful when the spot elevation step is omitted as will appear later.

Even when there is some control to guide the contouring this is not really the principal guide that must be heeded. Everywhere the attention must be given to geomorphic features related to true horizontality, and the visual checks utilized of keeping contours in plane, and keeping planes parallel and of equal interval. These geomorphic and visual criteria become the basis for the successful drawing of contours without the external guides. In this case the contours must be given the proper interval by one or more photogrammetric parallax measures made at suitable places on the model. A simple approximate parallax-elevation relationship will suffice, the best formula being:

$$p(\text{mm.}) = \frac{12i(\text{ft.})b(\text{mm.})}{f(\text{in.})S} = \frac{1000i(\text{m.})b(\text{mm.})}{f(\text{mm.})S},$$

in which p is the parallax difference corresponding to i which is the contour interval, and b is the photo base, f the focal length, and $1:S$ the photo scale. Theoretically, this formula is exact when the photos are without tilt, when b is corrected to the value it would have if the transferred photo center were at the elevation of the upper limit of i, and when $1:S$ is the photo scale corresponding to the elevation of the lower limit. Since all the factors but b are constant, in a given series of photos, it is convenient to solve this constant, and place it against one (the index) on the slide-rule, thus permitting the value of p to be read for all models on this single slide-rule setting. Having found p, one may use a floating dot parallax bar or parallax wedge to visibly judge this interval, as one needs it in checking the vertical interval between two contours.

Contours may also be sketched using adjusted floating lines as a guide. The theory and mechanics of these lines were described in an earlier article in PHOTOGRAMMETRIC ENGINEERING by the author.* Briefly, these are fine straight lines laid over each photo at approximately right angles to the photo base, the two groups of lines to fuse with each other in the stereoscopic examination. The lines over the photo to be contoured are ruled directly on it in ink, whereas the lines over the other photo, containing the annotations of the bedding outcrops, are provided on narrow individual strips of transparent film, the strips being mounted either to a sliding sheet of transparent film covering the entire photo and equipped with a parallax scale, or mounted directly to the photo.

When it is desired to utilize furnished known elevations in the floating line adjustment, the procedure described in the article cited as to the elevation-parallax calibration should be followed. This has complete theoretical exactitude and expresses the elevation-parallax relationship truly as a curved line graph. After the adjustment of the floating lines is made the contours are drawn quickly on the opposite photo at the intersection of the apparent topography with the plane of the floating lines, this being successively raised for each contour according to the parallax reading determined on the graph.

The chief virtue of the floating lines is in their ease of adjustment to express true horizontality in respect to the topography even without any outside control, thereby eliminating all effects of photo tilt. Therefore this is a practical means of guiding the drawing of contours in areas where there is no elevation control supplied. The floating lines are leveled up against all criteria for natural horizontality seen at any part of the topography at any level. They adhere to the geometric requirement that the lines be straight, and they are checked by

* Desjardins, Louis, "Contouring and elevation measurement on vertical aerial photographs," PHOTOGRAMMETRIC ENGINEERING, Vol. 9, No. 4, Oct.–Dec. 1943, pp. 214–224.

the very sensitive visual aid that the several lines lie precisely in a single plane. The contour interval determination in this case is simpler than in the last, the formula given above being sufficiently accurate to give parallax differences for the successive levels. The contours may refer to an arbitrary datum, or made to express approximate sea level if tied to some known point.

A simpler method using the principle of floating lines, but requiring more skill, is to mount the line strips directly on the photo containing annotated outcrops. They are individually adjusted and fastened to float at the approximate level of the highest parts of the topographic surface. This adjustment is much quicker than that of lines on a sliding sheet, and there is less tendency for false parallactic effects which often hamper the other method when the photos are perfectly flat. The next step is to make a number of pairs of spot readings with a floating-dot parallax bar, one reading of each pair on a selected point on the ground directly beneath one of the floating lines, and the other on the floating line itself directly above. The points selected should be along streams and ridges, and the number required greatly diminishes for the person who has acquired skill in contour sketching. The difference between the readings is converted to feet (or meters) from a slide-rule setting which is best gotten from a modified form of the formula used above. This is:

$$K(\text{ft.}) = \frac{f(\text{in.})S}{12b(\text{mm.})} \quad \text{or} \quad K(\text{m.}) = \frac{f(\text{mm.})S}{1000b(\text{mm.})},$$

where K is the elevation difference corresponding to 1 mm. of parallax, and other factors are as before. Again in this case all factors on the right side except b form a constant for an entire series of photos. Consequently if one sets this constant against b on the slide-rule, one can then read the corresponding elevation difference against any measured parallax difference. At each of the ground points in the process described above, the value of the elevation difference is marked on the photo to be contoured. The line strips are then removed from the other photo, and free-hand contour sketching proceeds guided by the evaluated points plus the usual topographic and visual controls. It makes no difference that these elevation values are greatest for lowest levels and vice versa. After the contours are drawn they may be given new numerical values in the right order.

Contours are best drawn in extremely fine black ink lines. Erasing and improving the lines is done freely, the eraser being merely a bit of moist cotton taped on the end of the penholder. Alternate photos in a series will be contoured, and in cases where there is no sea-level control this will mean that the contours of one photo will not join those of the next. Slight discordances of the interpreted horizontal in the overlapping portions can be tolerated, and an average of the two versions struck when these are used to guide the structural contours.

SPOT ELEVATIONS

The best known structural contouring procedure in most other geologic and geophysical methods is by means of determining the elevations of frequent points along selected beds or bedding planes, and contouring the numerical values of these spot elevations. The original photogeologic method of the author (see reference in the first footnote) follows this plan. Recently other quicker more direct methods without spot elevations have been used, to be described below. However, it is considered worthwhile to include the discussion of spot elevations here, and recommend their use to others who are accustomed to this approach, and to students of photogeology in any case, as invaluable training.

For purposes of the present article, the preceding processes of topographic contouring may be considered to be for the purpose of determining spot elevations, or they may be planned for quite other uses to be described later. Also, when spot elevations are used, they may be derived either from such contouring first prepared, or they may be derived in other ways to be discussed. Still later steps are possible omitting both of these steps, as will be seen.

The originally described method of structural contouring by spot elevations is still used. This is to place a transparent sheet over the photo with oûtcrop annotations, and on this mark the elevation readings estimated from the contours seen in the stereoscope from the other photo. Use colored pencils, the color to match that of each bed in question. Rather than make a dot with a figure written beside it, the figure alone, usually limited to the last two digits, is placed on the approximate position intended. This is consistent with the lack of pinpoint precision, as all spot elevations are regarded as approximate estimates. These are made with extreme rapidity compared with quantities derived from a measuring device, and they can therefore be made liberally with a dense distribution. Before making each estimate, however, one should take the occasion to make a quick inspection both of the bed and of the nearby contours, to see that they have been drawn properly in this immediate locality. It frequently may be noticed that either the bed or the contour might better have been placed a little lower or a little higher. The correction or improvement is made mentally, and the elevation estimate takes this into account. A few identification or tie points are marked on each overlay, for purposes of laying these into the form of a mosaic later.

There are two principal spot elevation methods without contours, and utilizing floating lines. The first is that with the lines mounted on the sliding sheet with attached parallax scale. The adjustments of the lines and calibration of elevation and parallax are as before. The plane of the floating lines is brought by sliding the device to the level of each of the selected spot points on the beds, a reading made on the parallax scale, and the corresponding elevation noted. Since the sheet covers the photo containing the beds, the noted points and their elevations are marked on the opposite photos. Transparent paper is not recommended. The elevation figures may best be printed very small in black ink, and underlined by their appropriate colors so that those belonging to each bed are clearly grouped. This method, though laborious, is suited to the worker with less skill than required for the next method.

This method is one that involves the preparation of a "correction graph" for tilt. One other writer has attempted to utilize such a method, but obviously with very little success.* Background information on the correction graph is given in Nowicki's article on the stereocomparagraph.† The author has already shown how a much better correction graph, with or without the benefit of furnished ground elevations, can be constructed from a distribution of points measured on adjusted floating lines.‡ In practice it has not been found adventageous to construct the correction graph if one has the sliding floating lines with attached parallax scale. When one does not have this equipment, but has a standard floating dot device and the simple individual floating line strips, the graph is made and used as follows: On the photo without annotated bedding,

* Nugent, L. E., Jr., "Aerial photographs in structural mapping," *A.A.P.G. Bul.* Vol. 31, No. 3, Mar. 1947, pp. 483–486, 491.

† Nowicki, A. L., "Practical applications of the stereocomparagraph," MANUAL OF PHOTOGRAMMETRY, 1st ed., 1944, pp. 469–476.

‡ Desjardins, Louis, PHOTOGRAMMETRIC ENGINEERING, Vol. 9, No. 4, Oct.–Dec. 1943, pp. 220–211.

the ink lines are ruled, and on that with bedding the strips are adjusted and fastened to fuse as a horizontal plane at a level just above most of the streams. On the first photo, an overlay sheet of tracing paper is fastened along one edge, hinge-like, to fold out of the way during stereo viewing. With the parallax device, a number of readings are made with the floating dot brought to regularly distributed points on the floating lines (not on the topographic surface). Each reading is recorded at the proper point on the tracing paper brought into position. The reading values are contoured, usually at five one-hundredth millimeter intervals, this contour pattern becoming the correction graph. These graph lines are then assigned a new set of values to serve as corrections, as follows: Label some central contour zero, then in the direction of originally decreasing numerical values, label the consecutive lines plus 5, 10, 15, etc., and in the other direction (larger original readings) minus 5, minus 10, etc. The strips may then be removed from the opposite photo, and ink lines erased from the first photo. Spot elevations on ground points may now be made by bringing the floating dot to each such point, reading the parallax dial, and applying the correction to this reading taken from the correction graph according to the point's location. The slide-rule setting last described (constant against *b*) will give comparative elevations against the corrected parallax readings. From here the procedure may be the same as before, that is, recording the elevations on the photo without annotations and underlining in colors. It is not necessary to convert the elevations to any particular datum, but one can use the figures that the slide-rule happens to give. Correspondence of these from one stereo model to the next is not to be expected. As will be seen later their complete use for structure is realized under these conditions.

PRELIMINARY STRUCTURAL CONTOURS

The preparation of preliminary structural contours, that is, contouring each outcropping bed over the area of its individual occurrence, is the usual step previous to drawing the final unified set of contours over the entire area mapped, or over as large an area as it is desired to contour on a single projected key bed. The omission of the preliminary contouring comes progressively with increased skill, and is progressively indicated as formations dip more steeply. In regions of gentle dip, a skilled worker will utilize this step in careful detailed work, but may omit it for reconnaissance work. Usually where the preceding steps of topographic contouring or spot elevation determination are included, preliminary structural contouring is also included.

If spot elevations have been made on individual beds from topographic contouring as described above, they are given on transparent paper overlays by small pencil numbers in various colors. Two types have been noted, the first being those from continuous contouring having sea-level datum. In this case the overlay sheets are assembled mosaic-fashion over a large sheet of white paper against which the colored numbers stand out clearly. The preliminary structural contours for each separate bed are drawn in the color corresponding to that bed, and throughout the area of that bed's occurrence. The areas of these sets of contours, of course, overlap, but the colors keep all lines distinguished. The other type, that where the spot elevations do not refer to sea level nor agree from one model to the next, requires the preliminary contours to be drawn on each overlay sheet separately and completely, and then they are brought together as a mosaic. Occasional discordance will be noted in the contours of particular colors where these are duplicated in the overlap of the sheets. Conspicuous discordance denotes lack of skill in judging and adjusting for the horizontal. Usually the final structural contours (see below) are merely made to express an average both as to direction and spacing of the two versions of the preliminaries not quite in agreement.

When spot elevations have been derived from parallax readings rather than topographic contours, with the figures recorded on the photos instead of overlays, preliminary structural contours may also be drawn on the photos, in neat ink lines of the proper color. However, it is possible to use transparent or tracing paper for this step (and for the preceding one of recording the elevations), if one wishes to keep the photos relatively clean, or to have a permanent record of these intermediate steps. The preference for working directly on the photo as much as possible is in seeing everything on the stereo model as one works, besides the greater simplicity and speed. These steps lend themselves to direct photo annotation, as there is very little need for erasures and corrections, as in various other steps.

The most satisfactory method of preparing preliminary structural contours is not by spot elevations, however, but by drawing them directly in the stereo view of beds combined with topographic contours of the same or double interval or other simple multiple or fractional part. Double the interval is the best from the standpoint of economy in preparing topographic contours and accuracy in estimating the positions of the intermediate structural contours. One may use either pencil and transparent paper over the photo with the topographic contours, or draw the preliminary contours directly on this photo in colored ink. The first contours to draw are those which pass through the apparent intersections of the beds with the topographic contours, especially for beds that make two or more such intersections close together on the same contour. The lines through the other intersections are guided in direction by parallelism with those first drawn, and by an estimate of the local strike of the beds. The last lines drawn are those not indicated by intersections, but through estimated points where beds have an elevation midway between two topographic contours (or other fractional part required).

Not included in the present article, but mentioned here in passing, are additional uses that might be made of preliminary contours made in any of the above ways. These are stratigraphic and structural cross sections, and stratigraphic columns to scale. If one wishes to refer final structural contouring to one single key bed a great distance beyond its outcrop, this bed can be extended on such a cross section in both groundward and airward directions, and its elevations so derived can be marked on the photos or overlays to guide such contouring.

The next two methods for preparing preliminary structural contours are recommended only for workers of considerable skill who wish to bypass most of the preceding steps and draw final structural contours with the minimum of guidance. In these cases the preliminary contours have no definite interval, but are merely structural form lines or strike lines. These methods apply where the dip is too gentle for the strike direction to be judged accurately by inspection. They also apply where the relief is so great and the topography so dissected that topographic contouring would be extremely slow and tedious. In both of these methods the sliding floating line sheet is used. In the first the lines are adjusted to horizontality, and in the second they are adjusted to float in the bedding planes.

In the first method, the horizontally adjusted floating lines are brought to the highest level where bedding is encountered, and then brought to successively lower levels until they reach the lowest streams. At each position the bedding is observed for instances of bedding planes cutting the floating plane. Fine dotted lines are drawn giving the direction of the strike. The other method is appropriate where bedding is nearly horizontal and is best expressed in the upper parts of a rugged topography, in which horizontality is more easily interpreted at stream level. The floating lines are adjusted to give a plane parallel to bedding planes, and then brought down nearly to stream level, where the direction of the strike becomes more apparent, and a number of strike lines can be drawn. It may be thought that the first method could accomplish all that this one does, but the superiority of the latter lies in the greater precision and quickness of adjusting lines to float in bedding planes, and the great extension and visibility it gives these planes. Estimating the strike directions takes more skill, however. Both of these methods aim at a skill that also permits estimating the final contour spacing without requiring that this be established in the preliminary contours or strike lines.

FINAL STRUCTURAL CONTOURS

Before discussing methodology in connection with the final structural contours, the considerations governing the selection of and definition of the key bed are important. Customary geologic practice is to contour an actual bed, over a considerable distance, and usually over the entire area of a given map. Since the outcrop belt of this bed is usually small in comparison to this total area, the bed is projected for contouring purposes as far as necessary both into the air and into the ground. When changes in formational thickness are known and taken into account, the computed contour pattern for this projected bed may depart considerably from the contour pattern possessed locally by outcropping beds. Even though photogeology may give the data for making such projections and calculations, or supplementary data may be incorporated for this purpose, this is not considered to be the logical original contribution from photogeology, as far as structural information is concerned, which should be the surface structural picture impartially and equally in all parts of the area. Consequently no one key bed assumes any more importance than any other. A concept of structural contouring is required that will express the structure of surface beds in all parts. For this purpose we define the key bed as a phantom horizon whose plane is everywhere parallel to the bedding planes of surface formations. This simply amounts to replacing the preliminary structural contours derived in preceding steps with a single set of contours that everywhere follow the directions as faithfully as possible of the preliminaries, and at the same time adhere to their spacing. Where formations change in thickness this double condition cannot be met indefinitely, and an occasional contour has to drop out. This is better than the continuous zones of disjointed contours that would be required by dividing the area up into a number of separate contour systems, each on a different key bed. The numbers placed on contours can refer to arbitrary levels, and they can avoid the places where contours disappear. According to this, a given contour traced very far may be found to bear two different numbers, but against this disadvantage is the fact that the contours will give an entirely acceptable quantitative measure of all essential structural elements concerned in interpretation and evaluation, such as the magnitude of anticlines, their structural relief or closure, amount of fault displacement, etc.

The methodology of drawing final contours from preliminaries is very simple. When the preliminary contours are given on overlay sheets, these may be put together as a mosaic, and a fresh transparent sheet laid over the whole, on which to sketch the final contours. A black pencil is used, and erasing and improving the lines is liberally resorted to. As hinted above, these final contours follow the approximate direction and receive the approximate spacing of the preliminaries; occasionally, to avoid serious violation of these rules, a contour is dropped out. In the event that there is a noticeable angular unconformity in the beds, requiring several such adjustments, it is preferable to consider this as a special case, and instead of trying to distribute them as far from each other as possible, they should be brought together into a single zone to be labeled as an unconformity.

In the cases where the preliminary contours are drawn as colored lines on original photos, the final contours should be sketched on sheets of tracing paper laid over the opposite photos. The tracing paper will be sufficiently transparent to allow stereo fusion, but sufficiently opaque to mask the colored lines of the outcrops so that these will not cause confusion with the colored lines of the preliminary contours seen on the other photo. All the work appearing on that photo may be considered to have no permanent value, and be completely cleaned off after the final contours are drawn. This permits these contours then to be transferred stereoscopically back to this clean photo in neat fine ink lines. The tracing paper is then discarded, and the final contours are examined everywhere stereoscopically to verify all of the structural features revealed. Minor revisions are made, especially to give correct local expression to visible changes in steepness of dip, to details of flexures, etc. This added step of final improvement is highly recommended.

The skilled photogeologist will tend to omit or shorten many of the steps described in this article, and sketch the final contours interpretationally under the stereoscope. Where dips are gentle in areas of low relief, he should still utilize topographic contouring, which can be done in this case very quickly, especially using a large interval. Where gentle dips occur in areas of high relief, he may use the help of occasional strike lines or preliminary contours. His only remaining problem is determining the contour spacing. The first contour, of course, is drawn anywhere over the picture merely in the direction of the strike. The required spacing for succeeding contours can be determined readily if a stratigraphic column has already been made showing the intervals between the beds locally present. By laying a scale marked with the structural interval against this column, he can pick a stratigraphic horizon that lies the amount of this interval below or above any bed seen in the stereoscope at a contour crossing. He then estimates a point where this new horizon has this same elevation, through which the next contour must pass. This contour is carried out across the photo according to the strike. Each contour is established by one or more such stratigraphic determinations until all contouring is completed. Where there is no such measured column, the determination of the contour spacing requires the parallax equivalent of the contour interval and the determination of points on beds that are higher or lower than contour crossings on these same beds by the amount of the interval. Either movable or fixed floating lines help apply this measure so that there is no appreciable error from tilt, or the amount may be estimated to agree with a check height as described in the next paragraph.

Where dips become more pronounced, that is, beyond a degree or two, a skilled worker can learn to draw final contours immediately under the stereoscope, without visible aids to horizontality, or visible preliminary determinations of the strike directions. It is necessary, of course, that he shall have attained considerable skill in judging the horizontal plane. Less skilled workers had best start such unaided contouring with a greater degree of dip. The loss of accuracy that might result from this extreme simplicity of procedure is usually a matter of error in comparing structural elevations over a considerable distance, while for all the useful purposes of structural evaluation, both qualitatively and quantitatively, the method is adequate. One should preface the contour sketching by computing the parallax equivalent of the contour interval for each model, and have it available in a visible form for checking. Seeing a floating dot at this height above the ground may suffice, or drawing fragments of two topographic contours having this difference in elevation on a suitable hillside. With the check height well in mind, one may proceed to draw the final contours, starting any-

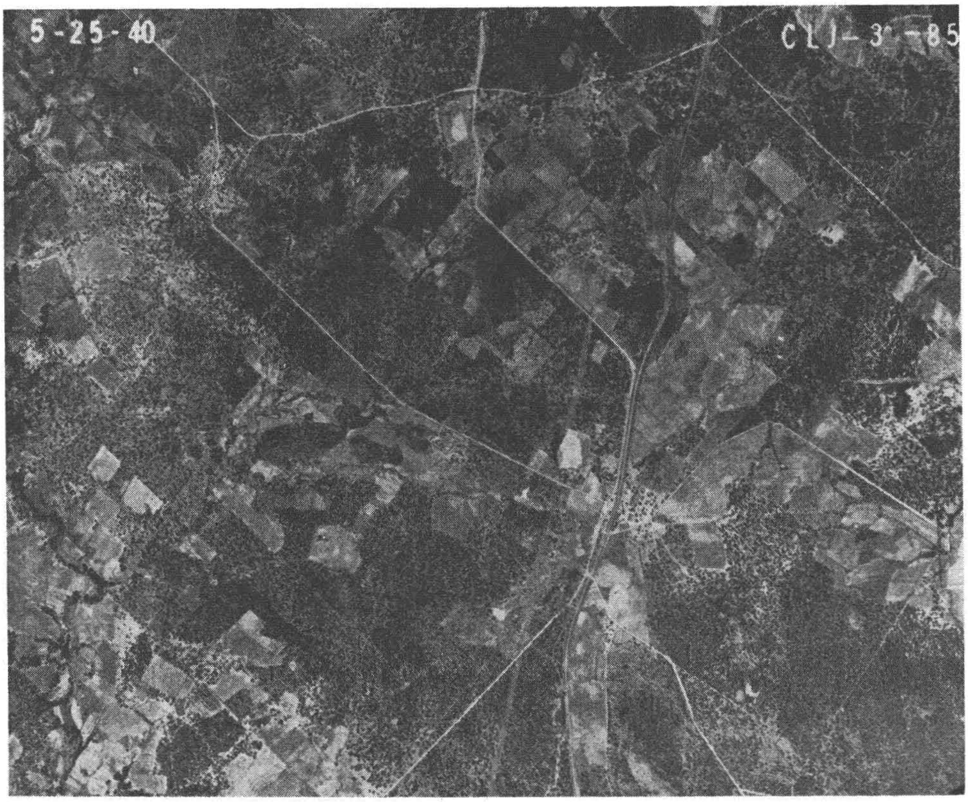

FIG. 1

where, or starting with those transferred from adjoining areas. Since the best stereoscopic view is demanded, the lines should be drawn on the photo itself, and rather fine black ink lines should be used. Erasures and revisions may be frequent.

The fact that each contour must constantly fulfill two conditions, namely, follow the strike and maintain a certain spacing from the next contour above and below, gives an automatic check on the accuracy as one proceeds. Many special situations are discovered which furnish additional checks, making the process self-correcting to a considerable degree. For instance, if the estimate of the strike direction is poorly indicated locally, and a contour given a wrong steer, a little distance away another contour will be well controlled in this respect, and the spacing demanded will lead to a revision of the first contour. Thus any situation of good control spreads itself over a considerable distance, as was the case with the adjustment of floating lines for giving true horizontality over an entire photo.

In areas of steep dips, that is, over 10°, final structural contours are the easiest drawn with no preliminary help. Strike directions are obviously easier to follow. A larger contour interval is usually selected for steep dips. The contour spacing in this case is best determined from the dip angle, the measuring or estimating of this being a familiar task to all photogeologists.* Only a few dip measurements need be made on each photo model, and estimates made at

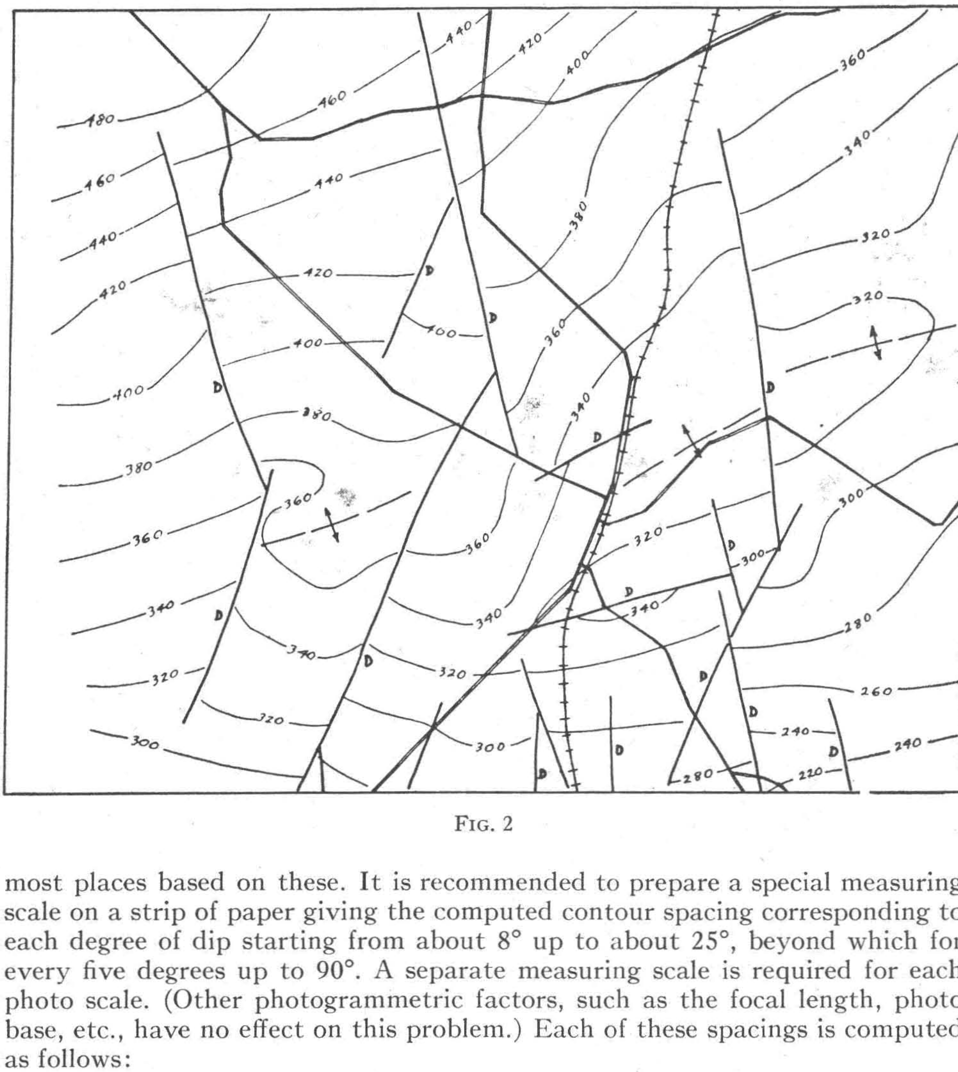

FIG. 2

most places based on these. It is recommended to prepare a special measuring scale on a strip of paper giving the computed contour spacing corresponding to each degree of dip starting from about 8° up to about 25°, beyond which for every five degrees up to 90°. A separate measuring scale is required for each photo scale. (Other photogrammetric factors, such as the focal length, photo base, etc., have no effect on this problem.) Each of these spacings is computed as follows:

$$x(\text{mm.}) = \frac{304.8i(\text{ft.})}{S \tan d} = \frac{1000i(\text{m.})}{S \tan d},$$

* Desjardins, Louis, "Measurement of dip angles on aerial photographs," *A.A.P.G. Bul.*, Vol. 27, No. 11, Nov. 1943, pp. 1534–1538. See also:

Miller, V. C., "Rapid dip estimation in photogeological reconnaissance," *A.A.P.G. Bul.*, Vol. 34, No. 8, Aug. 1950, pp. 1739–1743.

in which x is the spacing, i the contour interval, $1:S$ the photo scale, and d the dip angle.

THE FIGURES

Figure 1 is a photo selected at random in Lee County, Texas, in an area whose relief is about a hundred feet, and whose surface beds consist of sand and clay of the Yegua (Eocene) formation.

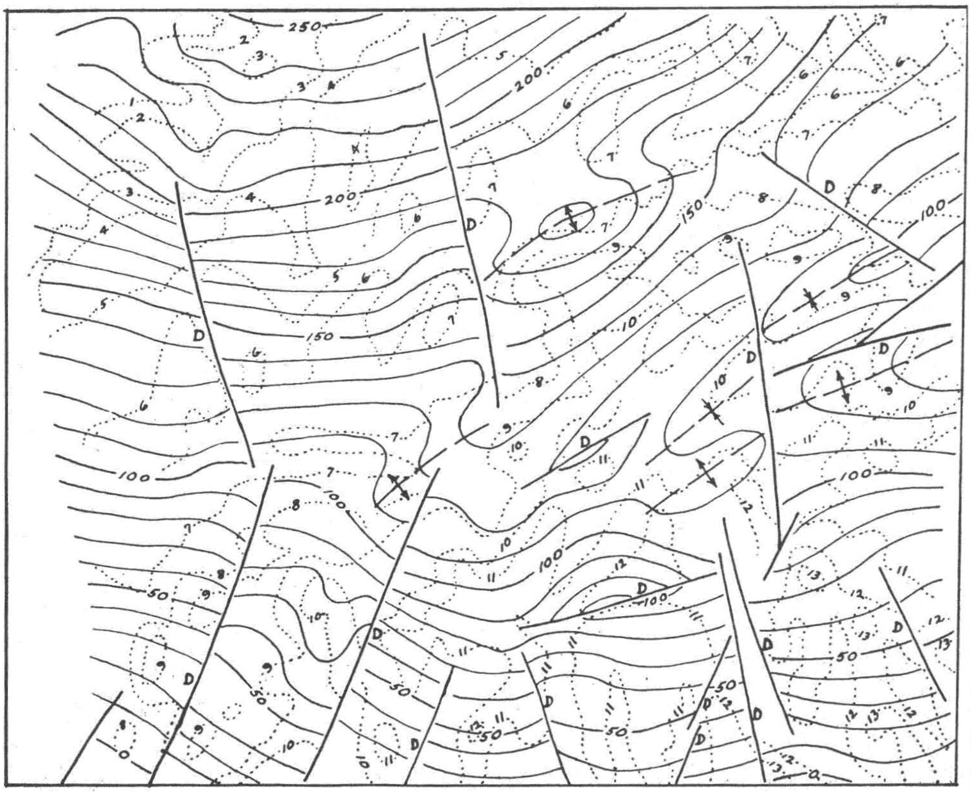

FIG. 3

Figure 2 is a reconnaissance version of structural contouring of this photo based on a reconnaissance outcrop pattern (not shown). The contours were drawn completely free free-hand (without topographic contouring, spot elevations, or preliminary structural contours), and were guided only by computing the parallax equivalent of the structural interval (20 feet), and observing its apparent magnitude by the setting of a floating dot at this height above the ground. These "reconnaissance structural contours" have an important role in petroleum exploration in view of their extreme rapidity and economy.

Figure 3 is a more detailed contour version of the same photo on a 10-foot interval based on a revision of the outcrop pattern (shown by dotted lines). These structural contours were prepared by (a) carefully adjusted fixed floating lines, (b) floating dot readings at frequent points on these and the ground points beneath to get comparative elevation figures on the latter, (c) careful topographic contouring on a 20-foot interval, (d) preliminary structural contours on each bed, and (e) the final contours as shown. The most impressive result of this example is the success of the free-style reconnaissance contours, in bringing about the discovery of the locations, approximate dimensions, etc., of the structural features of interest, particularly the anticlinal flexures which are marked. The discrepancy of strike along the extreme west edge is indicative of faulty estimating of both horizontality and strike along the edge in the reconnaissance version, and failure to get the benefit of extending the work in this direction.

SELECTION OF AERIAL PHOTOGRAPHS FOR TEACHING GEOLOGY

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INTRODUCTION

FOR several years the University of Illinois department of geology has been assembling a collection of aerial photographs for use as teaching aids in elementary physical geology, geomorphology, structural geology and for research. The collection now numbers more than 5,000 photographs and several hundred photo-index sheets and mosaics.

Selection of particular photographs desired for the collection has generally been made through ordering photo-index sheets of desired areas, and selecting from them outstanding or especially typical photos of the region in question. In some other cases, visits to photo laboratories of government agencies, where albums of photo-indexes are on file, aided in discovering outstanding groups of photographs. Some areas were selected because of familiar topographic maps which have for years been used to illustrate certain types of land forms in laboratory teaching. In some such cases the photo proves to be surprisingly unlike the map. Thus the Moses Lake, Washington quadrangle, shows only regular crescentic barchane sand dunes, whereas the photos show various combinations of barchanes, longitudinal seif dunes and transverse dune ridges, correcting an erroneous impression derived from the map. Many other areas selected were based on personal familiarity by members of the staff. Lists of outstanding aerial photographs for geologic use have been issued by the Air Forces* and by the Geological Survey of Canada.†

Although the search for outstanding or good photographs has been in a sense haphazard, and no doubt many equally suitable or even better photographs exist which have not come to our attention, this short paper calls attention to some of the more satisfactory photographs in the collection. A complete subject index of the collection has been prepared, and copies of this may be secured by interested persons through writing the author of this paper. A selected list is in the course of preparation for distribution to geology teachers by the American Geological Institute. It is hoped that it will be available within a few months.

The prints have been ordered on semi-matte double weight paper for greater durability since they are intended for class use, and because mapping can be done and subsequently erased from semi-matte paper. For display purposes

* Index to Aerial and Ground Photographic Illustrations of Geologic and Topographic Features throughout the World. Headquarters Army Air Forces, September 30, 1946; and Supplement 1, 1949.

† Interim Catalogue of the Geological Survey Collections of Outstanding Air Photographs by Lang, Bostock, and Fortier. Paper 47-26, 1947.