Chapter 7

Control

39. Ground Control. Ground control is divided into (1) horizontal control and (2) vertical control.

In nearly all the practical methods in use today, a certain amount of ground surveying is required. Control stations are usually selected after the photographs are taken because then the points which show up best on the photographs can be selected. It is best to have these stations in a form of a triangulation system so that angles can be read with a transit and distances measured. Third-order triangulation methods can then be used to compute the coordinates of all ground stations. This is *horizontal control.* Levels are also taken to determine the elevations of all control stations. This is *vertical control.*

In selecting the control stations, points on the tops of hills do not in general make the best stations as in terrestrial surveying, but rather points at average elevations of the terrain to be mapped. The reason for not using the tops of hills is evident from the fact that too much change of scale may be introduced because the value of H is reduced and therefore the scale fraction H/f is reduced.

The selection and identification of all control points should be made with the photographs under a stereoscope. All control points should be marked with small pin pricks and circled with colored pencils. It is advisable to use different colors for different types of control, such as ground control and picture control.

Ground-control points are located on the ground by terrestrial survey methods (traverses, triangulation, etc.) and should be points which can be definitely spotted on the photographs. Good control points are such detail as road intersections, fence corners, railroad and stream crossings, buildings, intersections of walks and paths, and culverts.

40. Picture Control. Picture control is that control which can be identified easily on the photograph but for which there is no ground control. This type of control usually supplements the ground control.

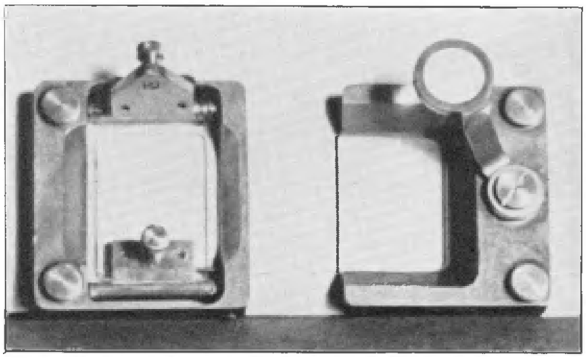

FIG. 62*a*. Point Selectors.

Point Selectors. Point selectors are available for identification of control points on photographs. (See Fig. 62*a*.)

This instrument consists of two small bronze frames which carry flat pieces of glass etched on the lower side with symmetrical black crosses. The glass of one frame may be raised out of its horizontal position and the position of the intersection marked by means of a small pricker attached to the frame.

When the pair of frames is used to transfer a control from one photograph to another, the following procedure is followed:

1. Place a stereoscopic pair of photographs under a stereoscope so as to get good stereoscopic fusion.

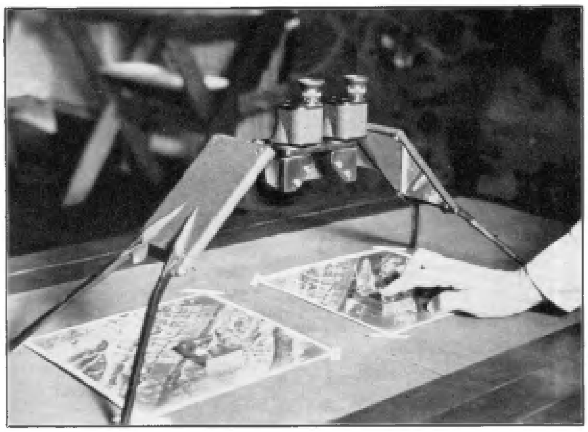

Fig. 62*b*. Stereoscope and Point Selectors.

2. Place the left frame over the control point in the left photograph. Use the magnifying glass attached to the frame for fine adjustment and hold firmly in place.

3. Place the right frame on the right photograph and bring it gradually toward right or left until a fusion of the etched cross is accomplished.

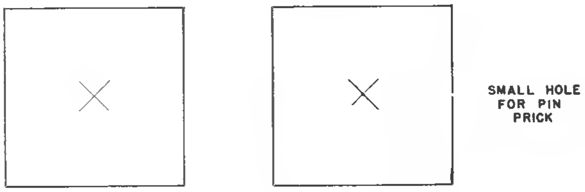

Fig. 62*c*.

4. Hold the right frame in place, raise the glass, and lower the pricker. This is the desired point and is the position of the control point transferred to the right photograph (Fig. 62*b*).

It is possible to make a point selector from two pieces of transparent celluloid. They should be cut about 2 inches square and on them should be drawn or etched intersecting black lines as shown in Fig. 62*c*.

A small hole in the right celluloid at the intersection of the black lines will provide a means of transferring the intersections to the photograph by means of a needle point.

The operation of these two celluloid selectors is the same as used in the first case.

41. Orientation. In order to assemble a series of photographs taken in a flight strip so as to make a continuous map without serious error, the photographs must be carefully oriented with respect to each other and with respect to a meridian (true north). This is a source of considerable difficulty to the mapper. To accomplish the exact orientation involves considerable computation. Various graphical methods have been used and for certain purposes give very good results.

In the analytical method, which will only be mentioned here, there are the following elements which must be determined. They are listed here simply to show the various elements which affect the orientation. (See Chapter 10.)

The two general classes are:

(1) Elements of *interior orientation.*
(2) Elements of *exterior orientation.*

Elements of interior orientation are the elements of the negative and camera and may be classed as:

(1) The x coordinate on the plate of the principal point.
(2) The y coordinate on the plate of the principal point.
(3) The principal distance of the camera.

Elements of exterior orientation are the elements which affect the location of the camera station and photograph with respect to other camera stations in a flight strip. They are used in assembling a series of photographs to make one continuous map. They are:

(1) Tilt.
(2) Swing.
(3) The survey azimuth of the principal plane.

Professor Earl Church of Syracuse University has done much in developing an analytical solution for each of the above elements and has published this information in a series of bulletins.

42. Graphical Methods. Graphical Methods may be classified as follows:

(1) Straight-line method.
(2) Section-line method.
(3) Three-point method.
(4) Radial method.
(5) Template method.
(6) Slotted-template method.

In all these methods attempts are made to match photographs by intersections in somewhat the same manner that is used in ordinary plane-table orientation.

An aerial photograph may be considered a record on a plane, of directions to objects projected through a point (the lens) at a known distance (equivalent focal length) perpendicularly above the marked principal point of the photograph. This distance and angle relations are fixed in each modern air camera and are determined by calibration.

The accuracy with which directions may be determined from aerial photographs varies with the aberrations of the lenses, the grain of the high-speed emulsions, shrinkage or distortion of the sensitized material, and other sources of error.

In general directions may be determined with an error of about 12 seconds when all precautions and the best equipment are used. Errors as great as 6 or 7 minutes may occur in ordinary paper prints. The amount of displacement caused by small angular errors at a distance of one mile is shown in the following table. This shows the comparison of the photographic camera with the theodolite or transit.

Dist.	1st Order Theodolite	3rd Order Theodolite	12-in. Air Camera Glass Plates	6-in. Air Camera Non-shrink Film
	1 sec.	5 sec.	12 sec.	1 min.
1 mi.	0.0256 ft.	0.128 ft.	0.307 ft.	1.536 ft.

Dist.	Tilt Distortion 3 degrees	Tilt and Paper Distortion (max.)
1 mi.	3 min. 4.608 ft.	6 min. 9.216 ft.

With skillful flying and careful photography it has been found that 85 per cent of the photographs taken with modern equipment will be tilted less than 1 degree with perhaps 12 per cent between 1 and 2 degrees, and only in exceptional cases should any photograph be tilted more than 3 degrees.

In ordinary practice a photograph having less than 3 degrees of tilt is used without making any correction. The maximum difference in radial direction of objects on a photograph tilted 3 degrees is 4 minutes 36 seconds at 45 degrees from the axis of tilt.

Since variations in altitude of 100 feet or more are likely on account of variable air currents and barometric pressure, considerable variation is to be expected in scale of the many photographs used for compiling a map. In general a scale variation of 2 per cent in any one series of photographs is not considered excessive.

If greater precision is desired, the photographs are rectified by methods already discussed. The tilt is taken out and all photographs are brought to one uniform scale.

Straight-Line Method

In this method the principal point of each photograph is located and by means of a straight edge an attempt is made to match the prints so that the principal points fall on this straight line. Points of detail are also matched, such as road intersections and prominent buildings, and at least two points are selected in the first print which fall on the straight line. These points are then located in print 2 which overlap 1. The straight line joining the two points on print 1 is made to coincide with the straight line joining the image of the same two points on print 2. Then two other points are selected on print 2 which also appear on print 3, and the procedure is repeated until the strip is complete.

Section-Line Method

This method is somewhat similar to the first method except that the section lines of the public lands division are used for matching.

Three-Point Method

This method is similar to the graphical solution of the three-point problem used to orient a plane table. Three well-defined points are selected as control points on each photograph and lines are drawn from the principal point through each point. The location of the control points with respect to each other is figured by a system of triangulation and they are plotted on tracing cloth or celluloid sheets to the scale of the map. Place the tracing over the photograph and shift until the lines on the photograph pass through their respective control station on the tracing. Mark the position of the photograph on the tracing and proceed with the next in like manner. The detail is traced on the tracing cloth using only the central portion of each print to avoid distortion due to displacement. If the final map is to be at a different scale from the one just plotted, it can be changed by the use of a pantograph, ratio projector or rephotographed.

Radial-Line Method

In this method the principal point may be used as the origin of radial directions of the displacements of objects shown on photographs tilted less than 3 degrees without plottable error when the relief is less than 10 per cent of the camera altitude. Let us consider the principal point of the photographs as an "instrument station." Lines radiating from it may be drawn on the photograph through objects which have been or which are to be plotted on the map. These will correspond with directions taken with a plane-table alidade or transit. The photograph may be plotted on a tracing of the map by causing the radial lines which pass through the control stations as located on the photographs to pass through their corresponding plotted positions on the map.

When the photograph has been oriented and plotted on the map in this manner, the lines radiating to other objects which it is desired to locate may be traced on the map. A second overlapped photograph may also be plotted by its radial through the control and the radials through its new objects traced off to intersect the corresponding radials from the first photograph at the map positions of the new objects. The locations of the new objects may be used in turn to plot the next photograph along the flight and new intersections obtained to objects further along the strip. In this manner a graphic triangulation may be extended over the area photographed.

The difference between this method and the three-point method previously discussed is that in the former method the control stations were accurately located and used in getting the scale and intersections. In the latter method numerous points are selected such as road intersections, buildings, and other prominent points. Intersections are then used to these points. With a large number of such points a good orientation is accomplished. Control stations are used as in the three-point method with the additional check of numerous other points.

Steps in Radial-Line Plotting.

1. A certain amount of ground control must be run and the horizontal and vertical positions determined from precise surveying methods. There should be at least three ground-control points visible in each photograph, and these should be at an approximate average elevation of the pictured terrain. This is preferable but not always possible. Every third or fourth photograph will suffice. The control points may be selected before or after the photographs are taken. The advantage of selecting the ground control after is that the photograph may be studied under a stereoscope and a selection of points made which are sure to be visible and more nearly of average elevation.

2. Select and mark on the photographs these ground-control points with a small blue circle.

3. Determine and mark the principal point of the photograph with a small red circle. This can be done by the marks registered at the time of exposure at the corners of the photograph (fiducial marks). This principal point may then be used as an instrument station from which radiating lines may be drawn on the photograph to the previously marked ground-control points.

4. Select a large sheet of low-shrink celluloid (specially prepared celluloid can be purchased for this purpose) and, on this, plot the ground-control points to the scale of the desired map.

5. Place the photograph 1, previously referred to, under the celluloid and cause the radial lines on the photograph to pass through the respective ground-control points on the celluloid. This corresponds to the three-point fix commonly used in plane-table work.

6. Select about nine picture-control points, three near the upper margin of print 1, three across the center, and three across the bottom. These should

be distributed so that three fall near the right edge of the photograph, three through the center, and three near the left edge. The picture-control points are selected best by studying the adjacent photographs of a flight strip in a stereoscope. They are points such as road intersections, prominent houses, and any other features which can be easily identified in two or more prints. They are marked with small yellow circles and may be selected and marked at the same time that the ground-control points are marked. This will eliminate moving the photograph from under the celluloid after the orientation on the three control points.

7. With the photograph under the celluloid, draw on the celluloid radial lines from the principal point through each picture-control point.

8. Next, photograph 2 is oriented in the same manner, its control points spotted, some of which may occur in photograph 1 and radials drawn on the print through these points from the principal point of photograph 2.

9. As many of the picture control points as occur in photograph 1 are marked with yellow circles on print 2 and three new ones selected. The new ones are in the part of photograph 2 which does not overlap 1.

10. Photograph 2 is now placed under the celluloid sheet and radials drawn through each picture-control point. Six of these will intersect radials to corresponding points as drawn from photograph 1 with three new ones. The intersection of these radial lines is the approximate plotted position of the picture-control point.

11. Next draw radials in picture 3 in the same manner. From this photograph a third radial will intersect the three lower picture-control points and should intersect the other two radials in the previously drawn same points. Owing to tilt and other causes this may not result and a small triangle of error may result. Some specifications require that photographs should be taken with no resulting triangle of error while others allow for a small triangle.

12. After passing through a series of photographs in this manner the final fix of the photographs is made by shifting the photographs under the celluloid until the best fix is made, using both ground control and picture control. The position of the photograph is then marked and the detail traced. This is repeated for photograph 2 and so on, through the strip. Usually only the center portion of the print is used because of the distortion at the edges.

The resulting map from this method is a planimetric map showing all the cultural detail with the exception of contours. These are usually put on in the field by the ordinary plane-table method.

In plotting by the radial-line method, if a control point fails to check with the surrounding picture control, a field party is sent out with the photograph and surveying instruments, an attempt is made to find the error, and the necessary corrections are made. This method is quite similar to the template method, which is described in detail in the following pages.

Mapping from Single-Lens Aerial Photographs Template Method

The template method is a recent outgrowth of the well-known radial-line method. While the radial-line method is still popular and much employed, the template method is faster, easier, permits a division of the work, and is of equal accuracy. The extra cost of the necessary celluloid for templates is small, and is entirely overbalanced by the saving in time. The method is described in detail in chronological order for mapping from single-lens photographs 7 inches by 9 inches or 9 inches by 9 inches.

Scope of Template Method. This method is limited to small-sized photographs, that is, those which are 7 inches by 9 inches or 9 inches by 9 inches. While the method applies equally well to larger photographs, the cost of the celluloid templates for large photographs and the difficulty of handling a great number of them makes the template method unsatisfactory for large multiple-lens pictures or enlarged single-lens photographs. Furthermore, it is impossible to use this method for five-lens photographs because of the large number of overlapped photographs. Inasmuch as many as seven composites depict the same area, the resulting thickness of the seven layers of celluloid would make the interpretation of the photographs difficult and inaccurate.

Preparation of Photographs. Upon receipt of the photographs, the first step in the compilation of the maps is preparation of the photographs. Some photographs have fiducial marks which photograph on the optical center of the photograph, usually called the principal point. However, the majority of photographs have corner points marked from which the principal point can be obtained by drawing intersecting lines from the diagonally opposite corners. The principal point of each photograph should be thus determined, pricked with a very fine needle, and circled with a colored pencil, preferably red. Because of the 60 per cent overlap which is allowed during the photography, each photograph will show, beside its own principal point, the principal point of the photograph immediately preceding and succeeding. These two principal points should be pricked with extreme care so that every photograph gives three principal points circled in red pencil.

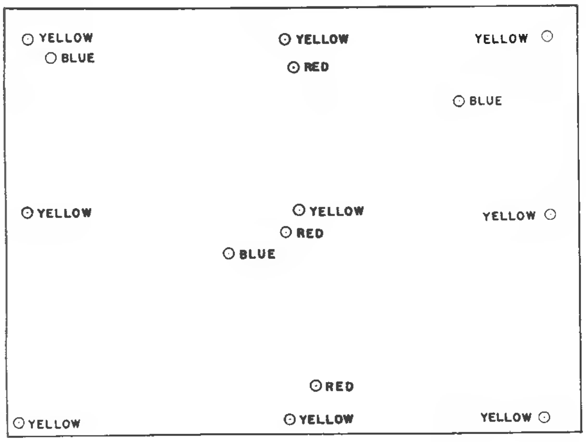

Fig. 63.

Location of the Ground Control. This step is perhaps one of the most important in the whole procedure and should not be attempted without the aid of a stereoscope. Complete descriptions of the control points are written up by the field parties, and it is the determination of the proper image points to correspond with the described control points which requires very careful study. Inasmuch as the same control points may appear in as many as three prints, the points should be located on each photograph in which they appear. It is well to circle these points with blue ink or blue pencil (Fig. 63).

Secondary Control. Next in importance to the accurate spotting of ground control on the photographs is the selection of the secondary or picture-control points. In this step also it is essential to study the picture stereoscopically. For the purpose of extending the ground control through photographs which do not include any ground points, nine secondary or picture-control points should be selected and marked on each individual photograph. This should be a minimum number, and the more such points there are, the greater will be the ease and the accuracy in the radial plot. The points should be well distributed throughout the photograph in three distinct rows. There should be a row of three points lying within an inch of the top of the photograph, three lying within a one-inch band through the middle of the print, and three within one inch of the bottom of the photograph. In each band of three, one point should be well out to the left, one in the center, and the other out to the right. In the selection of these points, an effort should be made to choose points which are easily identifiable and all on as nearly the average datum of the survey as can be found. To differentiate between principal points, ground-control points, and picture-control points, it is well to circle the latter with a yellow pencil (Fig. 63).

Inasmuch as the entire process of mapping from aerial photographs depends upon the accuracy with which the above-mentioned points are selected and interpreted, the care which should be exercised in this particular phase of the work cannot be overestimated. As mentioned previously, the stereoscope should be used freely in the study of the photographs. The simplicity of the principle of the stereoscope has, in the past, led to the construction of home-made devices or the purchase of a very cheap type of stereoscope. The importance of the initial phase of the aerial mapping work has finally been realized and has resulted in the selection of a more perfected type of stereoscope for this particular work. In brief, the stereoscope should be built as a precision instrument and equipped with lenses which permit an increase in stereoscopic perception at least two times.

It is only when the land is perfectly flat or nearly so that the above nine picture-control points will also suffice for the drafting of the detail. However, this is seldom the case. In general, it may be stated that for average country, picture-control points should be located throughout the photograph in such a way that no point is farther than 1½ inches from some other picture-control point. As the terrain becomes more rugged, the spacing of these points must be made smaller down to a point where the points may not be more than ½ inch distant from each other. This latter condition exists, however, only in exceptionally rugged country. The latter batch of points should be placed at a road intersection, along streams, along railroads, near prominent buildings, and at field corners.

After the prints are marked as mentioned above, the stage is set for the next step.

Preparation of the Template. The templates are made of transparent celluloid or photographic matte sheeting having a low-shrink characteristic. For the single-lens photographs, the template should be 8 inches by 10 inches or 10 inches by 10 inches. In order to draw ink lines directly on the celluloid, it may be necessary to rub down the surface with some mild abrasive. However, there are some celluloid inks manufactured which can be used directly on the celluloid without any preparation; these inks are proving quite satisfactory. Number each celluloid template to correspond with the photograph on which it is to be used. Template 1 then would be laid over photograph 1 and held in place accurately either by weights or thumb tacks. Stick a needle into the celluloid directly above the principal point of photograph 1 and let it stand there as a guide for the straight edge which is to be used. Draw lines from the principal point through all the points which have been previously marked on the photograph. While it makes distinction between the various lines much simpler to have the lines in the color ink corresponding to the color of the points through which they pass, it is more customary to use black ink throughout. It is not necessary for these radial lines to be solid from the principal point through the control points. A line drawn a half inch either side of the control point is sufficient (Fig. 64). When the templates for all the photographs in a flight strip are thus made, this particular step is finished.

The Projection Sheet. It must be remembered throughout this discussion that short cuts, special purposes, and "pet" theories may cause a deviation from the procedure as it is outlined. Hence, only the general method is dealt with in this description.

The projection sheet is a large sheet of celluloid which is as large in size as can be conveniently handled and must have very low-shrink characteristics. The surface of the celluloid projection sheet can be rubbed down with a mild abrasive or not—as desired.

A grid of latitude and longitude lines should next be very carefully drawn on the projection sheet. The latitude and longitude intervals will vary from one minute to five minutes, depending upon the scale of the photographs. The average scale of the photographs of the flight strip should be determined according to any one of the accepted methods. The average scale can be easily obtained by carefully matching successive photographs of a flight strip and comparing the distance between control points

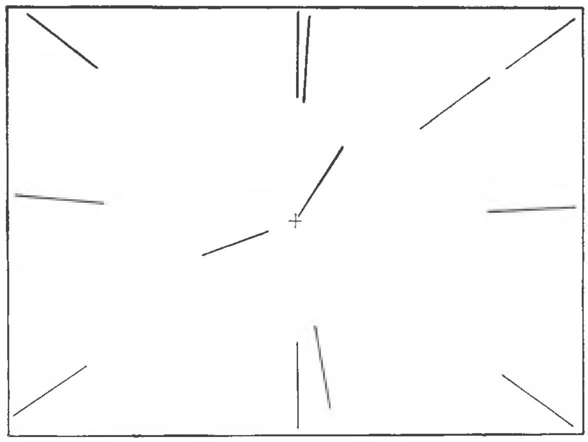

Fig. 64.

which are farthest apart on the photographs with the distance known from the ground survey between those same ground-control points. The latitude and longitude lines are laid out then at the desired interval for this scale. The projection should be made according to the polyconic system, using *Bulletin* 809, entitled *Formulas and Tables for the Construction of Polyconic Projection,* published by The U. S. Geological Survey. The ink lines used in the grid must be very fine black lines.

The latitude and longitude grid having been determined, it is next necessary to plot very accurately the ground-control stations. The ground-control stations should be marked with indelible ink so that they will be permanent.

Extending the Control. The ground control should have been so selected that at least three points are common to the first two photographs of the flight strip. In the following discussion let us assume that photographs 1 and 2 show three points of ground control, pictures 3, 4, and 5 show no ground control whatever, while photographs 6 and 7 show three more points of ground control.

Place template 1 on the projection sheet in such a way that the radial lines, which were drawn on the template in such a way as to pass through the ground-control points, now go through the ground-control points as they are plotted on the projection sheet. This orientation is exactly the same as the old "three-point fix" used in plane-table surveying. Great care should be exercised in having this fix as perfect as possible. When the fix is satisfactory, template 1 is held down in place by weights. Template 2 is then placed over template 1, which in turn is over the projection sheet, and 2 is oriented so that its ground-control radial lines pass through the plotted positions on the projection sheet of the ground-control points. An intersection is thus formed due to this superposition of the radial lines in the overlapped areas. It is of particular importance to note whether or not the principal point of photograph 2 falls on the radial line of photograph 1, which is supposed to go through the principal point of photograph 2 as it appears on photograph 1. It is only by exercising extreme care in this respect that the azimuth of the control plot can be held between successive sets of ground control. The intersecting radial lines represent the plan position of the points through which they were drawn on the photographs. The intersections formed at the top of photograph 1 represent the plan positions of control points which will also appear at the bottom of photograph 3. Template 3 is now adjusted by means of its radials so that each radial line passes through the intersection over the corresponding point as formed by the superposition of photographs 1 and 2. When this is satisfactorily finished, the templates are fastened to each other with strips of Scotch tape about an inch long. In some cases the three radial lines that should all intersect at one point do not do so. When they do not intersect in a single point, a small triangle is formed which is called a "triangle of error." The allowable size of the triangle of error depends entirely upon the accuracy desired in the final map. Photographs 4 and 5 are then oriented in the same manner as 3 was oriented with 2 and 1. When photographs 6 and 7 are reached, the draftsman is able to obtain a check in his work. The intersection of the radials from 6 and 7 through the ground-control points which are in the second band of control should fall directly over the plotted positions of the ground control on the projection sheet, or at least within the tolerable error. A perfect check, however, on the first try requires close checking to be certain that it was not an accident. If a satisfactory check is not obtained, the draftsman must warp the strip of templates by stretching and twisting in such a way as to cause the plot to check out on the second set of control points.

It is the simplicity of this method of adjusting the templates between ground-control points that is one of the chief advantages of the template method over the usual radial-line method. This stretching and twisting of the strip of template cannot be classed as fudging if all the work has been done carefully. There is a certain amount of latitude in the intersection of the radial lines which permits this stretching and twisting. Needless to say, this adjustment process can be carried to an extreme. Where careful work has been done, the amount of adjustment necessary should be small so that no doubtful intersections exist. After the templates have been adjusted between two sets of ground control, the remainder of the flight strip is done in exactly the same manner.

The next adjacent flight strip is now laid out in a similar manner. When it is completed, the overlapped portion of both flight strips is examined to see how close they coincide in this zone of overlap. If they coincide within the tolerance specified, the two strips can be pasted together with Scotch tape. However, a certain amount of adjustment will most likely be necessary. The two strips are adjusted with respect to one another, and then a check must be made back to see if, after adjustment, the individual flight strips still hold their proper relations with their own ground-control points. The other adjacent flight strips are tied into these first two in the same manner.

For most accurate results, both the temperature and humidity of the room in which the work is being done should be kept constant.

Tracing the Detail. The number of templates that can be laid out in the manner specified above depends entirely upon the facilities of the drafting office and the convenience of the draftsman. Assembled templates have been used as large as 15 feet wide by 20 feet long.

A very satisfactory and rapid method for tracing the detail where large assemblies of templates are used will be discussed later on. The present method herein described works very well on small assemblies of templates which embrace two-, three-, or four-flight strips.

The intersecting lines which are formed by the radials of the superimposed templates form intersections which represent the plan position of the picture-control points drawn to the average scale of the flight series. These points of intersection must be transferred in some manner to the projection sheet in proper relation to the ground control plotted thereon. This transferring can be accomplished in a number of ways. One method is to make sure that, with the assembly of templates lying over the projection sheet, the intersections which represent the ground control on the template are in coincidence with the ground-control points as plotted on the projection sheet. When this condition exists, the picture-control points of intersection can be pricked through the template to the projection sheet. Another method is to superimpose the projection sheet on the assembly of templates and shift the projection sheet until the plotted ground-control points coincide exactly with the intersecting points which represent the ground control on the templates. With this done, the intersections representing the picture-control points can be traced off onto the projection sheets with ruling pen and celluloid ink. The projection sheet as it now appears, with the ground control plotted upon it and the picture-control points all appearing in their proper relative positions, is sometimes called the "smooth plot." When this smooth plot is finished, the templates have served their purpose and may be dismounted and filed away.

The tracing of the detail can now be made from the photographs in exactly the same manner as is used in conjunction with the usual radial-line method. This particular phase of the work will now be discussed.

Photograph 1 is placed beneath the part of the projection sheet which contains the plan position of the control points which are pictured in photograph 1. If the terrain in photograph 1 is perfectly flat and the scale of the photograph is exactly that at which the smooth plot was constructed, the plotted control points fall exactly over the pictured control points. However, this is seldom if ever the case. The occurrence of tilt, relief, and scale difference in the prints makes direct tracing of detail from the prints impossible. The 60 per cent forward overlap and the 40 per cent side overlap make it possible to use only the center portion of each photograph from which to trace the detail. This naturally tends to cut down the errors due to displacements and lack of definition in aerial photographs.

Adjust photograph 1 then so that three of either the picture-control points or ground-control points (whichever are nearest to the center of the photograph) coincide with the points as plotted on the smooth plot. It may often be possible that three near-by points will coincide exactly. In that case, the detail within the triangle formed by these three points is traced off directly from the photograph. Use should be made of the usual topographic symbols in representing the various types of detail present in the photograph. Beside tracing the detail enclosed in the triangle formed by the three points, the detail on the outside of the triangle should be traced as far as one-third the distance toward the next nearest control point in each direction. By using two of the three control points just used, the next near-by point is chosen, another triangle is formed, and the detail is traced within that triangle and outside as far as one-third the distance, as previously mentioned. While the first three points may be found to coincide exactly with the plotted points, as the detail is traced farther from the center of the print it will be found that the points do not coincide exactly. In this situation it is necessary to use a simple process known as "proportioning." Proportioning is carried on in the following manner: The photograph is adjusted as nearly as possible to coincide or nearly coincide with four or five control points. Then one of the control points is brought into exact coincidence and the detail is traced toward one of the other control points for one-third of the distance to that control point. The control point toward which this drafting is done does not coincide probably with the pictured point by some small amount. The photograph is moved through half the distance of this discrepancy and the detail between the two points which we are working with is traced for another third of the distance. The photograph is again shifted until the second control point is in exact coincidence with the picture-control point and the remainder of the detail between the two points is traced. It must be remembered that during all this shifting an approximate coincidence with the four or five nearest control points should be held. The same method is carried on with respect to all the other control points until the detail of photograph 1 is completely traced from the central portion of the print. Photograph 2 is then placed under its proper portion of the smooth plot and the detail is traced in exactly the same manner. This method is carried out until all the desired detail is traced onto the projection sheet. Needless to say, the drafting work is very fine and requires a careful and accurate draftsman to obtain satisfactory results. While this method of tracing the detail sounds somewhat long and complicated, a little practice will prove that it is quite simple.

The next step is to letter the names of the towns, roads, streams, lakes, places, etc., and title the map.

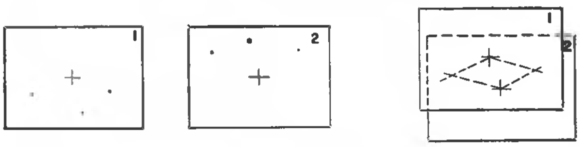

FIG. 65.

This can be done by hand lettering if desired. However, inasmuch as the map will be copied photographically in sections, there is a method that is somewhat more satisfactory. Printed letters can be obtained in any desired size, printed on non-photographic blue paper. These can be formed by cutting out the proper letters to spell the word and pasting the letters with the desired spacing to the projection sheet. The result is very pleasing to the eye, especially where the names of rivers and streams can be placed in such a way as to conform with the curves of the stream. The photographic copy of the projection sheet has a finished look when lettered in this manner.

The projection sheets, when copied photographically, are reduced to a publication scale which, in the case of the U. S. Geological Survey sheet, is 1 inch to the mile. This reduction in scale minimizes the slight drafting errors that are bound to occur and entirely eliminates the hand-made appearance of maps which are published at the same scale as that at which they are drawn. Furthermore, a method of reproduction in four colors has been perfected by the U. S. Geological Survey's printing office. However, this is only a method which can be afforded by a government.

Slotted-Template Method

The same principles are used in the radial-line, the template, and the slotted-template methods, the only difference being the mechanical way in which the work is carried out. When photographs with a small amount of tilt are used it may be considered (1) that points near the center of the photographs are nearly free from errors caused by tilt or elevation, and (2) that errors from tilt and elevation are in a radial direction from the principal point of the photograph. The true position of any point therefore lies on a line drawn from the principal point through the photographed position of the point. This enables one to fix the location of points in a manner similar to that used in plane-table plotting, provided the photographs have the proper overlap. The position of the principal point on the map would correspond to the station occupied by the plane table. Directions taken to any points would correspond to the radial lines on the photograph from the principal point to the object. These lines may be plotted on tracing cloth or photographic matte sheeting.

If a second picture is taken showing points to be plotted, its principal point would correspond to a second station occupied by the plane table. This second photograph may be oriented with respect to the tracing in a manner similar to that used in plane-table work. This requires that the principal point of each photograph occur in the next adjacent photograph and radial lines must have been drawn through these points. The other points will then be located on the tracing by drawing the radial lines for the second photograph, the intersection of the radial lines locating the points as shown in Fig. 65. It will be seen that in this procedure the scale has not been fixed and that the two principal points may be mapped at any distance apart, thus establishing the scale.

If three ground-control points occur in two photographs they may be oriented in the same manner as that used in the three-point problem with the plane table. This is to be preferred as the map may then be constructed at any desired scale.

These methods therefore are graphic triangulation which may be carried through any desired number of photographs.

Preparing Photographs

The photographs are prepared in the same manner for the radial-line, template, or slotted-template methods. The principal point should be located and marked on each photograph. This may be already marked or may be located by drawing diagonal lines from the marks at the corners of the photograph or the fiducial marks at the sides and top and bottom of the photograph. The principal point of each photograph should also be marked on each adjacent photograph of the flight strip. If this is found difficult, another point very near the principal point, which may be identified in the two adjacent pictures, may be used. This point should be on the line connecting the principal points of the two adjacent photographs or very close to it. In either case the point is used the same as the principal point in orienting the picture, but the radial lines are drawn from the true principal points.

Six other picture-control points are marked on the photograph, three near the right edge and three along the left edge, two being on a line with the principal point of each photograph, as shown in Fig. 66. It is convenient to number the rows of points consecutively throughout the strip and use the letters L, C, R to indicate the left, center, and right respectively.

These points should be marked with a pin prick and circled with a colored pencil. In selecting these points, the photographs should be examined under a stereoscope and points as near to the average elevation of the territory being mapped should be chosen. These points should be such that they are easily identifiable, and great care should be used in marking them.

The side control points should be common to two adjacent flight strips, and the adjacent strip should be studied to choose points which are satisfactory for both strips.

All ground-control points should be marked on all photographs in which they occur in a similar manner, but a different-colored pencil should be used so that these points will not be confused with the picture-control points.

Templates are now made for each photograph. They consist of transparent celluloid sheets and 8 inches by 10 inches should be used for photographs 7 inches by 9 inches. Celluloid ink may be used, and if the ink is water-soluble the templates may be washed and used as many times as desired.

The templates are numbered to correspond to the photographs. The first template is then laid over

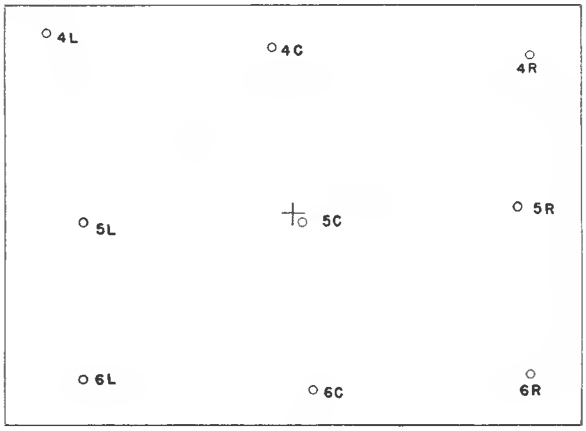

Fig. 66.

its photograph and held securely in place. A pin is stuck into the celluloid directly above the principal point of that photograph. This pin acts as a guide for the straight edge which is used in drawing the radial lines. Radial lines are now drawn on the template through all the picture-control points and ground-control points. (See Fig. 67.)

Figure 67a shows the assembly of three transparent templates with their radials intersecting. Note the three point intersections in the portion common to three templates. These intersections are the control points for further use in transferring the detail information from the photograph to the control sheet (same as template plotting).

Slotted templates for all the photographs are prepared in the following manner. Stiff cardboard 8 inches by 10 inches is used. The transparent templates are first placed on a sheet of cardboard and the principal point, picture-, and ground-control points pricked through to the cardboard. These points on the cardboard template should then be circled with colored pencil for identification. Radial slots $\frac{3}{16}$ inch wide and $2\frac{1}{2}$ inches long are then cut in the cardboard template as shown in Fig. 68.

The first template is placed on the drawing table with a "rivet" placed in each slot and the head un-

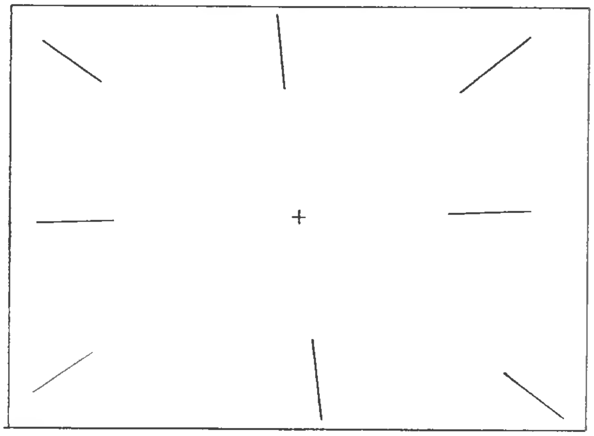

Fig. 67.

der the template. The second template is placed on the table overlapping the first so that the slots to the same control point fit on the corresponding rivet, placed in the first template. The rivets (Fig. 68*a*) have a hole through the center, through which

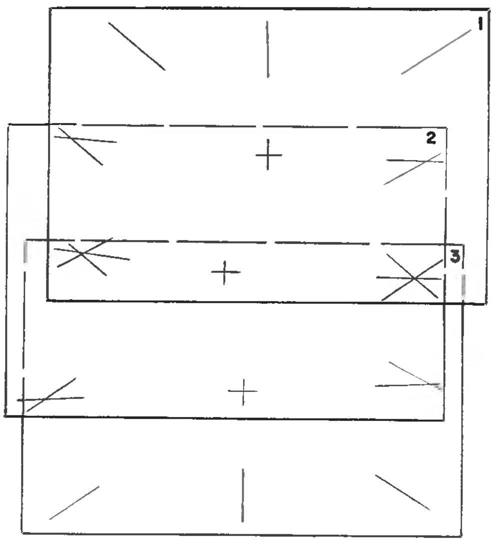

Fig. 67*a*.

a pin may be inserted to prick a point to locate the position of the control point on the celluloid mapping sheet. Any desired scale, within the limit set by the length of the slots, may be used. After two templates have been placed on the table, as described, the distance between the principal points of the two photographs may be adjusted to establish the desired scale. The rivet for each ground-

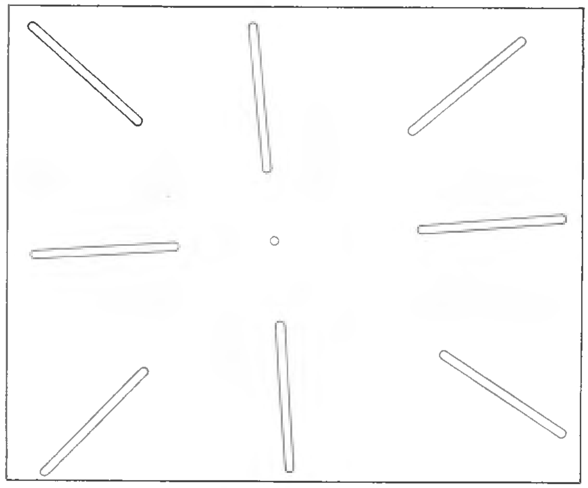

Fig. 68.

control point should fall exactly over its corresponding point as plotted on the celluloid mapping sheet. The templates are thus assembled with the adjoining flight strips tying on at the sides. The position

Fig. 68*a*.

of each ground-control point must check the location of that point on the mapping sheet as the work progresses. If it does not, adjustments must be made by shifting each template a small amount until all these points check.

It is possible to eliminate the transparent template in this method by laying the photograph directly on the cardboard. This requires making holes in the photograph in order to transfer the radials to the cardboard template and may be objectionable if the photograph is to be used for other purposes.

Slotting machines are available which punch the cardboard without marking the photograph, and the method is patented.

43. The Ratio Projector. The template method for the construction of maps from aerial photographs has been used extensively by many mapping agencies, among which the most prominent are the United States Forest Service in this country and the Canadian International Paper Company in Canada. In both cases, the above-mentioned mapping agencies have found it possible to speed up the mapping process by using some form of projecting machine. The following discussion is based on the use of the Forest Service's projection machine, a drawing of which is shown in Fig. 69.

A. This consists of a light hood which is open only on one side and is large enough for a man's head, shoulders, and arms.

B. This is a piece of clear glass.

C. This is a focusing bellows carrying a lens.

D. These are two lamps throwing light on the picture *G*.

E. This is a gimbal mount to permit a correction for tilt in the pictures to be made.

F. This is something like a drawing board, upon which the picture *G* can be thumb-tacked.

G. This is a 7 inch by 9 inch photograph, or whatever size photograph is used. It can be either a glossy or a dull-finished picture. The picture is thumb-tacked to the board *F*.

In front of the ratio projector, as the machine can be called, is a platform about 2 feet off the ground, upon which the draftsman stands when using the apparatus. The entire machine is about 7 feet high, 5 feet wide, and 4 feet deep.

The *overhead ratio projector* has replaced the model shown in Fig. 69. It is designed to project a photograph, drawing, map, or any print, down onto a table on which the drawing is to be reproduced. Figure 70 illustrates this instrument.

General Performance (Overhead Ratio Projector). 1. The pressure plate for holding various sizes of aerial contact photographs consists of a door within a door, each having its individual locking device with heatproof knobs and hinges. The doors are lined with dead black felt to reduce reflections when pictures are smaller than 10 inches by 10 inches. The felt also acts as matte to press photographs flat against a glass pressure plate. On removal of

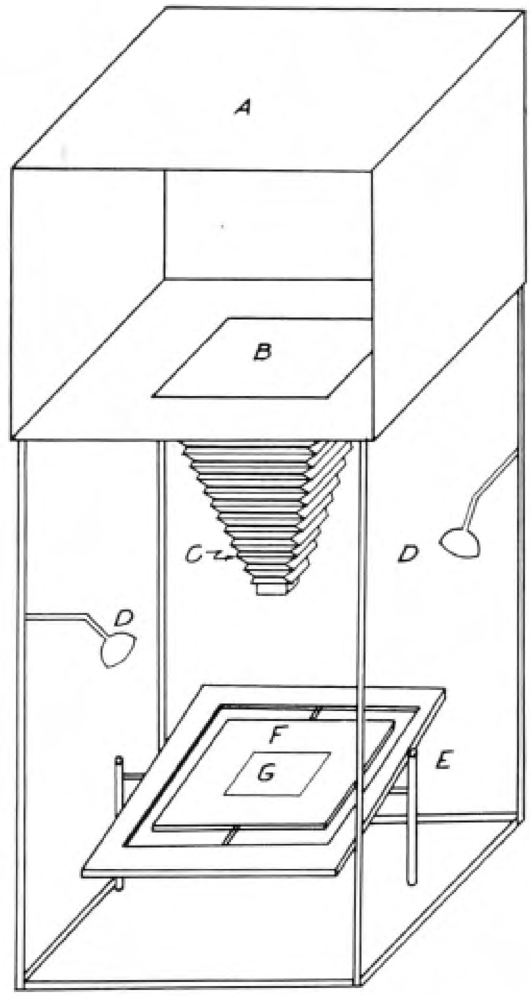

FIG. 69. Ratio Projector.

this aerial photo holder, a large map adaptor is furnished. This attachment is sufficiently rigid and of plane surface to hold any 10 inch by 10 inch section of a rolled map flat against the glass pressure plate; this is accomplished by spring tension and travels with the lamphouse along the horizontal ways. A flat, fixed pressure plate is made of clear, colorless glass without flaws or defects. This is used to keep flat the surface of the materials to be traced and perpendicular to the optical axis of the lens which shall intersect the photographic aerial print at its geometrical center. This aerial photo holder is rotatable through 90 degrees about the center of the photograph. The rotation is accomplished by means of an extended handle which is attached to rack and pinion motion. It is possible to interchange the aerial photographs during the operation

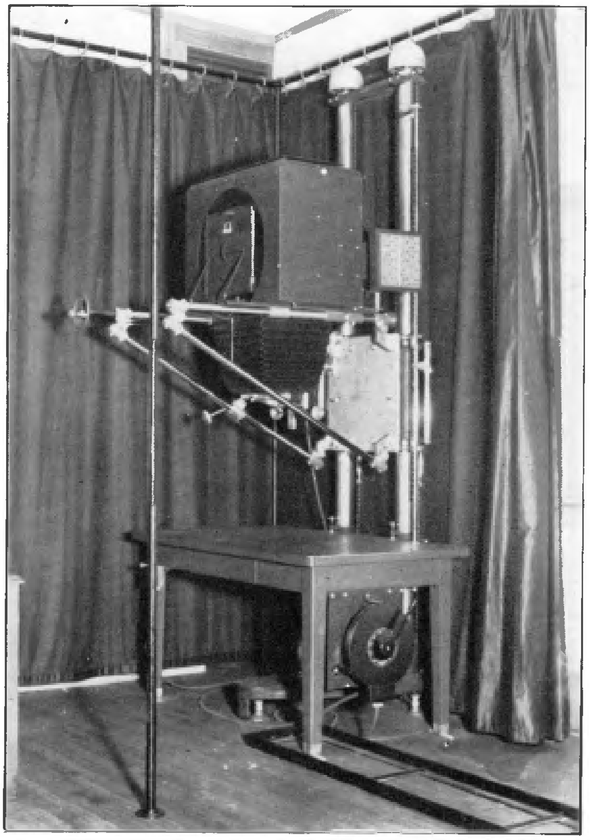

FIG. 70. The Overhead Ratio Projector.

of the machine through the rear of the holder which is within convenient reach.

2. The illuminating unit system furnishes at least 3.3 foot-candles at the projected image on a sheet of white bond paper at a full aperture of 4.5 and at a magnification of 2.5 times. Two prefocus base projection-type lamps are used of 500 watt. Reflectors of glass and mirroid are placed in full adjustable brackets to obtain best focus of light distribution. These reflectors are easily removed for cleaning purposes.

3. The ventilation is by forced means with a fan and motor and is sufficient to keep the aerial photograph or map, and all interior parts of the unit, at a temperature below the damaging point during the continuous projection. The motor is of universal type operated at 115 volts; this and the fan are mounted free from any vibration which will interfere with the performance of the instrument. A common switch makes it impossible for the lamps to burn unless the blower circuit is closed.

4. The diagonal mirror for erecting image is a first surface mirror. It is coated with chromium film faced with a deposit of aluminum known as a Chroluminum film. The mirror has sufficiently good optical surface to produce no visible distortion of the image formed by the projection lens. This mirror is mounted in a rigid holder to maintain the optical axis of the lens perpendicular to the photographic print but can be easily removed for cleaning purposes.

5. The projection lens is set in an interchangeable basis which permits the use of lenses with varied focal length. The instrument is designed mainly for a lens of 12-foot focal length, with an iris diaphragm giving varied *f* values. The lens is mounted so that its optical axis is perpendicular to the aerial photographic print and intersects the latter at its geometrical center. The optical axis, furthermore, is perpendicular to the base of the instrument. By using the 12-inch focal-length lens, a range of magnification of two point five diameter to a point four diameter is possible. The instrument can be furnished with a reduction adaptor; for example, an 8-inch lens and a magnification as low as point one seven can be had.

6. There are advantages of the projector and there is saving. With this apparatus it is possible to project the aerial photograph direct to a radial-plotted base sheet and to control the various changes in scale. This base sheet is metal-mounted. After all the delineation has been traced onto this sheet by the projection method, it is inked in and finally photographed for final publication.

The older method called for a transposition to a vellum sheet. This sheet because of irregular expansion had to be adjusted to the grids plotted on cellulose acetate. It has then to be inked in and transposed photographically onto our present metal-mounted sheet.

The process of proportioning between a control point in order to trace the detail correctly has been discussed. As previously mentioned, this proportioning method permits neat and accurate tracing of a detail without the consumption of an expressive amount of time when the method is used on small maps. However, while large maps are being dealt with, the above ratio projector can be used to cut down the time needed for proportioning between control points.

The conditions of the photograph which make this proportioning necessary are that the airplane often changes elevation slightly between successive photographs, causing the successive photographs to be of a slightly different scale from the average scale of the flight strip. Slight amounts of tilt are often present in the photographs due to the inability of the pilot and photographer to have both the plane and the camera level at the instant of exposure, and that relief in the terrain causes a different scale in different parts of the same photograph. In the ratio projector, the tilting board permits the small amounts of tilt which are sometimes encountered to be eliminated and the bellows carrying the lens permits of an adjustment whereby the differences in scale can be compensated for. However, there is no means whereby the displacement due to relief can be compensated for and consequently a small amount of proportioning is still sometimes necessary. However, the amount of proportioning is reduced to a minimum through the elimination of the tilt and scale errors. It will be noted from the construction of the machine that an inverted image of the photograph will be projected upon the glass drawing plate. Although the Canadian ratio projector has a means whereby an erect image is obtained on the drawing plate, the method of use of the ratio projector built by the Forest Service is such that the use of the inverted image in no way complicates the drafting methods.

Procedure (using Ratio Projector, Fig. 69). The entire procedure in the compilation of maps by the template method through the use of the ratio projector is exactly the same as that discussed above, up to the point at which the layout of the template is completed. With the layout of the templates complete, the entire assembly of templates is turned over. This move inverts the position of all the ground control and picture control located on the templates. On sheets of high-grade vellum, the plan positions of all the ground control and picture control points are traced off.

Photograph 1 is now placed on the tilting table, part *F* in the diagram, and the lights are turned on. The tracing vellum is placed on the clear glass drawing plate under the hood in such a way that the portion of the vellum carrying the plan position of the control point of photograph 1 is approximately centered over the clear glass. The inverted image of photograph 1 formed directly on the tracing vellum. Inasmuch as the control points on the vellum have been inverted by the process previously explained, the image points projected from the photograph should correspond to them. The vellum is shifted until the nearest coincidence between image points and control points that can be made is obtained. By adjusting the tilting table and the focusing bellows, an attempt is made to bring all image points into exact register with the plotted control points. It is not likely that this will be possible. However, when the majority of points are made to coincide, the remainder of the points will only be displaced by very small distances. These discrepancies are due to relief displacement which cannot be eliminated. While an attempt is made to achieve accuracy in the tracing of the detail, no effort is made to be neat. Thus, the drafting on the ratio projector is one of speed and accuracy. After all the detail is traced from picture 1, picture 2 is substituted, the vellum is shifted, and work goes on as above.

When one sheet of vellum is completely filled with detail traced from the photographs, the projection sheet, which so far contains the plotted ground-control points, is turned over, that is, turned face down on the drafting table. This, of course, reverses the positions of the control points. The tracing vellum which carries the detail as well as the plotted positions of the ground- and picture-control points is slipped beneath the proper projection sheet. The ground-control points on the projection sheet and those on the tracing vellum are brought into exact coincidence and then the detail contained on the vellum is carefully and accurately traced onto the projection sheet. Inasmuch as it is from the projection sheet that copies of the map are to be obtained for the production, great care must be exercised in the detailing of this sheet.

From this point on, the method is again similar to that stated above.