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AERIAL PHOTOGRAPHY

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TECHNICAL MANUAL No. 1-220

WAR DEPARTMENT,
WASHINGTON, July 8, 1941.

AERIAL PHOTOGRAPHY

Prepared under direction of the
Chief of the Air Corps

CHAPTER 1

GENERAL

1. General.—All photography accomplished from an aircraft is termed "aerial photography," regardless of the type of camera used. Aerial photographs may be taken singly with any length interval of time between, in which case they are known as stills, or the individual pictures may be taken rapidly in succession so as to record movement in the scene, in which case they are known as motion pic-

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tures. Motion-picture photography is sometimes referred to as "cinematography."

2. Aerial photographs.—The design of this manual is to teach the taking of all the types of aerial photographs used for military purposes. Aerial stills or still photographs are classified as vertical, oblique, and mosaic or composite photographs.

a. A vertical photograph is the picture of an area or objective made with the camera axis perpendicular to the earth.

b. An oblique photograph is any photograph made with the axis of the camera tilted sharply from the vertical.

c. A composite photograph is the finished product of a multi-lens camera. It is composed of a contact print of the vertical chamber and the prints of the oblique chambers after they have been projected in the proper rectifying printer designed for the camera.

3. Aerial cinematography.—Aerial cinematography may be either sound or silent, vertical or oblique.

4. Military aerial photography.—Military aerial photography is divided by its tactical employment and equipment into two general classes:

Mapping photography.
Intelligence photography.

Whereas maps may be compiled from either vertical, composite, or oblique photographs, only the vertical or composite photograph will be considered as a map-making aid. Inasmuch as the technique of the cameraman is much the same when using either a vertical or multi-lens camera, the technique of mapping photography will be treated from the standpoint of vertical camera operation.

5. Instructions for use of equipment.—A complete list of the standard cameras and accessories used by the Air Corps may be found in Air Corps Technical Order 00-1. Air Corps Technical Orders, series 10-10, describe in detail the installation, operation, and maintenance of the various types of cameras. The pertinent technical order will be consulted before operating equipment with which the cameraman is unfamiliar. In addition to cameras, Air Corps Technical Orders include necessary operation instructions for all types of photographic equipment or accessories and therefore detailed instructions concerning such auxiliary equipment will likewise be omitted from this manual.

CHAPTER 2

MAPPING PHOTOGRAPHY

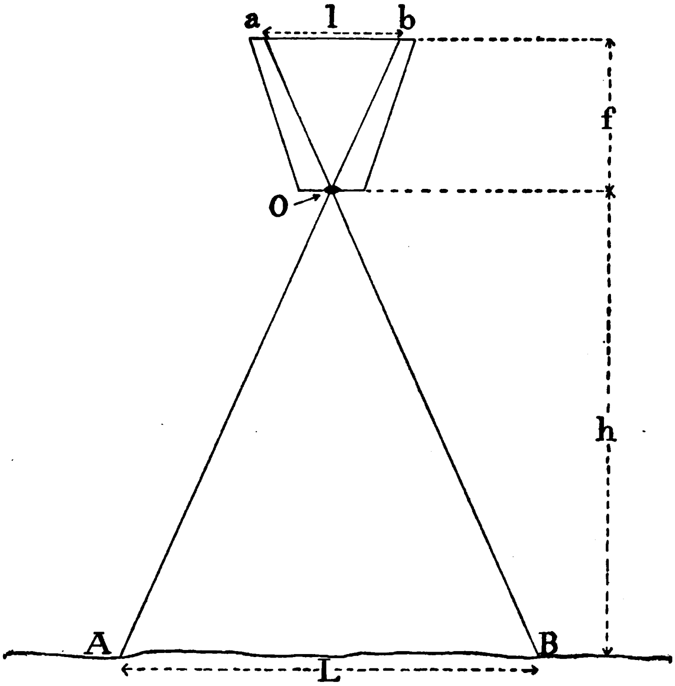
6. General requirements.—Mapping photography will be performed with the best and latest equipment available as it is a very precise operation and must be accomplished with the utmost skill and precision.

7. Preflight preparation.—*a.* The scale of a map or the scale of a photograph is the ratio existing between any distance on the ground and the representation of that distance in either the map or in the photograph. It must be computed with like units of measurement. The two factors for determining scale are focal length of the camera and altitude above the terrain. For example: It is impossible to obtain initially a vertical photograph at a scale of 1/40,000 with a camera of 24-inch focal length. To do so would involve flying at 80,000 feet. However, it is a simple matter to obtain it with a camera of 6-inch focal length, which requires flying at 20,000 feet above the terrain.

(1) *Methods of expressing scale.*—(*a*) The scale of any vertical photograph is the relation between any distance on the print to the corresponding distance on the ground. There are different methods of expressing the scale of aerial photographs and the methods used are the same as employed on line maps.

(*b*) The "representative fraction" (R. F.) of a map is one whose numerator shows the units of distance on the map and whose denominator shows the corresponding units of distance on the ground. Thus, scale 1/12,000 means that one unit on the map represents 12,000 of the same units on the ground, be it inches, feet, yards, or any other unit of measurement. In manuscript, the R. F. is usually written 1: 12,000.

(*c*) Another method of stating the scale is in words and figures, as 6 inches equal 1 mile, which means that 6 inches on the map represent 1 mile on the ground; 1 inch equals 800 feet, meaning that 1 inch on the map equals 800 feet on the ground. A scale of this kind can very easily be changed to a "natural" scale (the R. F. also is called "natural" scale), as for example, if 6 inches equal 1 mile, or 6 inches equal 63,360 inches, then 1 inch equals 10,560 inches, which of course gives the R. F. of 1:10,560, since both the numerator and the denominator are of the same units.



l. Focal plane.
f. Focal length.
O. Lens.
h. Altitude.
L. Ground coverage.

FIGURE 1.—Similar triangles.

(*d*) A graphic scale is a line or double line drawn on the map, divided into equal parts, each division being marked with the distance it represents on the ground.

(*e*) The scale of aerial photographs depends on the focal length of the lens and the altitude at which the photographs were taken. It will be seen that lines drawn from the sides of the sensitized material to the lens and from the lens to the sides of the area covered on the ground form two similar triangles (fig. 1).

(2) *Methods of finding scale.*—(*a*) Since the sides and altitude of the triangles are proportional, the scale of the photograph is the ratio between the altitude of the small triangle (the focal length of the lens *F*) and the altitude of the large triangle (the distance from the lens to the ground *A*), or the ratio between the base of the small triangle (distance on the film *d*) and the base of the large triangle (ground distance *D*).

Example: The focal length is 6 inches, the altitude 25,000 feet; $\frac{f}{a}$ equals R. F., which is $\frac{6}{25{,}000\times 12}$, which equals $\frac{6}{300{,}000}$ or 1: 50,000.

Both the numerator and the denominator must be of the same unit, so altitude is multiplied by 12, changing feet to inches. Or, the distance between two points on the ground is 3,000 feet, the corresponding distance on the film, 5 inches:

$$\frac{d}{D}=\text{R. F. } \frac{5}{3{,}000\times 12} \text{ or } 1:7{,}200.$$

NOTE.—When a 12-inch focal length lens is used, the denominator of the scale corresponds to the altitude required. If the desired scale is 1:12,500 the altitude is 12,500 feet.

(*b*) The first method of finding the scale is, of course, accurate only providing the altimeter is accurate, the airplane was flown at exactly the same altitude for each exposure, and the elevation of the ground did not change. However, such ideal conditions seldom exist. Consequently, the scale is only approximate, but accurate enough for ordinary calculations which do not involve projections.

b. Ground area included in vertical photographs and number of exposures required to cover certain areas.—(1) It was stated in *a* above that the ground distance and its image on the sensitized material are the bases of two similar triangles. Therefore, the sides and altitudes of one are proportional to similar sides and altitudes of the other. This gives the following equation for calculating the ground distance covered by one exposure, say 7- by 9-inch film, using a 12-inch focal length lens at an altitude of 11,000 feet.

For the 7-inch side:

$$\frac{F}{A}::\frac{d}{D} \text{ or } \frac{12}{11{,}000}::\frac{7}{X}$$

$$X=\frac{77{,}000}{12}=6{,}416 \text{ feet.}$$

For the 9-inch side:

$$\frac{12}{11{,}000}::\frac{9}{X}$$

$$X=\frac{99{,}000}{12}=8{,}250 \text{ feet.}$$

NOTE.—Since in both ratios the denominators are in feet, it is not necessary to reduce feet to inches.

(2) The number of exposures required to cover a certain area depends on the scale and the amount of overlap desired. It is customary to have an overlap of 60 percent between exposures in the direction of flight and 50 percent between strips. That means that we use only 40 percent of the negative on the 7-inch side and 60 percent on the 9-inch side. Suppose the area to be mapped is 10 by 15

miles (the direction of flight being the long way). The area covered by one exposure on a 7- by 9-inch film is 6.416 feet times 8,250 feet. Forty percent of 6,416 feet (6,416×40÷100) equals 2,566.4 feet. Sixty percent of 8,250 feet (8,250×60÷100) equals 4,950 feet. Dividing the length of the area by the distance used on the 7-inch side of the photograph gives the number of exposures for one strip, and dividing the width of the area by the distance used on the 9-inch

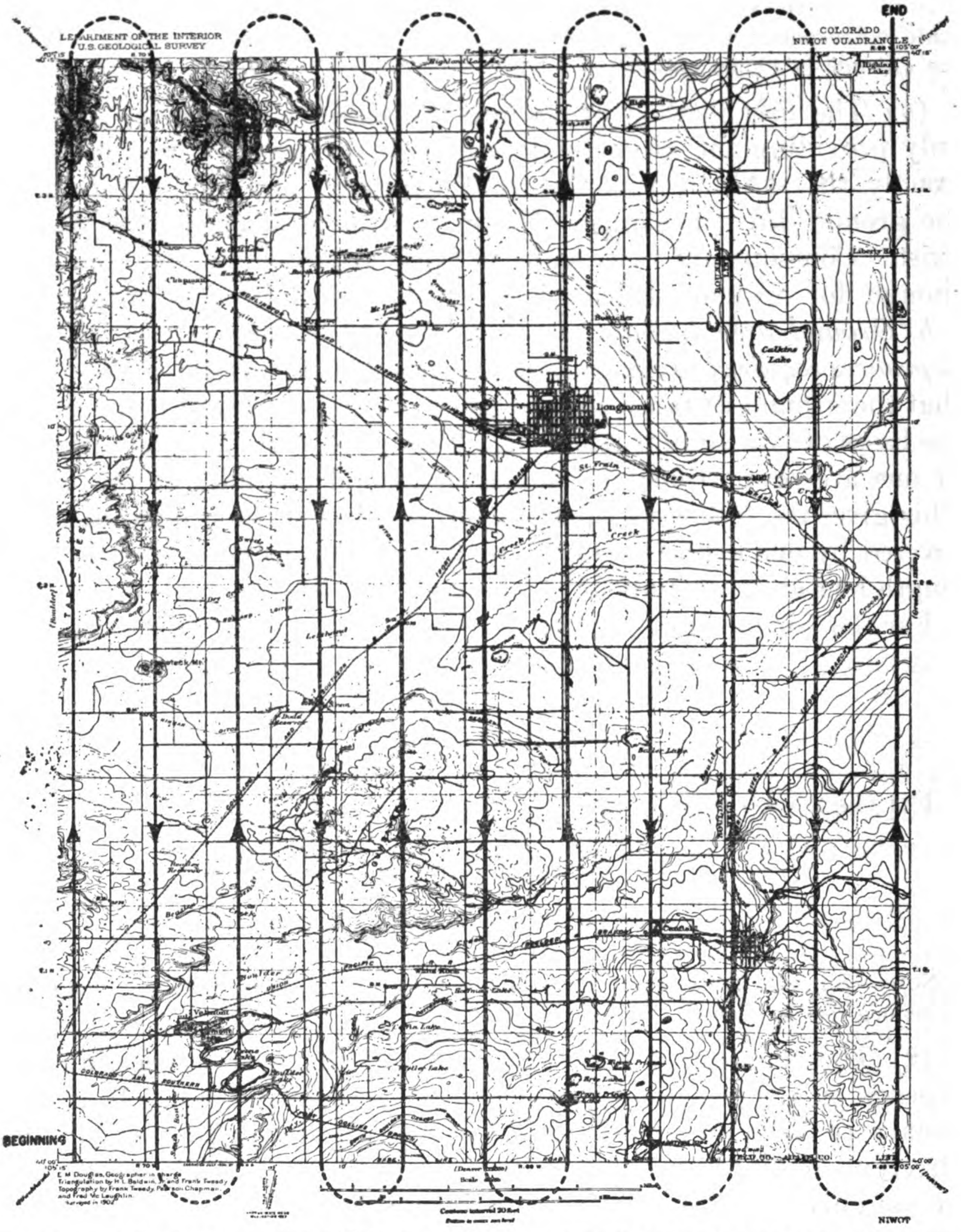


FIGURE 2.—Flight map. (Original scale 1 : 62,500—plotted for focal length lens 24 inches, focal plane 7 inches by 9 inches.)

side of the photograph gives the number of strips. Thus 15 miles, or 79,200 feet divided by 2,566 equals 30.8 exposures; and 10 miles, or 52,800 feet divided by 4,950 equals 10.6 plus strips. It would be necessary to make 31 exposures per strip and fly 11 strips, making a total of 341 exposures.

c. Flight map (fig. 2).—(1) The flight map is a map or sketch of the territory to be photographed. On this map or sketch, the flight lines are plotted to scale, indicating the number of flights to be made and the distance between the lines of flight. The flight lines are so spaced on the map that the strips of photographs overlap each other the desired amount. The flight map is a valuable guide to the pilot in selecting the lines of flight and indicates the beginning and end of each strip. The following examples will illustrate two methods of calculating the distance between the flight lines on the map having a scale of 1:62,500, allowing an overlap of 50 percent between strips. At an altitude of 30,000 feet, using a 24-inch focal length lens, a ground distance of 11,250 feet is covered by the 9-inch side of the film. Of this distance 60 percent is used (6,750 feet), which is reduced to a scale of 1:62,500.

$$\frac{6{,}750\times 12}{62{,}500}=\frac{81{,}000}{62{,}500}=1.30\text{ inches,}$$

or the length of the 9-inch film used is 5.4 inches (60 percent) and the scale of a negative at 30,000 feet altitude, using a 24-inch lens, is 1:15,000, which gives us the following equation:

$$\frac{\frac{1}{12{,}000}}{\frac{1}{62{,}500}}=\frac{5.4}{X}\text{ or }\frac{62{,}500}{15{,}000}=\frac{5.4}{X},X=\frac{81{,}000}{62{,}500}\text{ or }1.30$$

inches, which is the distance between the flight lines.

(2) The problems illustrated in the preceding paragraphs may be more briefly shown in the form of formulas. In each case let S equal the scale, expressed as representative fraction (R. F.), h equal height or altitude; f equal focal length, W equal width of ground area covered by photograph, w equal width of film, L equal length of ground area covered by photograph, and l equal length of film; then:

$$S=\frac{f}{h}$$

$$W=\frac{h}{f}\times w$$

$$L=\frac{h}{f}\times l$$

$$h=\frac{f}{s}$$

d. Installation of equipment.—(1) It is the cameraman's responsibility to install in the airplane all the photographic equipment required for an aerial mission, and to see that it is in operating condition. This equipment will include an aerial camera complete, of specified focal length, filter unit, sufficient film to accomplish the contemplated mission (whenever this exceeds one loading, additional film will be carried either in interchangeable magazines or in film spools available for daylight loading), mount, view finder or sight, electrical cables for automatic or semiautomatic operation, vacuum hose from camera to source of supply, intervalometer, data pad or flight record, exposure meter, safety wire, lens tissue, adhesive tape, pencil, altitude temperature computer, and adequate protective clothing.

(2) In the selection of a filter for the mission the following information will be found helpful. The filters supplied the Air Corps for aerial photography range in color from a light yellow to red and eliminate haze in proportion to the depth of color. Formerly, with the use of slower and less color-sensitive emulsions, the choice of a filter was a matter requiring considerable practical experience in aerial photography. Now, with very color-sensitive film the choice of a filter is not such a critical matter. Haze conditions in relation to aerial photography may be characterized under three classes, namely, approximate absence, light haze, and heavy haze. For vertical photography at altitudes below 2,000 feet, no filter is required; at altitudes from 2,000 to 5,000 feet no filter is required for the first class, a light filter for the second, and a deep yellow filter for the last; at altitudes from 5,000 to 10,000 feet, a light yellow filter is desirable for the first class, a deep yellow for the second, and a red filter may be desirable for heavy haze conditions; at altitudes above 10,000 feet there will probably be no change in filter use from the last indicated. Oblique photographs made at angles from 30° to 60° from the vertical require the use of the same filters designated for vertical photography at the same altitude. Oblique photographs made from angles of 60° to the vertical to and including the horizon require, in the approximate absence of haze, a light yellow filter; under light haze conditions, a deep yellow filter; and for heavy haze, a red filter. The choice of the filter for oblique photography depends more upon the angle at which the photograph is to be made than upon the altitude. For aerial photography ranging from vertical to 60° of vertical, it is desirable to use a filter which avoids excessive contrast and sufficiently excludes haze. The filter must be a compromise. For oblique photographs taken at angles ranging from greater than 60° of vertical

to and including horizon objects and sky, it will be necessary to use a filter of deeper color that may overcorrect in the foreground and produce undesirable contrast in the nearer portions of the photograph. The photographer must estimate his needs somewhere between these two, bearing in mind that any of the three filters may produce undesirable contrasts in the foreground, and base his choice on these conditions and upon experience. The average yellow filters require increased exposures, usually not more than two times normal. Use of the red filters requires approximately four times normal exposure.

(3) During installation the following precautions will be observed: Check to make certain sufficient oxygen is in the aircraft to complete the mission; cleanliness of camera compartment; cleanliness of inside and outside of fuselage near camera opening, especially for oil or fluids; test camera hatch or hatches for proper operation (this hatch should be kept closed during take-off and landing; when camera is mounted in bomb-bay, the bomb-bay doors are kept closed during take-off and landing); check a complete cycle of automatic operation after completing installation. The photographic crew must be prepared to execute the mission at any one of several altitudes whenever weather reports are inadequate or in the event that hostile territory is defended against aircraft.

8. Camera operation.—*a. Method.*—Aerial cameras may be operated by any one of the following methods: fully automatic, semiautomatic, manually, or remote control.

(1) Fully automatic operation involves the rewinding of the film and shutter mechanism by an electric motor, the use of an intervalometer for tripping the shutter, and signal lights to warn both the cameraman and the pilot when the next exposure is to be made.

(2) Semiautomatic operation requires the use of an electric motor to rewind the film and shutter mechanism. The shutter is tripped manually.

(3) The camera is said to be manually operated when the leveling of the camera, the shutter rewinding and shutter tripping are all manually performed.

(4) Aerial cameras may be operated by remote control by any one of several means. The camera may be mounted in some inaccessible part of the airplane, such as the bomb-bay, the leading edge of the wing, the tail of the airplane, or in the nose compartment. Remote control may be through mechanical gearing or by electrically controlled servo units. Cameras will be operated by remote control in all pressure-cabin type airplanes, and in other aircraft where it is desirable to locate the camera in a position inaccessible to an operator.

b. Determining crab and interval.—When the airplane has attained the altitude at which the mission is to be flown and reached the objective to be photographed, the airplane should be alined with the first flight line several miles prior to the boundary of the objective. The pilot or navigator signals the cameraman who determines the crab and interval by the use of the vertical view finder; the dark slide is then removed and about 10 seconds before reaching the objective the pilot or navigator again signals the cameraman to start his exposures.

c. Exposing first strip.—It is now the pilot's function to adhere as closely as possible to the track of the flight line and maintain the airplane laterally level and within the required altitude, plus or minus 50 feet. The cameraman must use the utmost precautions to secure photographs that are truly vertical, being positive the camera is level at the instant of exposure. He must check the view finder for crab after each exposure. When the flight line is finished the pilot or navigator notifies the cameraman to discontinue exposing.

d. Second strip.—The pilot continues on the course for 2 or 3 minutes before making the turn for the approach of the second flight line. After the turn has been made and the airplane alined on the approach of the second flight line, the pilot or navigator signals this fact to the cameraman, who checks the crab and interval, which usually must be changed with the change of direction. The second strip is then flown in the same manner as the first. This procedure is continued until the area to be mapped has been completely photographed.

e. Maintenance of record.—The cameraman must note the exposure meter reading at the beginning and ending of each flight line, the time of beginning and ending of camera operation on any particular mission, direction of flight on the various flight lines, and the order in which they are flown. When the area to be photographed is larger than that which can be covered in one loading, an additional magazine is installed if the camera permits interchangeability of magazines. The data obtained by the cameraman should be attached to each magazine in order to be with the roll of film while being processed.

f. General information.—(1) Two prime factors must be remembered at all times: leveling of camera and overlap. The cameraman must have the camera level at the instant of exposure and secure the proper overlap in line of flight, and the pilot or navigator must be positive that side overlap is sufficiently covered as reflights over hostile territory to rephotograph "holes" would be impracticable.

(2) On long missions the filter, shutter, and general mechanism

of the camera should be periodically checked to be certain of proper mechanical functioning. In the event of camera failure the airplane commander will be notified immediately, the cameraman stating whether repairs can or cannot be made during flight, and if so, the length of time before camera operation can be resumed.

9. Completion of camera mission.—*a.* On the return flight after the completion of the photographic mission the cameraman should check the data cards for completeness, ascertaining that all data are recorded that will be necessary for the processing and identification of the film by laboratory technicians, maintenance of W. D., A. C. Form No. 45, any special data pertinent to the mission, and the legibility of all data.

b. Upon landing, it is the cameraman's responsibility that all film, with data cards, is delivered to the laboratory for processing. The camera and accessories should then be dismounted and thoroughly checked, and any repairs or alterations necessary should be made. All empty film magazines should be reloaded and installed on cameras, and all equipment prepared for another photographic mission.

CHAPTER 3

INTELLIGENCE PHOTOGRAPHY

SECTION I

VERTICAL PHOTOGRAPHY

10. General.—Intelligence photography gains information for a commander through the medium of stereoscopic pairs (vertical or oblique), reconnaissance strips, small mosaics, and some oblique photography.

11. Employment.—The cameraman's duties in securing vertical photographs for this class of aerial photography are essentially the same as in performing a mapping mission, the principal difference being that less time is afforded the cameraman before operation. While there will be no attempt to describe the different tactical situations under which intelligence photography is performed, it must be constantly borne in mind by the cameraman that intelligence photography frequently calls for securing photographs of fleeting objectives. This term is used here to denote not only moving objectives, but also objectives such as hostile aircraft on camouflaged airdromes that are not definitely located prior to the departure of the mission. The determination of whether an objective is photographed vertically or obliquely will depend upon the judgment of the cameraman as to the manner in which he can best secure the necessary coverage under the conditions existing at the time. It is obvious that cameramen employed on this duty must be readily responsive to the signals of the airplane commander.

12. Cameraman's duties.—It is of vital importance that the cameraman clearly indicate the time of exposure, the nature of the objective, its location, the altitude, and if possible, the direction of north. Upon returning to the base, it is the cameraman's duty to see that the exposed film is turned over to the photographic laboratory for processing, together with all essential data. Reports should also be rendered upon the functioning of all photographic equipment.

13. Mosaics.—Mosaics for the purpose of intelligence photography will be quite limited. They might consist of a mission calling for verticals of an objective whereby weather conditions will not permit the full coverage by a reconnaissance strip, thereby making it necessary for two or more short strips to be flown at a comparatively low altitude. In such cases, computations for flight lines and line-of-flight overlap should be computed as explained in paragraph 7*b*. The resultant photographs will then be susceptible of subsequent stereoscopic study.

14. Reconnaissance strips.—A reconnaissance strip is a series of overlapping vertical photographs made from an airplane flying a selected course.

15. Pinpointing.—When two or more aerial photographs are taken of a small area or point the result is called a "pinpoint." Such photographs are useful in intelligence work and therefore at least two overlapping pictures are taken of the objective so that the resultant photographs may be studied through a stereoscope. The pictures made in pinpointing are classed as vertical views and are essentially the same as those obtained in making reconnaissance strips or mosaics. The term pinpointing refers more to a type of photographic mission than to a kind of aerial photograph. As pinpoints must be taken so as to permit of subsequent stereoscopic study, certain precautions must be observed in the photographing. It should be remembered that the vertical view finder does not fully cover the area that will appear in the resultant photograph, and therefore care must be taken to see that—

a. The camera and finder are level at the moment of exposure.

b. The view finder shows as much margin as possible around the objective.

c. At the time of making the second exposure this objective still appears in the view finder and has traveled across it sufficiently from its position at the moment of the first exposure to afford the overlap required for stereoscopic viewing.

SECTION II

OBLIQUE PHOTOGRAPHY

16. General.—An oblique photograph is obtained by intentionally tilting the optical axis of the camera from the vertical.

17. Classification.—Oblique photographs may be classified as high or low obliques (fig. 3).

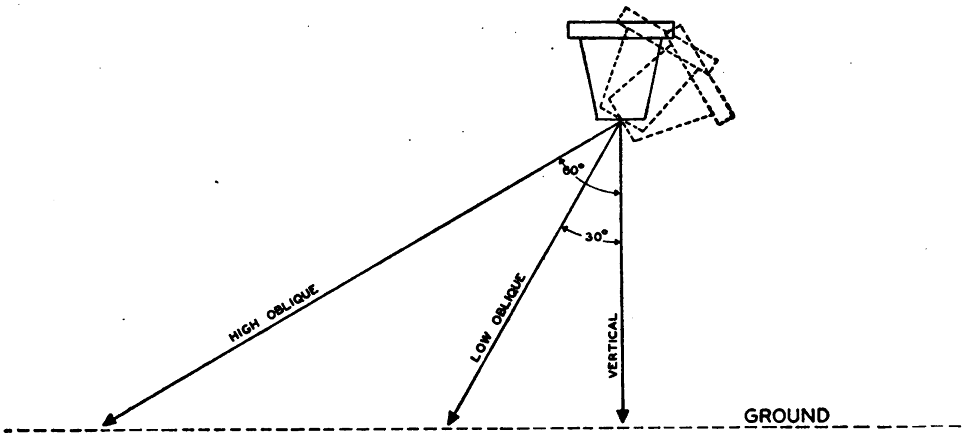


FIGURE 3.—Classification of oblique photograph.

a. A high oblique is one made with the axis of the camera at an angle of approximately 60° from the vertical and includes a portion of the horizon.

b. A low oblique is one made with the axis of the camera at an angle of approximately 30° from the vertical and does not include any of the horizon.

18. Composition.—It is desirable that the horizon be present whenever the altitude of the airplane and the nature of the objective permit. Photographs of airdromes should include some of the area just outside the boundaries of the landing field in order that an indication may be given of the nature of the approaches. When buildings are present on the airdrome the viewpoint selected should not place the buildings in the foreground. It is more desirable that they be along one side or in the background of the photograph. Photographs of buildings or structures should show at least two sides and will normally include the sunny side of the building. Similarly a photograph of a bridge will not be made from a viewpoint at right angles to the bridge but from some angle between 30° and 60° in order to reveal the construction of piers or supports. Photographs of terrain made for the purpose of yielding information to advancing troops should be made from as low an altitude as practicable and show the terrain to the horizon. Photographs of docks and wharves should be made at a fairly steep angle to show as much of the underwater structure as possible. Similarly photographs of obstructions placed under water at beaches should be made from a steep angle. In the latter type of photography the direction of the sun must always be considered, as reflection will completely obscure all underwater detail.

19. Technique.—Oblique photography requires greater effort on the part of the cameraman than does vertical photography. It also requires that the cameraman have a clear understanding of the nature of the objective and an ability to recognize it because under combat conditions it may be expected that acceleration forces will be present at the time of exposure, whereas the cameraman should expect this and not endeavor to aim the camera until just before making the exposure. It is essential that exposures made at different altitudes and times of day be made so as to secure negatives of about the same density, which will greatly facilitate processing in the laboratory. The simplest method of making oblique photographs, if the cameraman has a choice of positions, is to point the camera to the rear or in front of the airplane. If the photographs can be made directly ahead of the airplane more time is afforded the cameraman to compose the objective and secure the desired perspective. Active cooperation of the pilot is essential in all oblique photography as he must have a clear understanding of the coverage which may be expected at different altitudes and viewpoints; he must also realize the problems of the cameraman and avoid acceleration except when essential from a tactical viewpoint. The highest shutter speed that will yield a satisfactory exposure should always be used in oblique photography. This is especially important in low altitude photography where the relative motion is great, if the photograph is being made at right angles to the direction of flight. A common error is the alinement of the camera with some opening or part of the airplane which frequently produces photographs not square with the vertical. The camera should not at any time during exposure rest upon a metallic portion of the airplane as vibration of a ship will spoil photographs except when extremely high shutter speeds are used. The condition of the lens and the filter unit should be frequently inspected as should the vacuum supply, shutter mechanism, and film rewinding. Accurate and complete data regarding the nature, location of the objective, time, and altitude must be maintained.

20. **Aircraft processing.**—At this point it is considered opportune to enjoin the caution that whenever photographs are very rapidly processed in an aircraft while in flight, according to the method known as "quick work photography," in which a portable processing outfit is carried, care must be taken to prevent the spilling of chemicals and chemical solutions.

21. **Cameraman's duties.**—An important duty of the cameraman is to assist in the identification of the ground areas or objectives represented in the aerial photographs taken by him. His other duties and responsibilities are stated in paragraphs 18, 19, and 20.

22. **Additional information.**—Additional information on aerial photography concerning tactical employment, particularly with reference to the duties of members of the combat crew other than the cameraman, is contained in FM 1–35.

CHAPTER 4

AERIAL CINEMATOGRAPHY

23. General.—*a.* The Air Corps is charged with all cinematographic work from aircraft which may be either silent or sound, vertical or oblique.

b. Cinematography is based on an optical illusion. It has been found that if a series of pictures are presented to the eye in rapid succession, spaced by intervals of darkness, the eye retains momentarily the impression received from each picture until it is replaced by a new impression from the next picture. If the pictures vary one from the next only slightly, the impression of smooth gradual change is received and the illusion of motion is created.

c. The successive pictures must be presented to the eye at the rate of at least 16 pictures a second to fulfill the conditions outlined above. To meet this requirement a large number of pictures are needed. It has been found best to make these pictures, individually small in size, on long strips of film. Since the advent of sound recording on motion-picture film, the use of 24 frames a second has become standard.

d. A camera basically similar to the ordinary type cameras is required which will accommodate large rolls of film and a mechanism which will intermittently advance the film a frame at a time behind a closed shutter, and then hold the film stationary in the focal plane while the shutter opens and the exposure is made.

24. Motion-picture camera.—Figure 4 illustrates clearly the essential parts of a common type of motion-picture camera. These parts are a lens, a shutter, a film gate which is back of the lens, a mechanism for feeding the film and intermittently stopping and pulling it through the gate, a finder, a reel containing the roll of unexposed film, a take-up reel, and a mechanism for drawing the film through the camera, which actuates sprockets and rollers that keep the film at proper tension. The camera is driven by one or more of three methods, namely, hand drive, spring drive, or electric motor drive.

25. Technique.—*a. Camera check-up.*—As film is so easily and so rapidly exposed in a motion picture camera an especially careful check should be made before each mission not only to see that the camera is complete with all accessories possibly needed, but that there is a very ample supply of film.

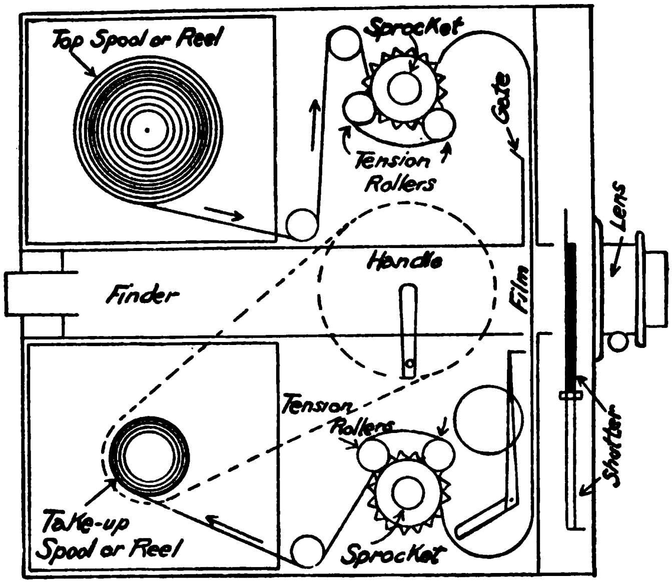


FIGURE 4.—General mechanism, motion-picture camera.

b. Importance of skill and training.—Because of the small field of view of the lens of the motion-picture camera, and the fact that the camera must be kept on the subject for long periods, the taking of motion pictures from aircraft requires considerable skill and practice. The work of the motion-picture cameraman when photographing from aircraft is analogous to that of the aerial machine gunner because each must be able to point the machine he is operating at the target and keep it there for a considerable time. In order to accomplish the purpose each must depend upon the pilot to put him in proper position to "shoot" and to keep him there regardless of the uncertain movements of the target. Panoraming and tilting of the camera in the airplane should be kept at a minimum.

c. Camera mount for aerial work.—In aerial cinematography any one of several mounts may be used. These include a special attachment designed for the machine gun tourelle, a floor mount for "shooting" out of an open door or window, and a floor mount for "shooting" out of the hole in the bottom of the ship (verticals). The two latter types may be constructed at the discretion of the aerial cinematographer, although some cameramen use the standard tripod by securing it in the airplane in such a manner that the vibration will not loosen it.

d. Position of camera in aircraft.—If the motion pictures can be taken from the nose or tail of aircraft the work of the photographer is considerably lessened, for his camera can be trained easily in almost any direction and the pilot can readily aid him in keeping the airplane in proper position. If the photographs are taken from the center station of an airplane, the field of view is limited to the sides and over the tail. In any case the relative motion between the camera and the ground objective should be kept as small as possible. This is enhanced by photographing toward the nose and tail of the airplane rather than at right angles to the direction of travel of the airplane.

e. Composition of picture.—The composition of the picture in the view finder of motion-picture cameras is similar to that exercised in making aerial obliques and verticals with "still" cameras.

f. Adjusting shutter for aerial work.—For aerial work use the largest shutter opening with which it is possible to stop the motion. The belief that the narrow shutter opening should be used in order to neutralize the effect of vibration is incorrect. If vibrations are severe enough to spoil single pictures they will spoil the strip. While each individual picture may be sharp when a narrow shutter opening is used, a succession of sharp pictures, separated by a large interval, will flicker on the screen. In order that the eye may be able to see a series of still pictures as a moving picture, the interval of motion between successive pictures must be small. It is better that the entire series be made with a larger shutter opening and small stop. To illustrate, it is assumed that the film is being exposed at the rate of 24 frames a second. We may choose either a 90-degree (small) shutter opening or 180-degree (large) shutter opening. In the case of the small shutter opening each frame receives $^{90}/_{360} \times {^1}/_{24} = {^1}/_{96}$ second exposure. This leaves $^{270}/_{360} \times {^1}/_{24} = {^3}/_{96}$ second for the shutter to be closed, the shutter open one-fourth the time and closed three-fourths of the time. In the case of the large shutter opening each frame receives $^{180}/_{360} \times {^1}/_{24} = {^1}/_{48}$ second exposure. This leaves $^{180}/_{360} \times {^1}/_{24} = {^1}/_{48}$ second for the shutter to be closed. The shutter is open one-half of the time and closed one-half of the time. It is obvious that in the second case the amount of time the shutter is closed is less, giving less time for the object to move between frames, thus reducing the flicker. True, there is more blur in each frame due to longer exposure, but this is not as noticeable in a series of pictures as the longer interval.

g. Camera speed for aerial work.—Aerial motion pictures should generally be filmed at a higher rate of speed than normal because of the speed of the airplane. This reduces the interval of motion between frames. (See *d* and *f* above.) Thirty to forty-eight frames a second are generally used at higher altitudes. As the altitude increases the camera can be run at slower speeds without causing flicker. In the case of a sound picture taken from the air, the deviation from 24 frames a second (sound camera speed), is not serious as the sound and picture are seldom synchronized. However, if life motion and exact sound synchronization are required, a camera speed of 24 frames a second must be used.

h. Lenses.—Long focal length lenses are not ordinarily used because of the effect of the movement of the airplane while using such lenses. However, medium focal length lenses may be used when photographing one or more airplanes from another. The focus of the lens is set at infinity except when the objective is less than infinity.

i. Filters.—Filters should not ordinarily be used at low altitudes or on clear days. Definite rules cannot be laid down regarding their use. However, the rules as applied to "still" aerial photography and photography in general apply as well to motion-picture photography.

j. Photographing airplanes in air.—When the subject is one or more airplanes flying in the same direction as the one in which the camera is mounted, a small shutter opening may be used provided the earth is not used as a background or if the altitude is at least 4,000 feet.

26. Exposure of negative.—*a.* The absolute exposure received by each single frame of a motion-picture negative depends upon several factors, namely, shutter opening in degrees, linear film speed, lens diaphragm stop, amount of incident light falling upon the subject, the reflection properties of the subject, the filter factor of the filter (if used), and speed (or light sensitivity) of film to be used.

b. For any one combination of the factors listed in *a* above, a definite shutter speed is determined and expressed as a fraction of a second. An exposure meter or exposure table will indicate the relative amount of light reflected from the subject. Knowing the emulsion speed and filter factor (if any), it is only necessary to adjust the diaphragm stop accordingly.

c. Although experience combined with exposure tables relative to lighting and illumination has been used, a reliable exposure meter is strongly advised. The error of personal judgment is thus greatly reduced. Exposure meters set for the emulsion speed rating, filter factor, and shutter speed will give the correct diaphragm stop when set at the indicated light reading.

d. The use of neutral density filter is recommended to compensate for a faster emulsion speed (when a fast film is being used and the illumination is suddenly increased), or when the minimum *f* value of the lens is not sufficiently small to give the correct exposure. An alternative of the latter is to reduce the shutter opening in degrees, which would automatically increase the shutter speed. It must be remembered, however, that reducing the shutter opening also increases the interval of motion between frames.

e. In shutter speed calculations, the actual time of exposure of each frame of a motion picture negative is determined by the speed at which the film passes through the gate and the shutter opening of the camera. A simple formula for determining such is as follows:

$$\frac{\text{Shutter opening in degrees}}{360} \times \frac{1}{\text{exposures per second}}$$

Example: Shutter opening 180°; exposures per second, 24. Find the shutter speed.

$$\frac{\text{S.O.}}{360} \times \frac{1}{24} = \frac{180}{360} \times \frac{1}{24} = \frac{1}{2} \times \frac{1}{24} = \frac{1}{48} \text{ second}$$

This fraction of a second is the one used in making exposure meter calculations for the indicated shutter opening and film travel. Some motion-picture cameras have a table of shutter speeds relative to these two factors printed or attached directly to the camera body for reference.

27. Maintenance of records.—It is essential that detailed and accurate data cards pertaining to the subject, weather conditions, altitude, time of day, location, and any other pertinent information, accompany each reel of film upon being delivered to the laboratory for processing. The cameraman should also include all data necessary for the maintenance of W. D., A. C. Forms Nos. 10 and 45.

CHAPTER 5

AERIAL PHOTOGRAPHIC MOSAICS AND MAPPING

SECTION I

GENERAL

28. General.—*a. Mosaics, how made.*—The greater the altitude at which a photograph is taken the greater the size of the ground area that will be included in the picture. However, there is a limit to the altitude that can be reached by an airplane and therefore it is often impossible to include in a single exposure the total ground area that may be desired. Resort is then had to the taking of a number of vertical photographs in such way that they can be joined to form a single picture. As the combining of the individual photographs resembles the art of joining pieces of colored glass, stones, tiles, etc., in the form of decorations or pictures called mosaics, the term "aerial photographic mosaic" has been applied to a group of overlapping vertical aerial photographs assembled to form a single composite picture. To be able to fit the photographs together, it is necessary that they all be of the same scale. The scale of an aerial photograph depends upon two factors, namely, the focal length of the lens used, and the altitude of the airplane at the moment the exposure was made. Therefore, in preparing to take photographs for the making of a mosaic, selection must be made of the aerial camera with reference to the focal length of the lens thereon, and decision reached as to the altitude at which the airplane will be flown. The flying problem involved consists of maintaining the airplane at a uniform distance from the earth's surface so that all the photographs can be taken from the same altitude. As there are a variety of available focal length lenses and the only limitation as to altitude is performance ability of the aircraft, it is possible, practically speaking to make a mosaic at almost any desired scale.

b. Importance.—Mosaic photographs are valuable for a variety of military purposes, especially when topographical maps are not available or are obsolete. They can be produced roughly under war conditions in a surprisingly short time with a degree of accuracy proportional to the time available and the accuracy of the photographs, and because of the fact that they represent current conditions and that every object on the ground is reproduced in the photograph in its proportional plan view size, they compare very favorably for military purposes with hasty topographic maps. In addition to this, proper study of an aerial mosaic indicates the details beyond the ability of topographic mapping symbols, that is, scattered or dense woods and approximate heights and kinds of trees.

c. Reconnaissance strip.—A reconnaissance strip is a single strip of overlapping photographs taken especially for reconnaissance purposes following a central line of interest.

29. Scale.—The scale, methods of finding, ground area included in vertical photographs and the number of exposures required to cover certain areas, the flight map, general information, routine of a photographic mission, ground preparation, season and time of the day, and photographic missions have been thoroughly covered in paragraph 7.

30. Index map (fig. 5).—*a. Uses.*—After the negatives of a vertical mission have been lettered and numbered consecutively as prescribed in Air Corps Circular 95-3, an index map should be made indicating the area covered by each individual negative. A map of average scale such as a 1:62,500 or 1:48,000 topographic map is usually selected. A map of this scale has detail in such quantity and sufficiently large to be used in the identification of the area covered by each negative. In the case of T-type photographs, a map of smaller scale might be used to advantage, since the area covered by each photograph will be much greater from a given altitude. The index map is useful for the following reasons:

(1) Indicates total area covered by a given flight or assignment.

(2) A suitable negative covering any particular point may be selected.

(3) The index map is used to determine the center of the mosaic so that in the case of a controlled mosaic, meridians and parallels of the polyconic projection may be properly located with respect to the center of the mount.

(4) Suitable stations may be selected from the computation of "average scale" of mosaic by triangulation for ground distances between said stations.

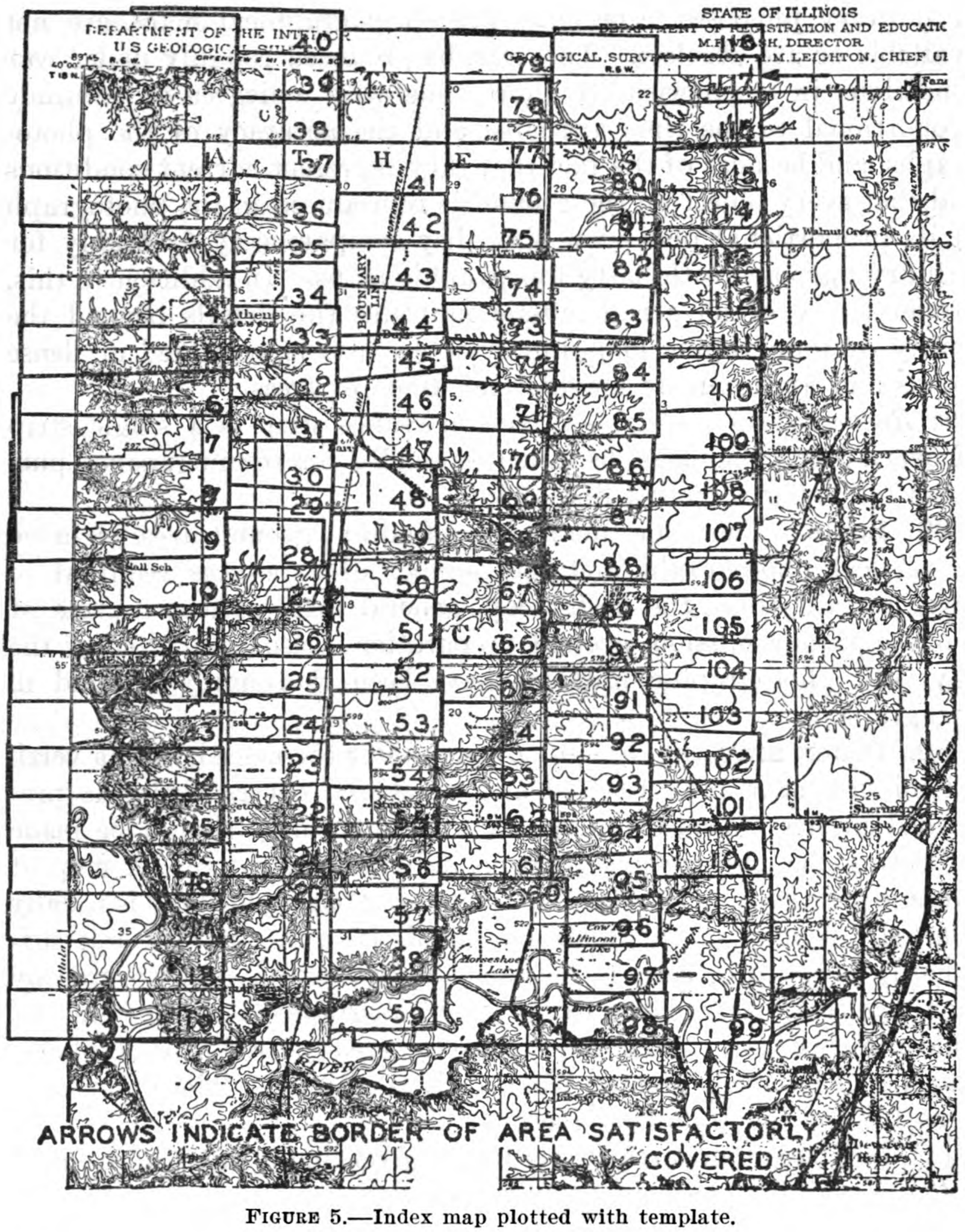


FIGURE 5.—Index map plotted with template.

b. Template.—In order to locate correctly the area covered by each negative on a map, two templates are constructed. A first template is made by cutting out a 7- by 9-inch area in a slightly larger piece of cardboard. The standard mounting board for photographs is well adapted to this use. The edges of this cut-out rectangle are graduated in inches and each graduation numbered. The second template is a miniature of the first, made of celluloid or other suitable transparent material. It has graduations to correspond to those of the larger cardboard template. These graduations and size of the small template are of course dependent on the map scale and the interval between graduations is determined by dividing each side of the template into the proper number of equal parts. These corresponding divisions on the large and small templates facilitate the proper orientation of the small template on the map. When this is done, a line is drawn around the template on the map to represent the perimeter of the area covered by the negative which is being plotted. When the areas of all negatives of the mission are indicated on the map in this manner, the map will show the results of the mission. Following is the formula for determining the template dimensions:

$$\frac{\text{Reciprocal photograph scale}}{\text{Reciprocal map scale}} = \frac{\text{side of template}}{\text{side of negative}}$$

or

$$\text{Side of template} = \frac{\text{reciprocal photograph scale} \times \text{side of negative}}{\text{reciprocal map scale}}$$

It is good practice to add 0.04 inch to each dimension of template to allow for pen or pencil point. Following is an example which will illustrate the method for determining template size:

Scale of photographs: $\frac{1}{15{,}000}$; scale of map: $\frac{1}{62{,}500}$.

Size of negatives: 7 by 9 inches; size of template: T by T_1 (each $+0.04$).

$$T = \frac{15{,}000 \times 7}{62{,}500} = 1.68\ (1.68 + 0.04) = 1.72 \text{ inches}$$

$$T_1 = \frac{15{,}000 \times 9}{62{,}500} = 2.16\ (2.16 + 0.04) = 2.20 \text{ inches}$$

The correct size of template is therefore 1.72 by 2.20 inches.

c. Other methods.—(1) If copying facilities are available the prints may be trimmed to the collimating marks and shingled together by matching detail, using the straight-line method, and so laid that the number of each print is visible. They may be held in place with transparent cellulose tape, thumbtacks, or paper clips. The assembly is then rephotographed and the prints used as an index.

(2) Another method is to plot the center of each photograph, then these points are plotted by small circles on the map with the number of the photograph being placed beside each circle.

(3) Still another method is cutting collimating notches in the center of the template in direction of flight, then marking these two points, remove template and join the points with a straight line. Continue this method through the remainder of index map.

(4) It is much more satisfactory and rapid to plot the index map direct from the prints rather than from the negatives. In this manner the orientation of the print may be simplified especially over terrain where map detail is at a minimum as detail can be located by matching the following print with one where the orientation has been made.

31. Mosaic print.—One set of prints should be made from each negative after numbering to be used for plotting, and at least two matched prints are made from each negative shown in the index map. These contact prints may be used for construction or scaling purposes.

Section II

RECONNAISSANCE STRIP

32. Reconnaissance strips.—When an airplane is flown so as to follow a straight line on the ground, made by such objects as a railroad, telephone line, section of a trench, etc., vertical aerial photographs can be taken from the plane with such frequency that the photographs will overlap and can be assembled in the form of a strip of photographs covering any desired length of the line. Such a strip is known as a reconnaissance strip rather than as a mosaic (which it might properly be considered) because it is ordinarily made for reconnaissance purposes.

33. Straight-line method.—*a.* The straight-line method can be most advantageously used to assemble aerial photographs when the common vertical type of photograph having large overlaps is used and the distortion of the images due to tilt of the camera, or to relief of the terrain, is a minimum. To utilize this method it is well to consider the photographs extending from one known control point to another control point as portions of a traverse line. The evenness and regularity with which the photographic work was accomplished and the amount of ground relief will then determine whether it is best to use a single straight line throughout for orientation, or break the flight up into several smaller sections. Presupposing a country of small surface relief, it will generally be possible to utilize a single straight line for orientation of the photographs.

b. The principal point of each photograph should be located approximately by drawing its two diagonals, after which the photographs should be laid out in regular order on a large table and fitted together as accurately as possible by photographic images alone. A straight edge is then placed on the assembled photographic strip and so adjusted that its edge will pass as closely as possible to the principal point of each of the photographs, keeping in mind the fact that a well selected line should have an equal number of principal points at equal distances to either side. The line indicated by the straight edge should be transferred to the end photograph that is uppermost in the strip of photographs, by carefully drawing a fine sharp line along the edge of the straight edge. (It should be noted that this line is drawn on only one photograph.) The photographs are then taken up from the drafting table in order to extend the straight line onto each photograph in turn. On the straight line drawn on the first photograph and in the region overlapped by the second photograph, select two points as far apart as possible. These points should be very sharply defined in order that they can be positively identified on the second photograph. Through these two points so recovered on the second photograph draw a fine sharp line and produce it to each side of the photograph. Repeat this process, using photographs two and three and so continue until this line has been carried over all the photographs in this strip. There now exists on each photograph a line that is identical in azimuth with all the other lines on the other photographs. With this line it is possible to orient these photographs by placing the first photograph over any right line drawn on any large sheet of paper as a guide, and so orienting it that the line on the photograph will superimpose the line on the paper. This photograph should be held in place in any convenient manner and the second photograph adjusted over the straight guide line and slipped along the same orientation, until any point on or near this line is exactly above the same point of the first photograph. These photographs are then as accurately joined as it is possible to do by this method and should be permanently fastened together in this position.

c. It is often possible to utilize a single straight line from beginning to end of a flight on account of the disposition of the photographs. If the airplane was badly "crabbed" with respect to the line of flight on account of adverse winds, or if the line of flight was irregular, it will be impossible to select a line throughout the flight that will not depart a considerable distance from the line of principal points. In this case a line should be selected that will fulfill the desired condition for as large a number of photographs as possible, when it will be necessary to select another straight line for the balance of that section. Usually, two lines will be sufficient to control the length of strip ordinarily occurring between fixed control points. The second straight line will make an angle with the first line, the size of this angle being determined by the lay of the photographs. In selecting this second line the photographs should be laid out and joined by their images as in the first case, the general direction of the line being determined by the position of the principal points of the pictures concerned. This direction is then transferred to that photograph on which it is desired to locate the bend in the line. The new line is then produced over the remaining photographs. Assembling the photographs in their final position in this case is done as described for the single straight line, with the exception that two straight lines are used. The angle that these lines make with one another is obtained from that photograph on which the bend occurs, and it should be noted that it is necessary to begin compiling these photographs at the bend and working both ways from that point.

d. When time considerations do not permit the use of the straight-line method assembly must be made by fitting the detail of adjacent photographs for the best match.

Section III

AERIAL MOSAIC

34. Mosaics.—*a. Types.*—Aerial mosaics are of two general types:

(1) Controlled mosaics, wherein each photograph has been adjusted as nearly as possible to the proper scale and each photograph is laid so that a minimum of error exists between the position of its image points and their corresponding position on the projection.

(2) Uncontrolled mosaics, which are made by assembling unrectified vertical photographs without accurate ground control.

b. Use.—(1) Mosaics are usually assembled to form pictorial representations of an area to show planimetry only. Elevations are usually not represented, although mosaics may be contoured or form-lined with engineer equipment if desired.

(2) Vertical photographs for mosaics should be as nearly free from tip and tilt and scale variation as it is possible to make them. If this

is done mosaics are easy to lay, and excellent results may be obtained even with uncontrolled mosaics. The overlap of photographs in the direction of flight should be 60 percent and the side lap between adjacent flights 30 percent and 50 percent, depending upon the nature of the terrain insofar as relief and the availability of suitable flight maps and clearly defined land marks are concerned.

35. Selection of material for mount.—*a. Ideal material.*—The material best suited for the mounting of prints in mosaic form should have a surface with proper texture to facilitate a firm and satisfactory adhesion of the prints. Above all, the mount should be of material that will not readily shrink with atmospheric changes and will permit drawing upon its surface and similar work connected with its preparation for use in assembling the mosaic, all of which is described in subsequent paragraphs.

b. Material available.—If the mosaic is to be small, ordinary wallboard, strawboard, or bristol board of good quality will prove satisfactory provided its surface is not too rough, or on the other hand, not too highly glazed. On a very smooth surface difficulty will be encountered in making the prints adhere. Rough assemblages of prints for trial or practice purposes can be made on a good grade of detail drawing paper, which has been shrunk and margins pasted to beaver board. The paper may be cut from the board and afterward the board used with another sheet of drawing paper. If it be desired to preserve the mosaic indefinitely, or a high degree of accuracy is sought in the assembly, some rigid substance should be used such as laminated wood of at least four-ply, sheet zinc, or sheet slate unglazed. The composition board known commercially as Vehisote Board has proved very satisfactory and the commercial compressed Fintex is sometimes used. It has the advantage of being light and it is possible to wash prints readily from its surface. Plate glass may be used, but its great weight and fragility are drawbacks. Laminated wood, marine grade, makes an excellent support when the mosaic is to be preserved permanently, due to the fact that before or after assembly the board may be sawed to any desired size or shape, a number of such boards may be closely fitted together, and in making the assembly, the prints can be pasted over the seams between boards. However, if the original mosaic is merely a step in the making of photographic copies of the mosaic, which really constitute the product sought and which will be circulated in preference to the original, the zinc, slate, or Vehisote Board, or compressed Fintex is recommended, as the prints may be soaked from the surface after the copy has been made and the mount used for future assemblies.

c. Size of mount.—The ideal size of the mosaic mount is 48 by 96 inches. A larger board is inconvenient to handle and will present greater difficulties when the mosaic is copied. A board of this size can be easily handled and if two or more boards are required for the mosaic they may be butted together, prints laid across the joint, and later separated with a razor blade. This is the only easy way to secure an even match between the parts of a mosaic laid on two or more boards.

36. Scaling of prints (fig. 6).—*a. Directly from dry prints.*—If a mosaic is to be controlled, it is necessary that the average scale of the prints be determined in order that the control points may be plotted to this scale on the mount. If the variation in the scale of the photographs to compose a mosaic is not great, the average scale of photographs may be adopted as the scale for the mosaic. Scaling directly from the dry prints to determine the average scale should be used only when pressed for time. The reason for this is that the shrinkage and stretch of prints when they are laid with gum arabic will vary about 1.5 percent from the dry print scale and this difference will increase the difficulty considerably when laying a controlled mosaic. A better method is the use of test strips.

b. Test strips.—When the map control is plotted on the index map a number of these accurately located points may usually be identified on the negatives or prints. This recovered control is marked on the index map and lines are drawn on this map between these points. From these lines prints are selected and an uncontrolled mosaic laid along these strips. Then the straight-line distance between the control points on this uncontrolled mosaic is very accurately measured.

c. Method of determining scale.—Various methods for determining the scale of vertical aerial photographs have been explained in paragraph 7. The most accurate method for scaling of prints embraces the relationship between a definitely known ground distance and accurately measured print distance:

$$sc = \text{scale}$$
$$GD = \text{ground distance}$$
$$PD = \text{print distance}$$

$$\textbf{Then: } sc = \frac{PD}{GD}$$

Example:

$$\text{Given } PD = 21.4 \text{ inches}$$
$$GD = 3 \text{ miles}$$

Find the scale of the print.

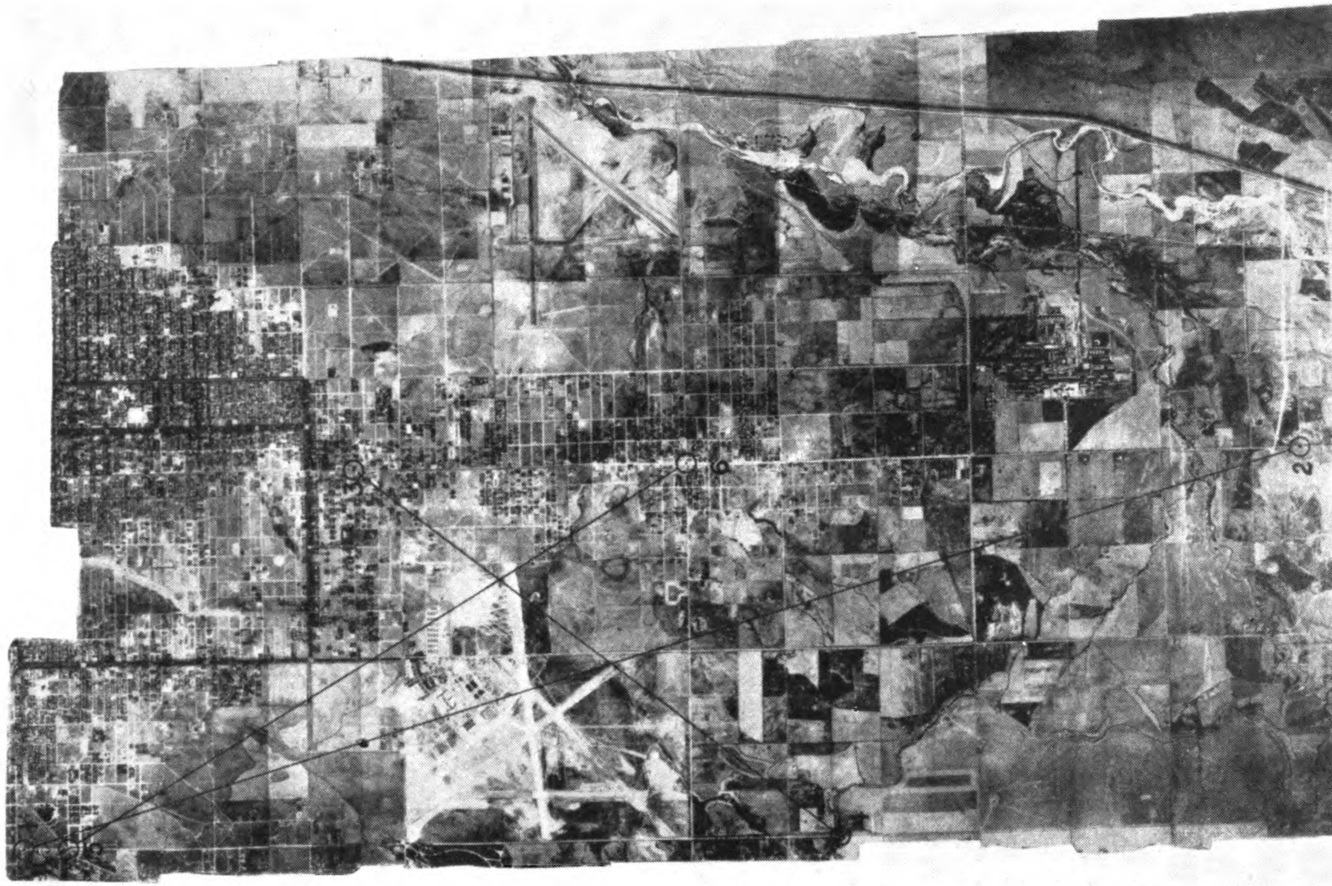


FIGURE 6.—Use of scale strip in conjunction with controlled mosaic.

321016°—41 (Face p. 30)

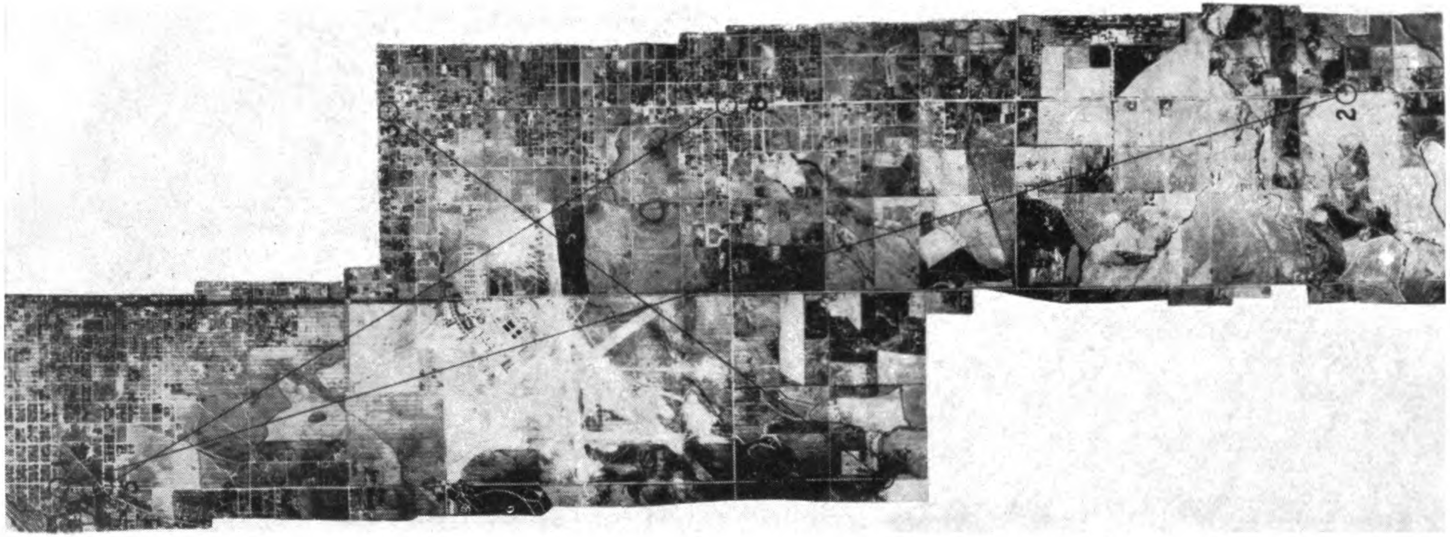


FIGURE 6.—Use of scale strip in conjunction with controlled mosaic—Continued.

321016°—41 (Face p. 31)

Solution:

$$SC=\frac{21.4}{63{,}360\times 3}=\frac{21.4}{190{,}080}\text{ or }\frac{1}{8{,}882.2}$$

$\therefore$ the scale of the photograph is 1/8,882.

This method of obtaining the average scale of the photographs is regarded as the most accurate. By this method a distance on the surface of the earth is calculated, as well as a distance on the surface of the prints, by the true latitude and longitude of two positions in connection with the tables published in TM 1–221. Obtaining the scale from this point resolves itself into a simple problem in square root. Having ascertained the latitude and longitude of two points, the true linear footage of two legs of a right triangle is known from the value of degrees, minutes, and seconds as given in the bulletin mentioned. These distances are next squared, added together, square root extracted, and the result is the length of the hypotenuse of the triangle, or the distance between the points desired.

(1) To illustrate: It will be supposed that the longitude and latitude of the stations selected are as follows:

Station No. 43—
Latitude 39°47′21.0″
Longitude 88°58′38.2″
Station No. 27—
Latitude 39°53′34.1″
Longitude 88°53′52.2″

(2) By subtraction, the difference in latitude will be found to be 373.1 seconds, and in longitude 286 seconds. Taking the mean latitude at the present minute, which would be 39°51′, enter the desired table from TM 1–221 and find the value of 1 second of latitude and 1 second of longitude for the average latitude which is 39°51′ to the nearest minute. These values are: 1″ latitude=101.18 feet; 1″ longitude=78.01 feet. Multiply these values by 373.1 and 286, respectively, which are the differences in seconds of latitude and longitude. The result will be the value in feet for the difference of latitude and the value in feet for the difference of longitude, or in other words, the two legs of the triangle. Square these and add, then extract the square root of the result, which is the value of the hypotenuse, or the distance in feet between stations No. 43 and No. 27. Assemble the prints as accurately as possible in the second method given above, and measure the distance between these two stations on the prints themselves. The ratio between the distance on the

prints and the distance on the ground will give the scale of the prints. In the method under consideration the stations selected should intersect diagonally as many strips as possible. Should stations of this kind not be found, there are other stations throughout the area which may be selected and the mean of the average scales thus obtained used as the average scale of the assembly.

d. Preparing guide on mount.—In case a mosaic is to be controlled, the next operation after scaling the prints as explained in *c* above is to prepare a guide on the mount for the assembling and pasting of prints. This control or guide may be transferred directly on the mount from survey data. Ordinarily, a polyconic projector is first laid on the mount and the survey data plotted directly on the mount, according to the projection. These methods of preparing the mount will be described in detail.

37. Controlling mosaic.—*a. General.*—Three methods are used in the Air Corps for controlling a mosaic. They are—

(1) Assembling according to details common in the overlapping photographs.

(2) Transferring to the mosaic mountant data appearing on a map of the area covered in the photographs.

(3) Assembling the photographs according to ground survey data which are first plotted on the mountant with reference to a polyconic projection. Each method will be discussed.

b. Matching detail.—A mosaic that has been laid according to this system is poor in accuracy as far as ground control is concerned. Errors in print scale including those resulting from distortion in the prints cannot be rectified. Nevertheless, as the individual prints composing such a mosaic can be nicely matched, the mosaic often presents a neater appearance than one laid with some degree of accuracy with regard to control points.

c. Pantograph.—(1) *General.*—When an accurate map exists of the territory of which a mosaic is about to be assembled, the control or guide to be placed on the mount may be transferred directly from the map by the use of a pantograph. The resultant mosaic, however, will be satisfactory only if the map is of recent date, is of excellent workmanship, has been well controlled (contains no shrinkage), and does not have too great a variation in scale from the mosaic. The pantograph is a drawing instrument used ordinarily to transfer data at one scale from a map or the like to drawing paper or similar surface at another desired scale. In principle this instrument is a flexible parallelogram. Since the angles are joined so as to be flexible, the sides of the parallelogram remain parallel regardless of the horizontal position in which the instrument may be placed. The process of transfer is therefore reduced to a proportion between the distances on two sides of the parallelogram of these sides extended. If the correct proportion is adjusted by the pointers on these two sides, as may be done by setting all moving parts at the same point on the graduated scales on the arms, data copied under one pointer will be produced under the other pointer parallel and proportionate to the original data. There are several forms of pantographs in use, the most accurate being classed as the precision pantograph. This pantograph is a steel arm suspension pantograph and is made with arms of various lengths with jeweled bearings and accurately finished. The longer the arms, the less the change of scale and the more accurate will be the data transferred by the pantograph as more accurate readings and settings may be made on the arm. Any inaccuracy which exists in the pantograph due to distortion in the arms or flexibility in the angles will cause an error to be introduced into the work of the pantograph. It is hardly possible to reproduce absolutely accurate work by pantograph methods, since in copying from a smaller to a larger scale any errors in tracing will be exaggerated. In tracing from a larger to a smaller scale these inaccuracies will be minimized, but will nevertheless exist. Therefore, whenever possible, or whenever the accuracy desired warrants, the pantograph should be disregarded and the actual points plotted on a new polyconic projection regardless of how accurate existing maps may be.

(2) *Formula for using pantograph.*—The formula for using a pantograph may be reduced to a simple proportion as follows: The limit of the pantograph is to the setting of the pantograph as a larger scale is to the smaller scale. For example: If an 84-cm. pantograph is used and it is desired to pantograph a map of a scale of 1/10,000 to a scale of 1/20,000, using the formula we have

$$84:X::\frac{1}{10{,}000}:\frac{1}{20{,}000} \text{ or } \frac{84}{X}=\frac{\frac{1}{10{,}000}}{\frac{1}{20{,}000}}$$

Solving the formula for X, we find that $X=42$, which is the setting for all movable parts on the pantograph. This problem both demonstrates and proves our formula since we know that the scale of 1/20,000 is just half of 1/10,000 and as our pantograph is an 84-cm. instrument, 42 cm. is just half the capacity of the instrument.

If it is desired to change the scale of 1/8,000 to 1/14,000, or vice versa, using the same pantograph, we have

$$\frac{8000\times 84}{14,000}=48$$

$$84:X::\frac{1}{8,000}:\frac{1}{14,000} \text{ or } \frac{84}{X}=\frac{\frac{1}{8,000}}{\frac{1}{14,000}}$$

and we get 48 for the setting on our movable parts. Should it be desired to change 1/8,000 to 1/14,000, the data are placed under the long arm of the pantograph and copied under the short arm. If it is desired to change 1/14,000 to 1/8,000, the data are placed under the short arm and copied under the long arm. Further instructions regarding the pantograph accompany each machine.

d. Polyconic projection.—(1) *Use of survey data.*—Usually a photographic mosaic is made of an area of which a recent accurate map does not exist, or the demand may be for a precision mosaic. In the latter event it is desired to avoid errors in the map that may have occurred in those processes of map making that follow the survey and therefore the control or guide for the assembly of the mosaic is placed on the mount directly from the survey data. To draw this guide properly on the mount, the operator must have a comprehensive understanding of the elementary principles of map making. Specifically, he should understand clearly what a map is; what is meant by a control in map making; the types and kinds of surveys; latitude and longitude; some common systems of projections used in map making; and the method of making a projection and of plotting control data thereon.

(2) *Drawing the projection.*—The drawing of a polyconic projection may seem to be a complicated operation to those unfamiliar with surveying methods. However, this impression begins to disappear when the fact is recalled that all the mathematical calculations required in the work have been made for every portion of the United States, and the results of these calculations are published in tabular form in TM 1–221. With the use of these tables the mere drawing of the polyconic projection becomes a simple drafting operation. The tables cited give the value of latitude or longitude in inches or meters at various scales for any locality in the world. They also give the necessary offsets for meridians or parallels for any desired number of minutes, so that the correct curvature of the meridians and parallels may be maintained at any scale. It will be obvious that from such data and the explanation contained in these

tables any good draftsman can readily construct a polyconic projection. Therefore, if it be desired to assemble a mosaic of considerable size (by that is meant any that embraces a territory of more than 5 miles square), a polyconic projection of the area should be drawn and the survey data or surveyor's field notes obtained. These notes will give various positions in latitude and longitude which have been located by the survey and these positions may be plotted on the polyconic projection from their geodetic coordinates. The projection should be drawn either at the average scale of the prints to be assembled or from the scale determined from the test strips. The prints are then assembled so that the points on the photographs which represent positions of known latitude and longitude as plotted on the board, are superposed on these positions. In this way, any error that may be inadvertently introduced in the assembly, due to inaccurate matching, slight distortion in the prints, or otherwise, will be checked each time a station of latitude or longitude which can be identified on the prints is reached, since the point in the photograph if superposed on the point plotted on the polyconic projection must be accurate, assuming the projection is true and at the same scale as the photographs.

(3) *Controlling the mosaic.*—(*a*) A map is a more or less accurate drawing of some portion of the earth's surface in topographic symbols. As this surface is curved and the paper on which the drawing is placed is flat, some system of drawing must be used in order to preserve approximately true relationships between the curved surface and the flat surface, unless the map be merely a sketch of a small area, in which event its accuracy is regulated by the skill of the draftsman in measuring angles and distances. Whenever areas of appreciable size are mapped, some form or control must be used in order that the relative distances between the ground objects and the representation of them in the drawing may be preserved. The aerial photographic mosaic is a pictorial reproduction of a portion of the earth's surface, and therefore it is necessary, if it is to have a creditable degree of accuracy as to scale, that it be assembled according to ground control as a map is made.

(*b*) In map-making work, a control is anything that will aid in the accurate fixation of data, such as accurately measured distances between two known points, the stations of a traverse, the latitude or longitude of points, triangulation stations, and grid coordinates of points.

(*c*) If the meridians and parallels as they exist on the surface of the earth could be accurately represented on a flat sheet of paper, the reproduction of an accurate map of a portion of the earth's surface would become a relatively simple matter, as these parallels and meridians would always tend to act as markers and usually localize any error that might otherwise appear if no system at all were used. All projection systems in common use are designed to represent the parallels and meridians as accurately as possible within the inherent limitations of the systems used.

SECTION IV

POLYCONIC PROJECTION

38. Polyconic projection (fig. 7).—In the making of a map, one is confronted at the outset with the problem of representing accurately on the plane surface of the map the details that exist on the surface of the earth. As this surface is spherical the map maker must resort to the use of a convention that will represent the surface with the least distortion. The systematic drawing on a plane surface of lines that represent reference lines on the spherical surface of the earth is called a map projection. There are many systems of projection, one of which is known as the polyconic projection. Data necessary for the construction of such a projection and instructions as to its use are contained in Bulletin 809, U. S. Geological Survey, and Special Publication No. 68, Elements of Map Projection, U. S. Coast and Geodetic Survey.

39. Latitude and longitude.—In order that the mosaic maker may have some conception of the value of control data of the commonest kinds, as well as the method in which projections are most generally obtained, it will be necessary to consider briefly latitude and longitude. In order that places or points on the earth's surface might be accurately fixed, the method of fixing position by latitude and longitude was adopted.

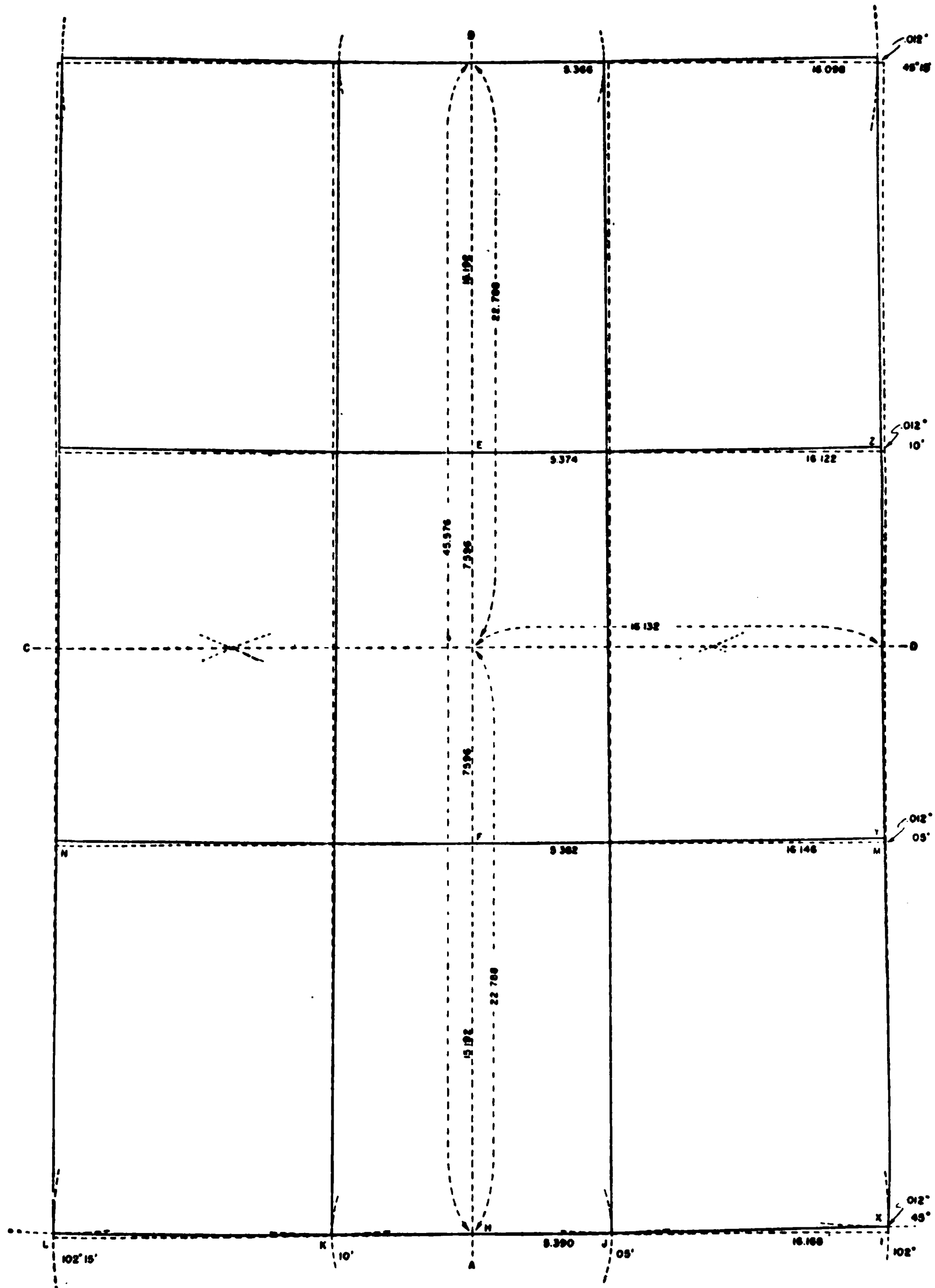


FIGURE 7.—Construction of a polyconic projection. (Original scale 1 : 24,000.)

40. Parallels.—Granting that every circle, regardless of its size, contains 360°, if a plane is passed through the earth at its equator, perpendicular to the axis of the earth, a circle will be formed in this plane which will contain 360°. This is considered as the prime parallel of latitude in a system of latitude and longitude. If another plane is passed through the poles it will, of course, be perpendicular to the circle at the equator, and will also contain 360°. It is apparent that since the earth is an oblate spheroid (a sphere slightly flattened at the poles), this circle will not be a true circle but an almost circular ellipse. It is usually regarded as a circle. One specific circle is considered as the prime meridian of longitude in the latitude and longitude system. In the international system of latitude and longitude, the prime parallel is the equator and the prime meridian or zero longitude passes through Greenwich, England. In any local system of latitude and longitude, the prime parallel may be taken as any parallel located in the country and the prime meridian as any meridian passing through the country. However, at the present time the international system using the equatorial parallel and the Greenwich meridian is in common use. If, starting at the equator on the prime meridian, we move north along the meridian 1° of its circumference and then pass another plane through the earth's surface parallel to the equator and the prime parallel, we will have a smaller circle 360° in circumference. Continuing northward degree by degree along the prime meridian, we may pass other planes through the surface of the earth, each plane being parallel to the equator and to all other planes which have been similarly passed through the earth's surface, and each contains 360°. In this way the system of parallels is built up.

41. Meridians.—If planes are passed through the two poles, moving for each plane 1° on the equator, a system of meridians will be built up which will completely encircle the earth. They are identified as east or west of Greenwich from zero to 180° and the parallels north or south of the equator from zero to 90° at the poles. Meridian circles, unlike the parallels, will all be great circles of the sphere, that is, pass through the center of the earth, and for this reason the value in miles of a degree on a meridian between parallels will vary but slightly as the poles are approached. This slight variation will be caused by the flattening of the earth toward the poles, as the shape of the earth draws away from the shape of a true sphere. On the other hand, since all meridians pass through the poles and therefore tend to converge at the poles, the value of a degree in miles on a parallel decreases very rapidly as the poles are approached, to zero at the poles. The value of a degree of longitude constantly decreases as the poles are approached. While the value of a degree of latitude increases slightly as the poles are approached, this variation for any two adjacent degrees is very small. The degrees of both latitude and longitude may further be divided into minutes and seconds by passing similar planes through the earth between the planes which have already been interposed, so that from this system of latitude and longitude, the correct and exact position for any object on the earth's surface may be accurately and definitely determined by the latitude and longitude. It is to be remembered that 60 seconds of angle equal 1 minute of angle and 60 minutes of angle equals 1° of angle. Tables have been published which will give in miles, feet, and inches, the value of a degree or fraction of a degree of latitude or longitude for any place on the surface of the earth, so that, knowing the exact latitude and longitude of two objects, the exact distance between these objects on the surface of the earth may be calculated.

42. Construction of polyconic projection (fig. 7).—*a.* The necessary directions for the construction of a polyconic projection may be stated as follows: First, find the central parallel and meridian of the area of which the projection is to be drawn. Then refer to the table in TM 1-221 for the scale desired and lay off accurately the necessary distance as given in the table. Usually for mosaic assembly, polyconic projections are drawn with the meridians and parallels plotted at minute or 30-second intervals, in order that the plotting of latitudinal and longitudinal coordinates or points may be accurate. By this method the error is limited and, if the positions are plotted with even a fair degree of skill, not more than one-half second of error should result. With care and attention, however, even some of this error may be eliminated. Since this frame or projection is the base of all the balance of the work it should be as accurate as drafting skill and care can make it.

b. The work of laying a polyconic projection is begun by carefully drawing two lines at right angles to each other through the center of the mosaic mount or sheet of drawing paper. Reference is then made to the table in TM 1-221 which will give to the scale of 1/20,000 the value in inches for a minute of latitude or longitude in the area of which the projection is being made. These longitude distances corrected for the test strip scale of the mosaic are then laid off on each side of the vertical line which has been drawn through the center of the board. Using the full distance as set off on a beam compass and always plotting from the original construction lines, other degrees of longitude are then plotted to the right and to the left of the vertical construction line.

c. Next, reference is made to the table which will give the required offset for each minute on the central parallel as the projection departs from the central meridian. These distances corrected for scale are then plotted north or south as the case may be (always north in the United States), and the curved line representing the central parallel is then drawn as a series of straight lines. This line will pass through the point of intersection of the two original lines drawn on the board. It is always well to recompute independently the change of scales from the table in TM 1–221 and check these item for item before drafting is begun.

d. Reference is next made to the table in TM 1–221 and the required distances corrected for mosaic scale, for the spacing of the north and south parallels, are laid off from the center of construction intersection. From these points now located, the north-south parallel intersections and the offset points of the principal parallel, arcs are swung and the other intersections of latitude and longitude accurately located. This is the most accurate simple form of projection for a localized area and should always be used when a controlled mosaic of appreciable size is desired. For small mosaics, that is, those under 15 minutes of latitude and longitude, the data obtained from TM 1–221 may be plotted in the form of rectangles, that is, the polyconic data will be used, but no attempt made to indicate the curvature of the meridians and parallels, since the curvature in the case of a small mosaic at scales smaller than 1/10,000 is so slight that it may be disregarded without the introduction of scalable error in the work. In fact, the errors caused by expansion, contraction, and inaccuracies in matching the prints will be greater than the inaccuracies resulting from plotting these data as straight lines.

43. Lettering projection.—Each line representing latitude or longitude should be accurately and carefully numbered and lettered so as to avoid confusion, and this lettering should be done carefully and neatly. The style of letters and figures used should be the same as those used in the legend of the mosaic and is usually done with lettering guides.

44. Advance plotting of projections.—Projections for controlled mosaics should not be plotted in advance, as the best estimate of the average scale of the prints will not be close enough for the final work. The proper values from the table in TM 1–221 may be outlined at 1/20,000 and checked to reduce them as soon as the mean test strip scale is determined, but beyond that, advance plotting of projections is inadvisable.

45. Plotting points on polyconic projection.—The survey data or surveyor's field notes will usually give the positions which the surveyor has located by their true terrestrial latitude and longitude. The polyconic projection represents a form of indicating latitude and longitude on a plane surface. Therefore, using the latitude and longitude values of the points given by the surveyor as rectilinear coordinates, these points may be plotted on the polyconic projection. Two methods are in general use and both are equally satisfactory. They are described in the following paragraphs.

46. Template.—*a. General.*—After the polyconic projection has been divided into rectangles of 1′ or a fraction thereof, a template is cut which is equal to the sides of the smallest rectangle. These sides are then divided into equal parts or seconds, and by placing the template in the proper rectangle, the correct point may be indicated at the corner of the template, if the template is moved back and forth until the required added seconds north and west are lined up with the border lines of the small quadrangle. It should be remembered in this connection that in the United States longitude is always read increasing from east to west and latitude increasing from south to north, or in other words, longitude increases as we move west and latitude as we move north. This may be easily borne in mind if it is remembered that Greenwich is the starting point of longtitude, and the Equator, of latitude. It is only worth

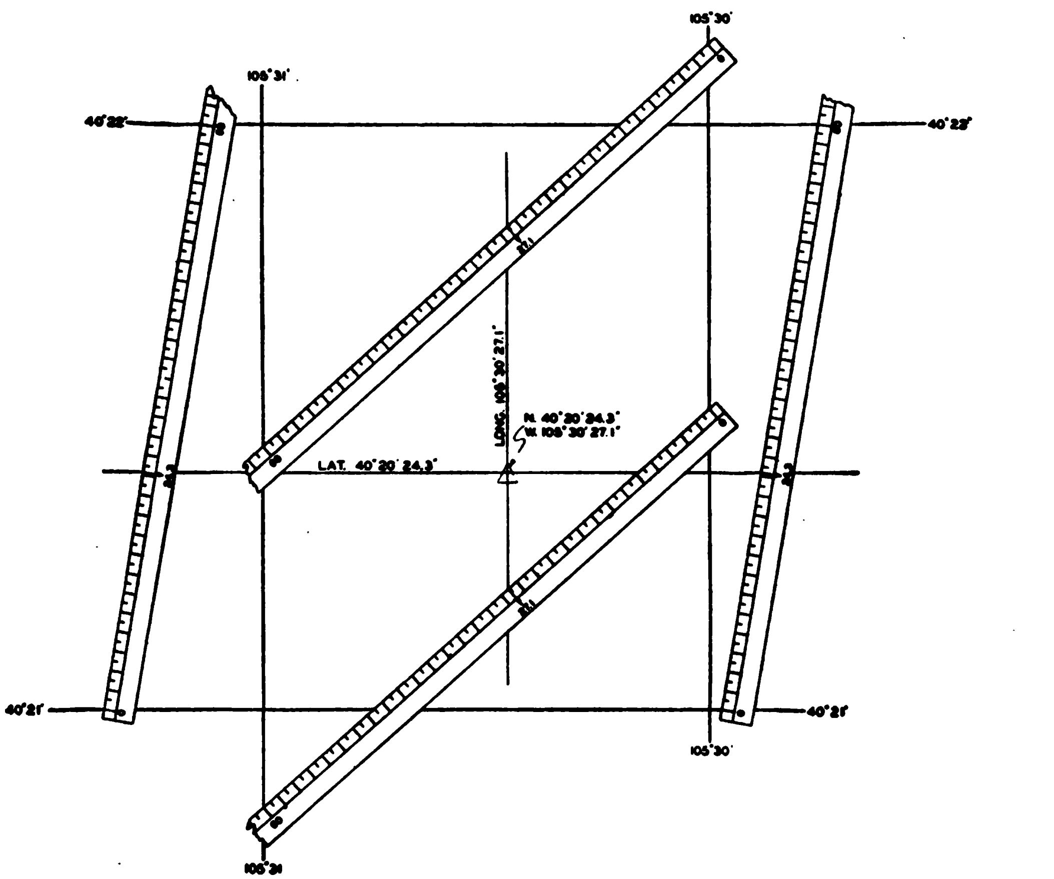


FIGURE 8.—Use of graduated scale for plotting points.

while to make a template of this kind when a large amount of control is to be plotted on this projection as it cannot be made up until the scale of the projection is determined and must be made with extreme accuracy.

b. Selection of control.—Much time and labor may be saved by plotting on the projection only those control points that can be accurately located on the photographs available.

47. Use of graduated scale (fig. 8).—After the polyconic projection has been divided into rectangles, control points may be plotted within their respective rectangles. To do this, select divisions on the scale which correspond to the second divisions of the rectangle, 60 seconds to 1 minute of arc, and lay off the desired number of seconds in each direction from east to west and south to north for latitude and longitude, and where the points coincide the position is located. Example: In using a 30-second quadrangle, select a scale divided into hundredths of an inch and place this scale between 2 meridians so that a multiple of 30 divisions on the scale lies between the 2 meridians. Divisions as fine as a tenth of a second can be estimated from the scale, which is as accurate as any but the most precise ground control. Now swing the scale so that a multiple of 30 divisions will lie between 2 parallels and points may again be plotted as above. The two points should be located for each reading and these points joined with straight lines. The intersection of these lines will locate the point which should be ringed and numbered for identification.

SECTION V

GRID SYSTEM

48. Grid system.—*a. Definition.*—The United States military grid, built upon polyconic projections, is a system for locating points in the United States on a rectangular grid. In the polyconic projection true latitudes and longitudes are plotted at any desired interval and scale. The United States military grid system consists of standard 1,000-yard squares on the surface of the earth. These 1,000-yard squares may be plotted on the mosaic at their proper scale and must be in proper relation to the polyconic projection. Whereas the polyconic projection represents a system of curved lines and various divisions of these curved lines, the grid system consists entirely of straight parallel and perpendicular lines and is made up of equal 1,000- or 5,000-yard squares.

b. Uses.—The value of the grid system is almost entirely military. It is used especially for controlling artillery fire, in which work the rectilinear grid coordinates of a target are given and with the battery position in similar coordinates, it is then possible by simple mathematical calculation for the artillery to lay their guns on the target and determine the exact range. Although the same result might be obtained by use of the latitude and longitude coordinates of target and battery, more difficult calculations are necessary. (It is easy to confuse the relationship between seconds and minutes and minutes and degrees.) The grid system can be used commercially to locate one point with reference to another and to read the distance between them. There are in many states local grid systems of various kinds.

c. Grid data.—Data and necessary information for the use of the military grid system for the whole United States and most of its possessions have been compiled and published by the United States Coast and Geodetic Survey in collaboration with the Corps of Engineers in book form in Special Publication No. 59 entitled "Grid System for Progressive Maps in the United States." It will be remembered that in the case of the polyconic projection it was found that if we placed a cone tangent to some parallel the information plotted on the projection would be true as projected for this parallel and adjacent to it, but that if we moved away from the line of tangency the information would gradually become more and more inaccurate. Since this is true, it was found necessary in the grid system to divide the United States into zones of limited extent east and west, and the United States has accordingly been divided into seven zones extending 9° on the parallel or longitude extending north and south through the United States. These zones overlap one another sufficiently so that information plotted in one zone will be relatively accurate when superposed on information plotted near the extremity of the adjacent zones. The zones for the United States with their control meridians and limiting meridians are as follows:

GRID ZONES

Designation	Central meridian	Limiting meridians
A	73°	63°30′- 77°30′
B	81°	76°30′- 85°30′
C	89°	84°30′- 93°30′
D	97°	92°30′-101°30′
E	105°	100°30′-109°30′
F	113°	108°30′-117°30′
G	121°	116°30′-125°30′

d. Origin of grid coordinates.—Any grid system is an arbitrary system, and any value for the grids may therefore be arbitrarily selected and any point of starting for the grids may also have arbitrary coordinates. The distance of 1,000 yards has been arbitrarily selected as the size of the grid for the United States. Most of the European countries used the 1,000-meter grid. Any distance, such as a 10-foot grid, 100-foot grid or 1,000-foot grid could be used, but the standard grid for the United States has been selected as 1,000 yards on a side. Also, since the system is arbitrary, any point of starting could have been selected. From the table in *C* above, the central meridians for the grids will be noted. These control meridians were selected and the grid which coincides with them was arbitrarily given the X value of 1,000,000 yards. This valuation was assigned in order that no minus X values could ever occur in a grid zone because before reaching a minus value another zone would have been entered. Similarly, the grid lines running east and west have been given an arbitrary Y value sufficient that no minus reading will be encountered no matter how far south the grid is carried in the United States, and there will be a minimum chance of confusion. Therefore, on the Pacific Coast the X grid reading will still be plus and in Southern California, Texas, and Florida, the Y grid reading will still be plus though in different zones. This point of $X=1{,}000{,}000$, $Y=2{,}000{,}000$ lines for each zone on the central meridian of the zone at the parallel N. 40° 30′ of latitude.

49. Standard grid compared with polyconic projections.—*a. General.*—For each zone the grid system is built up in the following manner: The 1,000,000-yard X grid line for the zone coincides with the central meridian for that zone, and if the central meridian for the zone be projected on a plane surface it will be represented as a straight line. All other grid lines for the zone are straight lines and parallel or perpendicular to this projection meridian. This does not apply to the other latitudes and longitudes as represented on this projection as the meridians converge to the north and the parallels are concave to the north. Consequently, when the military grid is superposed on a local projection other than the zone meridian the grid will not parallel the projection meridian but will incline to it east or west, depending on its location east or west from the zone meridian. In general, when an area within a zone lies to the east of the zone meridian, the grid will be inclined to the northeast as compared to the local meridian used to construct the polyconic projection.

b. Grid tables.—The grid tables as published in Special Publication No. 59 give the grid values for each 5-minute intersection of latitude and longitude within the United States. Therefore, if we know the latitude and longitude for any point in the United States, by reference to the tables, we can find the grid values of the point. The readings are given only in 5-minute intervals, and if the known point for which the grid values are to be determined is not of an even 5-minute interval, interpolation must be made for the particular intersection of latitude and longitude. This may be done by finding the grid values for the closest 5-minute intervals and interpolating for the particular intersection of latitude and longitude. Remembering that the meridians and parallels are not grid lines it is readily apparent that in general the X grid value found for some point of intersection of a meridian and parallel will not hold true if the intersection of the same meridian with some other parallel is desired. In other words, with the exception of the central meridian, the north and south grid lines will not coincide with the meridians, and the grid lines will apparently be tilted or bent away from the meridians.

50. Procedure in applying grid to polyconic projection (figs. 9 and 10).—*a. General.*—While the grid system may at first seem confusing and difficult, in actual practice when applied to a polyconic projection it is as simple as the construction of a polyconic projection, as all necessary calculations have been previously made and are available in tabulated form. It is to be remembered that in the grid system the X values increase to the east and the Y values to the north.

b. Procedure.—(1) Select the intersection of a parallel and a meridian somewhere near the southeast corner of the map. If possible, select a 5-minute intersection. (The tables are published in 5-minute intervals and if a 5-minute intersection is selected no interpolation will be necessary.) Enter the tables in Special Publication No. 59 and ascertain the grid value for the X and Y grid lines which pass through this point. Next, move northward along the same meridian to any other convenient intersection of parallel and again select a 5-minute parallel, if convenient. This parallel should be chosen in the northeast corner of the map if conditions will permit. Enter the table in Special Publication No. 59 and determine the grid values for this intersection of the original meridian with the new

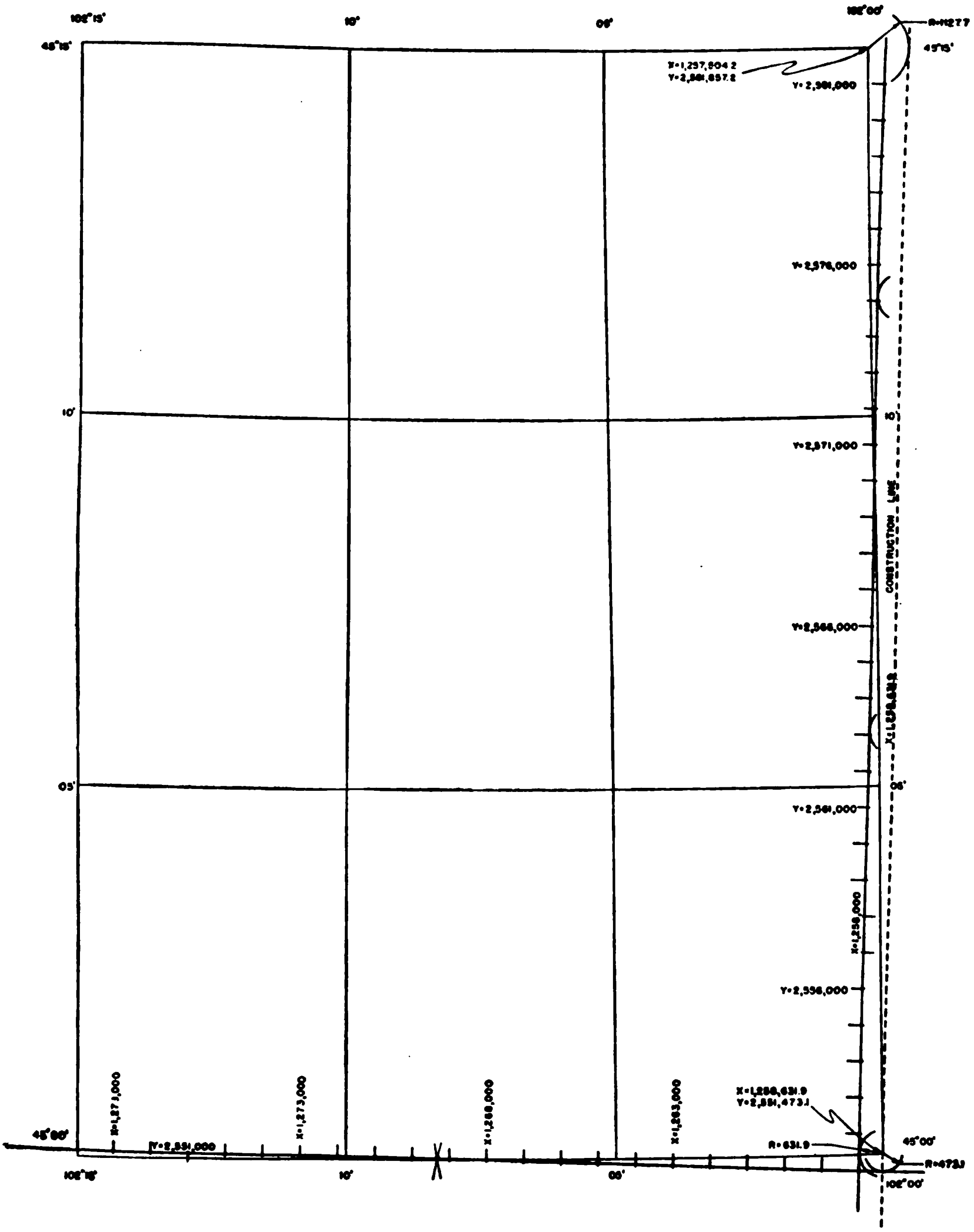


FIGURE 9.—Grid application to polyconic projection—first method.

parallel. Since the meridian apparently slopes, it progresses north in reference to the grid. This X value will be found to be different from the first X value. Next, subtract the smaller X value from the greater, and, using the difference as a radius, describe a circle around the proper intersection of the meridian and parallel, the larger X value. Then, using the circle and the point of intersection of parallel and meridian in the other corner of the map as guides,

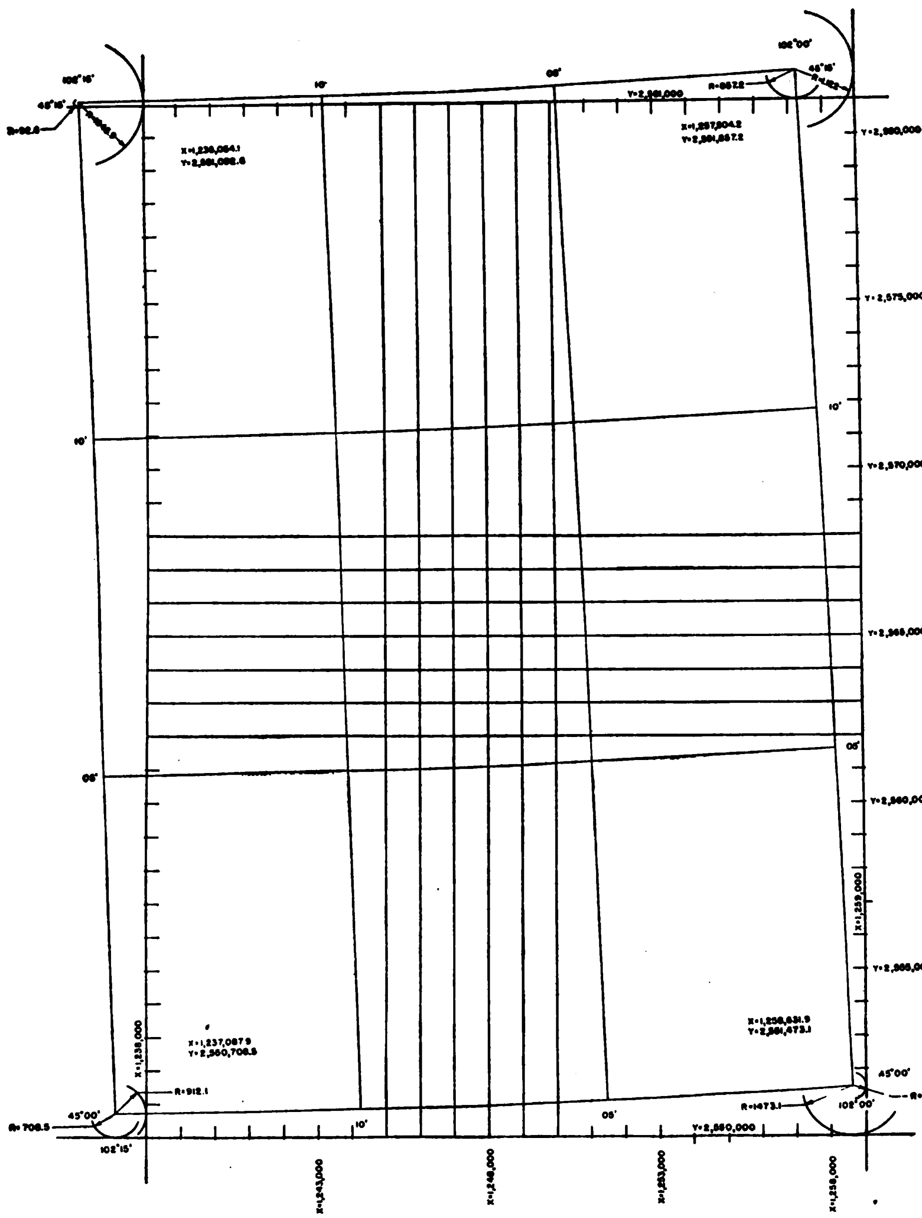


FIGURE 10.—Grid application to polyconic projection—alternate method.

construct a tangent to the circle from the point. This line then determines the angle of the grid system. If the meridian originally selected was of a smaller longitude than the central meridian for the zone, or if the X value is greater than 1,000,000 yards, this construction line would fall tangent to the east of the circle. If the meridians selected have a greater longitude than the central meridian of the zone, or if the X value is less than 1,000,000 yards, it would fall to the west and be the west tangent to the circle. The radius of the circle, or the difference in the two readings, is the X value in yards which must be added at the one intersection to reach a point where the X line that passes through the other intersection would normally pass, remembering always that the meridians converge to the north and the grid lines remain parallel to the projection meridian of the zone which is a different projection meridian than that of the local sheet. This construction line will in all probability not be an equal thousand-yard line, that is, its X value will not end in three zeros. Since the standard grid is applied in equal 1,000 or 5,000 yards this line must be moved east or west to the nearest 1,000- or 5,000-yard line within the area as a starting point for our grid overlay. The necessary odd number of yards is measured off west perpendicular to the construction line from the north point to scale and a new line parallel to the construction line is drawn. This is the first 1,000- or 5,000-yard X line of the grid system. To find the even 1,000- or 5,000-yard east and west line go back to the point of smaller X value and measure north or south along the initial construction line the difference in the yards between the Y value of the small X point corner and the nearest even 1,000- or 5,000-yard line and mark this point. Through this point draw a perpendicular to the initial construction line and this is the first even 1,000- or 5,000-yard east and west line in the area.

(2) The above method works well if extreme care is taken with each measurement but successive small errors in laying out the 1,000-yard blocks may amount to a considerable value if extreme care is not taken. An easier method is to repeat the original construction on the western edge of the map and locate the western 1,000-yard lines and then divide the perpendicular distance between the eastern and western 1,000-yard and north and south 1,000-yard lines into the proper number of equal parts. It takes a little longer but does minimize the errors in any one place and is recommended.

c. Alternate method (fig. 10).—Using the intersection of a meridian with two parallels find the X value at each intersection and determine for each point the difference between the X value in the table and the nearest common 1,000-yard X value. With these distances as radii construct at each intersection a circle to the proper scale. The common eastern tangent to these two circles if the area lies to the east of the zone meridian, or western tangent if the area lies to the west of the zone meridian, will then be the even 1,000-yard north and south grid line.

(1) Example: Selecting the following points—

Latitude 45°00′00″
Longitude 102°00′00″

and

Latitude 45°15′00″
Longitude 102°00′00″

entering the table, we find that—

45°00′00″) X—1,258,631.9
102°00′00″) Y—2,551,473.1
45°15′00″) X—1,257,504.2
102°00′00″) Y—2,581,857.2

If, as by the first method, the two X values are subtracted, it will be found that there is a difference of 1,127.7 yards and using this distance reduced to the scale of the map or mosaic as a radius, construct a circle to scale at the northern intersection on the map. By referring to the longitude it will be noted that it is less than the central meridian for the zone, since the central meridian for this zone is 105°. Also note that the value for X is greater than 1,000,000 yards. In this way a double check is had and it is known immediately that the line will be erected tangent to the east of the circle. This line as constructed will be X line 1,258,631.9 and to construct the even X=1,258,000 yard line a circle is drawn at point 45°00′00″–102°00′00″ with a radius of 631.9 yards corrected to scale and a tangent drawn to this circle on the western side parallel to the construction line. The western or left-hand tangent is drawn as it is apparent that the line X=1,258,000 will be to the west of X=1,258,631.9. To locate the nearest even 1,000-yard grid line to point 45°00′00″–102°00′00″, the best means is to measure down the construction line a distance of 473.1 yards and through this point draw a perpendicular to the construction line. This will be the line of Y=2,581,000.

(2) By the second method, draw a circle with point $\left\{\begin{matrix}45°00'00''\\102°00'00''\end{matrix}\right\}$ as a center and 368.1 yards as radius and another circle with point $\left\{\begin{matrix}45°15'00''\\102°00'00''\end{matrix}\right\}$ as a center and 1,495.8 yards as a radius. The common external eastern tangent to these circles will be line X=1,259,000. To determine the even thousand Y line at point 45°00′00″–102°00′00″ as center and with 473.1 yards as radius draw a circle, construct a tangent to this circle on the south side perpendicular to the X=1,259,000 line and the line is Y=2,551,000.

51. **Grid values.**—In the military grid system the values increase to the north and east, that is, the values of Y increase to the north and the values of X increase to the east. This must always be remembered since the meridians and parallels increase to the west and north, and the two must never be confused. The scale of the grid system must of course be applied to any particular map at the true scale of the map or the grid system is valueless. The X and Y values as given in the tables in Special Publication No. 59 are the values on the surface of the earth measured on the grid projection. Therefore, they may be reduced to values for the scale of any particular map by making use of the simple scale proportion as given in previous paragraphs.

52. **Accuracy necessary.**—The standard grid system should be applied to a mosaic map with the highest possible degree of accuracy in order that it will check with all other grids applied to maps of adjacent territory regardless of scale. All that will be necessary in order to locate distances or azimuths between two points extending over adjacent maps will be to read the grid coordinates from the scales of the adjacent maps, regardless of scales, and if the maps are reduced to the same scale the grid lines over the surface of the adjacent maps should be continuous regardless of the time at which the maps were made or the difference in personnel who gridded the maps.

SECTION VI

ASSEMBLING THE MOSAIC

53. **Assembling prints.**—By the term "assembling the prints" is meant the pasting of the photographs in mosaic form to the mount. This work is sometimes called laying or building the mosaic. The operations involved, stated in the sequence of performance, are as follows:

Selecting first print.
Cutting and tearing print.

Selecting adhesive.
Applying adhesive.
Affixing first print.
Repeating foregoing operations for each of the subsequent prints.

These operations will be explained in detail. In event these explanations are desired to be used as working directions, it is assumed that the operator has scaled the prints to be assembled and prepared on the mount the control or guide for assembling the prints.

54. Selection of first print.—In deciding which print should be first affixed to the mount, selection should be made of one covering any portion of the area but which contains three control points if possible. The first photograph laid down should show such points in order that the subsequent prints may be properly oriented. If two control points do not appear on any single print, then the prints between two control points should be matched together in order to obtain correct orientation. This matching is done by overlapping or superposing the prints so as to form a composite picture with images common to two points in register. The prints are held temporarily in this position by scotch tape until the adhesive is applied and they can be affixed to the mount. The most accurate means of locating the first print is by means of three control points on a single print. A piece of vellum is laid over the first print and the center of the print pricked through the vellum. Rays are then drawn on the vellum from the center point to the control points. The vellum is then placed on the projection and moved until the rays pass through the plotted positions of the three control points. The center of the vellum is then pricked on the control board and this point used to place the center on the first print, care being taken that the radial lines from the center of the print pass through the corresponding control points. This is done by drawing the rays lightly on the print and the projection, and moving the print about its center point as a pivot until the lines correspond. It fixes the print in location and orientation.

55. Cutting and tearing print.—*a.* Before attempting to tear a print, the operator should examine carefully all surrounding prints in order that the print about to be torn will be divided in such a way as to retain the best definition and color match. In tearing or cutting the print to the proper size, the operator has two methods from which to select and he may choose either for exclusive use or he may employ one or the other as the best results demand.

(1) *First method.*—Hold the print firmly between the thumb and forefinger at the point where it is desired to tear it, turn it face down, and tear by a continuous upward gentle pull on the remaining portion

of the photograph. The emulsion will separate at the division desired, and the paper support will tear so as to taper or bevel it; that is, it will leave an edge gradually increasing in thickness from the thinnest layer at its point of contact with the emulsion and extending back to the full thickness of the paper. The edge thus produced on the print is termed a "feather edge." In tearing the print so as to produce such an edge, it may be torn to follow any direction by varying the direction of pull.

(2) *Second method.*—The line on which it is desired to divide the print may be cut first with a safety razor held at slight angle and upon which just sufficient pressure is exerted to cut through the emulsions, and then torn according to the first method described. (This method is especially recommended.)

b. Whenever a feather edge is made, it is advisable to use fine sandpaper and "sand" the feather edge in order to remove any roughness. No attempt should be made to make a better or deeper feather edge in this manner, as good results cannot be obtained.

c. The first print laid down is always feather-edged and the portion of it removed by tearing or cutting, or both, consists of only the valueless margins of the print. A feather-edged print can be made to adhere better to the mount. Feather-edging also facilitates matching the colors of two prints, and the production of a composite photograph in which the junctures of the component prints cannot readily be detected.

d. In cutting or tearing the prints remaining after the initial photograph has been affixed to the mount, it is excellent practice to sever a print either along a road, fence line, or through a wooded area, so as to leave the whole road, for instance, on one print, and not attempt to join two halves of the road, as in so doing its width is likely to be changed. In tearing through woods or areas where no mark of definition occurs, the print should always be torn in a jagged manner in order that a straight-line tear will not be visible to the eye and the match will not be apparent.

56. Selection of adhesive.—Two kinds of adhesives are in common use in mosaic assembly, namely, gum arabic mucilage and rubber cement. The choice may be left to the individual preference of the operator as excellent results are obtainable with either mountant.

a. Gum arabic mucilage.—Gum arabic mucilage is an excellent adhesive, especially for the beginner. However, if it is desired that the mosaic assembled with the use of gum arabic be permanent, it should be coated with a protective varnish and kept away from moisture. Unless the finished mosaic is treated in this manner the prints will have a tendency to peel off the mount, especially in damp weather. A distinct advantage in mosaic assembly when gum arabic is used is that the print, after being placed in approximate position on the mount, may be moved slightly in any direction before becoming fast, thus permitting the operator to adjust it in exact position. A disadvantage of the gum arabic mucilage, however, is that owing to its water content, it expands the print to which applied, and therefore the operator must make allowance for this expansion when constructing and plotting the projection and control data. The most satisfactory method of doing this is to determine from prints that have been mounted with mucilage, the scale of the prints and the corresponding scale for constructing the projection and plotting the control points.

b. Rubber cement.—Rubber cement consists of pure rubber dissolved in benzol. The syrup is used extensively for patching rubber goods, especially the inner tubes of automobile tires. An advantage of rubber cement in mosaic assembly is that the cement does not expand the prints or the mount, and an allowance for expansion which is required when gum arabic mucilage is used is unnecessary when rubber cement has been selected as the adhesive. The disadvantage of the cement, however, is that as soon as any portion of the print comes into contact with the mount, the print cannot be moved without injury. Therefore, skill is necessary when using this adhesive, in order that prints may be laid exactly in their correct positions. A further slight disadvantage is that considerable loss of time results from waiting for the rubber cement to dry between the affixing of each print.

57. Application of adhesive.—*a. Gum arabic mucilage.*—When gum arabic mucilage is used as the adhesive, the operator must make sure that it is reasonably fresh and of proper consistency; it should be a thick liquid that will pour readily and not congeal into a jelly. The print to be mounted is placed face down on a suitable board or pad and a small quantity of the mucilage is brushed over the back of the print. This is rubbed well into the paper backing with the fingers, especially into the feather edges to insure that the print will adhere firmly to the mount without tendency to curl. Surplus mucilage is removed from the back of the print with the hand. The print will then be found to be slightly moist and very sticky. In this condition, it is placed on the mount in its proper position and gone over with a squeegee of smooth celluloid, piece of damp absorbent cotton, viscose fine-grain photographic sponge, or a damp elephant-ear sponge for the purpose of removing all air bubbles and squeezing out surplus mucilage from between the print and the mount.

The rubbing should be continued until the print is thoroughly fixed in position, and great care taken to insure the firm adhesion of the edges of the mount, as the gum arabic dries along the edges and there is a tendency for it to crystallize and push up the edges of the print. This may be avoided by working down the edges until all surplus adhesive is removed.

b. Rubber cement.—When rubber cement is used as the adhesive, the area covered by the print on the mount must first be covered with a light coating of the cement. It is then applied to the back of the print, great care being exercised to rub the cement well into the corners and feather edges before proceeding to cover fully the back of the print. The cement should be rubbed in as well as it will permit. Since it dries very quickly there is a tendency for it to roll up into small rolls of rubber. This should be guarded against as such a roll will cause a hump in the print when it is placed on the mount. The cement should therefore be rubbed in until it becomes too sticky to work with. Both mount and prints should then be allowed to dry until the rubber cement is thoroughly dry. This can be determined by the fact that it loses its gloss when dry. Under ideal conditions this will require from 5 to 15 minutes. A mount and prints thus treated may be allowed to dry for a period of weeks, at the end of which it will be found that they will still adhere firmly when brought into contact. There is no danger of an application of rubber cement on a mount or print becoming too dry. The danger is in the opposite direction, as a print will not adhere firmly to the mount unless both are dry. When the print and mount are dry the print is held over its position on the mount on a piece of transparent film. Great care must be exercised to place the print in absolutely its correct position for once the print touches the mount it cannot be moved again. The film is then slipped out and the print will adhere to the mount. A dry piece of absorbent cotton should be used in smoothing the print down, and all work of smoothing done in one direction in order not to cause bulges in the prints. No water can be used, as moisture will lessen the effect of the rubber cement. Once the assembly has been completed with the prints thoroughly dry, it is fairly permanent. The moisture will have no effect on a mosaic assembled with rubber cement, except to cause blisters due to the difference in the coefficient of expansion of the mount and that of the print.

58. Affixing first print.—*a. Uncontrolled mosaic.*—The first print of an uncontrolled mosaic should be selected near the center of the area oriented approximately, and successive pictures built out from the center. This enables the operator to minimize the errors between adjacent prints.

b. Controlled mosaic.—Controlled mosaics are assembled in the same order with the first print oriented and located as close to the center of the area as the plotted control permits.

59. Affixing print to control point.—The proper method for applying the adhesive and securing contact of the first print with the mount has been explained in preceding paragraphs. Whenever a control point occurs within the area of the photograph being affixed to the mount, the mosaic control point indicator should be used in order that the control point on the print may be accurately placed above the control point on the mount. This indicator is essentially a movable arm with a needle-point end, which may be raised or lowered as desired. By swinging the arm, the needle point is placed on control point on the mount. The needle is then raised and the print, already prepared with adhesive, placed under it and on the board. The needle is again lowered and the print moved until the control point on the print rests directly under the needle and matches the adjacent print detail.

60. Affixing subsequent prints.—*a.* After the first print has been affixed to the mount, the subsequent prints are matched to this first print as closely as possible from the details contained in the print. The assembly of the prints is thus continued until another control is reached, which in all probability will be at least a mile distant. Frequently control points are several miles apart, even in what is considered a well-surveyed section of the country, and it is not unusual that only three or four control stations will be available for a mosaic 4 feet square at a scale of 1/10,000. Fortunately, what has been termed in mosaic making "secondary control" can be used to advantage under such circumstances. This so-called secondary control is obtained from the prints themselves during the process of assembly. For instance, if a road is found to run straight on a single print, it may be reasonably expected that this road will continue to run straight until a curve or bend in it appears in some other print, and therefore, after the first print showing the road as straight has been placed on the mount, the road may be projected on the mount by the use of a straightedge as a straight line as far as permissible and used as a guide for other prints showing the road until such time as a turn in the road is observed. This will tend to eliminate swings and errors in the matching of two prints. Similarly, roads, railroads, property lines, and the like may be used as secondary control.

b. In order that the accuracy of the assembly may be preserved, it will be necessary to use great care in matching the details in the prints. It is also advisable that whenever possible only the center portion of a print be used, as this area has been less influenced by possible relief displacements and scale distortions than the outer edges of the print. Whenever a control point is reached in the progress of assembly, close matching of details should always be sacrificed to strict adherence to a control point. In this way, some little pictorial qualities in the mosaic may be lost, but the accuracy of the assembly for map purposes will be preserved.

c. The greatest care must be exercised in assembling a mosaic. It is work that requires the closest attention to the fine details. While the control points will tend to prevent errors, care must also be taken that errors between control stations are likewise eliminated if possible.

d. Due to the fact that the prints are usually assembled at an average scale for a large number of prints, it may be frequently necessary to stretch some individual print or prints to insure a good match between two prints. This practice is permissible if not carried to an excess. If it is found that the majority of prints in an assembly require stretching, it is evident that an error has been made in the scale of the projection and this error should be checked and the prints reassembled at their proper scale. There is no ready method of shrinking the print when it is found too large to match well with a print already laid down. A print can, however, be slightly contracted by dampening it and drying it rapidly.

e. During the process of assembly, care should be taken that the adhesive does not adhere to the surface of the print as it will not only soil the print but interfere with the making of a good copy. The adhesive used can be easily removed from the surface of the print as the work progresses. Gum arabic mucilage may be rubbed off with cotton dampened in water or alcohol. Rubber cement may be rubbed off with the fingers immediately after the print has been affixed to the mount.

61. Titling and finishing mosaic.—*a. Cleaning surface.*—Before the grid is applied, the surface of the mosaic should be cleaned with a damp sponge. If too much water is used there is danger of dampening the prints excessively and of their consequent loosening from the mount. It will usually be found when the grid is completed that there are a number of small white spots where the emulsion has been stripped from the prints even with the greatest of care. These spots should be touched out with light penciling using pencils of proper hardness from HB to 4H as a general rule. Ordinarily a border is added to the mosaic so as to form a clean rectilinear figure and thus enhance the appearance of the work. One side of the rectangle should run true north and south, that is, it should coincide with the polyconic projection and not with the grid system. The border should be so applied as to leave the mosaic of greatest possible area. If a large number of boards are to be copied so that the resultant copies will overlap, it will not be necessary to border the mosaic; or, if a border is applied, care should be taken that the border does not interfere with the overlap. In small mosaics it is sometimes necessary to make an irregular border due to the shape of the area covered by the mosaic. In so doing, care should be taken that no important area is covered by the border. Irregular borders should be avoided whenever possible as the rectangle will give a far neater appearance when the copy has been made.

b. Preparing title.—The title for the mosaic should next be lettered. Standard lettering guides should be used for the title. The title may be drawn up at the scale of the map, or it may be drawn at some convenient larger scale and then copied down to the scale of the map. For general use, it is recommended that the title be drawn up at a larger scale and then reduced to the scale of the map as in this way the letters, due to reduction, will lose some of the pen marks and will appear neater. It must be remembered in this connection that all letters should be made large enough so as not to lose their legibility when the reduction is made. Certain pertinent information should always be included in the title. The title usually states that the job is a mosaic, an aerial mosaic, a mosaic map, or an aerial map. It next describes the area included in the particular mosaic and the state in which this area is located. The longitude and latitude of the southeast corner of the area are usually given as part of the Geographic Index as provided in AR 300-15, and if the mosaic has been gridded, the grid zones for the area and the *X* and *Y* coordinates for the southwest corner of the map, that is, the grid intersection in the southwest corner of the map. The title should further include the average scale of the mosaic. It may also state the number of exposures necessary for the original mosaic, the flying time required, the altitude at which the photography was done, and the photo flight doing the work. In addition, all titles should include a visual scale of the mosaic, that is, a line graduated to represent the value on the mosaic of distances on the ground. This visual scale or graphic scale should be drawn up so that it will be true when the title is reduced; that is, when the title is applied to the mosaic, the values as stated on the graphic scale should be true for the mosaic and should be graduated in yards. Likewise the average scale as stated should be true for the scale at which the copy of the mosaic is to be reproduced. The title for a mosaic is usually placed in the southeast corner of the mosaic. However, it may be placed at any convenient position on the mosaic where it will not cover important information intended to be supplied by the mosaic. A north arrow should always appear on the title.

c. Importance of title.—Great care should be exercised in the making of titles as nothing detracts so much from a mosaic as a poorly made title, and on the other hand, a well-executed one will enhance the appearance of even a poor mosaic. It is customary for the observer to form an idea of the accuracy of a mosaic from the appearance of its title.

62. Reproduction of mosaics.—After the assembling and titling of the mosaic is accomplished it is ready to be reproduced to any desired scale by rephotographing or copying. This subject is thoroughly covered in TM 1-219.

SECTION VII

RESTITUTION

63. Restitutional printing.—*a.* Restitutional printing is projection printing for the purpose of minimizing variation in scale of prints from the true average scale.

b. It may be classified into two classes, direct ratio printing and printing with tipped and tilted easel. This is a very slow process requiring a wealth of recoverable control and can never make correction for relief displacements located far from the principal point of a negative.

64. Displacement because of relief.—It may be observed from figures 11 and 12 that when there is relief in an area covered by a vertical photograph, points of high altitude are displaced outward from the principal point of the negative from their true position on the ground with reference to other points. This is an inherent characteristic of photographs as compared with map projections, and from this it is clear that the central area of a vertical photograph has little of this distortion even when considerable relief is present. Hence the laying of a mosaic of country containing abrupt relief is much facilitated if the overlap in both directions is materially increased. The increase in overlap should be considered and accomplished by the photographic crew; if this is not done restitutional printing may be resorted to by the ground forces.

65. Procedure.—Granted the photographs are as nearly vertical as possible, it can be seen from ① of figure 13 that the right-hand margin of print is not of the same scale as the left-hand margin because the terrain on the right side of the print is closer to the camera, thereby changing the scale and increasing the size of the images on the right side. It may be possible to discover a match line between ① and ② of this figure, but this scale change carried through several photographs would cause serious error in matching control points as a considerable area would actually be off scale. If the average elevation can be determined from the map, and from this and the altitude the actual scale of the photograph computed, then the whole print may be reduced or enlarged to approximately the proper scale. This is adequate for tablelands of considerable elevation in the area of a mosaic, but cannot adjust the changes of scale from one edge of a print to another when the ground slopes

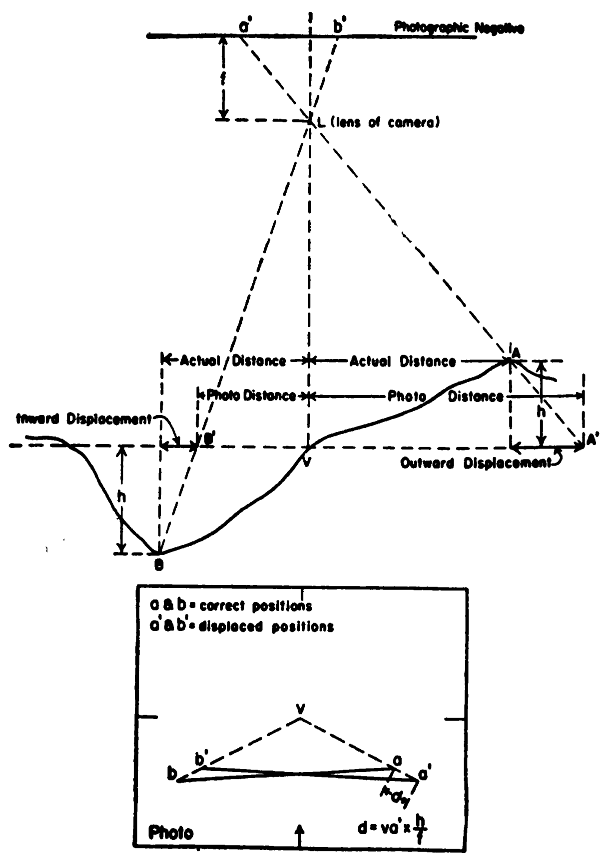


FIGURE 11.—Action of relief in area covered by vertical photograph.

sharply as in figure 14. In this case two prints may be made from the negative, one to contact scale and the other by projection computed for the mean elevation of the right-hand edge. This is slow but does help hold the scale.

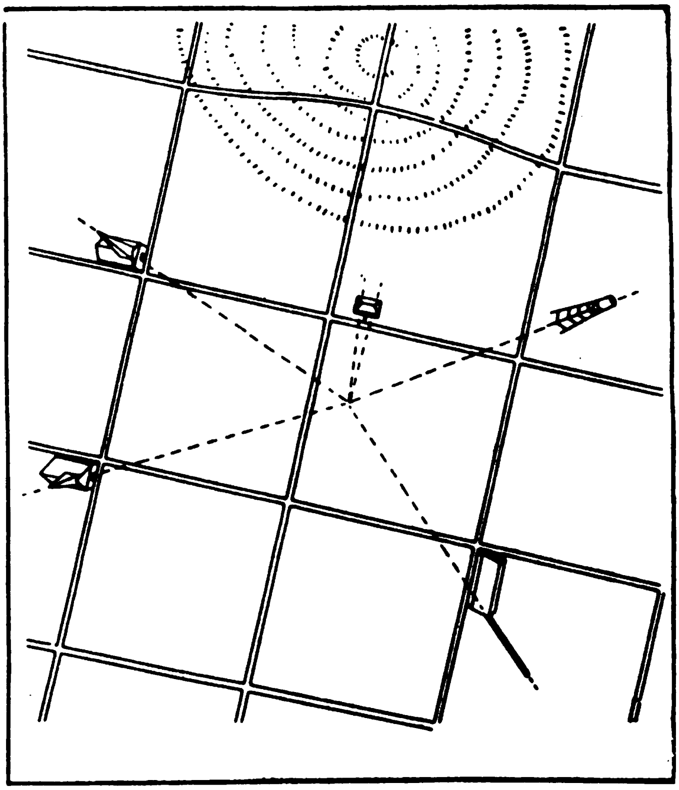


FIGURE 12.—Tall objects displaced outward in vertical photographs.

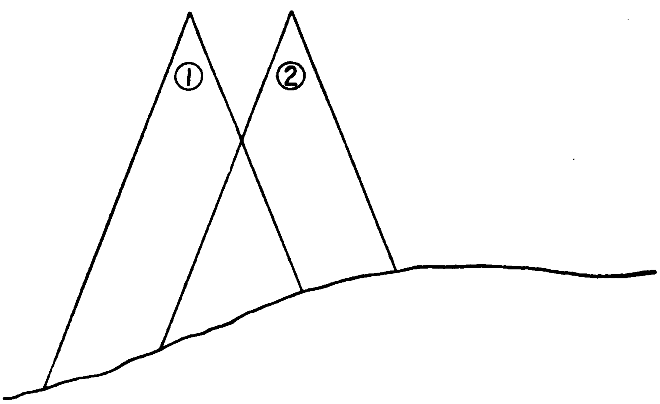


FIGURE 13.—Change in scale of photographs due to relief.

66. Tip and tilt restitution.—If the easel of a projection printer be tilted, the shape of the projected area will change. (See fig. 15.) This change in shape and scale will only truly represent the ground when the ground itself lies at an absolutely uniform slope and depressions and rises in the ground will be displaced as in vertical photographs (see fig. 16), but to a larger degree as the camera is tilted more and more from the vertical. Restitution printing of this kind should be used only as a last resort as it can never overcome the essential difference between the projections used in maps and the perspective projection of a camera, and control points plotted on the easel cannot be matched unless they be on the same horizontal plane.

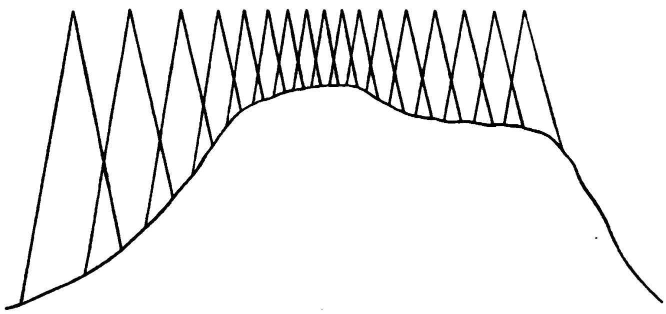


FIGURE 14.—Increase in size of image as ground slopes sharply.

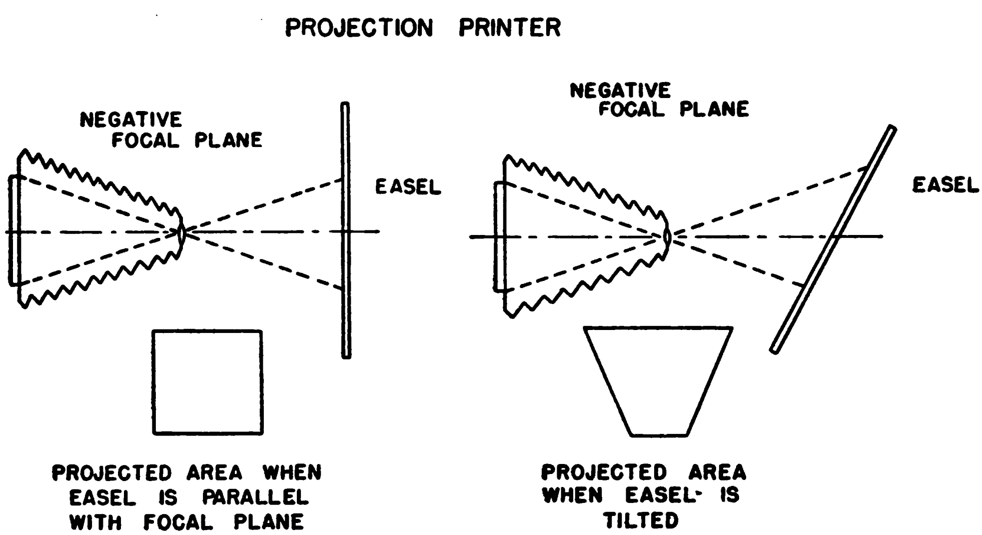


FIGURE 15.—Effect of tipped and tilted easel of projection printer.

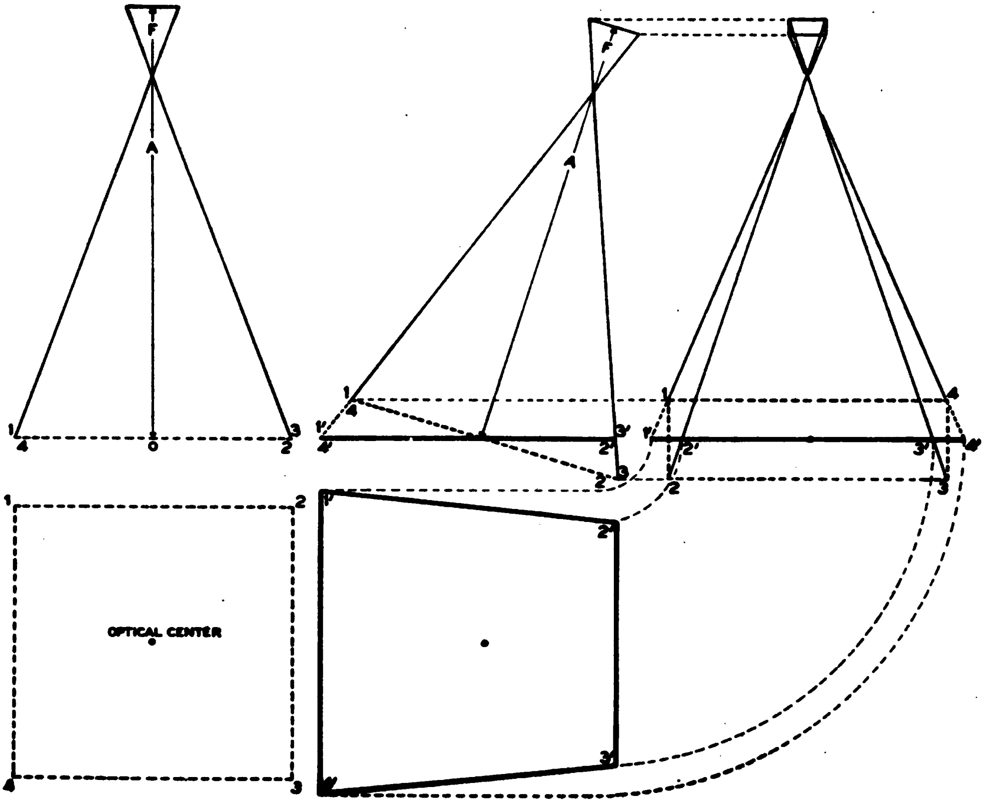


FIGURE 16.—Results of tip and tilt in camera at time of exposure.

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[A. G. 062.11 (1-14-41).]

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(For explanation of symbols see FM 21-6.)

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