FM 21-26

Advanced Map and Aerial Photograph Reading

There are two versions of this critical manual circulating. By far the most common is the September 1941 version, which I edited some time ago. The old manual was long, jargon-choked, adorned with confusing illustrations and dense text (one paragraph wandered on for four pages without a break), apparently written by a crazed mutant photogrammetrist locked in a subterranean cell at Fort Belvoir and fed only fish heads. I found it interesting, but by the time I had finished the analysis I was uncertain which end was up. I've been working maps for fifty years, and it confused me. The section on stereo viewing was even worse, and I have a doctorate in visual biophysics. It was just a book written by cartographers (map makers) for other cartographers.

The 1941 manual (as noted at the head of Section I) was changed on several occasions during the war and supplemented by training bulletins, training circulars, and other amendments. Finally the all-new manual appeared in December 1944.

We could be criticized for using the late-war manual instead of sticking with the 1941 monstrosity; however, the material as shown in this newer publication was available from 1942 through 1944 as changes and supplements were published, so it seemed fair to publish the whole thing together.

Why even inflict this torment on living historians?

The obvious answer—"because it's there"—doesn't suffice. This is the simple version: it's information critical to professionals, you really don't understand maps from a quick read of **FM 21-25** (Elementary Map and Aerial Photograph Reading, which is taught in Basic training and basic officer schools), and it's basically interesting if you can penetrate the air of mystery. The 1941 edition was like Rain Man's final paper in creative writing; the 1944 edition actually makes sense to any informed reader.

To make sense of this, you should first read **21-25**. The writers of the manual reproduced and annotated here presume only that the reader understands the basics of maps and is comfortable with plane geometry and trigonometry. All Americans who finished high school in the 30's and 40's had to pass those courses, so that wasn't much of a leap of faith. (Nowadays, God only knows what constitutes an acceptable math curriculum.)

WAR DEPARTMENT,
WASHINGTON 25, D. C., 23 December 1944.

FM 21-26, Advanced Map and Aerial Photograph Reading, is published for the information and guidance of all concerned.

[A.G. 062.11 (5-15-41)).]

BY ORDER OF THE SECRETARY OF WAR:

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

CONTENTS

This manual supersedes FM 21-26, 17 September 1941, incudingC1, 15 May 1942; TB 21-25-1, 2 March 1944; TB 21-26-1, 23 February 1944; and Training Circular No, 66, War Department, 1944.

SECTION I

INTRODUCTION

1. PURPOSE. The purpose of this manual is to provide a text on advanced map and aerial photograph reading for military personnel who thoroughly understand the basic material in **FM 21-25**.

2. SCOPE OF TRAINING. a. Need for training. All arms and services use maps and map substitutes. Personnel of all units must be able to read maps and aerial photographs accurately and easily. The ability to visualize the ground from a map is gained only by thorough practical training.

b. Types of maps used in training. Equipment used in training should be identical with that used in combat. Large-scale, colored maps with contour lines may not be available to small units in actual operations; training, therefore, must also cover small-scale maps, photomaps, and air photographs.

c. Training program. Training in the use of maps and aerial photographs must include both classroom and field work. The training program must include conventional signs and military symbols, distances and map scales, directions and azimuths, proper use of the compass, orientation without the compass, location of points by coordinates, visualization of terrain, use of marginal data, and interpretation of aerial photographs. Frequent practical tests should be given throughout the course of instruction to ascertain that students are making proper progress.

SECTION II

MAPS

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3. DEFINITION. A map is a line drawing, to scale, of an area of the earth's surface. It shows objects and features by conventional signs. Although drawn to scale, it is not absolutely accurate because it is flat while the earth's surface is curved. The map's accuracy depends on the method used in making it (see appendix). A discussion of the various map-making methods is given in TM 5-230.

4. CLASSIFICATION. AR 300-15 prescribes the classification of maps and the specifications for their preparation. Military maps are classified according to scale as tactical, strategic, and general. Scale is discussed in paragraph 8.

Maps for tactical use employ a narrow range of scales. For mechanized ground operations, the 1:50,000 is preferred—any smaller scale at the armor rate of movement would require frequent changes of map sheet. Infantry is best served by the 1:25,000. Some special maps (particularly for training) are available in 1:12,500. We will use mostly the latter.

Maps are often prepared for temporary or local use (the official map of Fort Indiantown Gap is one such, rendered in an unfamiliar scale and overprinted with warnings).

We will use such training aids—called “special maps”—routinely, such as the one-off 1:12,500 Indiantown Gap map.

a. Tactical. Maps of scale 1:125,000 and larger contain a great deal of detail and are intended to meet the tactical, technical, and administrative needs of field units. The scale of these maps normally is not larger than 1:20,000.

b. Strategic. Maps ranging in scale from 1:125,000 exclusive to 1:1,000,000 inclusive are required for planning operations, including movements and concentrations of troops and supplies.

c. General. Maps of smaller scale than 1:1,000,000 are needed for general planning and for strategical studies by commanders of large units.

5. CARE IN THE FIELD. Since the supply of maps is limited, they must be treated with care. If possible they are mounted on map boards and covered with a sheet of transparent material such as cellulose acetate. This affords some protection from moisture and permits marking with grease pencils. If carried by personnel in the field, maps should be folded in accordion fashion, as illustrated in **FM 21-25**, and placed in the pocket for protection from sun and moisture. Marks should be made lightly with pencil so they may be easily erased. For added protection the map may be covered with an issue transparent covering which is coated with an adhesive on one surface. This material adheres readily to the map, does not prevent folding, gives protection from moisture, and allows marking with graphite or grease pencil. Unmounted aerial photographs should be filed flat in some moisture-proof container; they should never be rolled. Photographs must not be placed near heating devices and should be mounted on stiff backing when exposed to changes in temperature.

SECTION III

CONVENTIONAL SIGNS AND MILITARY SYMBOLS

6. CONVENTIONAL SIGNS. a. Signs. Conventional signs are used on maps to indicate objects on the ground. Usually, they are simple drawings recognizable as the objects they represent. The meaning of some signs, however, is not obvious and must be learned. Complete lists of conventional signs authorized for use on United States military maps are found in **FM 21-30**; foreign conventional signs are shown in FM 30-22. When foreign maps are adapted and issued to troops conventional signs which differ from signs used on United States maps are explained in the map margin.

FM 21-30 has some problems, the chief being that it doesn't render well as a PDF file. Many of the downloadable products are rendered in black and white mode and at lower resolution, which makes some graphical information hard to interpret (e.g., textures for terrain types, which come out as empty squares). The version in this library had to be scanned piece by piece, a task I hope never to be obliged to repeat.

b. Colors. Colors are used on some maps to help identify terrain features. These colors are black, blue, brown, green, and red:

Black for works of man.
Blue for water and swamps.
Brown for contours, cuts and fills, and some cultivated fields on large-scale maps.
Green for woods and other vegetation.
Red for certain good roads.

7. MILITARY SYMBOLS. Military symbols have been developed to represent various types of military organizations, activities, and installations. These symbols are used to indicate size and identity of various units and installations, type and location of supporting weapons, and necessary lines and boundaries for an operation. Friendly installations are usually shown in blue, enemy installations in red. FM 21-30 lists the standard military symbols.

SECTION IV

MAP MEASUREMENTS

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8. SCALE. Ground distance can be determined from a map by the map scale. Scale is the relation between distance on the map and actual distance on the ground. It is expressed in one or more of the following ways:

a. Words and figures. Scale may be expressed by a simple statement like "3 inches equals 1 mile," meaning 3 inches on the map equals 1 mile on the ground. Similarly, "1 inch equals 200 feet" means that 1 inch on the map equals 200 feet on the ground.

b. Representative fraction. Scale may be shown by a fraction, called the representative fraction, abbreviated RF. The representative-fraction formula is:

$$RF = \frac{\text{Map distance (MD)}}{\text{Ground distance (GD)}}$$

in which the numerator and denominator are expressed in the same unit, as inches, feet, yards, meters, or miles. The *RF* appears in the margin as 1:20,000 or $\frac{1}{20,000}$ which means 1 unit of distance on the map equals 20,000 such units on the ground. The *larger* the denominator of the *RF,* the *smaller* the scale of the map. Thus, a 1:1,000,000 map is a small-scale map and a 1:20,000 map is a large scale map. (See **FM 21-25**.)

c. Graphic scale. Distances may also be measured by the graphic scale-a special ruler for the particular map, printed in the margin. (See **FM 21-25**.)

9. MEASURING DEVICES. a. Map measurer (fig. **1).** The map measurer is an instrument designed for quick measurement of distances or lines on a map. It consists of dial case, handle, and wheel or small roller. A moving pointer indicates on the dial the distance traveled by the wheel as it rolls along the line measured. To measure distance with a map measurer proceed as follows:

(1) Turn the roller until the indicator is set at zero.

(2) Place the roller on one of the given points and, with the handle vertical, roll it along the line to the second point.

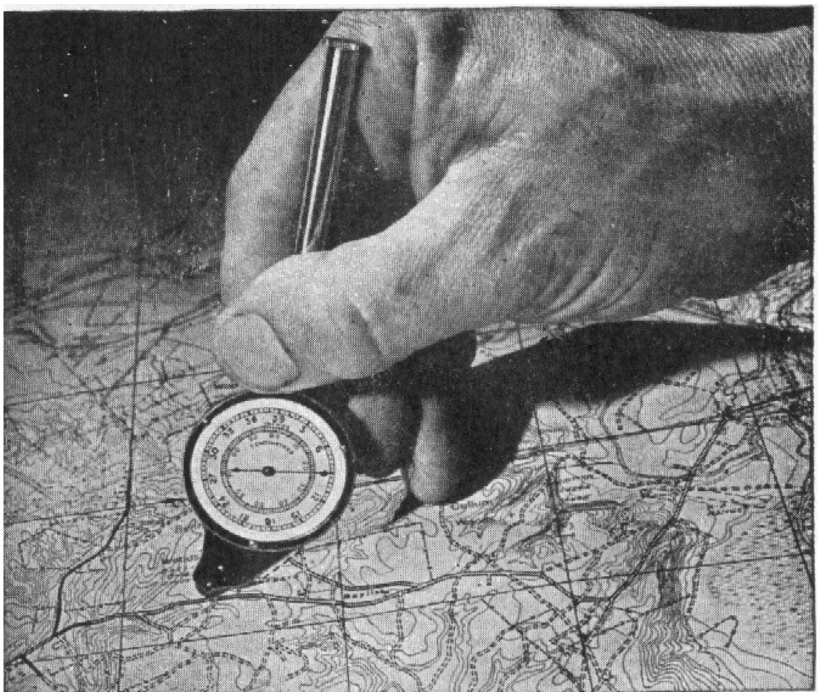


Figure 1. Map measurer.

(3) The indicator will register the number of inches or centimeters traversed. To convert this map distance to ground distance, place the measurer roller on the zero of the scale and roll it backward along the scale until the indicator moves back to zero. Read ground distance.

b. Engineer scale. If the map's *RF* is known, distance between two points can be determined with a scale divided into inches. An engineer scale divided into tenths of an inch is best. To obtain the number of inches on the ground, measure the distance in inches between the two points on the map and multiply **it** by the denominator of the *RF.* Convert into feet by dividing by 12, into yards by dividing by 36, or into miles by dividing by 63,360. For example, figure 2 shows a portion of a map whose scale is 1:62,500. To find the distance on the ground between Missouri Mill and the road junction at Triangle proceed as follows: the engineer scale shows that the map distance between the points is 3.07 inches.

$$\text{RF} = \frac{1}{62{,}500} = \frac{\text{Map distance (MD)}}{\text{Ground distance (GD)}}$$

Some old-fashioned terminology is helpful here. A "rule" is a device used for determining a linear measure; a "straightedge" is used to draw a line on a paper. Never use a rule as a straightedge. An engineer's rule is graduated in tenths of an inch; the more common architects's rule is in English measure.

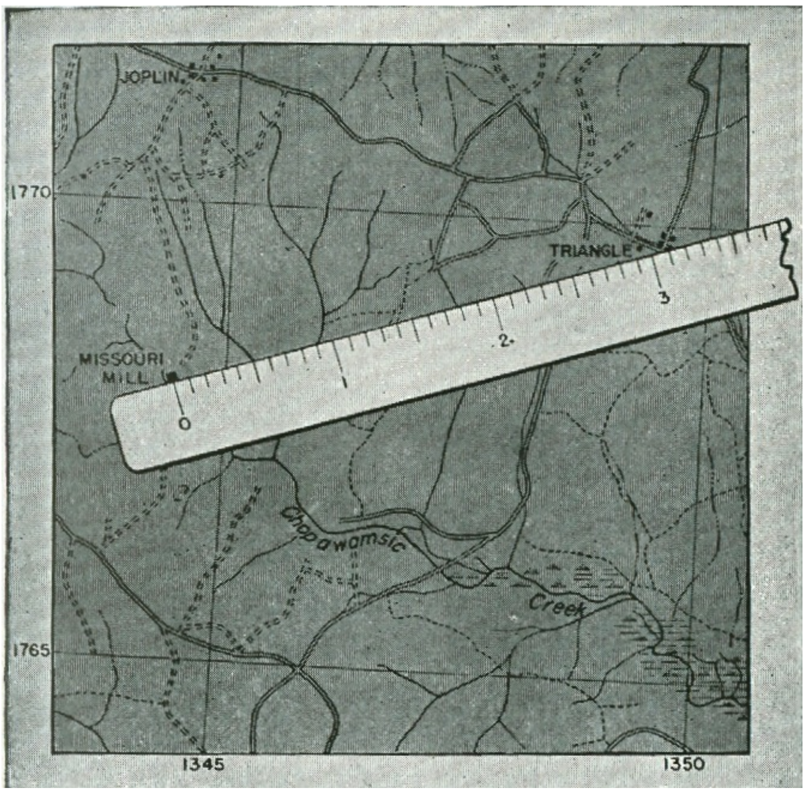
The M38 map ruler (not shown in this manual) is a heavyweight, triangular cross section device that includes a 6-inch engineer's rule and tables for scaling yards on maps of different scales and a small table of slope and grade calculations.

$$GD = MD \times 62{,}500$$

$$GD = 3.07 \times 62{,}500 = 191{,}875 \text{ inches}$$

To convert this distance into yards divide by 36:

$$\frac{191{,}875}{36} = 5{,}330 \text{ yards}$$



The engineer's rule is preferred for this application because it is far easier to multiply and divide decimals than proper fractions (0.5 inches v. ½ inch). An architect's rule was available in English measure because those are the dimensions in which building materials were cut. (In those days we regarded the metric system as the invention of effete foreigners.)

Figure 2. Measuring distance on a map with engineer's scale.

10. CONVERSION FACTORS. Distances may be ex- pressed in either the English or the metric system and it may be necessary to convert measurements of one system into those of another. Common units of metric linear measure and their English equivalents are:

1 mile = 1,760 yards = 1.609 kilometers = 1,609 meters

1 kilometer = 1,000 meters = 1,094 yards = 0.62 mile.

1 meter = 1.094 yards = 39.37 inches.

1 yard = 0.91 meter = 36 inches.

11. DETERMINATION OF MAP SCALE. If the scale data are missing from the margin of a map, the *RF* of the map can be determined from a ground measurement or from a measurement on a map of known scale.

a. By measurement of distance between two points on the ground. The scale of a map may be determined by comparing the distance between two points on the ground with the distance between the same two points on the map. For example, in figure 3, the bridge and the crossroads are 3 inches apart on the map. The ground distance between the two points may be measured by tape, by striding, or by any other reasonably accurate method. Suppose the points are found to be 1,650 yards or 59,400 inches apart on the ground. Now substitute in the formula:

$$RF = \frac{3}{59{,}400} = \frac{1}{19{,}800}$$

Map is apparently 1:20,000.

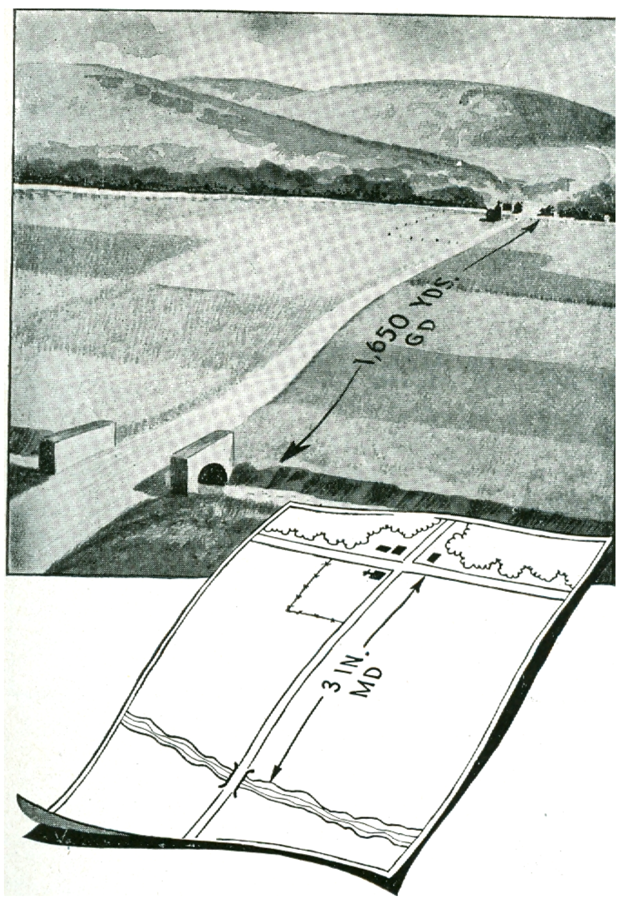
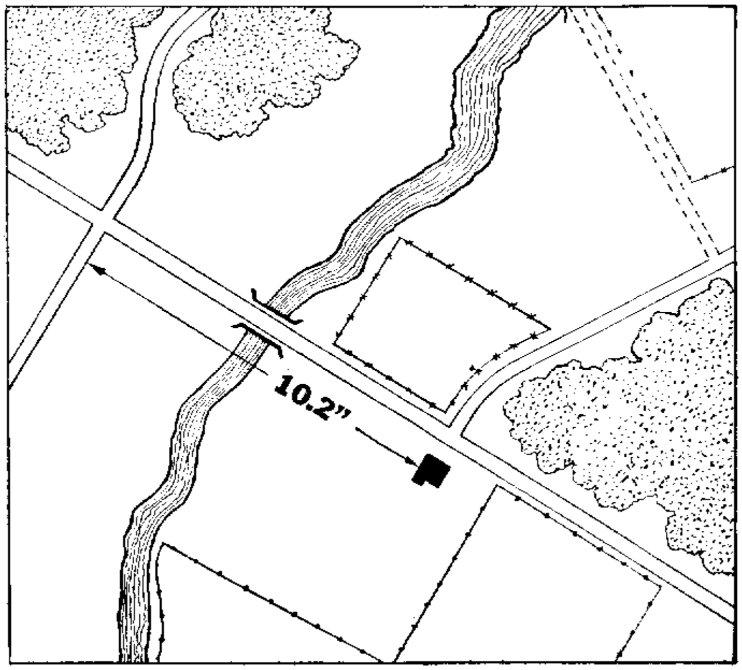
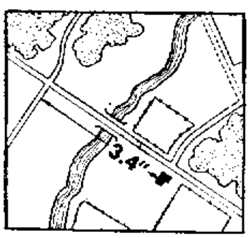


Figure 3. Scale of map may be determined when ground distance is known.



MAP A RF = 1:20,000



MAP B
RF = ?

Figure 4. Comparing scale of two maps representing identical area.

b. By measurement between two points on map of known scale. To determine the *RF* of a map with the aid of a map of known scale, select two points that appear on both maps and measure the distance between the two points. Then the ground distance between the two points can be figured from the map of known scale, and the scale of the other map may be determined by the process explained in a above. For example, in figure 4, map A has an *RF* of 1:20,000 and the *RF* of map B is unknown. The distance between the crossroads and the house on map A is 10.2 inches; on map B it is 3.4 inches. The ground distance between the crossroads and house is determined from map A:

$$GD = MD \times \text{denominator of } RF$$

$$GD = 10.2 \times 20{,}000 \text{ inches}$$

Using this ground distance, the *RF* of map B is found by substituting in the formula:

$$RF = \frac{3.4}{10.2 \times 20{,}000} = \frac{1}{60{,}000}$$

RF of map B is 1:60,000.

12. TO CONSTRUCT A GRAPHIC SCALE. To construct a 5,000-yard graphic scale for use on a map whose *RF* is 1:20,000 proceed as follows:

a. Determine the length of the scale by the *RF* formula. In the formula the length of the scale is the map distance, 5,000 yards is the ground distance, and $\frac{1}{20{,}000}$ is the *RF* . Ground distance of 5,000 yards must be converted to inches by multiplying by 36. Now substituting in the formula:

$$\frac{1}{20{,}000} = \frac{MD}{5{,}000 \times 36}$$

$$MD = \frac{5{,}000 \times 36}{20{,}000} = 9 \text{ inches}$$

The scale must be 9 inches long to represent 5,000 yards.

b. Using an engineer scale, lay off the line *ab 9* inches long (fig. 5).

c. Lay off, at any acute angle, line *ab′* representing 5 convenient equal divisions of the engineer scale. Draw the line *b′b,* and through each division of the line *ab*' draw lines parallel to *bb*'. This divides line *ab* into 5 equal parts, each part representing 1,000 yards.

d. The 1,000-yard division at the left end of the scale is the extension and must be divided into 100- yard divisions. This is done by laying off the line *ad*', dividing it into 10 equal parts, and projecting these divisions to the extension as explained in c above.

For those who dozed through math in high school: *A* and *A'* ("*A* prime") and *A"* ("*A* prime prime") represent correspondences or transformations of point *A*. That is, the line *AB* (drawn from point *A* to point *B*) on a map of one scale is the same as the same line *AB* on a map of a different scale even if the line is longer or shorter measured on a map with a scale.

e. Mark the divisions of the scale as shown in figure 5.

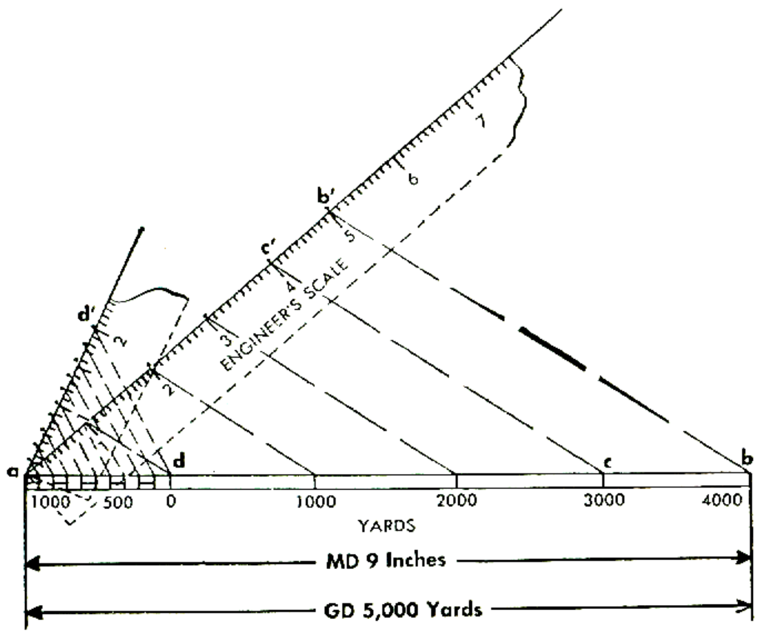


Figure 5. Constructing graphic scale.

13. TIME AND DISTANCE. a. Conversion of distance to march time. To determine how long it will take to move troops from one point to another, first determine the distance between the two points by one of the methods explained in paragraphs 8 and 9. This distance divided by the hourly rate of march gives the time required to move the troops. The average day-time rate of march for foot troops, making allowance for customary halts, is 2 ½ mph.

Anything faster is called a "forced march", a term that simply means "faster than route march." If you have ever done a ruck march in Ranger or Airmobile or whatever, you understand what "forced march" means on the ground.

The speed of a forced march is based on a calculation of how fast you absolutely, positively need to arrive at your destination, not a standard rate 0f march.

b. Conversion of march time to distance. It is often necessary to determine the distance a column can march in a given time. The distance is the product of the time in hours and the hourly rate of march or $D = T \times R$. For example, a motorized unit averaging 25 mph can cover 4 X 25 or 100 miles in 4 hours. This distance is measured along the road to locate the head of the column at the end of 4 hours. Thus the position of the head of the column at the end of any given time can be determined.

c. Rate of march. By substituting values of distance and time in the formula $D = T \times R$ and solving for R, the rate of march is determined.

14. TIME-DISTANCE SCALES. It may be desirable to construct a scale graduated into time intervals instead of distance intervals. This type of scale is useful in determining the position of a moving column at the end of any given time. For example, if an infantry column is marching 212 mph, a time-distance scale in hours and minutes on a map whose *RF* is 1:62,500 is made as follows:

a. In 1 hour the column marches 2½ miles or 2½ X 63,360 inches or 158,400 inches.

b. To obtain the length of the scale to represent this distance on the map, substitute in the formula:

$$\frac{1}{62{,}500} = \frac{MD}{158{,}400}$$

$$MD = \frac{158{,}400}{62{,}500} = 2.53 \text{ inches}$$

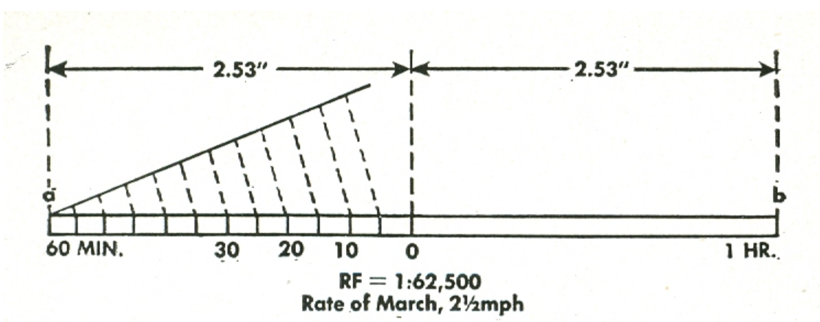


Figure 6. Constructing time-distance scale.

c. As shown in figure 6, lay off line *ab* on a sheet of paper. Then mark off on the scale as many 1-hour intervals of 2.53 inches as may be desired. The left interval is the scale extension and may be divided into 1-minute, 5-minute, or 10-minute graduations, depending on the reading desired. The extension is divided by the method explained in paragraph 12c. Mark the graduations appropriately, indicate the *RF* of the map to which the scale applies, and indicate the marching rate of the column.

SECTION V

DIRECTION AND AZIMUTH

15. GENERAL. Distance and direction are used to locate points or objects on the ground or on a map in relation to known points. The distance is measured, paced, or estimated, depending on the degree of accuracy required (see sec. IV). For military purposes, direction is always expressed as an angle from some fixed or easily established base direction line.

16. UNITS OF ANGULAR MEASUREMENT. a. General. The value of an angle is expressed in degrees (°), minutes (′), and seconds (″); or in mils (see fig. 7). Personnel in artillery or heavy weapons units use the mil since fire-control instruments are generally graduated in mils. Other personnel usually use degrees, minutes, and seconds.

b. Degrees, minutes, and seconds. When the circumference of a circle is divided into 360 equal parts by lines drawn from the center to the circumference, the angle between any 2 adjacent lines is 1°. Degrees are divided into minutes and seconds thus:

A circle =360° (degrees)

1° (degree) = 60′ (minutes)

1' (minute) = 60″ (seconds)

Angles are written as 137°45′ 23″.

c. Mils. If the circumference of a circle is divided into 6,400 equal parts by lines from the center to the circumference, the angle between any 2 adjacent lines is 1 mil. Thus an angle would be written in mils, as 1,327 mils. The mil is useful to artillery and heavy weapons units because it is an angle the tangent of which is approximately 1/1,000. Therefore a change of 1 mil in the direction of a machine-gun barrel changes the center of impact of a bullet 1 yard at a range of 1,000 yards or 2 yards at 2,000 yards.

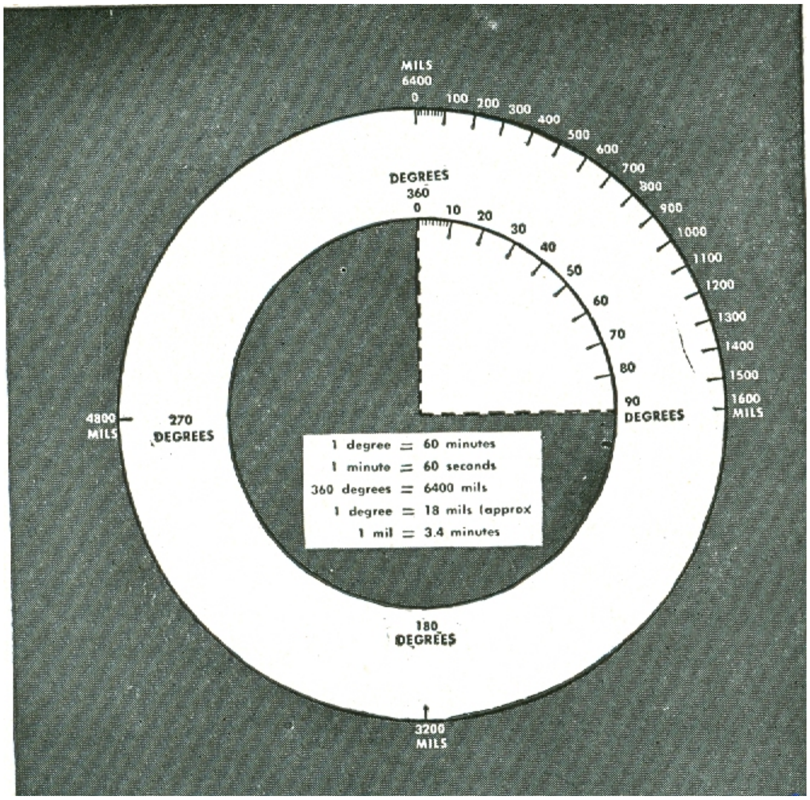


Figure 7. Angles expressed in degrees or mils.

d. **Relation between degrees and mils.** Degrees are changed to mils or mils to degrees by the following conversion factors:

$$360° = 6{,}400 \text{ mils}$$

$$1^{o} = \frac{6{,}400}{360} = 17.8 \text{ mils (or 18 approximately)}$$

Hence $10^{o} = 10 \text{ X } 17.8 = 178$ mils (or 180 approximately)

$$1 \text{ mil} = \frac{360}{6{,}400} = .056^{o} \text{ (or 3.4}' \text{ approximately)}$$

Hence 100 mils = 100 X .056 = 5.6 or 5.6^{o} or $5^{o}\,36'$

17. BASE DIRECTION. Direction from one point to another is always expressed as an angle from a base line. There are three base directions, namely, true north, magnetic north, and grid north, usually shown on maps by a star, half arrowhead, and the letter "y," respectively (fig. 8). Grid north

High school algebra strikes again. Remember that on a Cartesian grid, x is left-right and y is up-down.

may also be designated by "GN."

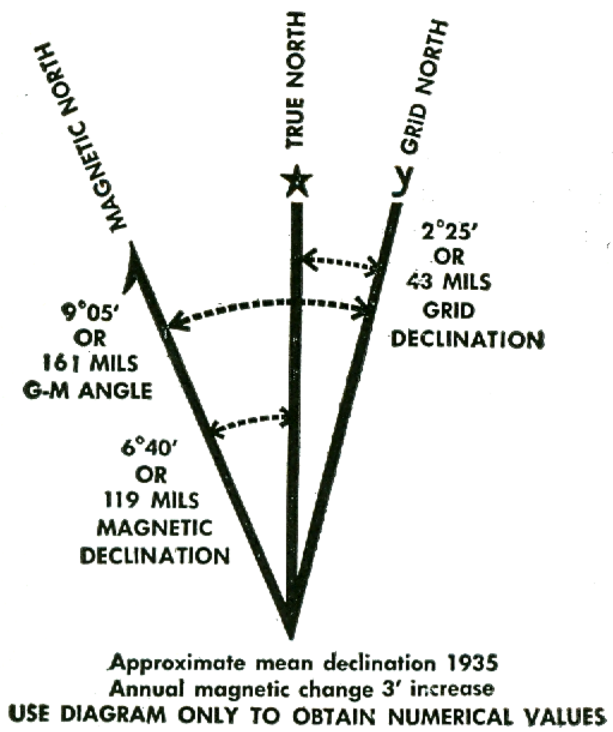


Figure 8. Declination diagram

a. True north. True north is the direction to the north pole. It is used in surveying where great accuracy is required but is not normally used by military personnel in the field. Meridian or longitude lines on a map represent true north and south directions.

b. Magnetic north. Magnetic north is the direction of the north magnetic pole. It is indicated by the N (northseeking) end of the compass needle. It is ordinarily used for field work because it can be found directly with the common compass.

c. Grid north. Grid north is the direction of the vertical grid lines usually found on military maps (see par. 27). Determination of direction by grid north is convenient because grid lines are located at frequent intervals on maps.

18. DECLINATION. a. General. Declination is the difference in direction between true north and magnetic north or between true north and grid north. There are therefore two

declinations, magnetic and grid. In figure 8, magnetic declination is 6º 40′ west and grid declination is 2° 25′ east.

b. Magnetic. Magnetic declination is the angle between true north and magnetic north. In localities where a compass needle points east of true north, magnetic declination is east. Where a compass needle points west of true north, magnetic declination is west. Where true north and magnetic north are the same, magnetic declination is zero. Lines joining points on the surface of the earth where magnetic declination is zero are called agonic lines. Lines joining points having the same magnetic declination are called isogonic lines. The magnetic declination in the United States varies from 250 east in Washington State to 22° west in Maine. Isogonic lines run generally north and south in the United States but are irregular because of local conditions. The magnetic declination at any one locality is subject to a gradual change, the amount of which can be predicted from past records. This change in some localities in the United States is as much as 4′ annually. For example, in figure 8 the annual increase is 3′. Hence, in the 9-year period 1935-1944, magnetic declination has increased 9 times 3′ or 27′, and the 1944 magnetic declination is 6° 40′ plus 27′, or 7º 07′ west of true north. When the magnetic prong is plotted in this position, the *G-M* angle (par. 19b) is increased 27′, from 9º 05′ to 9° 32′. Annual change is frequently expressed as E or W to avoid ambiguity in the change of direction.

One of the many graces (or the few, depending on what experience you might have had there) of Fort Benning Georgia, Pearl of the Chattahoochee and home of the Infantry School in those days (now combined with Armor as the Maneuver Center of Excellence), is that it lies on an isogonic line. This is a great relief to students at the Benning School for Boys stumbling around the pine woods at night with a compass.

We now know that the drift of the mag north pole is caused by precession of the spin of molten ferrous metal at the earth's core. In the 40's the Infantry School just attributed to God's dislike of the Infantry.

c. Grid. Grid declination or gisement is the fixed difference in direction between true north and grid north. Grid declination varies in different localities. Actually, it varies at different points on any one map, but on a tactical map the variation is so slight that the average declination can be used without introducing an appreciable error. Figure 9 shows the reason for grid declination. The rectangle *abcd* is a mapped area or zone with the lines *ef* and *gh* shown as military grid lines. The dashed lines are the true north and south lines. The grid line *JK* is parallel to the central meridian, a true north-south line. Other grid lines in the zone are drawn parallel to *JK.* Hence a map made at position I has grid declination west, while a map made at position II has grid declination east. In the military grid system, grid declination ranges from 3º east to 3º west in the United States.

Elsewhere in the world, when other grid systems are used, the maximum grid declination is much greater and depends upon the width of the zone. Military maps show in diagrammatic form the average grid declination for the area represented.

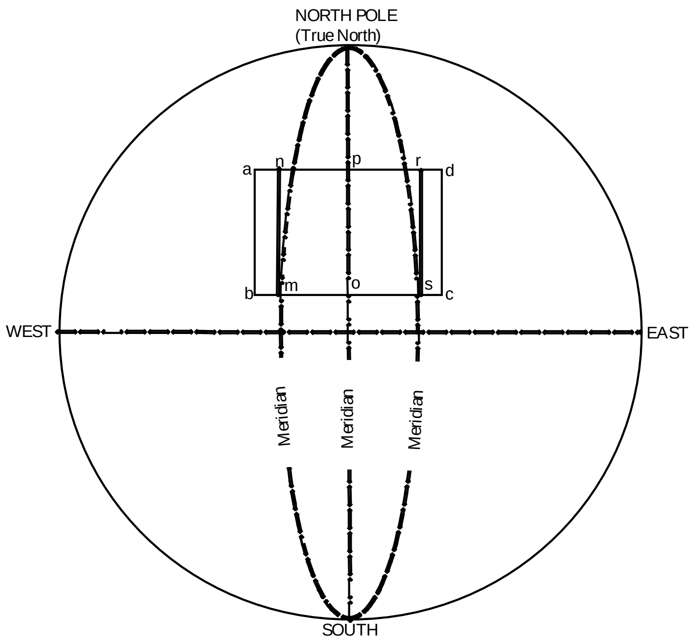


Figure 9. Diagram illustrating reason for grid declination.

See the appendix and the description of polyconic projection if you are really interested in this.

19. DECLINATION DIAGRAMS. a. General. A declination diagram is printed on the margin of military maps. It has three prongs showing the directions of true, magnetic, and grid norths. The angles between prongs are usually drawn accurately and can be used for graphic work on the map. For reasons given below declination diagrams should be verified by measurement before being used for this purpose. On some maps when the declination is small the diagram is exaggerated. In these cases, and generally on maps printed since 1943 the following note appears under the diagram:

USE DIAGRAM ONLY TO OBTAIN NUMERICAL VALUES

Diagrams so marked will not be used for graphical purposes. See figure 8.

b. G-M angle. (1) The angle between grid north and magnetic north is commonly called the *G-M* angle. The angle is west when magnetic north is west of grid north; east when magnetic north is east of grid north. It is used frequently in field map reading and its exact value is given in degrees on the declination diagram of new maps. However, its value may not be listed on older maps. In such cases, the *G-M* angle is computed by adding magnetic and grid declinations when magnetic and grid prongs are on opposite sides of the true-north prong and by subtracting when they are on the same side. Once the *G-M* angle has been computed, it should be written on the map for easy reference.

(2) An increase in annual magnetic change may increase or decrease the *G-M* angle. If the magnetic prong moves toward the grid prong, the *G-M* angle is decreased; if it moves away, the *G-M* angle is increased.

c. Two-pronged diagrams. As explained in chapter 6, the world is divided into zones for map-making purposes; each zone has a military grid drawn parallel to the central meridian of the zone. Hence, the grid declinations of adjoining zones are different and any map of a border line area has two grid systems and two grid declinations (see fig. 10). In such cases, a two-pronged diagram showing the relation between true and magnetic north at the center of the sheet is shown in black in the margin. Adjacent to the diagram are notes giving the grid declination for the center of each gridded area. These notes are usually in the color of the grid to which they refer.

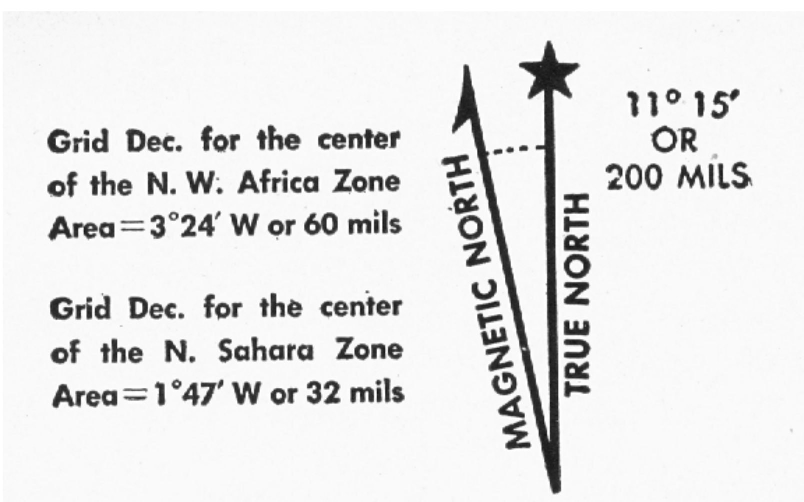


Fig 10. Declination diagram for map on which two zones appear.

20. AZIMUTH. In describing the position of one point on a map or in the field with reference to some other point, the army uses the azimuth system of measuring direction. Military azimuths are horizontal angles measured clockwise from magnetic-, true-, or grid-north base lines.

a. **Magnetic azimuth.** The magnetic azimuth of any line is the horizontal angle measured clockwise from magnetic north to the line. For example, in figure 11 the magnetic azimuth of the line from the road junction to the church is 60°.

b. **Grid azimuth.** The grid azimuth of any line is the horizontal angle measured clockwise from grid north to the line. In figure 11 the grid azimuth is 51°.

c. **True azimuth.** The true azimuth of any line is the horizontal angle measured clockwise from true north to the line. In figure 11 it is 54°.

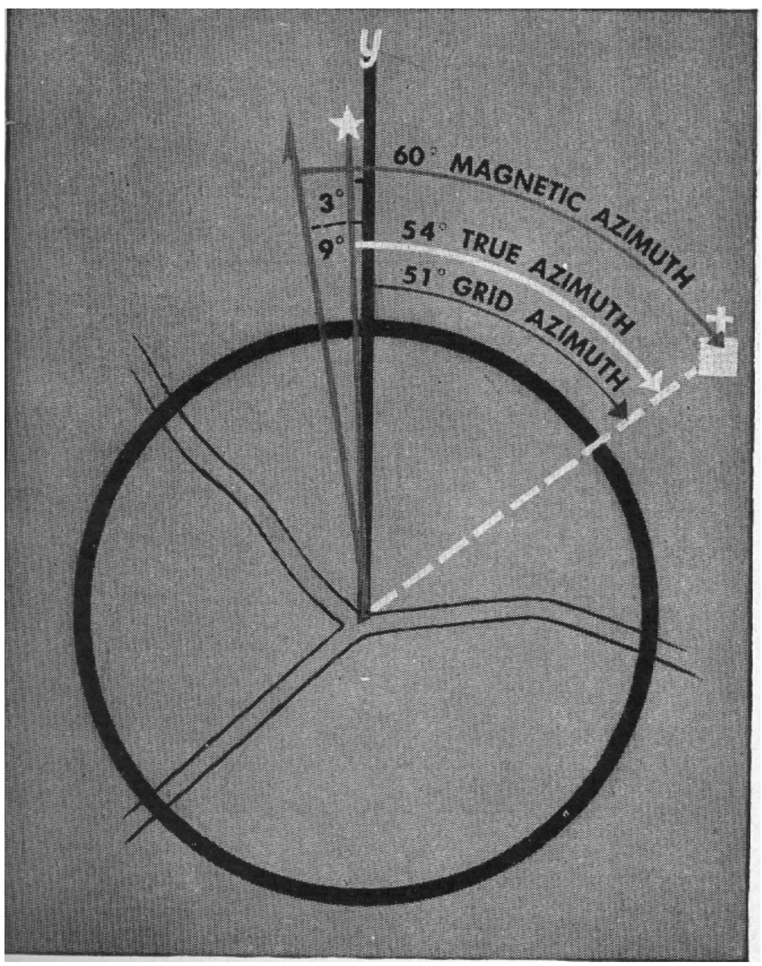


Figure 11. Three kinds of azimuth.

d. Relation between magnetic and grid azimuth. In the field, magnetic azimuths are read directly from the compass. If the map is one with the protractor and pivot point (see **FM 21-25**), the magnetic north line may be drawn easily on the map, and that line used to plot compass reading. However, on older maps, a compass reading is usually converted to grid azimuth before it is plotted on the map. The difference between grid and magnetic azimuth is the *G-M* angle.

(1) When magnetic north is *east* of grid north: grid azimuth = magnetic azimuth *plus G-M* angle.

(2) When magnetic north is *west* of grid north: grid azimuth = magnetic azimuth *minus G-M* angle. For example, in figure 11 grid azimuth = 60° - 9° = 51°.

e. Back azimuth. Back azimuth is simply the azimuth of a line viewed backward. (See **FM 21-25**.) The back azimuth of a line is its forward azimuth plus 180°, of if this sum is greater than 360°, the back azimuth is the forward azimuth minus 1800. For example, if the forward azimuth of a line is 50°, the back azimuth is 50° + 180° = 230°. Or if the forward azimuth of a line is 310°, the back azimuth is 310°-180° = 130°.

21. BEARING. Bearings are used to express directions by the service watch compass, many of which are still in use. The bearing of a line is its horizontal angle and direction with respect to either north or south direction line *and never exceeds 90°*. Figure 12① shows how bearings are measured and indicates the relationship between bearings and azimuths. If bearings are magnetic the azimuths likewise are magnetic. Figure 12② illustrates how to express a typical direction in each quadrant both as an azimuth and as a bearing.

This is most often a Navy term. The Navy is anal about bearings and other navigational niceties. If a soldier gets lost, he just sits around until somebody finds him or he starves. If a maritime navigator gets lost, his ship may go down with all hands. In the early 1700's Admiral Sir Cloudisley Shovell managed to drive a whole fleet on the rocks at the Scillies, prompting the monarch to promise a 1,000 pound prize for anybody who could invent a precise way of discovering where you are before you lose a fleet. (The answer turned out to be an accurate pocket watch.)

22. PROTRACTOR. A protractor is an instrument for measuring or laying off angles on a map. Figure 13① and ② illustrate two types; the semicircular type is the more common. The protractor represents half an azimuth circle but is graduated in two scales to represent a complete circle, one scale reading from 0° to 180° and the other from 180° to 3600. When the semicircular scale is placed as shown at the left in figure 14, only the scale 0° to 180° can be read. If the protractor is turned so the circular portion is to the left, the scale 180° to 360° can be read.

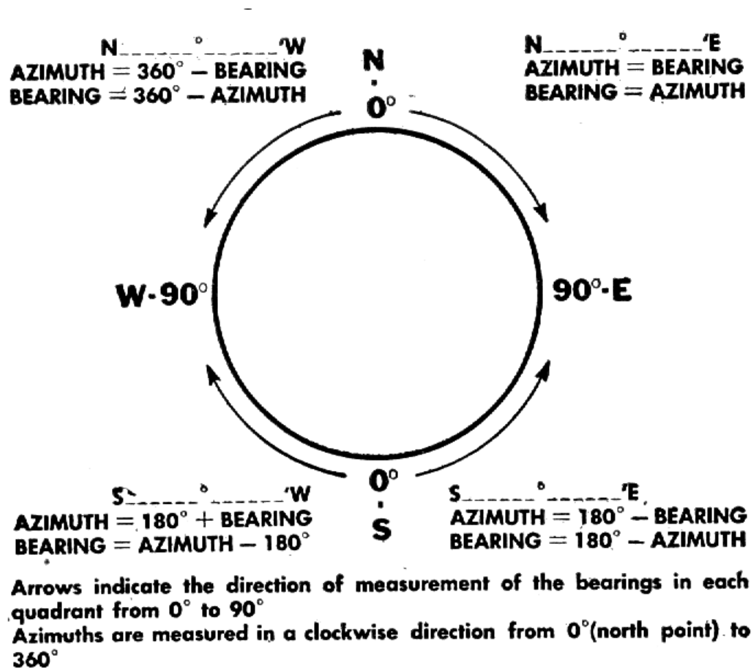
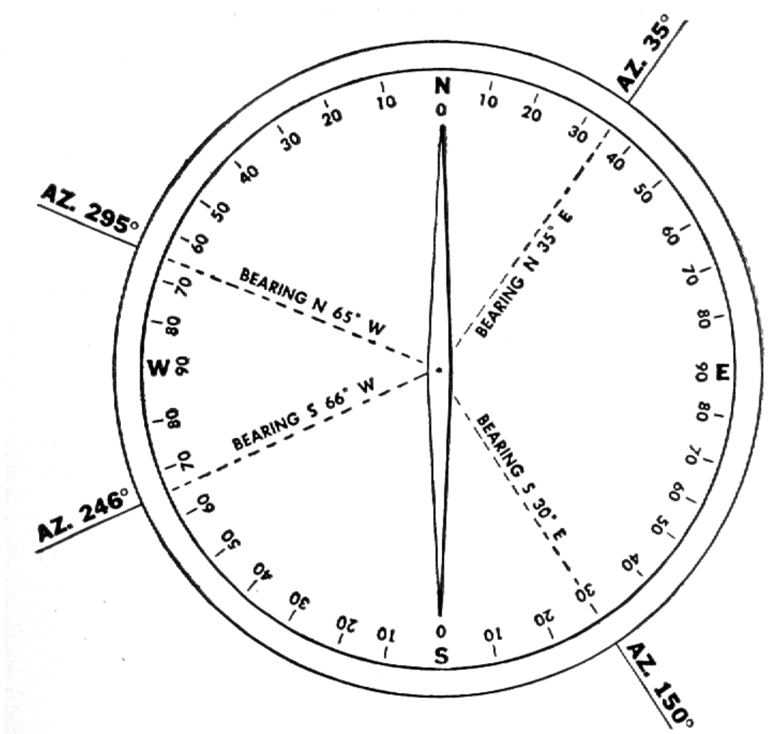
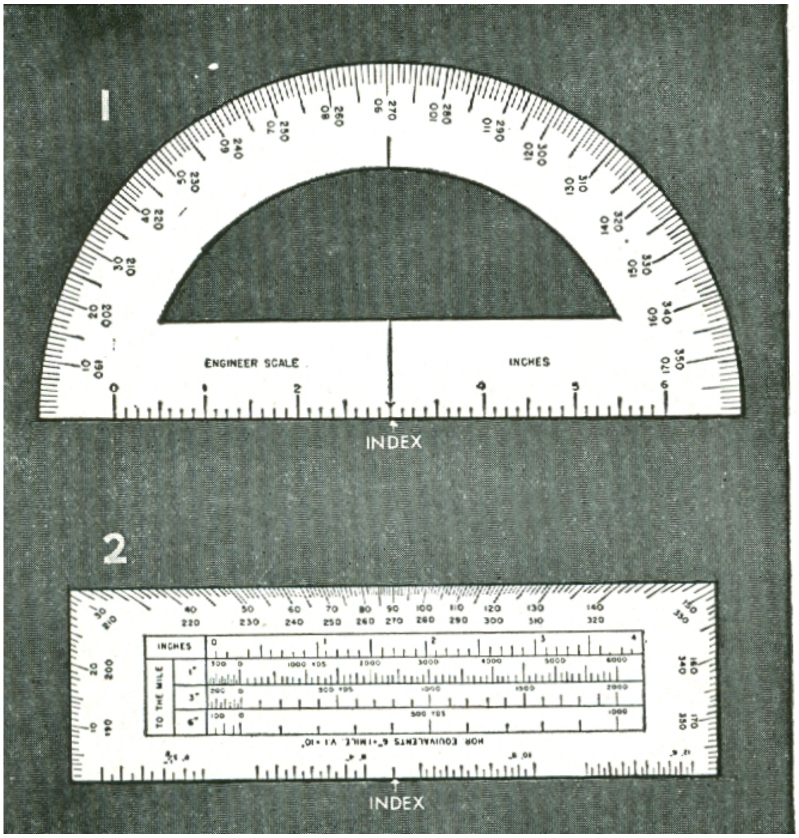


Figure 12. ← Relationships between azimuths and bearings.



↑ *Direction expressed in azimuths and bearings.*

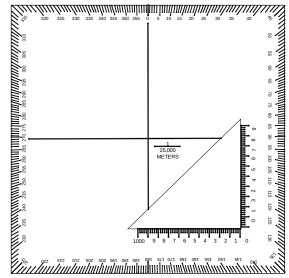
Figure 12. – Continued



① *Semicircular protractor.*

② *Rectangular protractor.*

Figure 13.



We will use a slightly more modern protractor (which was available in WWII, though not pictured in this manual), modified to use as a scale for 1:25,000 RF. A second version will be used for special maps at 1:12,500.

23. TO MEASURE AZIMUTH OF ANY LINE ON A MAP. Following are examples illustrating methods of finding azimuths on a map:

a. Problem 1. To find the *grid* azimuth of the line from the crossroads at *A* to the house at *B* in figure 14. Extend the line *AB* until it intersects the 349 grid line. Lay a protractor on the map with its index at this intersection and the straight portion lying along the 349 grid line. Read the grid azimuth of *AB*. It is 138°.

b. Problem 2. To find the *magnetic* azimuth of the line from the crossroads at C to house at *D*. Extend the line *CD* beyond the edge of the protractor. Lay the protractor on the map with its index at the intersection of *CD* with the 351 grid line and the straight portion lying along the 351 grid line. Since the azimuth of the line is greater than 180°, the scale reading from 180° to 360° is used. The grid azimuth of *CD* is 226°. The declination diagram shows the *G-M* angle to be 40 west, so it will have to be added to the grid azimuth. The magnetic azimuth is 226° + 4° = 230°. If the magnetic north line is plotted on the map with the aid of the map pivot point and partial protractor scale, the magnetic azimuth may be measured directly from this line.

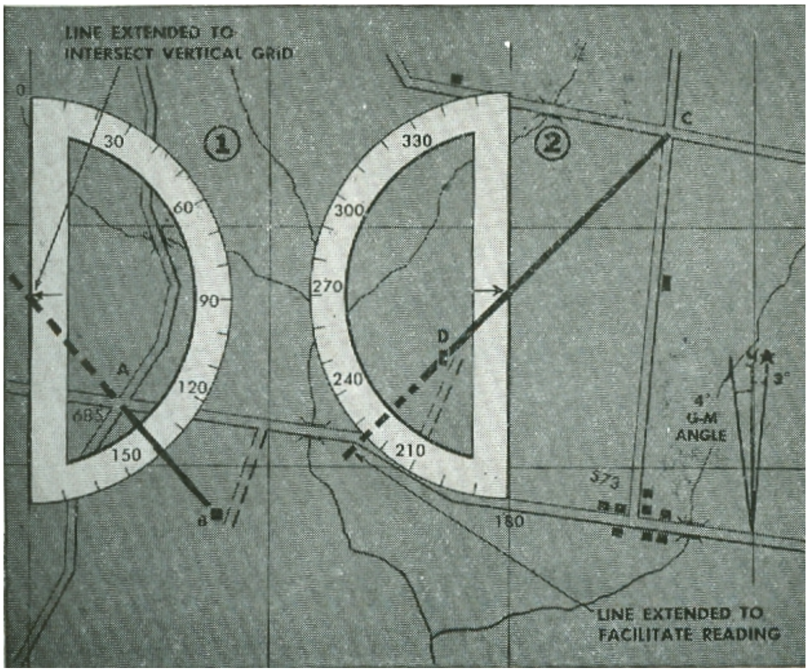
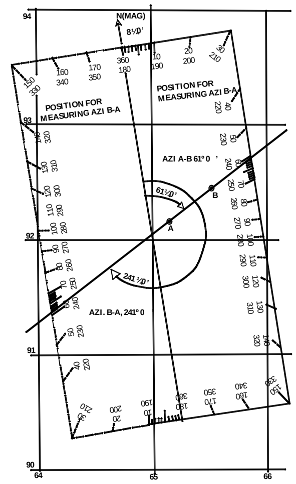


Figure 14. Schematic illustration showing use of protractor to measure azimuth on map.

24. TO PLOT AN AZIMUTH ON A MAP. a. Grid azimuth. Problem: To plot from CR 685 on figure 15 a line with a grid azimuth of 75°. Construct a line through the crossroads parallel to the north-south grid. Place a protractor on the map with its base on the line and its index at the crossroads. Plot the point *P* at the 75° reading on the protractor. Remove the protractor and draw a line from the crossroads through *P*.

b. Magnetic azimuth. To plot the magnetic azimuth of a line, follow the same procedure as in a above but construct the line through the crossroads parallel to magnetic north, rather than to the north-south grid or convert magnetic azimuth to grid azimuth and plot as directed in a above.

25. COMPASSES. **FM 21-25** explains how to use a compass. In addition to variation caused by magnetic declination, a magnetic compass is affected by the presence of iron, magnets, and charged electric wires and electric apparatus.



Above: use of the rectangular protractor. (For visual simplicity, the center scales of the protractor (see fig. 13) have been removed.)

Certain geographic areas have deposits of

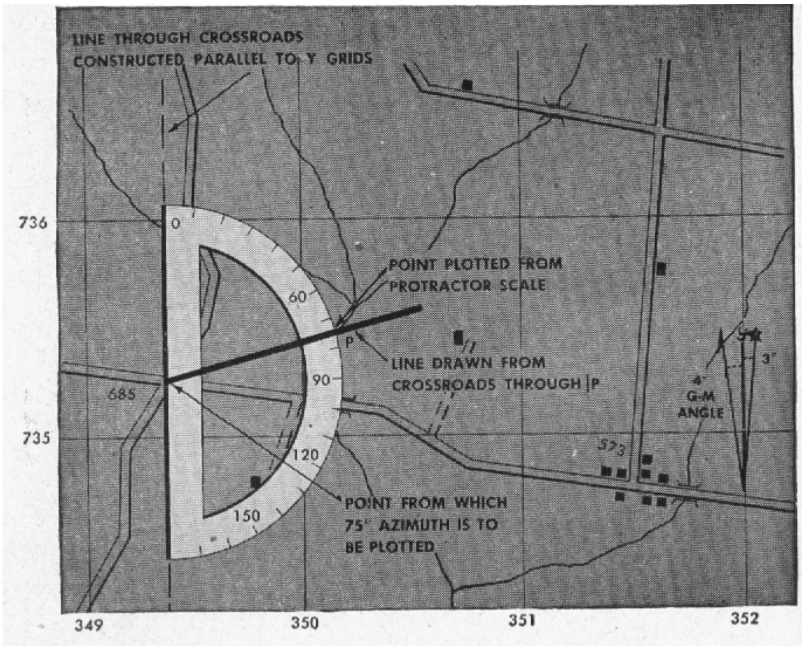


Figure 15. Schematic illustration showing use of protractor to plot a given azimuth on a map.

Figure 16. Watch compass gives direction in bearings.

mineralized rock (such as iron ore) which render a compass unreliable in those vicinities. Consequently, all visible masses of iron or electrical fields must be avoided when using the compass. The following are the minimum safe distances:

One of the largest such deposits is the Kursk Magnetic Anomaly in Russia. This complicated maneuvers during the huge armored battle there in 1943 (Operation Citadel). Of course, a Tiger tank is a magnetic anomaly in itself.

	Yards
High-tension power lines	60
Field gun	20
Automobile or tank	20
Telegraph wires	10
Barbed wire	10
Machine gun	3
Helmet or rifle	1

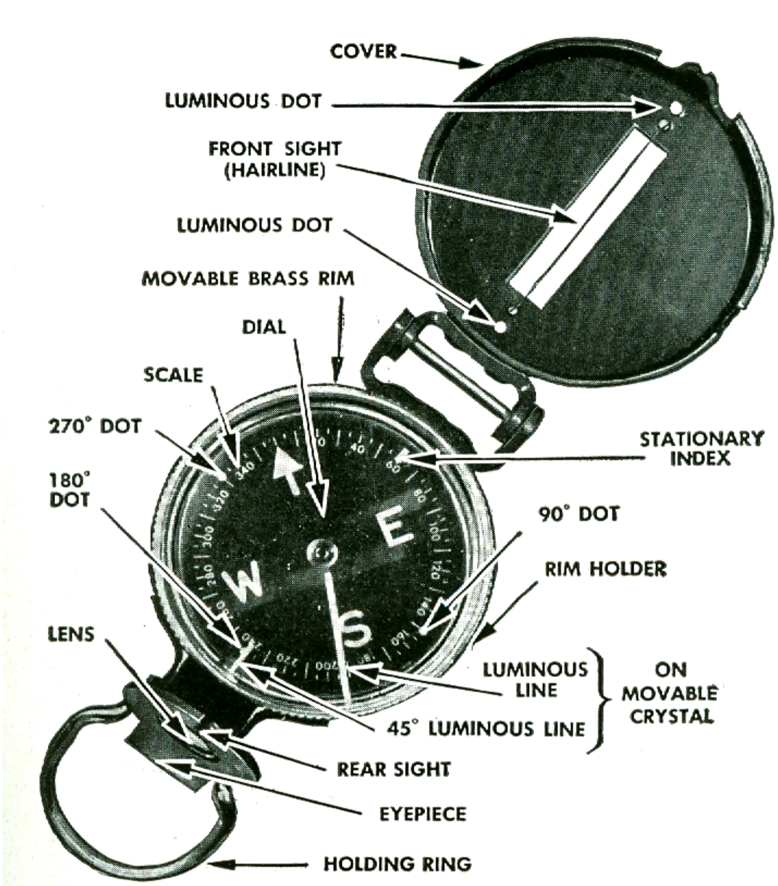


Figure 17. Nomenclature of old lensatic compass.

The four common types of compass are the watch, lensatic, prismatic, and wrist.

a. Watch compass. The face of the watch compass (fig. 16) is divided into quarters, or quadrants, of 90° each. Readings are given as bearings as explained in paragraph 21. This compass has no sights.

b. Lensatic compass. The standard compass for general use in our Army is the liquid-filled lensatic, so called because azimuths are read through a magnifying lens in the eye piece. Figure 17 shows the lensatic compass and its nomenclature. **FM 21-25** explains how to use it. The newest lensatic compass (fig. 18) differs from the model in figure 17 in that the floating dial is transparent and is graduated in mils as well as in degrees. Numbers on the dial are printed in black. There is a fixed luminous sector on the inside of the case which permits reading azimuths at night.

c. Prismatic compass. The prismatic compass shown in figure 19 differs from the lensatic compass in that azimuths are read from the dial through a prism rather than through a lens.

Figure 18. New issue lensatic compass.

(1) The compass consists of a case housing a magnetic dial, a hinged cover with a glass window, and an eyepiece containing a prism for reading graduations on the dial. The dial has two scales, the outer one to be read through the prism of the eye piece, the inner one to be read directly at the front sight. Both are graduated from 0° to 360°. The north point is indicated by a luminous arrow.

(2) The glass cover has an etched line which is used like the hair line on the lensatic. Closing the cover operates a lever which raises the dial off the pivot to protect it. To release the dial the lever at the side must be pushed forward.

Figure 19. Nomenclature of prismatic compass.

(3) When the cover of the compass is raised, a glass disk protects the dial. The luminous index line used in setting azimuths at night is painted on this disk. The index line can be set at any desired angle simply by loosening the set-screw on the side and revolving the corrugated brass ring which houses the glass disk.

(4) The outside of the compass case is graduated in degrees, counterclockwise. For night use the luminous index line is set opposite the desired azimuth indicated on the outside of the case. The compass is rotated until the luminous arrow on the dial points to the luminous index line. Now the two luminous markers on the hinged cover point along the desired azimuth or direction of march.

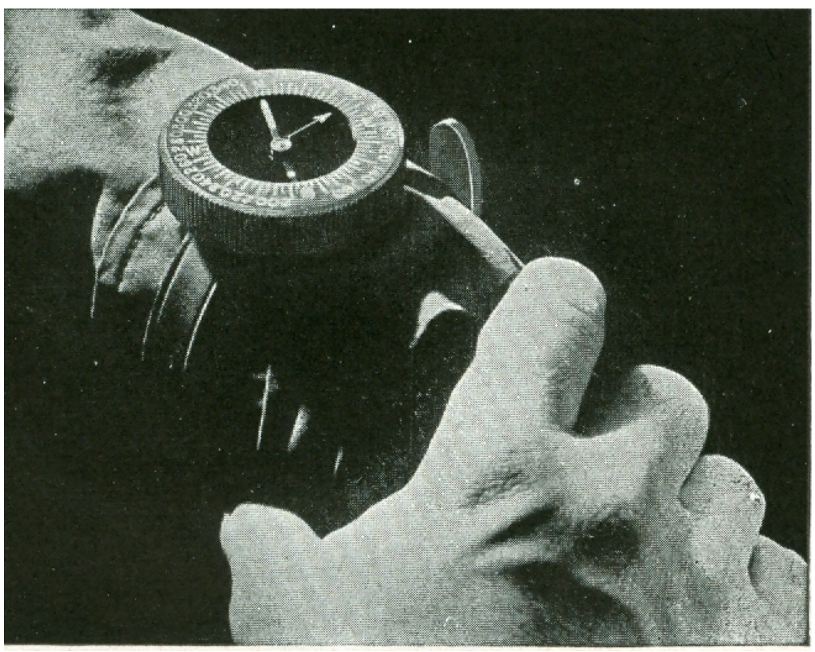


Figure 20. Wrist compass.

d. Wrist compass. The wrist compass is a liquid-filled compass designed to be worn strapped to the wrist as shown in figure 20. **FM 21-25** explains how it is used.

26. TRAVERSE. A traverse is a series of connected lines of known distance and direction. A traverse is useful in exploring unfamiliar terrain and in recording the course taken. To make one, start from a known point and follow observed compass courses from point to point, measuring distances. When plotted to scale on the map, these course lines and distances show graphically the course followed and the location of any desired point on the traverse. A typical traverse is shown in figure 21.

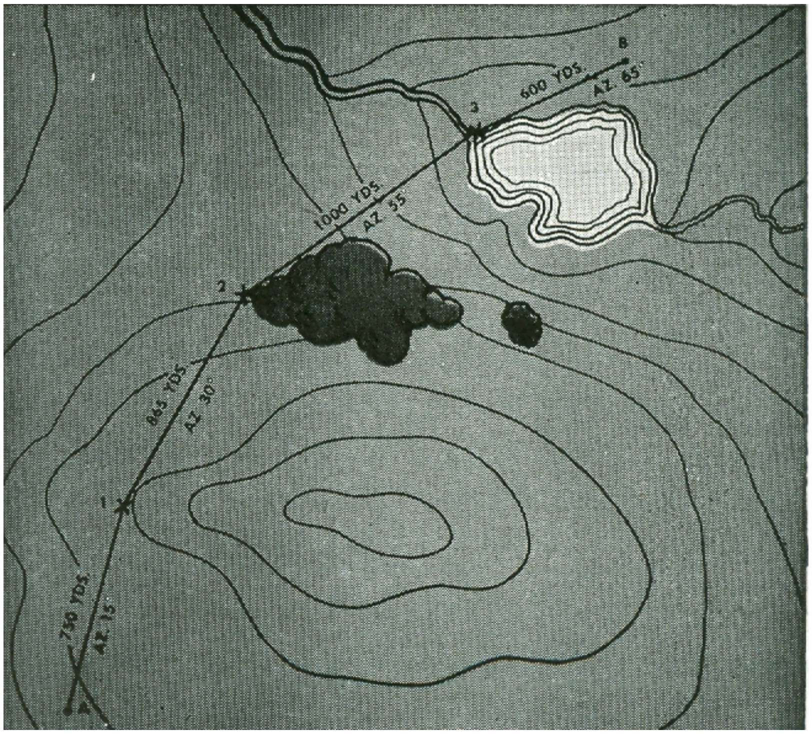


Figure 21. A traverse is a series of lines of known distances and directions

SECTION VI

GRIDS AND COORDINATES

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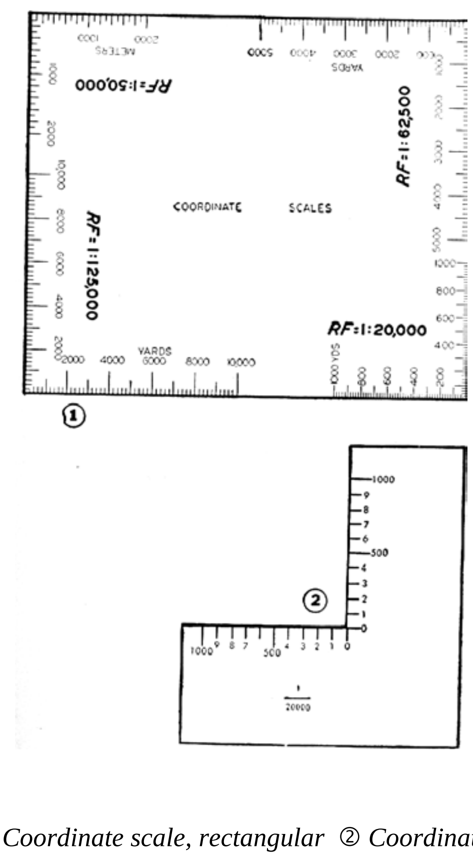
27. MILITARY GRID. A military grid is a network of squares made up of north-south lines showing distance east of an arbitrary origin, and east-west lines showing distances north of the same reference point. The distance between grid lines is 1,000, 5,000, or 10,000 yards (or meters), depending on the scale of the map. This distance is called the grid interval. See **FM 21-25** for a discussion and explanation of grid coordinates.

28. COORDINATE SCALE. a. General. The sides of grid squares may be divided with a reasonable accuracy by estimation, but it is easier and more accurate to use a coordinate scale. Two types are shown in figure 22 ① and ②. Either may be made by laying off the length of one side of a grid square and dividing it into tenths.



① *Coordinate scale, rectangular* ② *Coordinate scale, L-shape.*
Figure 22.

b. To read coordinates. To locate RJ 37 in figure 23, place the coordinate scale as shown. The marked horizontal edge is along the bottom of the grid square in which the road junction is located and the marked vertical edge passes through RJ 37. The horizontal edge of the scale gives the 100-yard and 20-yard points to the right of grid line 1369. The vertical edge of the scale gives the distance from grid line 1792 to the road junction. The coordinates of RJ 37 are (69.72-92.25).

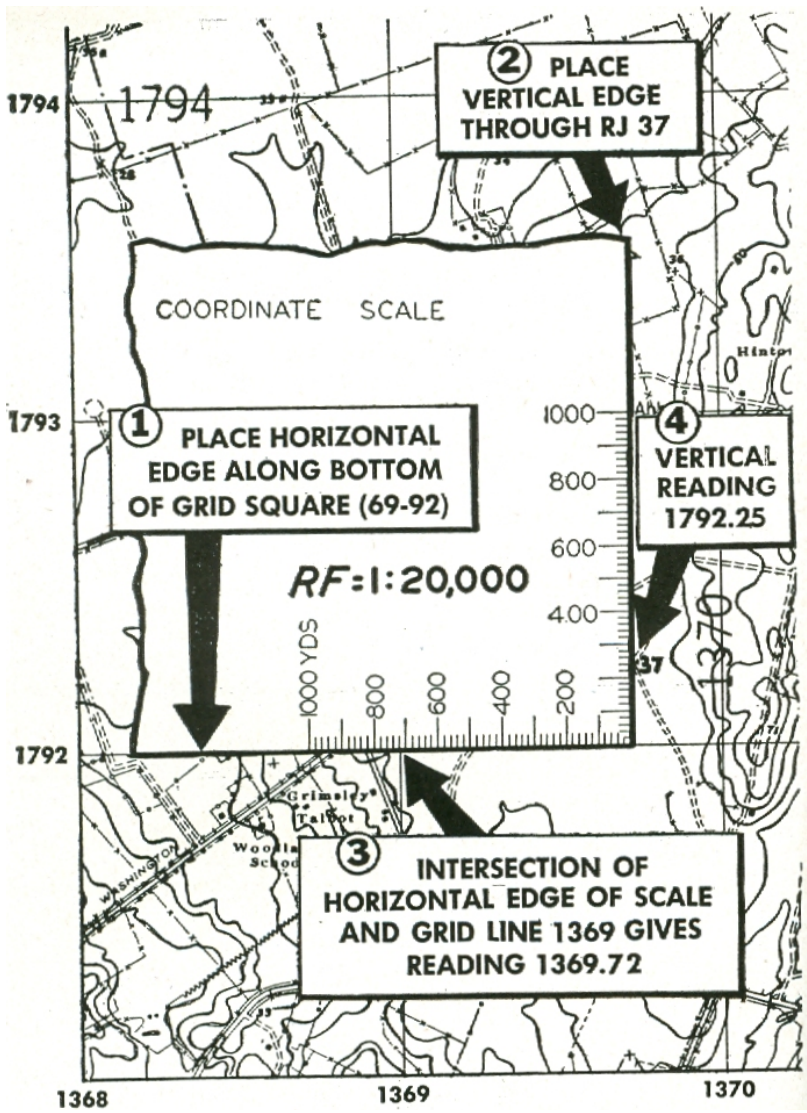


Figure 23. Coordinate scale used to read coordinates of a given position on map.

c. To plot a point. To locate the command post of the 1st Infantry Regiment at (74.60-92.47) place the coordinate scale as shown in figure 24 and mark the CP with a pencil.

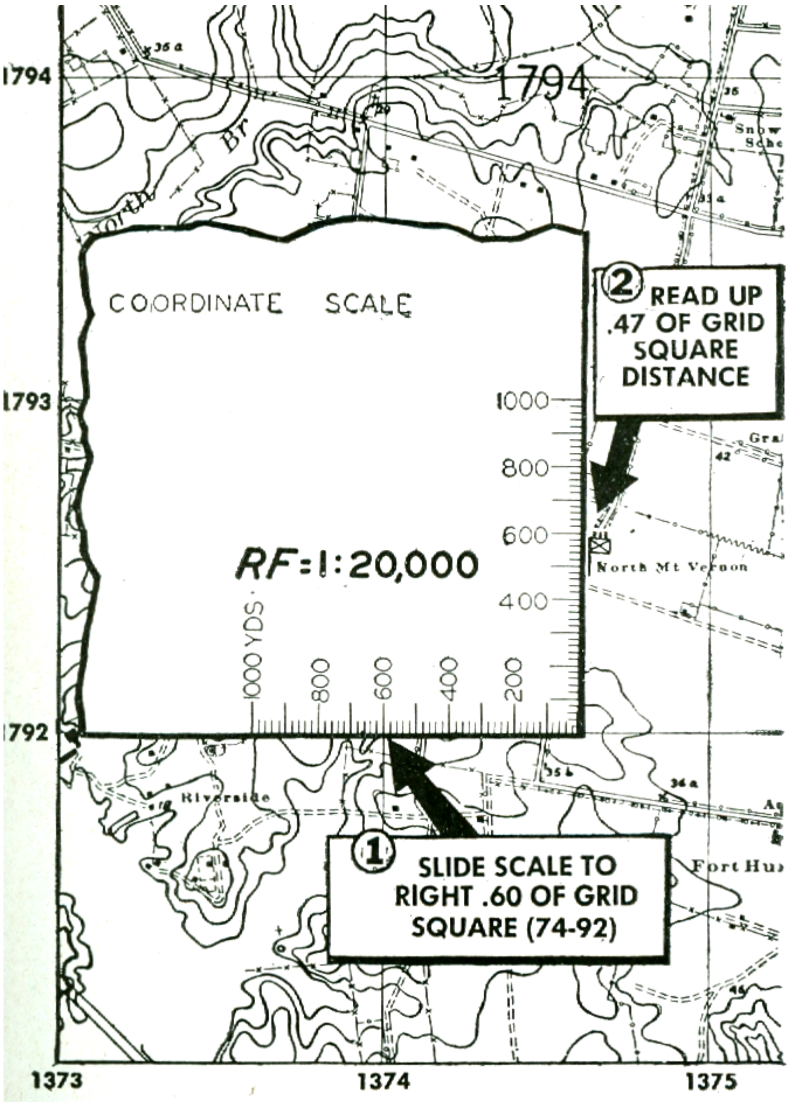


Figure 24. Coordinate scale used to plot position of known coordinates.

29. USING ENGINEER SCALE. The engineer scale may be used with the military grid to locate points. For example, to locate the headquarters of the 1st Infantry Regiment at (25.35-76.62), find the grid square (25-76) and place the scale *in* position ① figure 25, so that the "0" and "10" indicators are on successive vertical grid lines. The "0" of the scale is *always* placed on the lowest numbered grid line. Measure from the grid line 1325 along the scale to the thirty-fifth subdivision and make a mark on the map at *A*. Re-

peat this operation at position ② and mark *B* on the map. The line drawn between points *A* and *B* is the coordinate line 25.35 or the RIGHT reading. To get the coordinate 76.62 place the scale in position ③, so that the "0" and "10" indicators are on successive *horizontal* grid lines with *"0" always* on the lowest numbered line. Measure along the scale to the sixty-second subdivision and make a mark on the map at C. Move the scale to position ④ and mark map at *D*. A line drawn between points *C* and *D* is the reading UP or coordinate 76.62. The command post is located where lines *AB* and *CD* intersect.

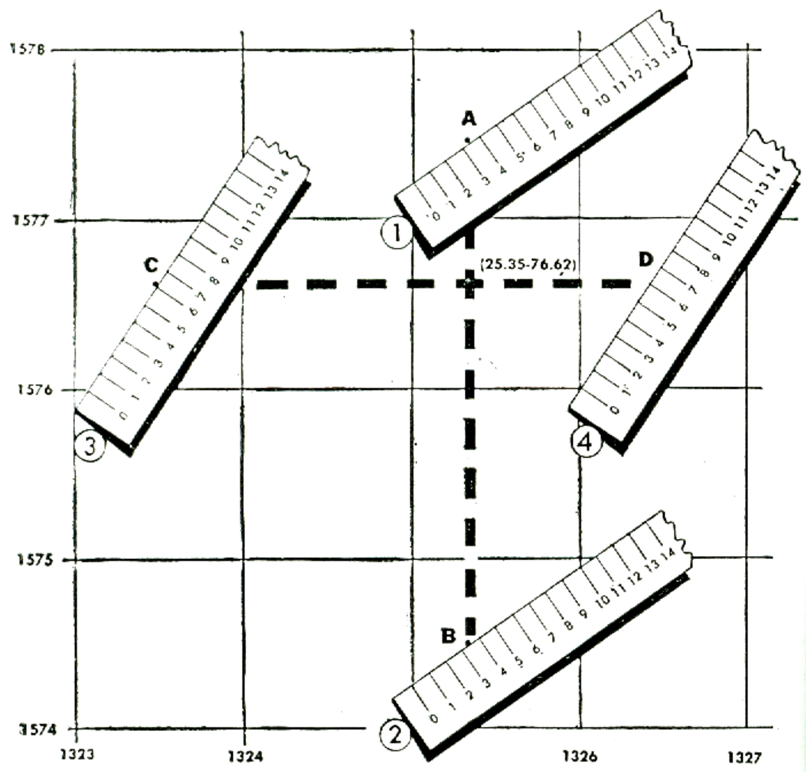


Figure 25. Engineer scale used to locate coordinates on a gridded map.

30. POLAR COORDINATES. Polar coordinates consist of an angle from a known base direction and a distance from a known starting point. The base direction is normally expressed as azimuth, the distance in any convenient unit. Polar coordinates are especially useful in the field because magnetic azimuth can be determined from the compass and distance can be estimated. For example, in figure 26, a patrol leader at observation post (OP) *A* observes enemy

guns in position at point *B*. He sends back information that an enemy artillery position is located 900 yards on a magnetic azimuth of 43° from OP *A* in Thorofare Village. On receiving the message the company commander. converts magnetic azimuth 43° to grid azimuth 35°. He plots the direction line from OP *A* and scales off 900 yards to the enemy position at point *B.*

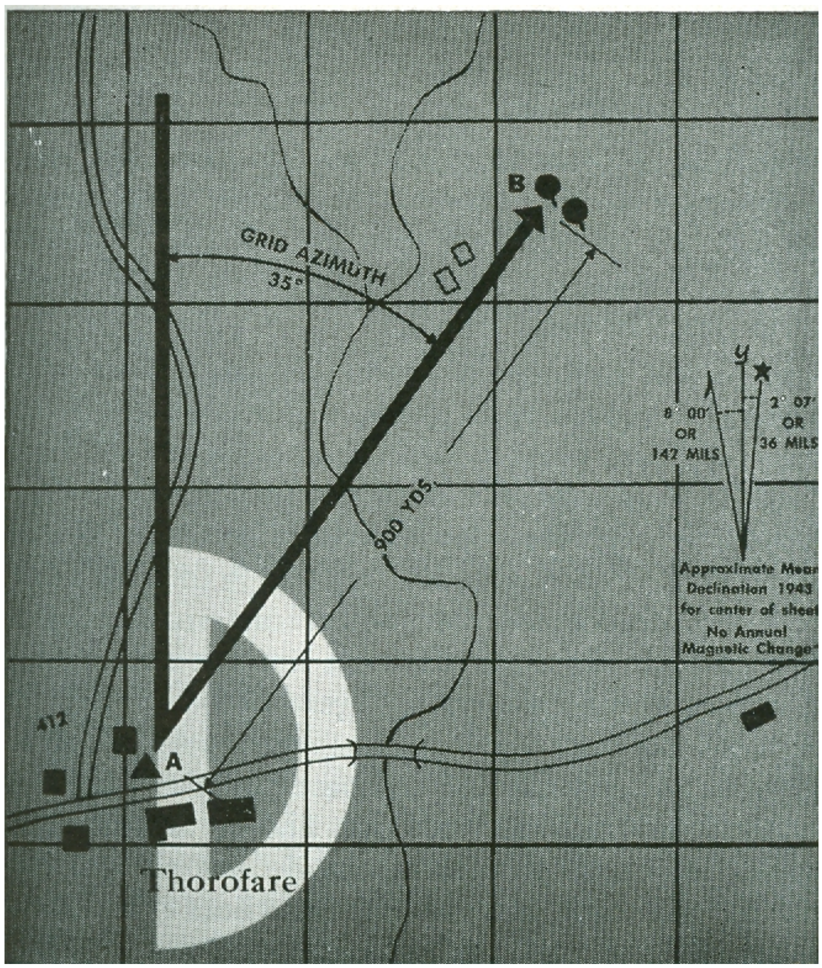
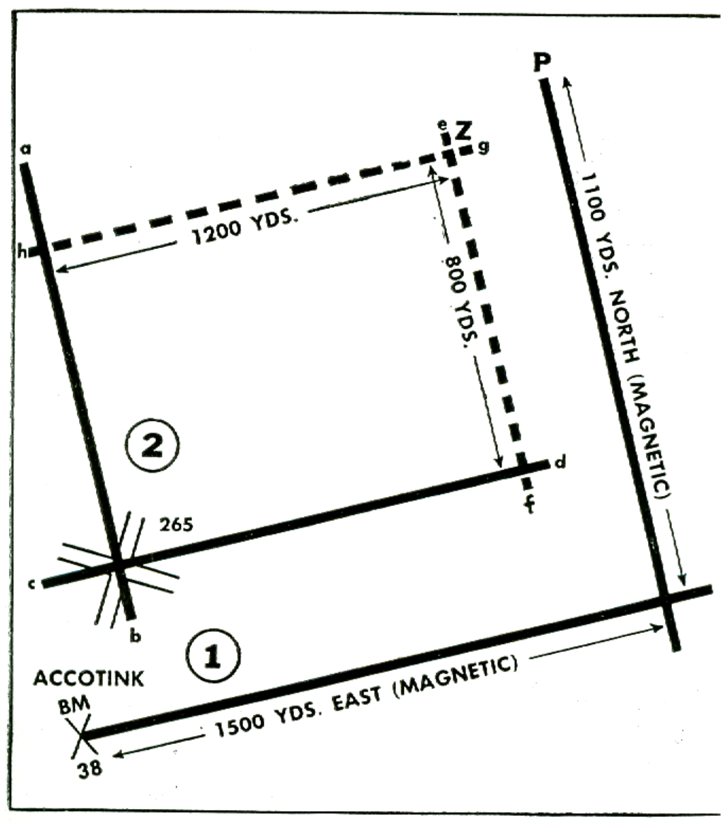


Figure 26. Polar coordinates used to designate position on map.

31. RECTANGULAR COORDINATES. a. **To plot map position by rectangular coordinates on ungridded maps.** Rectangular coordinates consist of two distances measured at right angles from a base position. For example, the problem in figure 27 (is to locate point *P,* 1,500 yards east (magnetic) and 1,100 yards north (magnetic) of bench mark (BM) 38 at Accotink. From BM 38 draw an east line 1,500 yards long and measure off 1,100 yards to the north. This locates point *P.* The

coordinate is written as BM 38, Accotink (village), 1,500 yards east (magnetic), 1,100 yards north (magnetic).

b. To find rectangular coordinates of a point with respect to a given base position and direction. From the base point, draw a guide line parallel to the base direction and a guide line perpendicular to the base direction. From the point whose rectangular coordinates are desired, drop perpendiculars to each of these lines. Scale the distance along the perpendiculars to the respective guide lines; these distances are the rectangular coordinates. For example, in figure 27 ① the problem is to find the rectangular coordinates of point *Z,* given the base position CR 265 and base direction magnetic north: Draw the base direction line *ab* and at right angles to it draw line *cd.* From Z draw the perpendiculars *ef* and *ga.* Measure along the lines *ef* and *ga* to derive the rectangular coordinates of point Z: 1,200 yards east (magnetic) and 800 yards north (magnetic).



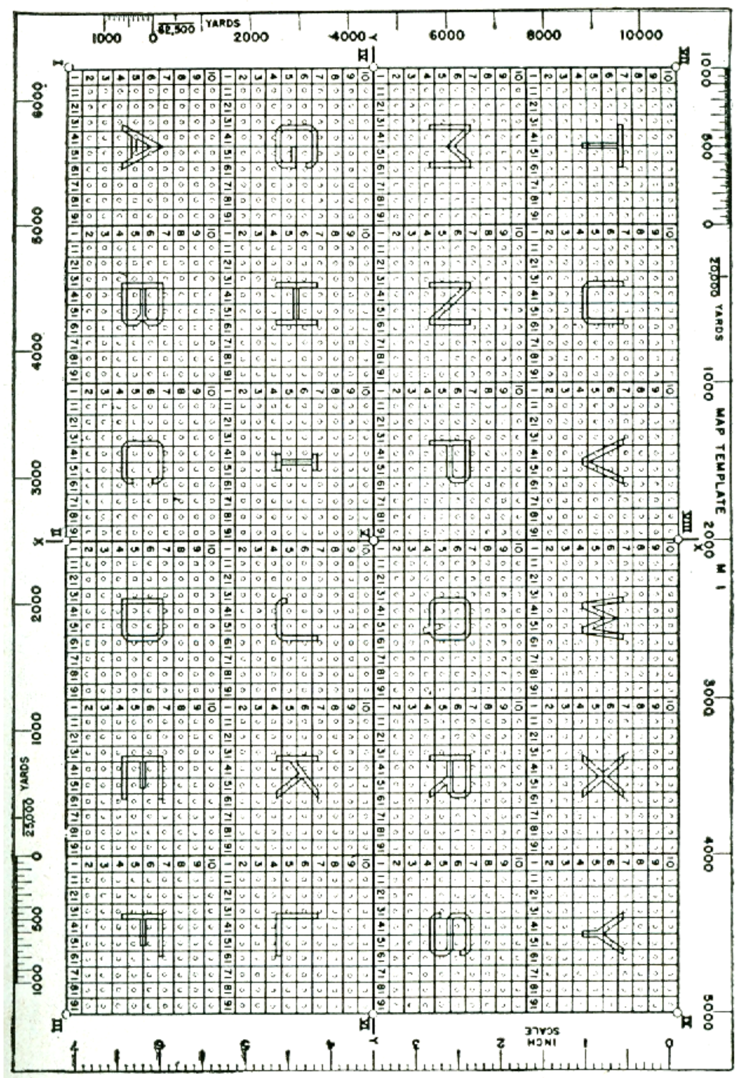
① Plotting position on map using rectangular coordinates on ungridded map.
② Determining of rectangular coordinates of a point with respect to a given base position and direction.
Figure 27.

32. THRUST LINE. In the thrust-line system, the base of all coordinates is a so-called thrust line designated by the commander. It is located on the map by two reference points or by a reference point and a direction. Somewhere on the thrust line is a base point from which all coordinates are measured. The commander names this base point at the time the thrust line is given. Points are located by giving the distance along the thrust line forward or back of the base point, *F* for *forward* and *B* for *back;* and, the distance at right angles from the thrust line, *R* for *right* and *L* for *left.* In determining whether a point is to the right or left of the thrust line, the map reader must assume that he is standing at the base point and facing forward along the line. The distance forward or back and right or left is given in miles, kilometers, yards, or meters; the scale of the map determines the accuracy of measurement. When the unit of measure is miles, the measurement is in tenths with the decimal point omitted. When yards or meters are used, the unit of measure is designated by the commander; no decimal point is involved in this case. See **FM 21-25** for a detailed description of the thrust line.

33. MAP TEMPLATES M1 AND M2. a. General. A map template is a device for locating points by coordinates on gridded or ungridded maps and aerial photographs. The template is a transparent sheet about 8½ by 12 inches, having 24 large squares 1.8 inches on a side. Squares are lettered from "A" to "Y" omitting "O". Each lettered square of the M1 template is divided into 100 small squares, 0.18 inches on a side; each square is marked either by a numeral or punched hole as shown in figure 28. On the M2 template the lettered squares are not subdivided into smaller squares, but the holes are provided. In addition, both templates have nine larger holes marked by Roman numerals I to IX. These holes are located at each corner, at the middle of each side, and at the center of the template. They are origin points for orienting the template on the map.

"O" is too easily mistaken for "0" (zero). When written, the numeric value 0 was drawn with a diagonal through it to avoid confusion with the letter.

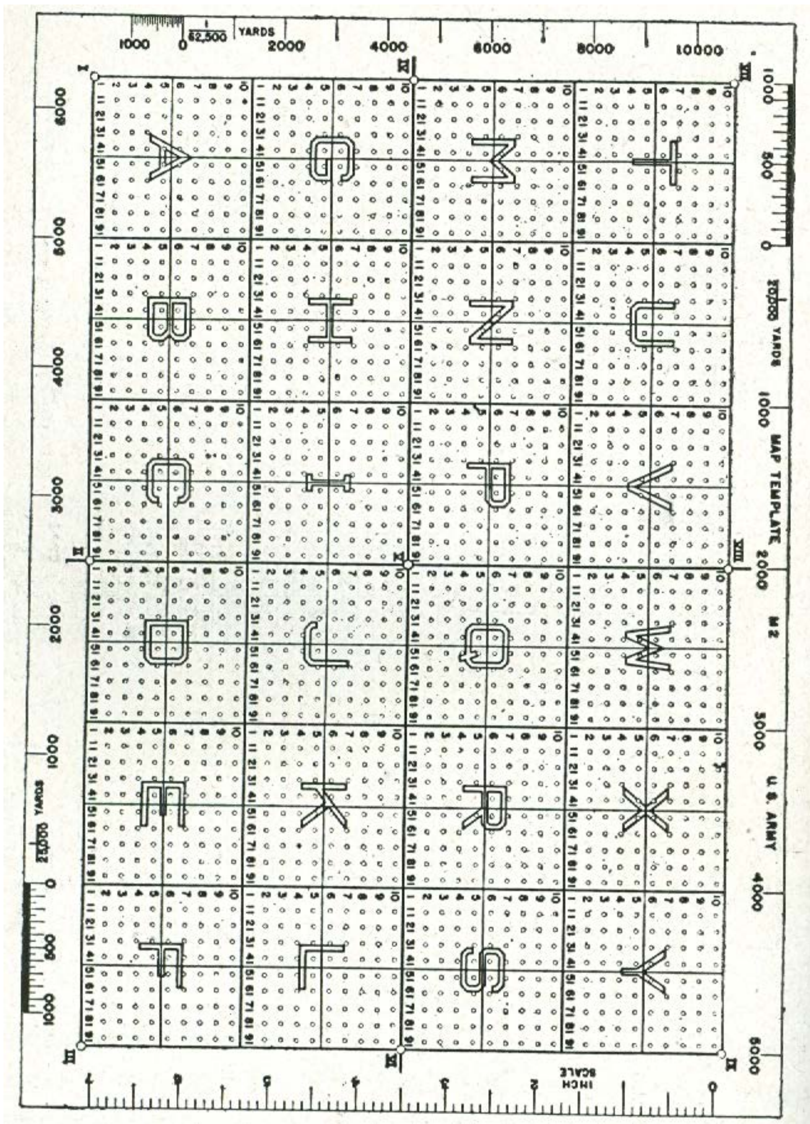
b. Orientation of the template. To use the template system, the commander specifies an origin point on the template and a reference point on the map over which The origin point is to be placed. He also specifies a template base line joining the template origin point and any other Roman-numeral point. He then designates a line on the map with which the template base line must coincide. The direction of the line on the map may be indicated by grid azimuth or as the line joining the map reference point with another map feature. The template is ready for use when the template origin point and base line are placed over the reference point and line on the map.



① *Map template M1.*

Figure 28.

The following message is a sample of a commander's instructions on orienting a template: "Reference special map A, 1:25,000. From 0900 to 1200, 24 Apr 1944, origin point I at BM 24. Line I-VII through schoolhouse NE of BM 24." As illustrated in figure 29, the map template is placed on the map with origin point I over BM 24 and pivoted until line I-VII coincides with a line drawn on the map from BM 24 through the schoolhouse symbol northeast of BM 24. The origin point and reference point may be ground features on the map given by map coordinates. Any Roman-numeral point can be used as an origin, and any line connecting the designated point with any other Roman-numeral point can be used as a base line.



② *Map template M2. Figure 28 – continued.*

c. Point designation. Once the template is oriented, a point is designated by the letter of the square in which it is located and by the number of the hole nearest it. For example, the building in the "U" square of figure 29 is in the sixth column from the left and in the third row from the bottom. Reading up the sixth column we count 51, 52, 53. The building would be designated as "U 53."

d. Security considerations. This method of using the map template provides, in certain situations, a convenient and rapid means of designating point locations. However, it should be emphasized that this method of use *is not intended to provide security.* Before the template can be used for purposes of secrecy instructions prepared by the Chief Signal Officer relative to the preparation and use of keys must be consulted.

Finally, the "why": use of the templates allows us to transmit map grid locations in a secure way—but only if we have the key and the enemy doesn't. I presume the key was changed regularly and published with the Signal Operating Instructions (SOI).

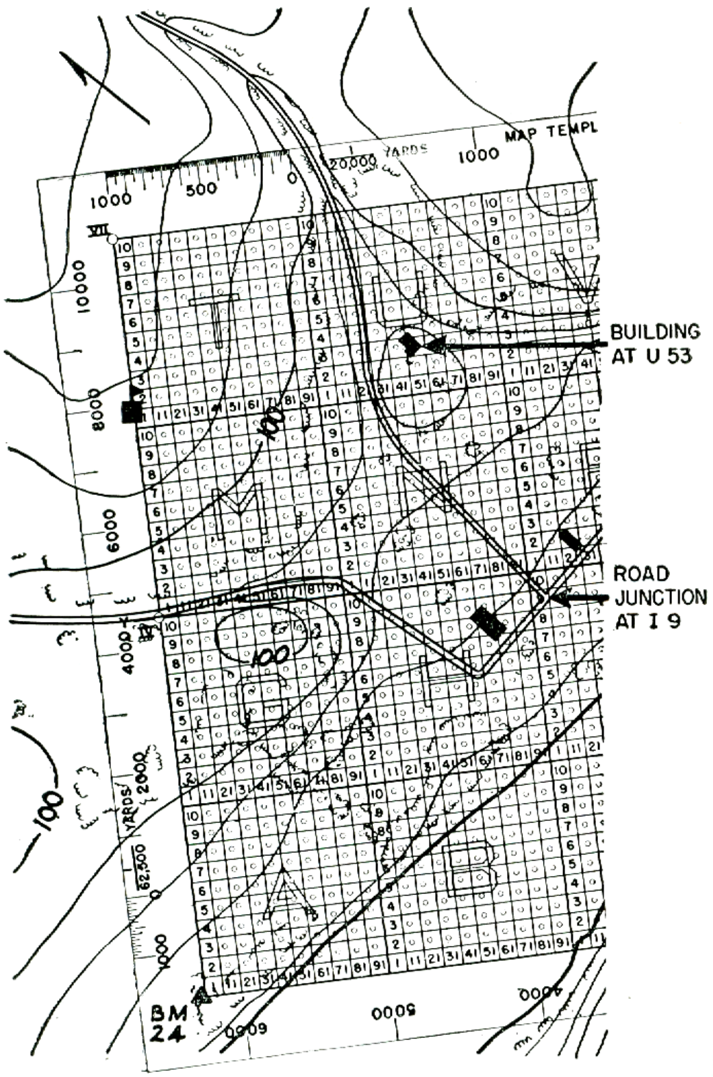


Figure 29. Use of map template M1.

34. GEOGRAPHIC COORDINATES. a. General. Unlike grid coordinates which are given in linear measure such as yards, geographic coordinates are stated in degrees (°), minutes (‘), and seconds (“). To understand these coordinates, one must be familiar with the line of latitude and longitude on the earth.

(1) The equator is an imaginary line round the earth halfway between the North and South Poles (fig. 30). Crossing the equator at regular intervals are north and south lines which pass through the poles. These are known as meridians of longitude or simply meridians. One is marked zero and is called the prime meridian. From this prime meridian, longitude is measured both east and west around the world. Lines east of the prime meridian are numbered from 0° to 180°, and are called east longitude. Lines west of the prime meridian are numbered from 0° to 180° and are called west longitude. The prime meridian on American and British maps is a line through Greenwich, England.

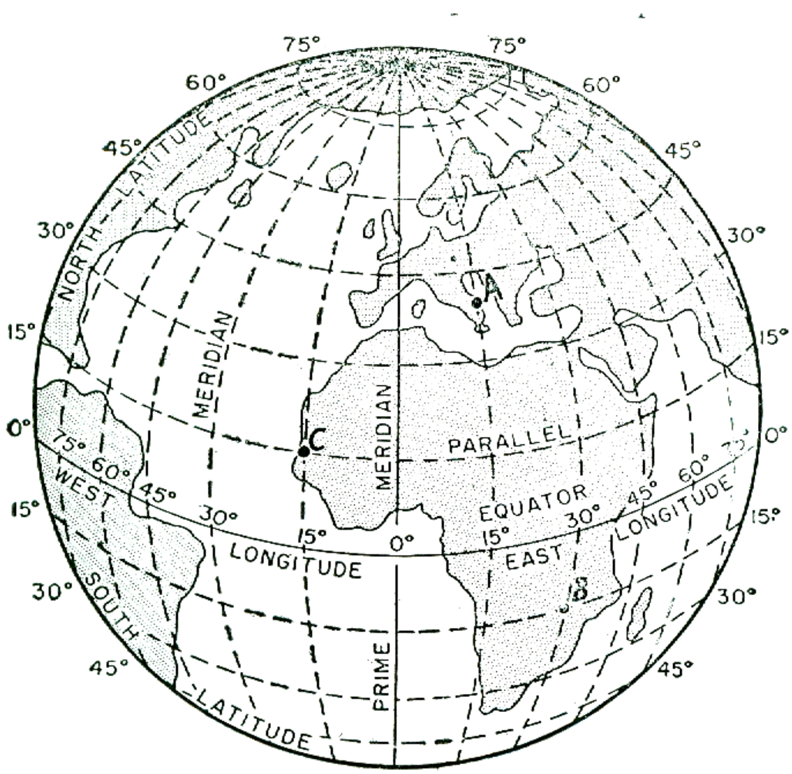


Figure 30. Geographic coordinates. Point A is latitude 40°00’00” N, longitude 15°00’00” E; point B is latitude 15°00’00” S, longitude 30°00’00”E; point C is latitude 15°00’00”, longitude 15°00’00” W.

(2) Crossing the meridians in an east-west direction between the equator and both poles are the parallels of latitude, called simply parallels. Starting at the equator, these are numbered from 0° to 90°. Thus, the parallel halfway between the equator and the North Pole is 45° north latitude.

b. Placing geographic coordinate grid on a map. (1) On most maps in common use, lines of latitude and longitude curve so little they appear to be straight lines. American military maps usually locate lines of latitude and longitude by ticks at the margins and crosses within the map. For example, in grid square (67-99) on figure 31 there is a marginal tick marked 47° 04′. Across the map horizontally to the left are three crosses. A line drawn through the tick and the crosses is parallel of latitude 47° 04′ N. Similar parallels north of this one are indicated by ticks at 1′ intervals. These ticks and crosses connected form the east-west lines of a geographic grid system.

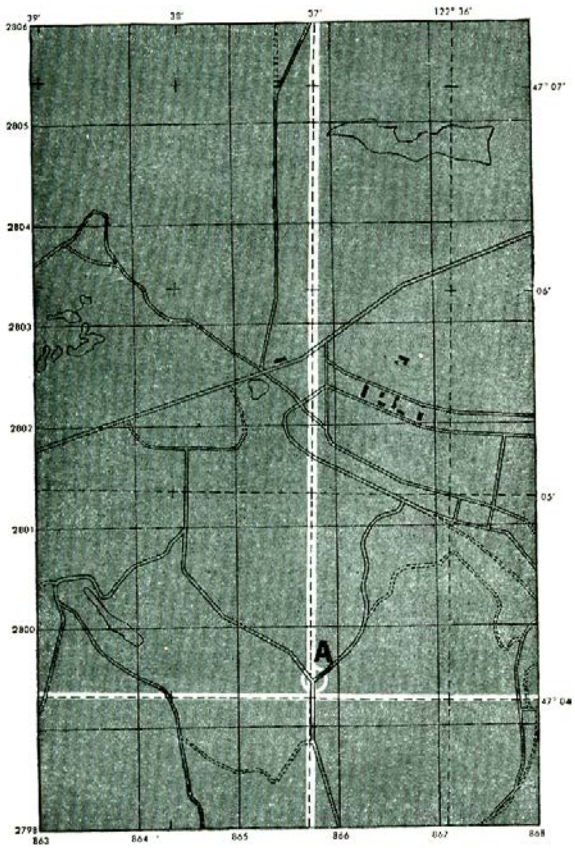


Figure 31. Lines of geographic coordinate grid plotted by connecting ticks and crosses.

Most topo maps include not only the military UTM grid, but also show the geographic coordinate tick marks (as shown here).

(2) Lines of longitude are indicated on the top margin of figure 31. In the grid square (67-05) there is a tick numbered 122° 36′ W. Vertically below this tick are four crosses and another tick at the bottom margin. The vertical line through these is a meridian of longitude 122° 36′ W. Similar meridians west of this one are indicated by ticks at 1′ intervals. If these ticks and crosses are connected, the lines formed will complete the north-south geographic grid lines.

(3) On British maps the term "graticule" is used instead of "geographic grid."

c. Writing and reading geographic coordinates. Some American and British maps have parallels and meridians printed as full lines. These are readily distinguished from grid lines by their numbering. Lines of latitude and longitude are always numbered in degrees and minutes, and, if necessary, in seconds. In locating a point by latitude and longitude, N or S represents latitude, and E or W represents longitude, for example 47° 04′ N, 122° 36′ W. The general world location of the area covered by a map is indicated by the numbers on latitude and longitude lines. If the latitude numbers increase from bottom to top on a map, the area is north of the equator; if they decrease, it is south. If the longitude numbers increase from left to right, it is east of the prime meridian; if they decrease, it is west. Applying these rules to figure 31, the area covered by the map is north of the equator and west of the prime meridian. In writing geographic coordinates, latitude is given first and parentheses are omitted. To illustrate, refer to RJ "A", grid coordinates (65.75-99.45), figure 31. The geographic coordinates of this point are: latitude 47° 04′ 05″ N, longitude 122° 37′ 00″ W.

d. To find geographic coordinates of a point. Problem: to find the geographic coordinates of point *A* on figure 32. The geographic grid interval is 1′, and since there are 60″ to a minute the sides of the grid quadrangle must be divided into 60 equal parts. To find the latitude of point *A,* the engineer scale is placed across the latitude lines so that 60 convenient divisions span the distance, position ①. Each of the 60 divisions represents 1″ of latitude. Longitude is found with the engineer scale in position ②. The complete geographic coordinates of point *A* are latitude 38° 42′ 20″ N., longitude

77° 13′ 30″ W. If the geographic grid interval is 5′, the sides of the quadrangle must be divided into 300 equal parts.

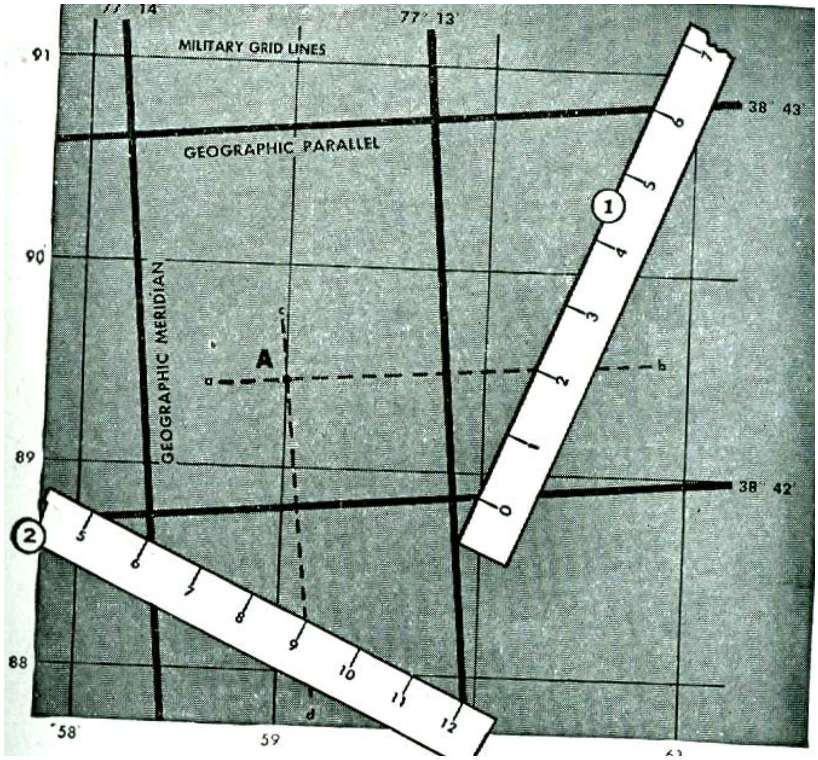


Figure 32. Engineer scale used to read geographic coordinates of a position on a map.

35. GEOGRAPHIC COORDINATES ON FOREIGN MAPS a. Prime meridian. Many foreign maps do not use the Greenwich meridian as a prime meridian. For example, French maps use the Paris meridian, and Italian maps the Rome meridian. Marginal data of foreign maps must be examined to determine the prime meridian used. Longitude measured from a foreign prime meridian may be converted to longitude with respect to Greenwich meridian by adding or subtracting the Greenwich longitude of the foreign prime meridian based on the Greenwich meridian. The following table gives the Greenwich longitude of some principal foreign prime meridians:

Greenwich longitude of foreign prime meridians
(Values used by Geodetic Section,
Army Map Service)

Meridian	Accepted Longitude (Based on Greenwich Meridian)
Paris, France	2 20' 13.95" E
Madrid, Spain	30 41' 14.55" W
Monte Mario, Rome, Italy	12° 27' 07.06" E
Batavia, Netherland East Indies	106° 48' 27.79" E
Padang, Sumatra, Netherland East Indies	1000 22' 01.42" E
Midden Meridian of South Sumatra, Netherland East Indies	1030 33' 27.79" E
Ferro, Canary Islands	17° 39' 46" E (170 40' 00" E used by Germans)
Amsterdam, Netherlands	40 53' 05.45" E
Lisbon (Observatory of Castelo de S. Jorge), Portugal	9° 07' 54.806" W
Naval Observatory at Genoa, Italy	8° 55' 15.929" E
Copenhagen, Denmark	12 34' 40.35" E
Athens, Greece	230 42' 58.5" E
Helsinki, Finland	240 57' 16.5" E
Pulkovo (near Leningrad), U.S.S.R	300 19' 38.49" E
San Fernando, Spain	6° 12' 17.43" W
Singkawang, Borneo	108° 59' 41" E
Istanbul, Turkey	280 58' 45.5" E

b. Grad. On most maps latitude and longitude are measured in degrees, minutes, and seconds, but the unit of measure on French maps is the grad. There are 400 grads in a circle as compared to 360 degrees in a circle so a grad

is $\frac{360}{400}$ or .9 of a degree. The grad is based on a decimal

system, that is:

1 grad = 100 minutes (‘)

1 minute = 100 seconds (“)

The angle 9.628 grads would be written 9º62’80”; symbols for minutes and seconds, in this system, incline from left to right.

c. Converting French geographic coordinates to standard coordinates. Using a French map the map reader locates a point, for example, latitude 39^o 71′ N, longitude 03^o 36′ W. To convert to coordinates based on the Greenwich meridian, proceed as follows:

First, grads are converted to degrees:

39^o 71′= 39.71G = (39.71 X .9) degrees = 35.7390

03^o 36′ = 03.36^o= (03.36 X .9) degrees 3.024°

Second, decimals of degrees are converted to minutes and seconds:

35.739° = 35^o 44′ 20.4″, found as follows:

$.739^o$ X 60 = 44.34′

.34′ X 60 = 20.4″

Similarly, 3.024^o = 3° 01′ 26.4″

Based on Paris meridian, the coordinates of the point are latitude 35^o 44′ 20.4″ N, longitude 3^o 01′ 26.4″ W. In this case the Paris meridian of 2° 20' 14" E must be subtracted from 3^o 01′ 26.4″, to obtain longitude based on Greenwich. Complete Greenwich coordinates are written latitude 35^o 44′ 20.4″ N, longitude 0° 41′ 12.4″ W.

36. U. S. DOMESTIC GRID SYSTEM. a. General. (1) The grid system covering the United States is called the "U. S. Domestic Grid." The country is divided into seven lettered zones, *A* through *G* (fig. 33); zones H and 7 were added when the system was expanded to form the World Polyconic Grid. Each zone extends through 9^o of longitude which includes a 1° overlap of adjacent zones ($½^o$ on each side); the net width of a zone is therefore 8°.

(2) Each zone has a different origin of coordinates. For example in figure 33, zone *A* has its origin at the intersection of central meridian 73^o W with parallel 40^o 30′ N while zone *B* has its origin at the intersection of central meridian 81° W and parallel 40°30' N. At the origin of each zone the north-south or vertical grid line (frequently called "Northing") is given an arbitrary value (frequently called "false coordinate") of 1,000,000 yards, and the east-west or horizontal grid line (frequently called "Easting") a value of 2,000,000 yards. This is done to avoid negative coordinates. A similar grid system covers Hawaii, Panama and the Phil-

ippines.

(3) The complete numerical value of the horizontal and vertical grid lines whose ends are nearest the southwest corner of the map is written in the margin on any map using this system. The last three ciphers are commonly omitted from other grid-line values shown in the margin, but occasionally where the 100- or 500-yard interval is used complete numbers are shown on all grid lines.

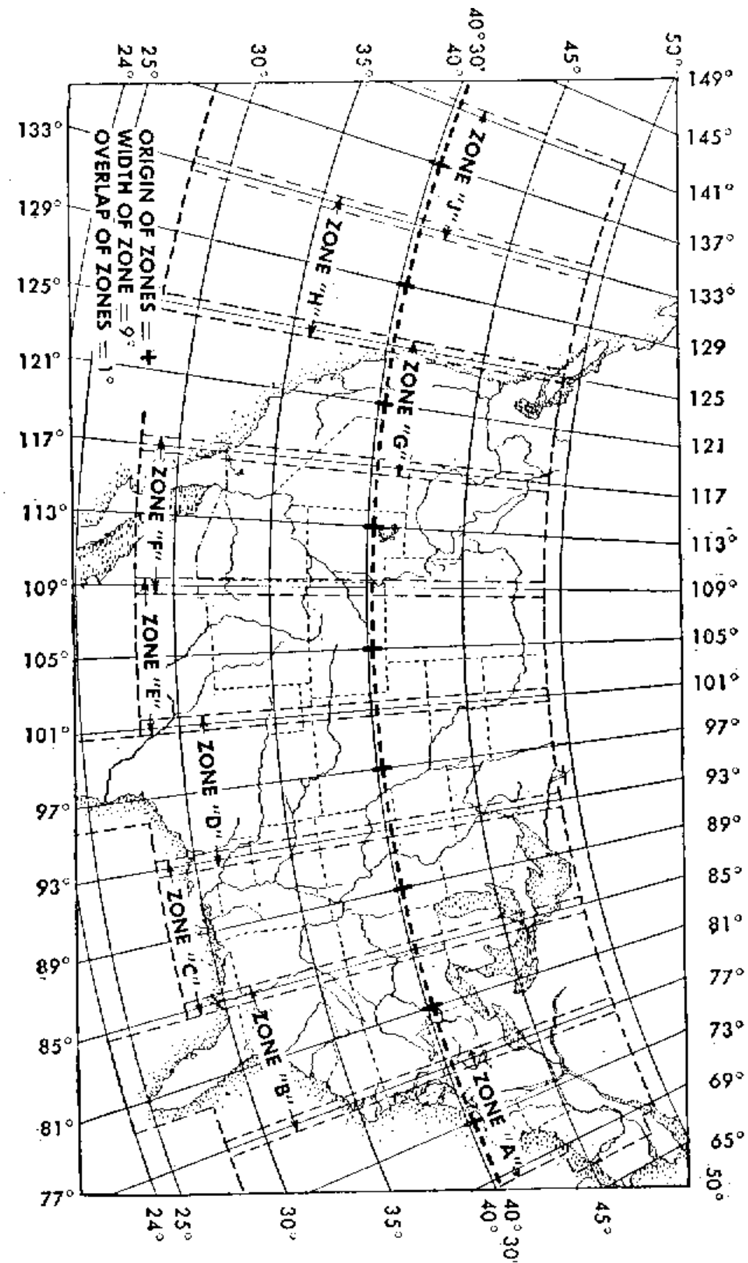


Figure 33. U. S. Domestic Grid System, extended by zones –J and H.

b. Identification. The U. S. Domestic Grid is identified by a grid note printed in the map margin. Its form is ....
THO USAND YARD GRID COMPUTED FROM "Grid System for Progressive Maps in the U. S." ZONE..........U. S. C. & G. S. SPECIAL PUBLICATION NO. 59.

Grid lines for this system are printed in black. Other American systems printed in black cover Hawaii, Panama, and the Philippines.

c. Map of area in overlap of two zones. On maps of scale 1:125,000 and larger that lie in two zones, the grid of one zone is shown in solid black lines, and the grid of the other zone is indicated by ticks 0.3 inch long along the border of the map. To use the grid of the second zone on these maps, draw in the grid lines by connecting the ticks with dotted lines as shown in figure 34.

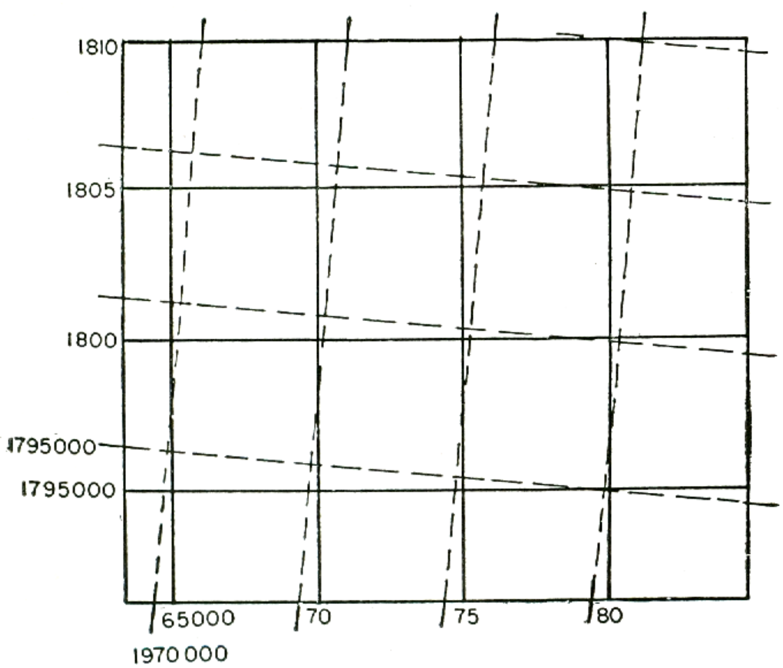


Figure 34. Grid lines on a map where two zones overlap (ticks connected by dotted lines).

d. Use. United States grid systems are used in the same general way as explained in paragraph 34. Careful attention to marginal notes on each map is essential.

37. WORLD POLYCONIC GRID. The World Polyconic Grid is an extension of the U. S. Domestic Grid System to cover parts of the world not gridded by the British and areas not previously gridded by the United States. The world is divided into five north-south divisions called "bands." Each band is made up of nine zones. The seven zones *A* to *G* in the U. S. Domestic Grid System and the extension zones *H* and 7 comprise the total width of band I, from longitude 68° 30′ W to 141° 30′ W. Band *I*, however, also takes in all the area between latitude 72° N and 72° S. Each band is divided at the equator and designated, for example, as band *I-N* for the north half and band *I-S* for the south half. Band II is west of band I and takes in the area from longitude 140° 30′ W to 146° 30′ E. Bands III, IV, and V are the next succeeding bands in a westerly direction. Each band is divided into nine standard size zones lettered from *A* to *J* in the same way as band *I*. Figure 35 shows an outline of the bands throughout the world. The blank portions are sections of the world covered by some other type of grid and for most of which gridded maps are available. World polyconic grid lines appear in purple on maps of scales smaller than 1:125,000; numbers and other pertinent detail are purple at all scales.

38. BRITISH GRID SYSTEM. a. General. Troops operating in Europe, Africa, Australia, India, China, and many islands of the South Pacific will use maps bearing British military grids. British grid systems subdivide the world into zones or belts identified by name and color, as: Northern European Zone III (Blue), Egypt Purple Belt, Egypt Red Belt, etc. Each of these grids has a specific origin and the grid lines are usually printed in the same color as the color designation of the area on maps of scales 1:250,000 and 1:500,000; thus, grid lines on maps covering the Northern European Zone III (Blue) appear in blue. The significance of color, however, no longer applies always to grid designation, but rather to grid differentiation on sheets carrying more than one system.

b. Grid squares. (1) A grid zone is ordinarily divided into squares 500,000 meters on a side. This basic square is assigned a letter, the letters being alphabetical and reading from left to right and down within a zone (fig. 36). Each 500,000-meter square is further divided into 100,000-meter squares each of which is also designated by a letter. Thus a 100,000-meter square of a zone may be identified by two letters. (See fig. 36.) However, some zones are so long that more than one 500,000-meter square is assigned the same letter, while in a few zones no letters are used.

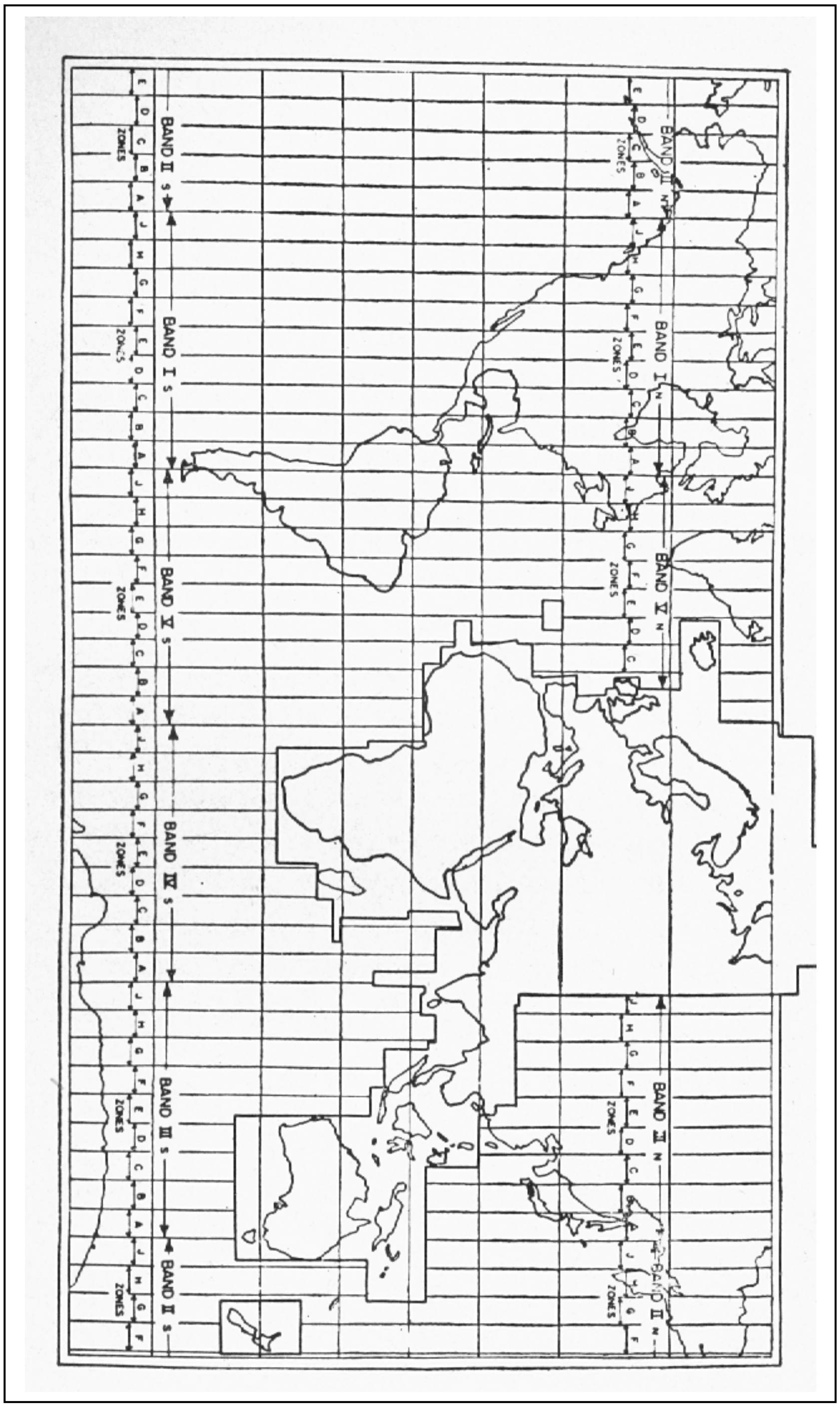


Figure 35. World Polyconic Grid System. Blank areas are covered by other grid systems.

(2) On maps of scales of 1:250,000 to 1:500,000, the letter identifying the 500,000-meter square and the 100,000-meter square letter are both shown on the face of the map. Ordinarily on maps of scales larger than 1:250,000, only the 100,000-meter square letters are shown, although the letter identifying the 500,000-meter square may be indicated by a grid index diagram in the margin.

(3) The frequency of the grid lines is controlled by the scale of the map as follows:

Scales	Interval
Larger than 1:5,000. ……………...	.100 meters (or yards)
1:5,000 to 1:100,000 inclusive.......	1,000 meters (or yards)
Smaller than 1:100,000 to 1:500.000	10.000 meters (or yards)

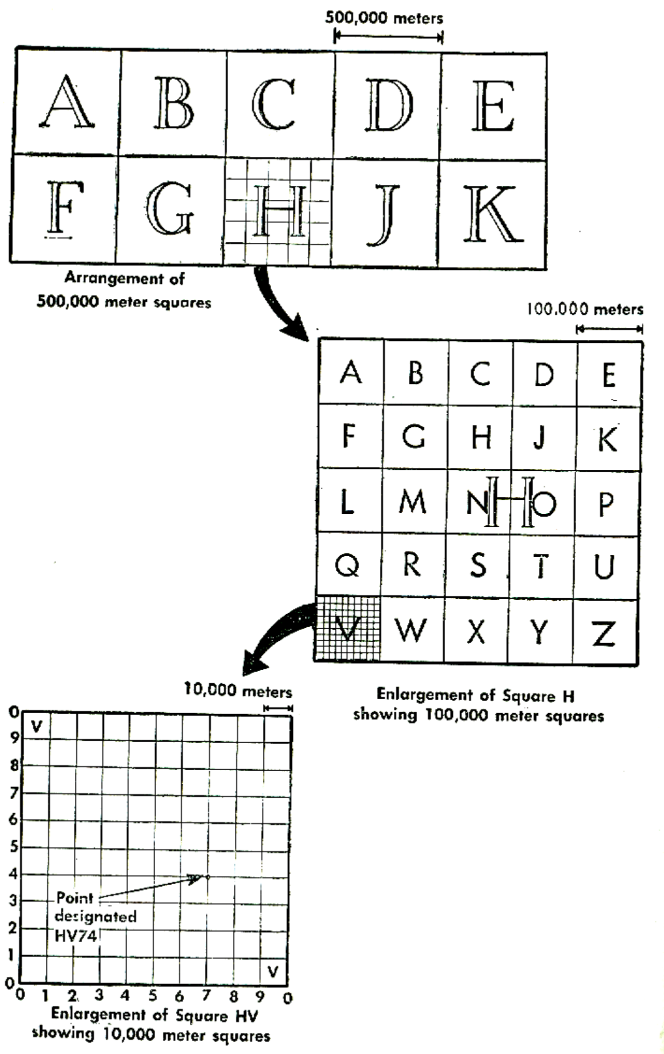


Figure 36. British Military Grid System.

c. Reading grid coordinates. Point identification by grid reference indicates, in order, the 500,000-meter square, the 100,000-meter square, the abbreviated east-west (easting) coordinate, and the abbreviated north-south (northing) coordinate. The procedure is as follows:

Maps available during Operation Desert Storm were derived from British maps drawn up after the WW I treaty that carved up the Ottoman Empire. Though modified many times in the years that followed, the “easting” and “northing” marks remained. US Soldiers generally did not know what these referred to and ignored them, but their presence on the map caused the largest battle of that war to be called “73 Easting”, the only labeled feature nearby on the map.

(1) Indicate the letter identifying the 500,000-meter square, as shown directly on the face of the map or as indicated by the grid index diagram.

(2) Indicate the 100,000-meter square as shown on the face of the map, normally by a large open block letter printed in the same color as the grid lines.

(3) Write the east-west coordinate in the same manner as with the United States military grid, omitting the small figure or figures which precede the enlarged grid number. The grid value is carried out by estimation or measurement to the minimum value desired. The hyphen or dash between "right" and "up" coordinates, always used in the United States domestic grid references, is omitted in British grid references.

(4) Write the north-south value in the same manner. The small numbers which precede the large figure at the end of the grid lines represent the total distance from the false origin of the grid coordinates and are always omitted in point designation. See figure 37 for illustration of point designation. Coordinates of Point *I* are written RY4010.

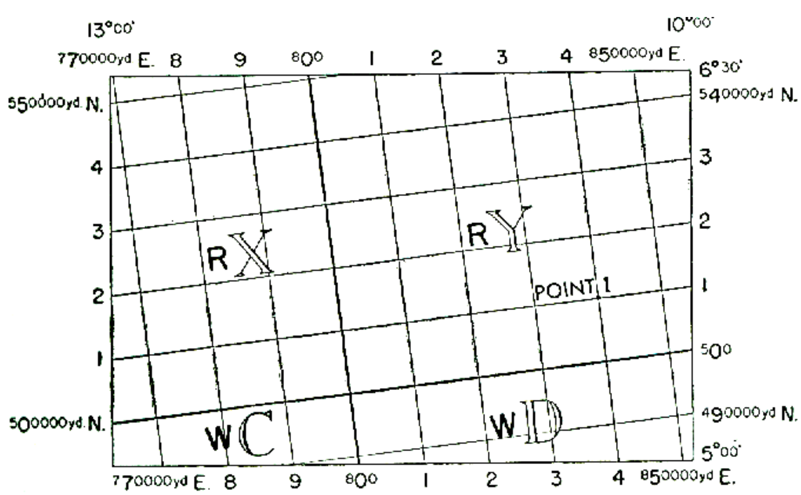


Figure 37. British Military Grid. Coordinates of point I are RY4010.

d. Marginal data. British maps and American re- productions of British maps employing the British grid systems always have full instructions for the expression of grid references somewhere in the margin. In a few British grid zones, the yard is used as a unit instead of the meter. The entire procedure in grid reference, however, is identical in either case.

39. AIR DEFENSE GRID. The Air Defense Grid is designed to satisfy the requirements of world-wide air defense and to permit easy transmission of accurate positional information. The Air Defense Grid is based entirely on lines of longitude and latitude, and divides and sub- divides all the earth's surface from latitude 80° N and 80° S in such a way as to keep the grid divisions and subdivisions approximately square. This is accomplished by changing the size of the grids in degrees and minutes of longitude several times between the equator and the poles. The only large variations in shape occur between latitudes 72° and 80° N and S where the top of the grid lines converge considerably toward the poles. Figure 38 illustrates the converging meridians and successive changes in grid lengths. Complete information on the Air Defense Grid can be found in TM 44-225.

40. FIRE-CONTROL GRID. **A** fire-control grid is a rectangular grid superimposed on a military map; on large-scale maps, the military grid serves as the fire-control grid. Grid interval is normally 1,000 yards. Fire-control grids must be accurate as to scale and azimuth. Fire-control maps are 1:25,000, but maps of. 1:50,000 or larger are considered usable substitutes. Photographs or photomaps used for fire control require the same scales as for maps. The battle maps of the United States conform to the standard military grid system of the United States. Other military maps may be provided with a standard grid for the particular theater of operations or with an arbitrary grid used for a single map or for a limited area. When an arbitrary grid is used, it is generally established on the spot by the firing unit on the basis of the best data available, whether that be by sound or visual survey. For example, the grid may originate as a division grid and be extended for corps control. When data become available, however, the standard military grid is

substituted for the arbitrary division or corps grid. Use of the fire-control grid is covered in TM 44-225.

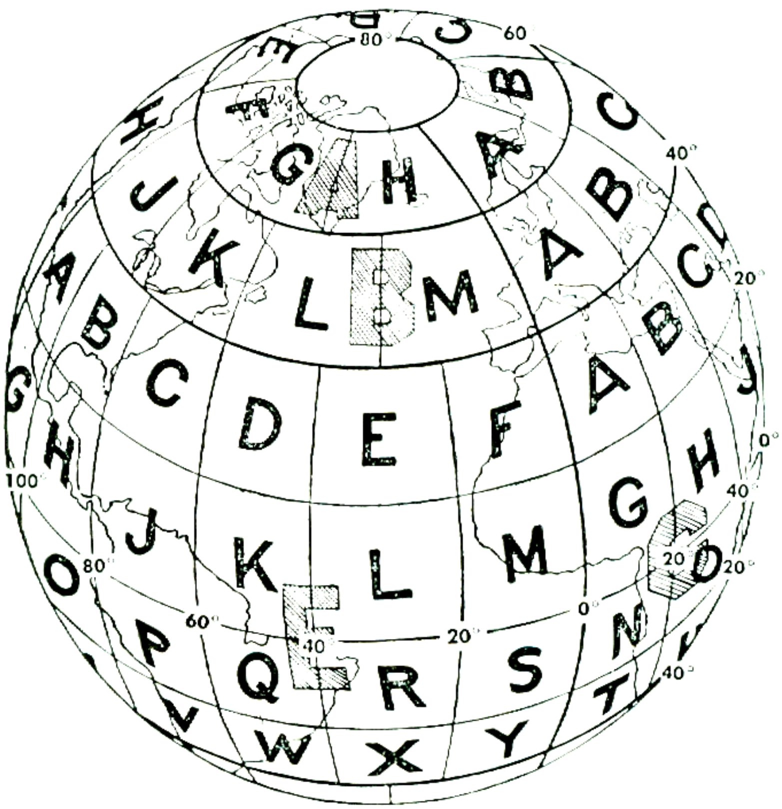


Figure 38. Air Defense Grid covers the world. Spherical presentation of first and second divisions.

41. POINT-DESIGNATION GRID. The point-designation grid is an arbitrary grid printed on aerial photographs. It is explained in paragraph 69.

SECTION VII

ELEVATION AND RELIEF

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42. GENERAL. a. Most of the earth's geographic features are the result of erosion, the wearing away by freezing, thawing, and draining of water from high to low ground. Relief is the variations in the elevations or heights of these features, such as ridges and valleys, hills and hollows, which divide terrain into two interlocking systems. Small streams join to form larger streams, and these join to make rivers, the whole net- work of water courses being known as a *drainage system.* Between the streams is high ground, the noses and hills of which form a system of their own called *ridge lines.* Points of abrupt change in elevation or important change in direction of ridges or streams are called *critical points.*

b. Ground forms, then, must be measured vertically as well as horizontally. The vertical distance is called elevation and is usually measured in feet or meters above mean sea level *(plus* elevation) or below sea level *(minus* elevation). (See **FM 21-25**.)

c. There are three main systems by which maps show the rise and fall of the earth's surface. In order of their importance, these methods are *contours, hachures,* and the *layer-tint system.* Other methods include approximate contours, form lines, or hill shading.

43. CONTOURS. a. General. *Contour lines* are drawn on maps to represent ground elevations. Each contour line passes through points which are *exactly* the *same height* above sea level. See **FM 21-25** for a discussion of contours. Contours have certain characteristics. Contours—

(1) Are smooth curves.

(2) Are approximately V-shaped in narrow valleys with the "V" pointing upstream.

(3) Are generally shaped as "U's" pointing down ridges.

(4) Are shaped as an "M" just above stream junctions.

(5) Tend to parallel streams.

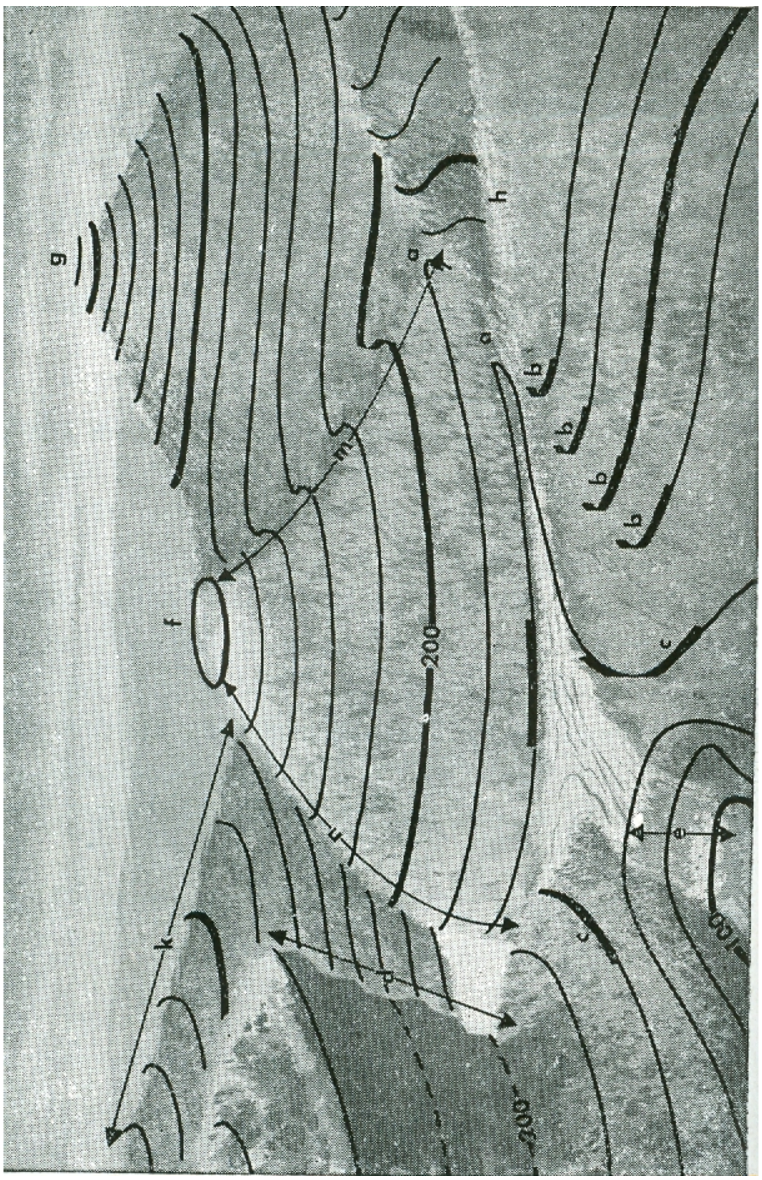
(6) Tend to parallel each other, each approximating the

shape of the ones above and below it. This reflects
the fact that changes in ground form are usually gradual.

(7) Never cross or touch, except at overhanging **or** vertical cliffs and at waterfalls.

(8) Never fork.

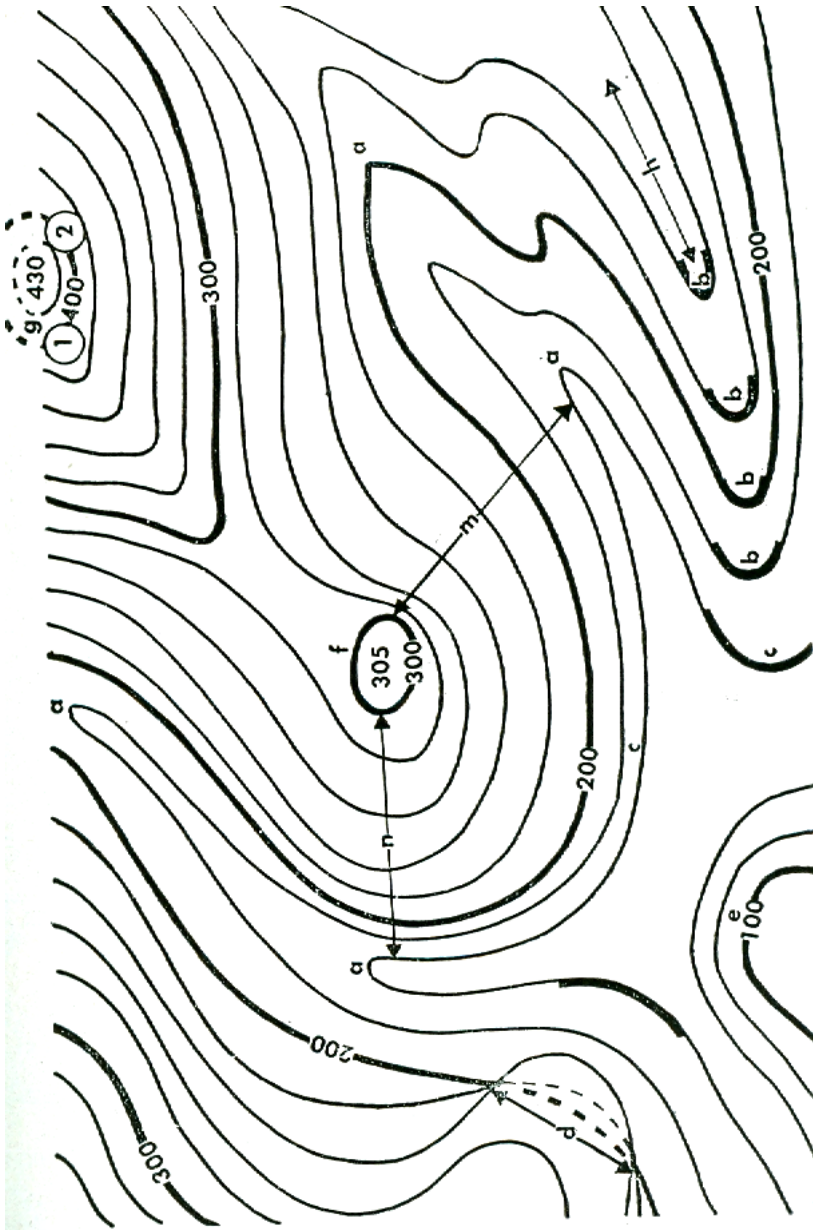
(9) Always close, *on* or *off* the map as indicated at "f," hill 305, and "g," hill 430 in figure 39 ①. The contour 400 leaves the map at ② and returns to map at ①.



① *Perspective view with schematic position of contours.*

Figure 39.

b. Depth curves. A contour showing points of equal elevation *below* the level of any body of water is called a depth curve. These curves indicate depths below a certain point, usually mean-low-water level for the body of water concerned. The vertical interval is frequently expressed in fathoms. One fathom is 6 feet.



② *Contour map of area shown above.*

Figure 39. – Continued.

44. HACHURES (fig. 40). The hachure method of re- presenting relief is used on the Strategic Map of the United States (scale 1:500,000) when relief data are inadequate to draw contours, and is frequently found on large- as well as small-scale foreign maps. Hachures are short parallel or slightly divergent lines drawn in the direction of slopes. They are closely spaced on steep slopes, wide apart on gentle slopes, and converge toward the tops of ridges and hills.

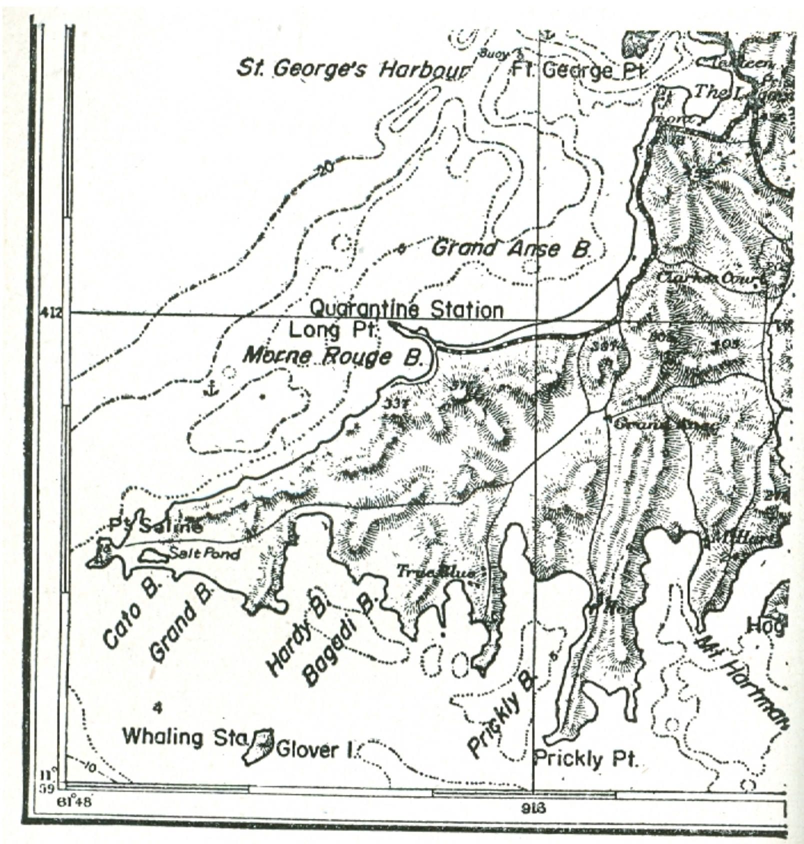
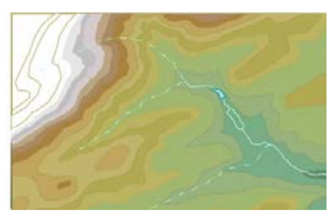


Figure 40. Hachure map.



Layer-tint of maneuver area at Fort Indiantown Gap.

45. LAYER-TINT SYSTEM. In addition to contours and hachures, relief is shown on some maps by the layer- tint system, used by the Army on aerial navigation charts. It is also used on the 1:1,000,000 International Map of the World (IMW). Different colors or different tones of the same color show different zones of elevation. Each zone is bounded by contours, usually shown on the map; contours within the zones are sometimes shown. The map margin carries a key showing the elevation of zones according to color.

46. RIDGE AND STREAM LINES. a. Purpose. To emphasize high and low ground, a system known as ridge lining and stream lining is often used. On ridge-lined or stream-lined maps or aerial photographs, the map reader neglects the great mass of detail to study key features. Three steps are followed in this process.

b. Stream lines. Study the map or aerial photograph and select the main streams and their tributaries. Draw over them in blue; this makes the drainage system stand out. In figure 41, the streams are marked with solid lines.

c. Ridge lines. Between the streams there must be higher ground or ridges. To emphasize this, draw lines on the map along the main ridges. These should be in brown so as not to obscure underlying features. Then select the minor ridges and trace their ridge lines. The number of minor ridges to be included depends on the emphasis desired. Do not carry the ridge lines all the way to the streams. Stop at the beginning of the flood plain as shown by the increase in space between con- tours. Ridge lines join in a systematic branching structure. In figure 41, ridge lines are marked with dotted lines.

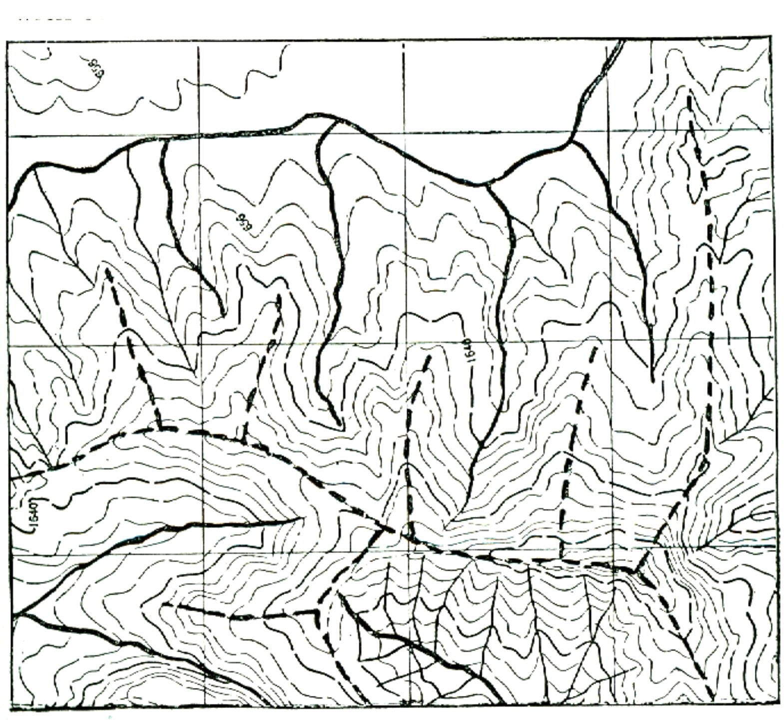


Figure 41. Contoured map with stream- and ridge-lines.

47. SLOPES. a. General. A slope is an inclined ground surface that forms an angle with the horizontal plane. The *degree of inclination* is also called slope. A knowledge of slope is important in selecting routes for the movement of units, in siting CP's and OP's and in choosing good fields of fire and areas defiladed from enemy fire. The trained map reader can visualize the slope of the ground by referring to contour lines on the map.

Slope or grade can be measured accurately at any given point with a simple surveyor's tool called an Abney level, a plumb gadget that hasn't evolved much since the Roman engineers used it. However, it is only good for one location, while we are more interested in longer grades. Hence this section.

b. Types (fig. 42). There are three types of slopes: *uniform, concave,* and *convex.*

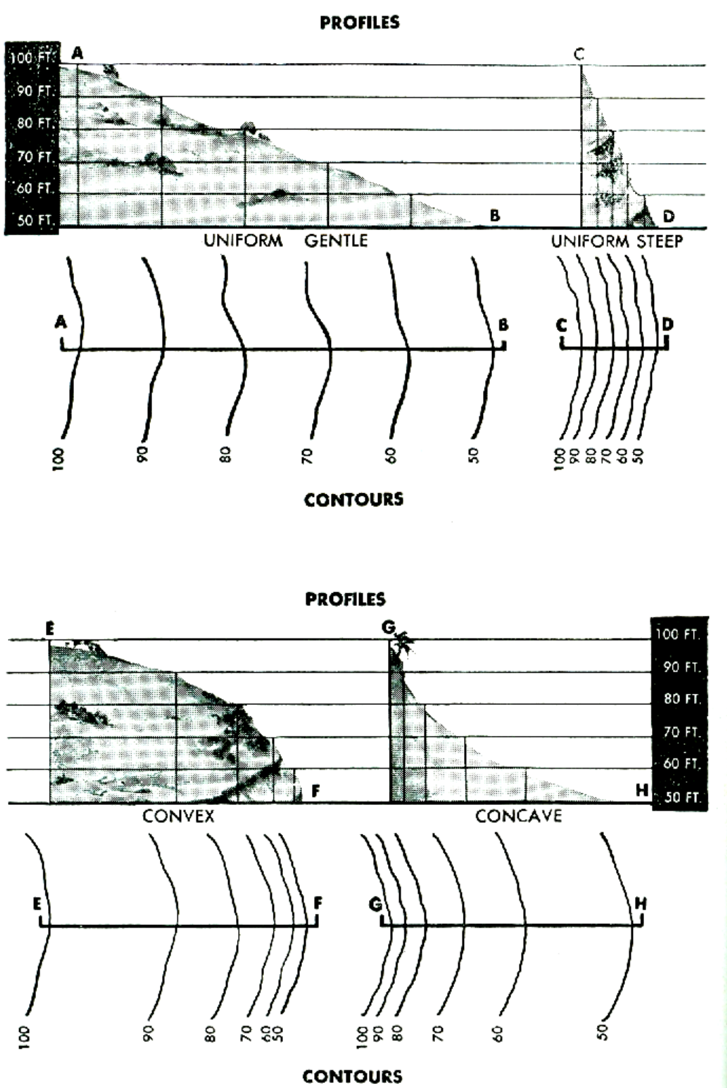


Figure 42. Types of slopes revealed by contour lines.

(1) *Uniform slope.* A uniform slope is a smooth slope with equally spaced contours. On a steep, uniform slope

the contours are equally and closely spaced; on a gentle, uniform slope the contours are equally spaced but far apart.

(2) *Concave slope.* This slope is caved-in; contours are close together at the top and far apart at the bottom.

(3) *Convex slope.* This slope is humped up; contours are spaced far apart at the top of the slope and close together at the bottom.

c. Slope in percent. The most common way to ex- press slope is in percent. A 1% slope rises or descends 1 unit in a horizontal distance of 100 units; a slope of 10% rises or descends 10 feet in a 100 feet. Thus, in figure 43, line *XY* represents a slope. If the horizontal distance from *X* to *Y* is 100 feet and the vertical distance at *Y* is 10 feet, the slope of $XY = \frac{10}{100}$ or .1. To change .1 to percent multiply by 100 = 10%. Thus the formula for slope in percent is:

$$\frac{\text{Vertical distance}}{\text{Horizontal distance}} \times 100 = \text{slope in percent}$$

The horizontal distance is scaled from the face of a map; the vertical distance is the difference in elevation of the two points and may be interpolated from a contour map. A rising slope is plus and a descending slope is minus; that is, the slope from *X to Y* is + 10%, but from *Y* to *X* is - 10%. For example, in figure 44, the problem is to find the slope between *A* and *B*. First measure the horizontal distance, 220 feet. Determine the vertical distance by subtracting the elevation of *X* from *B.* The rise is 559 minus 530 or 29 feet. The slope is:

$$\frac{29}{220} \times 100 = +13.2\%$$

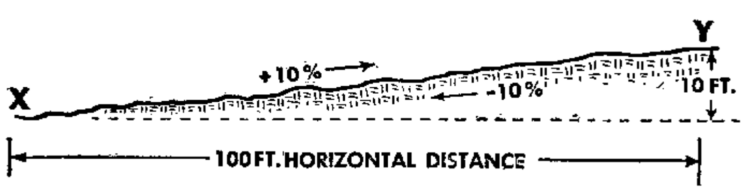


Figure 43. Expression of slope.

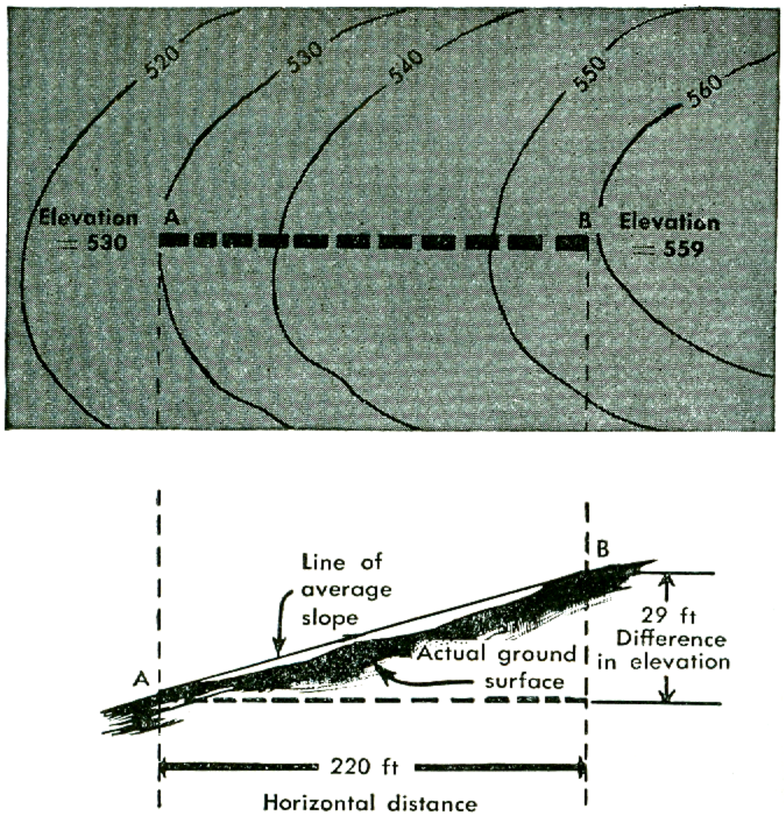


Fig 44. Slope interpreted from contour map.

d. Slope in mils. The value of a slope in mils (par. 16) is the angle in mils between the horizontal plane and the inclined ground surface. For slopes up to 350 mils the following approximate formula is used:

$$\frac{\text{Vertical distance}}{\text{Horizontal distance}} \times 1{,}000 = \text{slope in mils}$$

For example, in figure 45 ① the vertical distance (difference in elevation) is 268 units and the horizontal distance is 1,000 units. The slope is $\frac{268 \times 1{,}000}{1{,}000}$ = 268 mils.

In figure 45 ②, the slope is 100 mils.

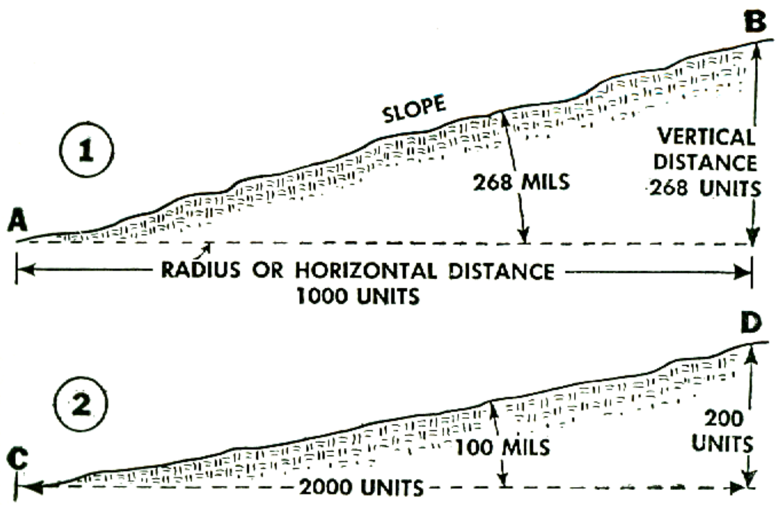


Figure 45. Slope expressed in mils.

Figure 45. Slope expressed in mils.

e. Slope in degrees. Many instruments for measuring slope are graduated in degrees. A degree is a unit of angular measurement. It is the angle subtended by an arc of 1 unit on a radius of 57.3 units. The value of a slope in degrees is the angle in degrees between the horizontal plane and the inclined ground surface. The vertical distance is not exactly equal to the distance along the arc, but for slopes up to 200 the variations are negligible and may be disregarded. The formula for slope in degrees is:

$$\frac{\text{Vertical distance}}{\text{Horizontal distance}} \times 57.3 = \text{slope in degrees}$$

For example, in figure 46 ①, the vertical distance is 16 units and the horizontal distance is 76.4 units. Slope in degrees is:

$$\frac{16}{76.4} \times 57.3 = 12^{o}$$

In figure 46 ② the slope in degrees is:

$$\frac{16 \times 57.3}{114.6} = 7.5^{o}$$

f. Grade. The elevation of the surface of roads and railroad lines is referred to as grade. The *degree of inclination* as compared with the horizontal is also called grade; it is usually given as percent slope and is calculated as described in c above.

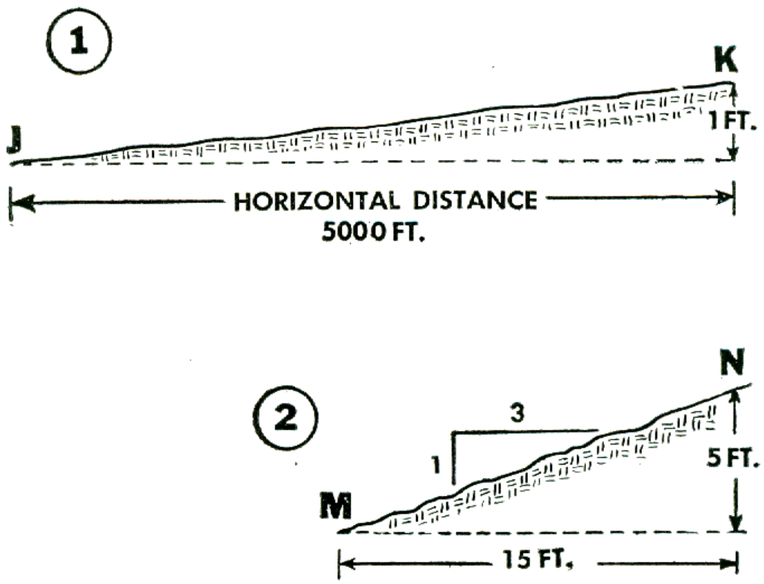


Fig 47. Slope expressed as gradient.

g. Gradient. The *rate of inclination* from the horizontal is called gradient. It is expressed either as the ratio of vertical to horizontal or horizontal to vertical distance. Hydraulic gradient is usually expressed as:

$$\frac{\text{Vertical}}{\text{Horizontal}}$$

For example, a stream in figure 47 ↑ has a vertical fall of 1 foot in a horizontal distance of 5,000 feet and has a

gradient of 1 to 5,000 sometimes written as $\frac{1}{5{,}000}$

1:5,000, or 1 in 5,000. The side slopes of earth fills or excavations are usually expressed as:

$$\frac{\text{Vertical}}{\text{Horizontal}}$$

For example, the face of an earth fill in figure 47 ① rises 5 feet in a horizontal distance of 15 feet. Its slope usually is expressed as 3 to 1, 3:1, or 3/1. To avoid misunderstanding when expressing slopes by rates, it is advisable always to state whether the slope is expressed as vertical over horizontal or horizontal over vertical. A convenient method of showing this graphically is illustrated by the small triangle on the sloped line in figure 47 ②

h. Conversion of slope expression units. Relations between angle of slope in degrees, percent slope, and slope ratio are shown in figure 48.

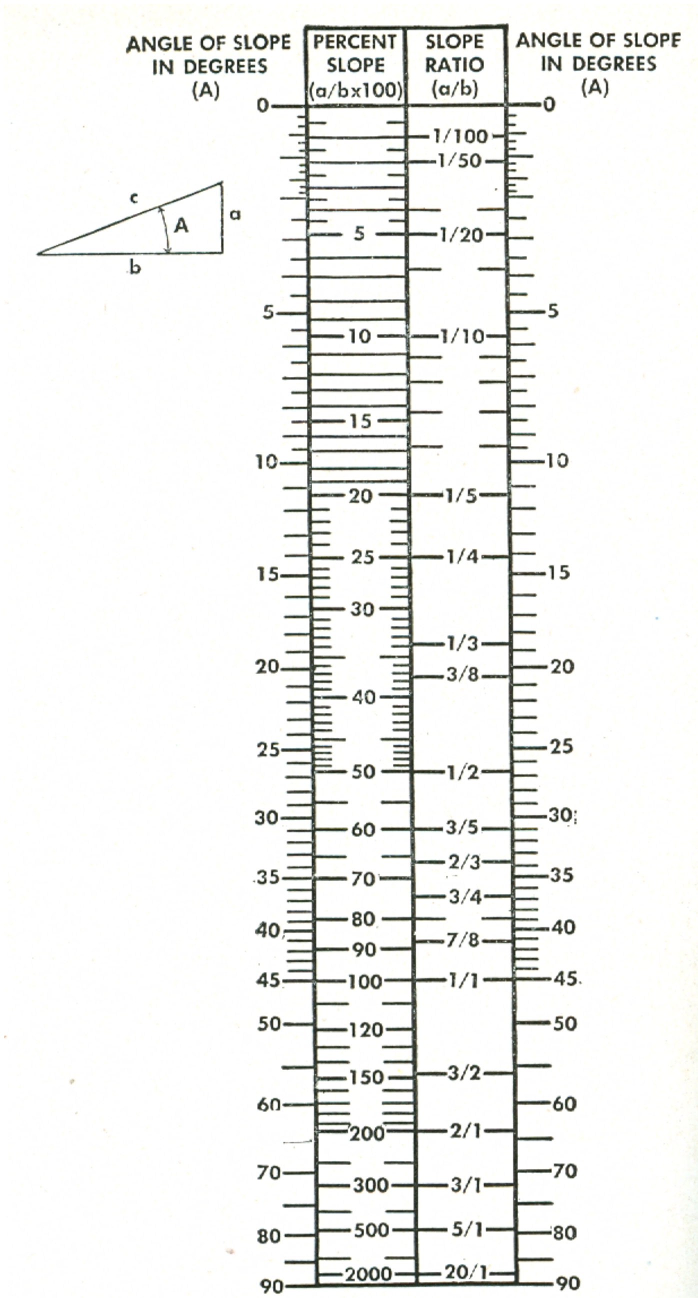


Fig 48. Conversion of slope expression units.

48. PROFILE. a. General. The most satisfactory way to study slopes shown on maps is to make a profile. A profile is an exaggerated cross section of the earth's surface. For example in figure 49 ① imagine a bayonet passed through the earth between points *A* and *B* and the front half of the hills and ridges removed. The outline of the surface of the remaining half is its profile as represented in figure 49 ②.

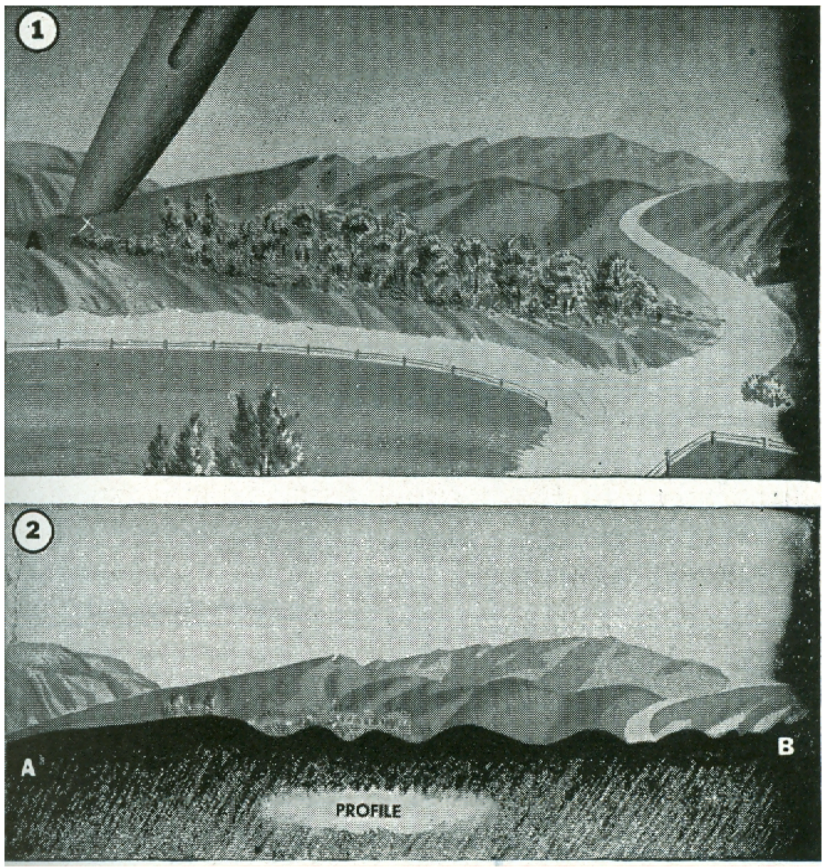


Fig 49. Explanation of profile.

b. To draw a profile. Figure 50 ① represents a portion of a contoured map. To construct a profile of the ground between points *A* and *B,* proceed as follows:

(1) Connect points *A* and *B* by a straight line and assume that a vertical plane is passed through this line.

(2) Take a piece of paper which has parallel horizontal lines equally spaced; cut or fold paper along one of these lines.

(3) Refer to map and determine highest and lowest elevation along the line *AB;* number the lines on the paper to correspond with the elevations, beginning with the highest elevation at the top of the paper as shown in figure 50 ②.

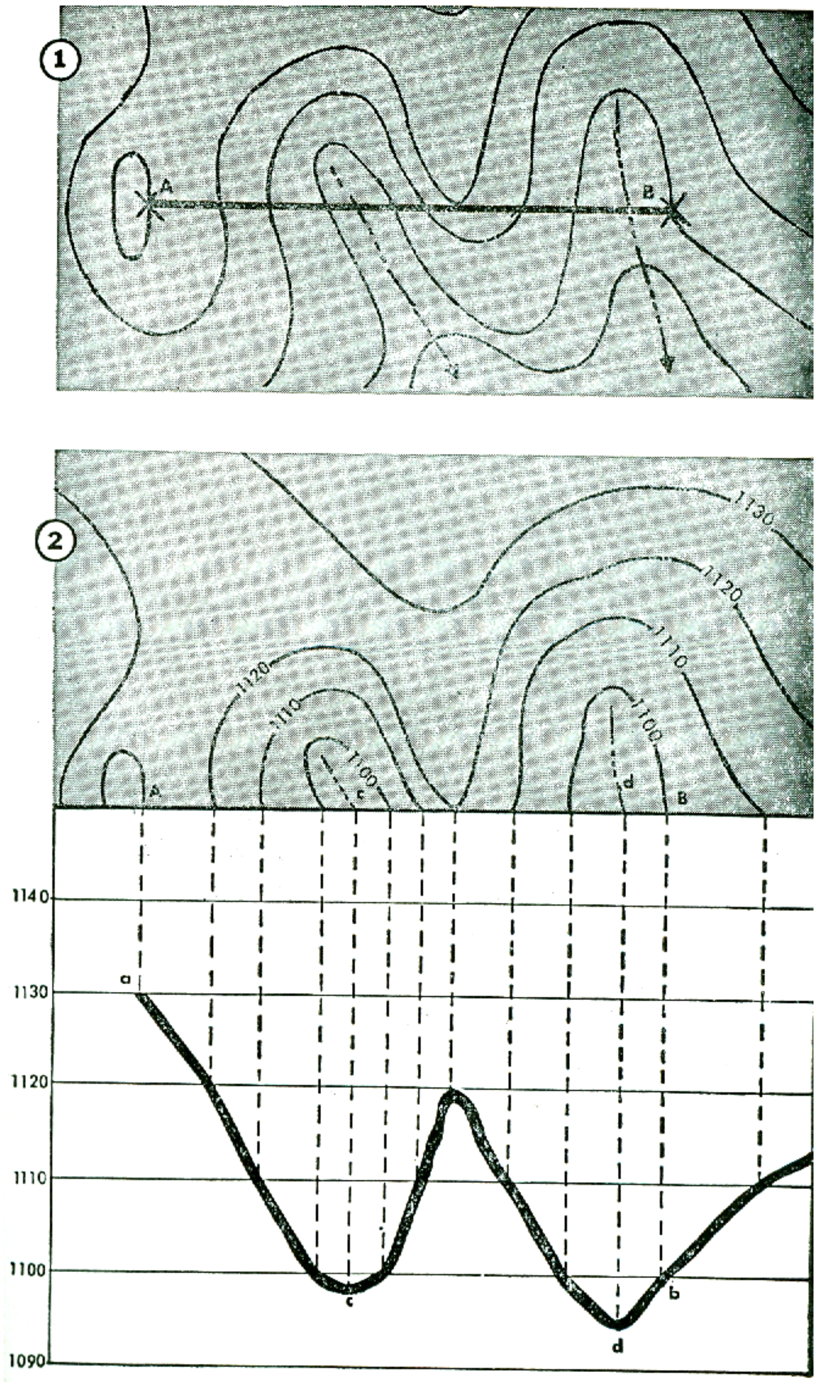


Figure 50. Constructing a profile.

(4) Place top edge of the paper along the line *AB,* and where the edge cuts each contour, drop perpendiculars to the horizontal line on the paper corresponding to the elevation of the contour.

(5) On the paper, connect points of intersection of the perpendiculars and the elevation lines by means of a smooth curved line. The profile is now complete.

(6) Elevations of intermediate areas such as valleys *c* and *d* in figure 50 ① are determined by estimation between adjacent contours of the same elevation.

(7) Where a line crosses a crest or a depression, an elevation is sometimes given on the map; this assists in completing the profile. Where such elevation numbers are missing, interpolate necessary elevations from the spacing of the contours.

(8) To make a profile of a winding line such as a road or trench, divide it into a series of approximately straight sections and plot as above; turn the paper at each angle to make a continuous profile.

c. Vertical scale. The horizontal scale of a profile is ordinarily the same as that of the map while the vertical scale is considerably exaggerated, as shown in figure 50 ②. In the figure, the lines represent 10-foot vertical intervals; for easier interpretation they could represent 5-foot intervals, thus further exaggerating the profile.

49. VISIBILITY. a. General. One of the important uses of maps for military purposes is to determine whether a point, a route of travel, or an area is visible from a given point or position.

b. Defilade. When two points are visible one from the other, they are *intervisible.* If there is a feature between them higher than both, such as a hump in slope, vegetation, or man-made works, they are in *sight-defilade.* A feature that interferes with visibility between points is called a *mask.* The term *height of mask* is the height of the feature above the line of sight between two points. In figure 51, points *B* and C are *intervisible;* points *B* and *A* are *sight defiladed, A* cannot be seen from *B;* point C is the *mask* between points *B* and *A* and the ground between *C* and *A* is defiladed from *B;* the "height of mask" *M* is the height of point *C* above the line of sight from *B* to *A*. Other terms like topo-graphical crest (the top of a hill), military crest (the highest part of the hill from which all of the valley can be observed), and defilade *D* are shown in figure 51.

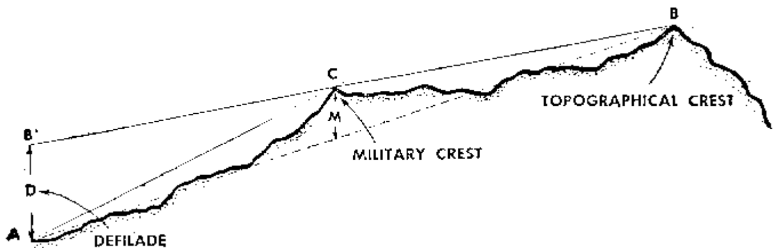


Figure 51. Defilade diagram.

c. Determination. (1) *By inspection.* To determine visibility from a map the following points are helpful:

(a) Points on opposite sides of a valley and well above intervening ground are *intervisible.*

(b) Two points separated by a feature higher than both are *not intervisible.*

(c) If two points are separated by a feature higher than one of the points, the points *may or may not be intervisible.*

(d) If the slope of the ground between the two points is convex, they are *not intervisible.*

(e) If the slope of the ground between the two points is concave, they are *probably intervisible.*

(f) When the ground between the two points is level, intervisibility depends on the vegetation and works of man.

(2) *By profile.* To determine by profile whether **or** not *B* is visible from *A*, proceed as follows:

(a) Construct profile as described in paragraph 48b and as shown in figure 52 ① and ②.

(b) In figure 52 ①, draw a line from a to the crest of *c* and thence to *h.* That portion of the ground between *c* and *h,* including *b,* is not visible from *a.* In the figure this area has been shaded.

(c) In the above example, points *a* and *b* were both at ground level. To determine whether a man at *a,* eyes 5 feet above the ground, could see a truck 8 feet high at *b,* it would be necessary to plot *a* in the profile with an elevation of 1,135 feet and *b* with an elevation of 1,108 feet. The map reader, however, is seldom concerned with the eye level of a man in a standing position, since observers in combat operations observe from as near the ground as possible.

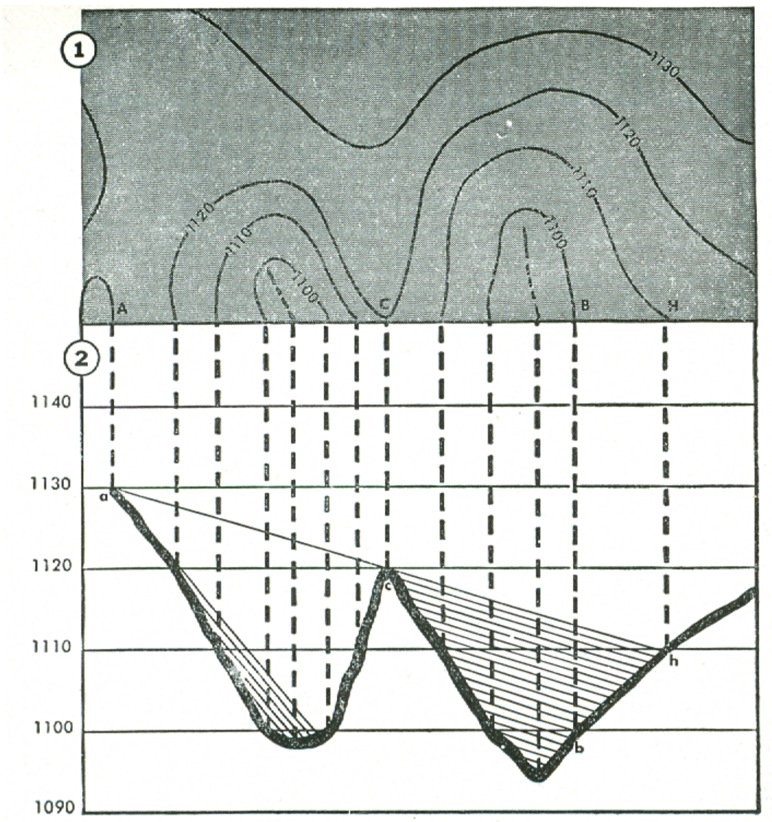


Figure 52. Determining visibility by profile method.

(3) *By hasty profile.* Many times it is necessary to make *a hasty profile* to determine whether a point can be observed from a particular location. Figure 53 shows a hasty profile. The problem is to determine if point *P* can be seen from point *A*. For a hasty profile, only the points that may mask the line of sight are plotted. These points are *B*', *C*', *D*', *E*', and *F*'. Plot *A*' and draw the lines of sight *A*'*B*' and *A*' *F*'. It is clear that the RJ at *P* cannot be seen from *A;* it is masked by the ridge at *F*.

d. Defiladed areas. Defiladed areas may be located by a map and a series of profiles. With an OP or gun position located on the map, draw a line in the principal direction of observation and call this the line *XY;* then lay off other

This is essential information for planning the deliberate defense of terrain. Never allow the enemy to find a place to go out of sight and plot mischief.

lines radiating from the OP at 100 intervals. Thus in figure 54 ② from observation post *X*, the lines of sight are *XY*, *XY2*, and *X.Y3*, Figure 54 ① shows the profiles of these lines of sight. These profiles show defiladed areas at *ab*, *a2b2*, *a3b3*, *cd*, *c2d2*, *c3f3*, *ef*, and *e2f2*. Project these points from the profiles on to the map along lines *XY*, *XY2*, and *XY3*, connect them, and shade them in as shown in figure 54 ③. These areas cannot be seen from *X*.

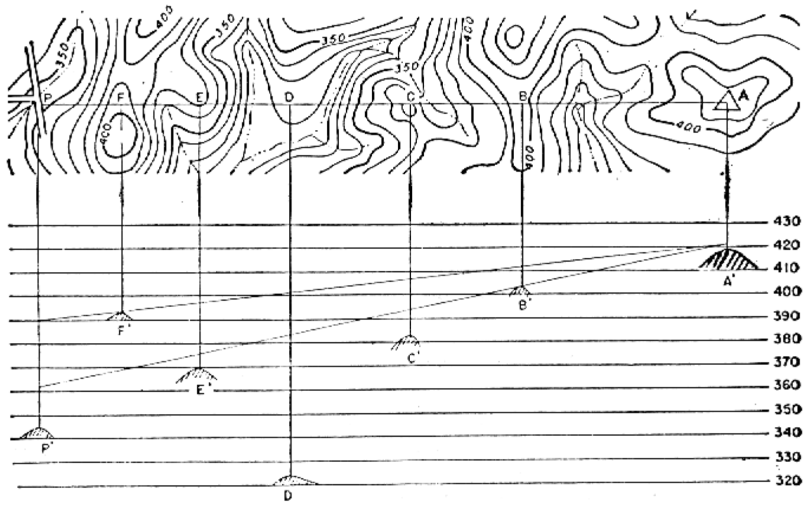
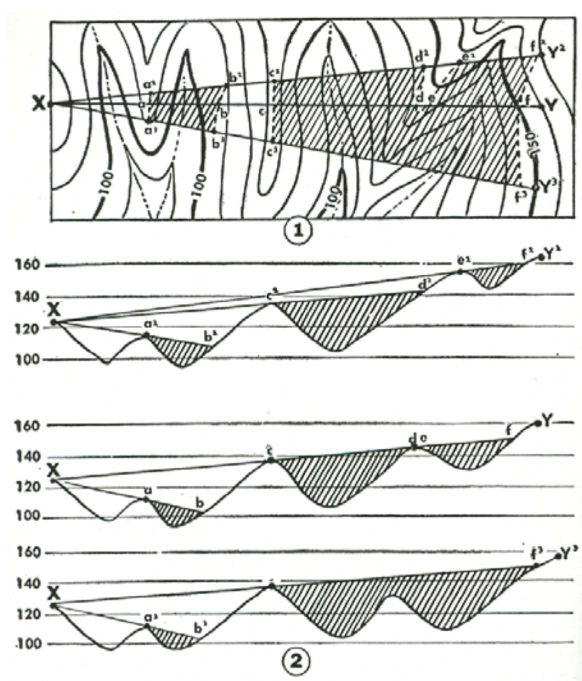


Figure 53. Determining visibility by hasty profile method.

e. Floating line. Paragraph 79 explains a way to determine intervisibility by a "floating line" on aerial photographic stereopairs.



① Contour map showing defiladed areas.
② Defiladed areas shown in three profiles.
Figure 54.

SECTION VIII

ORIENTATION

50. GENERAL. **FM 21-25** covers the most frequently used methods of orienting a map. In addition, this chapter gives further data on orientation and on location of points by resection and intersection.

51. EXPEDIENT METHODS OF DETERMINING TRUE NORTH. a. Finding compass declination (fig. 55). To find the declination of a compass, take a magnetic azimuth of the sun, a planet, or a bright star at its rising and setting on one day or at its setting one day and its rising the next. Add these two azimuths and take one-half the difference between their sum and 360°. If the sum is less than 360°, the declination of your compass is east; if the sum is greater than 360°, the declination is west. For example, in figure 55:

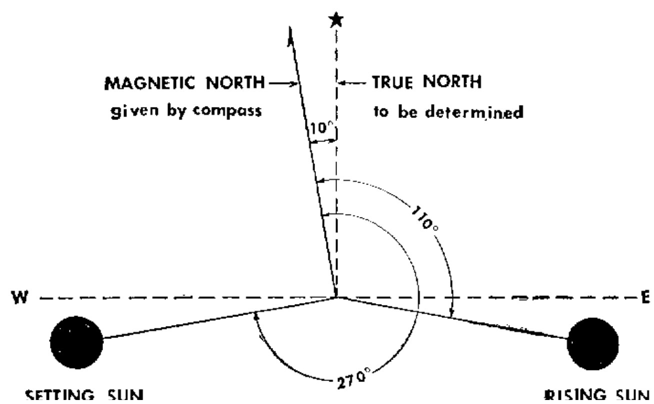


Figure 55. Determining north by rising and setting of sun.

Magnetic azimuth of rising sun ..... 110°
Magnetic azimuth of setting sun..... .270°

The sum .... 380°
The difference between this sum (380°) and 360° is .... 20°
Take half of this difference, which is .... 10°

Magnetic declination is 10° and it is a west declination because the sum of the azimuths is greater than 360°. Compass readings should be taken when the celestial body is just above the horizon or at a gradient of zero. If this cannot be done, obtain both the rising and setting reading at the same gradient. The gradient may be determined by a clinometer. When a star is used, choose one which rises nearly east of the point of observation. Points from which observations are taken must be within 10 miles of each other.

b. Sun and plumb line method. In the north temperate zone, true north can be found by the following method. On level ground, lean a pole in the general direction of north as shown in figure 56. Suspend a weight from the end of the pole so it nearly touches the ground. Drive a peg *a* in the ground under the weight. About one hour before noon, attach a piece of string to the peg, and attach a sharpened stick to the other end of the string. The length of the string *ab* is the distance from the peg *a* under the weight to the shadow of the tip of the pole *b.* Drive a peg under the shadow of the tip of the pole at *b;* with the sharpened stick, draw an arc *bcd* on the ground. About 1 hour after noon the shadow of the tip of the pole will again cross the arc at *d.* Drive a peg at this point and tie a string between the two pegs *bd* on the arc. Drive a peg at *e* halfway between *b* and *d* or divide the arc *bed* into two equal parts at *f.* For practical purposes, true north is in the direction of the line *aef.* In the south temperate zone the same procedure is used but the line *aef* points south.

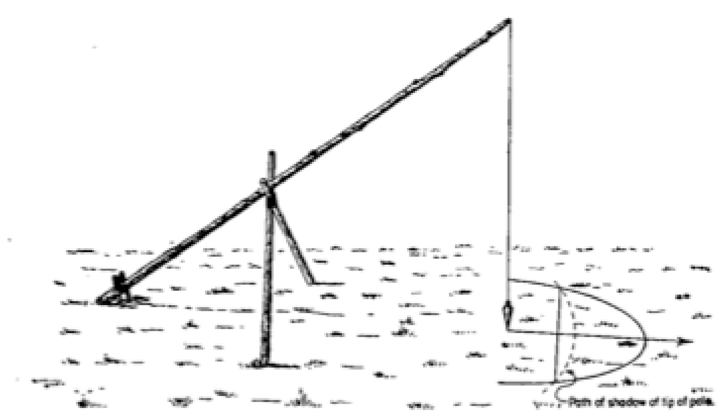


Figure 56. Determining north by sun and plumb line.

52. LOCATION OF DISTANT POINT BY INTERSECTION. a. With compass and protractor. Distant or inaccessible objects can be located on a map by intersecting lines from two points of known position. For example, to find the enemy gun position shown in figure 57 ①, compass readings are taken

from CR 685 and RJ 573. The readings of 46° and 333° are converted to grid azimuth and plotted on the map with a protractor. The intersection of the plotted lines marks the location of the enemy's piece, as shown in figure 57 ②.

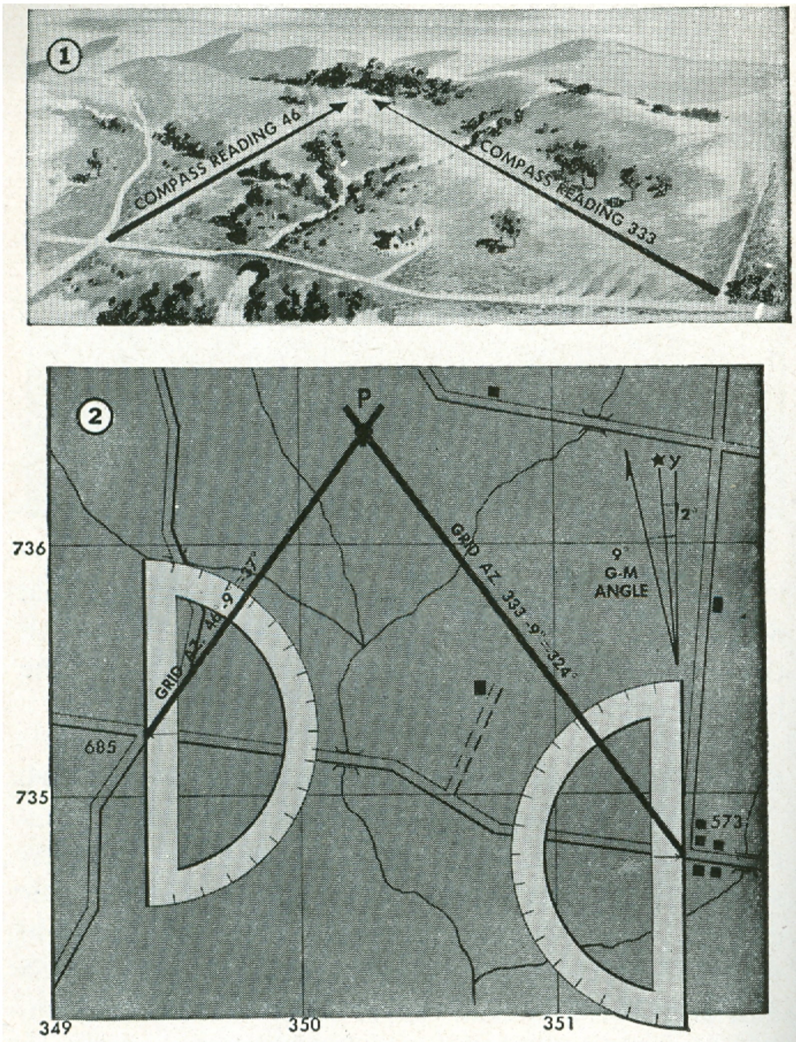


Figure 57 Distant point located on map by intersection, using compass and protractor.

This is commonly called "tri-angulation."

b. Graphic method. The gun can also be located graphically, as shown in figure 58. AT RJ 573, the observer orients his map by compass or by inspection, levels it, and places a pin in the map position of RJ 573. He places a straightedge against the pin, sights along it to the enemy position, and then draws a line on the map through the position. He moves to CR 685, orients and levels the map, and draws a similar line from CR 685. The intersection of the two lines locates the enemy position on the map.

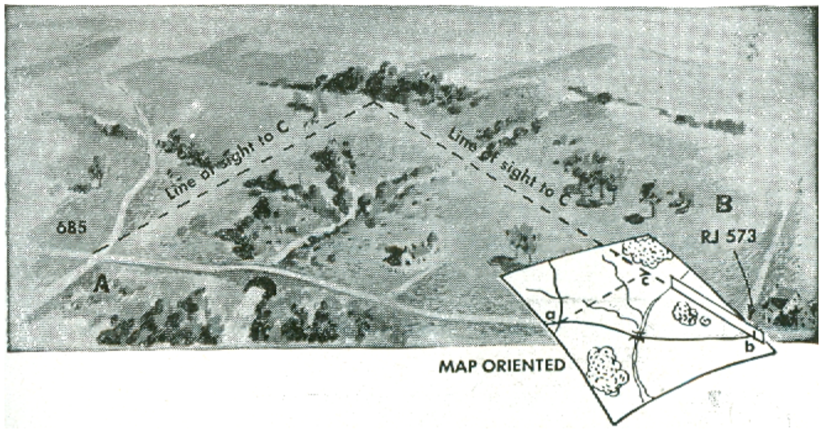


Figure 58. Distant point located on map by intersection (graphic method).

53. RESECTION. Resection is a method to locate one's own position on the map.

a. Resection with compass. In figure 59 ①, the problem is for the men in the forward OP to locate themselves on the map in figure 59 ②. Compass readings are taken from the OP to RJ 171 (323°) and to CR 162 (34°), which can be identified and located on the map. To plot this on the map the compass readings must be converted to back azimuth and then to grid azimuth. The forward magnetic azimuth of line "OP- RJ 171" is 332°, and the back magnetic azimuth is 332° minus 180°, or 152°. To find the grid azimuth the *G-M* angle 9° is subtracted; the answer is 143° grid azimuth. This procedure is repeated for line "OP-CR 162." The intersection of these lines is the location of the observation post. Location of the position is determined by reading two angles and plotting two lines.

b. Resection with map. Another method is to stick pins in the map positions of RJ 171 and CR 162 (fig. 60). Orient and level the map, lay a straightedge against a pin at CR 162, sight along it at the cross-roads, and draw a line on the map. Without moving the map, repeat the operation with the pin at RJ 171. Your position is where the lines intersect.

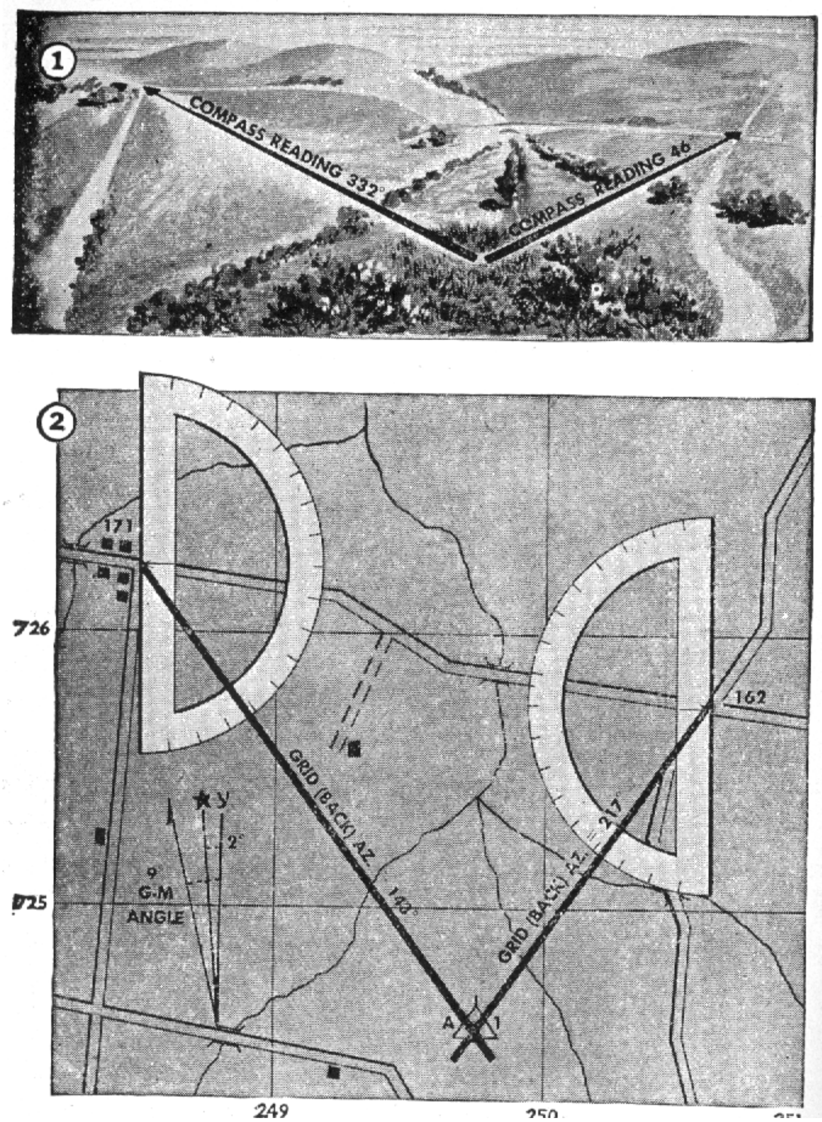


Fig 59. Position located on map by resection from two distant points, using compass and protractor.

c. Tracing-paper method. Tracing paper can also be used in resection. First, choose three distant objects represented on the map, for example, a church, the corner of a fence, a road junction (fig. 61). These points should be so located that lines to them from the occupied position make angles not less than 30° nor more than 150°. Stick a pin in the tracing paper at any convenient assumed position of the observer, place a straightedge against the pin, sight at each of the three objects in turn without moving the tracing paper, and draw a line toward each object from the pin. Lay the tracing paper on your map and move it around until each line passes through the conventional sight representing the object toward which it was sighted. Now, the pinhole in the paper is directly over your position on the map. The three-point resection should, if possible, be made on points which form a triangle containing the position sought.

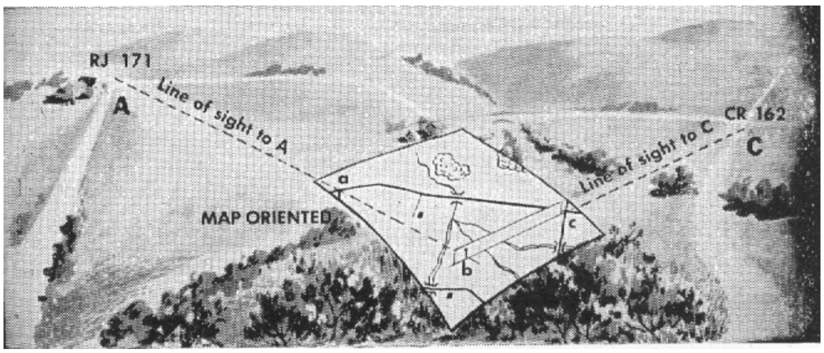


Fig 60. Position located on map by resection from two distant points (graphic method).

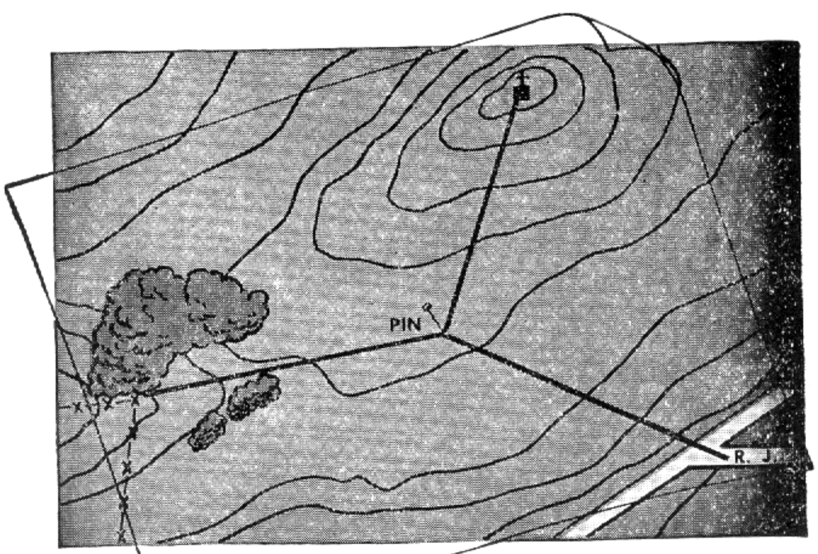


Fig 61. Position located on map by resection from three distant points (tracing-paper method).

SECTION IX

AERIAL PHOTOGRAPHS

54. GENERAL. Aerial photographs are used for many different purposes in military operations. In this manual they are considered principally in conjunction with or as substitutes for topographic maps. The ideal situation is to have an accurate topographic map and a recent aerial photograph or accurate photomap of the same area. A topographic map even a few years old can give a false picture of terrain because it shows conditions which existed when the surveys were made. Moreover on topographic maps, forest and woods are represented by their conventional signs regardless of their density; cultivated fields cannot be interpreted or recognized; and newly constructed roads, highways and bridges, and changes in features of the terrain due to storms, floods, and military operations are not indicated. A properly interpreted recent aerial photograph, however, shows all the above information and more. In fact, aerial photographs usually supply the only up-to-date map information available during the first few weeks of an operation in enemy territory. Photographs are used to determine distances and directions and to select routes in much the same manner as ordinary topographic maps are used. See **FM 21-25** and TM 5-246 for interpretation of aerial photographs.

Recall this is decades before the availability of downloadable satellite images (e.g., Google Earth). These images are non-oblique and of very high resolution. A large image, however, suffers from the same problem as old aerials—it's still a flat projection of the curved surface of the earth, so the outer edges will have slight distortion.

Reenactors seem to have a child-like fascination with aerial photographs, probably because they are now available for download. This can be a fatal attraction. However rich and entertaining it may be, an aerial photo is no substitute for a topographic map. The map has all the details needed to assess military opportunities and obstacles, and for navigation—things a photo lacks. Aerials are used to supplement actual surveyed maps, not to replace them.

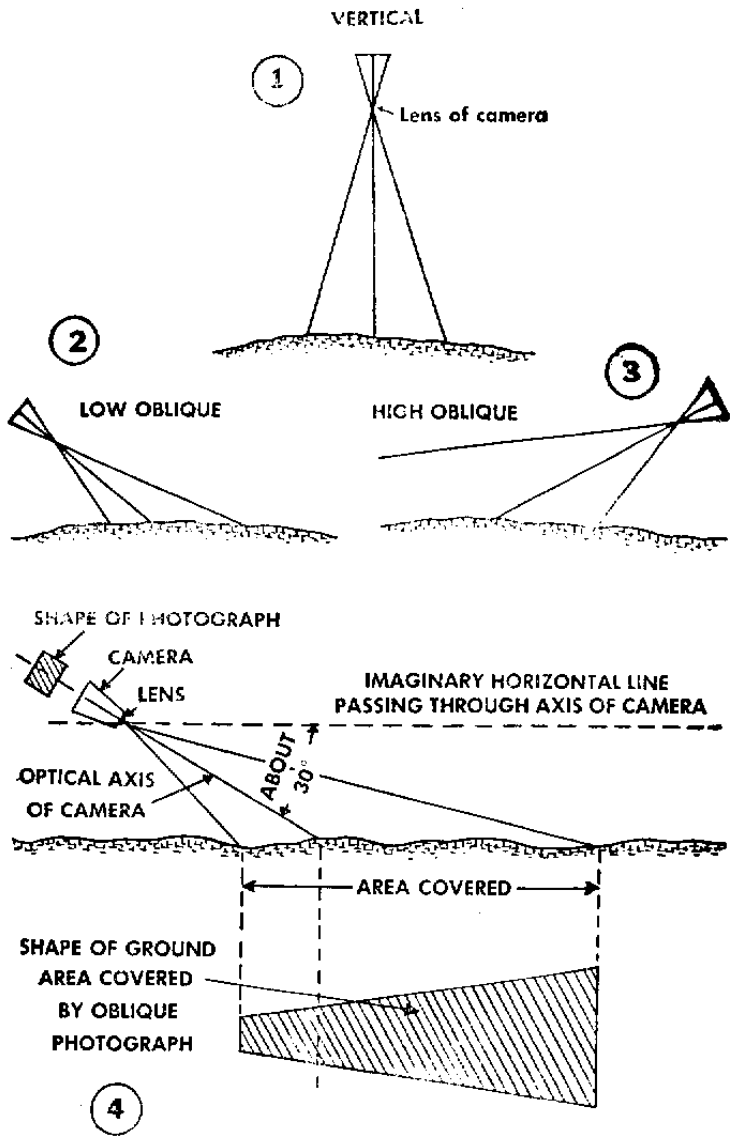
55. TYPES. The three general types of aerial photographs are *vertical, oblique,* and *composite.*

a. Vertical. Vertical photographs are taken with the axis of the camera perpendicular to the earth. Each photograph covers a small ground area and shows ground features such as roads, railways, buildings, and rivers in much the same way as they are shown on topographic maps of similar scale. When the scale of the photograph is known, the distances along roads and widths of rivers can be measured accurately. Vertical photographs are used for local operation, making photomaps, and in pairs for studying terrain by stereovision (see par. 75). An example of a vertical aerial photograph is shown in figure 62, with camera in position as shown in figure 63 ←.

Never forget: the plane of the camera is flat, the world is curved. In actuality, a straight from above camera view is “vertical” only at its center; error increases as you get farther to the sides.

Fig 62. Vertical photograph.

b. Obliques. Oblique photographs are taken with the camera tilted at an angle. The angle varies according to the mission, but is usually about 30° below the horizontal, as shown in figures 63 and 64. An oblique below the horizon is a low oblique; one including the horizon is a high oblique. Figure 63 ↓ shows the relationship between the trapezoid ground area covered by an oblique photograph and the rectangular shape of the photograph itself. Distances on oblique photographs cannot be accurately scaled, but since obliques are taken from a view point similar to that of an observer on a high hill, terrain features have a more normal appearance than they do in a vertical picture. This makes obliques useful for studying terrain, vegetation, buildings, and other features identified by their elevations. Obliques may accompany operations or field orders. As in figure 66, the line of departure, routes from bivouac to assault positions, assembly positions, objectives, boundaries between units, and information of the enemy, can be shown.



①, ②, and ③ Diagram of vertical, low-oblique, and high-oblique photography.
④ Oblique photograph of area compared with area's actual shape.
Fig 63.

c. Composites. Composite aerial photographs are made with cameras having one principal lens and two or more surrounding and oblique lenses. The photographs resulting from these cameras are combinations of two, four, or eight obliques surrounding one vertical. These oblique photographs are corrected or transformed in plotting so as to permit assembly as verticals with the same scale. The air corps type T-3A five-lens camera may be used, but this system is being superseded by the new trimetrogon system which comprises three cameras operated simultaneously. For further information, see paragraph 25, TM 5-230.

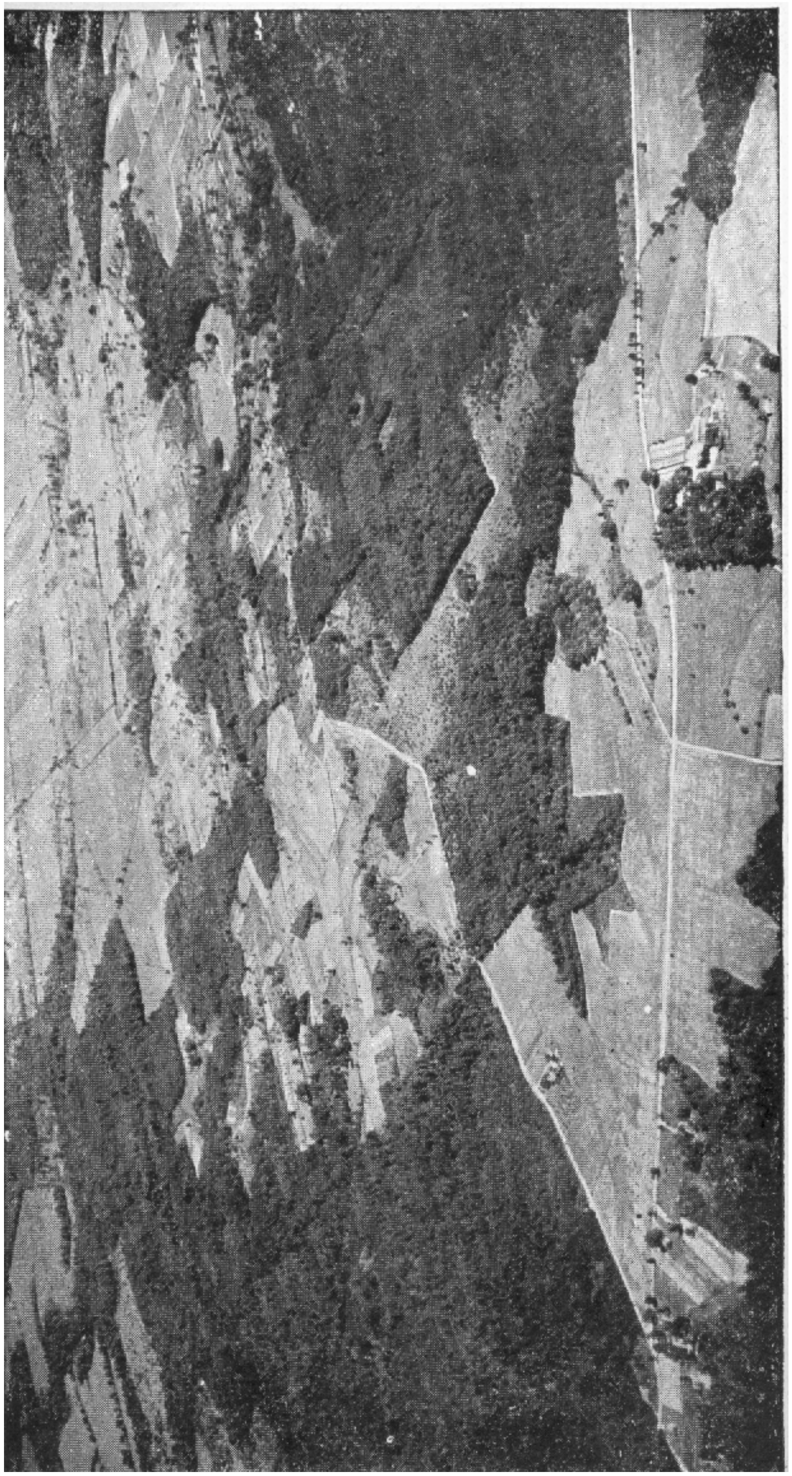


Fig 64. Low-oblique photograph.

Fig 65. High-oblique photograph.

56. PIN POINTS. Pin-point photographs are single vertical photographs, usually of large scale. Such features as airdromes, supply depots, dumps, road crossings, bridges, or bottlenecks on lines of communication are suitable objects for pin-point photographs. Adjacent pin-point photographs having proper overlap comprise a stereopair (see par. 75).

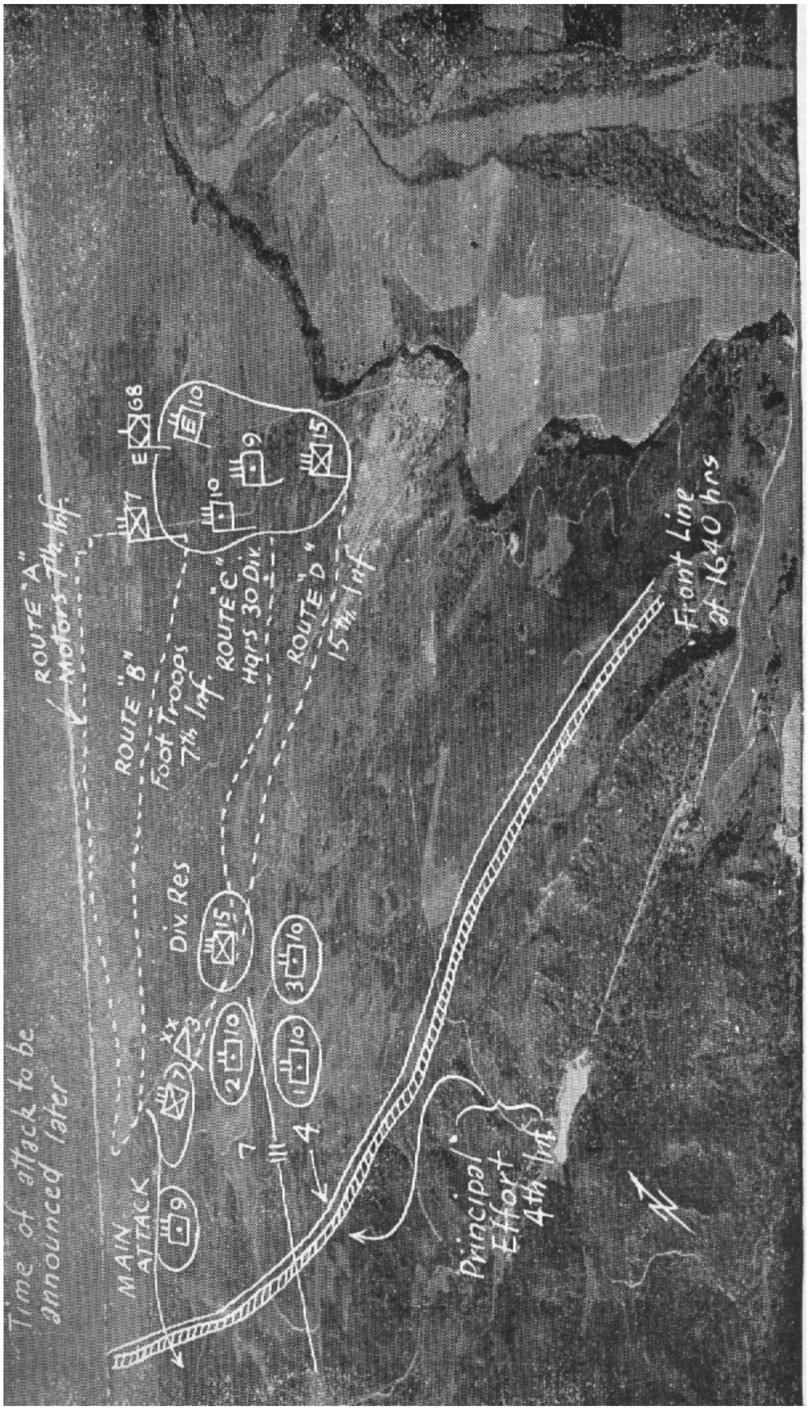


Fig 66. Oblique photograph used as a photomap to accompany a field order.

57. STRIPS. When a flight is made to obtain photo- graphic strips of an area, vertical pictures are made along a selected flight line or direction. The photographs of one run

make a photographic strip or a reconnaissance run. Exposures are so timed that each vertical photograph in a strip overlaps 60 percent in the direction of flight (fig. 67). When a single strip of photographs will not cover the area desired, parallel strips are flown, each having an approximate 20 percent sidelap with the adjacent strip; in wide-angle mapping, sidelap of photographs should be 30 percent. The photographs of a strip may be used for stereoscopic study or matched and secured in place to form a mosaic.

Fig 67. Line diagram showing relative positions of separate pictures in a photographic strip.

58. MOSAICS. A *mosaic* is formed by joining several vertical photographs (fig. 68). When several photographs of a single strip are joined together, the result is called a *strip mosaic.* Mosaics may be either *controlled or uncontrolled.*

a. *Uncontrolled mosaics* are produced when the photographs are put together by matching detail along their borders. This type of mosaic gives a good pictorial representation of the ground but contains errors in scale and direction because of differences in scale and distortion around the edges of each photograph. Care in mounting will improve the accuracy, but the only way an accurate scale can be obtained is by ground control.

b. *Controlled mosaics* are prepared by adjusting vertical aerial photographs to the plotted positions of ground control points. Unless an accurate map of the same scale as the photographs is available, an actual survey must be made in the field, and control points easily identified on photographs plotted on a mounting board to the *average scale* of the photographs. When these control points on the photographs are placed directly over the corresponding control points on the mounting board, the photographs are in true relation to each other. The controlled mosaic is accurate enough in scale and direction for most practical purpose. However, the ground features where the photographs are joined will not match because of distortion and variation in scale. For further reference see TM 5-230.

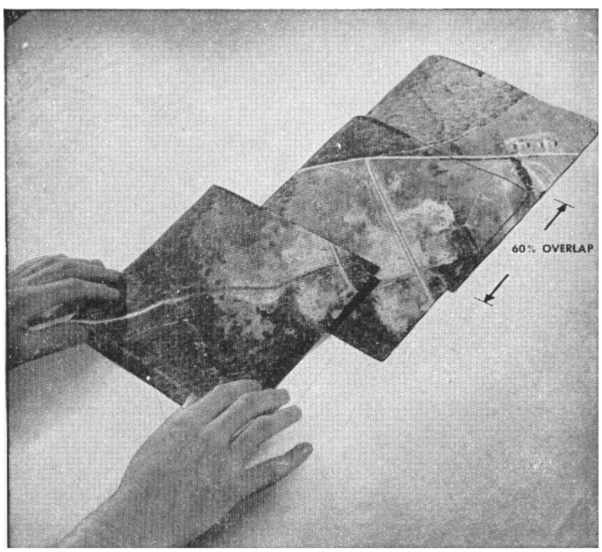


Fig 68. Matching three overlapping vertical photographs of a strip to form a mosaic.

The '60% overlap" is approximate and is prescribed to minimize distortion away from the center of the focal plane. As noted above, only the center is exactly vertical; the view becomes increasingly oblique away from the center.

59. MARGINAL DATA. a. General. The titling and identification of aerial photographs is the responsibility of the Army Air Forces but the data are actually placed on the negatives by the units making the photographic mission. Technically excellent photography may be rendered valueless because of improper or inadequate titling.

b. Minimum title data for all aerial photographs. The minimum data on all aerial photographs are the cataloging information which appears at the top. Following is an example: 137PS-3M109-11-V-121 (fig.69).

(1) *137PS.* Photograph made by 137th Photo Reconnaissance Squadron USAAF.

(2) *3M109.* The year is 1943, indicated by the fourth digit of the calendar year, that is, 3 for 1943. The letter M stands for mission, 109 for the mission number.

(3) *11-V.* Eleven (11) is the roll number; V means the camera was in a vertical position. Negatives from cameras used in the trimetrogon assembly indicate the positions of the cameras by having in their marginal data, the letters L for left camera, V for vertical camera, and R for the right camera. Negatives from the five-lens camera are numbered as follows with D closest to the front of the airplane:

As the war progressed, the old T-3A camera was replaced by the trimetrogon lens system.

D

A B C

E

Letters A, C, D, and E are obliques, while B is a vertical.

(4) *121.* The negative number is 121. Negatives are numbered consecutively starting with 1.

c. Additional title data to be placed on photographs used for intelligence and interpretation purposes. The following data are added to the cataloging information and are the minimum data required on photographs used for intelligence and interpretation purposes. Thus immediately following 137PS-3M109-11V-121 are the data, 12:28:1330-12:20000-V-842S14826E- Buna New Guinea-Confidential. The explanation is as follows:

(1) 12:28:1330. Date and hour, 28 December at 1330.

(2) 12:20000. Focal length of the camera, 12 inches, and altimeter reading, 20,000 feet. If possible, altimeter reading

should be adjusted to give height of plane above terrain photographed.

(3) *V.* V for vertical. If, however, the photograph were an oblique made with the camera tilted 45° from the vertical, it would read 0-45°.

(4) *842S14826E.* Geographic coordinates of the center of the photograph to the nearest minute: 8° 42' south latitude, 148° 26' east longitude.

(5) *Buna, New Guinea.* Descriptive title, including the locality and country or island group.

(6) *Confidential.* Security classification; only confidential and secret classifications are shown.

d. Further titling data for continuous strip mapping, charting and reconnaissance photography. In addition to the minimum titling that appears on all photographs, other data are added to the key negatives at the beginning and end of each strip of mapping, charting, and reconnaissance photography. Thus, immediately following 137PS-3M109-11-V-121 are the data 12:28:1330-6.03 :20000-842S14826E/816A14745E. The explanation is as follows:

(1) *12:28:1330.* Date and hour, 28 December at 1330.

Figure 69. Aerial photograph with titling data.

(2) *6.03:20000.* Focal length of camera in inches to nearest hundredth (6.03 inches) and altimeter reading 20,000 feet.

(3) 842S14826E/816S14745E. Geographic coordinates of the beginning and end of each continuous strip of photography to the nearest minute; beginning of strip is at 8° 42′ south latitude, 148° 26′ east longitude; end of strip at 8° 16' south latitude, 147° 45′ east longitude.

60. FIDUCIAL MARKS. Fiducial marks appear on nearly all aerial photographs. These are ticks, notches, lines, or half arrows, at the middle of each of the four sides of the negative. They are registered during exposure by a template in the camera. The use of fiducial marks to place a grid on the photograph is discussed in paragraph 69b.

61. SOURCE OF ERROR. All aerial photographs contain some error resulting from the tilt of the airplane in flight and from variations in ground elevations. The amount of error in any photograph is less at the center and increases toward the edges. These unavoidable errors may be disregarded for ordinary field use. However, photographs taken when the airplane was obviously badly tilted should be discarded.

SECTION X

AERIAL PHOTOGRAPHS

AS MAP SUBSTITUTES

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62. COMPARISON OF AERIAL PHOTOGRAPHS WITH LINE MAPS. A topographic map is a line drawing of the land, showing objects and features by exaggerated conventional signs. An aerial photograph is an actual picture of the earth's surface which shows terrain features as they appear from the air.

a. An aerial photograph has the following advantages over a topographic map:

(1) It has a wealth of detail which no map can equal.

(2) It has accuracy of form.

(3) It can be obtained and developed in a short time.

(4) If may be made of areas otherwise inaccessible for physical or military reasons.

(5) It is up to date.

(6) Unobscured military features can be studied and interpreted.

b. The vertical photograph is inferior to a topographic map in the following ways:

(1) Important military features emphasized on a map are sometimes obscured or hidden by other detail.

(2) Neither absolute position nor absolute elevation can be obtained.

(3) Relative relief is not readily apparent.

(4) Displacement of position caused by relief and camera tilt usually do not permit the accurate determination of either distance or direction.

(5) Because of a lack of contrast in tone, it is difficult to read in poor light.

(6) Marginal data furnished on maps are generally lacking.

63. IDENTIFICATION. Topographic identification is the art of identifying visible features of the terrain from their images on a photograph. See **FM 21-25** and TM 5-246 for the principles of aerial photograph reading.

64. SCALES. Scale affects the degree of interpretation possible. For example, note the differences in detail visible in figure 70 ① and ②. The scale of aerial photographs can be determined in the following ways:

a. Focal length and lens height. To find scale by focal length and lens height, look in the marginal data for the focal length of the lens in the camera and the altitude at which the picture was made. The focal length is given first, in inches; the altitude is given next, in feet. The information may appear as (12-20,000), which means the photograph was made with a 12-inch focal length at an altimeter reading of 20,000 feet (see par. 59c (1)). The diagram in figure 71 shows the relation between the focal length of the camera, altitude of the plane, ground distance *AB,* and photo distance *ab.* The *RF* of the photograph is the focal length in inches divided by the altitude in inches. Thus, if the focal length is 12 inches and the altitude is 20,000 feet, the *RF* of the photograph is found by the formula:

$$RF = \frac{\text{Focal length of the camera in inches}}{\text{Altitude of the camera above the ground in inches}} \text{ or } \frac{F}{H}$$

Then *RF* is $\frac{12}{20{,}000 \text{ X } 12} = \frac{1}{20{,}000}$ With a focal length

of 6 inches, the *RF* would be $\frac{6}{20{,}000 \text{ X } 12}$ or 1:40,000.

When altitude given is altitude above sea level, subtract the height of the ground above sea level from the altitude before using the equation. Thus, using examples just given, if the ground is 2,000 feet above sea level,

RF with a 12-inch focal length would be $\frac{1}{18{,}000}$, or scale

1:18,000; and with 6-inch focal length, $\frac{6}{18{,}000 \text{ X } 12}$

or scale 1:36,000.

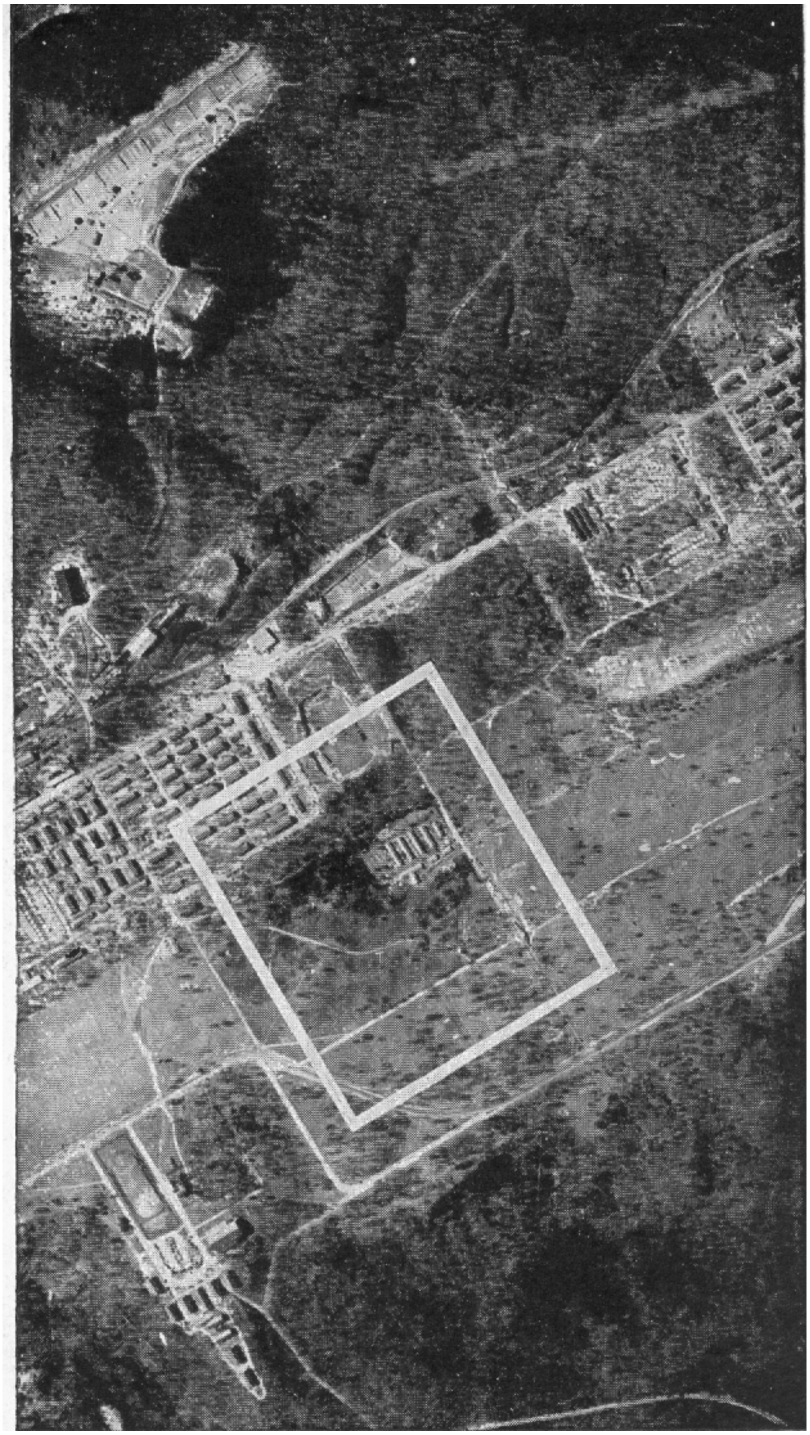


Fig 70. ① Vertical photograph from high altitude.

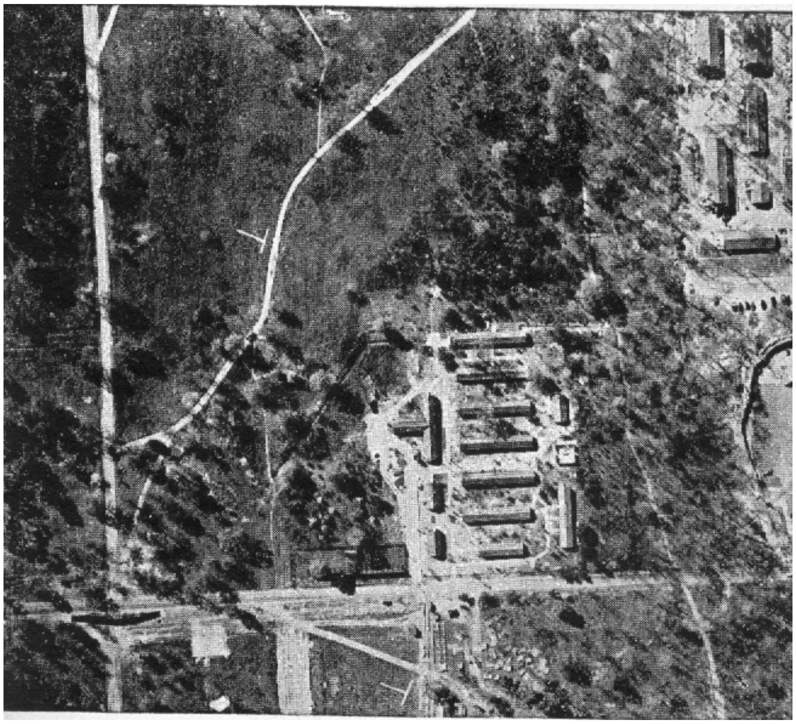


Fig 70 . ② Low-altitude view of same terrain.

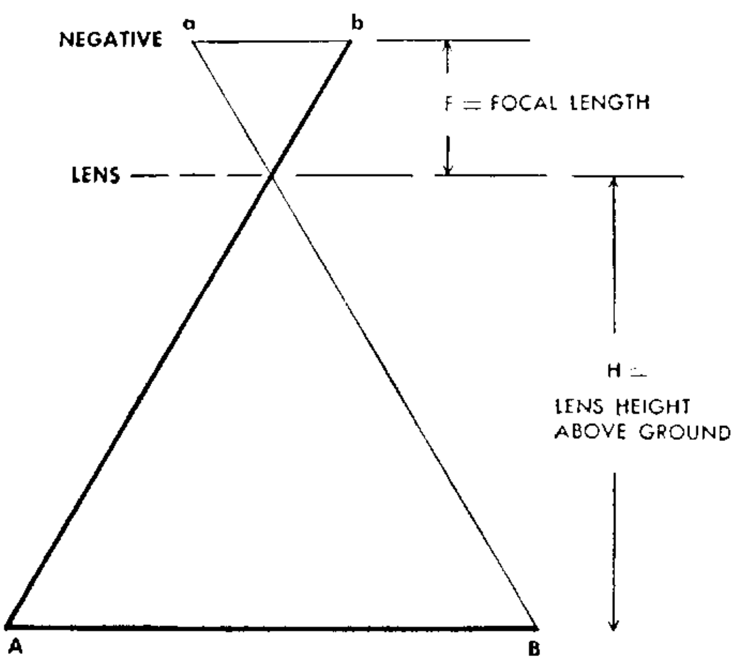


Fig 71. Determining scale from focal length and lens height.

b. By comparison with a map. The *RF* of a photograph can be determined by comparing it with a map. To do so, select two points on the photograph (such as crossroads or road junctions) that can be easily found on the map. A line between the points should pass as near the center of the photograph as possible, with the points about the same distance from the center of the picture and at approximately the same elevation. For example see line *AD* or line *CB* in figure 72. The distance along the line on the photograph is the photograph distance, or *PD,* in inches; this constitutes the numerator of the *RF*. Ground distance, *GD,* is obtained by scaling the distance from the map; this is the denominator. *RF* is written as $= \frac{\text{Photo distance}}{\text{Ground distance}}$ or $RF = \frac{PD}{GD}$. Thus, if the distance between two points along a line on the photograph is 6 inches, and the scaled ground distance from the map between the same points is 5,000 feet, then the $RF = \frac{6}{5{,}000 \times 12}$ or $\frac{1}{10{,}000}$ and the scale of the photograph is 1:10,000.

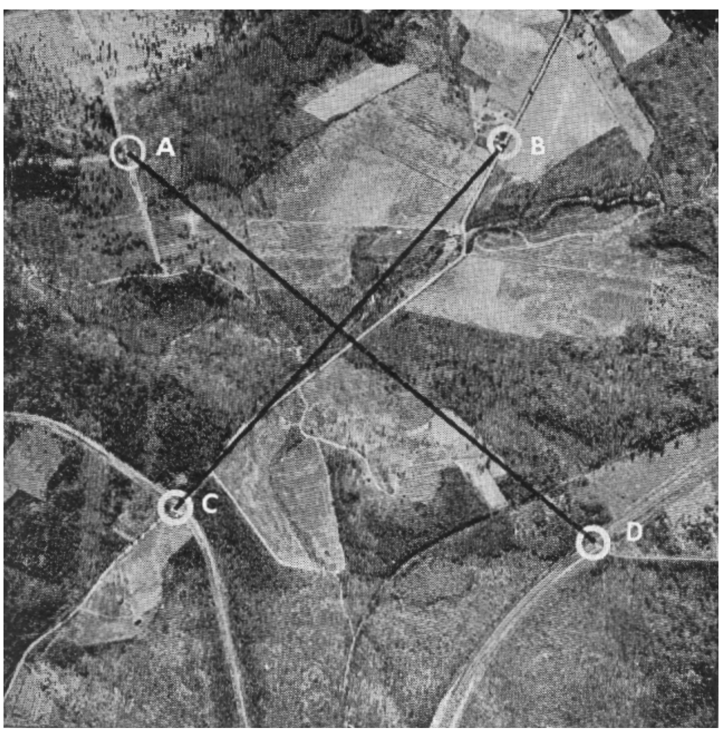


Figure 72. Determining scale of photograph by comparison with map.

c. By comparison with the ground. The *RF* of a photograph can be determined by comparison with ground distance if the two points selected on the photo-graph are accessible on the ground. This is done by measuring the distance between two points on the photograph and the actual ground distance between the same points. By the *RF* formula, if the distance on the photograph is 6 inches and the actual ground distance is 3,000 yards the *RF* of the photograph is

$$\frac{6}{3{,}000 \times 36} \text{ or } \frac{1}{18{,}000}$$

d. Average RF. A more accurate scale is found by figuring the *RF* from several different scale lines, then taking the average of all the denominators. Thus, if the *RF's* of two different scale lines were $\frac{1}{19{,}000}$ and $\frac{1}{21{,}000}$ the average scale would be $\frac{1}{20{,}000}$

65. GRAPHIC SCALE. Preparing a photograph as a map substitute may include constructing a graphic scale in yards or other appropriate units. If the *RF* of the photograph is known, the graphic scale is constructed by the methods employed in constructing graphic scales for maps (see par. 12). On mounted photographs place the scale on the lower margin of the mount. On unmounted photographs place it on the back of the photograph where it will not obscure valuable detail.

66. DISTANCE. After the *RF* of a photograph is deter- mined and a graphic scale is constructed, the map reader is ready to scale distances. The paper-strip method of measuring distances, discussed in **FM 21-25**, is the easiest method. The map measurer and the engineer scale may also be used.

67. DIRECTION. a. General. (1) For normal military uses, direction angles and azimuths on a photograph have the same significance as on a map and may be measured and laid out with the protractor in exactly the same manner. However, angles measured from the principal center point of the photograph more closely approximate their values as measured on the ground, since errors in position on a near vertical photo are radial from points falling near the center.

(2) To lay out or to measure directions on a photograph, magnetic, true, or grid north may be indicated on the photograph. Magnetic north is the most suitable base direction for photographs of unmapped country.

b. Finding north by shadows. (1) The shadow cast by objects in a photograph can be used to find true north on the photo. In the north temperate zone, shadows fall true north at noon, northwest in the morning, and northeast in the afternoon. If the note in the margin indicates the picture was made between 1000 and 1200, the shadows will be west of north. If made between 1200 and 1400, the shadows will be east of north. In the south temperate zone the directions are reversed.

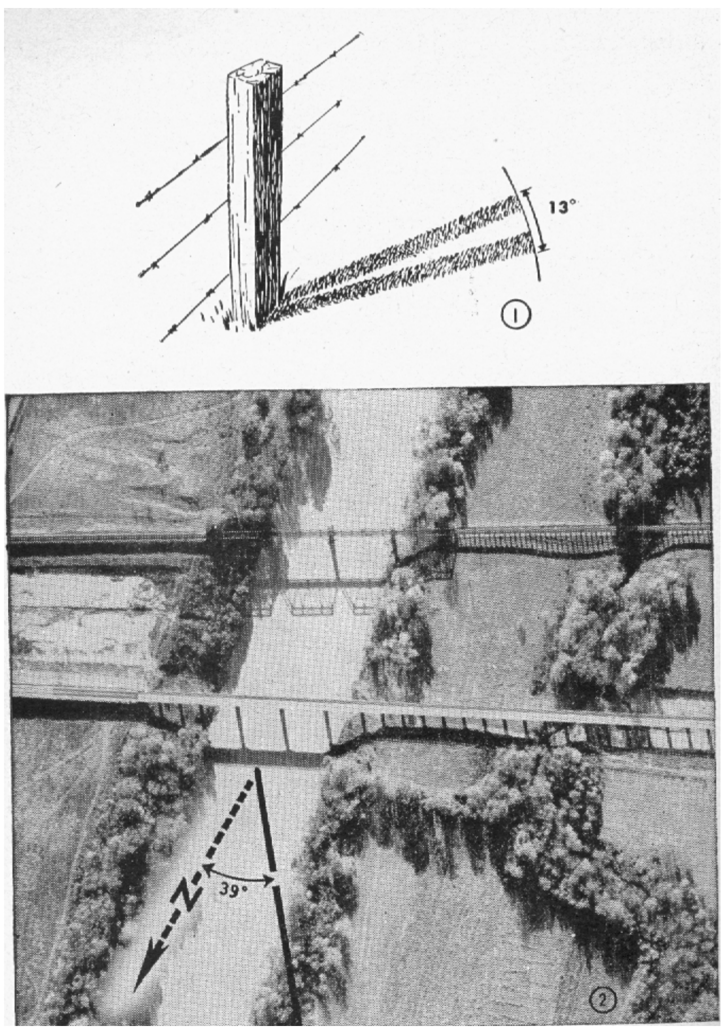


Fig 73. Finding north by shadows in photograph.

(2) In any particular locality, an hourly angular shadow variation may be obtained by measuring the angle through which a shadow moves in 1 hour, as in figure 73 ①. This value in degrees can then be applied as an adjustment to find true north on a photograph taken at any time.

(3) For example, assume that the position is north of the equator and that in 1 hour the sun moves the shadow through 13°. Then if the aerial photograph of that area shown in figure 73 ② was made at 0900, the *shadows would point 13° X 3 (hours) or 39 ° west of north.* Therefore, the *approximate true north-south line would be 39° to the right of the line of shadows.* Draw a line on the photograph in the direction of the shadows and measure 39° to the right with a protractor. The dashed line in figure 73① is approximately true north. If this same photograph had been made at 1500, true north would point 39° to the left of the line of shadows. South of the equator the directions are reversed. All time must be sun time.

c. Locating magnetic north on a photograph from a map. A map can be used to locate magnetic north on a photograph. First, choose two points (such as *A* and *P* in figure 74) which appear plainly on both photograph and map and are so located that a line joining them passes through or near the center of the photograph. With a protractor, find the grid azimuth of the line on the map. In this case, it is 45°and the magnetic azimuth is 54°. From the corresponding line *AP* on the photograph, measure 54° *counterclockwise.* A line drawn through the index of the protractor along this new direction is the same magnetic north as on the map.

68. ORIENTATION. Like a map, an aerial photograph must be oriented. This is done by turning the photograph until some well-defined line on it, such as a road, lies parallel to the same line on the ground. To check the orientation, place the compass on the magnetic line, found by methods used in paragraph 67, and rotate the photograph horizontally until the compass needle points along the line. Other methods of orienting photographs are covered in **FM 21-25**.

69. POINT-DESIGNATION GRID. a. Printing accurate grids on photographs is impracticable because of scale distortion. A special grid, known as the point-designation grid, may be

used. This grid has no relation to the actual scale or orientation of the photograph; it serves only for point or target designations and normally is not suitable for measuring distance or azimuth. For convenience, the dimension of the grid square is 1.44 inches. The 1:25,000 scale then can be used for determining and plotting the coordinates of points.

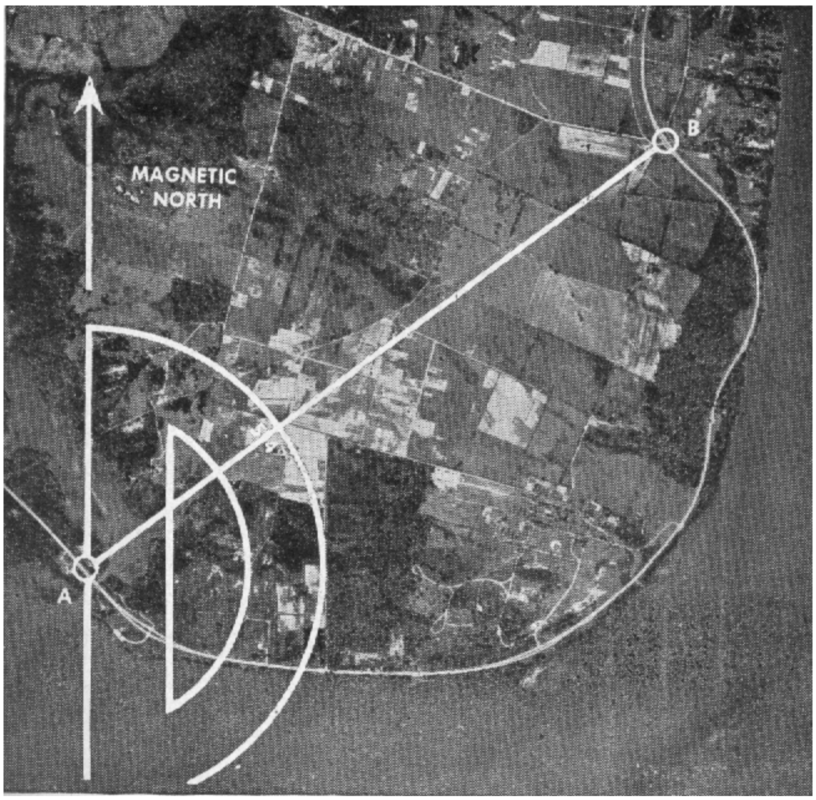


Fig 74. Using a map to locate magnetic north on photograph.

b. A point-designation grid may be printed on a photo or it may be printed on a transparent sheet—the point-designation grid template—for use on photographs not gridded. It is essential that all concerned place the grid or template on a photograph in exactly the same manner. For vertical photographs the procedure is, first, to turn the photograph so the marginal information, whether at the top or bottom, is in the normal reading position. Then draw grid line *A* through the fiducial marks at the top and bottom of the photograph and grid line *M* through the fiducial marks on the sides of the photograph (fig. 75). Additional grid lines are drawn parallel to grid lines *A* and *M* at 1.44- inch spacing. Those parallel to and above *M* are lettered from *M* to the top of the photograph *N, O, P, Q,* and so on. Those below *M* are lettered from *M* toward bottom of photograph in the order *Z, Y, X, W,* and so on. Lines to the right of *A* are lettered *B, C, D,* et cetera, and those to the left *L, K, J, I,* et cetera. When an oblique photograph is used, it is placed in the normal photo reading position with the foreground at the bottom, and grid lines are placed as described above. North does not necessarily point to the top of the picture (see north arrow in grid *KN*, fig. 75).

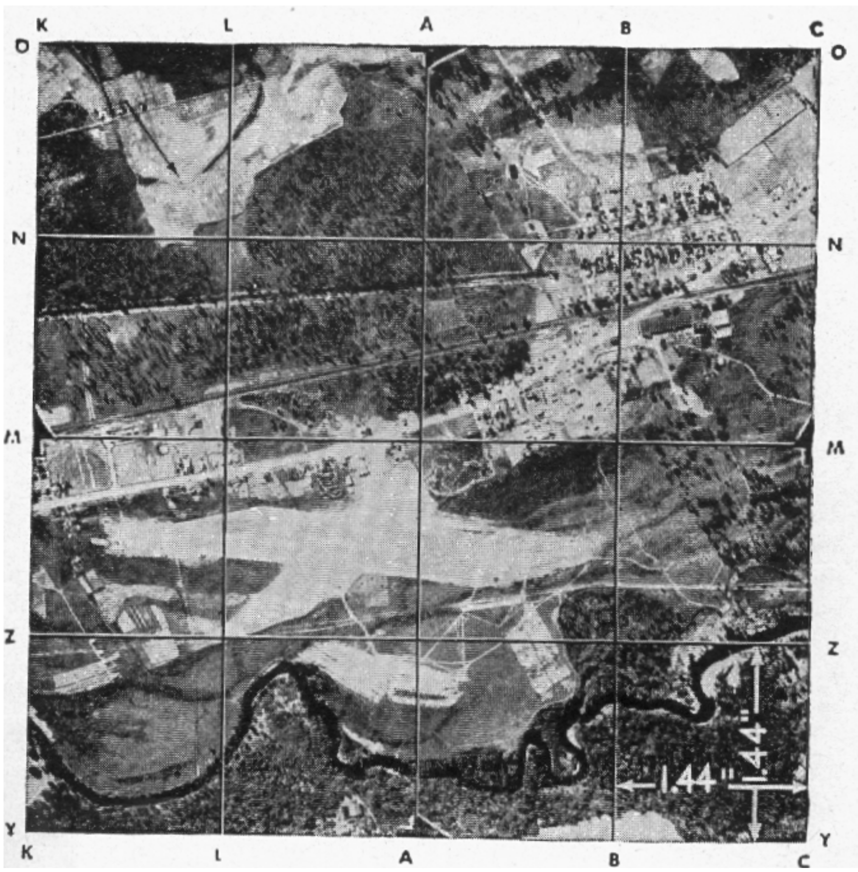


Figure 75. Point-designation grid.

c. To name the coordinates of a point, first indicate by two letters the intersecting grid lines at the lower left corner of the grid square in which the point is located; then read right and up to get the two numerical coordinates. For example, the coordinates of building indicated by the white arrow in figure 75 are AN4535, reading in hundredths. If less accuracy is sufficient, the coordinates in tenths are AN54.

70. EMPHASIZING AND CLARIFYING DETAIL. a. General. It is difficult to write on the face of a photograph; moreover, marks clutter up and hide important detail. Nevertheless, it may be desirable to emphasize certain points and lines such as routes of march, water and supply points, and other important features. The general pattern of the terrain may be clarified by tracing stream lines in blue, ridge lines in brown. Particular objects or points may be noted by placing a small number beside the item on the photograph and explaining its meaning in a key on a separate sheet of paper. An alternate method is to use an overlay.

b. Overlay. An overlay is a tracing of a photograph's detail on transparent material such as a light, tough, tissue-thin paper, or on materials such as tracing cloth and cellulose acetate. Cut the tracing paper a little larger than the photograph (fig. 76). With the photograph on a hard, flat surface, place the overlay on it and fasten it securely, leaving the bottom portion of the paper loose so it may be lifted in order to refer to points on the photograph. Register the overlay by tracing the outline of the photograph, by indicating the fiducial (collimation) marks, or by marking clearly defined terrain features such as road junctions, cross-roads, and streams. These marks allow the overlay to be exactly registered over the photograph. When the overlay paper is registered properly, the detail required is traced. Finally, a north arrow and title block are added. The latter includes title of overlay, and date, name, grade, and organization of the sketcher, and the sketcher's location. The photograph's serial number, *RF,* graphic scale, and classification should also be shown. For further information on this subject see **FM 21-35**.

71. TO INDEX AND PLOT AERIAL PHOTOGRAPHS. Examination and study of photographs is facilitated by first outlining on a map the area or areas covered by the photograph or photographs as indicated in figure 77. This is done by constructing templates or tracing paper which represent the area of the photograph at the scale of the map. For example, if the map has an *RF* of 1:20,000, and the ground area represented by a photograph is 7,000 by 9,000 feet, the template would measure:

$$\frac{7{,}000 \times 12}{20{,}000} \text{ by } \frac{9{,}000 \times 12}{20{,}000} \text{ or 4.2 by 5.4 inches}$$

The template is placed on the map and shifted about until its outline includes the details shown on the photograph. The area then is outlined on the map by marking around the template, and the serial number of the photograph is entered in the outline. The process is repeated for any number of photographs. The result is an index sheet of the photographs (sometimes called "sortie plot") showing the relation of the photographs one to another and to the area on the map.

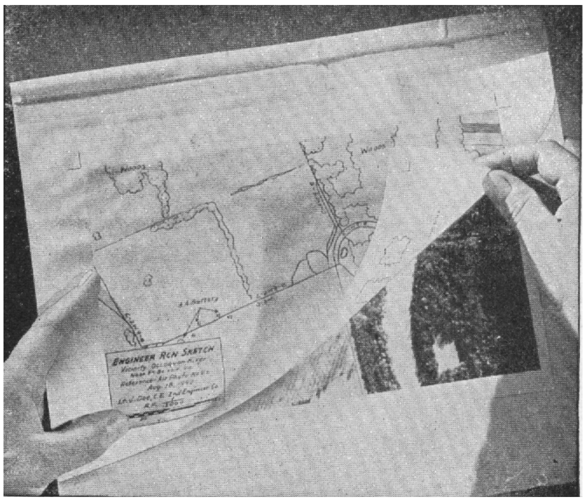


Figure 76. Use of overlay on a photograph.

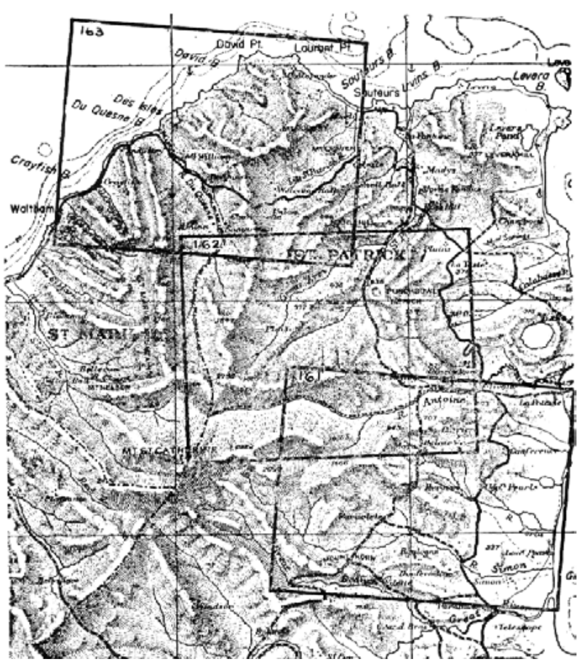


Figure 77. Method of indexing and plotting aerial photographs.

SECTION XI

PHOTOMAPS

72. TYPES OF PHOTOMAPS. A photomap is a reproduction of a photograph or mosaic on which grid lines, marginal data, and place names are added (fig. 78). While a photomap usually is a reproduction of a mosaic, either controlled or uncontrolled, it may be the reproduction of a single photograph of any type. Vertical photographs are usually reproduced with a point-designation grid (see par. 69). A photomap made from an uncontrolled mosaic gives a good picture of the terrain and can be prepared quickly, although it will have errors in scale and direction. A photomap made from a controlled mosaic takes much longer to prepare, but can be scaled accurately.

73. MARGINAL DATA. Marginal data for the reproduced individual photograph are given in paragraph 59, with the addition of the point-designation grid system. Photomaps which are made from mosaics and wide-coverage photographs may have, in addition, the following information:

a. Marginal information similar to that shown on maps, such as graphic scale, declination diagram, date made, and locality.

b. Name of towns, streams, mountains, highways, and other important features.

74. MILITARY GRID. While the military grid is not used on single photographs or on uncontrolled mosaics, it is highly desirable on controlled mosaics and photomaps. The military grid is used in the same manner as with a topographic map (see par. 27). The method of placing a military grid on a mosaic is shown in TM- 5-230.

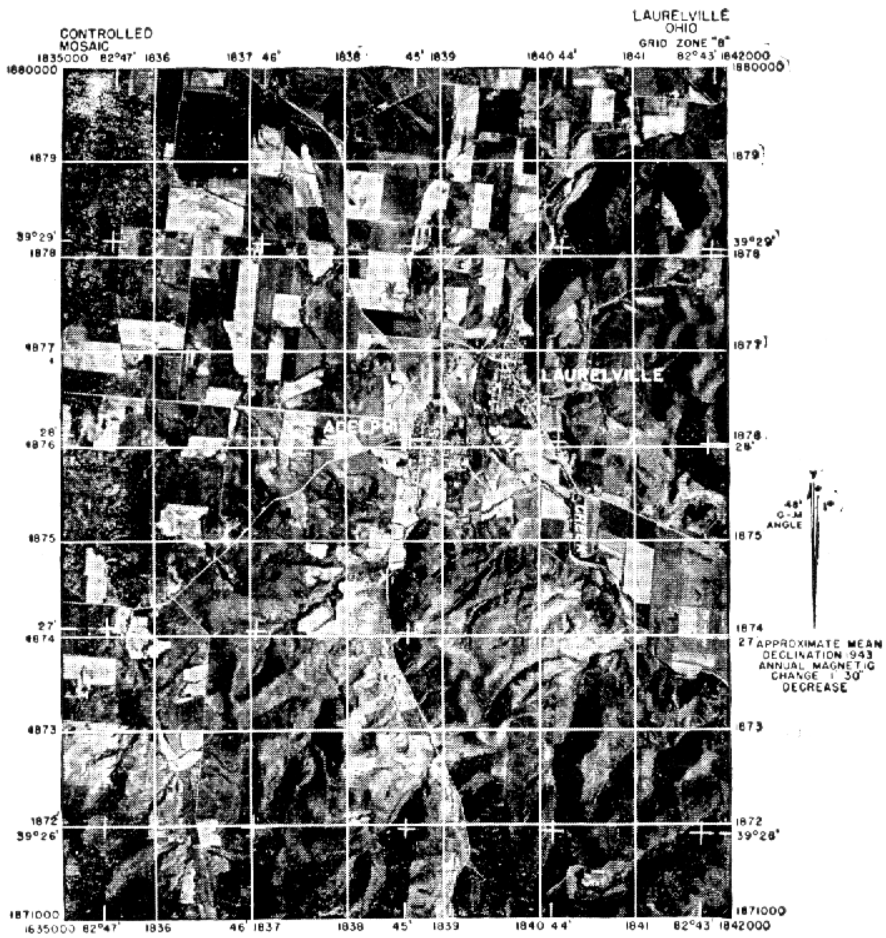


Figure 78. A photomap.

SECTION XII

STEREOVISION

75. GENERAL. Stereovision is the three-dimensional effect seen by blending into one image two pictures of the same object taken from different points. It is used when making a thorough study of terrain. Aerial photographs for stereovision are obtained by making two successive overlapping exposures with the axis of the camera lens vertical and the aircraft at the same altitude. The area that overlaps is suitable for stereoscopic study. The two pictures are called a stereo-pair. Trees, buildings, hills, and other terrain features in the overlap area rise in exaggerated relief when viewed stereoscopically. This enables the map reader to see through thin foliage of wooded areas; to detect camouflage; to study terrain to be fought over; to identify planes, ships, and important military installations behind the enemy's lines; and to determine the results of military action. Normally, stereo-pairs are examined with the aid of issue stereoscopes, but the naked eyes may be used if the individual has trained himself to see stereoscopically.

76. LEARNING TO USE A STEREOSCOPE. a. General. In teaching an individual to see stereoscopically it is often helpful to precede actual use of the stereoscope with preliminary eye exercises. The exercises and aids described in b and c below are included for this purpose.

b. Preliminary exercises. (1) *Finger exercise.* Finger exercises such as the "sausage" exercise shown in figure 79 ①, ②, and ③ are an aid in learning stereovision. To practice this exercise, focus the eyes on a window about 8 feet away. Hold both forefingers parallel to the ground and bring them into your line of vision from the sides without changing the focus of the eyes. As the tips of the fingers near each other, an image of a sausage appears suspended in mid-air between them.

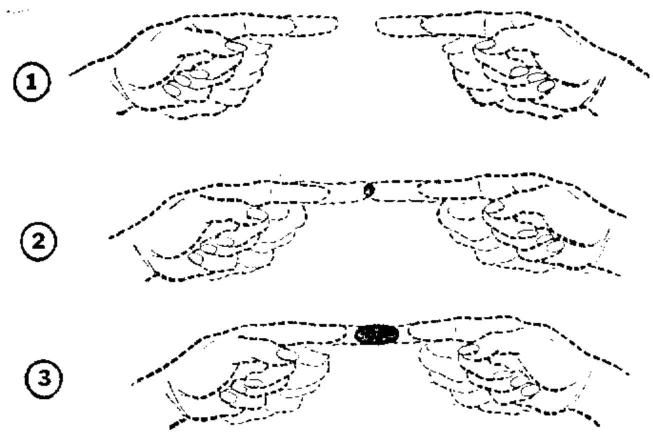


Fig 79. Sausage exercise.

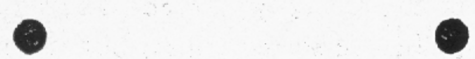


Figure 80. Fusion exercise.

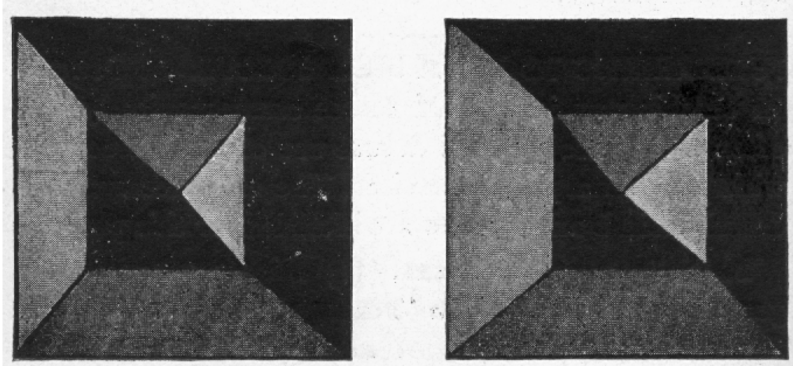


Fig 81. Depth perception exercise.

(2) *Fusion exercise.* The next exercise is to learn to fuse two drawings. Focus the eyes on a distant object and move the two dots in figure 80 into the line of sight, approximately 8 to 10 inches from the eyes. If four dots appear, move the manual away from or closer to the eyes until there are three dots. The center dot is in stereovision. If the field manual is turned slowly, the center dot appears to separate into two dots, one jumping out of the top of the other.

(3) *Exercise to see relief.* In figure 81, use the same method described above. The fused image in figure 81 is a pyramid protruding from the bottom of a square pit. In other words, instead of a flat line drawing, the reader sees the third dimension or *relief.*

c. Aids. Anaglyphs and vectographs may be used to help an individual to get the effect of stereovision for the first time. An anaglyph is two nearly superimposed aerial photographs each printed in a different color, red and blue-green, and is viewed through glasses with red and blue-green lenses. TM 5-230 gives a detailed discussion of anaglyphs. A vectograph uses the principle of polarized light to present a three-dimensional view.

77. STEREOSCOPES. The stereoscope consists of a pair of lenses set in a frame. The stereoscope gives a small amount of magnification. There are a number of different types but all are used similarly. The instrument is placed on overlapped photographs, as in figure 82.

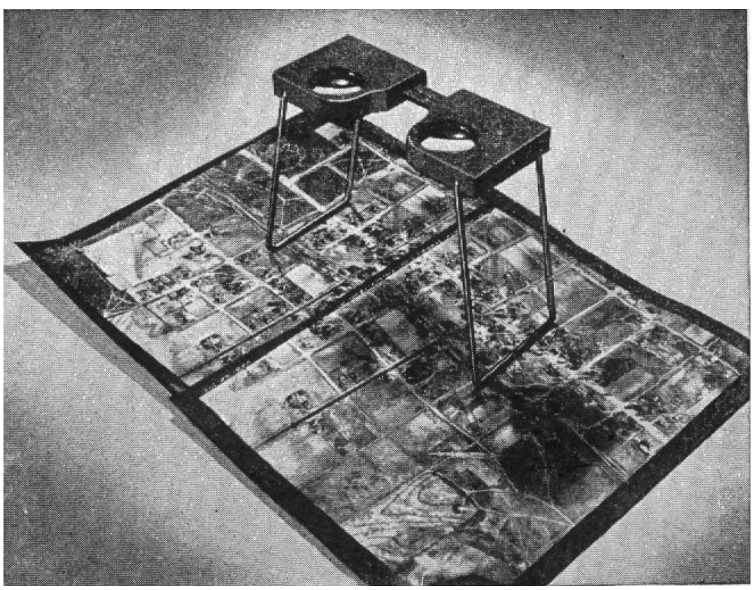


Figure 82. Lens stereoscope set up over a stereo-pair.

78. STUDY OF STEREO-PAIRS. a. General. To see photographs stereoscopically, they must be placed in the same relative positions as when they were taken. Any pair of overlapping vertical photographs taken at approximately the same elevation, can be viewed stereoscopically if arranged properly.

The anaglyph method was used in the early 1950's to produce popular 3-D comic books, which were printed using parallel images in red and blue (or cyan) ink. The degree of depth for a particular element was determined by the space between the images. The 3-D glasses used a red lens over one eye and a blue one on the other; the red lens filtered out the red image, the other filtered out the blue image, so each eye was seeing in effect a different image. The brain interpreted this as both eyes looking at a single image from two different locations, which is one way of perceiving visual depth (called *retinal disparity*).

Polarizing filters could also be used, and did not distort color. The glasses had two polarizing lenses, one vertical and the other horizontal. This had the same effect as the red-green anaglyphs; it was these glasses that made 3-D movies practical.

I learned how to view stereo images when I was 11 and was fascinated with 3-D comics and movies. It's actually easier than it sounds, but explaining it to somebody is almost impossible. The author tries in this marathon paragraph, but only induces eye strain.

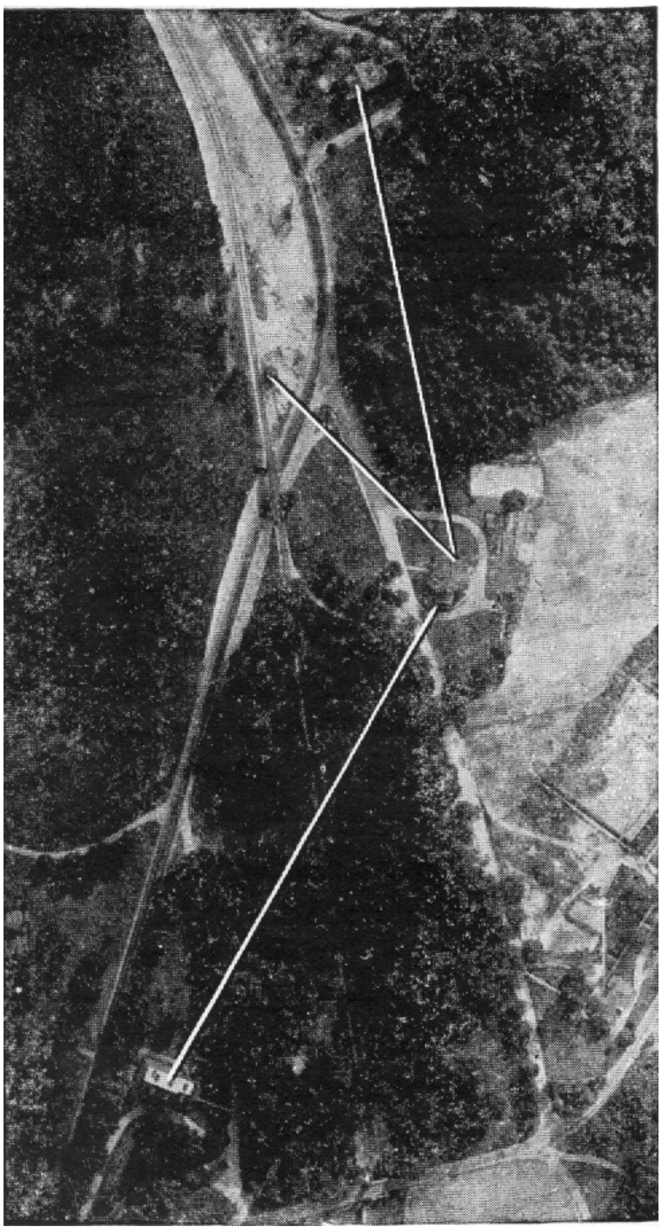
The old-fashioned stereopticon of the last century uses optical splitting to force each eye to see a different image (the semiautomatic version of the stereopticon was the Viewmaster, a cheap viewer that used multiimage disks of different subjects—there were hundreds available. For comics you had anaglyph glasses; for movies you had (and still have) polarizing glasses. My HD-3D TV display (yes, I have one) uses glasses that flicker alternately with each eye line to produce the same effect (which requires a special image signal).

Without these optical aids, you "just have to know" how to do it.

b. Arrangement of stereo-pairs. (1) Place one photograph on top of the other so the detail common to both roughly matches.

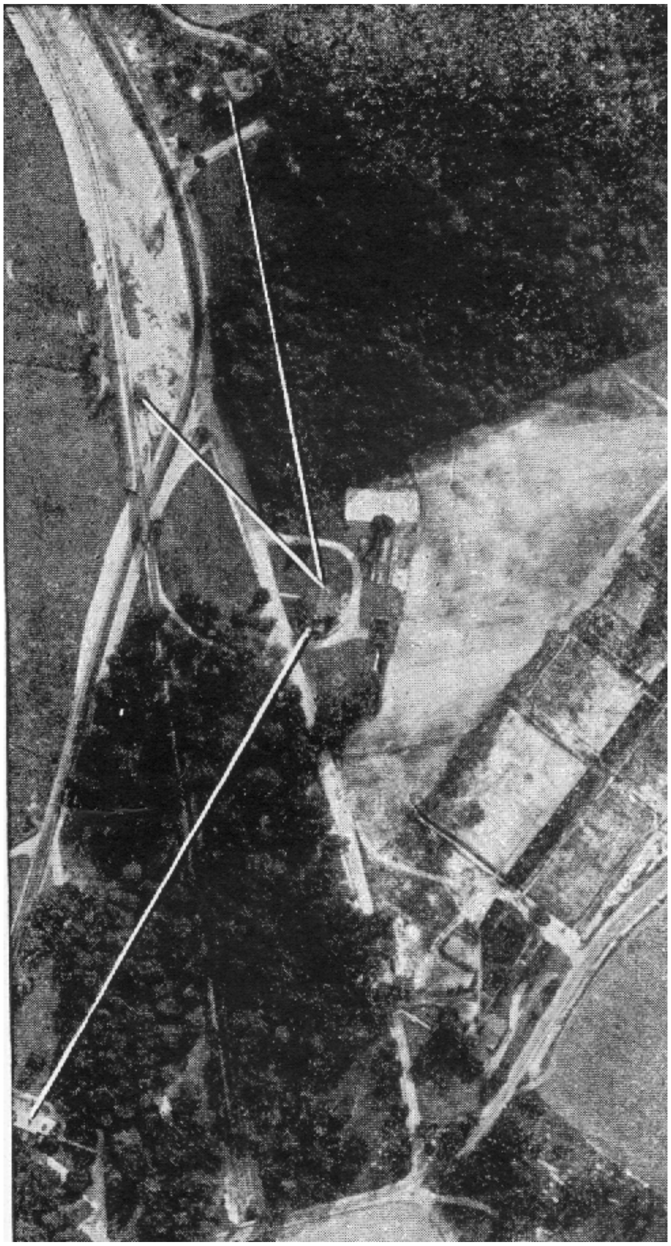
(2) Turn the photographs as a unit until your eyes are parallel to an imaginary line which runs across the approximate centers of the photographs.

(3) Place the stereoscope over the photographs so the left photograph is under the left lens and the right photograph is under the right lens.



① Left half of stereo-pair.
Figure 83.

Top: Red-green anaglyph.
Center: Anaglyphic glasses.
Bottom: Old-fashioned stereopticon images.



Top: Steropticon. This is more or less identical to device at fig. 76, below.

Bottom: Viewmaster: Stereopticon for the masses.

I wasted quite a long session in the lab years ago trying to show my wife how to see in stereo. Finally it dawned on me that she suffered from *amblyopia ex anopsia*, or "lazy eye", which makes the process almost impossible,

② *Right half of stereo-pair.*
Figure 83.

(4) Now separate the photographs along the line joining the centers, moving the right one toward the right and left toward the left. The photographs can be kept in proper relation by keeping parallel the details which appear in the overlap area, such as roads or streams. The two objects in

the overlap area which are to be studied should be separated so each is directly under the left and right lens respectively. By slight movements the photographs can be adjusted so the center images fuse and the effect of relief or depth is obtained. For a detailed discussion see TM 5-230.

(5) The stereo-pair in figure 83 ① and ② shows the overlapping portions of two vertical photographs. They are placed in the proper position for stereovision to be obtained.

79. THE FLOATING LINE. a. The special application of stereovision described below is useful in determining if a line of sight is free of obstructions. In figure 83 there are three black lines. If these lines are viewed stereoscopically, the relative elevation of terrain on either side may be clearly seen. The short line that runs from the roof of the house up to the left and across the road to a tree seems to float in the air; moreover, the end of the line at the tree is lower than at the roof ff the house. This line is lower than the tops of the trees around the house but is well above the ground. Therefore an observer at the house can see the tree across the road. Long lines run from the roof of the house in the center of the photograph to the roofs of houses above, and below it. These lines seem to float everywhere except where they move across wooded areas. The lines seem to cut furrows through the tops of the trees. This means that an observer sighting along these lines from the first house cannot see the roofs of the other houses.

b. To use this method, draw a fine ink line between the same two points on both the right and left pictures of a stereo-pair. The ends of the line appear to assume the elevation at their starting and stopping points. When stereo-pairs are reversed, moving the left photograph to the right of the right photograph, houses and trees will be depressed rather than in relief and that portion of a line which did not float in the original position *will* float freely. This checks the line of sight for obstructions.

c. To avoid drawing numerous lines on the stereo- pair, narrow strips of acetate on which lines have been scratched and inked in may be used. The strips are pivoted around pins stuck through the strips and fastened to the photographs at points from which lines of sight are being determined. By placing the other ends of the lines on the points in question on both photographs and viewing the pair stereoscopically, the presence or absence of obstructions to vision can be determined.

d. This method can not be used when the floating line is parallel, or nearly parallel to the line between centers of the photographs.

APPENDIX

PROJECTIONS

1. GENERAL. a. The geographic system of parallels and meridians can be easily drawn on a globe, but the surface of the globe cannot be stripped and flattened into a map without distortion. A perfect map representation, therefore, is impossible although there are many ways of getting approximate representations on a flat sheet. The simplest of these is to envelop the globe with a cylinder or cone or to lay a tangent plane against it, and to project upon the cylinder, cone, or plane a part of the geographic coordinate system of the globe. The cylinder or cone is then cut open and laid out flat. The system of parallels and meridians on the flattened paper is then the framework, or projection, upon which the map is constructed. A projection, then, is any orderly system of parallels and meridians on which a map is drawn.

b. Many kinds of projections have been devised. Some are particularly good for one purpose and some for another; no one projection is best suited for all shaped areas. Military maps of the United States are based on a series of seven polyconic projections; each one being **90** in width. This system has been extended to cover the earth between latitudes 72° N to 72° S and is known as the World Polyconic. It is used for all those areas not covered by the British grid system.

c. The British employ three systems of grid projection: Lambert Conical Orthomorphic, Transverse Mercator, and the Cassini projections. The type used depends upon the shape of the area to be mapped. Although British grids are based on these three map projections, practically all quadrangle projections for large-scale operational maps are plotted from polyconic tables. Ease of construction and existing tables dictate this practice. This is possible, since for small areas, differences between the polyconic projection and any of the other grid projections is unplottable. The grid of the area is then superimposed on the quadrangle.

d. Following are brief explanations of these projections. For more detailed information see TM 5-230 or any textbook on cartography.

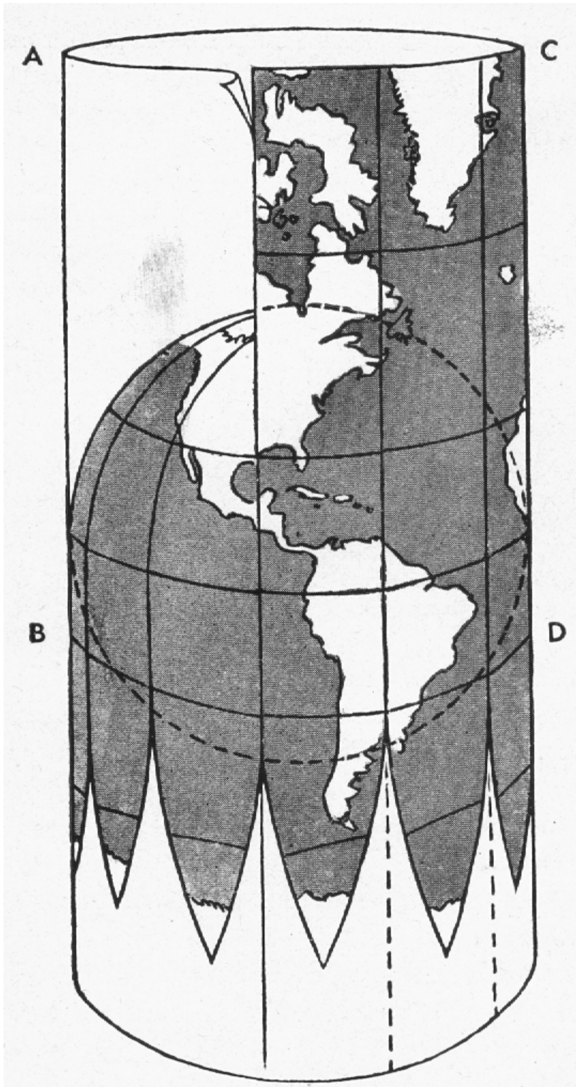
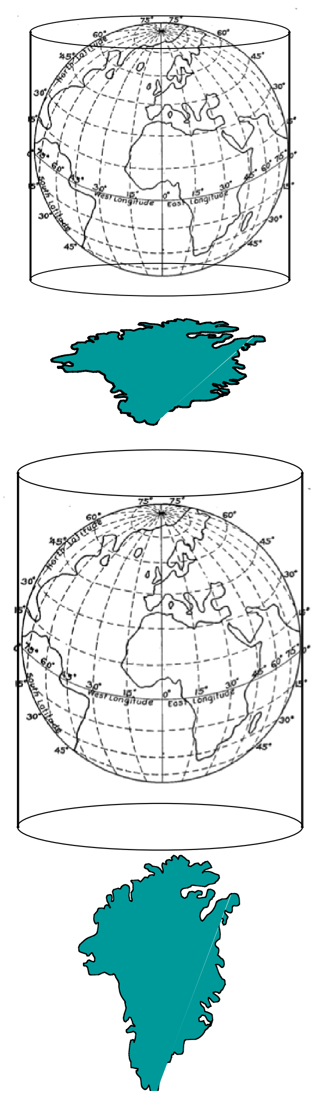


Figure 84. Cylindrical projection explains Mercator projection.

2. MERCATOR PROJECTION. a. This is a cylindrical projection in which parallels and meridians are projected onto a cylinder tangent to the earth at the equator (fig. 84). When the cylinder is laid out flat the meridians appear as vertical straight lines, evenly spaced, and true to scale on the equator (fig. 85), but true scale may be established at any latitude. The parallels are horizontal straight lines



Mercator's uncertainty principle (see 3, below): A common **Mercator projection**, composed such that the height of the cylinder of projection is equal to the diameter of the globe, tends to distort laterally (flatten) land masses in the polar regions, most notably Greenland. We can preserve the general shape by lengthening the axis of the cylinder, but at the cost of greatly enlarging the relative size of the feature. Most wall maps in schools are Mercator projections; students who sleep through a critical geospaced so that for and *small area* the relation of scale along the meridians and along the parallels is the same as on the globe. For example, at latitude 60° the parallels are twice as far apart as at the equator. Therefore, since the meridians on the map are the same distance from each other at every latitude, the scale of the map is doubly exaggerated at 600. At 80° the exaggeration is sixfold. It is obvious that the poles cannot be shown in this projection, because the expansion would be infinite. Therefore, maps on Mercator projections seldom are extended much beyond 80° of latitude.

graphy class grow up believing Greenland is as big as Africa. The only ways to solve this problem are (1) carry a globe around, or (2) stay awake in class.

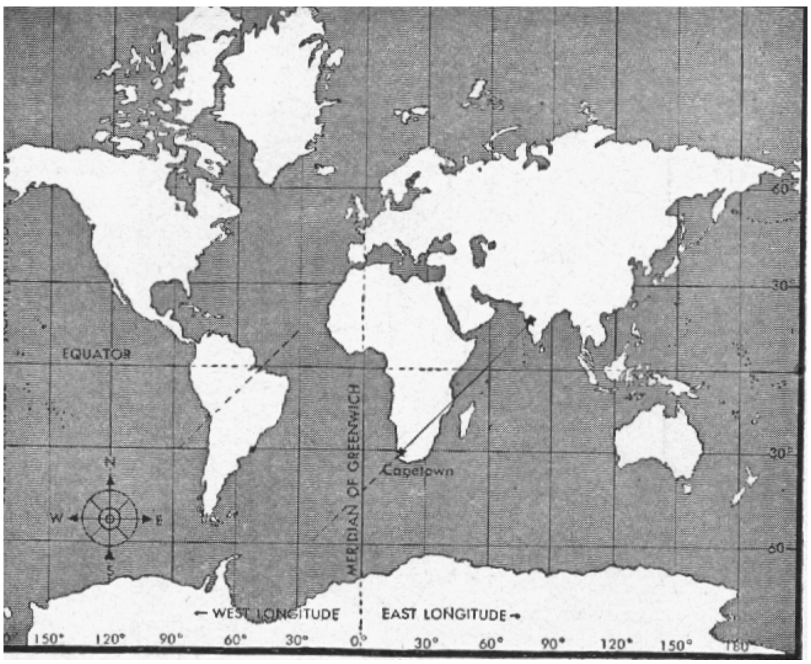


Fig 85. Mercator projection.

b. The advantages of the Mercator projection are ease of plotting or reading geographic coordinates because the parallels and meridians form a rectangular grid; and, ease of plotting and reading navigation courses of ships or aircraft. A compass course between any two points (such as Capetown and Bombay in fig. 85) can be shown by a straight line connecting them. Thus, the path of a ship or plane following a constant compass bearing appears as a straight line. Because the Mercator projection is used in instrumental navigation of ships and planes it is the standard projection for hydrographic charts (U. S. Navy), Navy air-navigation charts, and Army long-distance air-navigation charts of small scale.

c. One disadvantage of the Mercator projection is the increasing exaggeration toward the poles. On a Mercator map Greenland shows larger than South America though, in reality, South America is nine times larger than Greenland (fig. 86). Small-scale Mercator maps have the additional disadvantage that because of polar distortion usual type scales cannot be used to measure distance. However, this limitation does not apply to large-scale maps of small areas. It is important to know these characteristics to make proper use of Mercator maps and to guard against their false appearance.

3. TRANSVERSE MERCATOR PROJECTION. This projection is made on a cylinder tangent to a meridian. When laid out flat, the control meridian is a straight line; all other meridians and all parallels are curved lines similar in appearance to those of the polyconic projection described in paragraph 4. It is used for many British military maps of land areas, divided into belts that are long in the north-south direction and narrow in the east-west direction. Distortion in a grid on a map falling in a transverse Mercator Belt is a minimum because of the limited east-west area covered by the grid system.

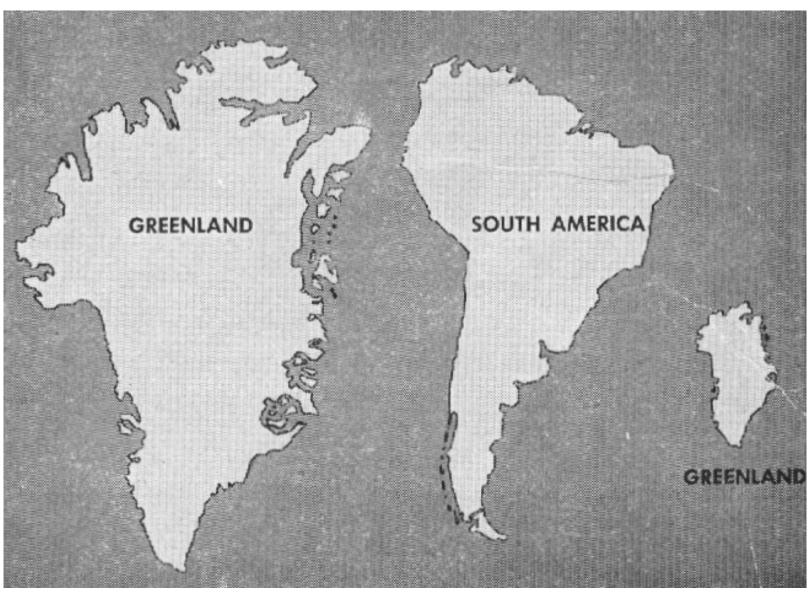


Figure 86. Example of distortion in Mercator projection.

4. POLYCONIC PROJECTION. a. The polyconic projection is used for U. S. military maps. The central meridian of the

area to be mapped is represented by a straight line, and the parallels are represented by arcs of circles that are not concentric but the centers of which all lie in the extension of the central meridian (fig. 87). The distances between the parallels along the central meridian are proportional to the true distances between the parallels of the earth. The radius of each parallel is determined by an element of the cone tangent to the earth along the given parallel. Distances between meridians are laid off on the parallels proportional to the true distances between meridians. Smooth curves drawn through the points thus determined give the respective meridians. Figure 87 shows the nature of the exaggeration introduced by this method of projection. The north-south distortion increases rapidly on polyconic maps of areas with large east-west dimension. Because of this, it is customary to limit the width of projection and to use the central meridian of the area to be mapped as the central meridian of the projection.

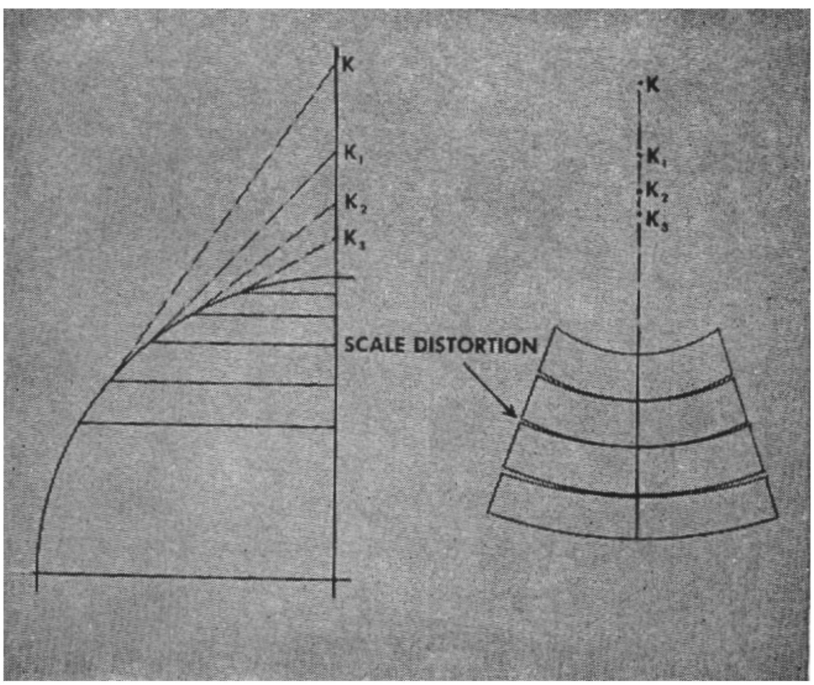


Fig 87. Development of polyconic projection.

b. The characteristics of the polyconic projection are true distance along its parallels of latitude, true distance along its central meridian, and exaggerated distance along all other longitude lines, with the greatest exaggeration at the east and west edges. Within a projection the width of the United States the distortion along the Pacific Coast would be around 7 percent in a north-south direction. The width of projection used for U. S. military maps is limited to 9° of longitude, and the maximum scale error in this width is only about one-fifth of 1 percent and therefore is negligible.

5. LAMBERT CONICAL ORTHOMORPHIC PROJECTION.

a. The Lambert conical orthomorphic projection (Lambert conformal conic) employs a simple cone tangent to the earth along a single parallel or intersecting the earth at two parallels known as the standard parallels for the area to be mapped (fig. 88). All meridians are converging straight lines that meet in a common point beyond the limits of the map. All parallels are concentric circles whose center is at the point of intersection of the meridians. Parallels and meridians intersect at right angles, and the angles formed by any two lines on the earth's surface are correctly represented on this projection.

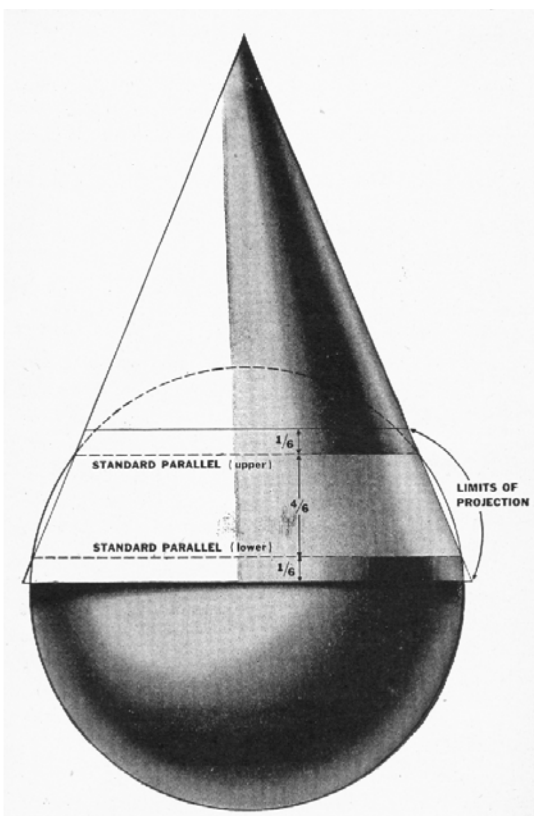


Figure 88. Lambert conformal conic projection.

b. To distribute scale error when two standard parallels are used, the standard parallels are chosen at one-sixth and five-sixths of the length of the central meridian to be represented. Between these parallels the scale will be too small, and beyond them too large. On military maps maximum scale error ordinarily does not exceed one-half c. This projection is specially suited for maps having a predominating east-west dimension. It was widely used in World War I and is used currently for many British maps. Because of its correct azimuth, it is also used for the Sectional Airway Maps of the United States.

6. CASSINI PROJECTION. On the Cassini projection the central meridian is a straight line. All other meridians and all parallels are curved lines similar in appearance to those on a polyconic projection. The Cassini projection is the basis of important maps of the United Kingdom and France. Its principal defect is that the north-south scale is exaggerated on each side of the central meridian. Beyond 220 miles from the central meridian this exaggeration is excessive for military purposes.

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