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THE UTILIZATION OF AERIAL PHOTOGRAPHS IN MAPPING AND STUDYING LAND FEATURES

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Division of Land Utilization
Land-Use Planning Section

THE UTILIZATION OF AERIAL PHOTOGRAPHS IN MAPPING AND STUDYING LAND FEATURES

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The primary purpose of this report is to present the advantages, disadvantages, and limitations of aerial photographs and mosaics in land-use planning and land classification studies.

The report is divided into two parts: Part I summarizes interpretation of aerial photographs and discusses their use as base in the field in lieu of outline maps; Part II deals with the methods and equipment used in taking aerial photographs. and was included in the belief that the information given will be of aid in understanding the discussion in Part I.

INTRODUCTION

While it is recognized that there are certain limitations in regard to accurate cadastral measurements inherent in all aerial photographs, recent experience has indicated that when used within their limitations for the purpose of base and area identification, location and picturization, aerial photographs contribute materially to the speed and facility of mapping, and to the compilation and study of data necessary in land classification and land-use planning projects.

For mapping features of Land Character and Land Use, aerial photographs perform two rather distinct functions, namely, identification and location. Contrary to some opinion, it is probably in the function of location that aerial photographs perform their greatest service to those who are mapping such features as vegetative types, soil characteristics, use of land, erosion characteristics, and slope.

The service of location does not depend solely on the photographs showing the boundaries and position of features to be mapped. Even where features are to be mapped, such as soil characteristics, whose boundaries the photographs show only occasionally, much time is gained through the fact that the boundaries may be located by reference to the boundaries of features which <u>do</u> appear on the photographs. In effect, each distinct feature shown on an aerial photograph, such as a tree, a field corner, or a bend in a stream, is a device by which the mapper may locate his own position, thereby locating the position of features not appearing on the photograph. The advantage of aerial photographs over line base maps lies in the showing of so many more such features which may be used by the mapper in keeping his location. In mapping upon base maps which show relatively few features, much time is consumed by the mapper in measuring distances and direction in order to locate properly the features he must map. The greater frequency of located points in aerial photographs reduces the amount of measuring necessary to locate other features.

Further, the fact that the boundaries of so many features are shown on aerial photographs, and that even trees, or edges of fields are, in effect, control for the field mapper, makes accuracy of location much greater than when boundaries are sketched in by estimating distance and direction, as is so often the practice.

The few features shown on outline maps, based on closely controlled theodolite or transit surveys, are generally accurately located, and distance and area measurements based on such points will show little or no error. In aerial photographs, however, tilt of the camera, lens distortion and displacement of image, cause errors to arise which will result in deviations from actual distances or areas. If the pictures meet contract specifications these errors generally slight, do not affect the value of photographs for land classification or land-use planning purposes. An example of the extent of error was demonstrated in an Agricultural Adjustment Administration project. Sixteen hundred and forty acres were measured from photographs, and later were accurately surveyed with tape and transit. When the figures were compared, it was found that those taken from the aerial photographs were less than three-tenths of one per cent in error.

The second function of aerial photographs, namely, the identification from the pictures of the kind or character of the features to be mapped, increases their usefulness as an aid to mapping many land characteristics, but is not, as is sometimes thought, the only or necessarily the principal justification for their use. In most cases identification of particular type, class, or character of the feature to be mapped must be obtained by actual visitation of the feature. Since, however, the boundaries of many features, such as cropped fields, forest types, etc. appear on the photographs, inspection of one part of such a feature will serve to identify it as a whole, and will save examining every portion.

When so much is shown, it is a simple matter to outline the various features being mapped, and to make the necessary annotation indicating their character on the pictures or on a superimposed transparent sheet. Aerial photographs, upon which the various features have been outlined, present a clear picturization of the area being studied, and permit rapid and accurate tracing or copying.

Part I

FIELD AND OFFICE INTERPRETATION AND USE OF AERIAL PHOTOGRAPHY

Use of Aerial Photographs in Field Surveys, Etc.

Mapping projects and surveys, based on aerial photographs, have been carried on extensively in recent years by the U. S. Coast and Geodetic Survey, the U. S. Geological Survey, U. S. Army Engineers, the Forest Service and other branches of the U. S. Department of Agriculture, various State governments and agencies, and numerous other public and private organizations.

Construction of Planemetric and Topographic Maps from Aerial Photographs

Accurate planemetric maps may be drawn from correctly rectified multiple-lens camera or vertical single-lens camera photographs by using a modified form of plane table triangulator, based on predetermined control points, to locate and orient points on the photographs so that they may be accurately plotted on the map under compilation.

In recent years, various instruments have been developed, utilizing stereoptical principles, which permit the drawing of topographic maps to an accuracy equal to 1/1,500 of the height of the airplane above the ground at the time the picture was taken. This accuracy is obtainable with a 5½ inch focal length camera, and varies with the focal length. There are reports of an instrument developed by Zeiss in Germany which permits an accuracy of one-tenth of one per cent, on 50 meter contour intervals.

Planemetric and topographic map compilation from aerial photographs offers many advantages over maps based on plane table surveys and field notes; control is often greater, and this feature, combined with the vast amount of detail in the pictures, makes more complete and accurate maps possible, frequently at much less expense.

Advantages and Disadvantages of Mosaic and Individual Pictures

Individual Pictures

Contact prints or enlarged copies of individual photographs taken by single-lens cameras are easier to interpret than mosaics, because they present a picture taken at a single point at a definite time.1/ This characteristic is in their favor, not only in the office, but also in the field, when the more uniform definition of the images is a distinct aid in identifying differences in cover types, etc., and when drawing in field and other boundaries.

The great advantage of the single photograph over the mosaic in field work is its size. A contact print from a negative, photographed at a scale of 1:20,000 covers a little over 6 square miles, and is only about 7 inches wide and 9 inches long. If a larger scale, such as 1:10,000 is desired, an enlarged print can be made from the same negative to a size of 14 inches by 18 inches. This size is about the limit for pictures to be used in field work, as any larger size would be awkward to handle.

The single photographs also offer an advantage in the limited area which they picture. A survey involving the mapping of land features in detail can cover only a relatively small section of the country in a day, and the single picture is the closest approach obtainable to the limits of a day's work. The single picture is, therefore, subject to much less handling and wear and tear than a mosaic, a factor which may be of importance, if maps or charts are to be compiled from the photograph. Constant handling soils photographs and causes cracks, dog-ears and similar blemishes which may interfere with accurate interpretation, or in the loss of recorded data.

Mosaics

Mosaics, because they are assembled from a number of photo-

1/ Variation in the angle at which photographs of an object or area are taken or variations in the height of the sun at the second of exposure of the negative will result in a difference in the appearance of the images of the object or area in different pictures. In single-lens photographs, the area pictured is photographed from a single point at a definite time. In mosaics, the pictures from which they are constructed may have been taken at various angles at different times, and a uniformity of appearance of similar objects and areas is frequently lacking. (See Part II.)

graphs taken from various points and at different times, present some difficulties in office interpretation, and are sometimes confusing in the field.2/

The greater area covered by mosaics, and the great number of control points they contain, are of sufficient value to compensate for the confusion of images characteristic of them when used for interpretation of a large area, or for planemetric mapping purposes, but in field work their very size is a distinct disadvantage.

When mosaics are assembled from photographs of large scale, the area covered must necessarily be quite small, if the resulting picture is not to be unwieldy for field use.

The Tennessee Valley Authority used mosaics having a scale of 1:24,000 in field work. Each field party covered about 20 square miles a day, and required a mosaic of at least 9 by 14 inches to picture the area to be surveyed. If, however, it had been necessary or advisable to work with a larger scale, such as 1:10,000, the mosaic necessary to cover the same area would have been about 22.5 x 35 inches, an extremely awkward size to handle in the field.

Mosaics, depending upon the work in which they are being used, may depict more area than it is possible for a field party to cover in a day. Consequently, the mosaic is handled excessively, images are smeared or obliterated, the picture is soiled and cracked, and data which have been entered become obscured. The ultimate result is that the value of the picture for mapping or other purposes is seriously impaired.

Office and Field Interpretation of Aerial Photographs and Mosaics. The principal limitations of aerial photographs are their inability accurately to define relief, and to indicate features hidden under natural cover. But the intelligent use of aerial photographs does not require any more skill or training than is necessary to use topographic and base maps. Successful interpretation is dependent upon good eyesight and a good understanding of topographic and cultural features combined with the use of interpretive imagination, tempered by sound judgment.

To one thoroughly familiar with aerial photographs, single pictures or a mosaic of an area will give a great deal of information. Fields, pastures, forests, streams, roads, buildings, and even types of buildings can be identified, while, if the scale is sufficiently large and the images are sharp, various types of cover can be determined.

2/ See note on preceding page.

Not all features may be determined from the photographs, however, and actual field work is always necessary if all images and areas on the mosaic or photograph are to be correctly indentified.

Glossy prints should be used in studying photographs or when area outlines and annotations are made on a transparent cover sheet in field work, as such prints show detail much more clearly than do dull finished pictures. When data are entered directly on the pictures, matte prints are more satisfactory for field work, as they take and hold ink and pencil notations with greater ease.

Methods, Use and Interpretation of Aerial Photographs

The following descriptive data on the methods of use and interpretation of aerial photographs summarize the material derived from various individuals and publications, and are believed to be generally usable and accurate.

Determination of Cardinal Points

Aerial photographs and mosaics will ordinarily have the north point indicated either on the back or somewhere along one of the sides, although occasionally directional indicators are missing. When such is the case, north can be determined by locating two images on the photograph and by drawing a line between them; then this line may be compared with a line connecting the same two images as indicated on a base map, or the direction of the line may be determined from direct observation between the two points in the field.

Determination of Scale

The scale of most mosaics and photographs is indicated on the back or at the foot, but if it is lacking, it may be determined by obtaining from an accurate map or survey data the exact distance between two points which appear clearly in the picture. Measuring the distance between the two images accurately, the scale may then be determined as follows: reduce all measurements to a common unit, such as one inch; then the ratio between the distance on the mosaic or picture and actual ground distance will give the scale. There may be slight variations in scale between contact prints taken on the same flight, but these, if the pictures are according to specifications, will be slight.

Method of Examination of Mosaic or Picture

After direction and scale have been determined, face the source of the light and hold the photograph or mosaic so that the shadows in the picture appear to fall toward you. If the photograph is held in this way, relief will appear naturally. If it is held with the shadows falling away from the eye, relief will appear inverted; cuts will look like embankments, hills like valleys, etc.

It is generally helpful to orient the photograph with a map when identifying important features, visual relief, etc. Oblique pictures of the area, field personnel notes, and other data aid in this work.

The pictures should be examined systematically with a glass, and attention should be concentrated on small areas rather than on the entire photograph. All images appearing in the picture as straight lines and regular forms may be accepted as the work of man, for there are no geometrical figures or straight lines in nature.

In general, objects which form regular lines in aerial photographs and are common topographic features such as fields, railroads, ditches, houses, streams, etc. are easy to identify, because in the photographs they appear much like the symbols used to identify them on topographic maps. Difficulty arises, however, in the case of small or concealed objects, and objects or areas which do not present any contrast of shade to surrounding objects or areas.

Shadows are helpful in many instances in identifying small or concealed images, and they are also useful in determining heights of objects by comparing the length of the shadows with those of objects of known height or depth.

Use of Aerial Photographs in Land Classification

The major activities to which aerial photographs and mosaics lend themselves in land classification and land-use planning are the actual mapping of an area under investigation, and the subsequent interpretation of the data entered on the map. The following summaries give the characteristics of aerial pictures which facilitate such operations and the methods of utilizing the characteristics in various types of surveys.

Methods of Delimiting and Annotating Features on Aerial Photographs. Two methods are used in annotating and delimiting areas on aerial photographs: one is to draw lines and make annotations directly on the picture; the other is to superimpose a transparent sheet of celluloid or similar material on the photograph, to trace the areas, and to make the notes on this sheet.

The first method generally gives a clearer picturization of conditions in the area, as it contains images of practically everything in the region, but if prints are scarce, it is not advisable, as once a print is marked up, it may not be usable again. Some difficulty may also be encountered in tracing outline copies of an area marked directly on the print, as dark areas may obscure inked outlines or notes.

The second method takes a little more care as the ink is not absorbed readily and may smear, but this method has several advantages. The outlines are easily traced from the transparent sheet, all notes and lines are clearly visible, and the print may be used many times for various surveys. By placing the tracing over the print, practically as clear a picturization is given as would be shown on a print on which the data had been entered directly.

Field and Office Identification. On an aerial photograph, the uniformity of images of similar areas on the ground is one of the characteristics of the pictures which contributes most to accurate and rapid mapping of the various features in an area.

Outlines of areas covered by similar features are generally clearly shown in the pictures, and identification of a portion of the area by visitation may be applied to the entire area covered by like images on the pictures. In some instances when greater detail is wanted, such as areas of unlike crops, the variations between which are not distinguishable on the picture, more field work is required to identify the differences. But even in work of this type the photographs aid, for a large part of the individual outlines are shown, and accurate location of other boundaries is a simple matter because of the many control points pictured in the photographs.

This method of identification has been applied successfully to forest type and stand classification, as similar types and stands are likely to have similar images.

Density of vegetative cover is also clearly indicated in most aerial photographs, and often more accurate information on this point may be obtained from the pictures than from mapping on the ground only.

Interpretation of Topography. It is, in many cases, desirable to have an accurate idea of the surface configuration or topography in evaluating land utility. No practicable method has been developed for use in the field to show relief clearly on aerial photographs, other than the simple stereoscope. This instrument indicates relief quite plainly, but it is seldom shown in true scale. There are stereoscopic instruments which permit quite accurate determination of topography, but they are large, costly and complicated, and suitable only for office use.

However, topography of an area may be inferred in various ways by studying the images of drainage patterns, shadows of hills, trees, forests, bends in roads, railroads, contour plowed and eroded fields, cuts and embankments. The relative location of these features is a good index to topographic conditions, especially in areas where the land-use pattern is well established, such as a region where smooth land is generally cultivated, and where hillsides are used as pasture or woodlots.

These features make the outlining of particular areas easy, since once the degree of slope is determined in the field, sufficient detail is generally shown in the pictures to delimit their extent accurately.

Soil Surveys. Soil maps delimit each body of land having soil characteristics different from adjacent bodies. Soil survey reports tell if these bodies are smooth or hilly, well drained or poorly drained, and they show the texture, structure, and certain chemical characteristics of soil and subsoil. All of these qualities must be determined by actual inspection on the ground, since most of them are not visible in aerial photographs.

Outline or topographic maps have ordinarily been used as base in such projects, but aerial photographs or mosaics as base offer many advantages over them.

The color of the soil, which may be an important indicator of certain soil characteristics, such as organic matter content, affects the image of various areas on the negative by variations in depth of shade. In places where the ground is not obscured by vegetative cover, the more strongly contrasted color differences are clearly seen on a photograph, and may be readily outlined.

Topographic differences frequently represent differences in soil characteristics. The characters of the soils at the tops, on the slopes, at the bottoms, and in the valleys of an area are often different. The indications of topographic features evident in aerial photographs facilitate the outlining of these various areas.

Perhaps the greatest usefulness of aerial photographs in soil mapping, however, is in the great saving in the amount of measuring necessary to determine the location of boundaries. This results, of course, from the aerial photograph having an enormously greater number of located points and landmarks than an ordinary line base map.

Erosion Surveys. Aerial photographs frequently picture clearly areas of gully erosion even in its early stages, and areas where sheet erosion has progressed to any extent may often be determined by the difference in shade on the negatives, between areas covered with top soil and those where the subsoil is exposed. As in soil surveys, erosion surveys require actual field investigation, but the same characteristics of aerial photographs facilitate the accurate and rapid mapping of the different areas.

Drainage and Water Resources Surveys. The evidences of topography shown on aerial photographs and mosaics make them particularly valuable in surveys of this type. Pools, ponds, reservoirs, lakes, streams, and canals are clearly pictured on photographs, and slopes, approximate drainage basin areas, etc. may be readily identified and outlined.

Surface water will vary in appearance on the photographs according to the time at which the pictures were taken; sometimes it will reflect darker than the general area, and at other times, it appears as a dead white in the picture, but there is seldom any difficulty encountered in accurately delimiting the areas of any body of water.

In underground water surveys, outcrops of water-bearing strata are sometimes shown in the pictures, while springs and wells may be easily and accurately located by relationship with adjacent cultural or physical features shown on the pictures. If well depth and other pertinent information is obtained, dip and strike of the various strata may in some instances be calculated, and prospective well sites determined.

Mapping of Property Lines, Etc. In areas or States which have not been subdivided according to the General Land Office rectangular survey, the drawing of property maps is generally a difficult operation, but aerial photographs can do much towards facilitating and simplifying this work.

The great amount of detail contained in an aerial photograph makes it possible for most landowners or operators to locate personally the boundaries of their property by reference to the various fields, pastures, woodlots or fences which appear on the photograph. This is practically an impossibility for some of them when they are confronted with an outline map of the area.

Property maps, the boundaries of which are located by reference to the landmarks shown on aerial photographs, while not accurate within close limitations, will give only minor errors in approximations of the size, shape, and distribution of the individual properties in an area. Maps of equal accuracy and detail could not otherwise be obtained readily without considerable expenditure of time and funds for ground instrumental survey.

In some instances a photogrammetric survey will provide even better results than the conventional ground survey. This is especially true when boundaries follow irregular and tortuous natural features, such as creeks and river banks in swampy ground, difficult of access but distinguishable on the photographs. This method has been used recently in connection with acquisition of rights-of-way and mineral properties in cases where an accurate ownership map was required.

Present Land Use, Vegetative or Cover Type Mapping. Surveys of present land-use represent one type of activity in which aerial photographs are of the greatest aid. Fields, pastures, woods, streams, buildings, etc. are shown in such great detail that it is a simple matter to outline their areas and even to identify some of their characteristics.

Fields of cultivated crops may generally be identified from their images in the pictures, but wild vegetative cover types ordinarily must be identified by ground inspection.

Corn or other row crops may frequently be differentiated from grass, small grain, or other broadcast crops, in aerial photographs, especially if the scale of the picture is large.

Orchards can readily be recognized in the photographs by the characteristic regular spacing of the trees. In some areas, with pictures of sufficiently large scale, type of orchard may be determined.

Woods photograph generally as dark masses frequently of irregular outline and size, but even when the boundaries are regular, they are easily identified in the pictures. Types of forests photograph differently: images of deciduous trees have a different shade in the photograph than do images of coniferous trees. Differentiation between forest types is also aided by seasonal conditions, as for example, when deciduous trees are bare. This condition is frequently valuable in making estimates of the number of coniferous or deciduous trees in mixed stands. Estimates have even been made of the amount of a particular species in forests composed largely of one genus. In New England, such an estimate was made based on the distinctive color of certain trees in the fall which gave their images in the photographs a different shade.

These characteristics of the images of crop and other cover type in photographs make it a simple matter to outline the areas of common features after they have been ascertained by field survey.

Community Pattern Maps. Mapping of community patterns is also aided considerably by the use of aerial photographs. Buildings are generally shown on the photographs. Roads, railroads, and other travel facilities are clearly indicated. Power and telephone lines are sometimes not as easily identified on the pictures, but a field survey, using the picture as a base, permits them to be easily and quickly mapped.

A completely outlined and annotated aerial photograph or mosaic gives a clear and accurate portrayal of the community pattern superior to that entered on an outline map, because of the completeness of detail, and greater accuracy of location.

The mapping of population distribution is also facilitated. Practically every house, school, church, etc., in an area is pictured in an aerial photograph, and simple annotations beside each building shown in the picture will give a complete and comprehensive presentation of the location of population in place.

Other Items. When the cultural and natural features of an area have been entered on a picture or mosaic, it may be desirable to have additional information shown, such as school district boundaries, or intent in ownership. This type of data may often be entered on the pictures in the office, and accurately located with respect to the various sections of the area easily and quickly.

Other Uses of Aerial Photographs and Mosaics

The detailed picturization of an area presented by aerial photographs has caused them to be used in connection with certain special types of work such as: tax equalization studies, valuation for tax assessment, etc. A survey of the above kind disclosed that in one county only about 60 percent of the taxable lands were on the records. In this case the additional revenue within one year paid for the cost of photographing the county.

In California one of the larger cities has used aerial photographs extensively in determining the advisability of extending public services and utilities into new areas.

Their use in such activities suggests their usefulness in rural zoning, civil division reorganization, and other activities where detailed and accurate presentation of natural, cultural and economic features are necessary. In line with activities of this type, the use of aerial photographs for educational purposes to acquaint the public with the problems and their treatment becomes evident.

Obtaining Aerial Photographs of an Area

Data on areas of the country which have been photographed are available in the Section of Photo Mapping, U. S. Geological Survey -Major J. H. Wheat, Chief; or in the Photogrammetry and Drafting Unit, Conservation Survey Section, Soil Conservation Service, Mr. M. S. Wright, Head. Both of these organizations can supply information regarding areas which have been photographed, the type of camera which was used, the scale at which the pictures were taken, the date on which they were taken, and whether prints or negatives are available, and if so, where. If such information is needed, however, it should be requested through Dr. C. P. Barnes, Land Classification Unit, Land-Use Planning Section, Land Utilization Division in the Washington office of the Resettlement Administration.

Many areas have been photographed by the U. S. Army, but unfortunately at present it is difficult to get prints. However, prints of the areas flown by the Army are in many cases available from the U. S. Coast and Geodetic Survey or from the U. S. Geological Survey, and may be borrowed for copying.

Pictures of other areas photographed by commercial firms may be purchased. When such pictures have been taken for U. S. Government agencies, a special price may be available to other Federal government units. In some cases, the negatives are the property of such agencies and may be borrowed from them for copying. When the negatives have not become the property of a governmental agency, but are retained by the photographing company and no price concession was arranged by the contracting agency for other governmental agencies, or if pictures are wanted of an area photographed for other than such agencies, market price will have to be paid for prints.

Before any photographs are purchased or copied, they should be carefully examined to determine their suitability for the purpose for which they are to be used. If they satisfy the requirements of the Standard Specifications of the American Society of Photogrammetry, of November 15, 1935, or the Standard Specifications for Aerial Photography for General Mapwork and Land Studies, now being compiled by various governmental agencies, they are likely to be satisfactory for most of the aspects of land-use planning in which aerial photographs are helpful. For some uses, it may not be necessary to hold to all of the requirements of these specifications, but in general it is very desirable that contracts should be based on the above specifications and stringently adhered to. This will insure their wide usefulness. No pictures should be accepted until they have been carefully examined as to their conformity with the specifications.

Part II

METHODS AND EQUIPMENT USED IN AERIAL PHOTOGRAPHY AND CHARACTERISTICS OF VARIOUS TYPES OF PICTURES

Flight Maps

On any aerial photographic project, except when a single picture or a survey strip of a definite and distinctive landmark such as a power line or stream is to be taken, flight maps are a necessity. Practically any map presenting adequate topographic and cultural features is satisfactory, but if such a map is not available, a special flight map may be made of the area to be photographed by sketching the major cultural and natural features from whatever source material exists.

Ground Control

To use the photographs in drawing accurate maps or in assembling satisfactory mosaics, the establishment of definite ground control points is necessary. These points are later used in scaling the pictures, in orienting and locating points in the pictures for mapping purposes through the radial line method, and in matching the pictures when compiling mosaics.

The points or stations selected should be such that they will be readily identified on the photographs, and their locations should be determined by accurate survey methods. Points may be Land Office section corners (generally at crossroads and easily located on the pictures), fence or building corners or any other fixed objects easily identified in the photograph. If suitable topographic features are not available, the control points are often indicated by a circle of lime or other white material, having a boundary four or five feet in width, and a diameter of fifty feet, about the center. White bunting or cheesecloth in pieces six to eight feet square may be staked out in the form of a cross, the point being the center.

Scales

Scale in an aerial photograph is the same as the scale on a map, and may serve the same purpose. The scale is generally expressed by the representative fraction "RF" such as 1:10,000, which indicates that 1 unit of length on the photograph is equal to 10,000 such units on the ground. The scale is sometimes expressed as: one inch equals 1,320 feet, or some similar, easily understood ratio.

The ultimate use determines the scale at which aerial photographs will be taken. Photographs have been taken at different scales for the various governmental agencies in the past, but at a recent conference the Department of Agriculture Sub-committee on Specifications for Aerial Photographs endorsed a standard scale of 1:20,000 for contact prints. This scale is in agreement with the national mapping plan of the Board of Surveys and Maps, and will result in a greater applicability of pictures taken of an area to the many uses in which they are serviceable. 1:20,000 appears to be a scale which permits enlargement or reduction within the scope of scales found desirable by the various agencies, without loss of important detail.

In some areas, such as desert regions and regions with small populations, a scale smaller than the 1:20,000 recommended may be used, as detailed picturization is not as commonly of prime importance in such sections, and the decreased cost of photographing would make such a deviation from the standard desirable. The Sub-committee believed a scale of 1:31,680, or 2 inches to the mile, would be satisfactory for such areas.

The scale of the photograph is controlled by the focal length of the camera and the height of the plane <u>above the area being photographed</u>. The following formula expresses the relationship: S equals $\frac{l}{L}$ equals $\frac{f}{h}$ Where: S equals scale; L equals distance between two points on the ground; l equals the distance between the image of the same two points on the photograph; f equals the focal length of the camera; and h equals the height of the camera above the ground.

Tables have been compiled which show the various relationships between the different factors when pictures at a certain scale are desired. The following table is an example of such a compilation:

DATA FOR USE IN COMPILING SPECIFICATIONS FOR AERIAL PHOTOGRAPHS

K Type - 7 x 9 Single Lens

Exposures per loading - 110

Scale	1:12,000	1:18,000	1:24,000	1:30,000	1:36,000
Alt.-12 in.f.l.a/	12,000 ft.	18,000 ft.	24,000 ft.	--------	---------
Alt.-8.25 in.f.l.a/	8,250 ft.	12,400 ft.	16,500 ft.	20,600 ft.	24,800 ft
Alt.-6.0 in.f.l.a/	6,000 ft.	9,000 ft.	12,000 ft.	15,000 ft.	18,000 ft.
Gross Width b/	1.70 mi.	2.56 mi.	3.40 mi.	4.25 mi.	5.12 mi.
Net (70%)c/	1.20 mi.	1.80 mi.	2.38 mi.	2.97 mi.	3.58 mi.
Exposure Spacing	.52 mi.	.80 mi.	1.04 mi.	1.32 mi.	1.60 mi.
Gross Area b/	2.26 mi.	5.10 mi.	9.08 mi.	14.10 mi.	20.40 mi.
Net Area c/	.62 mi.	1.45 mi.	2.48 mi.	3.92 mi.	5.80 mi.
Area Per Load	70 mi.	160 mi.	275 mi.	430 mi.	640 mi.
Area per hour at 80 Miles Per Hour	96 mi.	144 mi.	190 mi.	238 mi.	287 mi.

a/ Altitude is height above ground.

b/ Width or area covered by each photograph without overlap. (See next two sections.)

c/ Unduplicated area or width covered by each photograph with overlap. (See next two sections.)

If photographs have not been taken so that contact prints are of the scale desired, they may be enlarged or reduced to a suitable scale. Enlargement up to three diameters may be made from a negative with little loss in definition.

The greater the height of the airplane, the smaller the scale of the photographs. It has been general practice to take pictures at as small an "RF" as is practical for use in the manner intended, because that is most economical. Another advantage in smaller scale pictures is that the greater the height of the airplane, the smaller is the displacement of ground images on the plate due to topography. (See Fig. IV)

Flight Lines

After determining the scale at which the photographs are to be taken, flight lines to be followed by the pilot are drawn on the map or sketch to be used as a flight map. The flight lines must be sufficiently close together to insure proper overlap of the picture along the edge. A table such as that shown above is used to determine their interval. It will be noted that the table shows the width of the ground area covered by photographs of various scales. The flight lines are generally drawn by the contractor on maps supplied by the party letting the contract.

Overlap

Aerial photographs for use in map making and mosaics must be flown with considerable overlap of pictures. The overlap along the long axis of the flight lines, it is generally agreed, should be 60 percent, with a variance of not more than 5 percent either way, while the side overlap of each strip should be 30 percent, with a variance of not more than 15 percent either way.

In multiple-lens camera photographs, longitudinal overlap is based upon the center vertical picture as on the single-lens camera pictures, while lateral overlap is based on the wing pictures.

The longitudinal overlap is needed in order that every point of the ground control will appear in at least three consecutive prints. This is necessary if the radial line method is to be used in compiling maps.

The lateral overlap is necessary if the two flights are to be tied together properly; it also strengthens the entire net of graphic control.

Cameras, Pictures and Mosaics

The cameras used in aerial photography are of two general types: single and multiple lens with a number of variations and combinations in each type according to focal length, number of lenses, etc. The ultimate use of the photographs determines the type of camera which will be used.

Multiple-Lens Cameras and Pictures

The multiple-lens camera has evolved from a three- to a five-lens unit, and the Coast and Geodetic Survey is now experimenting with a nine-lens unit. Combinations have also been used, such as mounting two five-lens cameras in tandem, one being in standard position and the other turned so that the longitudinal and lateral axes are at an angle of 45° to the same axis of the first camera. The purpose behind this combination is to fill in the blank area between the wing pictures of the regular five-lens camera. (See Fig. II-B in the appendix.)

Since the fall of 1935, most United States Army photographs have been taken with five-lens cameras. Prior to that time, four-lens units were in general use. The three-lens cameras have not been used for several years, and it is doubtful if there are any in existence at present.

The value in increasing the number of lenses in a camera lies in the greater ground area covered by the pictures and the consequent increase in the number of control points which it is possible to include in each set of photographs.

As can be seen from Figs. I-b and II-a in the appendix, the central or B-lens of a multiple-lens camera takes a vertical picture, but the A, C, D, and E lenses take oblique pictures.

A photograph taken with a vertical camera shows all topographic features in approximately the same scale and proportion, but an oblique photograph contains perspective; that is, distant objects are pictured at a relatively smaller scale than nearby ones, and there is no uniformity of scale. For this reason oblique pictures are unsuited for mapping purposes, unless transformed onto a plane of the horizon.

Transforming is done with a special camera, each aerial camera having its own transforming unit which is not suitable for use with any other camera. The transformer is built to certain geometrical and optical measurements, matched to the lenses of the particular camera to which it is an accessory so that it will accurately perform its functions. The Geological Survey has a universal transformer which may be adjusted to fit any camera. It is believed to be the only one in the country, and is not used except under extraordinary circumstances, as it is a highly complicated instrument and very expensive to operate.

The principle of the transformer is based on the fact that the points on any ground line parallel to the horizontal plane of the negative in its original position in an oblique camera, are in their true relative positions on the image of the line on the negative, but images on such lines near to the camera are pictured at a larger scale than those at a distance. The transformer enlarges distant images and reduces nearby ones in such a way that the resulting picture is the same as it would have been if the original negative were parallel to the plane at the moment of exposure. The photograph resulting from the transforming of the original oblique negative has the form of an isosceles trapezoid, and represents the area covered by the photograph in true proportion throughout. Figure III illustrates this principle.

Multiple-lens camera photographs are satisfactory for planemetric mapping of areas where ground control is scarce. The pictures cover a wider area than do single-lens photographs taken at the same altitude. This wider coverage allows more control points to be shown in the pictures, and permits flight lines to be spaced at greater intervals. The increased distance between flight lines is reflected in lower costs, as fewer flights are required and fewer pictures must be taken.

The greater number of control points included, and the accentuation of relief, causes multiple-lens pictures to be easier to adjust when they picture areas containing few ground controls. This is particularly true when topographic features are used as controls. Hills, ridges, etc., are more clearly pictured in oblique pictures than in vertical pictures, and as a result the compilation of maps by the Radial Line method is sometimes facilitated. This accentuation of topographic detail, however, is one of the features which presents a serious drawback to the use of oblique pictures in certain types of work. The accentuation is due to the smaller angle at which the optical axis of the camera meets the plane of the horizon. This results in more displacement of images than is encountered in vertical pictures and complete visibility of the entire area is prevented. (Figure IV in the appendix illustrates the reason for this displacement). Image displacement handicaps accurate matching of pictures for mosaic purposes, especially in areas of rough topography, and the omission or hiding of many areas makes their use inadvisable for surveys or maps of the kind necessary in land-use mapping or land classification work.

Single-Lens Cameras and Pictures

Single-lens cameras are the type generally used in taking photographs for most mapping purposes. They take a vertical picture which shows all topographic features in approximately the same scale and in greater detail than multiple-lens cameras, without excessive displacement of image. However, they offer some difficulty in interpreting topographic features, which must often be deduced from patterns in the picture, and they cover much less area than a multiple-lens camera photograph taken at the same altitude. (See Fig. II-A in the appendix.) Most of the commercial aerial photograph firms use single-lens cameras.

Single-lens camera pictures taken at high altitudes can cover nearly as much area as multiple-lens camera pictures, and will include almost as many control points with less distortion and with much less image displacement. They are, however, more expensive to take because of the height at which the airplane must fly, and they must be enlarged to a much greater extent for use. If enlargement beyond four or five diameters is required, sharpness of line and image is generally sacrificed.

Because of their full picturization of an area and their closer approach to a uniform scale, single-lens camera pictures are the most satisfactory for use in compiling maps and mosaics for land-use mapping and land classification purposes. The pictures, however, should be taken using a sufficiently large scale, such as that recommended by the Subcommittee on Specifications for Aerial Photographs of the Department of Agriculture.

In areas containing many cultural features, such as cities, low altitude single-lens camera pictures are most satisfactory. The pictures are on a comparatively large scale, and may be successfully enlarged four or five times without too great a sacrifice of clarity. The original cost of such photography is high, but the sharpness of image and detail present in the picture makes their use in such cases desirable.

Mosaics

Mosaics are composite pictures constructed from the small center portions of vertical pictures, and the inside and central areas of oblique pictures so as to give as nearly as possible the effect which would be obtained from a single vertical picture of the area shown. All pictures used in the construction must be accurately transformed and printed to a uniform scale. The center and inside sections only are used, because in the central portion of all pictures lens distortion is at a minimum, while the inside area of oblique pictures has less displacement of image. Even when care is taken in scaling and transforming, mosaics do not present areas and distances accurately, and are generally unsatisfactory if constructed from oblique pictures, because of the amount of image displacement present. Mosaics constructed from vertical pictures, however, contain a wealth of information not shown on even the finest maps, and are excellent for use as base in field surveys and for area picturization, as inaccuracies are seldom sufficiently serious to interfere with their use for such purposes.

Controlled mosaics of an area of low relief, constructed from vertical photographs, approach in correctness a map accurately drawn from ground surveys. They picture clearly and locate quite accurately almost all topographic and cultural features, and when used in estimating area and distance, give reasonably accurate answers.

Flying the Camera

The accuracy of scale and sufficiency of overlap in aerial photographs depend entirely upon the skill of the pilot and his photographer. The high quality of much of the work which has been done speaks for them.

Uniformity of scale in an aerial photograph is approximate only, even in country of low relief, as contour variations are pictured at varying scales depending on their distance from the camera.

Pictures at a uniform scale may be obtained only if the plane is flown at a constant elevation above the ground. Any variation in airplane altitude above the ground between exposures of the negatives will result in a difference in scale between pictures. Consequently, depending on the extent and direction of the deviation of the ship from the given height the resulting photographs will have to be enlarged or reduced, in varying ratios, to a common scale.

Of even greater importance is tilt of the camera. Tilt results in a single-lens camera giving a picture similar to that taken by one of the wing compartments of a multiple-lens camera, with the added disadvantage that such a picture is extremely difficult if not impossible to transform accurately. In a multiple-lens camera tilt results in a distortion of the uniformity of relationship between the various pictures which is practically impossible to correct. If, however, tilt is less than 3°, distortion is not sufficiently serious to affect the accuracy of pictures for ordinary use.

One error-creating factor impossible of correction or control is the actual slope of the terrain. This will cause distortion, even where the camera is horizontal, as its effect is the same on the negative as though the camera were tilted. However, in most areas it is not sufficiently important to affect seriously the use of the pictures for land classification or land-use mapping purposes.

Flying Conditions

Flying conditions are a considerable factor in determining the excellence of aerial photographs. Scattered clouds shadow underlying terrain and make otherwise perfect flying days useless as far as photographs are concerned.

The angle of the sun is also important. In latitude 40° N., the hours between 10 A. M. and 3 P. M. are generally best for photographing, as they result in less shadow and clearer pictures. If, however, accentuation of certain features is desired to give a greater sense of relief, later or earlier flights may be desirable.

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APPENDIX

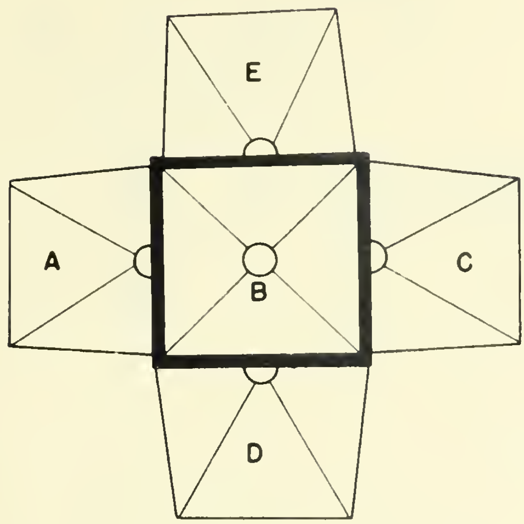


Figure I-A. Vertical view of arrangement of camera compartments in a multiple lens camera:

3-Lens camera has compartments A, B, and C.
4- " " " " A, B, C, and D.
5- " " " " A, B, C, D, and E.

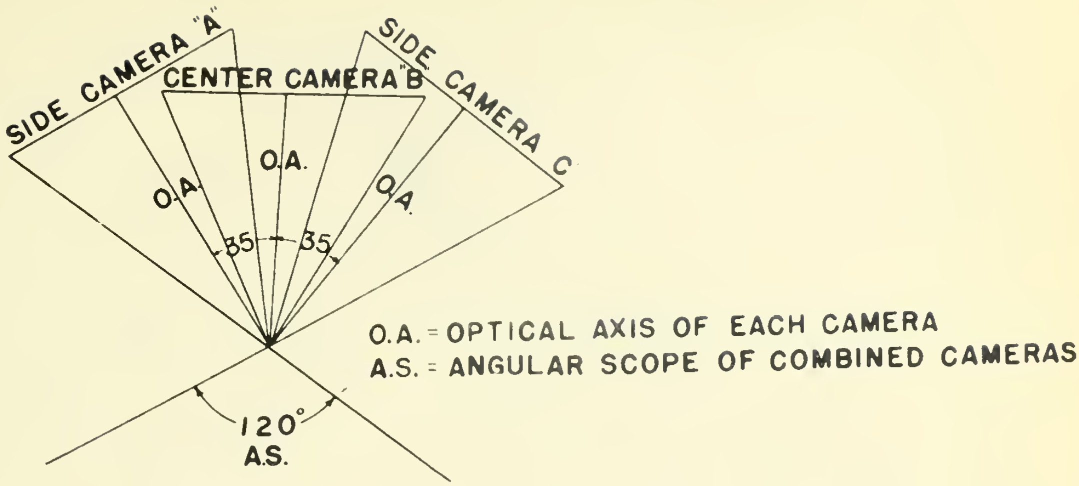
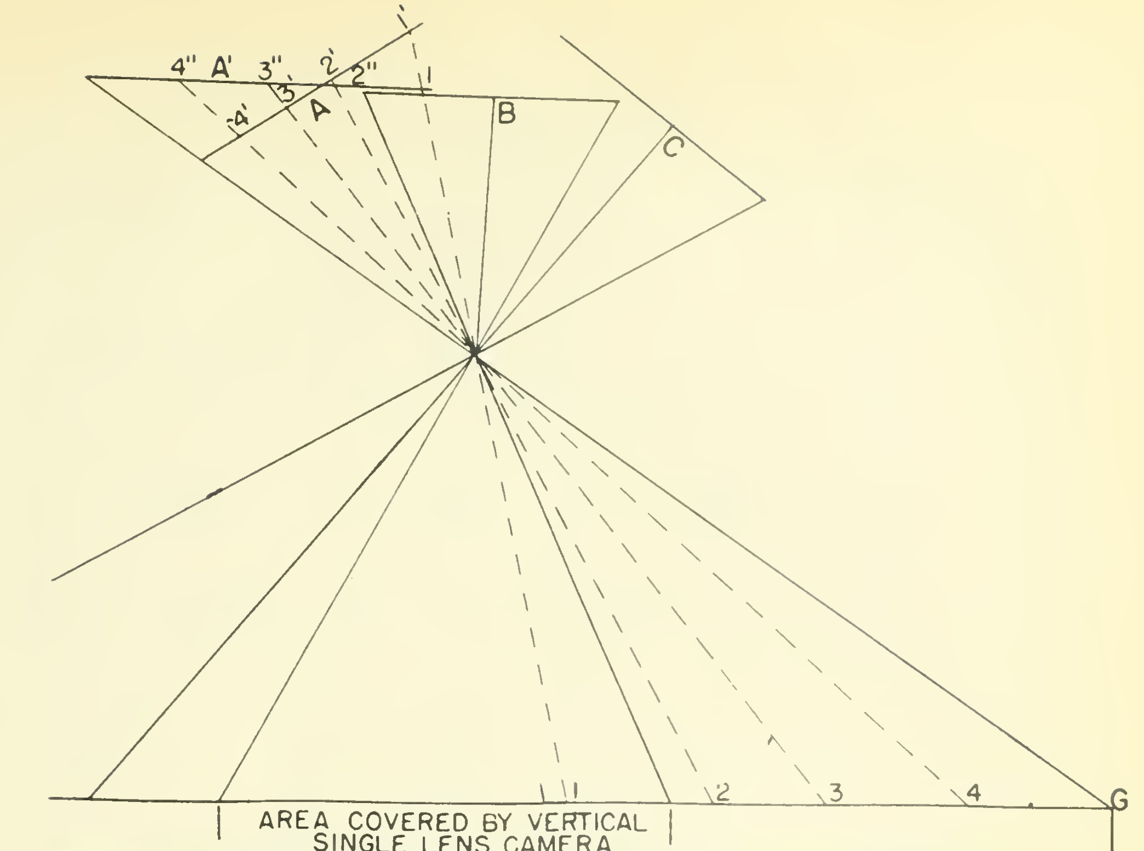


Figure I-B. Horizontal view of arrangement of plate holders and lenses in a multiple-lens camera. E and D cameras are arranged in the same relative positions to the "B" camera as A and C cameras, but they have fore and aft positions respectively.



AREA COVERED BY A MULTIPLE LENS CAMERA. PROPORTIONAL AREAS ALSO COVERED IN REAR AND FORWARD DIRECTIONS BY D & E LENS.

Figure II-A. Area covered by single and multiple-lens cameras; and relation of points on the ground to their images on the inclined negative, and to their images projected onto a horizontal plane.

A: The negative in its original position in the camera.

A': The relative position of the negative transformed to a plane parallel to G.

G: The ground area covered by the photograph. The points 1, 2, and 3, 4, delimit equal distances on "G".

The images of 1, 2 and 3, 4 on A; 1', 2' and 3', 4' respectively, do not delimit equal distances. Points 4', 3' are closer together than points 1', 2'. But if the points 1', 2' and 3',4' are projected to the horizontal plane "A'", the distances delimited by 1", 2" and 3", 4" are equal.

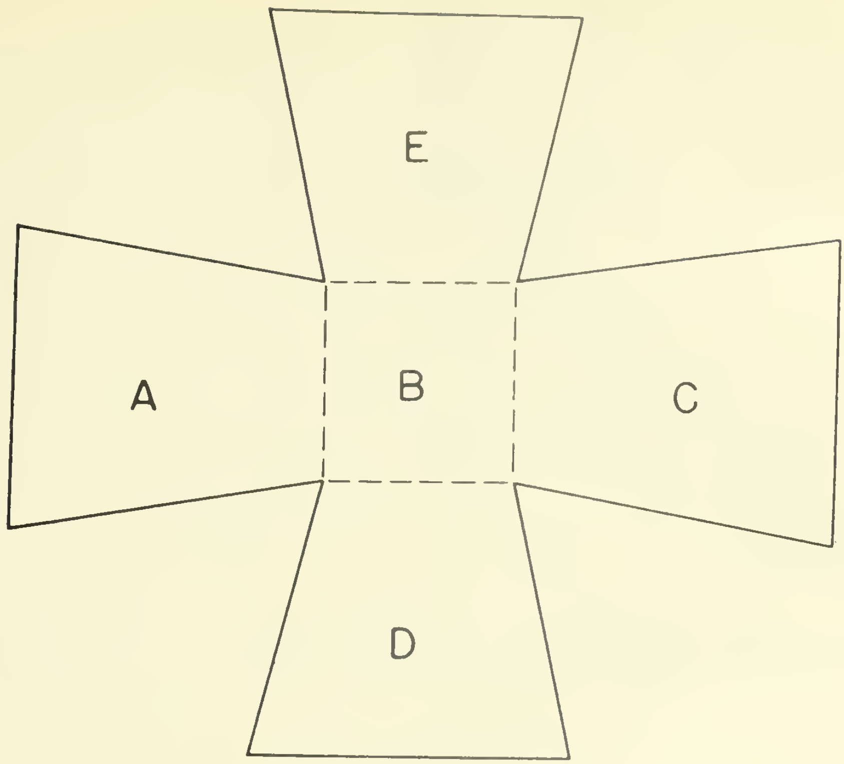


Figure II-B. Outline of ground area covered, and shape of transformed photographs taken with multiple-lens and single-lens cameras.
"B" is the outline of the ground area covered by a vertical picture taken with a single-lens camera; or the "B" camera of a multiple-lens camera. It does not require transforming to a common scale.
A, C, D and E represent the ground area covered by the wing cameras of a multiple-lens camera. The original wing negatives have the same shape as B, but transforming results in the shape shown. A three-lens camera covers a ground area as outlined by A, B and C, a four-lens camera, A, B, C, and D, and a five-lens camera, A, B, C, D, and E.

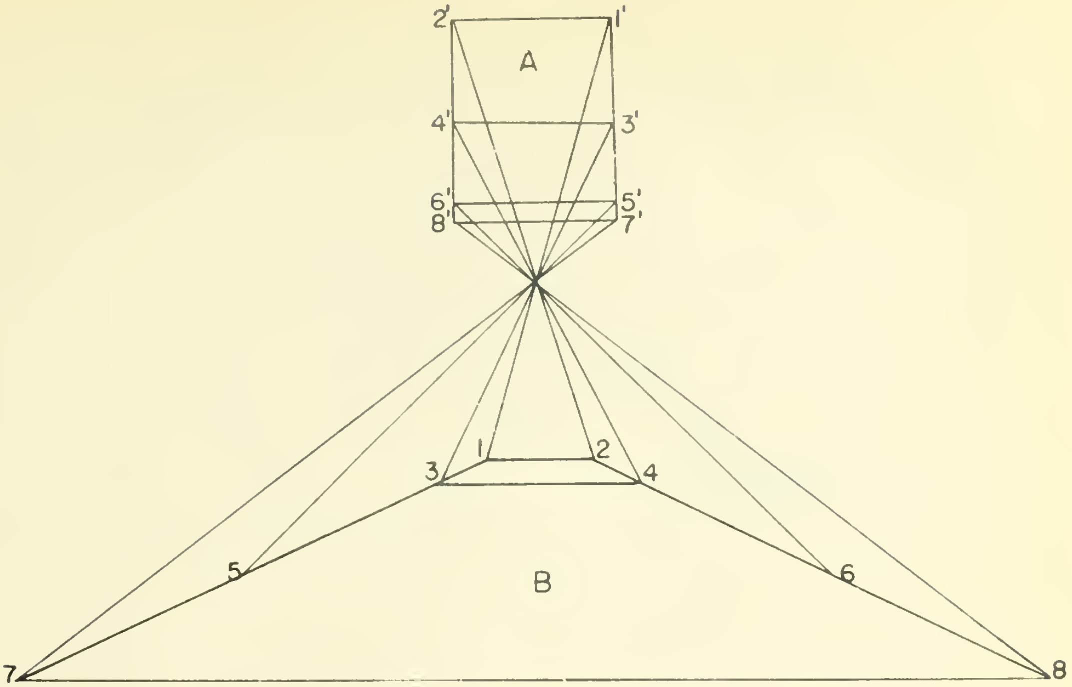


Figure III. Relation of the image lines, on an oblique negative, of lines on the ground parallel to the horizontal axis of the oblique negative. "B" outlines the ground area reflected on an oblique negative. "A" the negative.

The lines representing the distances between the points 1 and 2; 3 and 4; 5 and 6; and 7 and 8 vary on the ground "B", but the lines representing the distances between their images on the negative "A" are of equal length. Any image on any one of the lines reflected on "A" is in true proportion to any other image on the same line, but the ratio will vary (as can be seen from the figure) between images on different lines, inversely with the distance from the camera of the line on the ground.

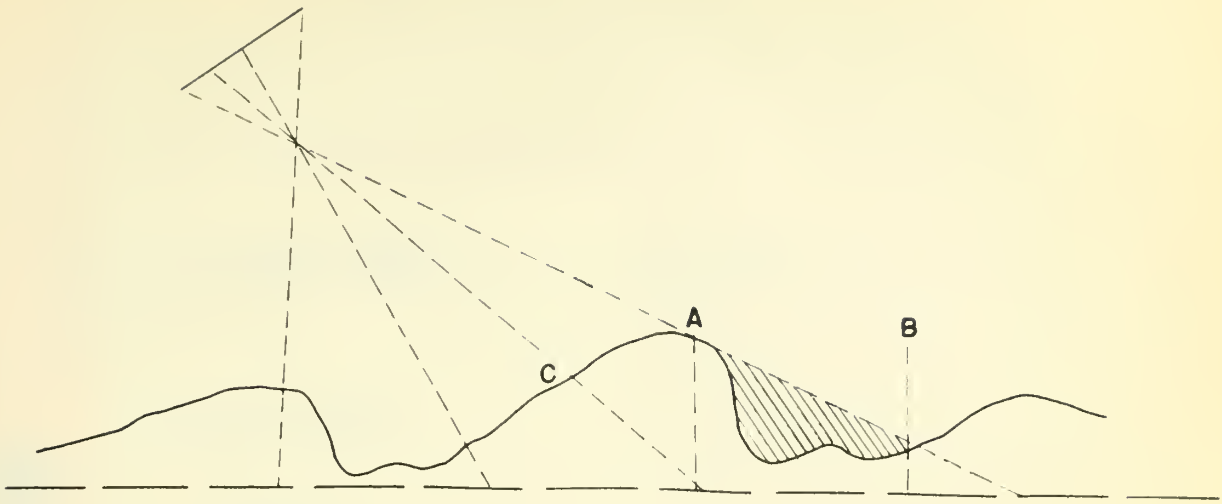


Figure IV. The effect of topography on the displacement of images on oblique photographs.
The hatched area between the lines A and B is omitted entirely from the photograph. The side of hill "C" completely obscures it.