*Problems of the Photogeologist in "Flatland" Regions of Low Dip**

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ABSTRACT: *The author first developed his techniques of geological interpretation of aerial photographs prior to 1930. Since then he has worked extensively in "flatland" regions of low dip, as well as in more mountainous regions in many different places around the world. Certain basic assumptions should underlie the work of the geological interpreter of aerial photographs in the broad eroded continental areas. Two of the most important ones are as follows:*

1. The assumption of more or less universal structural control of drainage patterns.

2. The assumption of almost universal superposition of drainage except for extremely local and minor streams. The proper use of these basic assumptions and other reliable generalizations in the interpretation of aerial photographs can yield important results in the geological discovery of structural anomalies which are quite obscure to other means of exploration.

The author feels that one of the major advances in geological science during the last one-half century has been the use of vertical aerial photographs for geological exploration. The results of their use have been especially significant in the "flatland" regions of low dip, and the full significance is not yet apparent.

INTRODUCTION

THE geological interpretation of aerial photographs (photo-geology, as it is commonly called), is indeed a very broad subject. It is comparable in its field of interest to the entire realm of geology. Accordingly, one should be duly cautious in generalizing about it. The field of photogeology may be broadly subdivided somewhat as follows:

1. Structural and Stratigraphic Mapping in Sedimentary Rock Terrane.
2. Structural and Mineralogical Mapping in Igneous and Metamorphic Rock Terrane.
3. Lithologic Mapping and Discovery of Abnormal Mineral and Structural Localities in General.

No set of rules can be given which will guide the photo-geologist in all of his interpretive work. Various rules can be given, however, to point the way to correct interpretation in different kinds of geological regions, such as geomorphic or structural provinces. Regardless of the geological region or province studied, the photo-geologist must be well and broadly trained. Photo-interpretation of geological features will be done best by broadly trained and widely experienced geologists who have good eyesight and a deep interest in the subject.

The author is aware that aerial photographs are being put to many uses at the present time; yet so far as geological use is concerned, he believes that the main emphasis is now in the field of structural mapping and lithologic (that is, "formation") mapping.

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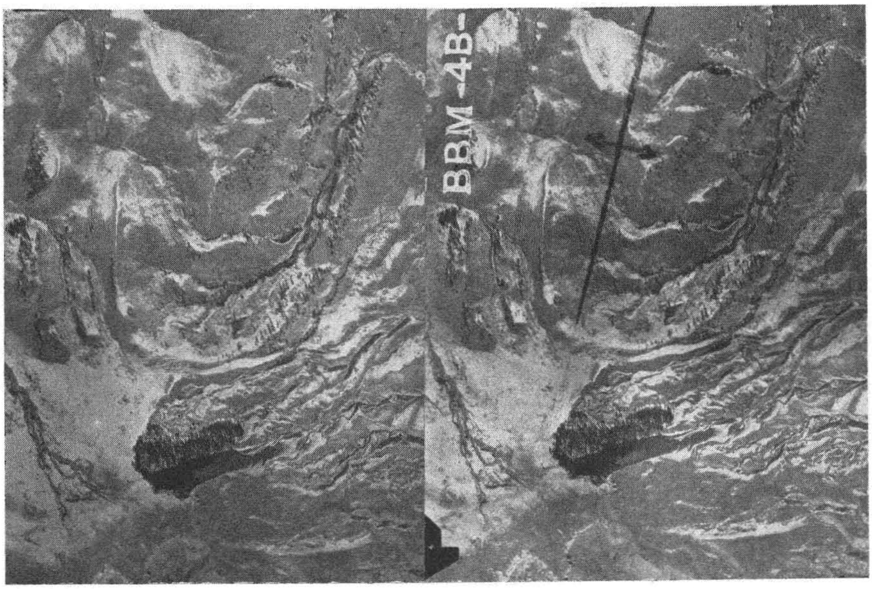

FIG. 1.—A stereo-pair of photographs showing a plunging anticline in rocks of Mesozoic age in Park County, Wyoming. The axis of the structure lies nearly parallel to the sides of the photographs. The direction of plunge is toward the bottom. These photographs seen stereoscopically illustrate the "coves" referred to in the text. A light snowfall covers most of the ground and in some measure emphasizes the topographic features. Photographs by the Commodity Stabilization Service of the U. S. Department of Agriculture, Salt Lake City, Utah.

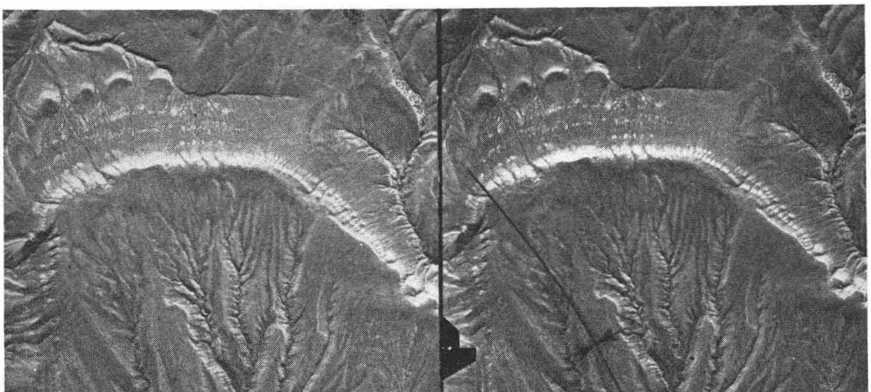

FIG. 2.—A plunging syncline is illustrated by this stereo-pair of photographs in Hot Springs County, Wyoming. The axis of the syncline lies diagonally to the sides of the photographs. The synclinal type of "cove" ridge is well shown. Photographs by the Commodity Stabilization Service, U. S. Department of Agriculture, Salt Lake City, Utah.

The Writer's Own Specialty of "Flatland" Photo-Geology

On the basis of his own photo-interpretation experience, which dates from 1926, the author believes that the field of geological discovery in flatland regions (that is, in plains and plateaus) is the most rewarding field for the use of aerial photographs.

There is considerable evidence to support the conclusion that much of the drainage of the broad continental areas of the world (probably between 25 and 75 per cent of it) is structurally controlled. By structural control of drainage, geologists mean that the drainage pattern reflects structural features, such as the outcrop of resistant formations above and below non-resistant formations, the dip and strike of these formations, the presence of faults, joints, and other local features.

Another generalization which the author believes to be true and which demands careful consideration, is the concept of essentially universal superimposition of drainage in flatland regions. The generalization will probably hold almost equally well in the mountainous and plateau regions, although in these other regions it may be complicated by the concept of antecedency, in which elevation of mountain ranges occurs while erosion is in progress. The concept of universal *superimposition* or *superposition* of streams must make an exception of local and more or less uncommon occurrences such as badland drainage in a thick outcropping shale. Likewise, deltaic streams, streams on volcanoes, lava flows, sand dune plains, till plains, etc., cannot of course be considered as superimposed, though they may now be in process of superimposition.

The peneplains, which have been the subject of much controversy in geological literature, are very common in the flatlands of the world, as well as in the mountains and plateaus. The common occurrence of peneplains supports the concept of regional superposition of drainage, since the very best opportunities for superposition in a regional manner would occur during the development and uplift of a peneplain.

The best results in the structural geological study of aerial photographs will, in the author's opinion, be realized by close attention to the generalizations just given: namely, (1) the structural control of most drainage, (2) the essential universal superposition of drainage, and (3) the common occurrence of elevated and dissected peneplains.

THE "LINEARS"

Long straight alignments of streams should be called to the attention of geologists. They are very common in the flatland regions of the world, and, in the author's opinion, are the effect of weathering and erosion along zones of joints which lie above, and are caused by, deep-seated faults in the basement rocks. These linears, which are probably due to deep-seated faulting, are in some respects more easily seen than faults in outcropping rocks where these rocks are lacking in resistance to weathering and erosion. Both influences, however, may be present at the same place in different aspects of the drainage pattern.

REVISED GEOMORPHIC GENERALIZATIONS

The geomorphology of structural features, such as anticlinal and synclinal axes, is best understood by the concept of "coves." Coves are recurved ridges on the axes of anticlines and synclines where weathering and erosion have cut through the sedimentary rocks, leaving the harder and more resistant formations standing above the less resistant outcrops. There are a great many varieties in the shape of coves, but the essential elements of all of them are the same, and an understanding of anticlinal and synclinal topographic relationships is helped by due attention to them.

For example, synclinal axes are usually occupied by streams which, if not directly in the axis, are close to it. Likewise, anticlinal axes are usually on or very near local divides. Exactly the reverse relationship has been thought to exist and is widely taught by textbooks of geology. This misconception that synclinal axes lie in high ground and anticlinal axes lie in low ground has ruled the thinking of conventional geomorphology for at least fifty years. This is a unique misconception of the true relationships which only a ground observer would make. For example, a cove developed on and around a synclinal axis when viewed by a ground observer outside of the cove, would appear to place the synclinal axis in an upland or

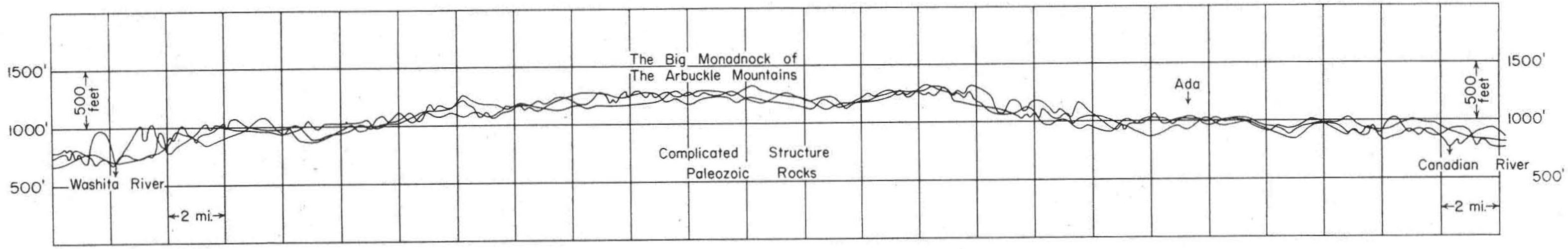

FIG. 3.—In this diagram three linear profiles made one mile apart are shown crossing the Big Monadnock of the Arbuckle Mountains in south-central Oklahoma. These profiles were made from the best available topographic maps and cover a distance of fifty miles. The numbers on the diagram show the horizontal scale as well as the vertical scale. There is an exaggeration of all vertical elevations by approximately twenty times. Three profiles were made along three parallel lines and then posted on the same sheet of cross-section paper. The resulting geomorphic picture is much more than three times as reliable as it would be with one profile.

The sedimentary rocks of this mountain system prevailingly stand at steep angles; hence any relatively flat surface is, of course, an erosional surface. Of particular importance is the pronounced elevated and dissected peneplain at about one thousand feet in elevation. It is present on both sides of the Arbuckle Mountains and in fact encircles the Big Monadnock which was a kind of "island hill" above this surface when it was a very flat lowland. This remarkable elevated and dissected peneplain has been named the Pawhuska Peneplain from the vicinity of Pawhuska, Oklahoma, where it is well developed. This surface is traceable from points near central Texas northeastward into southern Iowa. It is found in eastern Oklahoma, eastern Kansas, and northern Missouri, and it is bounded on the west by an important scarp throughout much of this distance. The age of this peneplain is either Miocene or Pliocene, but present evidence is not sufficient to determine the age accurately.

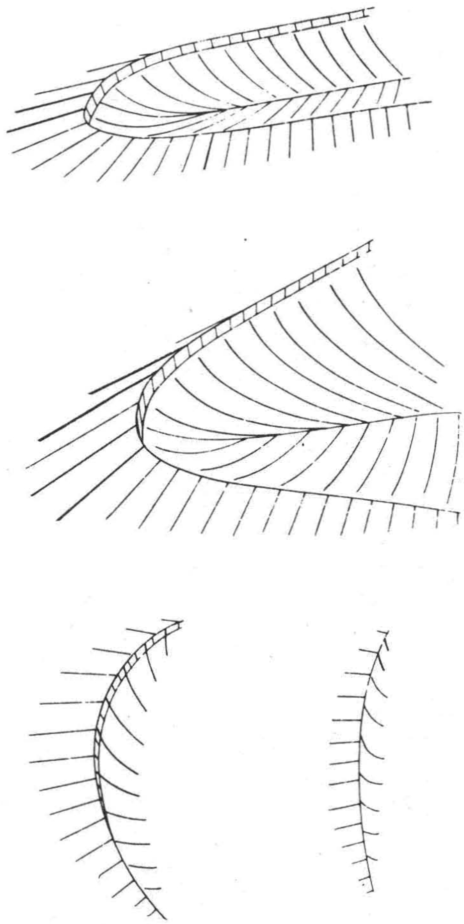

FIG. 4.—Oblique perspective drawing illustrating four types of anticlinal "coves." These are referred to in the text; the proper interpretation of such curving hogback ridges forms a considerable part of the geomorphologist's work in interpreting geologic structure from aerial photographs.

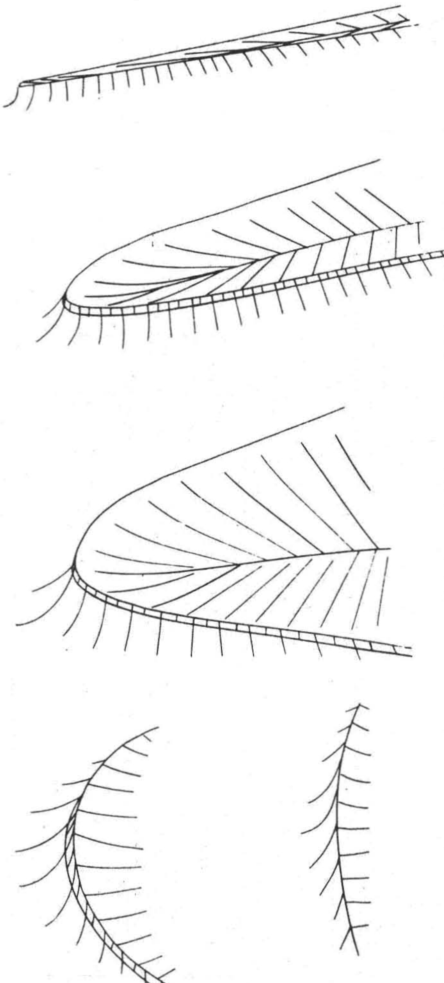

FIG. 5.—Oblique perspective drawing showing five types of synclinal "coves." The proper interpretation of curving hogback ridges of this type forms a considerable part of the work of the geomorphologist in interpreting geological structure from aerial photographs. It is noteworthy that the axis of synclines is usually occupied by stream valleys, and the axis of anticlines is prevailingly occupied by higher land which usually constitutes a local divide. The highest divides in the vicinity of such anticlinal and synclinal structures is usually the outcrop of the cove ridges or hogbacks of some resistant formation to one side of the structural axes.

elevated region, whereas, actually, just over the rim of the cove one may find a stream flowing for many miles exactly down the axis of the syncline.

In tectonically active regions—for example in the salt dome areas of the Gulf Coastal Plain—one expects to find Recent and perhaps continuing uplift responsible in part for the common association of local topographic and structural elevations. It seems unreasonable, however, to explain by continuing Recent uplift the same association of topographic prominence with structural elevations in the more rigid and stable continental nuclei. There, differential weathering and erosion is a more reasonable explanation in the light of present knowledge. The Central Kansas

Uplift, for example, will no doubt move upward whenever stresses in the crust are in a state of rapid change, but it is not yet established that the movement is continuous.

preferably with the photographs in hand, for an adequate understanding of the geology.

It appears, from investigations made by others, that color photographs have a definite place in this field of geological study, as do black and white photographs. In temperate and sub-arctic latitudes and climates, early spring or late winter photographs will, in most cases, have a more complete representation of rock color or "tone" than photographs made when the cover of vegetation is very dense. In tropical latitudes, the seasonal relationships may well be different. For the discovery and mapping of geologic features other than color anomalies, a cheap, rapid, and efficient method of photo-

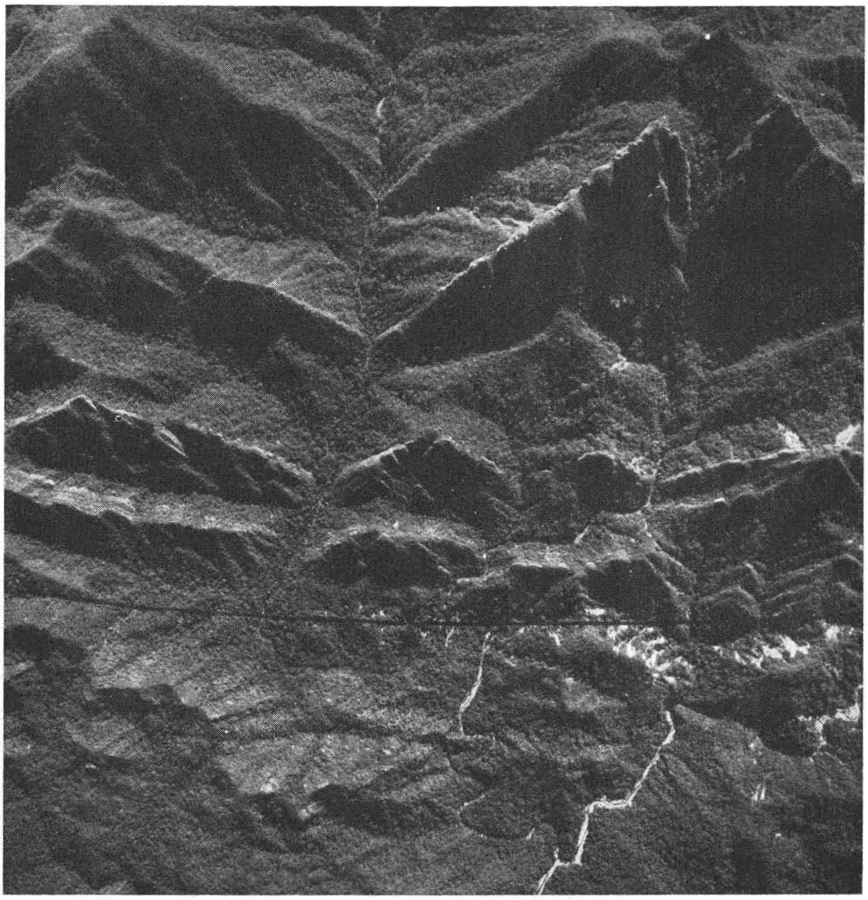

FIG. 6.—A single high vertical photograph showing dense tropical forest and prominent hogbacks on thick resistant strata. A sharp faulted syncline crosses the view just below the center. Gran Chaco region of Bolivia and Paraguay. Courtesy of the Fairchild Aerial Surveys, Los Angeles, California.

OTHER ASPECTS OF STRUCTURAL AND LITHOLOGIC MAPPING AND DISCOVERY

(I) IN IGNEOUS AND METAMORPHIC ROCKS

Discovery of hitherto unknown or abnormal structures and deposits, rather than detailed mapping, will probably be the most rewarding use of aerial photographs in this kind of terrane. The use of photographs alone is not adequate for detailed mapping of mineral deposits. It must be evident to all who have attempted this that ground study should be done, manipulation of color photographs has yet to be developed.

(II) IN SEDIMENTARY ROCK TERRANE

A. *In Mountainous and Steep-Dip Terrane:* In unknown regions, or in wilderness areas, aerial photographs of sedimentary rock terrane are used both for *discovery* purposes (that is, for the discovery of abnormal structural or other localities) and also for mapping to the maximum degree of detail attainable under the circumstances. In such mountainous or steep-dip regions, however, which are well settled and highly developed, aerial photographs are used only slightly for discovery purposes, but primarily for detailed mapping. The work is, of course, largely stereoscopic since good mosaics are difficult to lay in mountainous regions. When such mosaics are laid by competent photogrammetrists, they may still be of limited geological usefulness, although they may have great engineering value in their constant scale relationships. The best photo-geologic work in mountainous regions is done by competent field geologists who are also experienced in aerial photograph interpretation. Field work may be amplified by an office study of the photographs.

Instruments Used in Geological Study

FIG. 7.—A portion of a photo-index sheet showing a small area in northwestern Iberia Parish, Louisiana. The Jefferson Island Salt Dome underlies the lake at the southwest corner of the photograph. Subsidence in the area marginal to the dome is probably responsible for the preservation of the unusual meander-loop and meander-bars that are to be seen about one to three miles to the northeast of the lake. Such meander-loops and meander-bars were very common on this late Pleistocene marine terrace at an earlier date. The preservation of this one is no doubt due to its accidental protection from erosion through subsidence. Photograph by the Commodity Stabilization Service, U. S. Department of Agriculture, Washington, D. C.

of Mountainous and High-Dip Terrane.—The following points cannot easily be illustrated in a journal article because of the difficulty of presenting clear and sharp stereoscopic three-dimensional illustrations. Those who have access to any representative file of aerial photographs, however, will be able to find suitable illustrations without trouble.

Naked-eye stereovision (with parallel vision and with normal stereo-relief) has certain advantages as well as disadvantages. In certain types of large-scale or coarse-textured terrane of high relief there may be less apparent distortion of the dip of gently sloping beds with the unaided eye than when magnifying prismatic lens stereoscopes are used. This is probably due largely to the prism in the lenses, though the spherical correction (the magnification) may have something to do with it also, as does the distance from the eye to the pictures under observation. In most areas, however, naked-eye vision is not adequate, because not enough of the geomorphic detail can be seen to evaluate it properly. For example, in most terrane of ordinary relief it will usually be possible

FIG. 8.—This is a portion of a photo-index sheet near the northwestern corner of St. Mary Parish, Louisiana. The sediments which underlie this surface are natural levees of Bayou Teche and sediments of the deltaic plain. Bayou Teche makes an unusually abrupt turn just northeast of the center and near the Charenton oil field. This is fairly typical of river behavior where a slight difference in the over-all resistance of sediments or rocks to weathering and erosion interrupts the otherwise more or less uniform resistance to meandering which rivers encounter. Recent elevation of the Charenton area may have contributed to this abrupt river turning. The Jeanerette Salt Dome field is present about six miles to the west of the Charenton field must north of Bayou Teche. Surface indications of the presence of this salt dome structure are less evident than in the case of the Charenton structure but are present even here in the slight indications of subsidence to the south, to the northeast, and to the northwest. Photograph by the Commodity Stabilization Service of the U. S. Department of Agriculture, Washington, D. C.

to form a more accurate visual estimate of the position of the local base level of stream erosion with magnifying stereoscopes than with the naked eye, because with magnification one can better see the stream channels. Thus magnification may outweigh the disturbing effects of the prismatic component of the lenses.

On the other hand, the disadvantages of the small folding magnifying and prismatic stereoscopes in wide use include the uncomfortable and cramped position the operator must assume—a disadvantage when it must be maintained for long periods of time. Likewise, it is occasionally a disadvantage to be able to see only a small portion of the stereo-image at one time; however, if the photographic image is sufficiently fine-grained to stand magnification, the use of a magnifying stereoscope may have a compensating advantage.

Mirror stereoscopes have an advantage when the observer is looking especially at the outcrop of thick formations, or when he is interested in other large-featured aspects of the geomorphology that are also easily seen. Mirror stereoscopes, whether silvered on the front or back sides, have the disadvantage of placing the observer at a considerable distance from the photos; he is thus unable to see much of the detail. Mirror stereoscopes eliminate distortions inherent in magnifying prismatic lenses, but do not eliminate the distortions inherent in the film, in the prints and in the human eye. In addition, the mirror surfaces are occasionally uneven, thus introducing their own type of error.

The geologist should have adjustable stereoscopes that can be used for many hours daily without undue physical or ocular strain. Stereoscopic spectacles remove much physical strain, such as that caused by prolonged bending over a table; but they may introduce certain distortions if the lens mount is flexible.

It seems clear that stereoscopes designed for geological use have not yet been developed. Some of the existing magnifying stereoscopes are not of sufficiently high quality and many are not adjustable for varying ocular width. The available mirror stereoscopes place the observer too far from the photos and do not permit adequate illumination. Regardless of the instruments used, interpretation by trained and experienced geologists is necessary for satisfactory work.

B. *In "Flatland" Regions of Sedimentary Rock:* Discovery of hitherto unknown structural and lithologic anomalies is the chief use of vertical photographs in "flatland" or "plains" regions. Detailed geologic mapping is in some places important, but in general it is only incidental to the discovery aspects of aerial photo-interpretation. Vertical photographs are more useful than oblique in these regions. Relationships can be seen in the vertical photographs that field geologists on the ground have not seen; although they can usually, in some measure, verify the truth of what is seen or interpreted in the photographs.

The quality of aerial photographs is of the greatest importance in the study of the flat lands, and increasingly good photographs are being made by aerial photographers. So many factors are involved and so much has been said about the causes of good and bad photography that the author does not want to add more, except as his own experience as a consulting geologist prompts him to do so.

Everyone now understands that geologists need clear photos, flat-lying paper, and the finest possible emulsion grain in order that magnification may be used. The best photographs for geological use, however, depend upon the nature of the terrane to be studied; in coarse-textured terrane of high relief where the structural anomalies are of large size, one can usually employ shorter focal length photos than in the flat lands under discussion here. As stated above, the widely used lens of $8\frac{1}{4}$ inch focal length has produced most of the photographs available today. This lens is practically at the limit of geological usefulness for stereoscopic study of strike and dip in the flat lands. A longer focus would be better in these regions. The author believes that aerial photographic exploration and mapping with its great possibilities will not for long be handicapped by lack of proper photographs.

In addition to evaluating the significance of the larger features, geologists will probably always be searching for signs of bedding and other features up to the limit of visibility of the photographs. Professional photogrammetrists can no doubt measure dips and strikes more accurately than the photo-geologists; but the time and effort necessary to do this, and the possibility of confusion arising in the recognition of bedding, true dip-slopes, and other geologic features makes the undertaking prohibitively expensive for geological exploration. The photo-geologist can work much faster. Any new improvements in the quality and variety of vertical photographs available for economic exploration will be to the benefit of exploration companies and photographers as well as geologists.

About Stereoscopic Vision with Aerial Photographs

Human bioptic vision is of course stereoscopic vision, wherein each eye supplies the brain with its own separate retinal image of the same field of view as seen from the two positions of the two eyes. A similar arrangement of two photographic images of the same field of view (as seen by the aerial camera from two different positions), supplies the brain with the stereoscopic pair of images needed for aerial stereoscopic vision. The beauty and significance of stereoscopic vision of geomorphic features cannot be described in words; it can only be experienced. The author believes that the use of aerial photographs and stereoscopic vision is the major advance of geologic science of the past one-half century. But geomorphologists must be interested in the residue of imperfections which still remain in stereoscopic vision as well as in the perfections.

COMMON FAULTS

All students of aerial photos have noticed the concave bowl-shaped aspect of the stereo-model produced by nearly all the available photographs. Photo-engineers claim this is the result of inadequate lenses and of other factors such as tilt, unequal shrinkage, etc. Though sufficiently good lenses may have been designed, they are not yet in common use. For geological purposes aerial photos should not utilize the entire field of the lens unless it is understood that a considerable part of each photograph must be cut off. By proper cutting, a less distorted central part of each photograph may be made accessible for close study with a magnifying stereoscope. But unless the overlap has been planned to make this possible, certain parts of the photographed area may thus be lacking for closely detailed stereoscopic study. The best geological interpretation requires that only the central part of photographs be used, and that the lens have relatively long focal length—12 inches or even more if cost will permit.

Stereoscopic vision depends to a certain extent on the recognition or perception of detail. Stereo-pairs of aerial photos have occasionally been made of heavily wooded areas with all relationships normal except that one photo was made in the forenoon and the other in the afternoon, thus causing the tree shadows in the stereo-pair to fall in two nearly perpendicular directions. In such a stereo-pair, it may be impossible to resolve the topography into a stereoscopic model even though all other relationships may be normal.

CAUSES OF STEREO-IMAGE DISTORTION

In the author's opinion the following factors affect and distort the stereoscopic image as used by the geologist in country of low relief and low dip. They are arranged in a loose "order of importance" based on the author's own experience. That others will want to change the order is understandable, since the human eye is a varying instrument from person to person and from time to time in the same person, and also since the stereoscopic image is itself an optical illusion seen with varying degrees of clearness and intensity by the same person, under different conditions of illumination and fatigue.

Lenses with long focal lengths give a truer and less distorted image of gently dipping beds than the shorter ones, other qualities being equal. The use of short focal length cameras that expose the total visual field of the lens greatly hinders the geologist's evaluation of dips in the marginal portions of the stereo-image. For the study of gross drainage, or for the production of base maps of hitherto unmapped terrane, such photographs may be satisfactory; but for close geological study in the flat lands of the world they are nearly useless. Differences in the altitude of the plane when making successive overlapping photographs, lens imperfections, unequal shrinkage or expansion of the film and/or paper all account for some distortion of the stereoscopic image, and affect the geologist's interpretations. Failure to view the stereo-image directly perpendicular to the photographs introduces stereo-slopes that do not exist.

The two human eyes even after optical correction with glasses may not be equally effective in visualizing the stereo-image.

and may thus give rise to a so-called "one handedness" in its perception.

There are other causes of distortion of the stereoscopic image that are more uncertain and variable in their effects.

Final Statement

One of the major advances in geology during the last one-half century has been the use of vertical aerial photographs. The results of their use have been especially significant in the "flatland" regions; and the full significance is not yet realized.

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