PRELIMINARY OBSERVATIONS ON GEOLOGICAL USE OF AERIAL PHOTOGRAPHS*

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THE use of aerial photographs by geologists is a complicated technique which touches several fields of geologic thought and practice. It may be compared with the use of other instruments such as the petrographic microscope, which also touches the broad field of geology at many places. If the following comments seem too brief and too abrupt it is because the subject is broad and space is limited. Because of this limitation, some elementary concepts and photo-procedures, discussed rather fully elsewhere, are omitted. The paper aims to deal mainly with the geological interpretation of contact prints from the flight negatives as well as with the interpretation of photo-indexes and mosaics.

Common Faults of Stereoscopic Model of Topography

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. 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 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—10 or 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; this caused the tree shadows in the stereo-pair to fall in two directions, nearly perpendicular to each other. In such a stereo-pair, it may be impossible to resolve the topography into a stereoscopic model, even though the per cent of overlap may be normal, tilt and "crab" may be absent, and even though the scale of the two photos may be the same. Unless the hill-form is large and striking, it may be obscured by the divergent tree shadows.

Shadow Effect

It is a common belief that in viewing aerial photographs of hilly country, those hillsides in the sun-shadow must be oriented so that the sun appears to be above the observer's head. Failure to do this when one is viewing a single photo may lead inexperienced observers to "sense" the topography in reverse. More rarely it may cause the beginner when viewing a stereo-pair, to see even the stereoscopic image in reverse. However, those accustomed to using aerial photos will soon discover that, except in extremely rugged topography, the direction of the sun-shadow makes no appreciable difference. In fact, the full-time student of

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aerial photos, for ready comparison with maps, must frequently study them with the north direction "up" regardless of the direction of sun-shadows.

The vegetal growths on the protected north-facing hillsides (the "vegetal sun-shadow"), because they appear as dark areas, act much as a true sun-shadow in their effect on aerial photo study.

Stereoscopic Instruments

So much has been written about stereoscopes that it seems fitting for the writer to present merely the results of his experience in their geological use. This is perhaps best accomplished by lettering his observations in the order of their importance.

a. The geologist will want magnification in his stereoscopes, within the limit set by the size of grain in the pictures. It is true that in certain geological terrain, the formations and the structures are of such dimensions that they are clearly visible to the naked eye; yet in nearly every case certain important details will be visible only with magnification.

b. The geologist will need lenses of the highest quality. Since he will spend much of his time searching the photos for geological features near the limit of visibility, even the slightest irregularities and imperfections will introduce relatively great distortions. So far as the writer has been able to learn, lenses of high quality are not in common use.

c-d. The geologist will want bright illumination; and, during much of his study, will want to view the photos as close to the eye as is possible, consistent with clear vision. The reasons for these conclusions are the same as those supporting the foregoing statement ("a") about magnification.

e. The geologist will need a stereoscopic aid which is adjustable, or which has interchangeable lenses, for the varying width of overlap found in existing aerial photographs.

f. The geologist must have 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. The existing magnifying stereoscopes are not of sufficiently high quality and are not adjustable for varying overlap. The available mirror stereoscopes place the observer too far from the photos and do not permit adequate illumination. Inventors of stereoscopic equipment are urged to give thought to the problems of the geologist.

Vectographs and Anaglyphs

Devices which use polarized light or complementary colors to secure a separation of the images of a stereo-pair of photos are of little use to the exploratory geologist. They are very useful to illustrate geological ideas before large numbers of people. The expense, however, as well as the many opportunities for distortion during their manufacture, remove them, at present, from the class of aids to geological exploration.

Photo-Indexes

A rough mosaic of contact prints, in which none of the photographic image has been trimmed away, is known as a photo-index. It serves the purpose of an index to the contact prints and to the lines of flight. Although the photo-index was not designed for such a purpose, it is found to have considerable geological value in certain regions. Two scales have been in common use—1 inch per mile and 2 inches per mile. The photo-index sheet at 2 inches per mile, if carefully made, is of greater use to the geologist than indexes at the smaller scale; though at the present time only the 1-inch scale is specified in the contracts let by the Agricultural Adjustment Agency and the Soil Conservation Service.

In the "plains" country, where the relief is low, photo-index sheets are good picture maps, and show a wealth of detail which is useful in many ways. Large structures in thick formations are clearly visible. On the other hand, stereoscopic vision is not possible with them and some detail is always lost in photographing and printing these sheets. In country of high relief, such as is found in most mountain ranges and in plateaus, the contact prints from the flight negatives cannot be matched well enough to construct index sheets which are usable by geologists. Where relief is one-tenth to one-third of the camera height above the ground, the distortions due to relief are very great. The top of a 4,000-foot hill, rising above a flat base and situated at the edge of the field of view, would be displaced the scale equivalent of approximately 2,300 feet away from its true position, if the field of view of the camera lens were 60°. Photo-indexes of geological value in regions of high relief might be constructed by using lenses of long focal-length and by flying at heights much greater than has hitherto been done in most photographic mapping.

The discontinuities of photographic image, of tone, and of scale are a drawback in the use of photo-indexes. Yet since these discontinuities are perfectly obvious and uncamouflaged, the photo-index is in some respects safer to use than is the mosaic in which the arts of concealment must be employed. Good photo-index sheets of "low-strata-bench-lands" and true coastal-plain country are useful in geological exploration in proportion to the skill of the geological observer in interpreting drainage and topographic form.

Mosaics

The disadvantage of abrupt discontinuities in photographic image, in tone, and in scale, which are so obvious in the photo-index, are also present to a smaller degree in most mosaics. In this case, however, such discontinuities are not obvious, and differences of tone and scale have been in large part eliminated. The photo-matching which is important in the photo-index is of much greater importance in the mosaic. Here, it is frequently necessary to change the scale of contact prints from that of the flight negatives, and also to correct for tilt of the camera axis away from the vertical position. In addition, it has been necessary to develop the art of photo-matching, and to use all known means, including stretching and distortion, to produce a relatively continuous photographic image from the discontinuous pictures.

The best mosaics are quite expensive, since much labor is necessary to produce a picture map of constant scale. Even in these mosaics the photo-image and scale discontinuities are still present though so reduced in size that for engineering purposes they are insignificant. The procedures of (1) laying out the geodetic grid, (2) printing the best possible pictures for matching, and (3) tearing and camouflaging the torn edge, have been discussed in many publications. Here the writer is interested only in the resulting usefulness of mosaics for geological purposes.

To the geologist, the usefulness of a mosaic depends not so much on its constancy of scale as upon the way the photos were torn in matching one on another. If the photos are torn along natural objects such as hogback ridges, and narrow streams, to prevent the match being detected, the resulting mosaic may be of slight geological use. The geologist will be searching chiefly for signs of bedding (which at the prevailing scale of government photographs may be near or perhaps even beyond the limit of vision) and will very likely misinterpret any irregularity in photographic image. Mis-matchings that go unnoticed by the casual, though experienced, observer will in all probability be noticed by the geological observer studying the mosaic with a magnifying glass. Whether he notices the mis-match or whether he misinterprets its significance, it is still a hazard to the correct geological interpretation of the mosaic.

From his own experience in the geological interpretation of many kinds of aerial photographs, the writer recommends *that in laying mosaics of extensive areas, technicians with geological training be employed in matching the photos or, if this is impossible, in supervision of the work.* To do so may greatly increase the geological usefulness of the mosaic. In the rugged lands of the world where much aerial photography remains to be done, the mosaic may prove to be the only suitable device for securing a continuous picture map.

Geological Conclusions

In a field of thought and technology which touches many phases of geology, any brief remarks, though made with the best intentions, are sure to be a partial distortion of the truth. The following brief statements are no exception.

1. In mountainous terrain with thick lithologic units, the main structural irregularities stand out in great clearness. Accordingly the scale of photos is relatively unimportant. Drainage patterns may usually be relief upon to show the location, if not the exact nature, of structural features.

2. In mountainous terrain where structures, though steep, are small in relation to the thickness of lithologic units (as in a thick shale), neither drainage nor topographic form, considered separately or together, can be depended on exclusively for discovery of structures. Though there is ordinarily some genetic relationship, it is inconsistent from one locality to another.

3. In the "strata-bench-lands" of the world whether high or low (the plateaus and plains of some authors) as well as in those uncommon forms, the true depositional coastal plains, the drainage pattern alone, though important, can not be relied on for discovery. Experienced oil geologists know that there are commonly some drainage manifestations of local structure but they may not be consistent on neighboring structures.

4. Confusion may be introduced into topographic interpretation by the effects of weathering and erosion under the rigorous late Pleistocene climate of certain regions which are now much warmer and dryer. Other topographic "abnormalities" are very common in some regions, for example, creep and slump topography. The geological student of aerial photos will be compelled to spend much of his time learning to recognize the topographic effects of these so-called "abnormalities" in order that they may be subtracted from the composite topographic form. He will thus be better able to recognize the effects of bedrock stratification and thus to estimate the strike and dip.

5. Only experienced men with good eyesight will make much progress in the geologicals tudy of aerial photos. If larger-scale photographs become available the eye strain will not be so severe as at present.

6. When photos are used to construct good topographic maps, an expensive engineering problem arises. Ground surveying can not be eliminated or even much reduced, so great are the common distortions of the stereoscopic model.

7. The geological student of aerial photos will find that satisfactory progress depends not so much on an understanding of the physics, chemistry, and geometry of the pictures but chiefly on his ability to recognize bedding and to interpret the significance of topographic form correctly. More specifically he will have to recognize in the photos those geological features which simulate bedding but which are not bedding. To do this is very difficult in soft-rock terrain, because at 1/20,000 (the most common flight scale) the bedding at many places is invisible.

8. In unexplored regions, any geological method of exploration, including any type of oblique or vertical photography, will bring discoveries. Moreover, it is the writer's considered opinion that even where the search is difficult, aerial photos are of great value in the discovery of structures, though not necessarily in their detailed mapping. The exact degree of usefulness varies in different regions and is not yet too well known, for as yet but very few of the available photos have been made to the specifications of an experienced geologist or for geological purposes. The specifications thus far used were written mainly by engineers interested in the modification of water courses or in erosion and crop-acreage control. The prevailing scale in the United States of 1/20,000, is too small for geologic study in many regions.

As an experimental beginning in aerial photography for geological purposes the writer suggests: (1) that photographs for detail be made with a lens of 12-inch focal length, on a scale of 1/8,000 and that only the finest-grained film, and appropriate developing procedures be used; (2) that, in addition to such photographs for detail, high altitude photographs be taken at, say, 1/40,000 with lens of 6-inch focal length. The best scale and focal length in each case will depend on the relief of the ground to be photographed.

9. The writer is very optimistic about the future of aerial photography for geological discovery, not only in the wilderness but in certain regions with a long history of exploration by other methods. Especially in its use for discovery, the expense of aerial photography will be negligible in comparison with its returns.