PROCEDURES AND PROBLEMS OF PHOTOGEOLOGIC EVALUATION[1]

Robert F. Thurrell, Jr.,[2] Denver, Colorado

Introduction

THE term "photogeology" covers a very wide field. It includes all geologic applications of air photographs, such as soil studies, land form interpretation, petroleum exploration, mineral resources studies, teaching aids and others. It encompasses the problems inherent in interpretation, illustration and mapping. The intent of this paper is to discuss those problems immediately related to methods employed in the photogeologic processing of large areas for petroleum exploration. The same techniques are applicable in any photogeologic evaluation where large area mapping is involved.

This presentation will attempt to cover three main phases. First, specifications developed by experience testing; second, studies to improve current methods; and, third, studies for new applications and techniques. Before focusing on the details of individual problems confronting the photogeologist and the photo interpreter, it would be wise to qualify the broad objectives sought. The current commercial emphasis is placed upon a rapid evaluation of geologic conditions over large areas, frequently 10,000 square miles or more. In areas of persistent rock outcrops, this evaluation must show the stratigraphic units, the strike and approximate dip of the strata, the faults, and the surface structural interpretation. In areas of very limited outcrops the requirements are entirely different and may necessitate the location of possible outcrop areas on a base map showing details of drainage, roads and other cultural information to facilitate more rapid examination by field parties.

Maps are prepared at a scale best suited to balance the amount of geologic information available with the location accuracy needed. Either of two mapping scales, 1:48,000 or 1:63,360, is now generally used by the domestic oil companies with some complex areas being mapped at larger scales. In contrast, reconnaissance geologic maps of areas in foreign countries have been prepared from trimetrogon photography at smaller scales of 1:100,000 and 1:200,000-mapping scales suitable for the less detailed information obtainable. A consideration of the techniques employed to meet these varying requirements in both evaluation and mapping procedures brings many questions and problems to light.

Specifications for Photography

The characteristics of the photographs to be used are important. Photography desirable under one set of conditions may be inferior in other circumstances. Several factors are important in the proper selection of specifications.

VERTICALS VERSUS OBLIQUES

Oblique photographs have many advantages in qualitative studies. The perspective view is more natural for the human mind. The relationship between photo-portrayed information and the natural ground conditions is more readily apparent. For display purposes, for training or briefing, this medium is highly desirable. However, major problems exist for quantitative work. Primarily these are constant scale changes, inability to see the entire land surface and the

[1] Presented at Research and Development Board's Photogeology Symposium, February, 1952 and read in part at the Nineteenth Annual Meeting of the Society.

[2] Administrative Geologist, Geophoto Services.

necessity to use plotting instruments for any type of compilation meeting average reconnaissance mapping standards. Oblique photographs have been used in widespread reconnaissance work in foreign countries because available trimetrogon photography satisfies the very general requirements. Most domestic work undertaken with specifications for more detail has been with the use of vertical photography. The latter allows a far more accurate and rapid evaluation in quantitative terms.

SCALE

Photo scales from 1:5,000 to 1:50,000 have been used to establish the characteristics of information portrayed on the photographs and to determine the ability to interpret that information. A photo scale of approximately 1:20,000 or about three inches equals one mile is considered the most desirable. It combines the ability to interpret the features portrayed with economy in flying. When smaller scales are employed difficulty is frequently encountered in the interpretation of detailed information. Larger scale photography unduly increases the flying cost.

SIZE

Nine or ten inch square photographs are the most desirable size. Smaller size photographs create uneconomical flying and larger size photographs, particularly 9×18 as taken in the K-18 camera, are more difficult to handle, and very cumbersome to store.

TILT

Excessive tilt (over five degrees) distorts the stereoscopic model so much that interpretation is seriously restricted. Tilt of less than five degrees must be considered in terms of the dip of the rock strata in the area being evaluated. The appearance of steeply dipping strata is not seriously affected. However, if strata are dipping in an amount commensurate to the amount of tilt, it becomes very difficult to establish the true attitude of the strata. This introduces a major consideration. Inasmuch as the attitude of strata dipping less than one-half degree can not be accurately determined by stereoscopic examination of vertical air photographs, the primary desire of the interpreter would be to avoid photography with tilt in excess of one-half degree. Much research time has been spent striving to obtain absolute horizontal camera stabilization. It is the author's belief that most needs of interpreters and many problems of engineering in stereoscopic plotting instruments could be met by the stabilization of cameras within a tilt latitude of one-half degree.

FOCAL LENGTH

The wide angles of short focal length lenses create excessive radial displacement of the image on the photograph. When viewed through the stereoscope the image lacks a normal perspective. Also, a mental impression of a bowl-like surface is frequently created when viewing the stereoscopic model. Focal lengths of less than six inches are therefore considered unsatisfactory. The radial displacement caused by using a six-inch lens does not hamper interpretation, but in terrain of high relief it is sufficient to hinder mosaic construction. An $8\frac{1}{4}''$ focal length is best to average all conditions desired in interpretation because of the resultant base height ratio (discussed below). Longer focal lengths are useable, but become progressively less desirable since the apparent model height decreases.

OVERLAP AND THE BASE-HEIGHT RATIO

The vertical exaggeration present in a stereoscopic model is directly related to the base-height ratio. As the ratio increases the vertical exaggeration likewise increases. Photography must have 50 per cent overlap (and 60 per cent is normally specified) to assure complete stereoscopic coverage and control extension or bridging. Therefore, the focal length and the flight altitude become the controlling factors in the base-height ratio. When a constant scale and overlap is maintained, it follows that short focal length lenses allow a longer base distance and create a large vertical exaggeration, while long focal length lenses shorten the base distance and create a smaller vertical exaggeration. The application of this principle is immediately apparent in the focal lengths used in stereoscopic plotting instruments but has been given little consideration in the specifications for the interpreter.

The selection of a favorable exaggeration factor is extremely important in the evaluation of dips or slopes, with a high factor used for areas of low dip, and a low factor employed in areas of high dip. Also in physiographic interpretation, large vertical exaggeration is normally preferable in areas of low relief with the converse applying to areas of relatively high relief. A six-inch focal length gives the largest exaggeration factor normally needed by the interpreter, while a twelve-inch focal length provides the normal minimum. If both a high and low factor of vertical exaggeration are beneficial within the same area the suggested solution is different. By using a six-inch focal length with 80 per cent overlap a low base-height ratio (or exaggeration factor) is obtained in the consecutive photographs and the alternate photographs (with 60 per cent overlap) have a high ratio.

SEASON

Early spring and late fall are considered the best seasons for flying photography to be used in geologic interpretation. In areas of dense tree cover and farming this is mandatory, whereas in arid areas it is of little concern. No snow should be present on the surface of the ground, although in rare instances a thin film of snow will accentuate the character of the surface and the types of rock present. For detailed geologic evaluation there can be no cloud cover. Ten per cent cloud cover is the maximum tolerable for generalized reconnaissance work.

CLARITY AND RESOLUTION

It is sufficient to say that resolution and image clarity can never be too good for the interpreter. Extreme care must always be taken in the processing and development of film or prints for his use. In this regard, it should be pointed out that for most purposes double-weight semi-matte paper is the most desirable type available, but that there is a marked difference between brands in the physical surface character of the paper. Incident light is reflected from the pebble-like surface of many of these papers and creates a hazy appearance of the image in the stereoscopic model.

REGIONS OF INTERPRETATION

Any attempt to divide the surface of the earth into regions where special criteria for interpretation apply opens huge pitfalls. Where does one region begin and the other end? What should be done with the exceptions within a proposed region? How many regions should be established and how sharp should be the changes in interpretation procedures between regions? It would be better, therefore, to consider the major conditions which affect the interpretation of the photographs and then see if certain type localities can be defined which depict primary considerations for the interpreter.

DEGREE OF EXPOSURE

Alluvial and terrace deposits, glacial material, and other mantle covers are very detrimental in surface studies. Cultivation and farming restricted to the alluvial areas of river valleys is of minor concern, but if widespread in interstream areas the amount of surface geology visible on the air photographs is greatly reduced. Dense tree cover is a major handicap. If there is a high percentage of deciduous trees, then spring or fall photography will reduce the interference from foliage.

CHARACTER OF THE STRATA

Strata nearly homogeneous are eroded in a uniform manner. Unconsolidated strata create little topographic expression. In either case, the structural interpretation possible is much less than in areas of consolidated strata with varying lithology such as alternating sandstones, shales, and limestones. Stratigraphic units deposited uniformly over large areas are more easily traced at their outcrop than units with rapid lateral changes in lithology.

INCLINATION OF THE STRATA

When strata have a low dip, the contacts of formation units are usually widely separated. Then their application to the structural interpretation of an area becomes limited. To increase the detail, intraformational units called key beds are mapped. In steeply inclined strata the mapping of key beds is normally unnecessary. The formational contacts are more closely spaced, affording the desired detail for structural interpretation.

The attitude of the beds in an area has a direct bearing on the time consumed in the photogeologic evaluation of that area. The determination of dips of three degrees or less requires closer scrutiny than those between three and forty degrees. Because of the vertical exaggeration present, the analysis of dips in excess of forty degrees becomes increasingly difficult. However, the exact attitude of the more steeply dipping strata is of minor importance in surface reconnaissance mapping.

COMPLEXITY OF GEOLOGIC STRUCTURE

Structural interpretation is easiest in areas of gently folded, well-exposed strata. If folding is intense or if faulting is dominant, the structural interpretation becomes more complex, requiring much more detailed study.

Consideration of these diverse criteria indicates that certain areas represent typical conditions likely to be repeated in other localities. An outstanding example is the Rocky Mountain area. There the strata are well exposed and generally well consolidated, with exception of the basin areas. These are ideal conditions for widespread geologic evaluation. However, within this general area an infinite number of variations can be established; as shown by the low-dipping strata in the basin areas contrasted to the steeply-dipping strata in many of the mountain ranges.

A second type example is the Appalachian plateau area. Despite the high percentage of tree cover, the alternating sequences of resistant and non-resistant strata create such strong topographic expressions visible on the air photographs that photogeologic mapping is more feasible than field methods.

The Canadian plains belt east of the foothills represents a third typical area

Rock outcrops are limited, with widespread glacial debris present. Here identification of areas for potential field examination becomes of utmost importance. The Gulf Coast region represents still another type area with predominantly low dipping, generally unconsolidated strata, and large portions covered by terrace deposits. One of the more recent localities for widespread photogeologic evaluation, it is yielding satisfactorily to physiographic and geomorphic studies which have proven a correlation between surface expressions and sub-surface structure.

By these examples it can be seen that there is, in reality, no norm in geologic interpretation; each area has its own special considerations. They do, however, indicate one thing in common. No matter what the character of the area may be, information of importance to geologic study and evaluation can be obtained from the air photographs.

Color Film Versus Black and White Photography

Color photography has certain definite advantages in geologic evaluation, but to date it has undergone very limited use and testing in commercial work because of its many disadvantageous factors. It is useful in correlation of strata from one locality to another. In areas of low dip it may show changes in lithology which would not be otherwise recognizable. It is a great aid in the location of certain types of mineral deposits because of their strong color characteristics upon surface weathering. Color film positives can be enlarged many times more than is possible with black and white negatives and still retain clarity. Opposed to these advantages are the problems created by the greater expense, the necessity to work with film transparencies unless color copies of high cost and low fidelity are made, the difficulties of stereoscopic examination and plotting of information and the construction of mosaics. More extensive tests of the applications of color photography to geologic interpretation should be made.

Ground Checking of Photo Interpretations

Aside from academic problems and interests, areas of potential economic importance are the primary concern in ground checking of photogeologic interpretations. Large area reconnaissance work is undertaken fundamentally to define those areas which are more desirable for further investigation. Complex structural conditions demand a higher degree of field check than simple structural conditions. When an area is uniform in character and interpretations are similar throughout, checking the interpretations in scattered localities gives reasonable assurance that the area is adequately examined. Where the rocks are well exposed in steep-faced outcrops, such as river cuts, much information can be obtained from field examination and this is necessary where outcrops are limited. The contrary is true in the Gulf Coast region where the over-all character of an area of many square miles may be the basis for an interpretation and on the ground no significant information is visible.

All considered, the time spent in the field check for a large area reconnaissance evaluation is usually ten per cent or less of the total time involved. In sharp contrast are those smaller areas where detailed studies of structural conditions and lithologic changes are required. It is not uncommon in such circumstances to spend 50 per cent of the working time in field examination and correlation.

Identification of Lithologic Types

The accurate identification and description of soils and rock types has been dependent on field studies. In many respects this will continue to be true in the future. Under too many different conditions rock types cannot be accurately identified from air photographs. It is true that the number of types can be immediately restricted but the exact character of the strata remains in doubt. The publication by D. S. Jenkins *et al.* on soils identification[1] has been an invaluable aid for soils classification in remote areas. Further work of a similar nature should be undertaken in the detailed classification of sedimentary and igneous rocks.

Visual Estimation of Dip or Slope Angles

In large area reconnaissance evaluations the handicaps of time and cost make it highly impractical to use stereoscopic plotting instruments for the determination of dips of the rock strata. This would likewise apply to any other determinations of ground slopes. It is therefore necessary to establish some method by which an estimate can be made visually within a reasonable degree of accuracy in a minimum of time. It may be argued that dips should be determined in a few chosen localities by either field or stereoscopic plotting measurements, to use as guide. However, this leads to many inaccuracies.

The problems of what one sees in the stereoscopic model in comparison to the true surface model have occupied the author's interest for some time. In collaboration with Victor C. Miller, research investigations have been made to determine the amount of vertical exaggeration present to an individual viewer for any given stereoscopic model. The types of distortions in the apparent model have been determined and their effect quantitatively analyzed. The base height ratio has been established as the primary factor in vertical exaggeration of the stereoscopic model when viewing instruments are taken as a constant. This information is being tabulated so that a person may make an estimation of the apparent slope or dip in the stereoscopic model and read the true ground angle from a simple set of tables. The limiting factor becomes the accuracy with which a person can make a visual estimate.

Control Problems

The amount of geologic information which can be plotted on photography at a scale of 1:20,000 far exceeds the requirements of reconnaissance geologic mapping. However, the problems inherent in the transfer of this information to a base map by economical methods are numerous. If accurate topographic or planimetric maps are available the geographic and cultural information shown on these maps and identified on the air photographs can be used to control the plotting of geologic information from the air photographs to the base map. This may be accomplished by use of the vertical sketchmaster or by photo reduction methods. When no such map control is available it is necessary to resort to the construction of uncontrolled mosaics or radial plots.

Inasmuch as the construction of radial plots over very large areas becomes an expensive operation and normally requires the procurement of additional field control information, reconnaissance mapping has normally relied on the use of uncontrolled mosaics. On these mosaics scattered section corners or triangulation stations may be spotted to aid in the adjustment of information to the final map. As a result of inadequate horizontal control, valuable detailed geologic information may be inadvertantly mislocated by hundreds of feet on the map. If the photo center position of each photograph or even each alternate

[1] Jenkins, D. S., Belcher, D. J., Gregg, L. E., and Woods, K. B., "Origin, Distribution and Air Photo Identification of United States Soils," Civil Aeronautics Admin., Dept. of Commerce, 1946.

photograph were known to within fifty or one hundred feet of its true ground position, this problem could be entirely avoided. Shoran offers an answer to this problem but will not effectively solve it until such time as it becomes automatic that all photography flown be located in horizontal position in this fashion. Again, from a commercial point of view, the economy of the operation is a prime consideration.

For inexpensive vertical control for geologic purposes altimetry has seemed the logical solution for a long time. However, the erratic nature of the information obtained has made it impossible to use altimeters for precise work. In an attempt to improve upon the information obtainable several research projects on altimetry have been undertaken. With the introduction of the leap frog method attention was immediately drawn to its potentialities, and tests along the Front Range of the Rocky Mountains under severe conditions indicate this may be a method capable of giving consistent elevations with an average error of two feet or less when properly employed. Recent tests indicate that within limits the separation of the two altimeter stations and the difference in the elevation between the two stations has little bearing on the accuracy obtained in the readings. Within an area differential movements in the air column can be extremely localized and are the cause of the majority of errors encountered. Two-way radio has been introduced into the experiments in an attempt to analyze these errors by simultaneous readings. Routine methods for field use and limitations upon conditions and period of operations have not as yet been satisfactorily established.

The Future of Precise Geologic Mapping

The past decade has seen a revolution in topographic mapping by use of air photographs and stereoscopic plotting instruments. In contrast, detailed geologic mapping lags behind. The Geological Survey still does most of its geologic mapping by field surveying methods. Many oil companies now use air photographs for their reconnaissance surface geologic mapping. However, in detailed studies and precise mapping of structures being investigated for drilling, the use of photographs is limited. There is no reason why, in the course of the next decade, there cannot be the same revolution with the use of air photographs in geologic mapping. With the proper instruments detailed surface maps with high degree of location accuracy showing such information as structure contours and stratigraphic intervals will be prepared. The Kelsh Plotter with the improved stereoscopic model created by electronic scanning instruments bids strongly for a place in this field. It must be realized that no developments in geologic mapping can occur without pioneering and confidence in the method employed. Field examinations of areas so mapped would remain as important as in the past. It appears that untouched horizons lie ahead based on sound research and planning.