PROGRESS AND PROBLEMS IN PHOTOGEOLOGY*

H. T. U. Smith

PHOTOGEOLOGY may be defined as the technique of attacking geologic problems through the interpretation of aerial photos. It is a term which recently has come into widespread usage to denote a particular means of obtaining geologic information, just as petrography refers to the gathering of geologic data primarily by the use of the petrographic microscope. Although the term itself is perhaps used most frequently in connection with petroleum exploration, where its method of approach has been most fully exploited, the applications of photogeology are by no means limited to that particular field of applied geology, but have wide ramifications throughout all fields of surface geology, both basic and applied.

The main objective of photogeology generally is to obtain maximum geologic information with minimum field work. Sometimes an added objective is to obtain types of geologic information which are difficult or virtually impossible of acquisition through ground study alone. The particular type of information sought varies with the circumstances of individual investigations. In many instances it is the outlining of geologic structures which is of particular interest. In others it is the correlation and delineation of rock formations. And in still others it is the analysis and appraisal of various types of landforms and surficial deposits. Not infrequently, the resulting data have a direct bearing on the basic concepts of geologic science, and nearly always they add to the stockpile of needed factual information about particular areas or regions.

Photogeology is one specialized branch of the art and science of photo interpretation. It should be emphasized that photo interpretation goes far beyond mere photo reading. The latter has to do mainly with the identification of individual features seen on photos. The former, however, begins where reading as such leaves off; it is concerned with the interrelatedness of the observed features, and with their *meaning* in terms of what is not directly observable. It may be likened to detective work of a most refined and exacting sort. From available clues, however fragmentary or scattered, it seeks to reconstruct, in the mind's eye, a complete picture of actual conditions. Thus the geologic interpreter, observing only streaks of white or gray on a photo, and using his trained and disciplined imagination to bridge the gaps between them, can visualize a sequence of stratified rocks having definite structural relations. Or, looking at a hill of a particular shape, he recognizes it as a sand dune, formed by the heaping up of wind-blown sand, and knows that it probably is composed throughout predominantly of sand grains between $\frac{1}{2}$ and $\frac{1}{8}$ millimeter in diameter. Looking at another hill of somewhat different shape, he recognizes it as a drumlin, of glacial origin, and can predict that any excavation in it will encounter a heterogeneous mixture of material ranging from rock powder to boulders, and known as till.

Photogeology, in the sense noted above, has close affiliations both with other branches of geology and with related sciences. Stratigraphy, petrology, structural geology, and geomorphology are all involved, but particularly geomorphology. Indeed, photogeology, to a considerable extent, may be regarded as applied geomorphology; using surface features as a key to the interpretation of underground phenomena, it naturally draws most heavily on that branch of the

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science which is primarily concerned with the analysis of the earth's surface features. Among the other sciences, geography and botanical ecology are most closely related to photogeology. That phase of geography concerned with land utilization patterns contributes to the understanding of man-made features shown on photos—the degree to which they are influenced by geologic environment, and thus serve as indicators thereof, together with their not infrequent simulation of natural features, and possible confusion therewith. Ecology is concerned with the distribution of vegetal types, and their relation to environmental factors, such as soil, bedrock, and moisture conditions. Banding or other distinctive patterns in vegetation frequently give the first clue, and sometimes the only clue to geologic conditions, so that an understanding of them is a matter of considerable importance to the photogeologist. The terms, "photogeography," and "photoecology," might be appropriate for phases of these allied sciences which are concerned with photo interpretation.

The method of approach in photogeology consists primarily in the observation and analysis of *forms* and *patterns*. By forms I mean the unit features, and by patterns the orderly spatial arrangement of a given set of unit features. On the same photo there may be several different patterns: bedrock patterns, erosional and/or depositional patterns of various types, soil patterns, vegetal patterns, and divers types of man-made patterns, reflecting various activities dating from different points in time. It is the function of the photo interpreter first to distinguish between these various types of patterns, and then to study their significance individually and collectively.

It is the essence of the above type of study, that forms and patterns seen on the photo are matched with those in the interpreter's mind. Where the photographic detail is incomplete or inadequate, so that the desired geologic information is hidden or camouflaged by non-geologic features, either natural or man-made, then it is the mental pattern of the interpreter which provides the missing links, fills in the gaps, and contributes to a complete picture of geologic relationships. Where the geologic pattern is comparatively simple, and has optimum surface expression, as with flat-lying to regularly folded strata outcropping in arid regions, the pattern speaks for itself and there are few if any gaps to be filled in, so that only the most elementary sort of interpretation is required. In the many places where these ideal conditions do not exist, the story is different. Complicated geologic relations and/or poor surface expression challenge the interpreter's resourcefulness, and require that all of the mental patterns at his disposal be called forth for comparison with the confused or obscured photo patterns.

The success of the interpretation then rests on number and diversity of mental patterns on call, and on the individual's astuteness in recognizing similarities amid minor differences. Where no very close counterparts for the photo patterns can be found, the differences may be those of *degree* or of *kind*, and it is important that this distinction be made by the interpreter. If the differences are mainly those of degree, he may be justified in drawing conclusions by logical deduction from his general background of knowledge. But when forms or patterns differing in kind from those within previous experience are encountered, it may be necessary to seek additional information on the ground before sound conclusions can be reached. And where truly unique forms and patterns are found and recognized as such, they may lead to research studies which make new contributions to geologic knowledge.

The mental patterns, upon which the photogeologist draws in the course of his work, may be acquired in various ways. The first prerequisite is a general knowledge of the pertinent fields of geology, to provide the more generalized and idealized patterns. With this as a foundation, a knowledge of more specific and particularized patterns may be attained in one or more of the following ways: (1) First-hand field study of representative areas in the same region or regions, where the photos are to be studied, particularly if photos are actually used in the field. The value of this cannot be too strongly emphasized. Many regions have their own individual peculiarities, often represented by subtle markings on photos, and without a direct acquaintance with these characteristics, the interpreter may be unable to go more than part way to his goal. (2) First-hand field study of areas in regions other than those for which photos are to be examined, but having many elements in common. This type of preparation is second best. Under favorable circumstances, it may provide sufficient background for the interpreter to extract the main types of geologic data from photos. (3) Second-hand information obtained from such reference material as ground photos, published reports, and available geologic, topographic, and soil maps. The value of such reference material depends to a considerable degree on the extent to which ground features are or can be specifically correlated with detail on aerial photos. Properly annotated aerial photos may be particularly helpful.

In short, photogeology aims to translate photographic detail into terms of actual geologic conditions on the ground, and therefore requires that the interpreter have some familiarity with ground conditions. Broad field experience is the best way of acquiring this familiarity. Since particular regions and particular types of terrain have their distinctively individual characteristics, some acquaintance therewith is necessary to extract maximum information from photos; to gain this acquaintance, general field experience is best supplemented by specific field study in areas as nearly comparable as possible to those involved in particular interpretive studies, or, if that is not feasible, by access to second-hand information provided by the field studies of others. And where the slightest doubt or question arises as to the results of interpretation, it is most desirable that field checking be undertaken to ascertain the facts of the matter, and to provide that much additional background for the interpreter.

Having now considered the objectives of photogeology and its method of approach, some actual accomplishments to date may be reviewed. These may be considered with respect to: (1) the different fields of basic geology, (2) regional mapping, and (3) applied geology. Within the realm of basic geology, the major accomplishments have been in geomorphology. Perhaps first in point of time was the discovery of the unique features of the "Carolina Bays," by Professor F. A. Melton, in 1933. These oval depressions with their systematic alignment are widespread in the coastal plain of the Carolinas, but their characteristics were never realized until the advent of aerial photography. Professor Melton concluded from his studies of the photos that they were formed by the impact of a great swarm of meteorites. This interpretation has been argued pro and con ever since Melton's first report, with D. W. Johnson as the principal antagonist. Although no general agreement has yet been reached, the principal contestants have all made full use of photo interpretation in gathering factual data. The recent discovery of similar features in northern Alaska by Black and Barksdale, also through photogeologic studies, introduces new complications in the controversy.

In the study of sand dunes, great progress has been made possible by aerial photography. Dune forms and patterns, unrecognizable on available maps and difficult to distinguish on the ground, have been analyzed, and their distribution has been mapped over large areas by use of aerial photos. The published work of F. A. Melton, W. S. Cooper, J. T. Hack, and myself in this country is representative, and the as yet unpublished work of W. Armstrong Price will make valuable additions to present knowledge. Recent work of Capot-Rey and Lelubre in the Saharan desert, and of Madigan in Australia, extend similar studies to different types of dune terrain.

In glacial geomorphology, new varieties of landforms have been distinguished and types previously known have been studied in greater detail and mapped over wider areas through aerial photographic methods. Illustrative is the recognition and interpretation of a distinctive swell and swale pattern in the glacial drift of Iowa and adjoining states by C. S. Gwynne, the discovery of new evidence relating to the origin of drumlins by Armstrong and Tipper, working in British Columbia, and the study of large-scale grooving in bedrock by the present writer. In addition, areal mapping of various glacial features has been extended into relatively inaccessible areas, by several Canadian geologists, on the basis of photo interpretation. Numerous other workers find aerial photos extremely useful in expediting field studies.

In the investigation of coastal geomorphology, the use of aerial photos makes possible a new degree of refinement. Studies of J. B. Lucke on the New Jersey coast, and of A. D. Howard and of Nichols and Marston on shoreline changes by hurricane action, are typical. Coral reefs provide a particularly fertile field for photogeologic methods, as witnessed by the recent work of Curt Teichert and others.

The study of geomorphic phenomena and related engineering problems in regions of "permafrost," or perennially frozen ground, has recently assumed considerable importance and has undergone great expansion. Since the terrain concerned is particularly difficult of access, and many of the significant features are on a comparatively small scale, difficult to find and to see in proper perspective, photo interpretation, proceeding hand in hand with ground studies, has been particularly valuable, and has contributed substantially to such progress as has been made.

Other significant applications of photogeology to geomorphic problems are the studies of F. A. Melton on floodplain streams, of J. L. Rich and E. L. Krinitzky on soil mounds, and of various explorers on the shelf ice of the Antarctic continent.

In the field of sedimentation, dealing with the origin and characteristics of sedimentary rocks, the geologic axiom that "the present is a key to the past" applies with particular force. The study of present-day environments of deposition is essential to an understanding of ancient sediments dating back hundreds of millions of years. Photogeologic studies in the field of geomorphology, particularly those devoted to floodplain, delta, coastal, coral-reef, and desert environment are pertinent here, and studies of the shallow-water environments so clearly shown on many aerial photos, such as those of John L. Rich, are important. The potential value of aerial photos in this general field has been demonstrated, but remains to be more adequately exploited.

In the field of tectonic and structural geology, photogeology has contributed measurably in two ways. In the first place, it has facilitated the detailed mapping of structures in specific areas with greater refinement, thus to provide more and better factual data for the theorist to work with. The work of A. W. Joliffe in parts of the Canadian Shield is illustrative. In the second place, photogeology has provided a method of rapid reconnaissance of broad structural trends in unexplored or little known areas of the world, thus helping to fill in large blank spaces in the tectonic map of the globe. The work of J. Tuzo Wilson on the structural lineaments of vast areas in the Canadian Shield represents a pioneer undertaking in this direction.

In the more prosaic field of systematic regional mapping, photogeologic methods have made important though less spectacular contributions. It is safe to say that nearly all geologic mapping carried on in recent years has utilized aerial photos in one way or another, wherever photos were available. In some instances, photos are used merely as base maps or guide maps for field work. So used, they frequently enable the geologist to locate himself on the ground more readily and more precisely, and to plan his traversing so as to go by the easiest route directly to points where outcrops occur and geologic relationships can be studied. In this way much of the hard work and lost motion involved in the old-fashioned method of random traversing is avoided. Under favorable circumstances, photogeology expedites the work of mapping still further, by providing a basis for reliable interpolation between and extrapolation beyond widely separated points or traverse lines where field observations are made. Indeed, it frequently is found that outcrop patterns and structural features which are very difficult to see on the ground are readily apparent on photos. The net result in all cases is to speed up the mapping process to a marked degree, to make for greater economy, and frequently to achieve a much higher degree of accuracy and of refinement in detail than would be possible otherwise. Thus the work of decades in terms of former standards is being compressed into a comparatively brief span of years, and the solutions to many fundamental geologic problems, dependent on more adequate knowledge of the earth's land surface, are fast coming closer to realization.

Applied geology involves the application of basic data and principles to specific practical problems, notable in petroleum geology, mining geology, engineering geology, and military geology. Frequently, the aim is to obtain maximum geologic information in minimum time with least expense.

It is in connection with petroleum exploration that photogeology has found particularly wide acceptance. Probably a large majority of the full-time photogeologists now active are employed by the petroleum industry. Much of their work is of a preliminary or reconnaissance nature, being directed to the delimitation of areas favorable or unfavorable for more detailed follow-up examination. Sometimes they are called on to assess the commercial possibilities of foreign areas for which little or no definite geologic information is otherwise available. In other cases they carry out regular areal mapping, though generally with less attention to detail than is required where systematic areal mapping alone is the sole objective. Much of their work is of a confidential nature, and thus little specific information as to their actual accomplishments in terms of oil discoveries has been released. The fact of their widespread employment, however, speaks for itself.

The mining industry lags considerably behind the petroleum industry in its utilization of both geology and photogeology. Numerous examples of the use of aerial photos, both for prospecting and for the more detailed mapping required for mine development, have been reported, however, and it seems likely that this field of application may expand in the future.

The application of photogeology to engineering operations has been outlined recently at some length in the pages of this journal. Here it need only be noted that this field of application is comparatively new and seems very promising.

In military geology, photo interpretation often is the only means of obtaining vital information on landing beaches, areas suitable for moving men or equipment, possible sites for airfields, sources of construction materials, and other matters. Here, too, much of the information as to actual accomplishments is restricted in its distribution, but enough has been released to indicate that photogeology did play a part of real importance in the military operations of World War II, and may be expected to have a still more prominent role in any future war.

Having now reviewed the progress of photogeology, it is fitting that some mention be made also of the factors which have tended or may tend to limit progress. These may be considered under the following headings.

(1) Limitations of the terrain itself. Where the soil cover is thin and comparatively little vegetation is present, as in arid or semiarid regions, the surface expression of geologic features generally is at its best, and the amount of information which can be extracted by photogeologic methods is maximum. Conversely, where weathering is deep and a heavy forest cover is present, as in many humid regions, there is less geology to be seen on photos, so that the results of interpretation are more limited and less clean-cut. Under some conditions, bedrock geology is almost completely hidden, and even the details of surface configuration are obscured. In such places, photogeology yields small returns, and even ordinary methods of ground study, unless supplemented by test pits or drill holes, may be futile. Other factors of the terrain which interfere with photo interpretation could be listed, but the above are illustrative.

(2) Limitations of the photography. For many areas the photography now available is deficient in scale, definition, or contrast, and all photography has the great limitation that colors are shown only in black, white, and shades of gray. The interpreter is working under handicaps unless photography is available for study, is of good quality, on a scale suited to the type of terrain and the objectives of the investigation, and is made under the proper lighting conditions, at a season when natural foliage permits the best possible view of the ground.

(3) Limitations of the interpreter. Here the human factor enters. The ideal photogeologist should be thoroughly trained in all the basic branches of geologic science, should have unlimited field experience in the most widely diversified types of terrain, together with long experience in using photos, should be possessed of an encyclopedic knowledge of regional geology and geography, and should be gifted with acute powers of observation and a keen faculty for reasoning. Needless to say, this ideal individual exists only in imagination. But the farther the actual interpreter departs from the ideal, the more limited will his results be.

(4) Limitations of background information, To compensate for the limited knowledge and experience of the individual, it is desirable that he have access to such reference material as will provide collateral information on the area which he is studying, and give a basis of comparison between the known and the unknown. Existing reference material of this nature is quite spotty in its coverage, and leaves much to be desired.

(5) Limitations of confidence. Photogeology is unlikely to be given a chance to demonstrate its worth unless the persons concerned have a reasonable degree of confidence in its practicality. Overconfidence, on the other hand, may lead to disappointments and rejection. In some quarters, the requisite degree of confidence and understanding have been attained; in others, less headway has been made.

The main problems now confronting photogeology are those of evaluating, and, insofar as possible, overcoming the limitations. In individual projects, it is important that the interpreter be realistic as to the limitations of the terrain and the available photography. He should endeavor to see all that is to be seen on the photos, but not to imagine that he sees more than is really there. He should distinguish carefully between interpretation and guesswork. It is thus that the boundaries of effective application are drawn, and confidence in this method of attack is nurtured.

The problem of lessening the limitations of the photography is partly financial and partly technicological. Rarely is it economically feasible for the photogeologist to have photos made to his own specifications; generally he must use photos made to different specifications for some entirely different purpose, with quality often compromised with cost. There seems little prospect of improving this situation, except to a limited extent by using auxiliary photography such as the geologist himself might supply by using his own camera in a hired plane flying at low altitudes. Many geologists have found this procedure to produce excellent results. With respect to possible technicologic advances in the photographic process, the geologist probably will be the last to benefit. Insofar as these improvements are designed primarily to produce greater cartographic accuracy, they will be of little help. If color photography is placed on a satisfactory working basis, however, it will be enormously helpful. It is possible also that infra-red photography, or photography made with other combinations of film and special filters, would prove useful, and experimentation is desirable.

The problem of preparing better interpreters and thus reducing the human-limitations is, of course, largely one of education. The completeness of the interpretation will always be proportional to the interpreter's training—academic training plus professional experience. As the need for photogeology becomes more generally recognized, it is to be expected that photo interpretation and related subjects will come to have a more prominent place in academic curricula. And as the applications of photogeology become more widespread, it is to be hoped that opportunities for diversified, creative professional experience will increase.

The limitations of background information should yield to systematic effort. What is needed is a pooling of the accumulated experience of the many workers in the field—the difficulties which they encountered, the mistakes which they made, the ways in which repetition of these mistakes was avoided, the limitations met with in various circumstances, and the specific results. Case histories for diversified projects would be invaluable. Furthermore, the field geologist could contribute in an important way be including in his published report annoted aerial photos showing typical surface expression of specific rock formations and other geologic features within his area. The preparation and publication of manuals or handbooks summarizing the interpretation of particular types of terrain would be still another aid in supplying vicarious experience.

The limitations of confidence belong more to the past than to the present. The enormous importance of photo intelligence during the last war, and the resultant training given to countless geologists and other scientists in the use of photos, did much to publicize the new method of investigation, and create confidence in its general soundness. There remain some areas, however, where the inertia of traditional ways is yet to be overcome; gradual dissemination of information as to the tangible accomplishments of photogeology should lead ultimately to its recognition there also.

In conclusion, photogeology has now taken its place along with other standard methods of geologic investigation. Its value both as an aid in basic research and as a useful tool for applied geology has been demonstrated. It has become a full-time pursuit for a limited number of specialists, and a supplemental pursuit for innumerable other workers in the various fields of geology. Just as the microscope extended the range of the biologist's observation, so also has the aerial camera and the stereoscope enlarged the range and scope of the geologist's observation, giving a new perspective on the earth's surface, and a new degree of refinement in studying its varied phenomena.

BASIC FACTORS IN PHOTOGRAMMETRIC INSTRUMENT PERFORMANCE*

John V. Sharp, Bausch & Lomb Optical Co., Rochester, New York

INTRODUCTION

IT IS my privilege to speak on the practical aspects of the broad subject of "Basic Factors in Photogrammetric Instrument Performance." The Bausch & Lomb Optical Company and I extend sincere thanks for this opportunity to present our point of view on this debatable subject. Essentially, we believe that a thorough understanding and application of this subject to manufacturing photogrammetric instruments is our major responsibility to the profession; and it is, in fact, the responsibility of every reliable manufacturer who supplies photogrammetrists with their essential instruments and operating supplies. Unless these instruments and supplies meet practical basic specifications, the cost, quality, and rate of production of the maps produced are unfavorably affected. Of course, many factors affect performance, but we are primarily concerned with those factors which, through continued improvement of instrumental performance, can improve the economics or logistics of map production.

PURPOSE OF PANEL DISCUSSION

In the panel discussion which follows this paper,† it is not our intention to discuss the merits of specific instrumental approaches to photogrammetry. That is the purpose of the various exhibits at this meeting. Instead, we propose to discuss, in a logical sequence, questions concerning basic performance factors related to all types of photogrammetric instruments, accessories, and operating supplies. Particular emphasis is placed on those factors which directly affect practical performance in map production.

It is our further purpose to discuss these factors insofar as possible in the practical language of the engineer who operates the equipment and produces the map. These factors can then be understood more readily by the practical photogrammetric engineers and administrators who constitute the larger portion of this organization. These are the men who can apply the basic understanding of these principles in using optical instruments and photogrammetric supplies, to produce maps to specified standards for many other engineering purposes. We plan to discuss the more basic factors in order to evaluate their approximate economic or logistic performance.

Discussion of this subject is predicated on the fact that every practical photogrammetric system of instruments in use today requires about the same basic type of instruments, accessories, and supplies. These all have similar

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† The panel discussion will be included in a later number of this journal, probably the June issue.—*Editor.*