sq. mi. and on a scale of about 1:6,000. In some districts compared, which had had years of ground mapping, many important features were not observed or mapped by ground methods which were readily observed with the color photographs. In general, the relative efficiency of color photogeological mapping would be at least four to one when compared to ground methods. For complex, remote and inaccessible areas, the relative efficiency would be much greater than that.

MR. ROBERT COLWELL: I'd like to make a comment regarding the relative cost of color photography when compared to black and white. It was mentioned that a number of factors make it difficult to make a blanket comparison. However, in a recent test, in which considerable effort was made to take a typical mission and figure the cost of purchasing the film, flying the photography, and processing the material and getting it ready for viewing, first in black and white and then in color, the cost figures came out roughly as follows:

For panchromatic photographs, the cost would be around $650, and for aero-ektachrome, the color photography, the same mission would be $850. Either figure is surprisingly low, compared with the overall values attained.

*"Eagles of Geology"**

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ABSTRACT: *This paper briefly describes the historical development of aerial photography as a component part of the exploration teams in one segment of the petroleum industry. Progressing from early limited use of aerial photographs through the birth and present application of photogeology, many advantages and values are demonstrated by illustrations. It is pointed out that basic principles of good management are essential in the application of photogeology to an exploration program, if maximum results are to be expected. Well-trained personnel and adequate tools are of utmost importance. Some limitations may be removed through developments now in progress.*

DURING my many years of being closely related to the search for petroleum, I have learned of the trials and tribulations of the field geologist. Often, they have brought to mind the story of the tiny lad wandering frantically through a densely-packed circus crowd. A thoughtful man asked if he were lost. The lad bravely anwered, "I'm not lost; my mother is lost." The man then raised the lad high upon his shoulders, from which point of vantage he was quickly able to identify his mother.

Similarly, aerial photography has, to a large degree, lifted the field geologist out of the swamps, out of the jungles, over trackless deserts, frozen waste lands, and the tallest mountain ranges. Along with speed, it has given him the wings of an eagle, the ability to stalk, study and swoop down upon his prey—the elusive petroleum trap.

From infancy to maturity the art of adapting aerial photography to exploration for petroleum and mineral deposits, now commonly called photogeology, has passed through many phases. The "Eagles of Geology," equipped with the vastly improved air photos and highly developed instruments and techniques, can "soar" over large areas while seated in comfortable offices.

Efforts of earlier-day geologists were slowed by painstaking measures necessary

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to mapping their stations of observation accurately. Practically every step had to be surveyed before observations could be interpreted. In contrast, today's "Eagles of Geology" with their ability to "see above the crowds," can, with comparative ease, identify and locate in true relationship, the faults, formational contacts, attitudes of layers, drainage patterns, and other surface expressions related to structure. With the three-dimensional view of their areas, they can calculate and plot their observations to the earth's image with remarkable accuracy.

Today, on the exploration teams in the petroleum industry, the function of photogeology is realistically acknowledged, and has attained a position of major importance.

It may be of interest to note an early evaluation of the use of aerial photography in the search for petroleum. The following is a quotation from an article which appeared in the *Standard Oil Bulletin*, published by the Standard Oil Company of California, December, 1927:

"Adoption of airplane photographs as a part of the geologist's equipment when he goes hunting for new oilfields is a recent development. The photographs have been found very useful, and promise to be an important aid in future searches. In time pictorial delineation of the geologist at work may present him standing beside an airplane or carrying a sheaf of photographs, instead of astride a mule or working at a planetable. Many of the larger oil companies are now using aerial photographs in their geologic work in California, and the results indicate that their use may become a matter of routine. Experiments have shown that the shortcomings of photographs as accurate maps are not vital defects, while their wealth of detail, beyond that of any other type of map, has been found extremely valuable. The study of photographs never can take the place of actual examination of the formations, and it is not intended that they shall serve that purpose."

Since that article was written, and particularly during the last few years, acceptance and application of the art of photogeology in the search for oil has rapidly accelerated. It is doubtful, however, whether the known present potential is being fully realized.

In the United States, the full application and use of the art of photogeology is restricted only in relation to the size of budgets and trained personnel. Operators, large and small, can participate in the advantages it offers.

FIG. 1. Folded structures revealed by aerial photographs in area of no outcrops.

Aerial photographs, when first introduced into the field of exploration, primarily served the geologist with a means of maintaining geographic location and provided him an accurate road map.

In relatively rapid progression, the photos were found to be valuable aids for plotting the geology as traced on the ground. It was discovered that the surface geology could be seen on the photographs almost as well as, and in some cases better than, on the ground. The following figures illustrate some of the values.

Figure 1 is a relatively old aerial photograph. It shows folds in very gentle topography where outcrops are non-existent and bedding is obscured from the ground observer. These folds are quite evident on the photographs but were, in fact, missed completely by early surface geologic mappers without photographs.

Figure 2 shows a particular anticlinal structure that had originally been mapped as a nearly symmetrical anticline. A cursory examination with the stereoscope allows one to see how the traced beds rapidly steepen and become overturned as they approach the fault. This type of interpretation can be done practically in details on the photographs, appreciably shortening the field time. Thus, study of photographs of areas previously mapped without the

FIG. 2. Overturned structure mapped from aerial photographs. This was originally mapped as a symmetrical structure by ground methods.

aid of photographs can be easily conducted to insure that no structural anomalies have been overlooked, incorrectly mapped or interpreted.

The anticlinal axis, illustrated in Figure 3 is apparent from examination of photographs. Low relief and farming activities obscure this data on the ground. The axis could be interpreted from surface work on the flanks but accurate positioning and existence in the west half of photographed area can best be accomplished by photo study.

Similar to benefits derived from the development of the jeep and helicopter, greater benefits were being realized from the use of aerial photographs in petroleum exploration. Hazards were decreased and terrain obstacles became less and less insurmountable. The photographs were recognized and accepted as valid means of obtaining continuity across terrain between ground controlled stations. Also, they afforded the geologist a means to geologically map areas extremely difficult of access which conceivably could disclose existing phenomena not easily observed in very costly and time consuming ground surveys.

Figure 4 depicts a relatively inaccessible area on which the formational contacts can be easily mapped. Three units are present in the area, each with its own particular weathering characteristics. Unit 1 is a competent resistant volcanic flow, characteristically a capping unit. Unit 2 is a thin conglomeritic formation, normally a cliff former. Unit 3 is a poorly resistant series of clays and sand siltstones which weather out into irregular rounded hills often forming badland topography. It is also possible, in examination of Unit 1, to see how direction of strike and dip can be determined and to measure much more accurately than by observation of a single local outcrop in the field.

Figure 5 is a photograph showing gilsonite veins easily traced on photographs, but traced only with great difficulty on the ground. The surface rocks are fluviatile formations, interbedded with poorly sorted, locally silty, generally cross-bedded channel sands. The rocks dip gently (1 degree–2 degrees).

The value of photographs in stratigraphic mapping is illustrated in Figure 6. The outlined sand body which is thick in

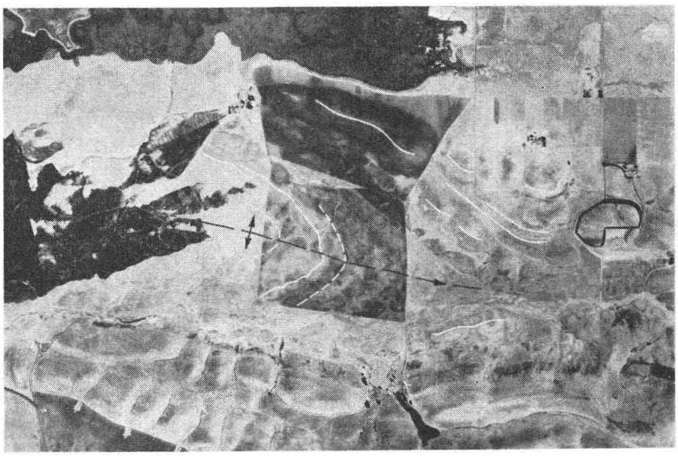

FIG. 3. Anticlinal structure mapped from aerial photographs of an area obscured by farming activities.

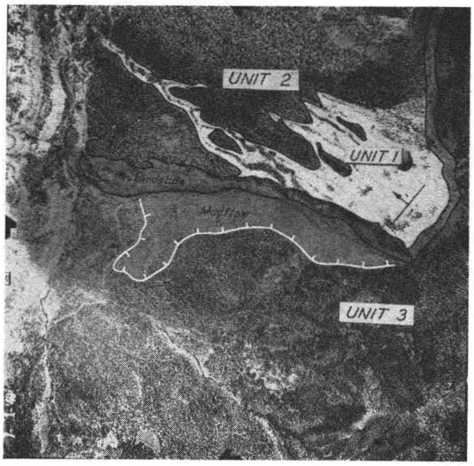

FIG. 4. Inaccessible area mapped from aerial photographs. The general strike and dip is more readily apparent from photographs than from local field measurements.

the upper left portion of the picture can be seen to thin radically by shale-out in the lower right portion. These relationships are not so obvious on the ground, but easily traced on the photograph.

Figure 7 is an annotated photograph of densely jungle-covered, rugged terrain showing an example of structure revealed by use of photographs. In terrain of this type, the value of photo examination can readily be seen.

Figure 8 is a photo mosaic of a densely jungle-covered area in the tropics, mapped in detail from air photos. Dip-slopes were found not to be present. The drainage system was used in analyzing the structure of this area, which led to the conception of a very broad, gentle sloping, closed structure reflected in the surface features by its drainage down the slopes and plunges.

Seismic survey confirmed the structural picture obtained from the air photos. Evidence of faulting found on some of the survey lines proved to be strikingly in alignment with the fault trends interpreted from the drainage pattern. The existence of these faults was confirmed by the wells drilled during development of the field. Some of the wells penetrated the faults as predicted, substantiated by electric log correlation.

With the expanding use of aerial photographs came the discovery that accurate measurements of geologic strike and reasonable approximations of dip could be

FIG. 5. Aerial photograph showing traces of gilsonite veins in sedimentary rocks. Note dark spots (pits) indicating trace of veins. Solid lines indicate general locations of veins.

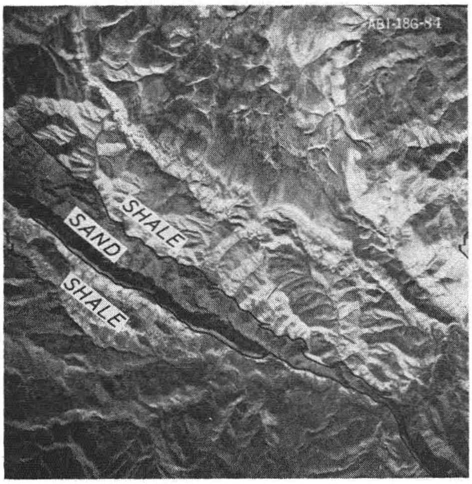

FIG. 6. Thinning of sandstone formation revealed by aerial photograph study.

made. They were readily recognized as a useful tool in working out surface geologic structure. Aerial photographic examinations, with proper field checks, evolved into an accepted method of conducting a complete geological survey, particularly useful for reconnaissance of large areas. This was the birth of Photogeology.

Vast areas considered to hold petroleum possibilities have been surveyed with photogeologic methods. The speed in accomplishment has provided a relatively inexpensive reconnaissance evaluation. Management has been served with early logical bases for coordination and integration of exploration programs.

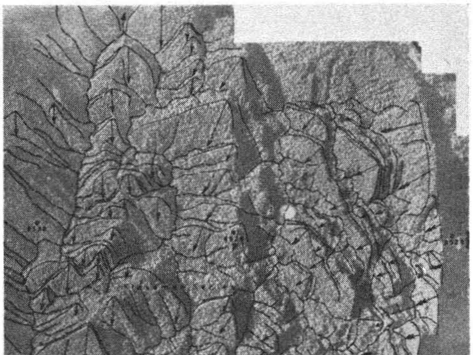

FIG. 7. Structure in sedimentary rocks of heavily vegetated jungle area clearly shown on aerial photographs.

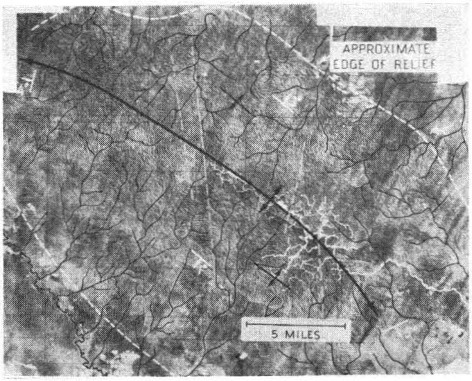

FIG. 8. Anticlinal structure in jungle-covered area revealed by analysis of drainage pattern.

A large part of private photogeologic surveys have been accomplished in the past ten years. The basic geologic teams in the petroleum industry could not have performed such a monumental task. It is a welcome opportunity to pay special tribute to the consulting photogeologic organizations, which, with their highly trained and experienced personnel, have not only made such early coverage possible, but have contributed immeasurably to recognition of the values and potential rewards from the art.

Extremely important to an exploration program have been the subsequent developments aimed at quantifying the geology and increasing the over-all accuracy. Many photogrammetric techniques and their instrumentation have been effectively utilized.

Figures 9 through 13 demonstrate a relatively recent photogeologic project in an area of rugged terrain where geologic data is of meager unresolved nature and spurred by intensive interest. Time is of the essence.

Aerial geologic reconnaissance and pertinent oblique photography is rapidly accomplished, with the use of a helicopter (Figure 9). Note the rough character of the terrain. Closure on the plunge of the structure can be seen.

Vertical aerial photographs are obtained, examined stereoscopically, and annotated. Simultaneously, a semi-controlled mosaic is constructed for area study. This is accomplished by one of several methods, depending on the required accuracy. Annotated data are field checked to resolve questionable interpretation (Figure 10). The data are then transferred to topo-

FIG. 9. Anticlinal structure and plunge of fold shown by helicopter reconnaissance of an area.

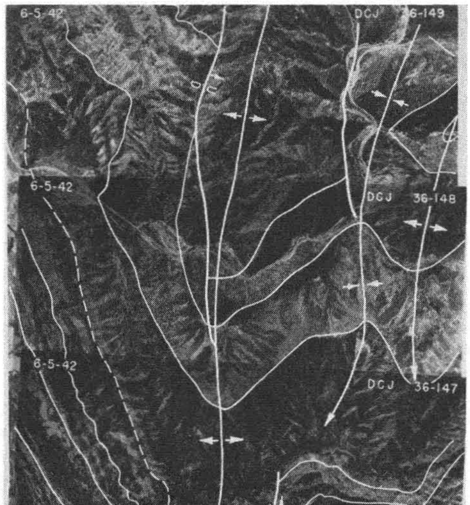

FIG. 10. Mosaic showing annotated geologic data. Data are field checked to resolve questionable interpretation.

graphic maps. (Figure 11). With the aid of the annotated bedding lines and thickness, and topographic contours, strikes and dips are computed with amazing accuracy. Based on the available data, structure sections are then constructed (Figure 12). Thorough analysis of all assembled data makes possible the construction of a reasonably accurate structure contour map as shown in Figure 13.

A project of this type can be completed in a matter of a few weeks, in contrast with the *months* which would be required by field work without photographs. From this evaluation, it is possible for management to reach an early decision. Minimum area lands considered desirable for acquisition could be easily outlined and a drill site selected if considered warranted.

Fundamental Requirements

In accepting photogeology as a component part of an exploration team function, basic principles of administration must be applied. With intelligent application, rewarding results can be obtained, not possible by any other known means at comparative cost and time. Management should recognize that certain requirements are essential if maximum benefits are to be realized. A high degree of performance and accomplishment can only be achieved by utilizing well-trained personnel equipped with adequate tools.

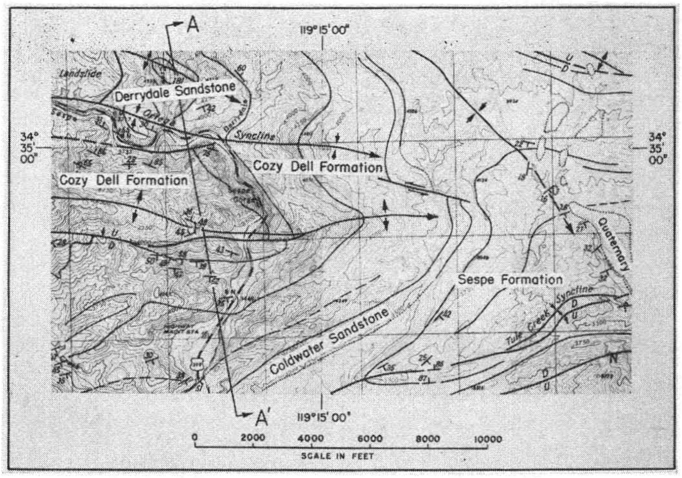

FIG. 11. Geologic map compiled on topographic base from aerial photographs. Structure may be analyzed from geologic data in conjunction with topography.

Unfortunately, many of our institutions of learning have not been able to integrate or to include in their curricula broad training in photogeology and photogrammetry. It is believed the need is well recognized and methods will be evolved to effectively provide such early training. Until that time, industry and other organizations with large geologic staffs must bear a time-consuming training burden.

Some difficulty is encountered in finding personnel that want to perform this type of work continuously. Also, there are those who do not have an aptitude for work on air photos. However, it is considered that:

1. All field geologists should be able to interpret geology on air photos when they have the required visual skills. With training, experience and, if necessary, reasonable corrective measures, a relatively high degree of skills can be attained. For an exceptionally comprehensive treatise on visual skill, I refer you to the paper by Dr. Ellis L. Rabben—"PHOTOGRAMMETRIC ENGINEERING"—September, 1955.
2. Careful, intensive training is essential for the less experienced geologists in qualitative and quantitative geologic interpretation on air photos, involving new techniques, instrumentation and photogrammetric fundamentals. Careful annotation should be emphasized. This training can be accomplished with seminars conducted

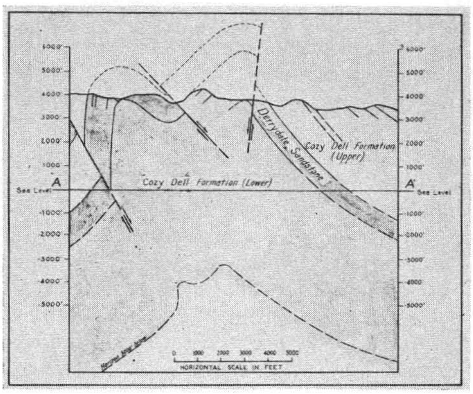

FIG. 12. Example of structure section constructed from geologic-topographic map.

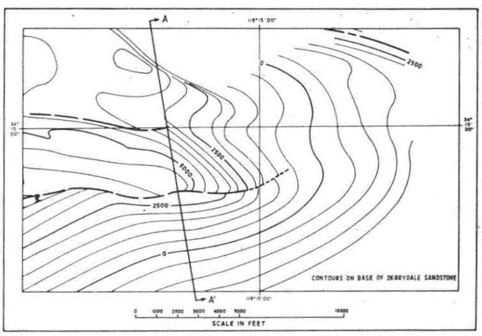

FIG. 13. Structure contour map compiled from photo-interpreted and field data.

by highly trained personnel within a large organization or through the services of consulting specialists. Lack of experience and training affect exhaustive use of the photogeologic art, and also create a feeling of inadequacy and thus prevent a complete acknowledgment of its worth.

3. Aerial photographs of highest quality with adequate stereoscopic coverage are of vital importance to photogeologic interpretation and ultimate mapping. Oblique, horizontal and high altitude photography play an important role in the photogeologic surveys and study. It is believed that they are not used as extensively as they should be. Mosaics, semi-controlled or highly controlled, as the occasion warrants, are most desirable for regional study and continuity mapping.
4. Since nearly every project presents a different problem, particularly in widespread operations, consideration must be given to, among other things, the evaluation of the adaptability of methods and instrumentation. This includes thorough analysis of the instruments now available, their application, and constant alertness to new developments.
5. Intelligent and comprehensive selection of areas to be examined should receive major consideration.
6. Timing and coordination with other phases of exploration operations are essential.
7. Finally, the survey accomplishments and concepts must be reflected on adequate maps to insure maximum benefits in end use.

Ultimate Potential

The ultimate potential of the aerial photograph and instrumentation for use in photogeology can only be conjectured. Like all other works of man, improvements will be made and unique innovations developed, probably far beyond our expectations. These will evolve from diversified and widely scattered sources.

1. The values of color photography are now recognized. The day is not too far distant when it will be economically within reach, and extensively complement the black and white photography for many purposes. In certain cases, it will replace the black and white.
2. Orthophoto maps will become a reality and utilized to great advantage in many operational phases of the industry.
3. Electronics application will have considerable impact, and today's dream of map making with use of that medium may soon be realized.

We are indeed fortunate that, as in the past, we can all be early informed of the thinking and new advances through the efforts of this Society, other organizations, and the wide cooperation of individuals comprising the memberships.

Conclusions

Evaluation of the contribution of photogeology to the petroleum industry in dollars and cents is, of course, not possible. Although this contribution has been considerable, enthusiasm must be tempered with the realization that it is only a tool with which to complement the field geology. It can never dig a pit, take a sample, or measure a vegetation-covered section. It has come a long way in the last thirty years. The "little boy" has become a man. The "Eagles of Geology" are flying higher, with greater speed and keener sight. The many who have patiently and persistently, nurtured and developed the art of photogeology to its present status can look upon their achievements with justifiable pride.

Discussion of Mr. Christensen's Paper

MR. THEODORE A. CHENEY: You stated that universities are not providing the people that you want. I agree.

But there is also fouling of some of our graduate students who every day do the type of work you showed on your slides, as part of their work. One boy that I know is getting his Master's degree in Air Photo Analysis. He wrote one of our country's leading and most talked about photo interpretation companies, and said I am getting my Master's in interpretation; my thesis is on the identification of or location of ground water resources through photos; my minor subject is photogrammetry; and I'd like a job. The reply was: we make mosaics; we don't need any more photogrammetrists or cartographers. Why they ignored the fact that he was getting a degree in photo analysis and in interpretation and was a graduate geologist, I don't know. I hope if some of these boys write to you, you will listen to them.

MR. CHRISTENSEN: Personally I think that eventually they will receive proper consideration, because it is now beginning to be realized that photogrammetry in its relation to photogeology and photo interpretation takes a great deal of training.

MR. ROBERT FOX: I should like to know the policy of Standard Oil of California in training men who are primarily geologists, but qualifying them in photogeologic interpretation or analysis is desired. Are you sending them to such commercial companies as Geophoto in Denver, or similar companies? Or do you arrange for their training program? Or for them to take a training program at such as Cornell?

MR. CHRISTENSEN: We have utilized the training that has been offered by the Geological Survey. Also in some instances we have utilized the consulting photogeologic organizations which offer such a training course. Also, when our own people have become well trained, they take over the training of younger geologists who lack that particular training.

DR. FRANK A. MELTON: I'd like to ask Mr. Christensen if he knows whether trained photogrammetrists have been combined with trained geologists; I mean, trained in geologic interpretation of aerial photographs.

MR. CHRISTENSEN: Geologists, Dr. Melton, are being trained in the fundamentals of photogrammetry.

DR. MELTON: I desire to comment on that. In dealing with geologic interpretation, I believe that up to the Master's degree level, it will be very difficult to find students with sufficient experience in the interpretation of the photographs, together with the photogrammetry required. It seems to me that better results all around might be attained if persons experienced in photo interpretation—geological interpretation—were teamed with photogrammetrists, rather than expecting one man to do both.

MR. CHRISTENSEN: That is a very good point. I think that it will receive consideration in the future, in our geological organization.

MR. FISCHER: I take this last opportunity to thank the panel for their interesting presentations, for the frankness with which they have answered the questions, and for taking the time and trouble and effort to come great distances to be here today.