PHOTOGEOLOGY AIDS OIL EXPLORATION*

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A NEW science looms on the horizon of the petroleum industry. Photogeology, although originated before the war, has finally arrived as a tried and true method of exploration. Several factors have contributed to the current interest in photogeological exploration. One is the great increase in crude demand and the decreasing rate of new field discovery. Another is based on the important role of photographic interpretation in the war and the peacetime applications of these war-perfected techniques.

The relationship of petroleum exploration to the discovery of new oil fields is directly affected by the inception of new or refined exploratory techniques. This is a subject which has concerned many engaged in petroleum exploration. In the Symposium on Petroleum Discovery Methods issued by the American Association of Petroleum Geologists much emphasis was placed on the fact that surface mapping should not be regarded as an exploratory "has been" but that refined surface mapping techniques combined with an appreciation of geomorphology give promise of pointing the way to new reserves.

Photogeology as an improved and speedy method of reconnaissance surface mapping can no longer be regarded as some new-fangled, "long-haired" research project. It is already being successfully used in many areas in the United States and foreign countries.

The purpose of this paper is to review the latest advances in aerial photography and photogeological techniques and to illustrate how these factors are being applied to modern petroleum exploration.

World War I Use

One of the first instances of the use of photogeology dates from World War I when Col. A. H. Brooks, Chief geologist to the AEF, mapped geological formations in enemy territory by means of aerial photographs (1).[1] In the 1920's many geologists used aerial photographic mosaics as base maps in the field. Although this procedure could not be truly rated as photogeological exploration, the time saved in location of outcrops, and in knowing in advance where to go to find outcrops was of great value. Perhaps the first example of true photogeologic mapping in the U. S. was done on aerial photographs of the Elk Hills field, California, in connection with a lawsuit.

During the ten years prior to World War II, photo mosaics were in greater use and it was in this period that several major companies set up photogeological units in their exploration departments. In those days the science was still earthbound in that stereoscopic examination of contact prints was done by field geologists concurrently with their field mapping programs. Except in one or two instances the specialized photogeologist of today has not arrived.

In World War II many petroleum geologists who had worked with aerial photographs were taken into the armed forces as photographic intelligence officers. Other geologists who had no previous experience with aerial photographs were accepted because it was known that a geological education was an excellent background for combat photo intelligence work. The geologist's appreciation of terrain, his knowledge of maps, and his attention to detail when applied to searching out hidden gun batteries or the conditions of an enemy landing beach rendered him admirably efficient in photo intelligence.

Photogeology should be regarded as a potent tool in the hands of the explora-

* Reprinted from The Oil Weekly. December 1946.

[1] Numbers in parentheses refer to papers listed in "References," p. 285.

tion geologist. Like any tool it is not the end result but an important aid. To carry the analogy further, there are other phases of petroleum exploration which can be done better by the tools of geophysics or core drilling or subsurface studies as the case may be. Photogeology fills the need for a rapid and comparatively inexpensive technique with which large areas can be evaluated. The smaller blocks which show surface evidence of favorable structural anomalies can then be evaluated in further detail, if necessary, by one of the other accepted exploration tools. In this way expensive geophysical or detailed surface mapping of many large areas can be eliminated. There are other factors which render photogeology the ideal approach for preliminary exploration. In working rough terrain, accessibility of the area is not important, whereas the speed of conventional surface mapping is directly influenced by the roughness of the country.

Adverse weather is another detrimental factor to surface mapping which has no effect on the speed of photogeologic studies once the photographs have been obtained. An ideal setup for high latitude areas is to do the photogeologic work during the winter months when the area is probably snow covered. Favorable anomalies can be given a field check in the spring and the most promising areas can be blocked before competitors have an opportunity to do any surface work in the region.

Secrecy of Operation

In the highly competitive oil industry secrecy of exploration activities is very desirable. Photogeology is the only reconnaissance evaluation method by which it is possible to attain proper secrecy of operation. Photographs can be worked many miles from the area which is to be evaluated and quick field checks can be made without throwing suspicion on the play.

The expert photogeologist is a scientist who is not only an able field geologist and structural geologist but who is thoroughly versed in the related study of geomorphology and he must also know the fundamentals of vegetation ecology and soil distribution. For it is the recognition and interpretation of all the minutiae exhibited by the tones and stereoscopic relief of an aerial photograph which enables the photogeologist to translate these observations into the important criteria necessary for an accurate surface geological evaluation of an area.

Visual reconnaissance from an airplane vs. stereoscopic examination of aerial photographs is an oft-argued point. Both methods have their advantages but the writer from his war-time experiences in both methods prefers aerial photo examination. The chief disadvantage of visual observation is that the field of view is never constant enough to afford a detailed observation of any one area and the human eye cannot retain the mass of detail which can be recorded on an aerial photograph. The practical development of the helicopter may see the day when the photogeologist will supplement his aerial photo studies from a hovering plane. Another disadvantage is that visual observation cannot afford the photogrammetric measurements essential in detailed photogeologic evaluation. Also, it is well known that at an altitude high enough to afford a sufficiently wide visual field the terrain appears flat except in very rugged areas. The relief model as seen through a magnifying stereoscope is exaggerated in the vertical component. This is a decided advantage in a qualitative evaluation of the dips and strikes of the outcrops of an area.

The air view, whether it be by visual observation or by photoexamination, truly gives the normally earthbound geologist an entirely new slant and appreciation of his profession. Unlike the bear who laboriously climbs the hill to see

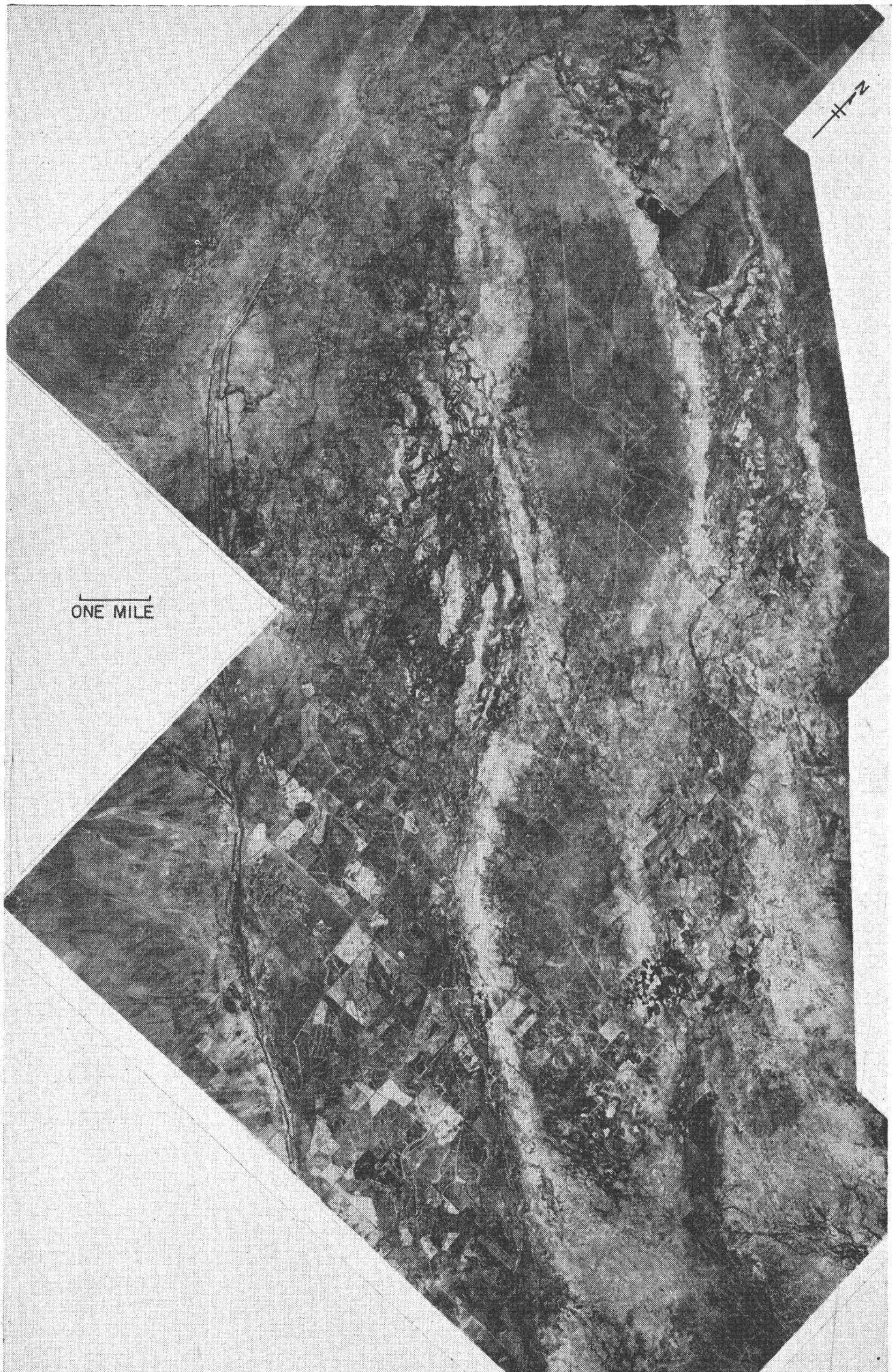

FIG. 1. Mosaic of Buttonwillow Gas Field, California. "This field was not discovered directly by means of aerial photography but its striking appearance from the air led to a detailed topographic survey, which outlined the structure and resulted in the drilling of the discovery well" (9). There are no outcrops on the structure but the outline of the slight topographic high which marks the field has been accentuated by recurrent flooding of the flat alluvial plain at which times the higher ground was an island. The white band around the structure marks the highest advances of the flood waters. (Courtesy Fairchild Aerial Surveys, Inc., Los Angeles.)

what is on the other side the photogeologist can see both sides at once. He can easily bridge canyons and high ridges and carry his correlations along while the same work on the ground would require much more time and effort. In areas of scattered outcrops it would be necessary for the ground geologist to traverse every acre in order to be certain that no diagnostic exposures were omitted. When such areas amount to several hundred square miles, this becomes a major project of walking ridges and valleys. The photogeologist can spot all the outcrops in such an area in a matter of a few hours, unless they are covered by dense vegetation, and if his photo studies did nothing more than indicate where the geologist should go in the field to find those outcrops, the work would be more than justified.

But photogeology carries the evaluation of an area much further. In many cases it is actually easier to correlate units on photos than on the ground. Dr. W. G. Woolnough, chief geologist to the Australian government (2), cites a case in the sandstone outcrops of Western Australia where cross bedding and lenticularity observed at close quarters on the ground made dip and strike readings extremely difficult. The aerial view eliminated these irregularities to a large degree and indicated the presence of very large lithological features, the existence of which could be determined at close quarters only by time-consuming and expensive detailed surveying.

The expert photogeologist is able to pick up details of bedding and structure which are difficult or impossible to note on the ground. An example of this is seen on the Elk Basin structure on the Montana-Wyoming line. Steeply dipping Upper Cretaceous and Eocene rocks on the southeast flank of the structure are obscured by a high gravel bench. On the ground individual units cannot be traced beneath this bench, but they can be clearly delineated on aerial photographs of the area.

L. T. Eliel (3) of the Fairchild Corporation cites a case in California where a portion of an anticline was quite evident on the ground, but where the hills gave way to a flat uncultivated valley all evidence of bedding was lost to the ground observer. On aerial photos bedding was traced four miles into the flat valley and the anticlinal axis was projected the same distance.

C. R. Robbins (4) of the Aircraft Operating Company, Ltd., of South Africa, has noted that one of the greatest values of geological information from aerial photos lies in the recognition of features which are not visible or appreciated on the ground. He mentions that faulting can be discovered although buried by thousands of feet of younger, post-fault rocks; and that dikes and fractures completely covered by bush and many feet of overburden can still be discovered.

During the war the photographic interpretation of underwater phenomena was advanced to a very high degree. Thousands of American lives and millions of dollars worth of equipment were saved through offshore beach studies in which the depth of the water was determined from aerial photographs and accurate evaluation of the bottom conditions was made. Kodacolor reversal film proved valuable in underwater photo analysis. The same techniques should be successful in photogeological mapping along many of the nearshore areas of the world adjacent to prospective or proven petroliferous provinces. H. C. Rea (5) has noted that the Elwood anticline off the Santa Barbara, Calif., coast is delineated by kelp adhering to submarine outcrops of Monterrey shale.

Method of Attack

Determination of dips and strikes on aerial photographs is one of the most important functions in photogeological evaluation.

In areas where the ground surface is fairly flat and the dips greater than

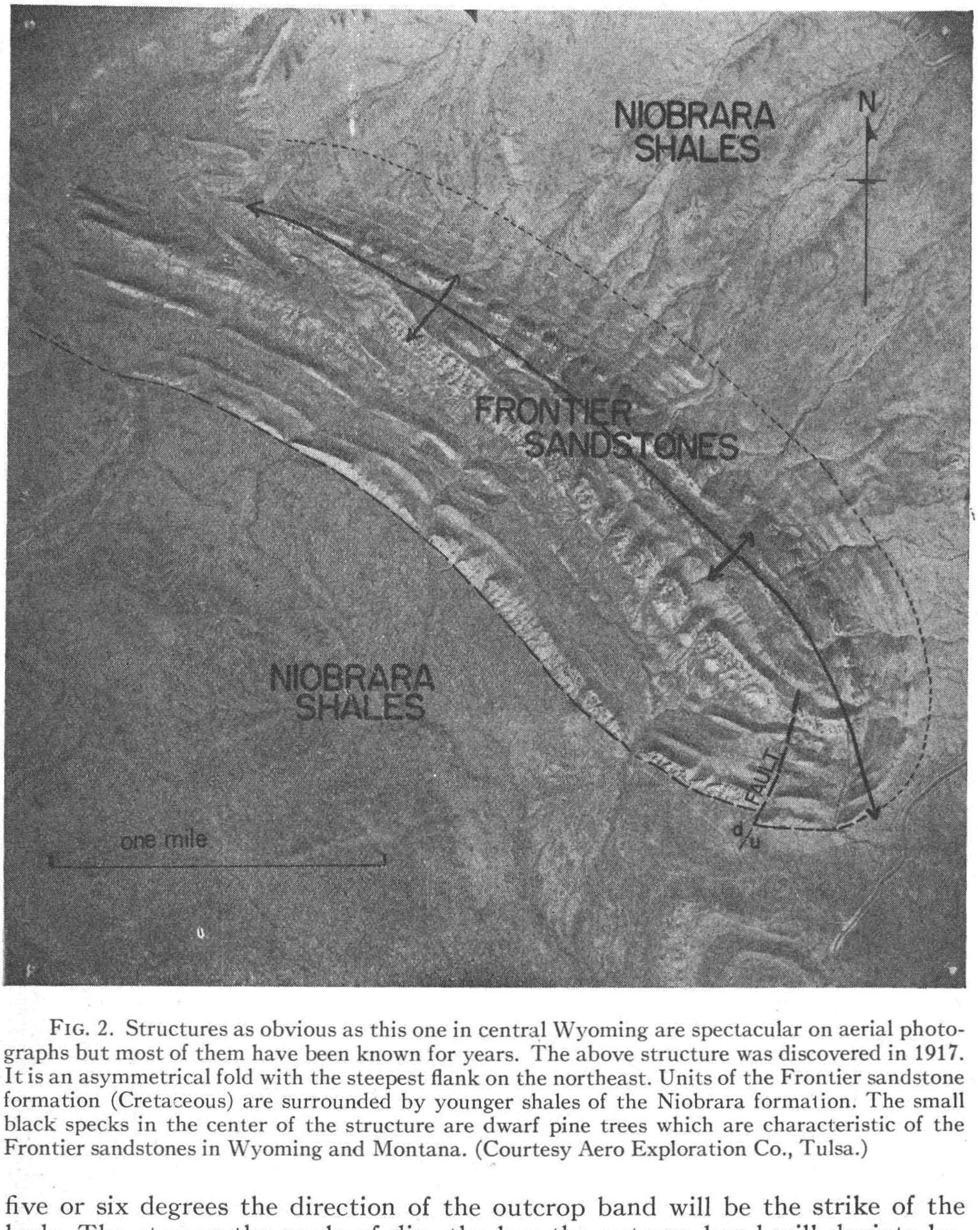

FIG. 2. Structures as obvious as this one in central Wyoming are spectacular on aerial photographs but most of them have been known for years. The above structure was discovered in 1917. It is an asymmetrical fold with the steepest flank on the northeast. Units of the Frontier sandstone formation (Cretaceous) are surrounded by younger shales of the Niobrara formation. The small black specks in the center of the structure are dwarf pine trees which are characteristic of the Frontier sandstones in Wyoming and Montana. (Courtesy Aero Exploration Co., Tulsa.)

five or six degrees the direction of the outcrop band will be the strike of the beds. The steeper the angle of dip, the less the outcrop band will deviate because of topographic differences. A good example of this is in the steeply dipping pre-Tertiary hogbacks of the Rocky Mountain region.

For very flat beds the dip and strike are quite difficult to estimate by eye. In dissected topography the strike of the beds can be obtained by measuring the direction of two points of equal elevation on the same contact on opposite sides of a valley or opposite sides of a hill. Elevations can be estimated under the stereoscope but a more accurate method is to use a photogrammetric instrument.

While the direction of dip usually can be determined by visual observation except on very gently dipping beds, the accurate estimation of the true angle of

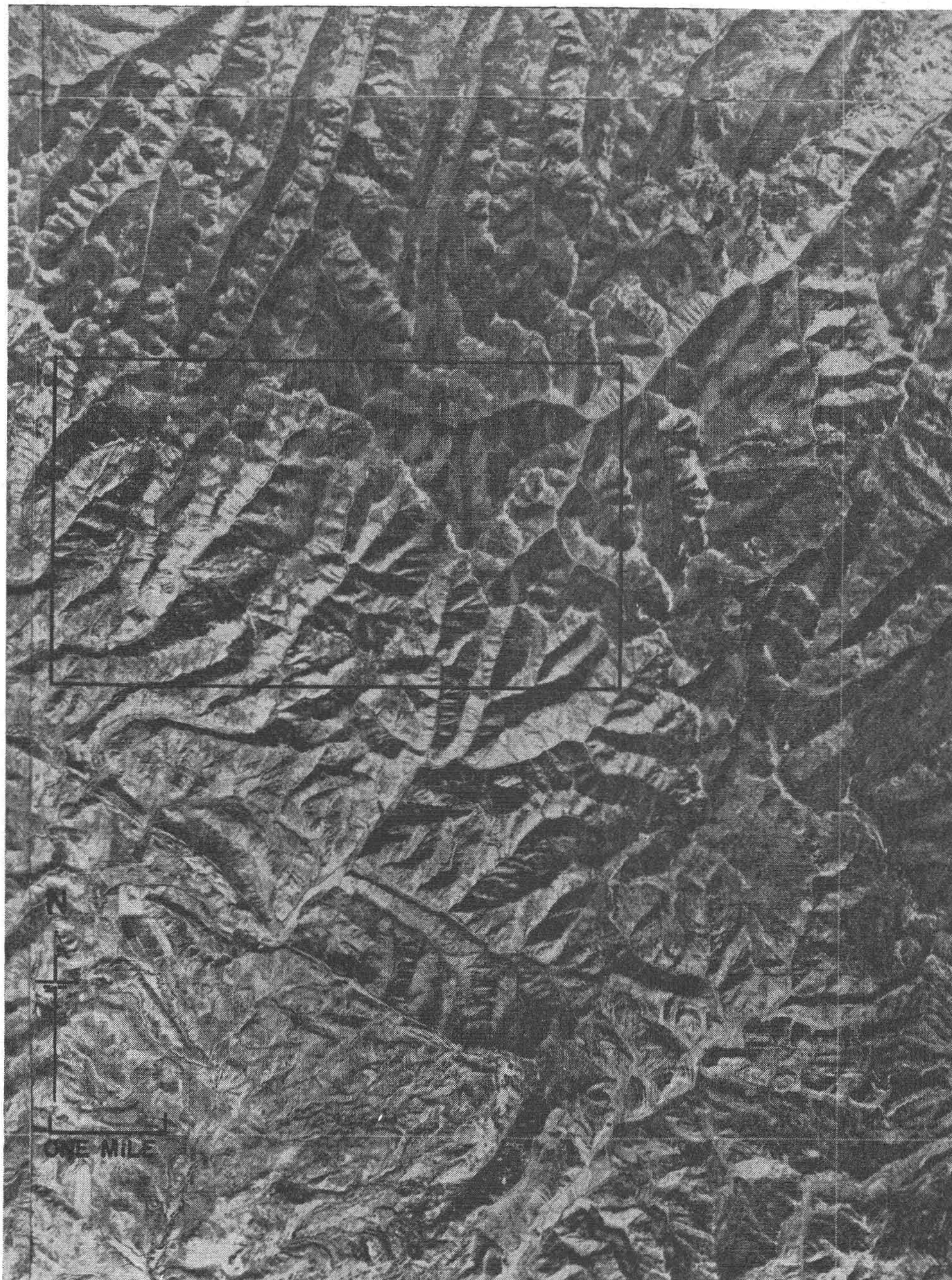

FIG. 3. Mosaic of a portion of Moffat and Rio Blanco counties, Colorado. The highly dissected topography of the area and the vegetation cover have rendered an accurate photogeological evaluation almost impossible on the mosaic. (Courtesy of U. S. Dept. of Agriculture.)

dip by stereoscopic means is subject to exaggerations in relief and distortions of the stereoscopic model. The tendency is to estimate a much steeper dip than the beds actually have. Several methods have been evolved for the determination of dip angles on aerial photographs. One is a utilization of the well-known three-point method; the elevations of the dipping surface at each point being determined by photogrammetric means. Another process is suggested by Desjardins (6).

As on the ground, the more outcrops which can be traced on aerial photographs the more complete the evaluation of the area will be. In some areas

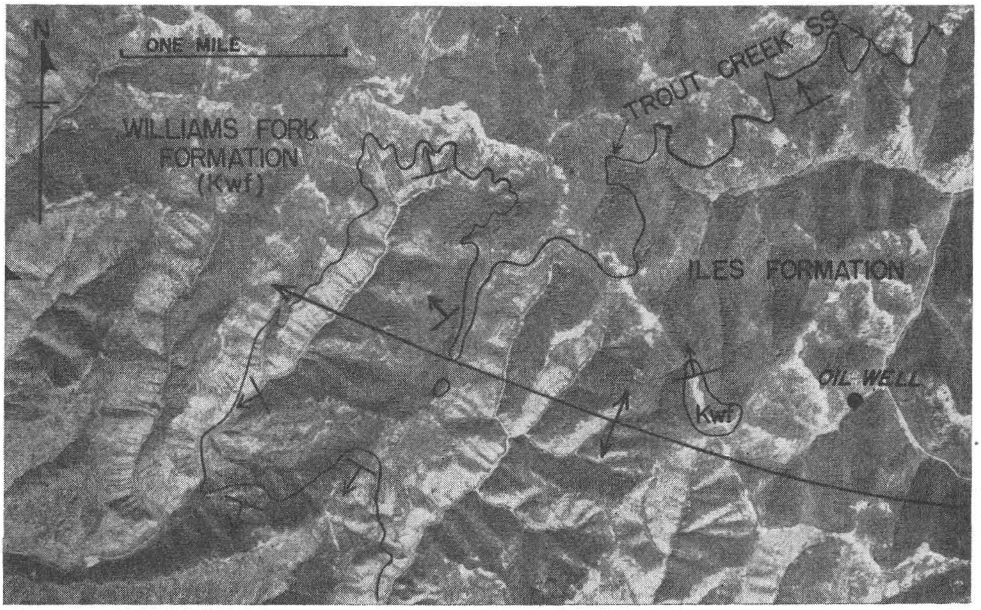

FIG. 4. A portion of a 9″×9″ photo covering the area outlined in Figure 3. Stereoscopic examination of the contact prints affords a wealth of detail which cannot be seen in the mosaic. This photograph shows the western end of the Wilson Creek oil field of Rio Blanco County which is one of the topographically highest producing structures in the United States. The average elevation of the field is 8000 feet above sea level. (Courtesy of U. S. Dept. Agriculture.)

the outcrop pattern is restricted and instead of being able to trace units over considerable distances the photogeologist must rely on dip and strike determination on a number of scattered exposures to build up his structural conception of the area. This is particularly true of many of the Tertiary basins of the Rocky Mountain area. These basins are perfect examples of the efficiency of photogeological evaluation studies. Very little surface mapping has been undertaken there because of the scarcity of outcrops and the difficulties in accessibility. Aerial photographic analysis has been responsible for accurate and speedy evaluation of large Tertiary areas which would normally require one or more complete field seasons to accomplish on the ground.

In cases where a sedimentary sequence is obvious or where it can be built up through the identification of surface features directly influenced by bedding such as breaks in slope, vegetation bands and soil texture, a stratigraphic section can be arrived at which will be the basis for constructing a structural contour map of the area.

After long experience in aerial photo analysis, the expert photogeologist can actually identify lithologic units such as shales, sandstones, lava, granite, etc. Characteristics of weathering, topographic expression and associated vegetation are all clues toward the identification of rock types. These characteristics will vary from area to area and between formations composed of the same rock type, but when a photogeologist becomes familiar with a specific area he can use a system of "key textures" to aid him in correlating and tracing beds.

The above statement may be an over-simplification and there are many pitfalls of which the photogeologist must be aware in order to arrive at an accurate evaluation of an area. The idea of using vegetation to identity formational contacts or units within a formation is not as simple as it sounds. The Reklaw-Carrizo contact in South Texas is often pointed to as an example of this. In that area the Carrizo sand provides a natural habitat for blackjack growth and the more argillaceous Reklaw is favored by mesquite shrubs. On aerial photographs the lines of demarcation between the two vegetative types is quite distinct but not always does this line mark the actual formational boundary since the unconsolidated Carrizo sand, containing blackjack growth, is often washed over the Reklaw. Then again, the type of vegetation growing on the same formation will be dependent on such factors as rainfall, altitude, and the local character of the formation. The photogeologist must be cognizant of these factors in order to arrive at a correct answer.

Differences in vegetation are often good indications of faults or dikes. Even in some jungle country it is surprising that vegetation can be used to get an idea of structural irregularities.

Levings (7) mentions a personal communication from K. C. Heald in which the latter says: "Sometimes changes in vegetation or soil color, which would be unnoticed by geologists on the ground, show up in a very striking way on the airplane photographs." Heald states that the first well on the Santa Rosa structure of eastern Venezuela was located on seismograph work and it proved to be a dry hole. Study of aerial photos showed an "egg-shaped patch about two miles from the location of this first well where the tone of the photograph was distinctly lighter than the surrounding area. Investigation proved that this light spot was the top of the Santa Rosa dome."

Dr. Woolnough (8), who is one of the first geologists to realize the potentialities of photogeology, cites an interesting example of soil differentiation in Queensland, Australia, which could only be seen on aerial photographs. Months of detailed surface investigations in this area failed to disclose any reliable geological information. An aerial survey of the locality indicated a conspicuous symmetrical soil pattern which was evidently a reflection of sub-surface geological structure in deeply decomposed sedimentary rocks. The marked soil differences could not be traced on the ground at first and it was only after extremely detailed comparison of features on the photographs and on the ground that a slight variation in soil texture could be seen. This variation was noticeable on the ground only where sheep had picked up the soil.

Since the aim of commercial photogeology is to gain an understanding of the structural conditions of an area, the types of maps which can be prepared to present this information are of prime importance.

In maps used for photogeological presentation purposes some accuracy must be sacrificed for speed and cost of preparation. We prepare two types of maps. The cheapest and more quickly prepared consists of a tracing from government 1:63,630 mosaics of the important drainage and cultural features of the area. The photogeological information is then transferred to the mosaics and traced

FIG. 5. Mosaic of Ship Rock area in the San Juan Basin of northwestern New Mexico which is one of many extensive areas of the U. S. not fully mapped on the surface. This mosaic shows an example of the surface geology of the region. Ship Rock is an igneous plug with spectacular radiating dikes. The Beautiful Mountain anticline is a long, relatively narrow fold, the northern portion of which is shown on the mosaic. The maximum closure on the structure is about 150 feet. A well drilled in 1925 to the Dakota had a fair show of oil at 1727 feet but no commercial production was obtained. (Courtesy of Fairchild Aerial Surveys, Inc., Los Angeles.)

on the composite map. This system is best suited for the reconnaissance evaluation of areas in excess of 1000 square miles. For more accurate control we use the radial plot system with ground control from available township plats, topographic maps and grazing maps. In certain oil-producing or prospective oil-producing areas excellent controlled base maps prepared from aerial photographs are available from commercial sources. However, the areas which are being assigned for photogeological work today are usually devoid of accurate maps and the photogeologist must prepare his own.

Today an area is usually assigned for photogeological evaluation for one of two reasons. Most of the areas in proven petroliferous territory which contain well defined outcrops have already been worked to some degree on the ground. If the area which is to be evaluated by photogeologic means does contain well-defined outcrops, it is either too remote and inaccessible for economic ground investigation or it is situated in a region which has not been productive of oil. In many cases both conditions will be present. Areas which contain relatively few outcrops may or may not be remote, but the time and cost involved to cover these areas in sufficient detail on the ground in order to get an accurate idea of the structural conditions will be greater than by photogeological evaluation.

It is true that the most obvious areas for surface mapping have been covered already on the ground. The amount of detailed work and experience necessary for accurate photogeological evaluation of today's areas is therefore greater because of this fact. All the well-known pre-Tertiary "textbook" structures of Wyoming and Montana could have been discovered in a fraction of the time actually necessary for their mapping had photogeology been in vogue in the early 1920's. The same applies to many salt domes on the Gulf Coast and to structures in California, the Eastern producing states and the Mid-Continent.

In areas where outcrops are not common and the exposed rocks lack diagnostic characteristics which prevent correlations between outcrops, a structural interpretation map is relied upon to give a picture of the area. This type of map is based on the information afforded by as many dip and strike readings which can be obtained from the photographs. Areas of moderate to steep dips usually have a continuity of outcrops from which a stratigraphic section can be constructed, but in those areas in which the outcrops are poor the dips are usually low and structural anomalies are not at all obvious. A stereoscopic height-finding instrument is used to obtain measured dips and strikes and these readings are supplemented by dips and strikes obtained by visual observation through the stereoscope. Any other photogeological clues to the structure of the area such as vegetative differences, possible dip slopes, suspicious banding beneath gravel benches or other alluvial deposits, and physiographic indications of faults or anticlinal anomalies are also indicated on a structural interpretation map. The Tertiary basins of the Rocky Mountain region are examples of areas in which this type of map is used.

Structural Contour Map

The other type of map which it is possible to construct through photogeological studies is the conventional structural contour map. This can be done in those areas having sufficient outcrops which can be built up into stratigraphic section. After the section has been established, elevations are obtained on key horizons either by reference to available topographic contour maps of the area or by photogrammetric means from the photographs. In the latter case it is necessary to establish a sufficient number of ground elevation control points by altimeter or plane table traverses.

The writer and his associates wish to emphasize that field checks are necessary corollaries to photogeologic evaluations except in preliminary reconnaissance studies of remote areas where it is only desired to ascertain if there are indications of structural anomalies. Field checks are for the purpose of investigating the less obvious indications of structures and to look for small critical exposures which may be obscured on the photographs by overhanging ledges or by heavily wooded areas. Also, in some areas where the lithologic units are not distinct, the prevailing scale now in use (1/20,000) does not allow accurate determination of dip and strike. It is therefore necessary to supplement the photogeologic work with field measured dips and strikes. However, study of the photographs will still be of great value in that the geologist will have prior knowledge of where to go in the field.

The outlook for photogeology is brighter today than any other time in the history of petroleum exploration. The need for expert photogeologists is increasing, but only long experience with aerial photographs coupled with a flair for detailed observation and the ability to realize the significance of the subtle clues contained in the varying tones of a photographic print will enable a geologist to produce accurate work. Excellent eyesight is also a most important attribute of the photogeologist, since long hours must be spent in looking through a stereoscope.

Photogeology in its correct niche as a valuable adjunct to petroleum exploration will enable the oil operator to select smaller portions of large tracts for detailed evaluation by other methods. The time and money saved by this system have already more than justified the acceptance of photogeology as a standard operating procedure.

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