PHOTOGEOLOGIC CHARACTERISTICS OF PALEOZOIC ROCKS ON THE MONUMENT UPWARP, UTAH

Sherman A. Wengerd, University of New Mexico

ABSTRACT

Paleozoic rocks of southeastern Utah are exposed as a result of the antecedent San Juan River cutting through the Monument Upwarp, and the stripping away of Mesozoic beds by intermittent streams and slope-forming agencies during uplift. Although the San Juan River cuts through this major uplift with little regard for the major structure, certain parts of the river and all of its tributaries have adjusted themselves closely to structures of importance in oil exploration. In this arid region, where vegetation and soil are sparse, the close correlation of slope form and lithology is evident, and formation identification is not difficult. Structural mapping from photographs, however, is complicated by numerous factors.

Topography which makes accurate photographic interpretation difficult include the deep canyons, talus slides, scree slopes, steep-gradient ephemeral streams, and terrace gravels. Stratigraphic factors which cause interpretation difficulties include gradational formation contacts, lateral lithofacies gradation, and the massiveness of the Cedar Mesa sandstone. Structural factors include the predominant northeast-trending joint patterns, the low stratal dips, and the exceedingly slight stratigraphic throw on recognizable faults. Photographic difficulties encountered include excessive tilt, and great radial relief displacement.

Aerial and field reconnaissance after photogeologic mapping has proved the validity of careful photographic interpretation of not only the Paleozoic terranes, but the Mesozoic terranes as well in southern Utah and northern Arizona.

INTRODUCTION

GENERAL CONSIDERATIONS

UTILIZATION of aerial photographs by the geologist in varying terranes requires wide field experience; however, their applications to oil exploration problems depend not only on the ability of the geologist but also on the quality of the photographs and the character of the country to be analyzed. Numerous variations exist in the quality of photogeologic maps prepared by company and consulting geologists. Certain analysts prefer to believe the aerial photograph to be capable of precise interpretation and, with sufficient ground control, to yield enough data to prepare a geologic structural contour map without field checking. Others feel that a structural form-line map can be prepared with few field data and the utilization of only the stereoscope; whereas some believe that contact mapping by interpretation followed by radial-line plot and height determination by stereocomparagraph will suffice. Several workers use aerial photographs only for regional interpretation, placing strike and dip symbols on a planimetric map in sufficient density to suggest areas where field parties should be sent before leases are purchased.

In considering geologic characteristics of sedimentary rocks in the semi-arid southwest in relation to the quality of Soil Conservation photographs at a scale of two inches to one mile, the writer feels strongly that structural contour maps produced by any photogrammetric or interpretive means less accurate than the plane table are too expensive prior to acreage purchase and too unreliable for well location without additional field mapping. It has been proved, however, that certain instrumental techniques, combined with accurate field elevations and astute geologic interpretation, can result in photogeologic maps of higher accuracy than plane table maps (*Wengerd*, 1947).

Recognizing that time is of the essence in a well-planned photogeologic reconnaissance immediately followed by lease investment, it appears that the reconnaissance nature of photogeology should be stressed. Such photogeologic maps result from accurate radial-line plots upon which are placed strike and dip symbols, formation contacts, interpreted axes, approximate areas of closure, faults, topographic declivities of importance to field checking, streams, roads, and towns. The maps must be of such planimetric accuracy and scale that they may be used as plane table sheets in rapid assemblies of contact elevations in the field after a decision is made to drill the newly-purchased block of acreage. The value of these maps in the compilation of structural data with the surveying aneroid has already been proved. With certain exceptions, this type of photogeologic map, if carefully done, is sufficient for accurate delineation of acreage that is structurally suitable for purchase as a potential oil and gas property. Its value as a base for final field checking and structural mapping is now recognized.

LOCATION OF AREA

A small area on the Monument Uplift is used as an example of the photogeologic mapping possible over Paleozoic terranes in the southern Rocky Mountain and Colorado Plateau provinces (Figure 1). Mesozoic rocks lend themselves as readily to photogeologic interpretation, with the exception that certain special techniques must be used to avoid serious mistakes. This region, virtually isolated from major highways and railroads, lies in southern San Juan County, Utah, near the San Juan River. The nearest trading post is at Mexican Hat, Utah, scene of a short-lived oil boom between 1907 and 1912.

This article is based on photogeologic analyses of the Monument Upwarp, three field trips over the upland parts of the upwarp, a boat trip from Mexican Hat, Utah, to Lees Ferry, Arizona, and a search of the published literature on the area.

REGIONAL GEOLOGY

STRATIGRAPHY

Paleozoic rocks exposed on the Monument Upwarp include the Pennsylvanian Hermosa formation, the Permian-Pennsylvanian Rico formation, and the Permian Cutler formation. Abundant marine fossils are found in the Hermosa section and some terrestrial fossils are found in the Cutler formation. The sedimentary history indicates a progressive change from regular marine conditions to irregular continental conditions during Permian time in this part of the southwest. Regional variations in these strata affect very little the interpretation of local structural conditions on the Monument Upwarp. Subdivision of the stratigraphic section is shown in Figure 2.

STRUCTURE

The Monument Upwarp (*Miser, 1924 Bull.* p. 131). extends from the Comb Ridge on the east to the Waterpocket fold and the Great Bend of the San Juan River on the west (Figure 1). It trends northward from the Black Mesa Basin in northeastern Arizona to the vicinity of Moab, Utah. Blandings Basin lies on the east, Paradox-Salt Valley Basin on the north, and the Monument Valley Basin on the west. This broad regional upwarp, although itself having a very steep east limb and gentle west limb, encompasses several smaller north and northeast trending anticlines which have great length. The anticlines located near the crest of the upwarp are essentially symmetrical. From east to west, these anticlines have been named Lime Ridge, Organ Rock, Balanced Rock and Waterpocket-Navajo Mountain (*Miser*, 1924, *WSP*, pl. 15) (*Gregory*, 1938,

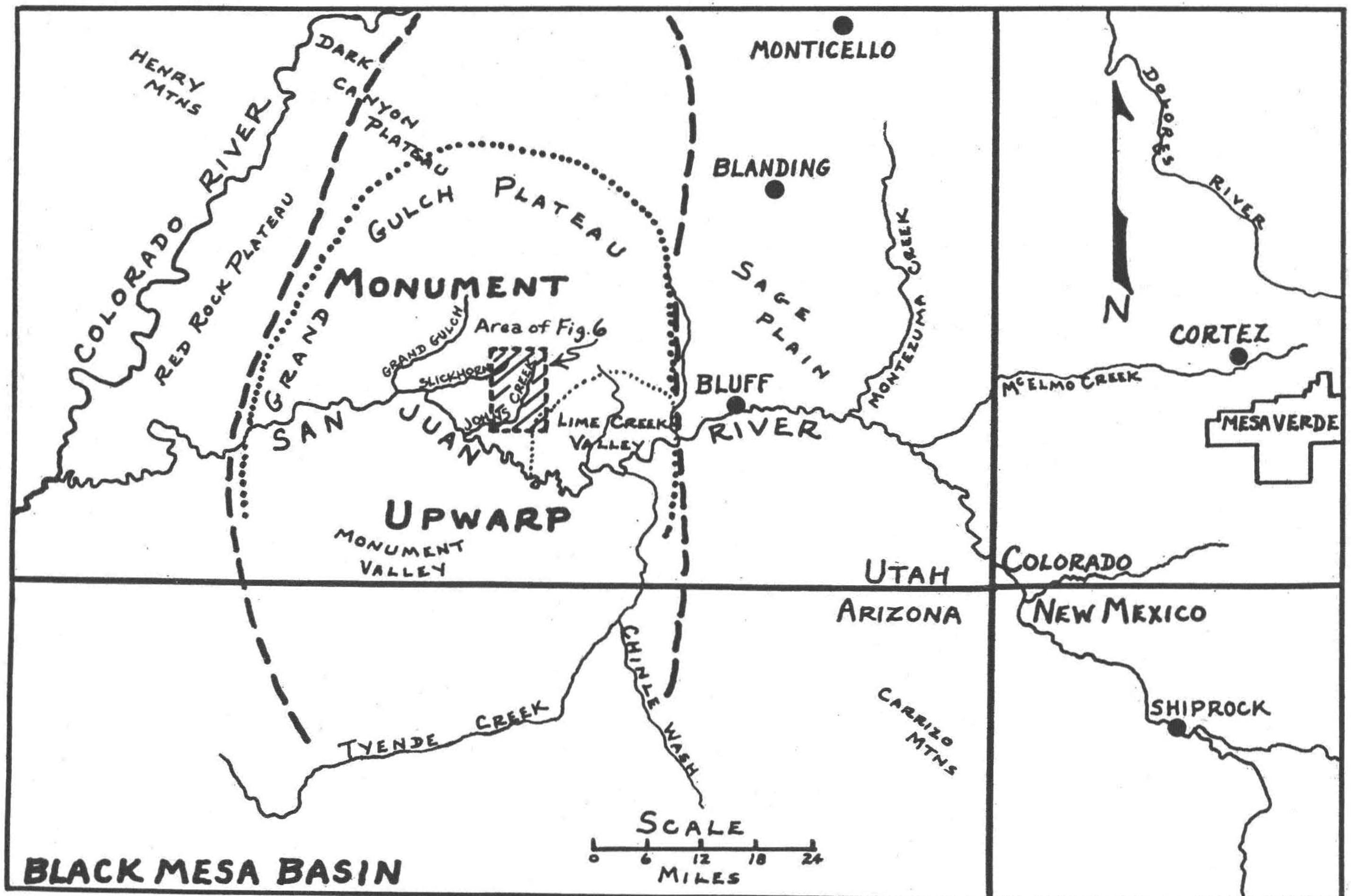

FIG. 1. Index Map, Monument Upwarp, Southeastern Utah.

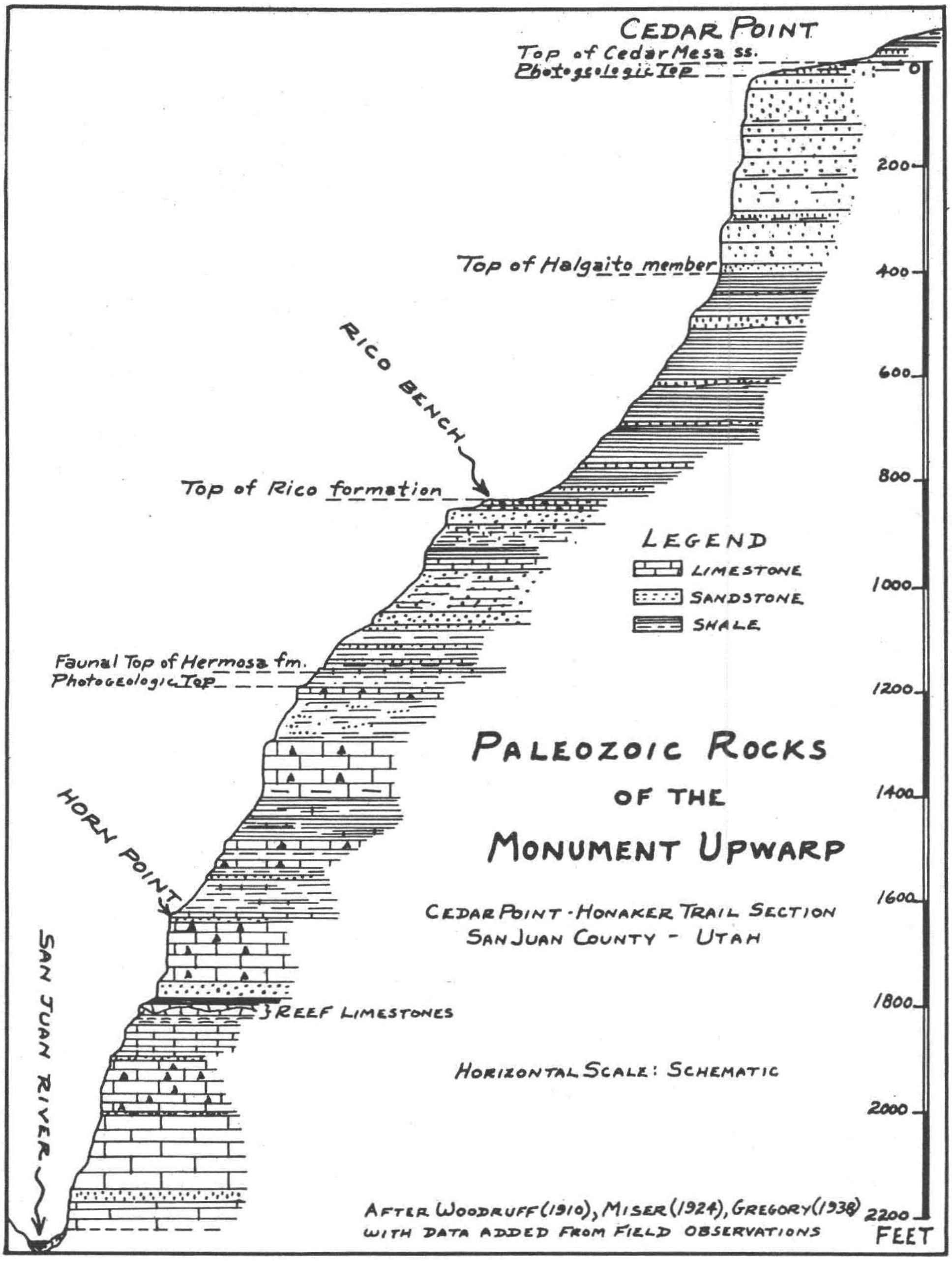

FIG. 2. Stratigraphic section showing the relationship of lithology and slope in Paleozoic rocks of the Monument Upwarp, Utah.

(pl. 1). The area discussed in this paper lies in the Johns Canyon sector of the Mitten Butte-Cedar Mesa anticline (Figure 1) Age of major folding in the area is believed to be pre-Tertiary and post-upper Cretaceous (*Gregory*, 1938, p. 85), hence of Laramide age. Regional uplift with some warping probably occurred in Tertiary time.

TOPOGRAPHY

The San Juan Country is an area of high mesas, deep canyons, wide esplanades, and broad benches. Sparse vegetation is found in the deeper valleys and on the edges of the higher mesas. Since the underlying rocks are of low dip, the massive sandstones and limestones break into vertical walls where underlain by less durable shales. Gravity-produced scree, and rock-fall slopes are common. Ephemeral tributary streams have insufficient water to keep their mouths at grade with the major San Juan River, hence their steep gradients are made up of steps controlled by the lithology of the underlying rocks. Ancient stream terraces, covered with coarse gravels, lie with discordance across slightly tilted rocks, high above the present channel or the lower San Juan River (*Miser*, 1924, p. 126). The slopes produced on various strata are shown in Figures 2, 3 and 4.

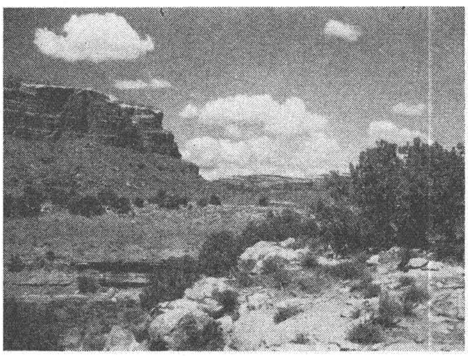

FIG. 3. Johns Canyon, view northeast from center of north half, Section 35, T40S, R17E. The massive sandstone on left is Cedar Mesa, lying on the Halgaito sandy shale. The Halgaito-Rico bench and the top of the Rico formation forming the rim of the box canyon, are in the left foreground.

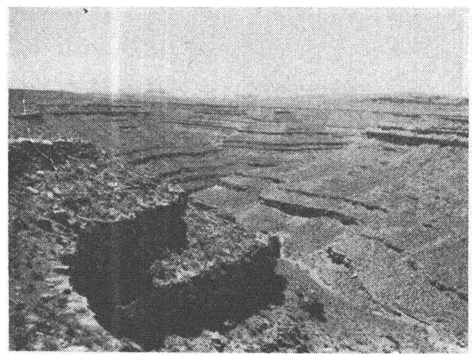

FIG. 4. Canyon tributary to the San Juan River, view southwest from Section 12, T41S, R17E. Left foreground and distinctly traceable is the Rico bench, with the top of the Hermosa formation prominently exposed as a sloping bench from the center to lower right foreground.

CORRELATION OF TOPOGRAPHY AND LITHOLOGY

HERMOSA FORMATION

The Hermosa formation comprises limestone, shale, and sandstone which weather to form steep cliffs on limestone and durable sandstone, with gentler slopes on shales and less durable sandstone. The formation is predominantly limestone in the lower half, resulting in a very steep trench-like canyon being cut into the highest part of the Monument Upwarp by the San Juan River. The upper half of the section is red and gray sandy shale which forms slopes broken by ledges of gray limestone and sandstone forming vertical declivities (Figures 2 and 4). Throughout the San Juan Canyon, from the Raplee anticline to disappearance of the Hermosa section into the subsurface near Grand Gulch, the slopes and ledges are easily traced on aerial photographs, and readily correlated with published measured sections (*Woodruff*, 1910, pp. 81–82) (*Miser*, 1924, pp. 127–130).

Talus produced by weathering and gravity movement across the Hermosa section is readily swept away by the San Juan River and its tributaries; therefore, little of the formation is seriously hidden from aerial view.

RICO FORMATION

The Rico formation is predominantly reddish shale, sandy shale, gray sandstone, and reddish gray sandstone. The greater part of the formation weathers to form slopes ranging from 30° to 40° in steepness, broken by low walls caused by vertical slabbing of the more durable limestone and sandstone. The top of the formation is readily mapped owing to the presence of the McKim limestone member, 3 to 20 feet thick, which lies just below the base of the Halgaito member of the Cutler formation.

The predominance of slope on the Rico formation results in abundant talus which locally covers thinner prominent ledges that might be mapped on aerial photographs.

CUTLER FORMATION

Three members of the Cutler formation are represented on the Mitten Butte-Cedar Mesa anticline. The *Halgaito* member at the base comprises red shale, siltstone, and sandy shale which weathers into a slope, strewn by Cedar Mesa rubble from above. The resistance of this member is considerably less than that of the Rico formation causing a broad platform which everywhere characterizes the lower part of the Halgaito section (Figures 2 and 3). With the exception of the headwalls of ephemeral streams where the Halgaito forms a steep profile continuous with the Rico slope, this platform provides access to the country by narrow wagon road and trail (Figures 3 and 5).

The *Cedar Mesa* sandstone forms a prominent cliff above the Halgaito section and provides abundant sandstone blocks which in but few places ride

FIG. 5. Part of a vertical aerial photograph of Johns Canyon. Top of Rico formation (Box Canyon) disappears underground to northeast in center of photograph. Cedar Mesa sandstone forms the prominent mesa edge with Halgaito beds forming slope between Cedar Mesa and Rico strata. Circle is the principal point, and the north arrow shaft is one mile long.

down over the Rico-Halgaito contact prior to their complete disintegration. This blocky talus effectively masks the minor sandstone ledges of the Halgaito section, but the massive Cedar Mesa sandstone is everywhere easily differentiated from the Halgaito member, excepting on the Comb Wash monocline on the east side of the Monument Upwarp.

The uppermost member of the Cutler formation found on the central part of the Monument Upwarp is the *Organ Rock* tongue. This member is predominantly red sandy shale with a few thin sandstones that weather into steep slopes. By tracing these slopes, obviously related to intra-member sandstones, structural information of great value is gained across the broad expanses underlain mainly by the massive Cedar Mesa sandstone (*Andrews and Hunt*, 1948).

CORRELATION OF TOPOGRAPHY AND STRUCTURE

AREAL SUBDIVISIONS

The Monument Upwarp may be divided into several topographic provinces developed on Paleozoic rocks. Although this topography is locally controlled by lithology, regional distribution of major subdivisions such as deep canyons and high mesas, is influenced by structure.

The major topographic subdivisions include: *Grand Gulch Plateau* underlain by Cedar Mesa sandstone virtually unbreached by streams which are now working headward and downward toward accordance with the deeply-incised San Juan River. *Grand Flat*, *Polly Mesa*, and *Cedar Mesa* project southward from the Grand Gulch Plateau and are separated by the three important San Juan tributaries, Grand Gulch, Slickhorn Gulch, and Johns Canyon. These mesas are underlain by Cedar Mesa sandstone and Organ Rock beds whereas the tributary canyons are incised into Halgaito, Rico, and Hermosa rocks. *Lime Creek Valley* is an acutely dissected area where Rico and Hermosa beds are exposed on the Raplee anticline, yet the Rico-McKim limestone underlies the entire Lime Ridge anticline with a remarkable conformity of topography and structure. The Mexican Hat syncline contains protected Halgaito beds; however, an outlier in the structurally higher sag between the Lime Ridge and Raplee anticline contains both Halgaito and Cedar Mesa shale and sandstone.

STREAMS

San Juan Canyon itself is cut by a former mature to old-age meandering stream that has incised itself deeply during Tertiary and Recent time to accentuate the bench-like mesa and canyon topography of the Monument Upwarp.

Generally, the Monument Upwarp has a steep east limb where erosion has produced distinctive hogbacks striking northward and southward from the San Juan River. On the west side of the Upwarp, the rocks dip westward very gently, and no hogbacks are present. Any reversal, however slight, can be mapped on aerial photographs only by noting stream shift, ragged downdip mesa edges of Cedar Mesa sandstone, and by applying the three-point solution to exposed Halgaito-Cedar Mesa contacts on untilted photographs.

In general, stream and slope erosion have produced a bold topography. Slickhorn Creek and Johns Creek, tributary to the San Juan River, adjusted themselves to structure by attacking across the crests of minor anticlines in following the prominent joint pattern, then turning northward in their headward erosion to follow the axes of the folds. Unfortunately we are living at a stage in the desert erosion cycle when only about one-third of the erosion process by these two streams is completed. After more advanced erosion across Grand Gulch Plateau, other crestal culminations along the Cedar Mesa axis will be accentuated. Present interpretation of structure based on topographic developments relies heavily on the minor sandstones in the Organ Rock tongue, whereas in the future, these tributary streams will uncover the much more reliable Cedar Mesa-Halgaito contact. Grand Gulch is also in this difficult stage where it is cutting only in the Cedar Mesa sandstone, excepting near the San Juan River. The rounded knob and rincon weathering of the Cedar Mesa sandstone adjacent to Grand Gulch makes structural determination hazardous, and accurate delineation of the actual upper contact of the sandstone virtually impossible.

SEDIMENTS

Differences in soils, talus, stream gravels, and the position of ancient terrace gravels are of little aid in structure interpretation on the Monument Upwarp. Type and distribution of talus is but an aid in identifying formations whose slope characteristics are the best indicators of lithology. Talus slides on the head and sidewalls of steep tributary canyons transpose talus across the Rico-Halgaito contact in places, but the slides are generally narrow. Very little solifluction or massive land slide action is evident owing to the rock types and the low annual rainfall (six inches). Soils are scant, but best developed on the Halgaito bench just above the uppermost Rico limestone and shale. Sand dunes are rare on the Paleozoic terranes of the Monument Upwarp.

VEGETATION

Vegetation is best developed along seepage areas of the tributary streams, on the edge of Cedar Mesa where the sandstone provides some interstitial water, and on the Cedar Mesa-Halgaito contact. The low scrubby oak and juniper on the Halgaito sandy shale aids in differentiating it from the barren Rico section; however, the upper Rico limestone bench is the best indicator of the Rico-Halgaito contact (Figures 3 and 4).

INTERPRETATION DIFFICULTIES

GEOLOGIC

Every geologic province presents difficulties of photo-geologic interpretation inherent to the stratigraphy, structure, and topography of that province. Numerous summaries of general difficulties have already been published; hence the following notations apply as peculiar particularly to the Monument Upwarp.

Hermosa-Rico contact:—Nowhere on the Monument Upwarp is the lower contact of the Hermosa limestone continuously exposed; therefore, the upper Hermosa contact with Rico beds is of especial concern as the lowest stratigraphic control in mapping these Utah structures. The Hermosa-Rico contact is both faunally and lithologically gradational (*Gregory*, 1938, p. 40–41) (*Miser*, 1924, pp. 127–129) (*Woodruff*, 1910, pp. 80–86). The change from predominantly limestone-sandy shale strata of the Hermosa section to the sandy shales and sandstone of the Rico section occurs in the stratigraphic and faunal vicinity of a 12 foot limestone bed containing Upper Goodridge (Rico) fauna. This 12 foot bed is not everywhere mappable in the field or on aerial photographs, and the 27 foot shale section beneath is not definitely known to be of Hermosa age (Figure 2). Beneath the shale lies a prominent cherty limestone, 20 feet thick, which is virtually continuous in the area, and in keeping with the concept of mappable formations, the top of this limestone is considered to be the photogeologic contact of the Hermosa and Rico formations. Since faunal evidence indicates a highly indefinite contact ranging through 125 feet of this general section, the photogeologic contact is valid as well as for field mapping.

Rico-Halgaito contact:—The top of the Rico formation is considered to be the highest prominent limestone in this area (*Gregory*, 1938, p. 41). This limestone, named the McKim member by Dunn and Boreing (personal communication) contains evidence of marine life, whereas the clastic strata above contain only scattered remnants of terrestrial fauna and flora. The McKim limestone is prominently exposed wherever the base of the Halgaito section is uncovered by erosion. The top of the McKim limestone is thus a photogeologic contact which coincides with the field-mapped contact, and is a valid structural surface. Care must be exercised during interpretation, however, since the lower Halgaito contains some limy sandstones which form low cliffs. In tracing the Rico-Halgaito contact across talus slides, errors may be made by the inexperienced photogeologist resulting in planimetric misplacement of the contact and estimation of dips that do not exist.

Halgaito-Cedar Mesa contact:—This contact involves only clastic formations which are closely intergradational. Regionally the Cedar Mesa sandstone is not mappable as a distinct member in the Comb Wash area, yet the thickness of the Cutler formation is not appreciably different there from the thickness in the center of the Monument Upwarp. Apt discussion of this problem is provided by *Longwell et al.* (1923) and *Baker and Reeside* (1929). Over most of the Monument Upwarp, the Halgaito-Cedar Mesa contact is a clear-cut dividing line between steep cliff above and shale slope below. The vertical lithologic gradation is of short interval. Laterally the contact may wander up and down in the section as much as 100 feet in a distance of 10 miles. Since this discrepancy, as a formational contact, is of far lesser magnitude than the half degree dips which can be differentiated over the Monument Upwarp, no structural error is probable. Baker and Reeside consider the contact of these two intergradational members of the Cutler to be conformable (*Baker and Reeside*, 1929, p. 1432). Placement of the contact, based on lithology rather than time-stratigraphic planes, is thus valid for both field and photogeologic mapping, if it is recognized that the Cedar Mesa members cannot be mapped in certain areas because of lateral change to sandy shale and shaly sandstone (*Gregory*, 1938, p. 41). In certain localities, talus tends to pile across this important contact and care must be exercised in examining the inter-talus steep-gradient valleys.

Top of Cedar Mesa sandstone:—This contact is present over virtually all of the Grand Gulch plateau, yet a contact between the Cedar Mesa sandstone and the Organ Rock tongue is difficult to map owing to:

1. lithologic gradation between the two members
2. rounded boss-like and amphitheater weathering at the top of the Cedar Mesa sandstone.

Since this contact, or one near it, must be used because the Cedar Mesa sandstone covers such wide areas, the photogeologist has recourse to thin sandstones in the Organ Rock tongue above, or a massive sandstone approximately 30 feet below the slight unconformity between the Cedar Mesa sandstone and the Organ Rock sandy shale. This massive sandstone produces the cliff edge between the mesa top and deep canyons over most of the Monument Upwarp, and is thus easily mapped on photographs (Figures 5 and 6), with the exception of the Grand Gulch area on the west. Utilization of this sandstone provides an accurate structural surface, although the true contact of Organ Rock and Cedar

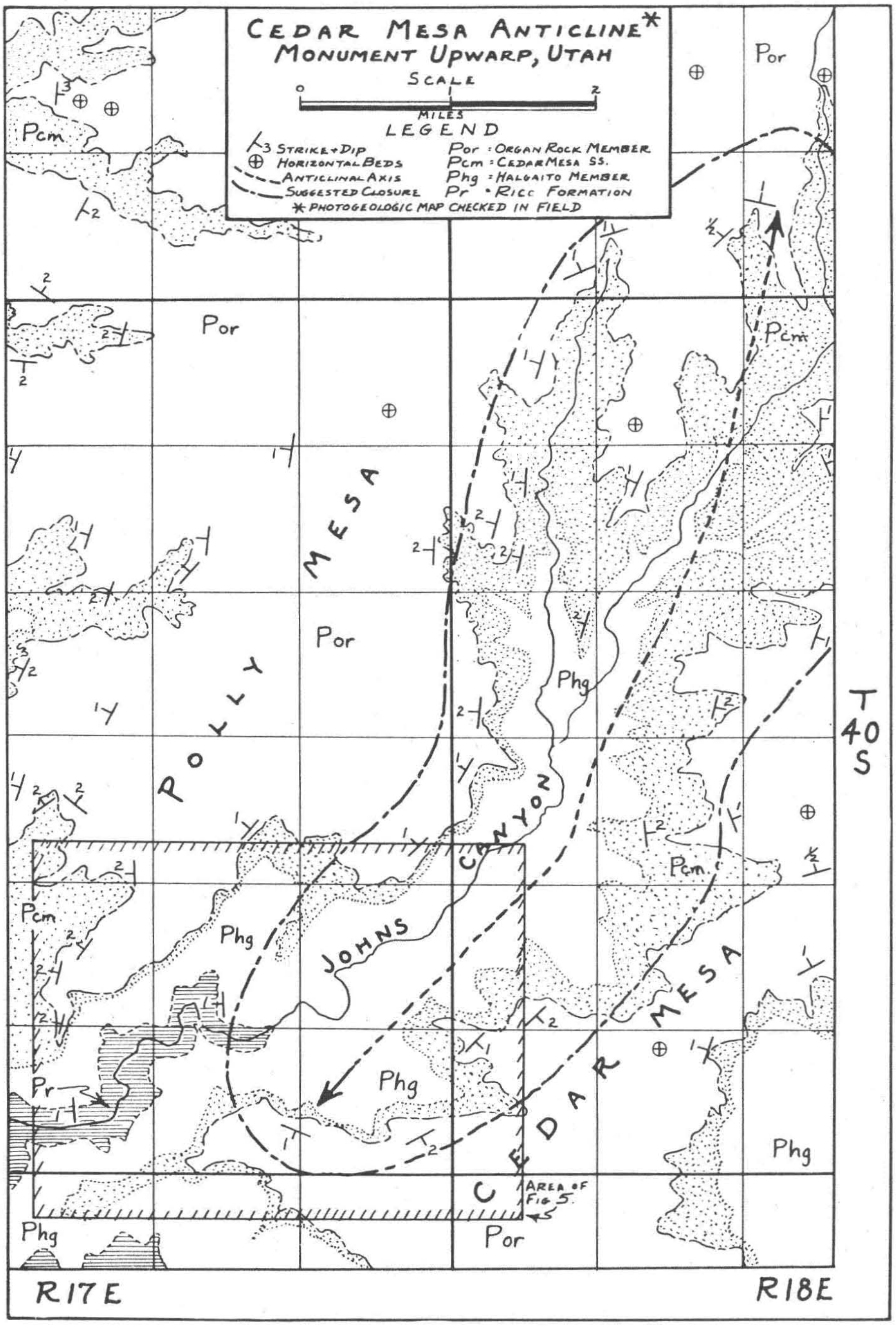

FIG. 6. Photogeologic map of a part of Johns Canyon showing contacts, axis, dip and strike of rocks and suggested area of closure.

Mesa may be as much as one mile away. Inasmuch as the major purpose of photogeologic mapping is structural analysis and this contact is exceedingly difficult to trace, even in the field, the massive sandstone near the top of the Cedar Mesa section fulfills the requirements for reconnaissance mapping.

Joints and Faults:—A well-defined northeast-trending joint system obliterates, through subsequent weathering, the critical bedding surfaces in the Cedar Mesa sandstones near Grand Gulch and in some localities south of the San Juan River. The structure can nevertheless be mapped by estimation of dip and strike where the Halgaito member is exposed. Few faults are present on the Monument Upwarp, and field mapping has revealed only a few along the San Juan River and to the east in the Lime Creek Valley (*Woodruff*, 1910, pl. 8) (*Miser*, 1924, pl. 15). A prominent fault, noted on the aerial photographs near Slickhorn Gulch, was examined in the field. Its stratigraphic throw ranges between four and twenty feet and an active oil seep from the fault exudes green oil into the San Juan River. No faults were noted in the Johns Canyon area (Figure 6).

PHOTOGRAPHIC

Aerial photographs flown 15 years ago over this area are four lens restitutions, and tilt computations show variations from 1° to 12° from the vertical, during photography. Without clear cut geomorphic evidence and careful structural analysis of at least three stereoscope couples of the same image, photogeology would be of little value. Once it can be determined that the photographs are badly tilted, the relationship of cliffs, talus slopes, gradients of streams, and many other geologic factors must be utilized rather than the dip of the rocks as they appear on the tilted photographs. The excellent, controlled, radial-line plots by the Soil Convervation Service at a scale of two inches to the mile (approximately the photographic scale) are of great help in appraising the tilted photographs and in speeding up photogeologic compilation of final maps.

Radial displacements due to high relief between canyon and mesa also cause trouble in strike and dip estimation near the edges of photographs. Since the photographic overlap is excellent, this difficulty can be obviated by using only the central parts of every photograph.

CONCLUSIONS

Field work on the Monument Upwarp in southeastern Utah has proved the efficiency of careful photogeologic mapping without the preparation of structure form-line maps. Photogeologic locations recommended for drilling, and surrounded by sufficient acreage to protect the drill sites, have been checked in the field and found to be within one or two locations of structural crests. Results of this work, only a small part of which is shown in Figure 6, have prompted the purchase of 26,000 acres on the Monument Upwarp for the purpose of drilling for oil and gas.

BIBLIOGRAPHY

Andrews, D. A. and C. B. Hunt (1948), "Geologic Map of Eastern and Southern Utah." *U. S. Geol. Survey*, Oil and Gas Prelim. Map 70.

Baker, A. A. and J. B. Reeside, Jr. (1929), "Correlation of Permian of Southern Utah, Northern Arizona, Northwestern New Mexico, and Southwestern Colorado." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, pp. 1431–1448.

Gregory, H. E. (1917), "Geology of the Navajo Country." *U. S. Geol. Survey*, Prof. Paper 93, pp. 1–161.

Gregory, H. E. (1938), "The San Juan Country." *U. S. Geol. Survey*, Prof. Paper 188, pp. 1–117.

Longwell, C. R., and H. D. Miser, R. C. Moore, Kirk Bryan, and Sidney Paige (1923), "Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona." *U. S. Geol. Survey*, Prof. Paper 132, pp. 1–23.

Miser, Hugh D. (1924), "The San Juan Canyon, Southeastern Utah." *U. S. Geol. Survey*, WSP. 538, pp. 1–80.

Miser, Hugh D. (1924), "Geologic Structure of the San Juan Canyon and Adjacent Country, Utah." *U. S. Geol. Survey*, Bull. 751D, pp. 115–155.

Miser, Hugh D. (1925), "Erosion in San Juan Canyon, Utah." *Geol. Soc. America*, Vol. 36, pp. 365–378.

Nugent, L. E., Jr. (1947), "Aerial Photographs in Structural Mapping of Sedimentary Formations." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, pp. 478–494.

Wengerd, Sherman A. (1947), "Newer Techniques in Aerial Surveying." *World Oil*, Vol. 127, No. 3, pp. 37–42; No. 4, pp. 46–54; No. 5, pp. 49–54; No. 6, pp. 136–142; No. 8, pp. 131–140.

Woodruff, E. G. (1910), "San Juan Oil Field, Utah." *U. S. Geol. Survey* Bull. 471, Contrib. to Econ. Geol., Part II, pp. 76–104.

NOTES ON RECENT LITERATURE RELATING TO PHOTOGEOLOGY

Prof. H. T. U. Smith, Geology Dept., Univ. of Kansas

Black, R. F., and Barksdale. W. L., Oriented lakes of northern Alaska: *Jour. Geol.*, vol. 57, 1949, p. 105–118.

This paper directs attention to the unusual occurrence of elongate lakes having essentially parallel orientation throughout an area of some 25,000 square miles in the Arctic Coastal Plain of northern Alaska. These lakes were studied with the aid of Trimetrogon photography, and the paper is illustrated with 8 air photos and several additional ground photos. Characteristics of the lakes are described in some detail; their relations to permafrost are discussed; and hypotheses of origin are considered. It is of interest to note that the Alaskan lakes are similar in many respects to the "bays," or elongate depressions of the Carolina coastal plain in this country, well known through the studies of F. A. Melton, Douglas Johnson, and others.

Cabot, E. C., The Northern Alaskan Coastal Plain interpreted from aerial photographs: *Geographical Rev.*, vol. 37, 1947, p. 639–648.

Typical lake and stream features and polygonal frost patterns of the region are described and illustrated with 8 aerial photos.

De Blieux, Charles, Photogeology in Gulf Coast exploration: *Bull Amer. Assoc. Petrol. Geol.*, vol. 33, 1949, p. 1251–1259.

The area discussed in this paper lies in the deltaic plain of the Mississippi River, which is characterized by "a net work of complicated natural-levee systems which rise above the general land level and divide the area into numerous swamp lowlands." In this area, geologic structures have no representation in surface geology, and their topographic expression commonly is obscure on the ground. By applying geomorphic principles to the interpretation of air photos, however, it is found that departures from the normal characteristics of the natural levees, together with other types of drainage anomalies, provide clues to the location of dome structures, and thus supply the petroleum geologist with a new approach in the search for oil. The paper is illustrated with four full-page, annotated mosaics.