E7.6-10.199
CR-146290

GEOLOGIC INTERPRETATION OF SKYLAB PHOTOGRAPHS

by

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and

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Remote Sensing Report 75-6

EREP Investigations 380

Contract NAS9-13394

National Aeronautics and Space Administration

(E76-10199) GEOLOGIC INTERPRETATION OF SKYLAB PHOTOGRAPHS (Colorado School of Mines) 85 p HC $5.00 CSCL 08G

N76-18618

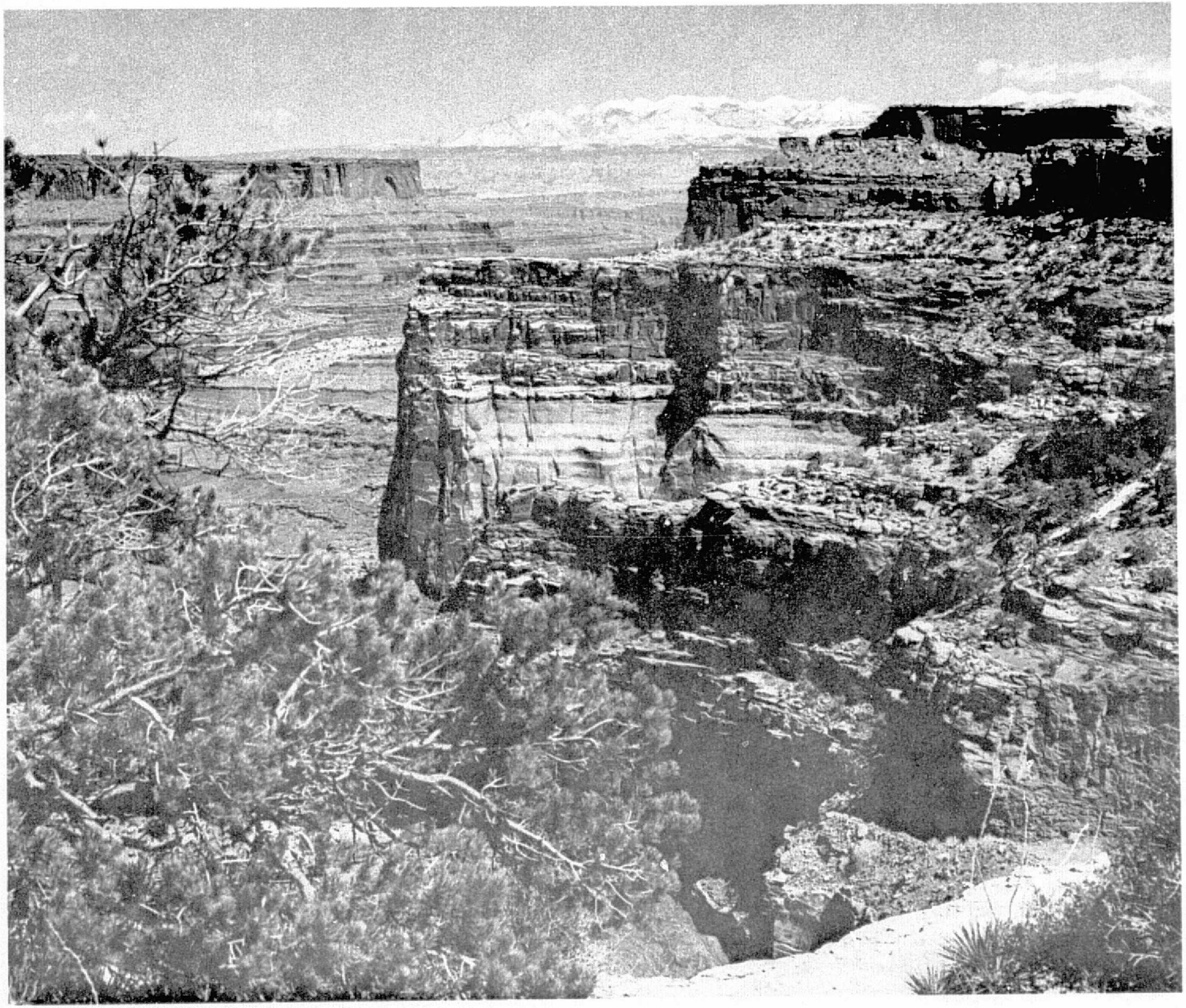
Unclas
G3/43 00199

December 1975

REMOTE SENSING PROJECTS

DEPARTMENT OF GEOLOGY

COLORADO SCHOOL OF MINES • GOLDEN, COLORADO



Frontispiece. View eastward from Island in the Sky area of Canyonlands National Park, across the canyon of the Colorado River, to the La Sal Mountains.

ABSTRACT

Satellite images contain the same geologic information as do conventional aerial photographs, but at a smaller scale and with correspondingly poorer resolution. As with aerial photographs, maximum geologic information currently is derived from photointerpretation, a deductive process best carried out by a geologist-interpreter.

Skylab photographs are superior to ERTS images for photogeologic interpretation, primarily because of improved resolution. Similarly, S190B photos provide more geologic information than do S190A photos. Multiband photography shows no apparent advantage over good color photography; S190B stereo color photos, where available, provide maximum geologic information.

Topography is the single most important surface phenomenon in photogeologic interpretation. Vegetation, especially coniferous forests, severely limits interpretation. Maximum information is extracted through the iterative process of photointerpretation and field checking.

More geologic information is contained in space images than can be interpreted or mapped at original scales. Interpretation is best with optical magnification of low-generation contact transparencies, with annotations put on

enlarged transparencies. Optimum scale for geologic mapping in this study area is about 1:62,500.

All stratigraphic units at or above formation-rank can be mapped in this area, and many formations can be effectively subdivided into members. Conjunctive use of topo maps permits estimation of section thicknesses and lateral thickness changes. Stratigraphic pinch-outs, intertonguing sedimentation, and lateral facies changes have been accurately mapped with S190B photos.

All major structures in the study area can be recognized on the space photographs. Major folds were mapped accurately, even those with very gentle flexures, as well as several secondary drag folds. Faulting is recognized in considerable detail, both large, fold-bounding faults and subsidiary collapse systems. The ability to interpret detailed stratigraphy and structure allows recognition of recurrent structural movement on some uplifts.

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INTRODUCTION

Because EREP is, by definition, an experimental package, much of the effort here is devoted to evaluating the results of the EREP missions rather than attempting to apply them. This report contains the results of the evaluation of the photographs from S190A and S190B for geologic information.

Early geologic evaluations of space images, from both ERTS and Skylab, have stressed the structural information content of the images, especially lineament interpretations. Whereas lineaments are apparent in all of the Skylab photos, definite attempts were made in this research to evaluate the photos in terms of their lithologic information content.

A difficulty arises in attempting to communicate to others the "lithologic information content" of a Skylab photograph. To state that the stratigraphy can be interpreted "in great detail" is insufficient, and good objective criteria, if they exist, are unknown to the authors. For this reason, it is important - it is imperative - that the reader study critically the enclosed geologic maps. The essence of this report is in the maps.

CASE STUDY I: GEOLOGIC INTERPRETATION OF S190A PHOTOGRAPHS

(R.J. Weimer)

INTRODUCTION

Approximately 40 hours were spent analyzing S190A color photographs from Skylab 3 covering an area in western Colorado and eastern Utah. The objectives of the study were 1) to prepare a photogeologic map to determine the geologic information content of the S190A photographs, 2) to compare the results of this work with a map of the general area prepared from ERTS imagery, and 3) to determine how accurately and rapidly a large area could be mapped by an experienced geologist with a working knowledge of the geology.

A photogeologic map was prepared for approximately 25,000 square kilometers covering the region of the Uncompahgre Uplift and the northern portion of the Paradox Basin. The region is bounded by Grand Junction on the north; Green River, Utah, on the west; Ouray, Colorado, on the southeast; and the Black Canyon of the Gunnison River on the northeast.

To facilitate comparison with S190-B photointerpretations and previously published geologic maps, the results of this study (Pl. 1) are plotted on the same base map - the Moab Quadrangle, at a scale of 1:250,000. Some parts of the present study area, therefore, are not shown on Plate 1.

Four frames of S190A color transparencies (~4X, 1:710,000) with stereoscopic coverage were used to study the geology of the region. The images were observed with a mirror stereoscope and interpretations transferred to a transparent overlay on color prints (~8X). The prints were taped together to give one continuous photomosaic of the region at a scale of approximately 1:360,000.

The investigator (RJW) was generally familiar with both the geology and geography of the region. Over a period of several years, detailed mapping had been conducted in small areas scattered throughout the region. Specifically, these areas are the Ridgway-Ouray area, the Salt Valley anticline in the Arches National Monument near Moab, and the Colorado National Monument near Grand Junction. By travel through the region, a good knowledge was acquired of the general geology and the distribution of mappable units (formations).

The observer was continually amazed at the excellent quality of the color photography, the ease of recognizing stratigraphic units and structural elements, and the accuracy of locating oneself relative to geographic points.

LITHOLOGY

Because of the large percentage of exposed bedrock in the area, this region is ideal for the study of Skylab photography. Difficulty in recognizing and tracing stratigraphic units was encountered only in the higher terrain, covered by vegetation.

Eight stratigraphic units with widely varying lithologies were selected for mapping purposes. These are indicated by the legend on Plate 1, and their areal distribution is presented on the photogeologic map. The selection of the units was based on ease of recognizing mappable contacts throughout the area and the mapping of sufficient detail to define the structural features, both folds and faults. Additional stratigraphic units could have been mapped, especially by subdividing the unit labeled Triassic and Jurassic (TJ). However, for the purposes of this project, the time required for mapping greater stratigraphic detail was judged to be inappropriate in achieving the stated objectives.

A general discussion of the stratigraphic units follows.

Precambrian (p€)

Rocks of Precambrian age are exposed in canyons cut through the sedimentary rocks in the Uncompahgre and Black Canyon uplifts (localities are indicated in Fig. 1). Normally, the dark colors of the amphibolite gneisses and schists are easily recognized on the color photography. In some instances, however, shadows may shade the deeper parts of the canyons, or soils and wind-blown sands may cover Precambrian areas, making it difficult to determine if, in fact, the Precambrian is exposed beneath the sedimentary

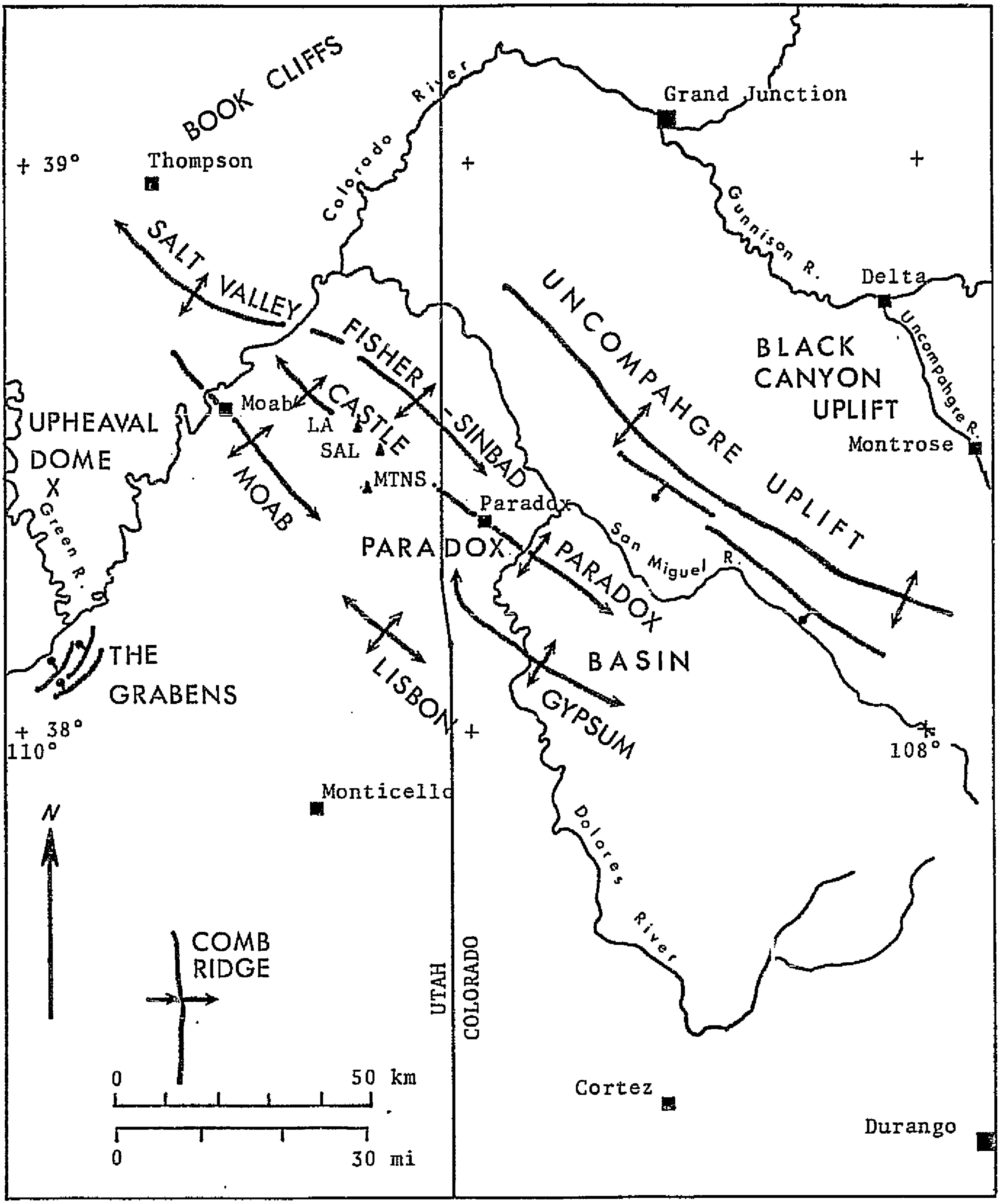


Figure 1. Index map of western Colorado and eastern Utah showing major geologic structures.

sequence. For these reasons, the photointerpretation of areas of Precambrian exposures is probably the least accurate of the map units on Plate 1.

Paradox Formation (Ⓟp)

The northern portion of the Paradox Basin is famous for the long linear "salt valley anticlines". The structures are believed to have formed as long, linear, narrow ridges by diapiric movement of evaporites that warped the overlying sedimentary sequence into anticlines with intervening synclines (Fig. 2). Subsequent erosion of the sedimentary rocks from the crests of the anticlines exposed salt, gypsum and associated strata that are collectively referred to as the Paradox Formation. The salt is easily removed by solution, so this material is found only in drill holes.

The Paradox Formation is observed on the color images as light-colored terrain in the core of several anticlines. Because of the diapiric nature of the formation the contact with surrounding units is mapped as a fault contact.

Cutler Formation (Pc)

Overlying the Paradox Formation and underlying the cliff-forming sandstones of the Triassic and Jurassic unit (TJ) is a red, soft-weathering sandstone and shale unit with some limestone. These strata are mapped as the Cutler

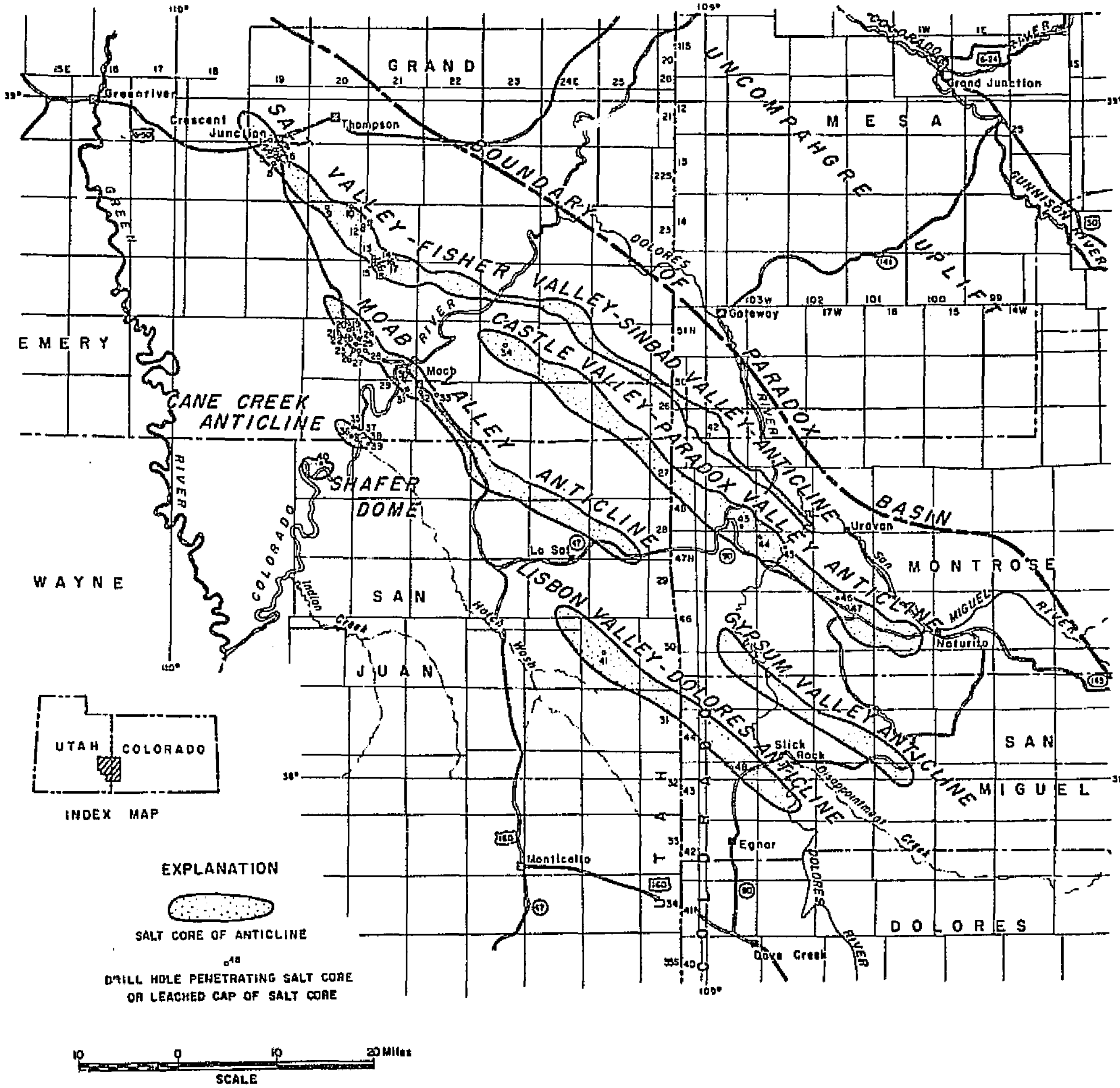


Figure 2. Map of salt cores of anticlines in Paradox Basin (from Shoemaker and others, 1958).

Formation of Pennsylvanian and Permian age. The upper contact may vary slightly from one part of the region to another, but overall the contact can be mapped accurately at the scale used.

Triassic-Jurassic undivided (TJ)

Of all of the selected mapped units, the Triassic-Jurassic undivided contains the most diverse lithologies and the greatest number of formations that are lumped together on Plate 1. The overall lithology is alternating red, cliff-forming sandstone and thin, red, gray and green shales, siltstones and limestones, capped by the soft-weathering shales and sandstones of the Morrison Formation. Although not all are present throughout the area, the following formations, listed in order from oldest to youngest, have been identified somewhere in the area: Moenkopi, Shinarump, Chinle, Wingate, Kayenta, Navajo, Carmel, Entrada, Summerville, and Morrison. Only the Morrison Fm. can be recognized throughout the area, and with time and effort it is possible to map the Morrison separately from the underlying units. This was done in the northwest portion of Plate 1 at the start of the mapping, but the effort was abandoned as too time-consuming and not necessary to define the geologic structure.

Dakota Group (Kd)

One of the most easily recognized stratigraphic units is the Cretaceous Dakota Group, which includes the upper Dakota Sandstone and a lower unit called either the Burro Canyon Formation or the Cedar Mesa Formation. Usually the Dakota Group is a sandstone and shale unit, resistant to weathering, forming hogbacks between the underlying and overlying claystones or shales, or capping mesas or cuestas. The unit can be mapped accurately except in the high terrain of the Uncompahgre Uplift where heavy tree cover masks the formations.

Mancos Shale (Km)

The Mancos Shale of Cretaceous age is a thick homogeneous mass of light-weathering shale that forms a wide outcrop band along the north, northwest and east portions of the region (Pl. 1). Because of the light colors and low topography, the unit is easily recognized and mapped. In the region of the Paradox Basin anticlines, the colors of the Mancos are much like the Paradox Formation; only by mapping the details of the structure and stratigraphic sequence can the two be separated.

Mesaverde Formation (Kmv)

The most impressive topographic feature in the area is the Book Cliffs, held up by the resistant Cretaceous sandstones of the Mesaverde Formation. The cliffs are present along the northwest portion of Plate 1.

The dark tones and resistant nature of the Mesaverde are in sharp contrast with the lighter-colored Mancos Shale. Because of the sharp contrast, it was possible to map a tongue of the Mancos Shale within the lower portion of Mesaverde Formation in the Book Cliffs (Fig. 3). This is indicated as Kmt -- Mancos Shale tongue, which disappears or thins so it cannot be recognized to the west. The sandstone member of the Mesaverde below the Mancos tongue feathers out to the east, and at the point of pinch out, the Mancos tongue merges with the main body of the Mancos.

Young (1955) mapped a sandstone and overlying Mancos Shale unit in this portion of the Book Cliffs. The sandstone was identified as the eastward extension of the Castlegate Member of the Mesaverde Fm. and the overlying shale as the Buck Tongue of the Mancos Shale.

Tertiary Intrusions (Ti)

The La Sal Mountains, east of Moab, Utah, are formed by Tertiary intrusions that cut the sedimentary sequence of the Paradox Basin. Because the igneous rock is more resistant to erosion than the sedimentary rocks, the intrusions form high topographic features that are heavily forested. The vegetation prevents the accurate mapping of the intrusive contacts with the sedimentary rocks; thus, the outlines of the intrusions on Plate 1 are not precise.

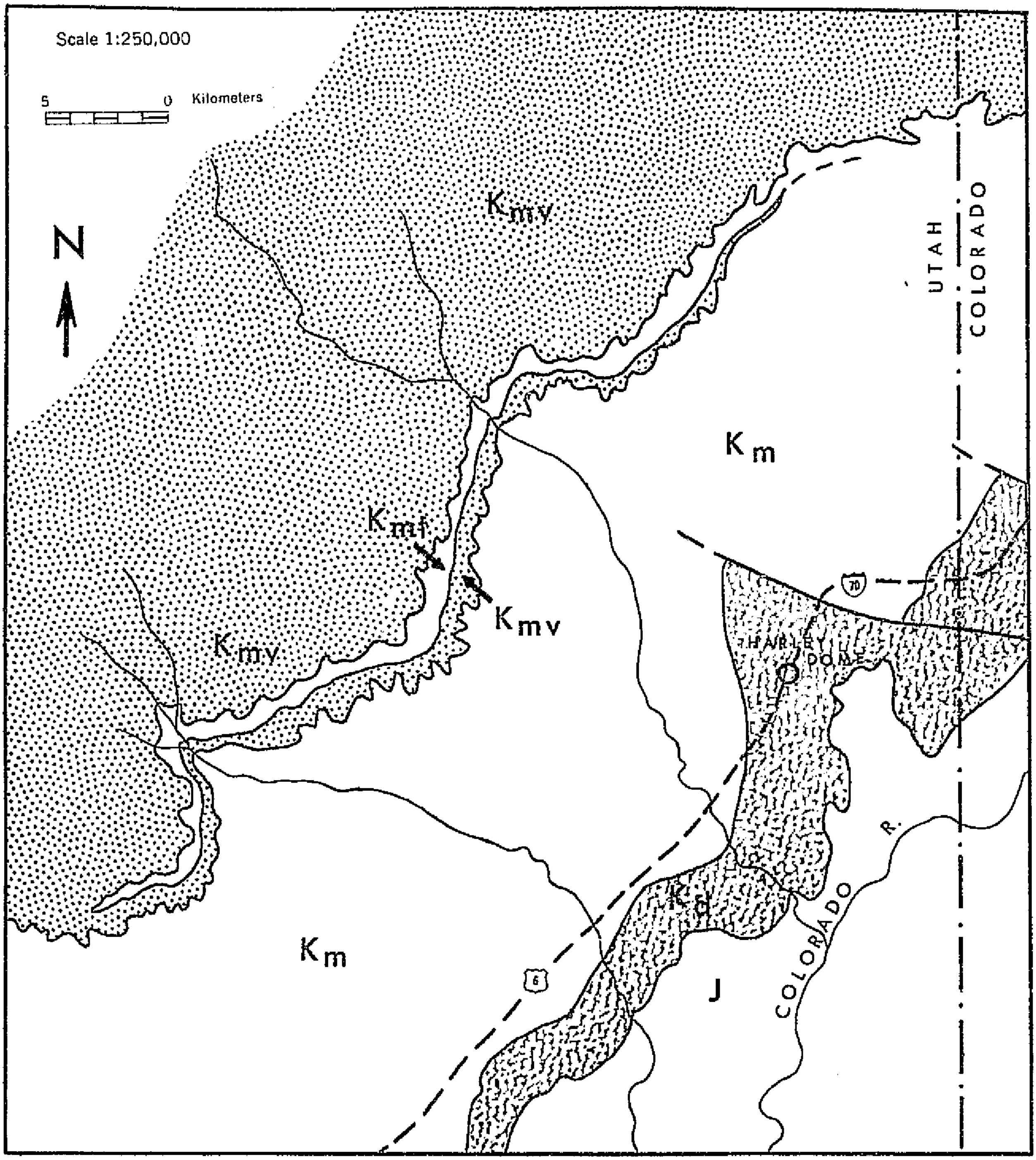


Figure 3. Relationship of Mancos Shale tongue (Kmt) to Mesaverde Formation (Kmv), northwestern end of Uncompahgre Uplift. Kd - Dakota Group, J - Jurassic undivided.

Quaternary Deposits

No effort was made to map Quaternary deposits in the region, although stream terraces, pediments, alluvial fans and other features can be recognized on the color photos. In addition, the volcanic sequence of the western San Juan Mountains was not mapped where it appears along the eastern margin of the region.

STRUCTURES

The relative ease of recognizing and tracing stratigraphic units throughout the area permits accurate mapping of geologic structure. Three major structural elements are recognized as the Uncompahgre Uplift, the Paradox Basin and the Black Canyon Uplift (Fig. 1). Five clearly-defined anticlinal trends, with intervening synclines, were mapped within the Paradox Basin. Both major and minor faults are clearly visible on the photography.

Folds

The largest and most significant structure is the Uncompahgre Uplift. The uplift is a large block approximately 160 km long and 60 km wide that is tilted to the northeast and trends N50W. A thin sedimentary sequence covers the uplift, with the Dakota Group or the

Triassic-Jurassic unit forming long north or northeast dip slopes. Precambrian rocks are exposed in deeply eroded canyons or arroyos (Pl. 1). Along the southern margin of the uplift, Precambrian rocks crop out on the north side of the major fault zone separating the uplift from the Paradox Basin. The major faults that have brought Precambrian rocks to a high structural position are believed to be high angle and are obviously basement-controlled systems.

The Black Canyon Uplift is similar to, but a much smaller fault block uplift than, the Uncompahgre Uplift. The north-tilted block, southeast of Delta, Colorado, was mapped over an area 40 km long and 25 km wide. The south margin of the block is broken by a significant fault zone that places Precambrian rocks in contact with the Cretaceous Mancos Shale. A syncline approximately 25 km wide separates the Black Canyon Uplift from the Uncompahgre Uplift.

The northern Paradox Basin contains numerous anticlines formed in Pennsylvanian through Cretaceous strata. The structural attitude of the sedimentary layers is indicated on Plate 1 by fold axes and direction of fold plunge, rather than by strike and dip symbols. Five major anticlinal trends have been delineated on the map. These are clearly expressed by both outcrop patterns and dip of strata. Some of the fold axes can be traced for more than 150 km.

The flanks of the folds vary in width from 5 to 10 km. Detailed surface observations, geophysical data, and subsurface data from wells indicate that the folds formed as a result of diapiric movement of Pennsylvanian evaporites. The long linear trends result from movement of evaporites into narrow ridges or blade-shaped bodies, probably initiated by basement-controlled faults. Subsequent erosion of the arched sediments over the evaporite ridge and removal of salt by solution caused the collapse of the core of the anticlines. Cliffs of Triassic and Jurassic sandstone now stand in sharp relief on the margin of the flat-floored valleys that mark the crestal region of the anticlines, hence the name "salt valley anticlines".

By tracing the stratigraphic units on the Skylab photographs, the history of the major structural elements can be reconstructed. The Paradox Basin contains Pennsylvanian and Permian stratigraphic units ($\mathbb{P}_p$ and Pc of Pl. 1) that are not present on the Uncompahgre or Black Canyon Uplifts. These observations indicate the uplifts were high areas during the Pennsylvanian and Permian, or that rocks of these ages were deposited and subsequently removed by erosion prior to deposition of the Triassic and Jurassic. Under either interpretation, and because the areas are uplifts today, the mapping indicated renewed tectonic movement of the two uplifts through geologic time.

Faults

The major structural features show numerous lineaments mapped as faults on Plate 1. Minor fault-block segments on the Uncompahgre Uplift are best observed in the region of the Colorado National Monument at the northwest plunge of the uplift. Individual faults trend east-west and northwest, defining blocks that are 5 to 15 km across. These minor faults, like the major ones, are believed to be basement-controlled high-angle faults.

Lineations on the photos were mapped as faults where the following features were observed: 1) Direct offset of strata, 2) omission of a portion of the stratigraphic sequence along a contact, 3) significant change in elevation from one side to another along a lineament, 4) unusually straight outcrop at edge of mesa or hogback, 5) unusually straight stream in anomalous drainage system, 6) lineaments that cross several drainage divides or that cause alignment of portions of different drainage systems, 7) vegetation variation from one side of a lineament to another, or 8) contact around diapiric evaporites in core of "salt valley anticlines" in Paradox Basin. Some of these features can also be caused by joints, paleovalleys, or lithologic contacts.

Many more faults have been mapped on the photos than appear on published maps of similar scale (Pl. 3). Ground checking the lineaments may eliminate some of those mapped as faults, but in general, it is believed that the Skylab S190-A photographs show many fault trends not heretofore known from published geologic maps of the area.

COMPARISON WITH ERTS IMAGERY

Photogeologic mapping of the area was conducted by use of both ERTS-1 and Skylab 3 imagery. Band 6 was used in mapping on an ERTS image, whereas color photography was used on Skylab.

The major folds, the general distribution of stratigraphic units, and major fault patterns were similar on both types of images. However, much more detailed and accurate information was available by use of the Skylab data. The ERTS imagery does not have stereoscopic coverage, and its use must definitely be classed as a reconnaissance mapping technique. By contrast, the quality of the Skylab S190-A photographs permits accurate, detailed mapping in a manner equal or superior to any other system of photogeology where an investigator wishes to map a large area in a short period of time.

CONCLUSIONS

1) The Skylab data permit rapid and accurate photogeologic mapping in areas of complex folding and faulting, if

outcrops are good. Approximately 25,000 square kilometers were mapped at a scale of about 1:360,000 in about 40 hours.

2) In areas of heavy vegetation, mapping accuracy is significantly reduced to a reconnaissance level.

3) By viewing large structural features of the earth's crust in one or two images, fault and fold patterns can be interpreted in a perspective not previously possible. As a result, significant photo lineaments have been observed that may represent mapping of new tectonic elements, if field checking confirms the lineaments as faults.

4) The Skylab photos are superior to the ERTS imagery. The Skylab maps may be equal to or greater in accuracy than published geologic maps. Therefore, the Skylab maps may present new data that could be important in mineral exploration programs. By contrast, mapping with the ERTS images is primarily reconnaissance in nature, and is especially useful in areas where there is little or no published information.

5) By recognizing and tracing stratigraphic units in detailed mapping, the major uplifts in the project area can be demonstrated to have recurrent structural movement. Pennsylvanian and Permian strata are absent on the uplifts, indicating Paleozoic or early Mesozoic uplift. The present structural relief in the area results from Cenozoic structural movement.

6) The intertonguing of gray marine shale of the Mancos Formation with sandstones of the Mesaverde Formation is recognized and mapped in the Book Cliffs. From this mapping, the direction of more continuous marine sedimentation is determined to be in an eastward direction. This is an example of the detailed stratigraphic information observable on the Skylab photos.

CASE STUDY II: GEOLOGIC INTERPRETATION OF S190B PHOTOGRAPHS

(Keenan Lee)

INTRODUCTION

The original objectives of this study were to determine the geologic information content of both ERTS and EREP images. The area selected for this common study is the southwestern part of Colorado and the southeastern part of Utah. This area was selected as a study site because it met the following criteria:

(1) the area has good coverage by satellite images from both ERTS and EREP sensors,

(2) bedrock exposures are relatively good,

(3) the area has existing published geologic maps at a scale of 1:250,000,

(4) portions of the study area have published geologic maps at scales as detailed as 1:24,000, and

(5) the principal interpreter (K.L.) had no familiarity with the geology at the beginning of the study.

Some other areas of Colorado met the same criteria (for example, south-central Colorado), but the EREP photography was neither as extensive nor as good as that from the southwestern part of Colorado

The approach followed in the course of this study was to use a designated training area, in which area each type of satellite image was interpreted in a conjunctive way with published geologic maps. Experience derived from this training area was then used to photointerpret the geology of an "unknown" area. Specifically, the study was broken into three phases, as follows:

Phase 1 A training area was defined as the Cortez 2° sheet plus the southern one-third of the Moab 2° sheet. In this training area, ERTS images were first studied in conjunctive use with the published geologic map (1:250,000). Following the ERTS interpretation, the same area was interpreted using EREP S190A photography, followed by study of the EREP S190B photography. This sequence was selected because it was anticipated that each succession of satellite images would provide progressively more geologic information. The results from the initial study of Phase 1 were summarized and published in Lee and others (1974).

Phase 2 A test area was defined as the northern two-thirds of the Moab 2° sheet (Fig. 4). The sequence of images studied in this area also progressed from ERTS images to EREP S190A photographs to EREP S190B photographs. During this phase of the study, it became obvious that the S190B photographs contained considerably more geologic information than the other types of images, and emphasis was duly placed on the interpretation of these photographs. It further became obvious during this study that there was more

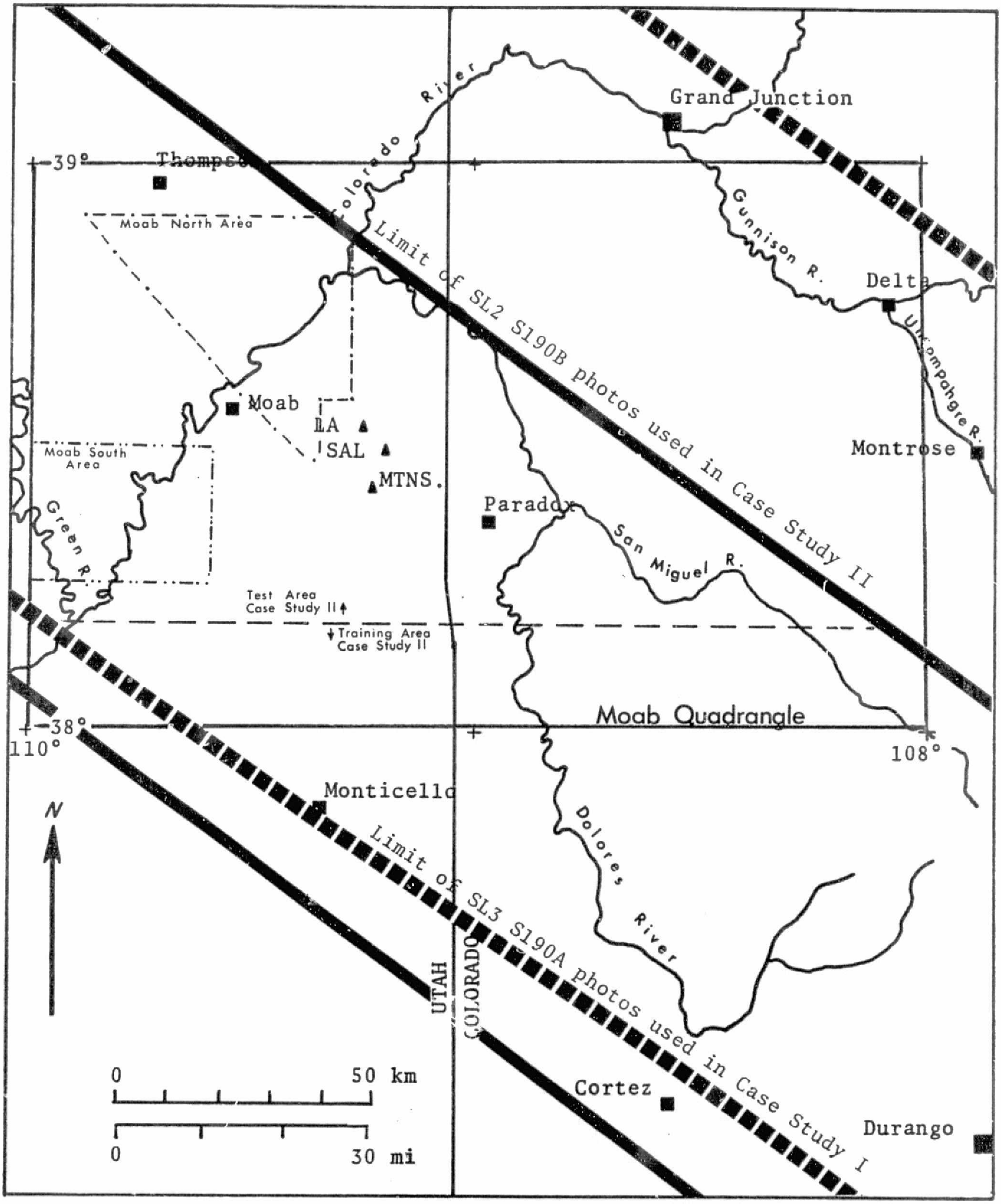


Figure 4. Index map showing Skylab photo coverage and study area.

information in the S190B photographs than could be annotated at the original scales used (1:250,000). A resulting substudy, therefore, was an evaluation of the different scales that could be used for optimum photogeologic interpretation. At the conclusion of the photointerpretation of this unknown area, a field check was scheduled to examine representative areas, complex areas, and areas where the geologic information was not clear on the photographs. At this point of the study, the output data products consisted of geologic maps derived from photointerpretation, along with minimal field checking, of a geologically "unknown" area. These geologic maps (Pls. 2, 4, and 5), therefore, represent what would be an application end product were the EREP photography to be used in a truly unknown area.

Phase 3 The final phase of this study consists of the evaluation of the interpretations made from the space images. The accuracy and completeness of the geologic maps was evaluated mainly by comparison with published geologic maps, with some additional field checking to determine, as best as possible, the "ground truth" in areas where the photo-interpretation maps and the published geologic maps conflict.

The remainder of this report is keyed to discuss these three phases of the study as follows:

Phase 1 - Training area results,

Phase 2 - Test area results, and

Phase 3 - Discussion of results.

Conclusions and recommendations are summarized at the end of the paper.

TRAINING AREA RESULTS

ERTS

ERTS images were studied in conjunction with, and referring to, published geologic maps of the Cortez Quadrangle, Colorado and Utah (Haynes and others, 1972) and the southern third of the Moab Quadrangle, Colorado and Utah (Williams, 1964). The images selected for study were frames 1155-17204-5 and 1156-17262-5, recorded on 25 and 26 December 1972.

The images used for interpretation were positive, black-and-white, 18.5 cm transparencies. The selected frames were imaged with a 23° sun angle, and the area had some snow cover at the time. The positive transparencies were studied on a Richards light table, using a low magnification mirror stereoscope in those areas where stereo side-lap was available.

Lithology

Lithologic discrimination, in general, is poor. Most lithologic discrimination is based on the recognition of topographic differences. Lithologic features amenable to yielding lithologic information are relative resistivity and drainage differences. Resistant vs. nonresistant beds form escarpments that serve to delineate geologic contacts. An example of this that occurs through large areas of the map is the Cretaceous Dakota-Burro Canyon Fm. overlying the Morrison Formation. Textural differences are occasionally useful for defining drainage density as a function of lithology. The Morrison Formation is discriminable from the underlying Jurassic and Triassic Formations on this basis.

Some lithologic discrimination is based on tonal differences. The Mancos Formation-Dakota Formation contact is an example of a contact recognizable by tonal differences; in this case the Mancos is relatively light. This tonal difference may be an inherent characteristic of the respective formations, but it is also possible that the tonal difference derives from a difference in topography; the relatively non-resistant Mancos Formation forms topographically low areas that often have alluvium and colluvium (or possibly soil) surficial deposits at the surface.

A second tonal phenomenon that serves to discriminate lithologies is along the Quaternary eolian deposits-Dakota Formation contact. Very good discrimination (white vs. light grey) is possible, based on the extent of snow cover. Continuous snow is retained on the eolian deposits, whereas the Dakota Formation shows apparently discontinuous snow cover. This is not a function of elevation, since the snow-free areas occur topographically above and below the snow-covered areas. Possible reasons for the underlying phenomenon may be (1) differential melting due to thermal diffusivity differences,

(2) vegetation differences, with the Dakota supporting more vegetation and the vegetation appearing above the ground snow cover, or (3) surface roughness (macro) differences, with the eolian deposits relatively smooth, and the Dakota irregularly projecting above the snow. Field checks were conducted in the summertime only, and as a result, a definitive answer to the above questions was not available. It seems likely that the vegetation differences would account for the tonal differences on the imagery.

Structures

Major folds could be observed (for example, Paradox structures) on the imagery. Dip-slopes of relatively low dip attitude (4°-10°) could be picked. Very few folds can be recognized by observing a tonal pattern that is immediately associated with a fold, most folds are determined by working out the dips and defining areas of dip reversals.

About 60 percent of the major faults (10-40 km length) are readily observable, and all major faults in the map area were observed except for three. Many small faults (less than 10 km) were observed; the smallest was 3 km in length.

Most faults were delineated by topography, especially escarpments and linear connected drainages. Faults were easiest to see along dip slopes and where escarpments occurred, usually with resistant vs. non-resistant formations across the faults. No faults were picked in areas of high relief; several faults that were traced in low-relief areas were lost as they were followed into the mountainous areas. Only a very few faults could be picked on the basis of tonal differences.

Seasonal Effects

The images used in the study described above were selected because it was felt they would yield maximum geologic information. To test whether this assumption was, in fact, valid, an ERTS image was selected for interpretation and evaluation that was diametrically opposed to the previous images in seasonal phenomena. ERTS 1317-17204-5, acquired 5 June 1973 with a 62° sun angle and only a trace of remaining snow, was interpreted. The geologic information content was very low compared to the winter images. No advantages were apparent in using this imagery compared to the low sun-angle, snow-covered imagery; many disadvantages were noted.

EREP S190A MULTISPECTRAL PHOTOGRAPHIC CAMERA

Initial photointerpretation studies using EREP photography used the S190-A multiband photography. First studies were conducted with the red band, 4X, positive transparencies. Frames were selected from Skylab 2, Roll 11, Frames 13 through 16, acquired on 5 June 1973. (Note that 5 June 1973 was the date that ERTS imagery was acquired over the same area. Comparative studies of the ERTS images concluded that this time of year was the less favorable time for geologic interpretation of the space images.) No rigorous comparisons were made between the different bands of the S190A photography, but each band was observed, and no advantage was apparent in any single band. The red band was used most (of the B/W bands) because of its good resolution and high contrast. The transparencies were studied on a light table with a mirror stereoscope.

Lithology

In general, there did not appear to be a significant change in interpreting the S190A black-and-white transparencies as compared with the ERTS images. All comments pertaining to lithologic discrimination from the ERTS study apply to the S190A black-and-white photography as well. One obvious exception is the effect of snow discrimination on the eolian deposits vs. Dakota Formation, but, although this contact is not as easily discriminated as it was with snow cover, there is no difficulty in picking the contact based on tonal differences.

Structures

Comments made previously regarding fold structures are equally applicable here. Fault information on the S190A photography is also similar; about 80 percent of the major faults in the area are readily observable. All faults greater than 10 km in length were observed except for two. Many faults less than 10 km are seen; the smallest fault noted is about 2 km long. Most of the small faults that are not recognizable on the photographs occur in closely spaced sets parallel to major fault systems. Somewhat more detailed fault information is available on the black-and-white S190A photos than on the ERTS images.

EREP S190B, EARTH TERRAIN CAMERA

The S190B photography studied in conjunction with the geologic maps is color photography (Skylab 2, Roll 81, Frame 19) acquired 5 June 1973 (simultaneously with the S190A photography described above). 2X positive transparencies were studied stereoscopically on the light table with a mirror stereoscope.

Lithology

The lithologic discrimination capability of S190B color photography is dramatically superior to S190A black-and-white photography and ERTS imagery. The addition of color, combined with the increased ground resolution, markedly increases the ability to subdivide lithologic units. Most of the formations broken out on the 1:250,000 scale geologic maps can be discriminated and mapped where scale/resolution permits. Whereas the S190A black-and-white photography (red band) permitted the subdivision of the map area into five formations, with S190B color photography it was possible to break out (at least in some places) eleven mappable units:

S190B COLOR	S190A B & W
Qe, Qa	Q
Kmv	Km
Km	Kdb
Kdb	J
Jsm	̄R
̄RJne	
̄Rkw	
̄Rc	
̄Rm	
Pc	
̄Ph	

For an explanation of these map symbols, see the Explanation on Plate 2.

Even though the increase in lithologic information is great, in that eleven map units were cappable of geing detailed vs. five map units, this does not represent the full potential of the S190B color photography. As will be seen in subsequent portions of this report, many of the map units listed above could be further subdivided.

Structures

All comments made above regarding structural interpretation of ERTS and S190A black-and-white photography apply here as well. In addition, many more structures were mapped because of the high resolution (ground resolution is difficult to describe; some roads were easily seen that are on the order of 10 m wide, some narrow outcrop patterns were seen that are about 200 m wide, and joint spacings of less than 200 m are readily apparent). Much more dip information is available because of the fine topographic detail seen. Whereas on ERTS images and S190A black-and-white photos all large folds could be interpretated, they were sometimes difficult to work out. The same interpretations were much easier on this photography. Folds are also easier to interpret because of the addition of much more information on lithologic distribution (described above).

About 95 percent of all major faults were observed. All faults greater than 10 km in length were seen except for two. The results of interpretation of faults less than 10 km long were about like the S190A photos described above; the smallest observed fault is about 2 km long. In one area of high density fracturing, individual fractures about 1 km long can be seen that have a joint frequency of about 200 m or less.

TEST AREA RESULTS

The initial procedure involved in photointerpretation of the test area consisted of establishing the photointerpretation keys used for discriminating the different geologic map units. On the basis of the appearance of each of the mappable units in the training area, these interpretive keys were compiled and are shown here as Table 1. It is apparent when observing the final geologic maps that the interpretive keys described in this table were used only as rough guidelines. Nonetheless, these keys served well to establish the basic stratigraphic sequence in the unknown area.

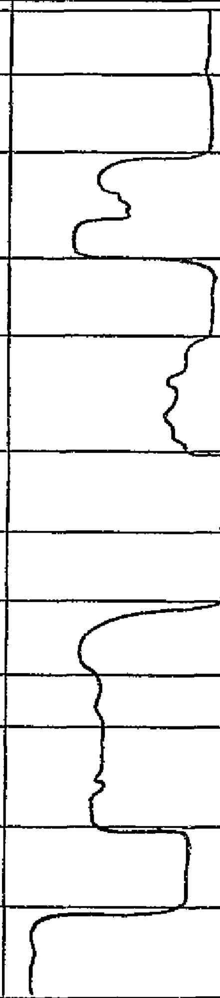
1:250,000 MAPPING - MOAB QUADRANGLE

Photointerpretation was conducted using 2X enlargement positive transparencies of the S190B photographs. Geologic information was annotated directly onto clear acetate overlays on top of the positive transparencies, using a 00 rapidograph pen. Stereo interpretation was conducted with a mirror stereoscope with an effective magnification range of 1-2X, so these positive transparencies were examined at about 1:500,000 to 1:250,000 scale. During photointerpretation of these transparencies, the original-scale (~1:1,000,000) contact duplicate transparencies were kept on another light table with a zoom stereoscope. Where geologic information

TABLE 1

PHOTOINTERPRETATION KEYS - MOAB-CORTEZ AREA

S190B PHOTOGRAPHS

Formation	Color	Texture	Drainage	Topography	Erosional Resistance →	Distinguishing Features
Dakota	medium brown	fairly uniform, fine	coarse	secondary hogback		uniform texture
Burro Canyon	dark brown-grey	mottled	moderately coarse	hogback		resistant, light at base
Morrison-Summerville	dark brown-grey	mottled end faces, dark dip slopes	fine dendritic	slopes with central ledge		position, color
Entrada	very light tan	fine light lines		cliff		color, fine lines
Navajo	very light tan	banded-mottled	coarse, occ. parallel	hummocks		light mottled color
Kayenta	dark brown	dark mottled	coarse	ledgy		dark brown, ledgy
Wingate	light brown	irregularly mottled	coarse dendritic	cliff		topography
Chinle	dark red brown			slope		position
Moenkopi	red-brown			weak ledge		position
Cutler	dark red-brown	finely banded	medium coarse dendritic	irregular ledges		color, fine bands
Upper Hermosa Mbr.	medium brown-grey	coarse banded		hogback		position (rarely seen)
Paradox Member	very light tan	mottled	fine dendritic	hummocks		anticlinal cores

was apparent on the 2X enlargements, the information was directly annotated; areas of structural complexity or subtle detail were studied concurrently on the contact transparencies at high optical magnification.

Geologic interpretations were transferred from the clear acetate overlays onto topographic maps (1:250,000) of the Moab Quadrangle using a zoom transfer scope for the 200% scale change. Annotations were transferred to the topographic map in pencil, and a 00 rapidograph pen was then used to finalize the location of the contacts and structures using the topographic information as a secondary control. It was often necessary to go back to the original duplicate positive on the zoom stereoscope for resolving detail and resolving complex structures. It was sometimes necessary to annotate interpretations from the zoom stereoscope onto 4X (1:250,000 scale) positive prints with a clear acetate overlay.

Hand-coloring of the photointerpreted geologic map in many cases pointed out problem areas. In almost all cases, these problem areas were resolved (where resolution was possible) using the zoom stereoscope and the original-scale contact transparencies.

Lithology

All of the formation-rank units that are shown on the published 1:250,000 scale geologic map were recognized on the S190B photographs, at least in some areas. Several of the formations, however, are not readily distinguishable from contiguous formations, and subsequently were mapped as combined units. For example, the Kayenta and Wingate formations were easily separated (Pls. 9, 10*) where their dip was fairly steep, such as in Lisbon Valley anticline (65.7/422.8 on Pl. 2**), but in most of the map area where dip attitudes are relatively low and these formations form nearly vertical cliffs, the two formations were mapped as a single undifferentiated unit. On the other hand, there were several instances where individual formations could be subdivided into member-rank units. Such an example would be the Morrison Formation, where it is separable into the Salt Wash Member and the Brushy Basin Member in the highlands area north of Arches National Park (63/430, Pl. 2).

Whereas relative thicknesses of stratigraphic units could be estimated on the S190B photographs, lack of experience with photographs at this extremely small scale (compared to conventional photointerpretation scales)

* Plates 8, 9 and 10 are color prints of S190B photographs. Reference will be made to these photos throughout the report. So as not to obscure features on these photos, they are not annotated and features on the photos will be referenced by giving their location on the corresponding map. There is sufficient detail on these photos so the reader should have no difficulty in correlating maps and photos.

** Geographic references for Plates 1-3 are given in UTM grid numbers. For example, Moab is at 62.7/427.1.

precluded determining absolute thicknesses. When formation contacts were transferred to the topographic maps, however, the topographic information provided sufficient control for at least rough estimates of formation thicknesses.

In some cases, surprisingly detailed stratigraphic information was available in the S190B photographs. One surprising capability demonstrated was the ability to delineate the horizontal extent of formations, suggesting lateral stratigraphic changes either by facies change or by pinch-out. For example, the Triassic-Jurassic Navajo Sandstone appears to be absent in the Paradox Valley area (68/425, Pl. 2) and the area immediately to the east and northeast of the Paradox Valley. A similar case of stratigraphic pinch-out occurs in the southwestern part of the Moab Quadrangle, where a key bed at the top of the Cutler Formation, the White Rim Sandstone Member, pinches out toward the northeast (60.6/425, Pl. 2).

Figure 5 shows a composite stratigraphic column of the Moab area that was derived from photointerpretation of the S190B photographs at a scale of 1:500,000. Rather than describe each formation in detail, this figure is offered to show the amount and detail of stratigraphic information available in the photographs.

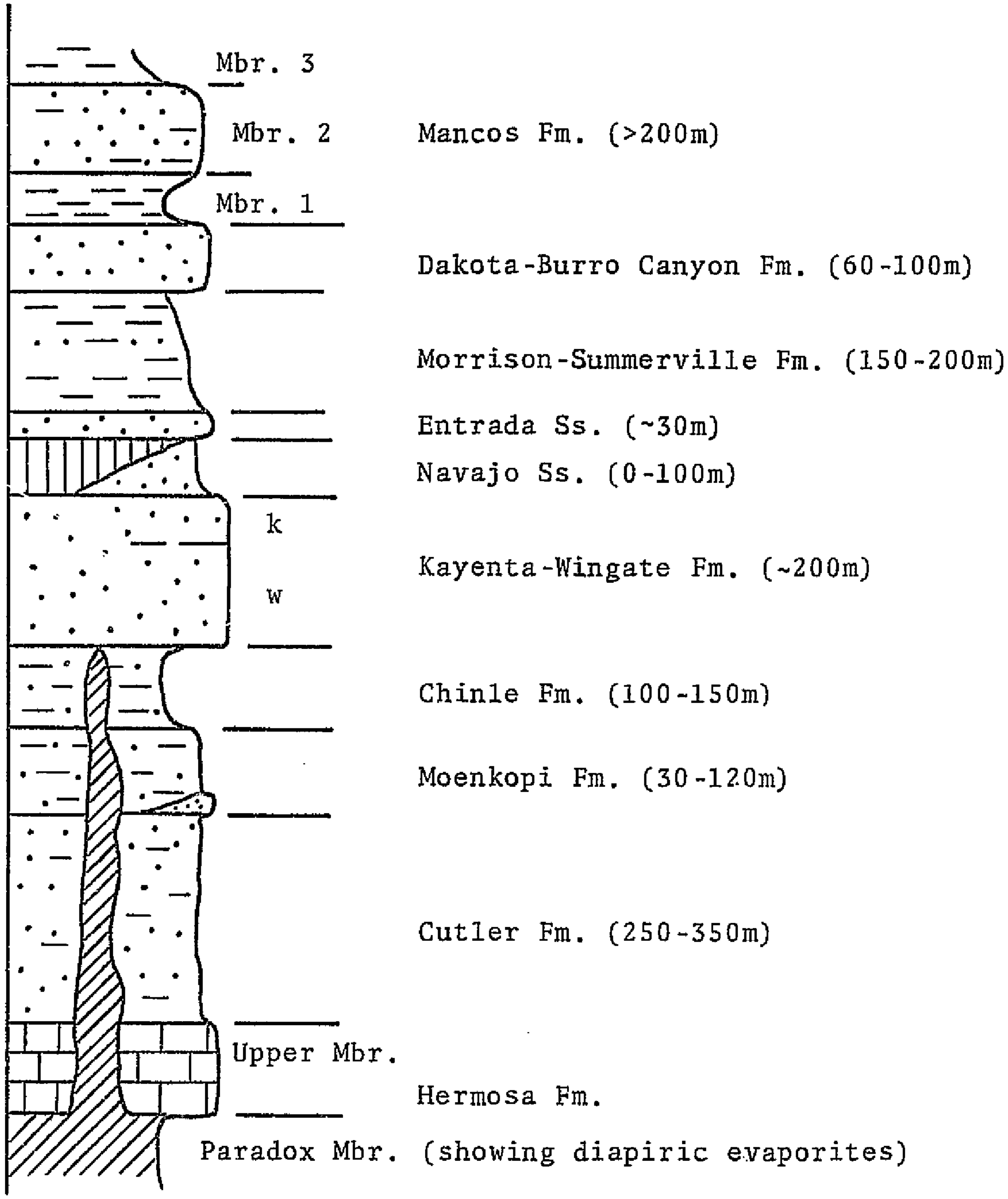


Figure 5. Composite stratigraphic column of Moab Quadrangle from photointerpretation of S190B photos at 1:500,000.

Structure

All of the major structures of the Moab area were interpreted during this part of the study, as well as many secondary structures. Because the map area includes two different structural provinces, discussion will be separated into two parts: the area southwest of Spanish Valley-Lisbon Valley (63/427 to 67/422, Pl. 2) and the area north and east of this line. Southwest of the Spanish Valley-Lisbon Valley trend, the stratigraphic units are largely flat-lying, with dips throughout large portions of this area averaging less than 3°. Some structures diverging from this homocline are the following:

Courthouse-Arth's Pasture Syncline (61/428 to 63/426, Pl. 2) - an asymmetric syncline with a gentle northeast limb and a very gentle southwest limb; ends in a fault towards the northwest;

Shafer Basin - Big Flat Anticline (61.5/426, Pl. 2) - very gentle upwarp, with slightly steeper northeast limb; the anticline appears locally doubly plunging (northwest-southeast at the Colorado River; and

Upheaval Dome (59.4/425.4, Pl. 2) - this anomalous, circular dome area is immediately obvious on the photography. Interpretation of the geology during this phase of the study indicated a definite dome, although the center of the structure was not clearly identified.

A structural anomaly noted in this whole region of the map is the noticeable absence of faulting. The only faults mapped anywhere in the area were at the extreme southwest part of the map (59.8/422.4, Pl. 2) at the northeastern end of the grabens area, a series of parallel, slightly arcuate graben structures.

The remainder of the map area north and east of the Spanish Valley-Lisbon Valley trend consists of a series of northwest-trending folds, often with subparallel faulting. Northwest of the La Sal Mountains (65/426, Pl. 2), the structural trend is N40-45°W, whereas southeast of the La Sal Mountains the trend is N50-55°W.

The Moab Anticline (62.6/427.1, Pl. 2) is an asymmetric anticline, fault-bounded on the southwest. The anticline is complexly faulted, especially near the Arches National Park Headquarters. The anticline plunges to the northwest, where it is truncated by a northwest trending fault from Moab to Courthouse Pasture. Faults along the anticlinal structure are post-folding, and presumably are related to collapse of the anticlinal crest.

The Crescent Wash-Courthouse Syncline (60/430 to 64/426.6, Pl. 2) is a symmetrical, northwest plunging syncline. The syncline becomes slightly asymmetrical to the southeast with the southwest limb being more steeply dipping. The axis of the syncline may coincide with a fault to the northwest.

The Salt Valley-Cache Valley Anticline (61/430 to 63/428.8, Pl. 2) is a fairly symmetrical anticline at its northwestern end. The northwestern part of the anticline appears to have a fairly simple, subparallel collapse fault system. Where the Salt Valley turns more easterly to connect with the Cache Valley, the boundary faults appear to be at a high angle to the anticlinal trend, at least on the north side of the structure. In the Cache Valley, the anticline, if it is present, is much more subtle. The main structure in the Cache Valley area seems to be the collapse structures of the subparallel bounding faults. The relationship of the Salt Valley-Cache Valley structure to structures east and south of the Colorado River is problemmatical. The photo-interpretation during this phase of the study was inconclusive as to whether this structure trended to the southeast, through Dry Mesa, connecting with the Castle Valley Anticline (64/427.7, Pl. 2), or whether the structure continued more easterly and connected with the Fisher Valley Anticline (65/428.4, Pl. 2). A corollary of accepting the former interpretation is that the apparent areas of Hermosa Formation in Professor Valley and Fisher Valley (64.3/428.4 and 65/428.4, Pl. 2) would be interpreted as intrusive bodies rather than as structurally located and exposed formations.

The Castle Valley Anticline is a simple anticline that either plunges very gently to the northwest or continues through Dry Mesa and joins the Salt Valley Anticline. Round Mountain is a circular anomaly whose interpretation is questionable.

The Mary Jane Syncline (65/427.7, Pl. 2) is a very gentle, symmetrical syncline of only local extent.

In the Yellow Cat Flat-Highlands area (63/430, Pl. 2), the strata are very gently flexed into a northwest trending anticline and northwest trending syncline. These very gentle, open folds trend about N20-30°W.

The Cottonwood Canyon Graben (66/428.8, Pl. 2) and the Salt Creek Canyon Graben (68/427, Pl. 2) are similar graben structures that trend N51-53°E. These grabens are anomalous in that they are about perpendicular to the regional structural trend. Since both drainages head in Paleozoic anticlines, the grabens may be simply a collapse response to removal of subsurface evaporites. The Sinbad Valley Anticline (67.5/426.4, Pl. 2) is a simple, doubly-plunging anticline, faulted on the northeast flank. The anticline appears to have an intrusive center along the northwest part of the structure. The trend of the anticline, N40-45°W, matches structures to the northwest of the La Sal Mountains more than the closer Paradox structures.

The Paradox Valley Anticline-Syncline (68/425, Pl. 2) is a classic example of the salt anticline structure. The anticlinal nature of the structure is best seen by examining the outcrop patterns away from the bounding faults along the core of the structure. These dip slopes clearly indicate a large, more-or-less symmetrical anticline. Bedding attitudes within the valley-bounding faults, especially at the northwest and southeast ends (67.2/425.2 and 70.8/423.1, Pl. 2) clearly show an opposite - or synclinal - type of structure. This structural anomaly, where a syncline is superposed on an anticline, produces the curious structural situation where beds on either side of the bounding faults are dipping in opposite directions. Outcrops of the Paradox Member evaporites have a distribution in the core of the structure that definitely suggests an intrusive origin. (In contrast to the geologic maps of Case Study I, where such contacts are shown as fault contacts, these intrusive contacts are shown as normal formational contacts, similar to igneous intrusive contacts).

The Nucla Syncline (71/424, Pl. 2) and the Dry Creek Syncline (69/423, Pl. 2) are subparallel, gentle synclines that flank the Paradox Valley Anticline-Syncline. In both cases, the synclinal structures were defined by photointerpretation of very gentle dips, generally less than 5°.

1:62,500 MAPPING--MOAB NORTH AREA

When it became obvious, during the previously-described study, that there was more geologic information available in the S190B photos than could be annotated at a scale of 1:500,000, additional interpretations were conducted at scales of 1:250,000 and 1:125,000. Whereas the photogeologic interpretation previously described used positive transparencies at a scale of about 1:500,000 and transferred geology onto a topographic map at a scale of 1:250,000, the study described in this section is concerned with photointerpretation on positive transparencies at an enlarged scale of about 1:250,000 and data transferral onto a topo base map at a scale of 1:62,500. Techniques described in the previous section on photointerpretation apply to this study as well. As in the previous study, continuous referral to the original contact-scale transparency with a zoom stereoscope often was necessary.

Two portions of the Moab Quadrangle were selected for this additional study, areas that are here called Moab North and Moab South (Fig. 3). Moab North was selected because this area includes several complex structures, most of which are associated with salt tectonics.

Lithology

The general ability to subdivide stratigraphic map units is not significantly different on the 1:250,000 positive transparencies. Those units that are mappable at the enlarged scale are similar to the map units used in the 1:500,000 scale photographs, except that the Jurassic section could be more reliably and consistently subdivided. Whereas in many areas of the 1:500,000 transparencies, only one stratigraphic unit was mapped between Kayenta Formation and the Dakota Group, the enlarged photographs permitted subdivision into the Entrada Sandstone, the Summerville Formation, and a subdivision of the Morrison Formation into the Salt Wash Member and the Brushy Basin Member.

Formation contacts were mapped in considerably more detail at the enlarged map scale. Formation thicknesses, as a result, are considerably changed, sometimes dramatically; the thickness of the lower member of the Mancos Formation was estimated at about 100 m on the 1:250,000 map, whereas the enlarged map interpretation gave a thickness of about 25 m. In general, the additional detail available provides more reliability for the interpretation of the contacts and presumably greater accuracy.

The increased accuracy in picking formation contacts provides considerably more detail on actual outcrop distribution. For example, the Dakota-Morrison contact and the Brushy Basin Member/Salt Wash Member contacts are shown in considerably more detail on the 1:62,500 map than on the 1:250,000 map. In order to make this comparison, examine the Poison Strip area (63.2/430.3) on Plate 2 with the same area (T.22S., R.22E.) on Plate 4.

A few significant interpretive changes result from a different interpretation of the formation exposed at the surface. In the Dome Plateau area (NW cor. T.24S., R.23E., Pl. 4), the outcrop is interpreted as the Navajo Formation, whereas on the 1:250,000 map (63.8/428.9, Pl. 2), this area was mapped as undifferentiated Kayenta-Wingate.

A similar difference in assigning formation names occurs in the Parriott Mesa area (SW cor. T.24S., R.23E., Pl. 4; 63.8/428.1, Pl. 2), where a different interpretation centers on differentiating the Moenkopi Formation from the underlying

Cutler Formation. This contact is rather subtle, and cannot always be picked with reliability even in the field.

Structure

Little significant structural information was added concerning the major structural elements. The larger-scale photographs and maps provide more detail on formation contacts, as noted above, that led to improved interpretation of minor, secondary structures and possible refinement of attitude estimations.

The actual differences in structural interpretation between the two different scale maps is relatively minor. Several of the secondary faults mapped, especially along the collapsed anticlines, are somewhat different in orientation, extent, or existance, but do not significantly change a structural interpretation. In most cases, additional information on these minor faults clarifies the structural picture. A good example of this is the faulting along the Moab Anticline near the Arches National Park Headquarters (Sec. 20, T.25S., R.21E., Pl. 4; 62.1/427.5, Pl. 2), where the larger scale map clarifies, rather than changes, the structural interpretation in this area.

None of the folds in this map area were interpreted differently on the larger scale map. The only change between the two maps occurs at the Mary Jane Syncline, whose axis was shifted somewhat to the southwest on the larger scale map (Sec. 13, T.25S., R.23E., Pl. 4; 64.9/427.7, Pl. 2).

In addition to the minor changes in interpretation going from the small scale to the large scale map, several secondary minor structures were interpreted as new information. Two anticlines were interpreted that appear related to the major salt anticlines as flanking drag structures, probably formed in association with collapse of the central portion of the anticlines. These secondary structures appear at Winter Camp Wash (Sec. 4, T.24S., R.22E., Pl. 4) and at the Arches National Park Headquarters (Sec. 21, T.25S., R.21E., Pl. 4). Another new structure interpreted was the open gentle syncline through Dry Mesa (Sec. 21, 22, T.24S., R.22E., Pl. 4).

The ability to interpret the relatively subtle syncline at Dry Mesa, mentioned above, resolves the question of the structural interpretation at the southeast end of the Salt Valley-Cache Valley Anticline. The structural interpretation compiled on the 1:250,000 map left ambiguous the possible connection of this anticline with either the Castle Valley Anticline or the Fisher Valley Anticline. The existance of the Dry Mesa Syncline effectively negates the possible connection of the Cache Valley structure with the Castle Valley Anticline.

1:62,500 MAPPING - MOAB SOUTH AREA

A second study on the affect of scale differences on interpreting geologic information from EREP photographs was conducted in an area southwest of Moab, Utah. The S190B color photographs of this area were enlarged about eight times to a scale of approximately 1:125,000. Enlarged transparencies were made of stereo pairs so that continuous stereoscopic interpretation of the area was possible. The procedure followed was similar to that described in preceding sections - that is, the enlarged transparencies were studied with a mirror stereoscope, information was annotated directly onto the enlarged transparencies, and geologic information was then compiled onto a topo base map at 1:62,500. Continuous referral to the original contact-scale transparency with zoom stereo magnification was necessary.

The area chosen for this study was selected because of a relative absence of geologic structures, whereas the area north of Moab was selected for the previous study primarily because of its fairly complex structures. Because the Canyonlands area southwest of Moab has relatively few structures, the area provided a good base for determining the detail of stratigraphic information that was available from the enlarged transparencies.

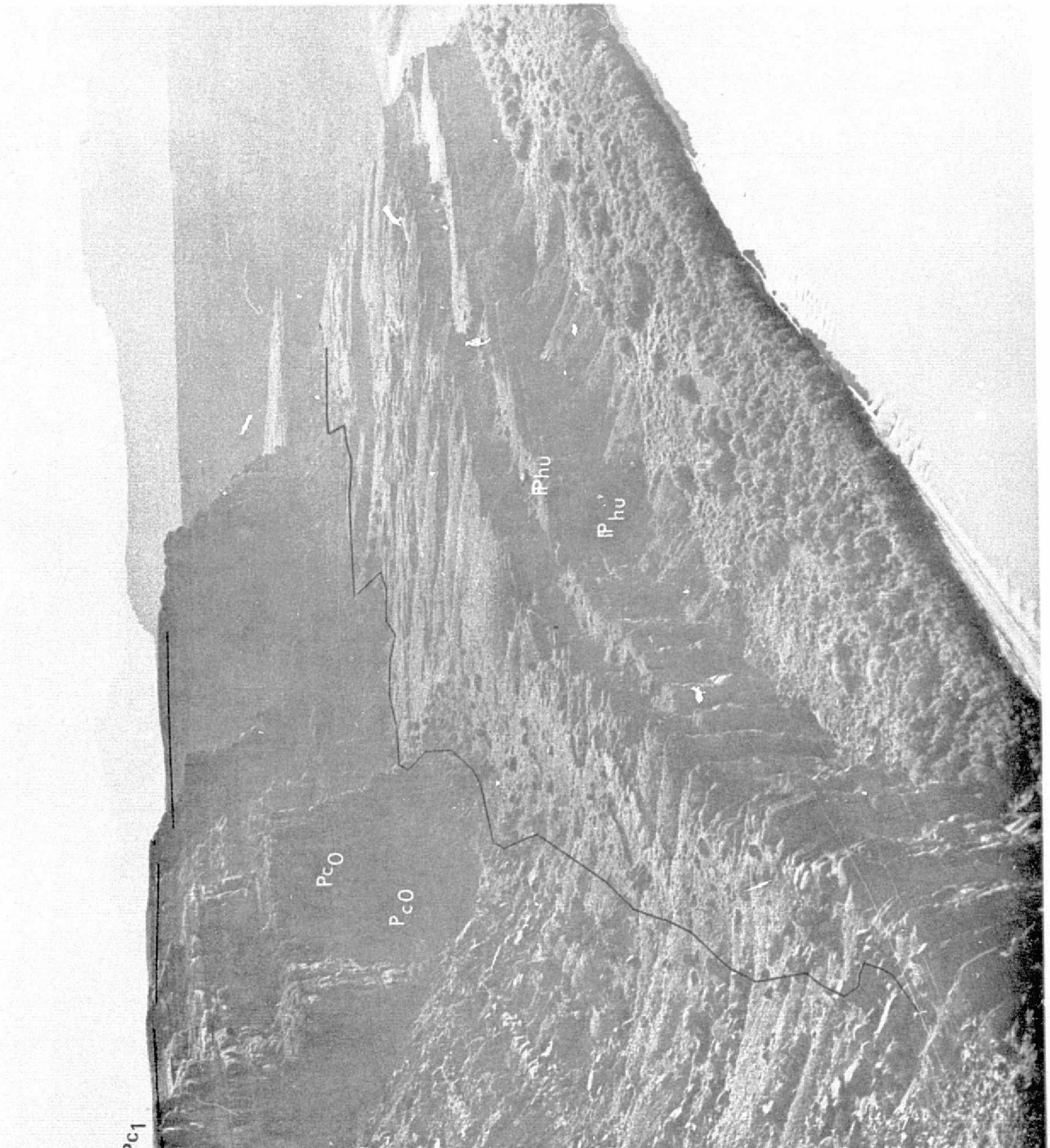
Lithology

The general ability to discriminate stratigraphic units is significantly increased on the 1:125,000 scale transparencies as compared with the 1:500,000 scale transparencies. A brief comparison of Plates 2 and 5 indicates the amount of stratigraphic subdivision possible. The following is a brief description of each of the map units that can be interpreted on the S190B color photographs.

$\underline{P_{hu}}$ The oldest mappable unit exposed in this area is the Upper Member of the Hermosa Formation. Outcrops are restricted to small areas at the south and north parts of the map area where the Colorado River has cut down into positive structures. Limited exposures occur in the center of the Shafer Dome (Secs. 15, 16 and 22, T.27S., R.20E., Pl. 5; Fig. 6) and near the confluence of the Colorado River with the Green River (G.2/9.6, Pl. 5).

$\underline{P_{c0}}$ The distribution of this basal member of the Cutler Formation, and its contact with the underlying Hermosa Formation, are difficult to map accurately because they are exposed only along the very steep canyon walls of the Colorado River. Good outcrops occur at Shafer Basin, (Fig. 6) and in the southern part of the area (as described above for the Hermosa Formation); additional outcrops occur in Lockhart Canyon (Sec. 16, T.28S., R.20E., Pl. 5).

$\underline{P_{c1}}$ This map unit is a resistant bench-former that is seen only in the Shafer Dome area (Fig. 6) and at the mouth of Lockhart Canyon. Although the units above and below it are exposed farther south along the Colorado River, this unit cannot be readily broken out of the Cutler Formation south of Lockhart Canyon. This unit appears grey on the photographs, and during mapping on the 1:500,000 photographs it was questionable as to whether this area would be subdivided as


Pc1
Pco
Pco
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the upper part of the Hermosa Formation. The present interpretation stems from the recognition of red beds beneath this unit (P_{c0}) in the Shafer Dome area. Thus, rather than being mapped as part of the Pennsylvanian Hermosa, it is included as part of the Cutler Formation (it may be part of the Rico Formation). The contacts at the top and bottom of the P_{c1} unit are fairly easily picked.

<u>P_{c2}</u> This unit is a moderate to light red brown, nonresistant slope former. It is a difficult unit to map because it is clearly recognizable only in the northern part of the map area. For example, in Secs. 9 and 10, T.27S., R.20E., (Pl. 5), its upper and lower contacts can be picked readily, but in the southern half of the map area the underlying P_{c1} ledge-forming unit is not recognized, and south and west of Junction Butte (E.0/8.4, Pl. 5) the Upper Cutler Member is not recognized. Thus, this unit, while it may extend throughout the map area, is recognizable only along the Colorado River in its upper reaches.

<u>P_{c3}</u> This map unit is a moderately dark, red-brown, moderately resistant slope former. The uppermost part of the unit is a more resistant, somewhat darker red-brown unit (Fig. 7). This upper part of the unit was originally subdivided on the photointerpretive geologic map, but later field considerations caused it to be included with the P_{c3} unit, because it is often very difficult to pick because of the overhang of the unit overlying it (kl). Therefore, this

Figure 7. Uppermost part of Cutler Formation. Aerial view to southwest of Monument Basin (F.5/8.3 on Pl.5) with Junction Butte on right skyline. P_{c3} - Member 3. k1 - Keybed 1 is White Rim Sandstone Member.

map unit is carried only as far south as the ridge below Junction Butte, whereas, in actuality, it may persist as a vertical cliff beneath kl farther west. The overall distribution of the P_{c3} unit appears somewhat odd. This unit, even if it does not pinch out entirely near Junction Butte, is certainly very thin at the southern part of the map area. If the bottom contact of the unit has been accurately interpreted in the central and northern part of the map area, the unit is about 120 m thick in the Lathrop Canyon area (H.0/5.0) and appears to thin to about 70 m near Deadhorse Point (Secs. 3 and 4, T.27S., R.20E.). Whereas the recognized P_{c3} unit appears thin to the southwest, in fact the unit may simply be a facies equivalent of P_{c2} unit or the undifferentiated P_c unit to the southwest.

<u>kl</u> This unit is a resistant, well developed bench-former in the southwest part of the map area (Fig. 7). It is a good key bed and was recognized and mapped at 1:250,000. Whereas it is a very obvious white to light tan unit, it cannot be carried northeast of Shafer Canyon (Sec. 7, T.27S., R.20E., Pl. 5), nor can it be recognized east of the Colorado River. This unit may be in part correlative with the uppermost dark red-brown resistant part of the P_{c3} unit.

<u>Ꞧm</u> The Moenkopi is a non-resistant, red-brown slope former (Fig. 8). Southwest of Little Bridge Canyon (Sec. 31, T.27S., R.20E., Pl. 5) the unit is very easily delimited by contacts with the underlying key bed, kl, and the overlying

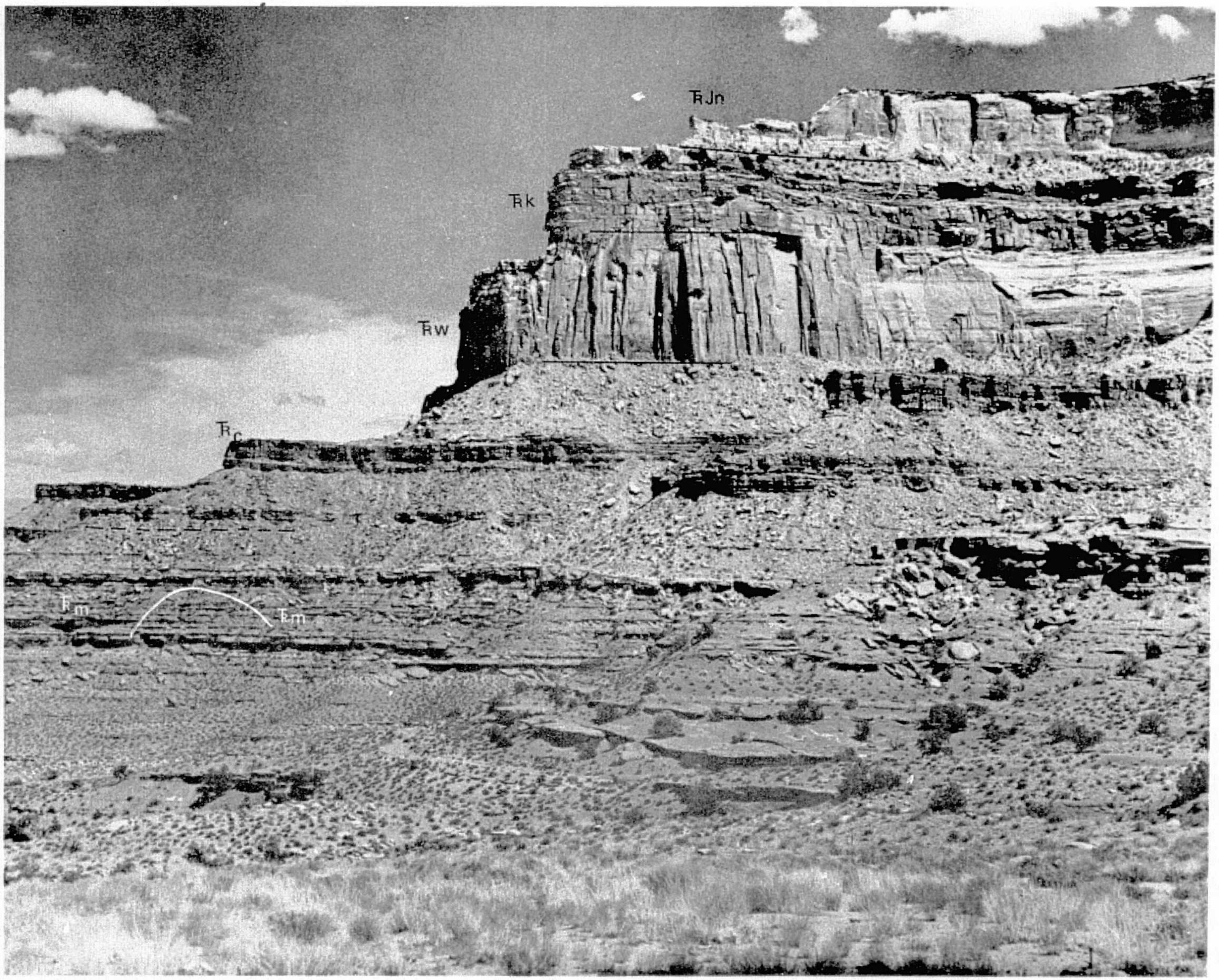


Figure 8. Triassic stratigraphic section. View south from Shafer Trail to mesa at G.0/2.1 on Plate 5. m - Moenkopi Fm., c - Chinle Fm., w - Wingate Ss., k - Kayenta Fm., and n - Navajo Ss.

key bed, k2. Throughout this region it can be subdivided fairly easily into an upper, somewhat more resistant unit, and a lower, less resistant, thinner member. North of Little Bridge Canyon, where the k2 unit cannot be carried, the Chinle-Moenkopi contact is sometimes difficult to pick.

k2 This key bed is a resistant, light reddish-brown to purplish red-brown, moderately resistant ledge-former or bench-former. The unit forms a prominent marker bed in the southwest part of the area, but cannot be carried with reliability northeast of Little Bridge Canyon. Although this key bed has not been identified east of the Colorado River, it may be correlative with the purplish white, moderately resistant unit in a similar stratigraphic position at Lockhart Basin (Sec. 36, T.28S., R.20E.).

TRc The Chinle Formation is a relatively non-resistant, red slope-former (Fig. 8) that appears uniform in color and texture on the space photography.

TRkw The Kayenta-Wingate unit is a very resistant, red-brown to brown, massive rim rock (Fig. 8). The bottom contact with the Chinle Formation is easy to see on the photography, but difficult to map accurately because of the near-vertical cliffs. The Kayenta-Wingate contact generally cannot be differentiated because the contact occurs on a near-vertical cliff face (Fig. 9), but where moderate dips occur, such as at Upheaval Dome, the contact can be picked easily.

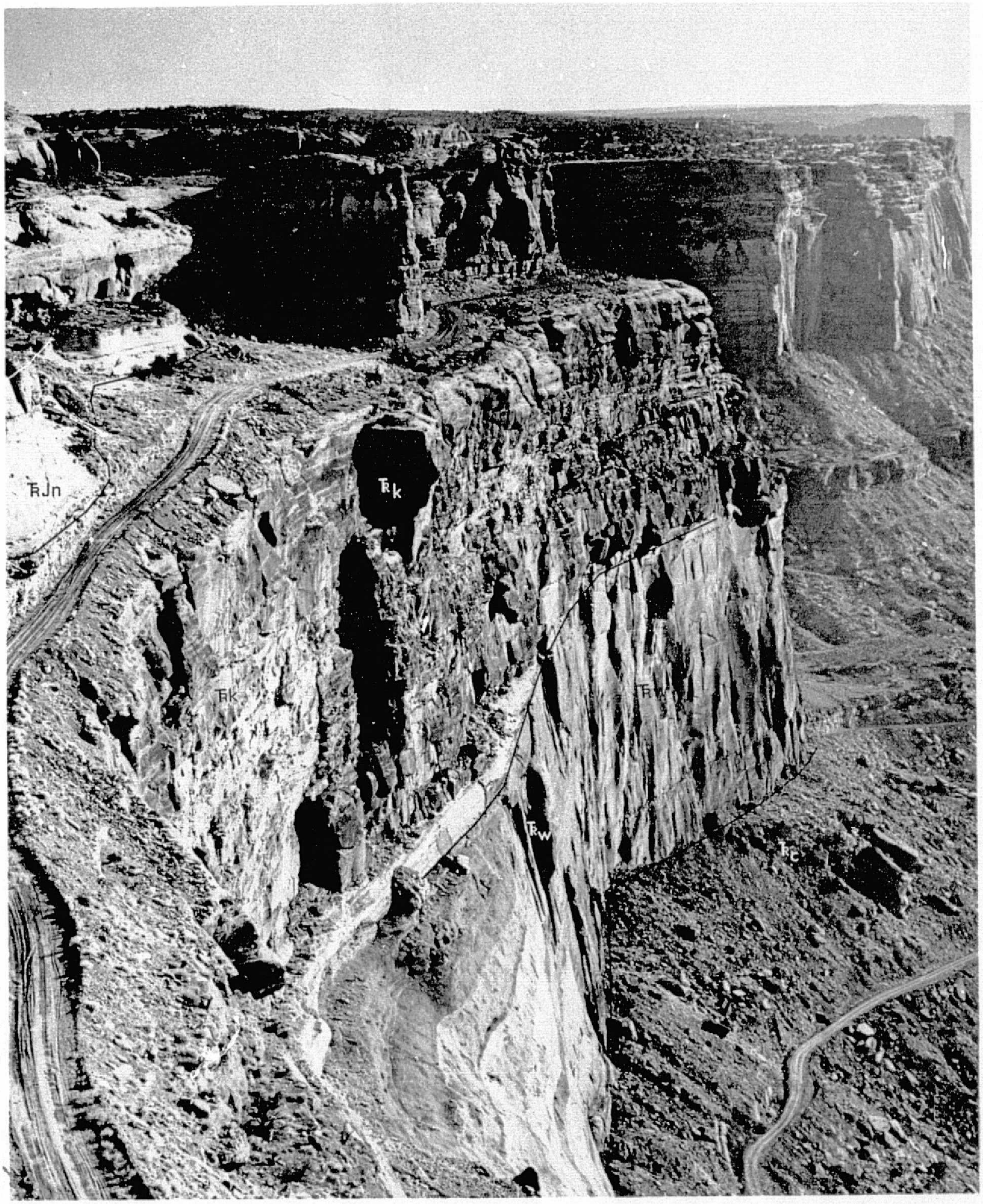


Figure 9. Upper Triassic stratigraphic section along Shafer Trail at the Neck (F.7/1.9 on Pl.5). c - Chinle Fm., w - Wingate Ss., k - Kayenta Fm., and n - Navajo Ss.

$\overline{R}J_n$ The Navajo Sandstone is a moderately resistant, tan to brown unit (Figs. 8 and 9). Although bedding can sometimes be seen, the unit generally appears massive. The Navajo is present only on the tops of the Canyonlands plateaus, and the bottom contact with the $\overline{R}_{kw}$ is often difficult to pick; both units are relatively resistant, and tone differences must be used.

Structure

A first-order structural approximation of the entire map area would be flat-lying, layer-cake geology. There are only three significant exceptions to this approximation: the Shafer Dome, the Lockhart Basin structures, and Upheaval Dome. The latter was recognized on the small-scale photography, but the former two represent new structural interpretations.

Shafer Dome This structure (centered on SE cor, Sec. 16, T.27S., R.20E., Pl.5) is clearly a positive structural element, although the exact nature and configuration of the structure is not obvious. It is called a dome because in the simplest sense dips are everywhere away from the center noted. Initial photointerpretation of the structure, however, suggested that the structure more closely resembled two superposed anticlines; one with a trend of approximately N40°E and the second with a N70°W trend. In fact, the northwest trending structure is so subtle that in its northwestern end it was originally interpreted as a monocline with a southwest flexure. The exact nature and shape of this structure is best observed by studying the outcrop distribution of P_{c1}. One area on the northern part of the structure (Sec. 16, T.27S., R.20E.) shows a fairly steep dip to the northwest on the top of the P_{c1} unit; all other dips off the flank of the structure were interpreted to be relatively gentle, probably less than 10°.

Lockhart Basin Structures Lockhart Basin (southeasternmost T.28S., R.20E.) was interpreted as a northwest-plunging syncline that abruptly changes northwestward into an anticline, with parallel and orthogonal normal faults. The synclinal fold is fairly well established by interpretation of attitudes on the Wingate-Chinle contact. Dips on the southwest flank of the structure are more gentle than the northeast flank. Although the nature of the fold is apparent, the actual location of the surface trace of the synclinal axis cannot be accurately located. The attitude of the bedding can be best estimated by observing the contact between the Chinle and the Moenkopi formations. Although the k2 keybed is not recognized in this area, the same stratigraphic position is occupied by a purplish-white unit previously described.

Four normal faults were originally interpreted in this area. Two of the faults trend northeast, normal to the fold axis, and define a small graben. The northwesternmost of these two faults (Sec. 25, T.28S., R.20E.) was interprete with confidence as a normal, down-to-the-east fault. Its northeastward extension on top of Hatch Point, and its southwestern extension on the southwest side of Lockhart Canyon, are questionable interpretations. A subparallel, down-to-the-northwest normal fault is interpreted with somewhat less confidence, as displacement appears to be minor and the fault is not as clear as the previously described one.

The small northwest-trending, down-to-the-northeast normal fault (Secs. 2, 2, T.29S., R.20E) cannot be interpreted with any reliability. The position of this fault is inferred only to account for a lack of clearly interpreted stratigraphy. A longer, northwest-trending, down-to-the southwest fault was originally interpreted northeast of the Kayenta-Wingate contact in Sec. 31, T.28S., R.21E. No surface evidence for this fault was seen at all, but the fault's location and existance were hypothesized to account for the topographically low Wingate Sandstone in the valley. An alternate explanation would be a fairly steep monoclinal flexure in the same position (later field observations suggest the latter interpretation).

<u>Upheaval Dome</u> This structure is one of the most obvious features on any of the Skylab photography in this area. The extreme contrast between very flat-lying strata and this

strongly folded structure make it stand out clearly to even the most casual observer. Upheaval Dome was interpreted correctly in the earlier small-scale study as a dome, and its position and outcrop pattern were fairly accurately mapped. Subsequent photointerpretation of the larger 1:125,000 scale photography, however, significantly reinterpreted the formations that occur in the core of the structure, and more detailed interpretation of their distribution more accurately delimits the domal structure and, for the first time, reveals clearly the presence of a secondary, peripheral rim syncline.

Both the central dome and the peripheral syncline are amazingly symmetrical circular features. This symmetry is well defined by the pattern of the Navajo-Kayenta contact (C.4/3.1, Pl. 5). The doming appears to be somewhat steeper on the south and southwest sides of the structure. The ring syncline is well developed on the north, northeast and southwest flanks, and flattens somewhat on the southeast side. Some concentric, down-to-the-center faulting was interpreted on the northwest side and along the synclinal axis on the southwest side of the structure.

The oldest formation exposed in the center of the dome was interpreted to be Moenkopi. This interpretation differs from that of the small-scale photography in which the core formation was interpreted to be the Paradox Member of the Hermosa Formation. The latter stratigraphic designation was an assumption based on inference from the salt anticlinal structures to the north; the reinterpretation of the central formation as being Moenkopi is based on more detailed photo-interpretation and delineation of stratigraphic units.

FIELD CHECKS

The accuracy and validity of the photointerpretation maps were checked in the field. Field observations consisted of examining areas characteristic of the geology of each map area, as well as investigation of areas where geologic interpretations were complex or where no geologic interpretation could be made from the photographs. Accessibility in this entire region is very poor, and a large percentage of field time was devoted simply to driving between points to be checked. Accessibility to some key areas was so poor that aircraft observations were required.

The amount of time spent field chec'ing the small-scale 1:250,000 geologic map is difficult to estimate accurately. Because of the nature of this study, considerable time was spent in southern portions of the Moab Quadrangle field checking early photogeologic interpretations of the training area. Additional field time was devoted to establishing photointerpretation keys by field observations in the Paradox-Sinbad Valley areas.

The subsidiary study areas, Moab North and Moab South, were areas in which no geologic observations were made prior to the field check subsequent to photointerpretation. Two days were spent field checking the area north of Moab; and two days were spent in the Moab South area.

DISCUSSION AND EVALUATION

The described research was conducted, and this report was written, so that the data products at this point in the research represent data products that would be obtained from an application of photointerpretation, using Skylab S190B photography, to areas that are geologically unknown or geologically poorly known. Continuous efforts were made throughout the research to help insure that the photointerpreter would not become biased by geologic information from sources other than the EREP photography.

The geologic maps shown as Plates 2, 4 and 5 represent geologic mapping by photointerpretation on Skylab S190B photographs, supplemented by minimal field checking. In general, the correlation between the photogeologic maps and the published geologic maps is excellent. Obviously this is a statement of judgement, and the accuracy or utility of this statement can be evaluated only by carefully comparing the maps (Pl. 2 with Pl. 3; Pl. 4 with Pl. 3; and Pl. 5 with Pls. 3, 6, and 7). It is suggested that the serious reader remove these plates and make a comparison of the geologic interpretations both before and during the discussion that follows.

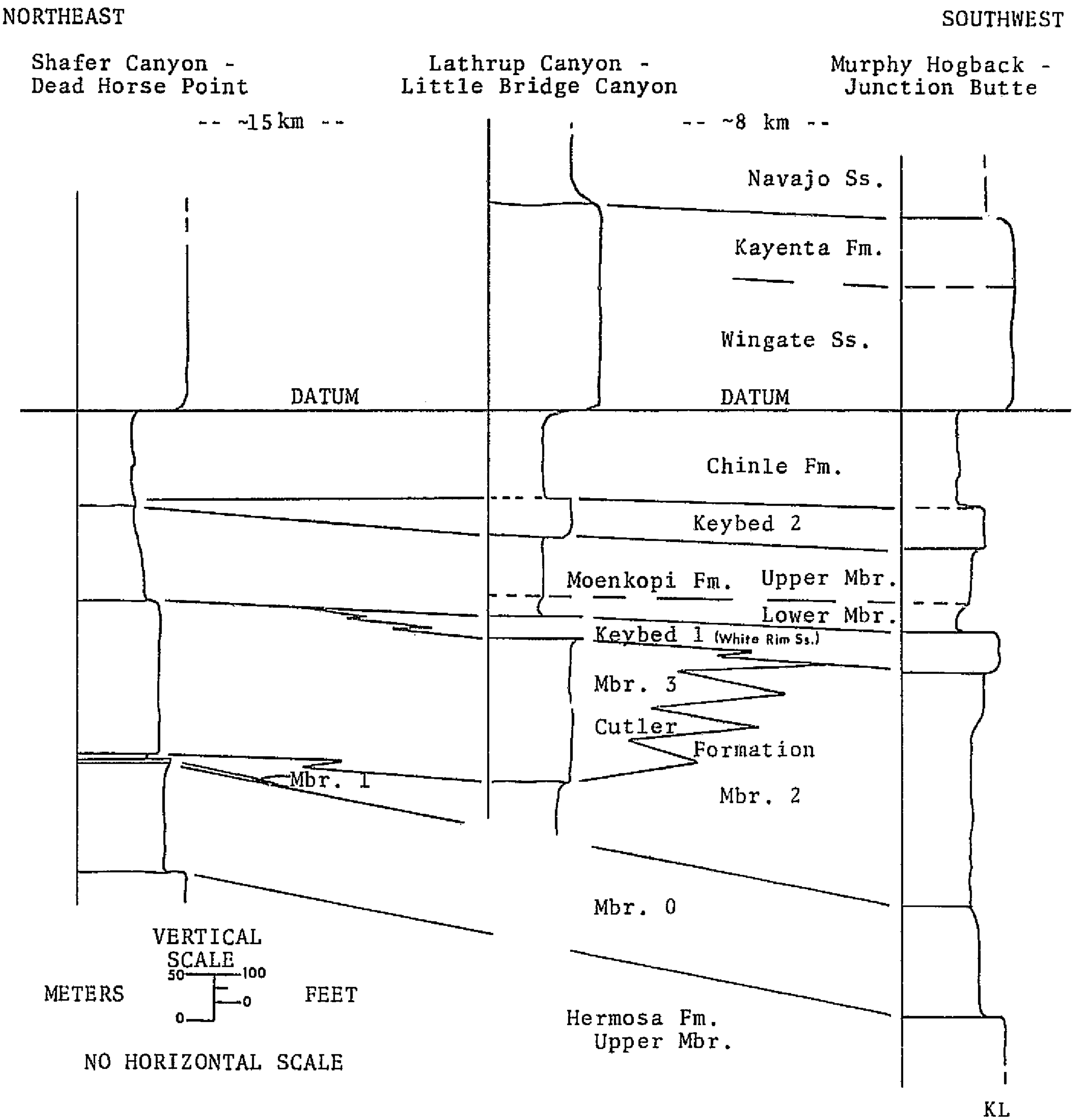
LITHOLOGY

The maximum amount of stratigraphic information derived from the EREP photographs was obtained in Moab south area. Surprisingly detailed stratigraphic information was available in this area. The following section describes the sedimentary units mapped in the area and compares them with published descriptions of the lithologic units.

The results of the stratigraphic subdivision in Moab South area are shown in Figure 9 (cf. Fig. 4). Even casual inspection of Figure 9 forcibly brings out one salient feature of this photointerpretation: not only can formations and members be interpreted from the EREP photographs, but stratigraphic lateral variations can be determined as well. The generalized stratigraphic sections and correlations illustrate variations from the southwestern part of the map area (Murphy Hogback (sic) - Junction Butte) through the central portion of the map area (Lathrop Canyon - Little Bridge Canyon) to the northeast (Shafer Canyon - Dead Horse Point).

Using the base of the Wingate Sandstone as a datum, Figure 9 clearly shows stratigraphic thickening toward the southwest. Almost all of this thickening can be accounted for by changes within the Permian Cutler Formation, but this relationship persists into the Triassic, as evidenced by the pinch-out/facies change of the Permian White Rim Sandstone and the Triassic keybed 2 in a northeasterly direction.

The ability to determine stratigraphic thicknesses is quite good. Obviously this capability stems from, and is



Fi: .e 10. Generalized stratigraphic sections and correlations based on photointerpretation of Skylab S190-B photographs, Moab South area, Utah.

dependent upon, the conjunctive use of accurate topographic base maps. As an illustration of thickness determination, consider the thickness of the stratigraphic section below the Wingate Sandstone and above the Hermosa Formation. In the Shafer Canyon-Dead Horse Point area, this thickness totals about 500 m (1650 ft), and the same section thickens to the southwest to about 670 m (2200 ft). Interpolation of measured stratigraphic sections by McKnight (1940) gives corresponding thicknesses of about 525 m (1720 ft), thickening to 730 m (2403 ft). Using McKnight's data as the true thicknesses, the thicknesses determined from photointerpretive studies are in error by about 4 percent and 8 percent respectively.

Hermosa Formation Upper Member

Outcrops of the Hermosa Formation were interpreted in the Shafer Dome area and in the southernmost part of the map area along the Colorado River. The Hermosa Formation is distinguished from the overlying Cutler Formation by its higher resistance and grey color compared to the red Cutler. The thickness of the Hermosa cannot be determined because the base is covered, but it is greater than about 50 m (160 ft).

Cutler Formation

The Cutler Formation in this area is quite complex, more so than any other stratigraphic unit in the area. Initial photointerpretation of the Cutler Formation subdivided the formation into three members, called simply Member 1, Member 2 and Member 3. Later photointerpretation in the Shafer Dome area broke out a lower unit which was then called Member 0, and the prominent keybed (k1) at the top of the Cutler Formation was subsequently identified as the White Rim Sandstone and included in the Cutler Formation. Thus, the Cutler Formation, as used here, consists of five members; Members 0 through 3 plus Keybed 1.

Member 0 - Published geologic maps suggest that Member 0 is the Pennsylvanian-Permian Rico Formation (Bates, 1955; Williams, 1964), but there is some doubt that this in fact is the Rico Formation. Its outcrop in this area is confined only to the canyon bottoms, precluding field checking of the unit, and hence the terminology Member 0 of the Cutler Formation is retained. Member 0 is differentiated from the underlying Hermosa by its red color and lower resistance, and it is differentiated from the overlying Member 1 by the same criteria. Thickness of Member 0 is estimated at about 120 m (400 ft). This compares with an estimate of 177 m (580 ft) by McKnight (1940), but McKnight included in the Rico Formation what is here designated as Member 1 and part of what is here designated as Member 2.

Member 1 - Member 1 is a very resistant, grey, carbonate unit among the Cutler redbeds. Although the unit is only about 3 m (10 ft) thick, because of its resistance it forms benches and ledges such that the member is exposed over fairly wide areas (for example, see Sec. 10, T.27S., R.20E., Pl. 5). Field examination shows this unit to be a somewhat rubbly, brachiopodal crinoidal lime wackestone. Baars (1975) makes a strong case for calling this unit a part of the Elephant Canyon Formation.

Member 2 - Much of the complexity of the Cutler Formation hinges upon the relationship between Member 2 and Member 3. The interpretation derived from this study suggests that Member 2 is very thin in the north part of the area, approximately 12 m (40 ft) thick in the Shafer Dome area where it underlies Member 3, and thickens to about 260 m (850 ft) in the south. It cannot be shown conclusively that this is one continuous unit, however. Member 2 is characterized by a pink to red to red-brown color and relative non-resistance to erosion.

Member 3 - Member 3 is differentiated from Member 2 by having a darker red to a maroon color and by being relatively more resistant. The relationship between Member 3 and Member 2 is not entirely clear; this photointerpretation suggests that the two members are at least in part facies equivalents (Fig. 9). Where the two members are recognized at one location, Member 3 is above Member 2.

Member 2 appears to correspond to the Cedar Mesa Sandstone Member of Williams (1964) and Baars (1975) and to a transition zone where the Cedar Mesa Sandstone Member interfingers with an unnamed arkose and arkose conglomerate. Member 3 appears to correspond well with Williams' unnamed arkose and arkosic conglomerate and Baars' "Cutler arkosic red beds from the east". The upper dark red part of Member 3 may be part of the Organ Rock Tongue. It is interesting to note that geologic mapping at a scale of 1:62,500 (McKnight, 1940) apparently was unable to subdivide the Cutler Formation effectively. The combined thickness of Members 2 and 3 in the north part of the area is interpreted at about 165 m (550 ft), compared with a measured thickness by McKnight of about 150 m (500 ft). The same stratigraphic interval thickens to the south to an estimated 260 m (850 ft) that compares well with McKnight's measurement of 251 m (823 ft).

Keybed 1 - Keybed 1 is an excellent marker bed throughout its area of outcrop. It forms a prominent and conspicuous white ledge that stands out sharply against the red-brown colors of the units beneath and above it. This member is relatively thin, yet forms extensive areas of outcrop because of its high resistance to erosion (for example, see outcrops of this member in Monument Basin - F.4/8.4, Pl. 5 and Fig. 6).

Keybed 1 is the White Rim Sandstone that is considered by most authors to be the uppermost member of the Cutler Formation. The sandstone was estimated to be about 45 m (150 ft) thick in the southwest part of the map area, which does not compare well with McKnight's measurement of about 17 m (55 ft), but agrees well with Baars (1975) isopach thickness of 30-45 m. This discrepency probably is due to the difficulty in picking a bottom contact on the vertical cliff exposures of this sandstone. The White Rim Sandstone thins continuously toward the northeast, where it goes to zero thickness at Shafer Canyon (Sec. 7, T.27S., R.20E.).

It is significant to note that the point of pinchout of this member could not be more accurately determined from observations in the field than it was determined from interpretation of the S190B photographs. It is obvious that the nature of the pinchout could not be interpreted from the photographs. McKnight (1940) states that the White Rim Sandstone disappears to the northeast by lateral gradation into the basal two or three meters of the upper brown member of the Cutler Formation (McKnight considered the unit directly above the White Rim Sandstone Member as part of the Cutler Formation, even though he mapped this unit as part of the Moenkopi Formation).

Moenkopi Formation

The Moenkopi Formation consists of about 90 m (300 ft) of brown and reddish-brown siltstones and relatively non-resistant sandstones. The formation is differentiated from the underlying Cutler Formation with ease where the White Rim Sandstone Member is present and with difficulty where this unit is missing. In the southern part of the map area, the Moenkopi Formation can be subdivided into two members, a relatively non-resistant, thin lower member and a more resistant, thicker upper member. This subdivision becomes unworkable north of Little Bridge Canyon. An estimated thickness of 90 m for the Moenkopi Formation compares well with measured sections by McKnight (1940) of 87 to 114 m (285 to 375 ft).

Chinle Formation

Keybed 2 - The lowermost part of the Chinle Formation can be mapped separately in the southern part of the area. In this area, the keybed is a light red-brown to purple red-brown ledge-former or bench-former. The keybed cannot be carried north and east of Little Bridge Canyon, although it may be correlative with the purplish-white, moderately resistant unit at the base of the Chinle Formation in the Lockhart Basin (Sec. 36, T.28S., R.20E., Pl. 5). Although the keybed cannot be carried on the photographs through the northern part of the map area, field observations suggest that it is present, although considerably thinner. This keybed corresponds to what was originally called the Shinarump Conglomerate (McKnight, 1940; Bates, 1955; Detterman, 1955), although later workers (Lowman, 1974; Stewart and others, 1972; O'Sullivan and MacLachlan, 1975) have designated this unit as the Mossback Member of the Chinle Formation.

Above the Shinarump/Mossback keybed, the Chinle Formation consists of red-brown, relatively non-resistant siltstones and shales. Thickness of the Chinle Formation above Keybed 2 was estimated at 105 to 130 m (350 to 420 ft). This compares well with McKnight's estimate of "about 400 [122 m] feet".

Post-Chinle Stratigraphy

Stratigraphic units younger than the Chinle Formation generally can be recognized and mapped without difficulty. Because the purpose of this report is only to demonstrate the level of geologic detail available in the Skylab S190B photos, a continued description of stratigraphy is not warranted. Reference to the stratigraphic subdivisions contained in the Explanation of Plate 4 or Plate 5, plus continued comparisons of these plates with published geologic maps and literature (e.g., Craig and Shaw, 1975) will provide sufficient information on the younger units.

In areas where bedrock is fairly well exposed, and where structural complexities are not greater than the resolution of the photography, there are few significant differences between the interpreted geology and the published geology. A few notable differences do exist, however, and these warrant some discussion.

In the Dome Plateau area (Sec. 6, T.24S., R.23E., Pl. 4), the southeastward extent of the Navajo Sandstone goes considerably farther on the photogeologic map. It was not possible to field check this area, so a resolution of the apparent conflict is not possible. An earlier geologic map, however, at a scale of 1:62,500 (Dane, 1935) shows the Navajo Sandstone extending approximately as far southeast as the photogeologic map does.

In the highlands area (for example, sec. 12, T.23S., R.22E., Pl. 4), a very wide outcrop of Summerville Formation is mapped between exposures of the Entrada and Morrison formations. Although the 1:250,000 published geologic map (Pl. 3) does not subdivide the Entrada from the Summerville Formation, the more detailed geologic map of Dane (1935) does subdivide these formations and shows a very narrow Summerville outcrop and a very broad outcrop of the underlying Entrada Sandstone. A field check was made in this area to attempt to resolve the apparent conflict; ground observations show that the area in question is totally covered by a veneer of eolian deposits. Although the eolian cover precludes resolving the question, the actual difference in interpretation is only a matter of a few feet in the vertical stratigraphic sense.

STRUCTURES

As an illustration of the level of detail of structural interpretation possible with the S190B photographs, the following discussion will be keyed to the area north and west of Moab, Utah.

Folds

Interpretation of the major folds of this area on the S190B photographs is excellent. A comparison of Plates 2 and 4 with the published geologic maps (Pl. 3, Sheet 2) shows this correlation clearly. In the area covered by Plate 4 there are three first-order anticlinal trends: the Moab-Spanish Valley Anticline, the Castle Valley Anticline, and the Salt Valley-Cache Valley-Fisher Valley Anticline. The Moab-Spanish Valley Anticline is separated from the Salt Valley Anticline and the Castle Valley Anticline by the prominent Courthouse Syncline. The Castle Valley Anticline is separated from the Fisher Valley Anticline by a very gentle syncline whose axis is shown at Adobe Mesa (Sec. 12, T.25S., R.23E., Pl. 4). This syncline is not named on the published structure map (Pl. 3, Sheet 2), although the structure contour map clearly show its location slightly northeast of Adobe Mesa.

Several second-order folds are also capable of being interpreted on the photography. Two of these, in the northern part of the map area, are broad open folds, trending northwest, parallel to the Sagers Wash Syncline shown on Plate 3, Sheet 2. Although the published map does not name nor show structural axes of these folds, the structure contours accurately delineate the folds. The anticlinal fold in this area (T.23S., R.22E., Pl. 4) is called the Yellow Cat Dome on the published geologic map (T.23S., R.22E., Pl. 3, Sheet 2), even though the structure contour map shows a definite elongation in a northwest-southeast direction. In fact, an argument could be made for connecting this anticline with the Fisher Valley Anticline to the southeast.

Several second-order folds are located beside and parallel to the major anticlines. Some of these, such as the Dry Mesa Syncline (Secs. 19-22, T.24S., R.22E., Pl. 4) may be a result of the tectonism responsible for the main anticlinal salt structures. Several of the second-order folds, however, appear to be the result of subsequent collapse of the salt anticlines, and appear as drag folds on the distal parts of the anticlines. Examples of this are the Moab Anticline (Secs. 17, 18, 21, T.25S., R.21E., Pl. 4; Pl. 3, Sheet 2), and the Delicate Arch Anticline (Secs. 2-6, 12, T.24S., R.22E., Pl. 4; Pl. 3, Sheet 2).

One small monocline is mapped in the Castle Valley area (Sec. 36, T.24S., R.22E., Pl. 4), but this small fold was observed in the field and was not recognized on the space photography.

Fractures

All of the major first-order faults in the area were defined on the space photography. In general, these faults correspond extremely well with mapped faults, although many of the complexities of the secondary, small faults were not interpretable on the EREP photography.

The Salt Valley-Cache Valley Anticline (T.22S., R.19E. to T.24S., R.22E., Pl. 4) shows a central collapsed portion bounded by normal down-toward-the-axis faults. This structural configuration is clearly shown on the S190B photographs, although due to the close spacing of the faults, many individual faults are not resolved.

A fault was mapped in Cache Valley (NW¼ SE¼, Sec. 9, T.24S., R.22E., Pl. 4) to account for the juxtaposition of the Morrison Formation with the Mancos Formation. This fault does not appear on the published geologic maps, where a normal stratigraphic succession is shown. Interpretation of the fault obviously stems from the inability to recognize the Dakota-Burro Canyon Formation in this area (early mapping in this area (Dane, 1935) did not breakout the Burro Canyon Formation, but included it in the Morrison Formation).

The Professor Creek Graben (Secs. 19-24, T.24S., R.23E., Pl. 4) forms a structural connection between the collapsed portion of the Cache Valley Anticline and the western end of the Fisher Valley Anticline (T.24S., R.23E., Pl. 3). Although the graben as shown does not conflict with the interpretation shown in the published geologic maps, the faulting shown is more extensive and through-going. With the time spent in the field it was not possible to resolve the interpretation of this structure, so the graben is shown with questionable status. It may be that the collapse structures from Cache Valley to Fisher Valley are more accurately seen on the space photography than they are in the field.

SUMMARY

Optimum scale for regional geologic mapping by photointerpretation of Skylab S190B photographs is about 1:62,500. This conclusion, however, may be valid only for this particular study area. Initial study of Skylab photography suggested that photointerpretation at a scale of 1:24,000 was not feasible, and photointerpretation of a large area (Moab Quadrangle) has shown that 1:250,000 is too small a scale.

Significantly more geologic information can be extracted from the Skylab photographs when the photographs are used at an enlarged scale. This increase in geologic information does not come from the larger scale per se, because critical interpretations were always made with the original contact-scale photographs using a zoom stereoscope; the increase in information stems from the attempt and the necessity to force geologic information to match the scale both of the photographic enlargement used for annotation and the topographic base map used for final compilation.

In contrast with the above, however, an increase in geologic information is associated with increase in scale when comparing the S190A and S190B photography. System resolution is approximately the same for each camera, but ground resolution of the S190B is superior because of its longer focal length and correspondingly greater scale. There

is little doubt that an increase in resolution can be directly translated into an increase in geologic information.

All of the stratigraphic units at formation rank and above that were defined in the training area were mapped into the unknown test area. In some cases, individual formations were mapped together, but this was done because their contacts were not resolvable at the map scales due to their exposure on cliff faces.

In many cases, stratigraphic units at ranks below formation level could be established in the test area. Half of the formations that were carried from the training area into the test area were ultimately capable of being subdivided. As a result, the test area was mapped to a large extent at member level; seventeen members were mapped in the test area.

Not only can vertical variations in the lithology be interpreted, as evidenced by subdividing rock units into formations and members, but some lateral variations can be interpreted as well. The Navajo Sandstone, present throughout most of the map area, is shown to pinch out to the northeast. Several members of the Cutler Formation are shown to have limited areal distribution; the uppermost member pinches out entirely to the northeast, and Member 2 and Member 3 appear to be lateral facies equivalents, at least in part.

The area southwest of the Moab Valley is characterized by flat-lying to very gently dipping beds with a few local domes and normal faults. The area north and east of Moab Valley is characterized by a series of parallel, northwest trending anticlines that show extensive axial collapse structures.

All of the major structures in the study area were recognized on the EREP photographs. In several of the collapsed areas, numerous secondary normal faults were recognized on the S190B photos. Subsequent field checking showed that many of the main boundary faults are actually small en echelon fault systems.

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