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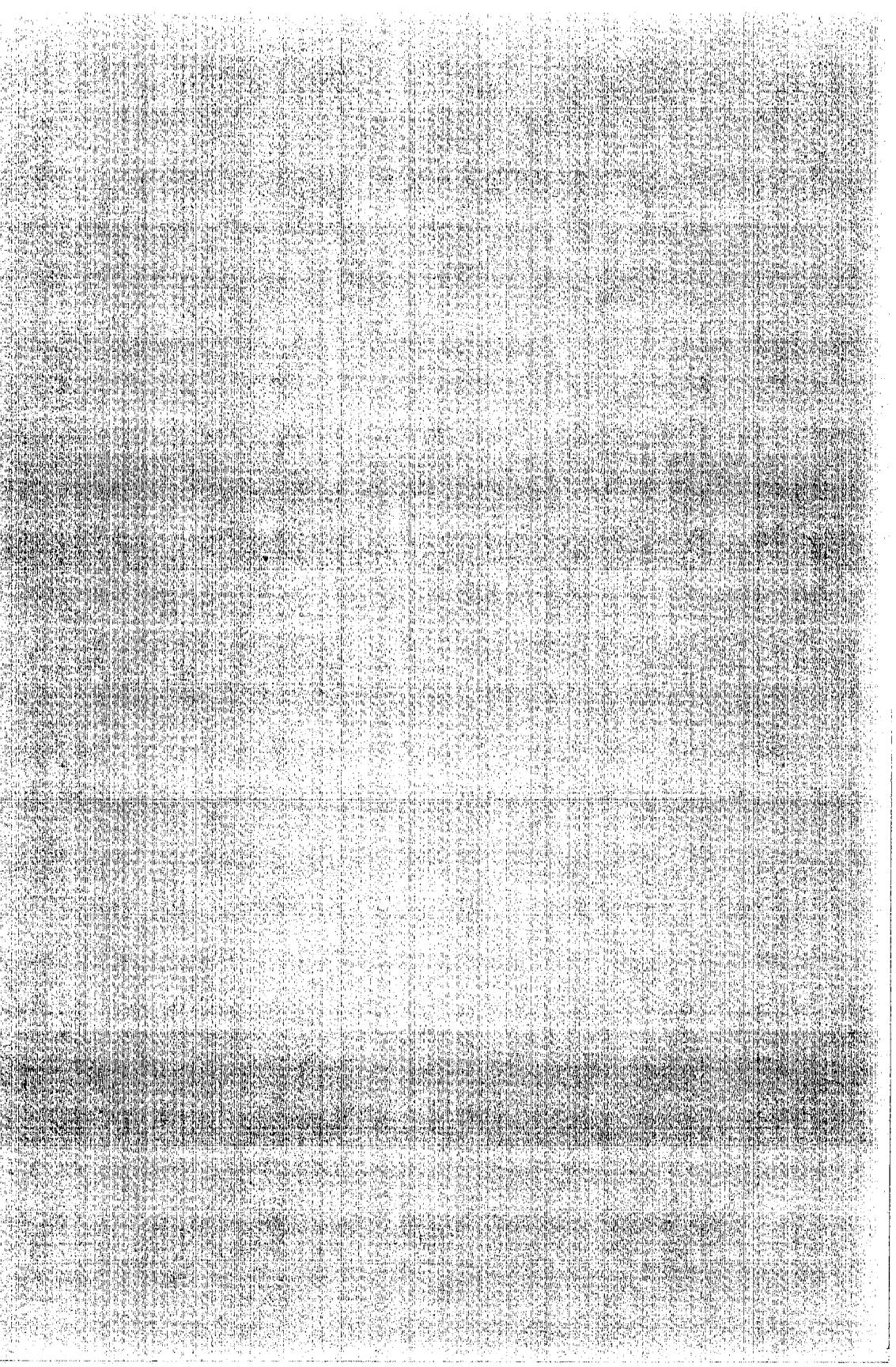
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CONTENTS

The Nature and Development of the Esplanade in the Grand Canyon, Arizona	William L. Chesser	3
Paragenesis and Mineralogy of the Burgin Mine, East Tintic District, Utah County, Utah	Robert F. Mahfoud	49
Mineralogy and Trace Element Study of the Manganese Oxide Deposits in the Burgin Mine, East Tintic Mining District, Utah County, Utah	Samuel M. Smith	105
Rapid Analysis of Basalts by Atomic Absorption Spectrophotometry	Willis H. Brimhall and Glenn F. Embree	123
The Permian-Triassic Unconformity and Its Relationship to the Moenkopi, Kaibab, and White Rim formations in and near the San Rafael Swell, Utah	Jeffrey R. Orgill	131
Publications and maps of the Geology Department		180



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The Permian-Triassic Unconformity and Its Relationship to the Moenkopi, Kaibab, and White Rim Formations in and near the San Rafael Swell, Utah*

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ABSTRACT.—The Permian-Triassic boundary in and near the San Rafael Swell is a disconformity representing a hiatus from lower upper Permian to lower Triassic. The disconformity is characterized by (1) moderate channeling which was observed to cut as deep as fifteen feet into the underlying Permian formations; (2) the presence of a paleosol which exhibits bedded chert derived from either the weathering of Kaibab carbonates or volcanic debris; and (3) a basal Moenkopi unit composed of coarse clastic debris derived from weathered Permian strata. The basal unit of the Moenkopi varies from a chert-pebble conglomerate to a coarse-grained sandstone, in response to its proximity to either the chert-bearing Kaibab Formation or the White Rim Sandstone.

The White Rim Sandstone is characterized by a series of north-south trending topographic irregularities. Kaibab deposition upon this surface resulted in a time transgressive unconformity marked by sands which were shed from White Rim positive areas into the flanking Kaibab sediments. Some of the White Rim highs probably remained above the limits of Kaibab deposition and acted as source areas for the sandy units within the Moenkopi Formation. The concordance of the Moenkopi and Kaibab thicks and thins also suggests that the Moenkopi Formation was deposited on a topography inherited from the White Rim Sandstone.

Possible future petroleum prospects include (1) the projection of White Rim "bar" trends into the subsurface; (2) the possible occurrence of algal bioherms in the Hermosa Formation on the flanks of the Emery Uplift; and (3) the occurrence of stratigraphic traps associated with the pinchouts of White Rim derived sands in the lower member of the Moenkopi Formation.

CONTENTS

Text	page	2. Tectonic map	135
Introduction	132	3. Isopach map of the	
Acknowledgments	133	Kaibab Formation	137
Methods	134	4. Isopach map of the lower	
Regional Tectonic Setting	135	member of the Moenkopi	
Stratigraphy-General	136	Formation	138
Permian System	139	5. Diagrammatic sketch of road	
White Rim Sandstone	139	cut along Interstate 70	152
Pre-Kaibab Unconformity	146	5a. Legend of lithologic symbols ..	153
Kaibab Formation	147	6. Cross section from west	
Triassic System	150	to east across the San	
Moenkopi Formation	150	Rafael Swell	154
Permian-Triassic Boundry	156	7. Generalized geologic history	
Oil and Gas Possibilities	161	of the study interval in and	
Summary	162	near the San Rafael Swell	163
Appendix A. Detailed Description			
of Measured Sections	165		
Appendix B. Subsurface Data	176		
References Cited	177		
		Plates	page
		1. Photomicrographs and internal	
		structure of the White Rim	
		Sandstone	140
		2. Bioturbation of the White	
		Rim Sandstone	142

ILLUSTRATIONS

Text-figures	page
1. Index map	132

*A thesis submitted to the faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science.

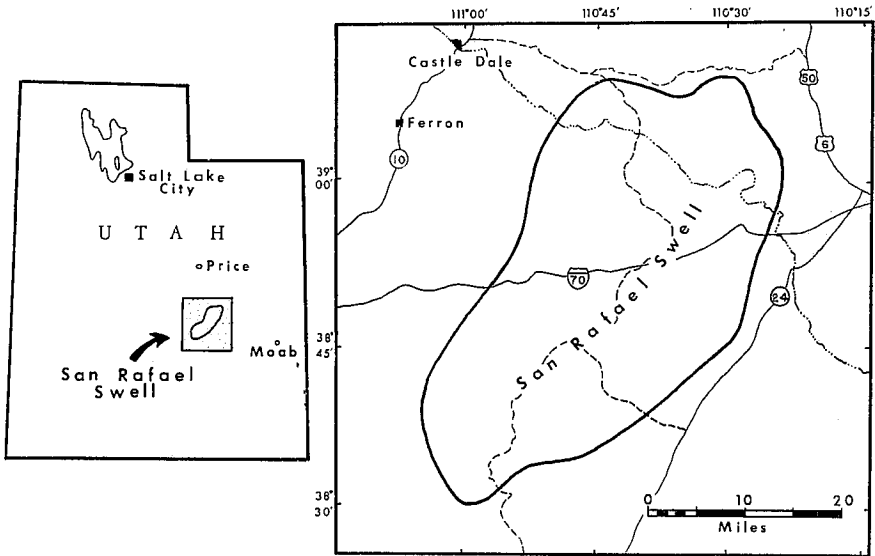
<p>3. Topographic relief on the White Rim Sandstone and the gradational contact between it and the Kaibab Formation 144</p>	<p>4. Moenkopi Formation— general 151</p> <p>5. Moenkopi Formation— basal conglomerate 159</p>
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INTRODUCTION

The San Rafael Swell forms the core of a Laramide structure set in the Colorado Plateau of east central Utah (Text-fig. 1). It is a northeast trending, doubly plunging, asymmetrical anticline with a nearly vertical eastern limb, which passes rapidly eastward into horizontal beds. The San Rafael Swell has been extensively breached, with more than a thousand feet of Cretaceous and older rocks stripped away to expose Permian rocks of the Kaibab and White Rim Formations throughout the core of the structure. Local exposures of even older rocks outcrop in some of the deeper canyons on the eastern flank. Hallgarth (1962, p. 1495) reports measuring 100 feet of the Hermosa (?) Formation (Pennsylvanian?) in Straight Wash Canyon.

Epeirogenic uplift throughout the plateau at or near the close of the Permian resulted in minor regional deformation and extensive erosion which is now expressed as a Permian-Triassic unconformity. This erosional surface forms a disconformity marking a hiatus ranging from lower upper Permian rocks of the Kaibab Formation to Lower Triassic rocks of the Moenkopi Formation (McKee, 1954a, p. 33, 34). It is characterized by local channeling, variations in the thickness of the Kaibab Formation, and a well-developed basal chert-pebble conglomerate in the overlying Triassic Moenkopi Formation.

Previous workers have mentioned the nature of the unconformity in local areas, but there are few well-documented regional studies. Gilluly (1929, p. 81, 82) provides one of the best studies of the unconformity in the San Rafael Swell. He cites the irregular upper surface of the Kaibab, the regional



TEXT-FIGURE 1.—Index map showing location of study area.

disappearance and reappearance of the Kaibab, and the nature of the basal Moenkopi conglomerate as evidences of the unconformity, but he makes no attempt to interpret it. Numerous other individuals have mentioned the unconformity in the San Rafael Swell as a part of their stratigraphic studies, but again none has made any detailed study of the surface (Baker, 1946; Stewart and Smith, 1954; Herman and Sharps, 1956; Hallgarth, 1962; Hawley et al., 1968).

Regional studies of the Permian-Triassic unconformity are few and widely scattered over the Colorado Plateau and adjacent basin and range provinces. Dake (1920) probably provides us with the first attempt to delimit the extent of the unconformity in the Colorado Plateau area. He summarized existing data but dealt mostly with the missing strata in local areas rather than with the nature of the surface itself. Longwell (1925, p. 106) suggested that the hill and valley topography and channeling along the unconformity in the eastern Basin and Range were the result of widespread rapid flooding of a subaerially eroded surface. Dane (1935, p. 52-53) proposed that farther to the east, in a portion of the Salt Anticline region of the Paradox Basin, the "smooth contact seemed to indicate marine planation rather than subaerial channeling." He also proposed that coastal-plain peneplanation during Lower Triassic transgression on a previously reduced surface may account for the nature of the surface. McKee (1938, p. 54-61) provides much additional data from various localities throughout the Colorado Plateau; and he basically agrees with Longwell's conclusions. A more recent paper by McKee (1954, p. 36) suggests that variations in the nature of the contact from north to south and from west to east may be due to the lag in initiation of Moenkopi deposition caused by a southeastward transgressing sea.

McKnight (1940, p. 58), in his paper dealing with the Monument Upwarp area, documents the angular nature of the unconformity along the Moab Fault Zone where Hermosa beds form a four degree angle with the overlying Moenkopi Formation. In his tectonic summary of the Four Corners area, Kelley (1955, p. 114) indicates that the unconformity represents a period of stability in the Plateau Province during which extensive bevelling removed much of the Permian record. Baars (1962, p. 209, 210) believes that the disconformable nature of the unconformity is indicative of mild epeirogenic warping during Late Permian. However, Newell (1967, p. 357-365) implies that the low relief and lack of observed karst topography on the "paraconformity" represent a "long protected stillstand of relative sea level adjacent to very low land surfaces." Repenning et al. (1969, p. 6, 7) indicate that progressively less time is represented by Triassic rocks from east to west in the Navajo Country of the Four Corners area, indicating a westward transgression in this area.

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Drs. Harold J. Bissell and Morris S. Petersen served as committee members and provided counsel and helpful criticism of the manuscript. Dr. J. Keith Rigby gave freely of his time in advising the writer on the preparation of illustrations. For the unselfish donation of their time, and for their helpful suggestions, the writer wishes to express his sincere gratitude.

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Special appreciation and gratitude are offered to my wife, Nanette, for typing, field and laboratory assistance, and for her never-ending loyalty and patience.

METHODS

Eleven surface sections were measured and described at strategic localities throughout the San Rafael Swell (Text-fig. 3). The sections were measured from a suitable distance below the unconformity through the lower member of the Moenkopi Formation to the base of the Sinbad Member of the Moenkopi Formation. The sections were described and systematically collected at five-foot intervals and at major lithologic breaks (Appendix A). Particular care in sampling was taken through the unconformity and the basal unit of the Moenkopi Formation to provide sufficient data necessary to make inferences concerning the nature and mode of formation of the unconformable surface. Data was also derived from forty-two wells scattered throughout the Swell and adjacent areas (Text-fig. 3). This data was interpreted to support and add to the overall interpretation of the unconformity and the bounding formations.

A petrographic review of samples collected along the measured sections was made to provide further information concerning the composition and textural relationships of the rocks. This information was then plotted along with the field data on charts containing a diagrammatic weathering section of the field relationships in order to provide a base for comparison of the sections.

Fossils were collected along the measured sections. Although numerous fossiliferous beds were encountered, the generally poor state of preservation prevented identification in most cases. However, cross sections of shell debris in the rocks did lend themselves to breakdown according to phyla and aided in interpreting the marine or nonmarine nature of the depositional environment. Further attempts to obtain fossil information pertinent to determining the duration of the hiatus led to a search for microfossils. Conodonts and conodont fragments were disaggregated from critical limestone and dolomite samples by dissolving coarsely crushed samples in a 10 percent acetic acid solution. Heavy liquid (tetrabromoethane) separations were then run on the residues to concentrate the conodonts in order to facilitate picking. The conodonts were identified by comparison with figured specimens in pertinent works by Clark and Ethington (1962), Muller (1956), Clark (1959), and Mosher (1968).

The base of the Sinbad Member was used as a marker horizon on which measured sections and well data were correlated in an endeavor to reconstruct the paleogeography. This was accomplished by assuming that the Sinbad represented a sedimentation unit that was deposited during a relatively short period of geologic time as a uniform blanket over the entire study area. The thickness of the underlying Lower Moenkopi Member was then isopached in the belief that any fluctuations in the thickness of the lower member would reflect the topography over which it was deposited.

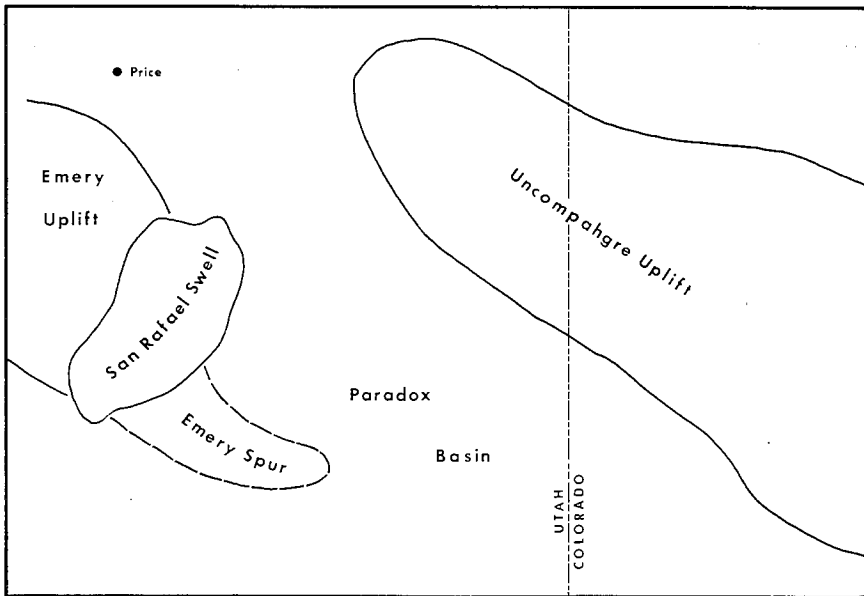
An isopach map of the Kaibab Formation was made from data obtained from measured sections and available well log information. This map was then compared with the isopach of the lower Moenkopi Member to indicate the nature of Permian and Triassic sedimentation.

REGIONAL TECTONIC SETTING

The Colorado Plateau is considered a relatively stable area set between two more tectonically active provinces, the Rocky Mountains on the east and the Basin and Range on the west. Despite its reputation, the Colorado Plateau has been subjected to numerous periods of deformation ranging in intensity from slight epeirogenic warping to moderately intense orogenic folding.

Tectonic deformation of the Plateau began in Pennsylvanian time and continued intermittently through the Mesozoic and much of the Tertiary. Pennsylvanian tectonism was widespread and resulted in a series of positive features collectively termed the Ancestral Rockies. Two of the features, the ancestral Uncompahgre and Emery uplifts, are of primary interest in this study, and their tectonic history will be briefly considered (Text-fig. 2).

The ancestral Uncompahgre Uplift is an asymmetrical anticline located north and east of the study area in Utah and Colorado. This structure along with its southern extension, the San Juan Uplift, dominated the Pennsylvanian and Permian periods from their inception in Des Moines time through their temporary culmination sometime in Middle to Late Permian. Kelley (1955, p. 112) envisioned a landmass whose southern side may have attained 10,000



TEXT-FIGURE 2.—Tectonic map modified after Fetzner (1960, p. 1374, 1375) showing the relation between and location of various tectonic structures of the Colorado Plateau.

feet of tectonic relief by the end of Permian deposition. This raising landmass provided many thousands of feet of Pennsylvanian and Permian sediments in the form of deltic wedges which transgressed debris southwestward into the adjacent foredeep (Paradox Basin). Reworking of this detritus by marine currents spread fine-grained and more mature clastic debris farther to the southwest into the vicinity of the present-day San Rafael Desert.

By early Triassic, the Colorado Plateau had attained relative stability and had undergone extensive erosion to produce a vast plain on which Lower Triassic rocks were deposited in a variety of shallow, marginal marine, and continental environments. Kelley (1955, p. 114) believes that there may have been a slight rejuvenation of ancestral Uncompahgre Uplift as early as Middle Triassic, but he documents a more intense monoclinical flexing of the southern limb during the later part of the period.

The Jurassic Period once again marked an interval of relative stability. Kelley (1955, p. 114) cites the presence of Late Jurassic rocks overlapping much of the ancestral Uncompahgre as evidence for this period of stability and resulting planation. Laramide tectonism marked a renewed uplift of the Uncompahgre in either Late Jurassic or Early Cretaceous.

The Laramide Orogeny affected most of the Colorado Plateau. It is evidenced by many anticlinal structures, including the San Rafael Swell, and by numerous structural basins. The effects of the Laramide were continuous well into the Tertiary, and Kelley (1955, p. 116) believes that basin subsidence "continued at least until the Late Eocene."

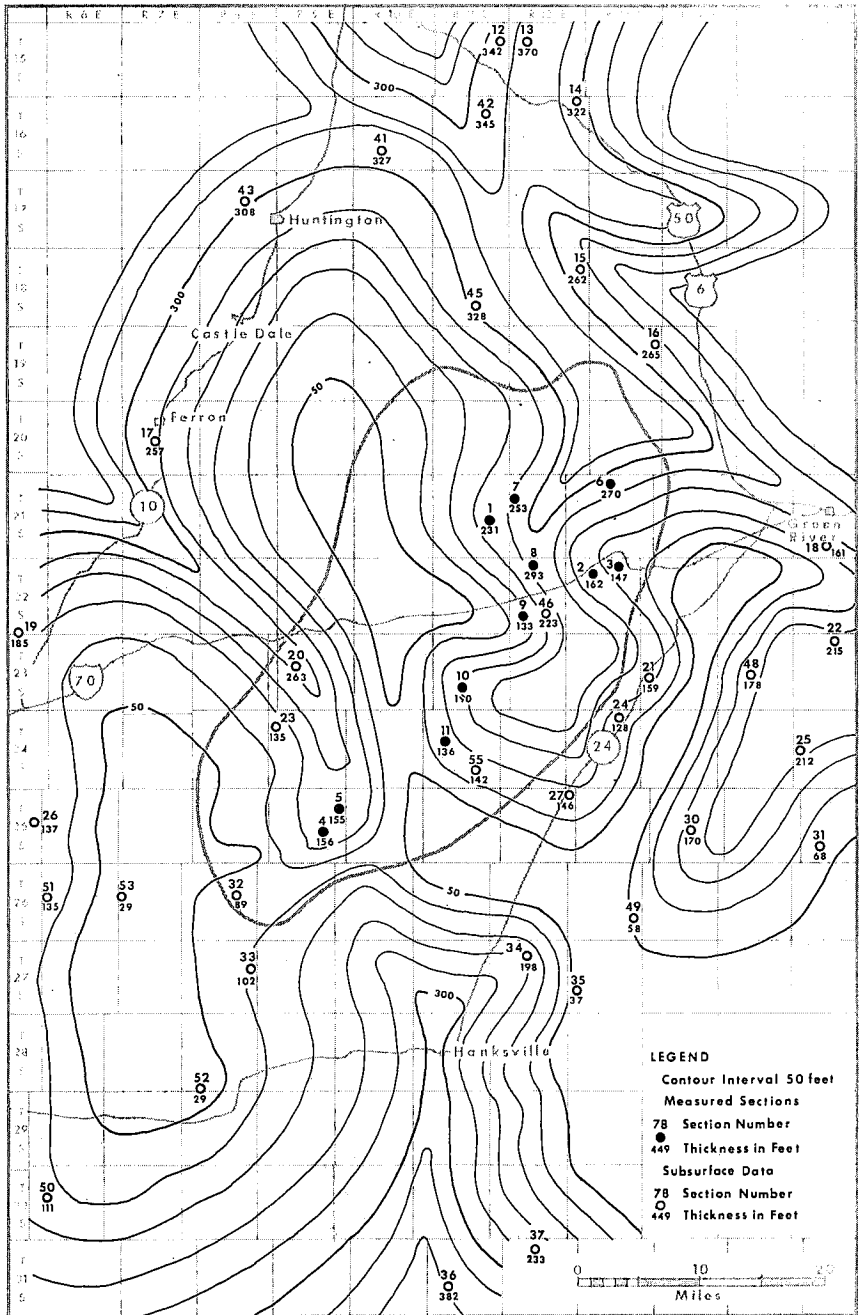
The Emery Uplift is another of the ancestral structures which directly affected the study area (Text-fig. 2). It lies mainly to the west of the San Rafael Swell; but Fetzner (1960, p. 1374-1375) portrays a structure with a southeasterly projecting spur which passes beneath and beyond the present swell area. Herman and Sharps (1956, p. 79) consider the Emery Uplift to have been tectonically active from early Des Moines through most of Virgil time, but Fetzner (1960, p. 1391-1393) believes that it remained active into early Permian time. Despite this controversy, most authors agree that the Emery Uplift never attained great vertical relief, and some believe that it never broke the surface of Pennsylvanian seas.

The Colorado Plateau was subjected to extensive subaerial erosion following the active period of the Emery Uplift. Baars (1962, p. 161) states "most of southeastern Utah and adjoining areas were subjected to Late Pennsylvanian or earliest Permian erosion related to intensive bevelling of the Emery Uplift." He also pointed out that this extensive bevelling produced a widespread unconformity which is expressed locally in the San Rafael Swell and Cataract Canyon areas by Wolfcampian sediments resting on Mississippian rocks.

STRATIGRAPHY-GENERAL

Strata exposed in the San Rafael Swell constitute a well-defined stratigraphic section ranging from Pennsylvanian rocks of the Hermosa Formation (Hallgarth, 1962, p. 1495) through Upper Jurassic rocks of the Morrison Formation (Hawley et al., 1968, p. 27). Erosion of the core has produced a rolling topography underlain and partially formed by Permian and Triassic strata throughout the broad domal interior of the structure.

Exposures in the central and western portions of the elongate core are dominated by outcrops of the White Rim Sandstone of Permian age. The



TEXT-FIGURE 4.—Isopach map of the lower member of the Moenkopi Formation.

overlying Kaibab Formation, also of Permian age, is absent in the core (Text-fig. 3) but is well exposed in peripheral outcrops except on the western side where it is covered by younger rocks. Both of these Permian units have been subjected to erosion prior to being unconformably overlain by the Moenkopi Formation of early Triassic age. Comparison of Text-figures 3 and 4 illustrates the nature of this contact where rocks of the lower Moenkopi overlie the White Rim Sandstone in the core and the Kaibab Formation around the periphery.

PERMIAN SYSTEM

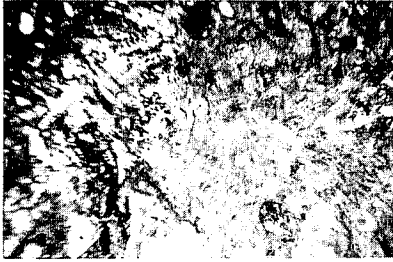
White Rim Sandstone

The White Rim Sandstone was named by Baker and Reeside (1929, p. 1444) for exposures in a cliff along the Green River near its confluence with the Colorado River. At its type locality the White Rim Sandstone overlies the Organ Rock Tongue of the Cutler Formation with which it grades from red siltstones and shales of the Organ Rock Shale into the clean, well-sorted sandstones of the White Rim. The White Rim is also gradational, with undifferentiated Cutler redbeds at its eastern pinchout along a line approximated by the Colorado River (Baker, 1946, p. 46, 47; Kunkel, 1958, p. 167; and Baars and Seager, 1970, p. 711).

The White Rim Sandstone forms a wedge-shaped unit that thickens markedly to the west at the expense of the underlying Organ Rock Shale, which thins to its termination near the eastern edge of the San Rafael Swell. At this point the White Rim and Cedar Mesa Sandstones, which were formerly separated by the Organ Rock Shale, merge and remain inseparable toward the west (Kunkel, 1958, p. 167; and Baars, 1962, p. 155, 191). From these relationships it would seem that the White Rim and Cedar Mesa sandstones form a facies of the Cutler Formation which extends toward the west into the vicinity of the San Rafael Swell. However, Stewart et al. (1959, p. 194) indicate that the practice has been to refer to the clean cross-bedded Permian sandstones in southeastern Utah as Coconino, where no interfingering Cutler redbeds are present.

The massive, light-colored, cross-bedded Permian Sandstone exposed in the San Rafael Swell has long been correlated with the Coconino Sandstone of the Grand Canyon area on the basis of lithology, internal structure, and stratigraphic position (Baker, 1946, p. 49, 50). However, McKee (1954, p. 23) has pointed out that it is impossible to physically trace the type Coconino into southeastern Utah; and he has inferred that any attempt to correlate the two would be very tenuous. For this reason, and due to the ease with which the White Rim Sandstone can be traced from its type locality northwestward into the San Rafael Swell, the writer prefers to refer to the Permian Sandstone of the study area as White Rim Sandstone rather than Coconino as proposed by earlier workers.

The White Rim Sandstone of the San Rafael Swell is discontinuously exposed throughout the core of the structure and is unconformably overlain by both the Kaibab and Moenkopi formations. It consists of a generally well-sorted, uniformly fine- to medium-grained quartz sandstone composed of rounded to subrounded quartz grains bound by a poorly developed carbonate cement. The sandstone is generally friable, with a well-developed, intergranular, porosity which is often accentuated by hydrocarbon staining. However, fluctua-



1



2



3



4

EXPLANATION OF PLATE 1

- FIG. 1.—Photograph of a thin section of a typical bioclastic dolomite from the Kaibab Formation showing destruction of fossil material by dolomitization and the resultant porosity. (x 20)
- FIG. 2.—Photograph of a thin section of a silicified burrow in the zone of bioturbation of the White Rim Sandstone. The section shows silicification of fecal pellets and hydrocarbon stain. (x 25)
- FIG. 3.—Photograph showing the bimodal nature of the White Rim Sandstone.
- FIG. 4.—Photograph showing truncation of cross-bedded White Rim Sandstones by horizontally bedded sandstones.

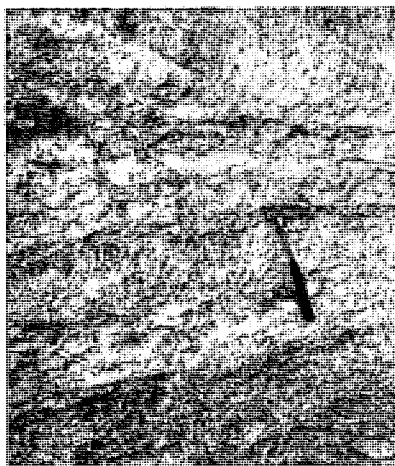
tions in the degree of cementation cause the sandstone to be locally less friable and to have less porosity due to partial calcite filling of the interstices.

The White Rim is characteristically a bimodal sandstone, but a unimodal character was observed locally throughout the Swell. Plate 1, figure 3 illustrates a typical bimodal occurrence in section 1 (Appendix A). The picture represents a nearly horizontal surface on which the darker colored, coarser grained sands formed circular to elliptical patterns in the lighter colored, finer grained sands. In this particular outcrop the coarser grained fraction seemed to taper downward toward the center, possibly representing the filling of scoures by alternating coarse and fine grained sands in response to fluctuations in energy levels. However, in other sections the coarser grained sands did not form any systematic patterns that could be related to the nature of the surface or conditions of sedimentation.

The White Rim Sandstone has long been noted for its locally well-developed cross-beds. Baker (1946, p. 45) characterizes the unit as being highly cross-bedded, with both tangential and angular types of cross-strata expressed. Earlier workers have allowed the cross-bedded nature of the unit to overshadow other physical characteristics of the rock, for they used it and stratigraphic position as the primary basis for correlating the formation with the Coconino Sandstone of northern Arizona. Careful study of the formation in the San Rafael Swell reveals that it is actually made up of a series of cross-strata which are generally separated by sets of horizontally bedded sands (Pl. 1, fig. 4). Hallgarth (1962, p. 1499) reported one cross-bedded unit fifty-five feet thick; but most of the sets observed by the writer are relatively thin, ranging from two to twenty feet and are interbedded with horizontally-bedded units.

The character of the bedding changes markedly in the upper unit of the White Rim, where it exhibits a very crude horizontal bedding that has been partially destroyed by reworking. This upper unit ranges in thickness from less than five feet (section 3, Appendix A) to a maximum of thirty-five feet (Section 11, Appendix A), is generally bioturbated, and shows a marked variation in lithology (Pl. 2, fig. 1). In general, the unit becomes much more calcareous toward the south and west as it gradually changes from poorly cemented sandstones and siltstones in the vicinity of sections 1, 2, and 3 (Appendix A) (Text-fig. 3) to calcareous siltstones and mudstones in section 11. In sections 4 and 5, some thin carbonate units at the top of the White Rim Sandstone have led some mappers to refer to them as Kaibab Limestone. Field examination of these beds reveals that they are interbedded with bioturbated calcareous siltstones and sandstones that have a very close affinity to the underlying well-sorted and often cross-bedded White Rim Sandstone. In general, the southward and westward increases in calcareous units is accompanied by an increase in the thickness of the zone of bioturbation and reworking, which itself becomes more calcareous upward. Plate 2, figure 1 illustrates a portion of the intensely bioturbated zone in section 11 (Appendix A) where predominately horizontal burrowers have completely reworked the entire zone destroying most of the bedding. The burrowing organisms appear to have been quite varied as is evidenced by the variety of burrows (Pl. 2, figs. 2 and 3). Only two major types are preserved well enough to lend themselves to study.

Plate 2, figure 2 depicts one type of burrow consisting of rather narrow, elongate, partially silicified tubes rarely exceeding three-quarters of an inch in diameter. They have a smooth outer wall with locally expanded areas where



1



2



3



4

EXPLANATION OF PLATE 2

- FIG. 1.—Photograph showing the intensity of the bioturbation in a portion of the White Rim Sandstone.
- FIG. 2.—Predominate horizontal burrows on a bedding plane of a calcareous mudstone within the White Rim Sandstone.
- FIG. 3.—Vertical burrows of *Ophiomorpha* which are confined to calcareous siltstones below the mud burrowers shown in plate 2, figure 2.
- FIG. 4.—Geodes formed by silicification of burrows in the White Rim Sandstone. A thin section of one such geode is figured in plate 1, figure 2.

the organism may have enlarged the tube to serve as a temporary living chamber. These burrows meander aimlessly across the bedding surface, but they may abruptly change their course and burrow vertically into the underlying calcareous mudstone. Despite the abundance of these forms, poor preservation precluded any accurate identification of their traces.

The second type of ichnofossil (Pl. 4, fig. 3) preserved in the zone of bioturbation is expressed as nearly circular depressions in the fairly clean, fine-grained quartz sandstones that underlie the calcareous mudstones mentioned above. Burrows range from one to four inches in diameter and generally have a slightly raised lip which protrudes above the surrounding rock, exposing a knobby exterior. A similar burrow has been reported from the underlying Cedar Mesa Sandstone by Baer (1971, p. 366), who classified it as *Ophiomorpha*. Hoyt and Weimer (1965) characterize *Ophiomorpha* as a sometimes branching burrow with a knobby exterior, which they believe is indicative of shallow marginal marine conditions. These structures represent the first *Ophiomorpha* reported from the White Rim Sandstone and point toward a shallow marine origin for the formation in the San Rafael Swell area. They are abundant in the lower 10 feet measured in section 11 (Appendix A), but decrease upward into the calcareous siltstones and mudstones where other types of burrows in this upper zone have been silicified forming chert geodes ranging in size from less than an inch to about four inches in diameter (Pl. 2, fig. 4). When broken open these geodes emit a pronounced petroliferous odor from the abundant hydrocarbons preserved within the impermeable case. The hydrocarbons are associated with and fill voids between pelletal structures presumed to be the fecal material of the burrowing organisms (Pl. 1, fig. 2). The secondary silicification of these geodal structures, coupled with the general upward and southwestward increase in the calcareous nature of the upper zone of bioturbation, is believed to reflect a gradual northeast transgression of the Kaibab Sea, which may have been responsible for the observed reworking of the upper portion of the bioturbated zone in the White Rim Sandstone.

The transgressing Kaibab Sea encountered many topographic irregularities in the San Rafael Swell, some of which probably remained as islands throughout much, if not all, of Kaibab deposition. The features of relief on the White Rim vary from small structures less than ten feet high to large structures showing tens of feet of topographic relief. A low-lying elongate bar-type structure was observed in section 11 (Appendix A) (Pl. 3, fig. 1). It exhibits a maximum of ten feet of relief and is traceable for a distance of approximately 300 feet along a general north-south trend. The "bar" is made up of horizontally bedded calcareous mudstones and siltstones which were built up into a mound on top of the aforementioned zone of bioturbation. The flanking Kaibab rocks consisted of dolomitic, silty limestones and silty limestones with the floating silt sized particles probably representing reworking of the "bar" itself.

Farther to the north at section 9 (Appendix A) pre-Kaibab relief is seen on a larger scale. Here the Kaibab can be seen in an obvious onlap relationship with the underlying White Rim Sandstone. Plate 3, figure 2 shows the Kaibab on the skyline, thickening from about six or seven feet on the right-hand side (south) to approximately fifteen feet within a distance of 300 feet toward the north. The onlapping nature of the Kaibab Formation is observable for an additional 1,200 feet upstream where it attains a maximum thickness of about 40 feet before the White Rim is lost in the subsurface. Observations of the entire exposure reveals the onlap nature of the contact as the lowermost Kai-



1



2



3



4

EXPLANATION OF PLATE 3

- FIG. 1.—Relief on the surface of the White Rim Sandstone. The Kaibab Formation laps onto the side of a White Rim high which is shown as a horizontally bedded calcareous mudstone.
- FIG. 2.—Onlap of Kaibab onto a White Rim high. The Kaibab Formation on the skyline thins toward the right from fifteen feet to seven feet within 300 feet by the pinch-out of basal beds.
- FIG. 3.—Onlap of Kaibab onto a minor White Rim high.
- FIG. 4.—Gradational contact between the White Rim and Kaibab Formations.
- Zone A - Bioturbated, slightly calcareous siltstones
 Zone B - Intensely bioturbated calcareous mudstones
 Zone C - Silty limestone of the Kaibab Formation
 Zone D - Normal Kaibab carbonates

bab beds thin and progressively pinchout against the White Rim high as they encroach upon it from the north. The nature of this relationship is shown on a smaller scale in Plate 3, figure 3, where the lowermost Kaibab gradually thins across a small White Rim high in section 3 (Appendix A).

The correlation of the White Rim Sandstone of the San Rafael Swell with the Coconino Sandstone of northern Arizona and the locally well-defined cross-bedding within the unit have caused numerous workers to refer to it as an eolian deposit. In recent works some individuals have made an attempt to divorce themselves from the tradition of referring to cross-bedded sands as being indicative of eolian environments. Hallgarth (1962, p. 1498) points out that his studies of the Straight Wash Canyon section on the eastern flank of the Swell indicate that the "Coconino" sandstone most probably represented "deposition in and near the fluctuating shore of a sea that probably covered a large part of Utah." He believes that "the sand collected as a beach deposit along the shore of a shallow sea, and was drifted landward into a lacustrine and dune deposits by prevailing northwesterly winds." However, he further states that "the intercalated flat-bedded and cross-bedded units indicate periods of inundations and withdrawals by the sea."

Baars and Seager (1970, p. 712) cite internal geometry, nature of cross stratification, nature of rippled surfaces, and regional relationships as evidence for a marine origin for the White Rim Sandstone. They believe (p. 716) that the cross-bedded "bars" represent deposition in a regressive sea because of their relationship to the underlying, horizontally bedded units which they presume to represent the initial transgressive phase. The White Rim of the San Rafael Swell reflects many of the attributes mentioned by Baars and Seager, and the writer agrees with their postulated marine origin.

The intercalated cross-bedded and horizontally bedded sets of sandstone seem to represent deposition in an aqueous environment where fluctuations in sea level had a marked effect on the depositing currents and hence the bottom configuration. A general reconnaissance study was made of cross-bedding directions. Data collected from field observations and plotted on a stereonet resulted in a strong central tendency toward the southeast as has been reported by several authors (Hallgarth, 1962, p. 1498; Baars and Seager, 1970, p. 715, and others). However, sets of cross-beds dipping to the southwest, north-northwest, and northeast were observed interbedded with those trending to the southeast. This type of sediment dispersal pattern is not indicative of eolian environments, which form in response to prevailing wind directions and show only minor fluctuations. It is more characteristic of those found in shallow marine environments where numerous currents can interact in response to minor fluctuations in water depth and relation to the shoreline and its configuration.

The bioturbated nature of the uppermost portion of the White Rim Sandstone, coupled with the marked topographic relief along elongate structures also seems to point to a marine origin for at least the upper third of the formation. Hoyt and Weimer (1965, p. 204) point out that the ichnofossil *Ophiomorpha* is "most commonly preserved in well-sorted marine sandstone of near shore, shallow neritic, and littoral origin. They further indicate (1965, p. 204) that "where associated fossils are found, they (*Ophiomorpha*) always have marine affinities."

The onlap relation of the overlying Kaibab onto the topographic White Rim highs suggests a change in conditions of deposition that may be interpreted in various ways. Kunkel (1958, p. 167) believes that the "Coconino" of the

San Rafael Swell represents "the shoreward facies of the upper part of the Toroweap Formation." On the other hand, Ohlen and McIntyre (1965, p. 2025) envision the upper surface of the White Rim Sandstone as the reworking of the dune sandstone by the advancing Kaibab Sea. However, this concept does not account for the marine nature of the White Rim observed by Baars and Seager (1970) far to the east of the limits of Kaibab deposition.

Pre-Kaibab Unconformity

Observations of the White Rim-Kaibab boundary during this study have revealed a generally gradational contact between the two formations. The gradation is typified by the sequence observed below the measured portion of section 3 (Appendix A). Plate 3, figure 4 shows an upward gradation from clean, well-sorted quartz sandstone into slightly bioturbated siltstones of the White Rim Sandstone which become generally more calcareous upward. A rather abrupt change occurs at the top of the calcareous siltstones where highly calcareous siltstones representing the basal Kaibab grade rapidly upward into the more characteristic Kaibab carbonates. The writer thinks that this rather abrupt gradation represents the reworking of the uppermost part of the bioturbated zone in the White Rim Sandstone by a transgressing Kaibab Sea.

The existence of an unconformity between the White Rim and Kaibab Formations of the San Rafael Swell has been the subject of controversy for many years. Gilluly and Reeside (1928, p. 63) originally proposed that the contact was conformable; however, in a paper published the following year, Gilluly (1929, p. 81) cast some doubt on the conformable nature of the contact. He proposed that the topographic relief evidenced on the top of the White Rim Sandstone and the lack of typical White Rim joint patterns in the Kaibab presented possible evidence of unconformity, but he still seemed to favor continuous deposition in light of the gradational nature of the boundary. McKee (1938, p. 29-31) also observed the relief preserved at the top of the White Rim Sandstone, but, unlike Gilluly, he thought it represented definite proof of unconformity. However, Baker (1946, p. 49, 52-53) later challenged this by again stating that the gradational nature of the boundary is most indicative of conformity, and he proposed that "Coconino" clastics simply represented a shoreward facies of Kaibab Formation as it transgressed toward the northeast.

The gradational nature of the White Rim Sandstone and Kaibab Formation contact appears to have been the major point preventing acceptance of a pre-Kaibab Unconformity. It is a well-known fact that fluctuations in the physical conditions acting within a depocenter cause corresponding changes in the type and nature of sedimentation which are conducive to the formation of gradational boundaries and/or facies changes. However, this does not necessarily preclude the formation of a gradational contact by conditions that are not indicative of uninterrupted sedimentation. In a discussion involving unconformities associated with marine transgression, Weller (1960, p. 394) indicates that reworking of the underlying material by transgression across a surface of relatively low relief may result in the formation of an obscure or blended unconformity.

The relief observed on the top of the White Rim Sandstone presents an additional argument in favor of unconformity between it and the overlying Kaibab. The already mentioned onlap relation between the Kaibab and the positive

irregularities of the White Rim surface seems to favor the idea of a time break between the two formations, but by itself it doesn't provide conclusive evidence. However, these positive elements appear to have had a pronounced lithologic effect on the flanking carbonate deposits which might prove more useful in documenting the existence of the proposed lacuna. Close examination of the measured sections (Appendix A) and lithologs of wells in the area indicate the presence of numerous units of clastic material interstratified with the normal Kaibab carbonates. These clastic units range from slightly silty and sandy limestones and dolomites to only slightly calcareous sandstones and siltstones that appear to thicken and become more numerous towards White Rim highs suggesting that the positive areas were being reworked during deposition of the flanking basal Kaibab carbonates.

In conclusion, it should be pointed out that in the absence of fossil evidence of a hiatus, supporting physical evidence strongly points to the presence of either an unconformity or diastem at the base of the Kaibab Formation.

Kaibab Formation

The Kaibab Formation of the southwestern United States is exposed in two areas of greatly differing aerial extent. The larger of the two areas contains the type section and covers roughly 36,000 square miles in southwestern Utah, southern Nevada, and northern Arizona. The smaller exposure of Kaibab material is located in the San Rafael Swell and Circle Cliffs areas of southeastern Utah, no less than seventy miles north-northeast of the closest known Kaibab (McKee, 1938, p. 48). This smaller isolated occurrence covers approximately 2,400 square miles in an elongate, fairly restricted series of outcrops (McKee, 1938, p. 45, 48, 49, 53, 54) which have been correlated with the type Kaibab on the basis of similarities of lithologies and their stratigraphic position, marking the top of the Permian and overlying a light colored cross-bedded sandstone (McKee, 1938, p. 48, 49, 53, 54).

Gilluly and Reeside (1928, p. 64) cast some doubt on the validity of the correlation between the two Kaibab sequences by indicating that the Kaibab fauna of the San Rafael Swell area had a closer affinity to faunas in "the Upper (Phosphoria) part of the Park City" group of the Uinta Mountains, than to that of the type Kaibab. McKee (1938, p. 48, 49, 53, 54) acknowledged the tenuous nature of such a correlation but proceeded to treat them as more or less contemporaneous units by assigning the Kaibab of the San Rafael Swell and Circle Cliffs areas to his Alpha and Beta Members proposed as subdivisions of the type Kaibab. In a subsequent paper McKee (1954, p. 23) again pointed out the problems connected with a correlation between the two areas, stating that "comparison of the San Rafael Swell fauna with faunal assemblages of Permian sections in the southern Wasatch Mountains of central Utah and in the Confusion Range of western Utah indicates that it is represented high in these sections. Its diagnostic brachiopods, *Neospirifer pseudocameratus* (Girty) and *Punctospirifer pulchra* (Meek), are in the upper 4,000 feet, assigned to the Phosphoria Formation by Newell, in the Confusion Range. In both places, the characteristic large dictyoclostids similar to *D. bassi* (McKee) of the type Kaibab are present considerably lower in the sections. Thus the marine limestone of the San Rafael Swell that has been referred to the Kaibab is younger than marine strata of the type Kaibab Limestone."

Faunal collections by the writer include several genera that further indicate

a close affinity between the Kaibab of the San Rafael Swell and the Phosphoria Formation of Wyoming and Idaho and its correlative Franson, Gerster, Meade Peak, and Rex Formations of the Upper Park City Group of northern Utah and Nevada. Useful genera include representatives of the conodonts and porifera. A single specimen of the lithistid sponge *Actinocoelia maeandrina* Finks was found in the upper portion of the Kaibab Formation in section 6 (Appendix A). This sponge was named by Finks (1960, p. 70) from specimens collected from Leonard age rocks of west Texas. On the basis of its occurrence in west Texas and in the Leonard age rocks of the Beta Member of the type Kaibab Formation, Finks et al. (1961, p. 567) concluded that it might represent an Upper Leonard age guide fossil. However Bissell (1970, p. 301) states that he "collected *Actinocoelia maeandrina* Finks more than 100 feet stratigraphically above a unit containing *Pseudogastrioceras*" in the "Phosphoria" Formation of Nevada, which Furnish and Glenister indicate "is suggestive of a Wordian to Capitanian age (Bissell, 1964, p. 631, 632)." *Actinocoelia maeandrina* has also been reported from the Franson Member of the Phosphoria Formation (Finks et al., 1961). Conodonts collected from the Kaibab Formation of the San Rafael Swell also show a close affinity with those reported from the Phosphoria Formation. *Streptognathodus* sp., *Subbryantodus* sp., *Apatognathus* (?), and *Hindeodella* (?) have all been reported from the Meade Peak Member of the Phosphoria Formation which is believed to be Wordian in age (Clark and Ethington, 1962, p. 107, 109, 112).

Faunal evidence reported by others and that obtained during this study indicate that the Kaibab of southeastern Utah is younger than the type Kaibab of northern Arizona. McKee (1954, p. 23) mentions that similarities in gross lithology but differences in faunal assemblages between the two Kaibab sequences "indicate one of two possible relationships. Either the rocks of these sections represent (1) similar environments (facies) that existed independently in the two areas at different times, or they were formed (2) as bodies of sediment that were once continuous across the region, crossing time planes as a result of transgression or regression." The seeming lack of fossil evidence substantiating a gradual vertical upward decrease in age of the type Kaibab tends to support deposition in two different basins at different times. However, it should be pointed out that extensive pre-Triassic erosion of the area might be responsible for the removal of the upper part of the type Kaibab, thus destroying any record of a gradual decrease in age. This seems unlikely in light of the well-defined stratigraphic succession reported in eastern Nevada and western Utah by Bissell (1964 and 1970) which shows the Kaibab successively overlain by the Plympton, Indian Canyon, and Gerster (Franson correlative) formations. Therefore, the writer considers the Kaibab Formation of southeastern Utah to be younger than the type Kaibab Formation and to be more closely allied with the formations which form the upper portion of the Park City Group in northern Utah, thus supporting its formation in a restricted arm of the Phosphoria sea which extended southward into a basin separated from that of the type Kaibab by both time and geography.

The Kaibab Formation of the San Rafael Swell consists of a series of interbedded, buff to medium brown, generally cherty carbonates, dominated by dolomite with minor interbeds of sandstones and siltstones. The carbonate units contain varying amounts of sand and silt-sized clastic particles (0-50 percent) which generally occur suspended in the carbonate matrix. They range from bioclastic limestones and dolomites to crystalline and micritic limestones

and dolomites, all of which occur interbedded throughout the formation. The sandstones and siltstones of the formation range from nearly pure quartz sandstones to highly calcareous sandstones and siltstones which show no obvious relation to the base or shoreward margin of the formation but rather seem to represent periodic floods of clastic debris from the various White Rim highs.

The formation was observed to be notably porous locally throughout the study area. The porosity consisted of a well-developed vugular type in many of the more massive limestone and dolomite units, and an exceptionally pronounced solution type in the bioclastic dolomites (Pl. 1, fig. 1). Hydrocarbon staining was commonly found associated with both types.

The formation shows a general thickening trend from zero in the vicinity of the present day San Rafael Desert to as much as 200 feet on the westernmost edge of the study area (Text-fig. 3). However, this trend is interpreted throughout the area, with Text-figure 3 showing numerous thicks and thins. The variation in the thickness of the formation may in part be due to removal by pre-Triassic erosion, but the major portion of the variation is believed to be due to deposition over an irregular topography as previously evidenced in the discussion on the pre-Kaibab Unconformity.

The Kaibab Formation of the San Rafael Swell contains locally profuse faunal assemblages which, owing to their generally poor state of preservation, did not lend themselves to generic breakdown. However, representatives of several phyla were recognized and aided in the interpretation of the formation. These fossil remains included members of the mollusks (bivalves and gastropods), brachiopods, porifera (*Actinocoelia maeandrina* Finks), echinoderms (fragmented crinoid pelmas), and conodonts (*Streptognathodus* sp., *Apatognathus* (?), *Hindeodella* (?), and *Subbryantodus* sp.). Selective silicification appeared to be one of the factors accounting for the difference in preservation of individuals. In general, the crinoidal debris was quite well preserved, owing to silicification, as was the sponge, *Actinocoelia maeandrina*, which was totally silicified. The shelly fauna, on the other hand, were everywhere poorly preserved and showed no signs of silica replacement. The difference in the state of preservation was most pronounced in the bioclastic dolomites where dolomitization and subsequent leaching have completely destroyed the shelly forms leaving only an outline of their shells to attest their former presence.

Dolomitization of the shelly fauna indicates that the majority of the carbonates were originally deposited as limestones, most of which have undergone later diagenetic dolomitization. This diagenetic alteration appears to have occurred very soon after deposition and points toward a syngenetic origin for the dolomites. This conclusion is based on the presence of seemingly unaltered limestone interbeds and the total lack of observed irregular dolomitization fronts. Pettijohn (1957, p. 661) indicates that authigenesis occurs in response to a drive toward chemical equilibrium between individual minerals and between minerals and interstratal fluids. Such a set of conditions could have reasonably existed during the deposition of the Kaibab carbonates in this area. As previously mentioned, the Kaibab of the San Rafael Swell appears to have been deposited near the shore of a narrow and restricted arm of the sea dominated by numerous topographic irregularities. Although such conditions of deposition might not have been restricted enough to produce sufficiently high salinities for the precipitation of primary dolomite, it seems likely that further concentration of magnesium in interstratal fluids might have been enough to initiate the authigenetic process soon after deposition.

The chert nodules which characterize much of the formation are found in both the limestones and dolomites. They are generally irregularly shaped nodular forms that are disseminated throughout the containing rocks. The selective silicification of invertebrate fossils and the irregular shape of the chert nodules indicate that they formed as secondary alterations of the Kaibab carbonates. This theory is in agreement with Pettijohn (1957, p. 439), Dunbar and Rodgers (1957, p. 251, 252), and Weller (1960, p. 70), who concur that the majority of nodular cherts in carbonate rocks appear to be of a secondary nature.

TRIASSIC SYSTEM

Moenkopi Formation

The Moenkopi Formation was named by Ward (1901, p. 403) for exposures along the Little Colorado River in northeastern Arizona. The formation forms the basal Triassic unit over much of the Colorado Plateau (McKee, 1954a, p. 5-9). McKee (1954a, p. 26) indicates that it is impossible to trace the Moenkopi Formation of southeastern Utah to its type locality along the Little Colorado River; however, both he and Gilluly and Reeside (1928, p. 66) point out that correlation of the two sequences across an interval of no less than sixty-five miles can be accomplished with assurance on the basis of lithologic similarity, stratigraphic position, and faunal relationships. Gilluly and Reeside (1928, p. 66) further use faunas collected from the Moenkopi of the San Rafael Swell as a basis for correlating the formation with "the Woodside, Thaynes, and Anakareh formations of the Western Uinta Mountain region."

The Moenkopi Formation of southeastern Utah shows a gradual northward thickening from zero in the Four Corners area to a maximum of 900 feet in the Capitol Reef area (Stewart et al., 1959, p. 497). Locally within the San Rafael Swell, Moenkopi thicknesses ranging from 465 feet to 800 feet have been reported by Hawley et al. (1968, p. 11). Here the Moenkopi is exposed in complete section only in areas adjacent to the flanks of the structure; however, the lower portions of the formation are exposed throughout the broad central dome as flat-topped buttes capped by a resistant limestone unit within the formation.

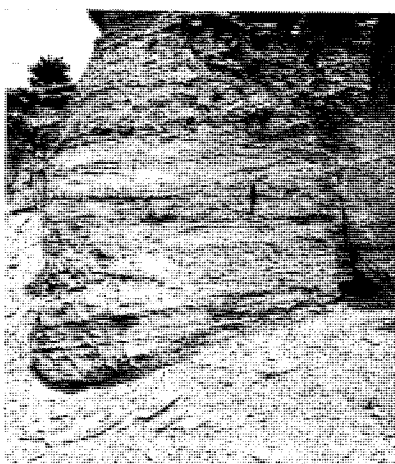
Gilluly and Reeside (1928, p. 65) and Gilluly (1929, p. 83-86) have subdivided the Moenkopi Formation of the San Rafael Swell and adjacent areas into three members (Text-fig. 6 and Pl. 4, fig. 1): a lower member consisting of interbedded sandstones and siltstones, a medial Sinbad Member, composed of marine limestones and dolomites with minor clastic interbeds, and an upper member, composed of interbedded sandstones, mudstones, and shales.

The lower member of the Moenkopi Formation is exposed discontinuously throughout the Swell area where its thickness was observed to range between 133 feet and 270 feet in measured sections, but subsurface data indicate a range from 29 feet to 382 feet in areas adjacent to the Swell. Text-figure 4 is an isopach map of the lower member illustrating the irregular thickening of the member in preferred directions radiating away from various isolated thins. This irregular thickening is thought to represent the topography upon which the lower member was deposited and will be discussed further in the section dealing with the nature of the Permian-Triassic Unconformity.

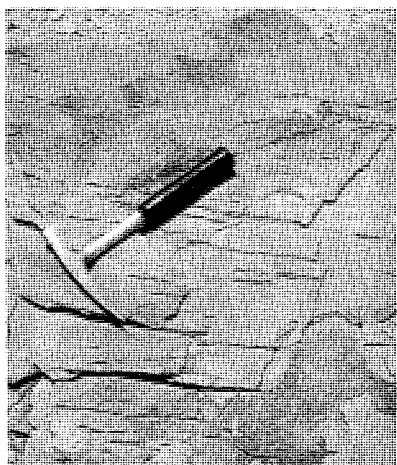
The lower member consists of two distinctly different lithologic types, representing different conditions of sedimentation. The lowest of these units forms a relatively thin basal conglomerate and coarse-grained sandstone com-



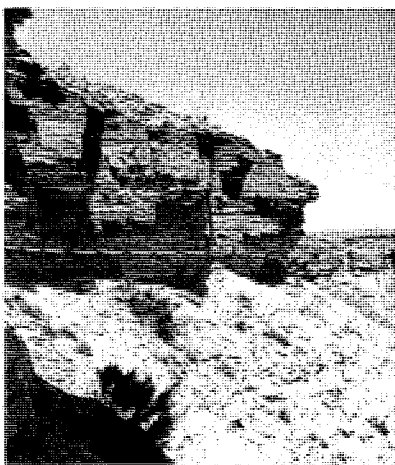
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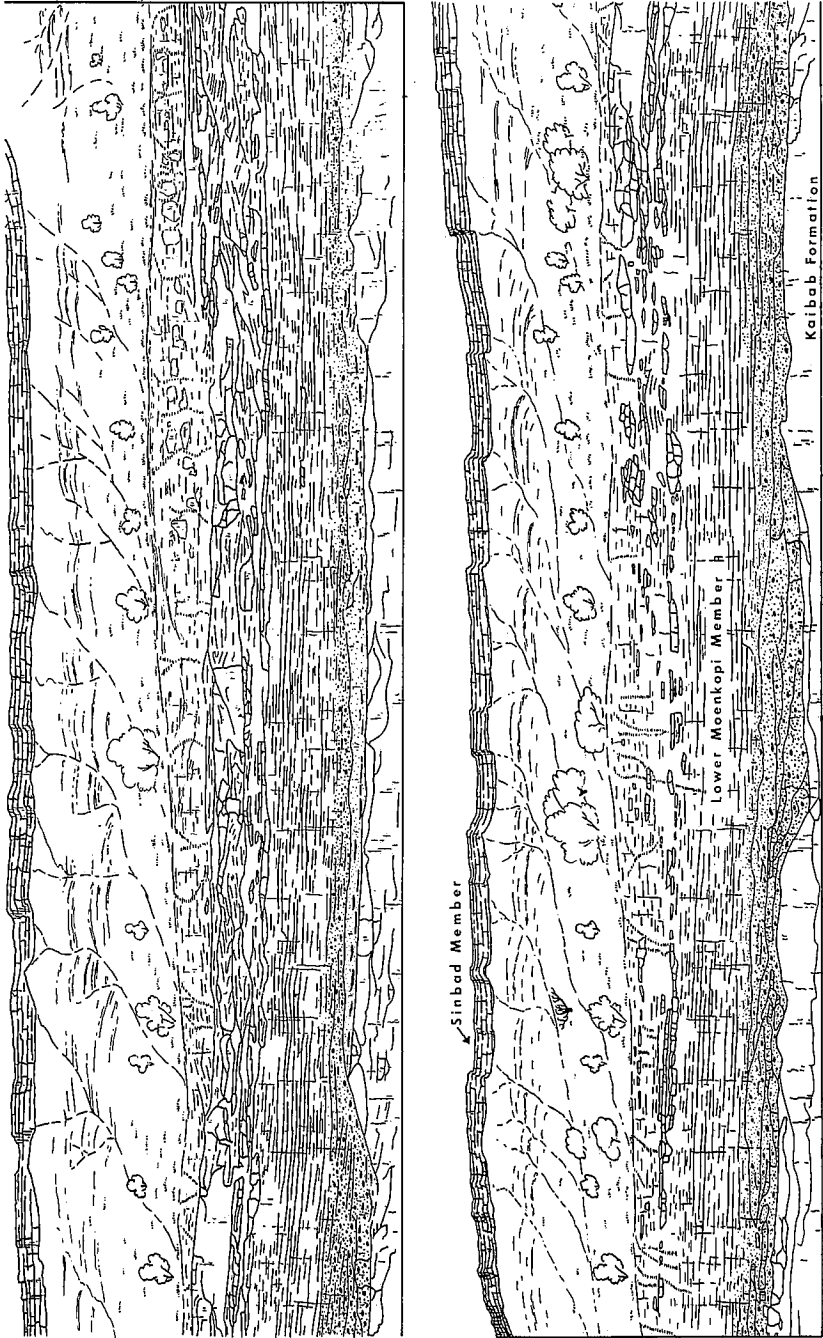
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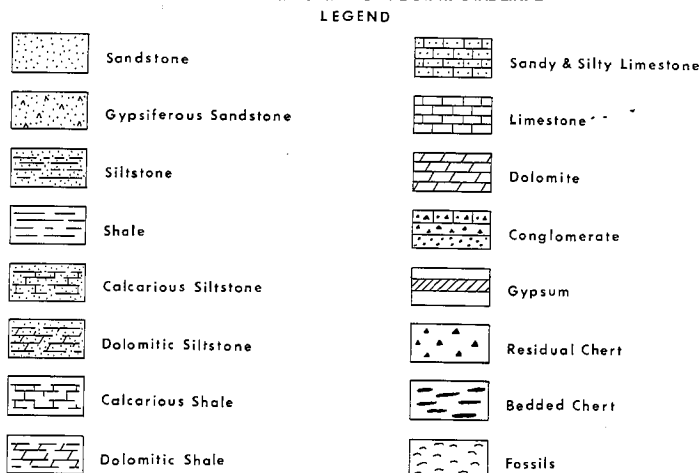
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EXPLANATION OF PLATE 4

- FIG. 1.—Photograph of the lower and medial members of the Moenkopi Formation. The lower member comprises that portion of the picture from the stream bed to the base of the massive cliff, which makes up the Sinbad Member.
- FIG. 2.—Cross-bedding in the lower member of the Moenkopi Formation.
- FIG. 3.—Subparallel horizontal burrows on a bedding plane of a slightly calcareous sandstone in the lower member of the Moenkopi Formation.
- FIG. 4.—Sinbad Member of the Moenkopi Formation showing the medium- to thick-bedded nature of the unit.



TEXT-FIGURE 5.—Diagrammatic sketch of a roadcut along I-70. Note the channeling into the upper surface of the Kaibab Formation, and the presence of a paleosol composed of bedded cherts.

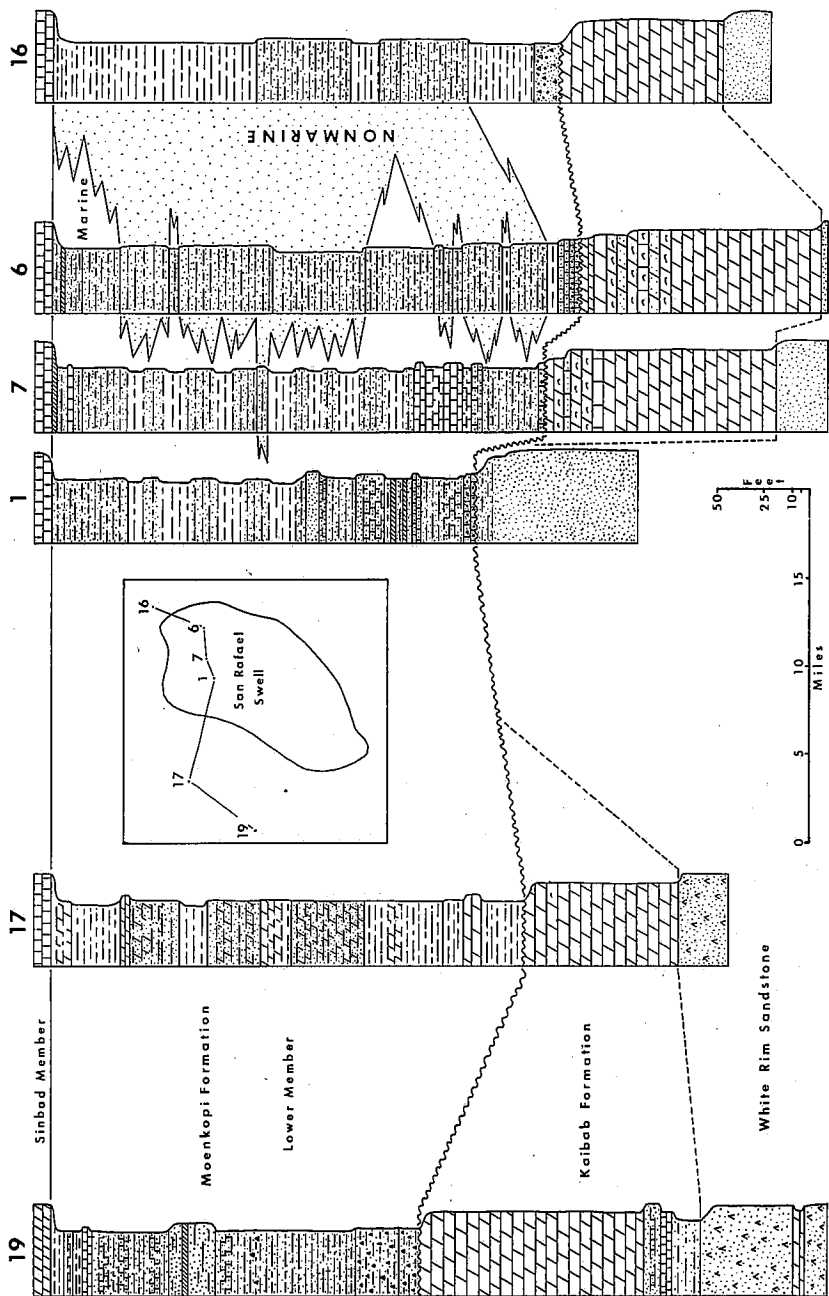


TEXT-FIGURE 5a.—Legend. Lithologic symbols portrayed here pertain to all sections and diagrams.

prised of angular to subangular chert clasts and rounded to subrounded quartz grains and local dolomite clasts, all of which are presumed to have been derived from debris formed by the weathering and erosion of the underlying Permian Formations. The clastic particles form varying proportions of the rock as a result of fluctuations in the amount of carbonate matrix, which ranges from as little as 5 percent in section 6 to as much as 60 percent in section 1 over a distance of about eleven miles. (Text-fig. 4). The percentage of carbonate matrix was observed to remain essentially constant toward the south along a line connecting sections 7, 8, 9, 10, 11, 5, and 4, indicating generally more marine conditions toward the west. However, it should be pointed out that such a generalization does not take into account time differences in the initiation of Moenkopi deposition due to irregularities in the topography.

The lower member of the Moenkopi Formation overlies and is gradational with the basal conglomerate. This portion of the lower member consists of broad blanket deposits of fine-grained sandstones and siltstones, with occasional interbeds of carbonate and gypstone units. The sandstones and siltstones are characteristically laminated to thinly bedded, are well sorted, and contain appreciable amounts of limonite (pyrite pseudomorphs) and hydrocarbons. The clastic-carbonate ratio decreases markedly in a general westward direction as the clastic units interfinger with and are replaced by carbonate units which generally thicken and become more numerous to the west (Text-fig. 6). These carbonates range from nearly pure limestones to calcareous and dolomitic sandstones and siltstones and contain marine fossils.

Paleocurrent dispersal patterns in the lower member indicate the interaction of a least two major systems of transport. Cross-bedding was evident in some of the sandier units, (Pl. 4, fig. 2) which exhibited a strong central tendency for currents flowing about 340° . This general current direction was reflected by asymmetrical ripple marks in both the sandstone and siltstone units, which indicated a current trending approximately 330° . However, numerous oscillation ripple marks were observed throughout the formation which indicated a wave generated current direction trending approximately north-south. This



TEXT-FIGURE 6.—Cross section showing the variability in the thickness of the Kaibab Formation and the lower member of the Moenkopi Formation which thicken and thin in unison across White Rim highs. The section also depicts the change from marine to nonmarine units within the lower member of the Moenkopi Formation.

paleocurrent analysis was based on too few readings to be conclusive, but the general trends are apparent and indicate the possible interaction of at least two current systems.

The Moenkopi formation of southeastern Utah is characteristically colored a weak reddish brown (Stewart, 1956, p. 85). However, exposures in the San Rafael Swell are dominantly buff to olive gray with the exception of the minor red unit reported in section 7 (Appendix A) and the thick red units reported in section 6 and at Temple Mountain by Baker (1946, p. 55). McKee (1954a, p. 26) suggests that this abnormal coloration of the lower member is due to "deoxidation processes" which altered the characteristically red units. Stewart and Smith (1954, p. 25) indicate that the reduction of the iron was facilitated by hydrogen sulfide associated with petroliferous material which is universally present in the greenish rocks of the lower member throughout the Swell. Reduction by introduced hydrocarbons may be the cause for some of the color change. Local areas of green gray rock were noted around porosity zones within red units, but they are relatively few when compared to the vast area of buff to olive gray rocks of the lower member exposed throughout the Swell. Gilluly (1929, p. 86) feels that the differences in color were primary rather than secondary and reflect deposition in different environments. He postulated that the red units were continental deposits, while the greenish rocks were more indicative of deposition in stagnant pools of a delta where oxidation was inhibited.

The writer generally agrees with Gilluly's conclusion that the change from greenish rocks to weakly reddish rocks marks the approximate location of the fluctuating shore zone of a lower Triassic sea, which deepened gradually to the northwest (Text-fig. 4). This conclusion is based primarily on the presence of the carbonate units, which increase both in thickness and number toward the west and which contain substantial quantities of conodont fragments. The conodont genus *Nioprioniodus* (?) was identified from a dolomite in the lower portion of the lower member in section 3 (Appendix A). Muller (1956) has reported finding the same genus in the lower Triassic Cephalopod (*Meekoceras*) bed near Montello, Nevada, thus supporting the possible connection of the two areas by a common sea. Locally in section 8 (Appendix A), sub-parallel burrows were also observed on the bedding plane of a fine-grained sandstone unit (Pl. 4, fig. 3). Supporting evidence includes the change in the character of the sandstone bodies from lenticular channel sands in southeastern Utah (Stewart et al., 1959, p. 497) to the blanket-type deposits characteristic of the Swell and the occurrence of oscillation ripple marks which show a north-south wave generated current superimposed on a northwest trending current which followed the paleoslope (Stewart et al., 1959, p. 497).

The Sinbad Member of the Moenkopi Formation conformably overlies the lower member throughout the Swell and much of southeastern Utah, west of its pinch-out in the vicinity of the Green River (McKee, 1954a, p. 25). The member is made up of medium to coarsely crystalline, basal, bioclastic limestone which is overlain by interbedded limestones, sandstones, and calcareous sandstones. The unit is medium to thick-bedded (Pl. 4, fig. 4) and is a medium to dark brown which is in part due to hydrocarbon staining. The Sinbad Member was not subjected to a thorough study; however, all measured sections were terminated at its base where fossils were collected. Such sampling revealed fossil representatives of the bivalves, brachiopods, and conodonts, of which only the conodonts proved to be important time indicators.

Prior sampling of the Sinbad Member in the San Rafael Swell by Gilluly and Reeside (1928, p. 66) revealed the presence of the middle Triassic guide fossil *Meekoceras*, which has formed the basis for correlating the Moenkopi Formation with the Woodside, Thaynes, and Anakareh formations to the north. McKee (1954a, p. 25, 26, 28) uses the occurrence of *Meekoceras* in the Sinbad Limestone as a basis for correlating it with the Timpoweap and Virgin Limestone members of the Moenkopi Formation in southern and southwestern Utah. Conodonts collected from the Sinbad Member during this study were identified as *Parachirognathus geiseri* Clack, *Lonchodina nevadensis* (?), and *Diplodella* sp.—all of which have been reported from the Lower Triassic of Nevada where *Parachirognathus geiseri* appears to be restricted to the *Meekoceras* zone (Clark, 1959; Muller, 1956; and Mosher, 1968), thus supporting the age and correlation of the Sinbad Member.

Based on its profuse fauna the Sinbad Limestone is universally accepted as a marine unit which marked a general southeastward transgression. Stewart et al. (1959, p. 499, 500), Stewart (1956, p. 87), Stewart and Smith (1954, p. 26) and McKee (1954a, p. 28) indicate that the Sinbad Member of the Moenkopi Formation marks an onlap sequence that becomes progressively closer to the base of the formation toward the southeast, ranging from as much as 200 feet above the base in the San Rafael Swell to zero in the Circle Cliffs area where it rests directly on the Kaibab Formation.

PERMIAN-TRIASSIC BOUNDARY

McKee (1938, p. 54) noted that the Permian-Triassic boundary of the Colorado Plateau has been recognized as an unconformity since the original works of Gilbert, Walcott, and Dutton in the late nineteenth century. Workers since these initial surveys have added much information concerning the extent of the surface which is now believed to cover more than 80,000 square miles (McKee, 1954a, p. 34). Baars (1962, p. 209, 210) cites the everywhere discomformable nature of the surface as evidence for mild epeirogenic warping after Kaibab deposition; however, the intense channeling reported by Longwell (1921, p. 49) suggests that more intense local deformation may have marked the close of the Permian in eastern Nevada. Local areas of angular discordance within the Paradox Salt Basin record deformation due to salt movements in that area (Kelley, 1955, p. 114), and McKnight (1940, p. 58) notes angular discordances of as much as four degrees along the Moab fault zone as evidence for anticlinal folding in the Monument Upwarp area.

The hiatus represented by the unconformity has been estimated in the tens of millions of years, representing the time between deposition of the Kaibab Formation (upper lower Permian) and the Moenkopi Formation (lower-Triassic) (McKee, 1938, p. 59 and McKee 1954a, p. 34). Evidence for such a significant time break has been based on faunal differences originally noted by Shimer (1919, p. 496, 497) and Girty (Reeside and Bassler, 1922, p. 68; Gilluly and Reeside, 1928, p. 66; and Gilluly, 1929, p. 82, 83, 86, 87) who pointed out that differences in the fauna of the Kaibab and Moenkopi Formations were pronounced and very distinctive. However, conodonts collected during this study indicate that the duration of the hiatus may not have been as great as previously reported. The presence of *Streptognathodus* sp., *Apatogarthus* (?), *Hindeodella* (?), and *Subbryantodus* sp. in the Kaibab point to its close affinity with Phosphoria equivalents which, according to Bissell

(1970, p. 301), may be as young as Capitanian, thus indicating that the Kaibab of southeastern Utah may be much younger than the proposed Leonard. Conodonts found in the lower member of the Moenkopi Formation have all been reported from the *Meekoceras* zone in western Utah and eastern Nevada and serve to substantiate the lower Triassic age previously assigned to the Moenkopi of southeastern Utah.

Within the San Rafael Swell the unconformity everywhere forms a disconformity characterized by the presence of a basal Moenkopi conglomerate, local channeling in Permian units, and the presence of paleosoils on top of the Kaibab Formation. The regional appearance and disappearance of the Kaibab Formation within the San Rafael Swell and adjacent areas of Utah have long been pointed out as evidence of extensive pre-Moenkopi erosion (Gilluly, 1929, p. 82; McKee, 1938, p. 57, 58; and McKee, 1954a, p. 35). Baker (1946, p. 51) states "erosion of the Kaibab Limestone before the Moenkopi was deposited resulted in the removal of part or all of the Kaibab in some areas and is the principal cause of the irregular variations in the thickness of the limestone. Regional relief at the base of the Moenkopi in the San Rafael Swell is equal to the maximum thickness of 102 feet of the Kaibab and may be somewhat greater, but it is impossible to determine the amount of the underlying Coconino Sandstone that may have been removed by pre-Moenkopi erosion in the areas where the Kaibab is absent." This generally held theory seems to have been based on erroneous observations in light of the onlap relation mentioned previously between the Kaibab Formation and the White Rim highs, where thickness increases amounting to as much as forty feet were observed within 500 yards at section 9 (Appendix A). The writer prefers to regard the major reason for thickness fluctuations in the Kaibab Formation as being due to the irregular surface over which it was deposited rather than to pre-Moenkopi erosion. This premise is further substantiated by close observation of the isopach maps of the Kaibab Formation and the lower member of the Moenkopi Formation (Text-fig. 3 and 4, respectively). Observation reveals that some of the thickest accumulations of the lower member of the Moenkopi Formation are coincident with some of the thickest deposits of the Kaibab Formation, and both formations can be seen to thin into approximately the same areas. If erosion is the cause for the variations in Kaibab thickness then either the area was severely channeled in which case the Moenkopi thicks would correspond with Kaibab thins or the entire region was subjected to extensive beveling of intensely folded Permian strata. This is not substantiated by any observable angular discordance between Permian and Triassic strata. Therefore the writer thinks that in areas where the Kaibab is thin to absent it represents very little erosion but rather marks topographic irregularities on the White Rim surface which were inherited by the Kaibab Formation due to its inability to fill the depressions before cessation of Permian deposition. The topographic irregularities at the top of the Kaibab Formation seem to be reflected by the lower member of the Moenkopi which generally thickens and thins in harmony with the underlying Kaibab (Text-fig. 6).

Channeling into the upper surface of the Kaibab Formation was observed at several locations, but it was most pronounced in a road cut at section 3 (Appendix A). Text-figure 5 is a diagrammatic sketch of this outcrop, showing an intricate channel system at the top of the Permian. The channel cuts approximately fifteen feet into the Kaibab Formation and is filled by siltstones,

sandstones, and conglomerates of the overlying Moenkopi Formation. In the upper half of Text-figure 5, the channel can be seen to truncate a well-developed paleosoil indicated by elongate black marks representing bedded chert in a silicified siltstone unit.

The bedded chert marking the paleosoil in section 3 was also observed in section 4. The individual chert beds represent silicification of the silts and clays that originally comprised the soil zone. Evidence supporting the secondary silicification of the soil zone includes (1) the presence of unaltered siltstone inclusions within the chert; (2) the presence of irregular silicification fronts in the siltstone; (3) the presence of isolated silicification centers within the siltstone; and (4) the presence of cross-bedding within the chert, which is believed to have been inherited from the original soil. Dunbar and Rodgers (1957, p. 249) and Weller (1960, p. 403) indicate that the rather common occurrence of bedded chert in the upper portions of weathered carbonate units may be indicative of leaching of disseminated silica by alkaline ground waters and its subsequent concentration and deposition near the exposed surface of the unit. The chemistry involved in such a reaction is extremely complex and is not totally understood, but the presence of either organic material or an extremely high pH appears necessary to induce deposition of silica. A second possible source for the silica observed in the paleosoils is the introduction of silica by airborne volcanics which were observed in the lower units of the lower member of the Moenkopi Formation.

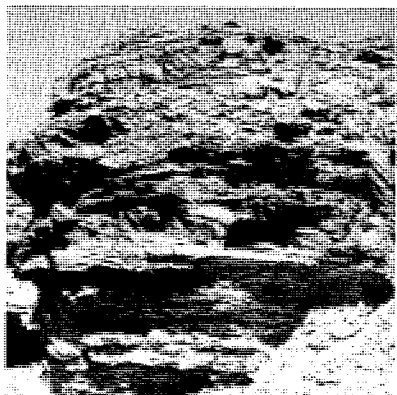
The presence of a high water table during pre-Moenkopi erosion of the San Rafael Swell is suggested by the total lack of karst topography in the carbonate units of the Kaibab Formation. Lack of such solution features in exposed carbonates is generally considered indicative of arid environment, high water table, or halmyrolysis. The fact that both the stream channels and the bedded chert were present seems to rule out extreme aridity and the lack of fossil evidence; and presence of paleosoils rule out halmyrolysis, in favor of a high static water table with relatively high pH. Such conditions would favor surface leaching of the carbonates to produce relatively smooth upper surfaces such as shown in Plate 5, figure 1, where basal Moenkopi conglomerates and sandstones rest on a nearly bedding plane surface of the Kaibab Formation.

EXPLANATION OF PLATE 5

- FIG. 1.—Lack of karst topography in the Kaibab Carbonates is evidenced by this bedding plane surface on which the basal conglomerate of the Moenkopi Formation was deposited.
- FIG. 2.—Variability in the nature of the basal Moenkopi conglomerate is evidenced in section 4 by complexly interbedded sandstones and chert pebble conglomerates.
- FIG. 3.—The irregular dispersal of chert clasts in the basal Moenkopi conglomerate reflects conditions of sedimentation and the availability of chert weathered from the underlying Kaibab Formation.
- FIG. 4.—Massive deposits of chert pebble conglomerate are composed of angular clasts which show an inverse relation with overlying silts as the clasts grade upward into the siltstones, reflecting the decrease in the availability of chert as the nearby Kaibab source was buried.
- FIG. 5.—The prolific abundance and angular nature of the chert suggests a lack of long transport and the formation of chert due to the weathering of silica-rich Kaibab carbonates.



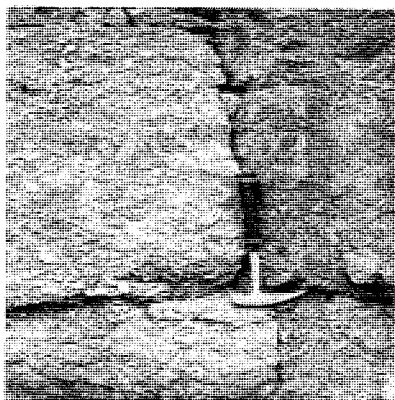
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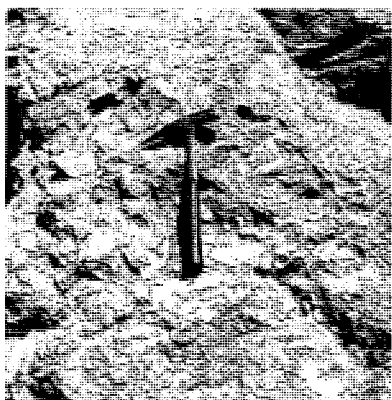
2



3



4



5

The basal conglomerate is the most diagnostic feature of the unconformity in the San Rafael Swell. However, it is not everywhere present and is quite variable in its expression in various areas. The conglomerate itself ranges from a true conglomerate (Section 6, Appendix A) to a rudaceous limestone (Section 1, Appendix A) containing as much as 60 percent limestone, with the remainder being made up of chert clasts and quartz grains. The basal chert-pebble conglomerate is also commonly interbedded with coarse-grained sandstone (Section 4, Appendix A) and locally it is totally replaced by coarse-grained sandstones (Section 9, Appendix A). Gilluly (1929, p. 82) and McKee (1938, p. 57) have both reported that the basal Moenkopi in the vicinity of Lockhart cabins on the San Rafael River consists of a "gritty white clay" which fills small hollows eroded in the top of the Kaibab Formation.

The chert clasts which comprise varying proportions of the basal unit range from locally spotty occurrences such as seen in plate 5, figure 3, to massive occurrences comprising as much as 85 percent of the unit as seen in Plate 4, figures 4 and 5. Plate 5, figures 4 and 5, also serves to illustrate the characteristically angular to subangular nature of the individual chert clasts; however, a few subrounded specimens have been observed in the stream channels illustrated in Text-figure 5 (Section 2, Appendix A). This predominate angular nature of the chert clasts, which range from less than 1 mm to greater than 15 cm in diameter, tends to indicate relatively short distances of transport, and hence the chert is believed to have been derived from the Kaibab Formation. This is in part substantiated by the gradational nature of the basal Moenkopi unit into the overlying material and the presence of dolomite clasts locally within the conglomerate sandstones. Text-figure 9 and Plate 5, figure 4, illustrate the inverse relationship of the chert which decreases upward into Moenkopi siltstones as the Kaibab is covered, rather than resulting in any drastic change in the mechanics of deposition.

The coarse-grained sandstones which are often found interbedded with or replacing the characteristic conglomerate are composed of well-rounded to subrounded quartz grains, with local occurrences of rounded to subangular chert in the sand size range. The sandstones are most prevalent in areas where the Moenkopi rests directly on the White Rim Sandstone or in adjacent areas where the Kaibab is notably thin. The percentage of chert clasts present in the sands was also observed to generally decrease into the areas where the thinning Kaibab pinched out against the White Rim Sandstone. These relationships apparently indicate a White Rim source for the basal sandstone, as well as for many of the sandstones higher in the section but topographically lower than White Rim exposures at the time of their deposition. The decrease in chert toward the White Rim highs also further substantiates the Kaibab as its source.

The basal unit is not only variable in its composition and distribution but exhibits marked variation in its thickness. The writer measured differences in thickness ranging from two feet in sections 6 and 7, to seventeen feet in section 4; and McKee (1938, p. 57) reports measuring as much as twenty-two feet near the San Rafael River. These thickness variations show no obvious relationship to topography, but they may represent deposition in poorly defined channels or depressions in the Permian strata. This is suggested by the presence of a small channel sixteen feet above the base of the Moenkopi in section 4.

The channel is marked by a lense of fine-grained chert pebble conglomerate one foot thick and approximately twenty feet wide, set in an otherwise

silty unit. The presence and nature of this channel indicates subaerial dispersal of Permian derived material, from an undetermined high, which still remained above the limits of Moenkopi deposition after more than 160 feet of sediment of the Lower Moenkopi Member had been deposited elsewhere (Text-fig. 4).

In summary, the Permian-Triassic unconformity of the San Rafael Swell records a complex history of formation. The erosion of the Permian units was not as great as previously believed by some geologists but was substantial enough to provide clastic debris for the basal unit of the Moenkopi Formation which was deposited in a time-transgressive fashion across a topography partially inherited from the White Rim Sandstone.

OIL AND GAS POSSIBILITIES

The search for oil and gas reserves in southeastern Utah has led to extensive drilling in the area of the San Rafael Swell where obvious hydrocarbon staining of the White Rim, Kaibab, and Moenkopi formations has stained much interest. All of the formations have well-developed porosities ranging from the secondary vugular type of the Sinbad and Kaibab units to the exceptionally well-developed intergranular type of the White Rim Sandstone. The common occurrence of hydrocarbons, porosity, and permeability in all of these units is notable, but breaching of the San Rafael Swell has rendered them locally useless in terms of recoverable reserves.

A survey of drilling operations in the San Rafael Swell shows a concentration along the axis of the present structure, which lies along the eastern margin of the Swell. This suggests a search for structural traps associated with the present Laramide structure. However, relatively few holes have been drilled in the broad central core which forms the western limb of the San Rafael Swell. Admittedly, drilling the flank of an anticlinal structure is generally less successful than drilling the crest, but the presence or absence of a structure should not rule out prospective stratigraphic and structural traps related to earlier events. In the case of the San Rafael Swell, the western limb has a low dip and exhibits several possibilities for further exploration.

The presence of a major Permian positive element on the western flank is evidenced by the elliptical zero isopach of the Kaibab Formation in Text-figure 3. This large high presents two interesting possibilities for further petroleum exploration in the San Rafael Swell and Circle Cliffs areas. Baars and Seager (1970) have indicated that topographic irregularities in the White Rim of the Elaterite Basin to the southeast represent offshore bars which mark the regressive phase of a pre-Kaibab sea. If the White Rim highs of the San Rafael Swell turn out to be bars of a similar nature, then detailed mapping of bar trends might indicate subsurface trends of similar bars in the areas adjacent to the San Rafael Swell. The second area of interest relates to the possibility of the White Rim irregularities representing structural rather than topographic highs.

A preliminary study of the joint systems in both the White Rim and Kaibab formations reveals that they are basically quite different. Such a difference in the joint patterns of different but adjacent lithologic units is thought to be due to one of two principal reasons: either the joints formed different sets due to differences in the lithologic response to an applied stress or those in the lower unit reflect a tectonic event prior to deposition of the upper unit and subsequent deformation of both units. In the case of the

latter possibility, one would expect to find joints representing both deformational stresses in the lower of the two units. This is in fact suggested in the San Rafael Swell where the White Rim Sandstone exhibits two joint systems. The major system has a strong central tendency trending about 345° , whereas the minor set reflects a central trend of about 280° . Examination of the joints in the overlying Kaibab Formation reveals a single joint set with a strong central tendency essentially paralleling the 280° set found in the White Rim. If this relationship is born out in more detailed studies, then the location of the proposed Permian structure presents some interesting petroleum possibilities.

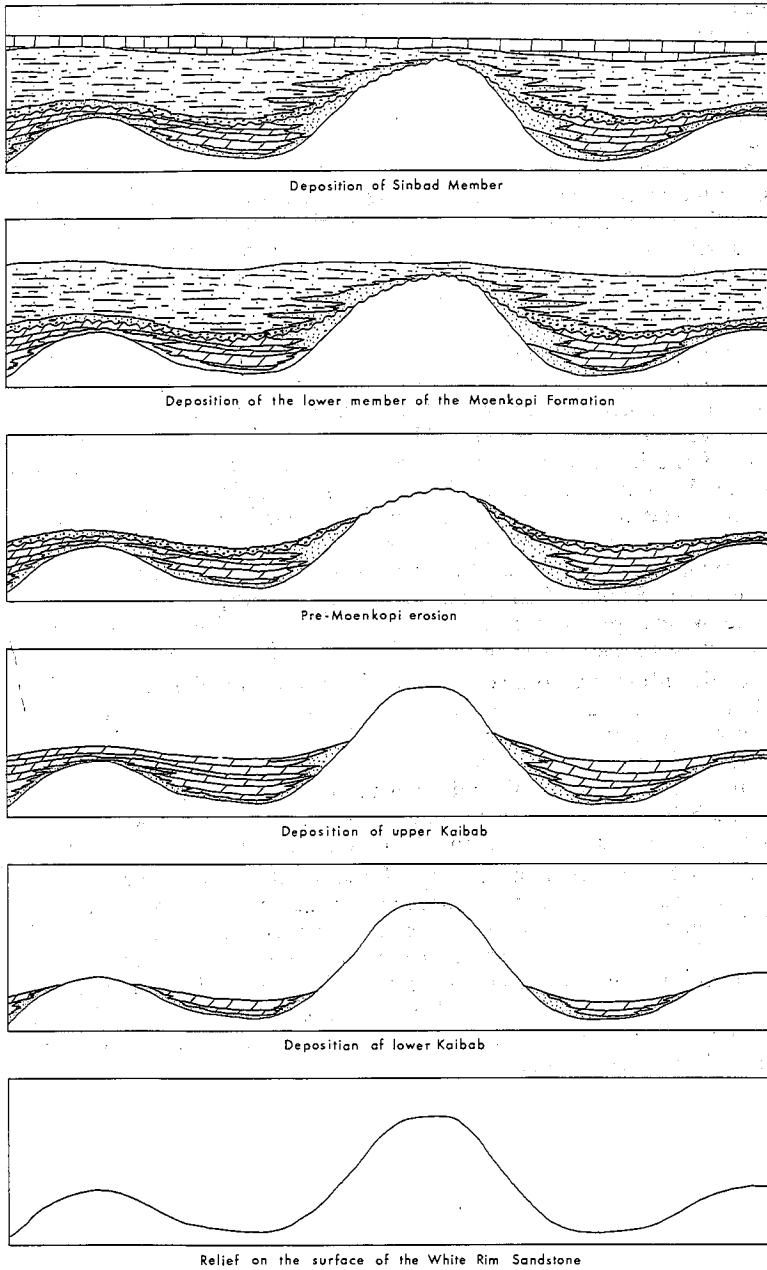
Text-figure 2 reveals that the proposed Permian structure overlies an area on the eastern margin of the Emery Spur which Fetzner (1960, p. 1392, 1393) cites as "an ideal depositional environment for the development of bioherms and biostromes from Des Moines to Wolfcamp time." The presence of such organic structures beneath a small structure provides the potential for an oil field similar to the Aneth Field in southeastern Utah, which also produces from Pennsylvanian algal bioherms of the Hermosa Formation.

SUMMARY

Pennsylvanian orogeny marked the beginning of a series of tectonic events which affected the San Rafael Swell and adjacent areas of the Colorado Plateau. The Emery Uplift acted as a relatively minor positive area from middle Pennsylvanian until sometime in the early Permian. The Uncompahgre Uplift, another of the Ancestral Rocky Mountain structures, remained active through most of the Permian and shed thousands of feet of clastic debris westward into the Paradox Basin.

Reworking of the Cutler arkoses, derived from the Uncompahgre Uplift, provided mature sands which were transported to the southeast by longshore currents into the vicinity of the San Rafael Swell where they were deposited as the White Rim and Cedar Mesa sandstones. The marine nature of these sandstones is evidenced by the presence of marine ichnofossils (*Ophiomorpha*), alternating sets of cross-bedded and horizontally bedded strata, a general southwestward increase in the calcareous nature of the formation, and the interaction of current systems that flow at various angles to the paleoslope. Prior to the deposition of the overlying Kaibab Formation, the White Rim Sandstone attained a marked topographic relief, which may have been the result of either tectonic or depositional forces (Text-fig. 7). The transgressing Kaibab sea encountered a series of generally north-south trending elongate positive features, some of which remained as islands through much if not all of Kaibab deposition. Evidence for the existence of such features includes onlap of Kaibab units onto the flanks of the White Rim highs, absence of Kaibab rocks over the top of the larger features, and the presence of White Rim derived sandy units throughout the Kaibab sequence. The presence of these observed features coupled with the rather abrupt gradation between the two formations points to the presence of either an unconformity or diastem between them.

The Kaibab Formation is dominated by syngenetic dolomites which formed soon after deposition as a result of interaction between high magnesium-bearing interstratal fluids and the originally deposited limestones. This is evidenced by the destruction of fossil debris during dolomitization, the presence of interbedded dolomites and unaltered limestones, and the lack of irregular dolomitization fronts. Faunal relationships and the lack of a physical connection



TEXT-FIGURE 7.—Generalized geologic history of the study interval, in/and near the San Rafael Swell (cross sections are east-west).

between the Kaibab of southeastern Utah and the type Kaibab suggest that the Kaibab of the San Rafael Swell is younger than the type Kaibab and is more correctly correlative with the Phosphoria Formation (Guadalupian) and its equivalents to the north.

Mild epeirogenic warping of the Colorado Plateau at or near the end of the Permian resulted in the cessation of Kaibab deposition and subsequent erosion of the exposed Permian strata. Marine transgression occurred in lower Triassic time when Moenkopi seas transgressed eastward to a fluctuating shore zone in the vicinity of the eastern limb of the present-day San Rafael Swell. The sea remained in this approximate position throughout the deposition of the lower member of the Moenkopi Formation. Evidence supporting this relationship includes the interfingering of greenish gray marine sediments with light red, floodplain deposits along the proposed shore zone; the presence of marine fossil-bearing carbonate units west of the shore zone which generally increase in both number and thickness toward the west; and the change in the character of the sand bodies from channel deposits of the floodplain to blanket deposits west of the shore zone. Many of the calcareous units in the lower member of the Moenkopi Formation contain conodonts that have been reported from the *Meekoceras* zone of Nevada, thus indicating a possible connection of the two areas by a common sea. Conodonts found in the *Meekoceras* bearing Sinbad Member of the Moenkopi Formation appear to be restricted to that zone, leaving little doubt that the areas were connected when the Sinbad was deposited. The Sinbad Member marks the rapid transgression of the previously restricted Moenkopi sea across much of southeastern Utah, forming an onlap relationship with the lower member of the Moenkopi Formation.

The disconformity, formed as a result of the late Permian Uplift of the San Rafael Swell and adjacent areas, is characterized by the presence of a basal Triassic conglomerate, local minor channeling in the Permian Formation, the formation of silicified paleosoils, and the distinctive faunal change from Permian to Triassic rocks. Faunal evidence from the lower Moenkopi and the upper Kaibab indicates that the hiatus represents the period of time from lower upper Permian (Capitanian ?) to sometime in the Lower Triassic.

The relief recognized on the top of the White Rim Sandstone presents at least two areas for further exploration for gas and oil in the area. If the relief is the result of tectonism, then a search for hydrocarbons in bioherm trends of the Hermosa Formation (Pennsylvanian) on the flanks of the Emery Uplift could locate a field comparable to the Aneth field. However, if the relief proves to be the result of bar type deposition, then detailed mapping of these bar trends and others in adjacent areas may reveal subsurface trends which could be investigated.

APPENDIX A

MEASURED STRATIGRAPHIC SECTIONS

Sections 1 through 11 were all measured by the writer during the summer of 1970 and the spring of 1971. An attempt was made to select strategic sections throughout the entire San Rafael Swell area in order to provide sufficient lithologic and facies controls necessary for logical interpretation of supporting well data. These eleven measured sections also provided most of the critical data on which conclusions were based concerning the nature of the Permian-Triassic boundary.

Section 1

Location: C NE SW Sec. 23, T. 21 S., R. 11 E.

Unit No.	Description	Unit Thickness in feet	Cumulative Thickness in feet
Moenkopi Formation			
<i>Sinbad Member</i>			
	Dolomite; dk. gry. to brn.; f. to m. xln.; fossiliferous. Minor ss. interbeds. Hydrocarbons concentrated in vugular porosity.		
<i>Lower Member</i>			
1	Covered; ss. predominates in float.	147	318
2	Sandstone; calc; buff to m. brn; w. srted. Qtz. clasts rd. to sbrd. Abundant limonite pseudomorph after pyrite.	1	171
3	Sandstone and siltstone; interbedded.	17	170
4	Sandstone; brn; f. gr.; p. srted. Hydrocarbon stained. Current ripple marks indicate a current direction of 304°.	4	153
5	Covered; buff siltst. predominates in float.	10	149
6	Limestone; silty; dk. gry.; f. xln. Thin gypsum layers in upper part. Unidentifiable conodont fragments present.	10	139
7	Siltstone; buff to gry-gn; f. gr. Numerous gypsum interbeds. Oscillation ripple marks indicate a current trending 11°.	15	129
8	Limestone; sandy; dk. gry.; f. xln. Quartz grains rd. to sbrd.; p. std.	5	114
9	Siltstone; lt. gn-gry. to tan; w. srted. Local conglomeratic interbeds; p. srted; w. rd. qtz.; ang. dol. Current ripples indicate a current direction of 335°. Oscillation ripple marks indicate a current trending 340°.	18	109
10	Siltstone; calc; lt. gn-gry.; mod. w. srted.	1	91
11	Limestone; lt. gry.; med. xln.; slightly slty.	1	90
12	Siltstone; calc; lg. gry. to buff. Grade laterally into arenaceous ls. containing up to 35% w. rd. dol. clasts. Crinoid pelmas and gastropods present locally.	1	89
13	Limestone; cgl.; dk. gry.; distinctly biomodal. Sand sized clasts consist of qtz.; w. rd. Cgl. material consists of chert; ang. to subang. Unidentifiable conodont fragments.	1	88
	TOTAL Lower Moenkopi Thickness	230	
Unconformity			
<i>White Rim Sandstone</i>			
1	Siltstone; calc; lt. to dk. gry.; intensely bioturbated. Qtz. grains are rd. to sbrd. Small bellerophon gastropods present locally.	1/2	87

2	Limestone; v. slty; dk. gry.; f. xln. Hydrocarbon stained.	1/2	86.5
3	Sandstone; qtz.; lt. to dk. gry.; m. grn.; fairly w. srted.; moderately bioturbated. Qtz. grains are rd. to w. rd. Hydrocarbon staining increases downward.	1	86
4	Sandstone; qtz.; lt. to dk. gry.; m. grn.; fairly w. srted.; moderately bioturbated; distinctly bimodal. Qtz. grains are rd. to sbrd. Hydrocarbon stained.	5	85
5	Sandstone; qtz.; dk. gry.; v. f. grn.; w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained.	10	80
6	Sandstone; qtz.; lt. gry.; m. grn.; mod. w. srted. Qtz. grains rd. to sbrd. Hydrocarbon stained.	5	70
7	Sandstone; qtz.; lt. to dk. gry.; f. grn.; w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained. Cross-bedded sets indicate current directions of 55°, 351°, & 297°.	30	65
8	Sandstone; qtz.; lt. to dk. gry.; m. grn.; mod. w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained cross-bedded sets indicate current direction of 43°, 302°, 342°, & 50°.	35	35

Section 2

Location C N/2 Sec. 9, T. 22 S., R. 13 E.

Moenkopi Formation

Sinbad Member

Limestone; bioclastic; dk. gry.; m. to c. xln. Vugular porosity and hydrocarbon stained. Fossils include bivalves, gastropods, brachiopods, and conodonts (*Parachiroganthus geiser* Clark, *Lonchodina nevadensis* (?), and *Diplododella* sp.).

Lower Member

1	Covered; ss. & sltst. predominate in float.	95	228
2	Siltstone; buff; w. srted. Qtz. grains are rd. to sbrd. Oscillation ripple marks indicate a current trending 45°.	5	133
3	Covered; sltst. predominates in float.	40	120
4	Sandstone; interbed. sltst.; lt. gry. to buff; f. grn.; thin bed.	2	88
5	Sandstone; calc.; cgl.; bimodal. Qtz. grains are rd. to sbrd. (1/16-1/4 mm). Chert clasts are ang. to subang. (4-16 mm).	3	86
6	Sandstone; calc.; w. srted. Qtz. grains are rd. to sbrd. Oscillation ripple marks in lower 2 feet indicate a current trending 13°.	9	83
7	Siltstone; buff to lt. gry.; w. srted.	2	74
8	Sandstone dirty; v. p. srted. Qtz. grains are rd. to sbrd. (60% of rock). Volc. shards are ang. to subang. (30% of rock).	2	72
9	Siltstone; w. srted. Qtz. grains are rd. to sbrd. Two inch gyp. beds present throughout unit.	2	70
10	Siltstone; buff w. srted. conglomerate; buff to m. gry.; p. srted.; bimodal. Qtz. grains are rd. to sbrd. (1/16-2 mm). Chert clasts are ang. to sbrd. (1-64 mm).	3 ?	68

NOTE: This unit forms channel fill deposits in well-defined channels, that have cut as deeply as fifteen feet into the underlying Kaibab Formation, and paleosol.

TOTAL Lower Moenkopi Thickness 160

Unconformity

Kaibab Formation

1	Dolomite; buff to m. brn.; f. xln. Porcellaneous chert nodules contain secondary calc. xl. Unidentifiable conodont fragments were found.	10	65
2	Dolomite; slty.; buff to m. brn.; f. xln. Unidentifiable conodont fragments were found.	5	55
3	Dolomite; bioclastic; buff to m. brn.; f. xln. Conodonts were found (<i>Apatognathus</i> (?)).	5	50
4	Dolomite; bioclastic (?); buff to m. brn.; f. xln. Conodont fragments were found.	10	45
5	Limestone; buff to m. brn.; f. xln.	5	35
6	Dolomite; slty.; buff to m. brn.; f. xln.	5	30
7	Limestone; buff to m. brn.; f. xln.	5	25
8	Limestone; slty.; buff to m. brn.; f. xln.	5	20
9	Limestone; buff to m. brn.; f. xln. Abundant chert nodules. Conodont fragments were found.	5	15
	TOTAL Kaibab Thickness	50	

Unconformity

White Rim Sandstone

1	Sandstone; qtz.; lt. gry.; mod. w. srtd. Qtz. grains are rd. to sbrd. Hydrocarbon stained.	5	10
2	Sandstone; qtz.; lt. to dk. gry.; w. srtd. Qtz. grains are rd. to sbrd. Hydrocarbon stained.	5	5

Section 3

Location: C W/2 W/2 NW, Sec. 2, T. 22 S., R. 13 E.

Moenkopi Formation

Simbad Member

Calcirudite; dk. brn.; overlain by sltst., ss., & ls. Conodonts were found (*Parachiroganthus geiseri* Clark, & *Lonchadina nevadensis*).

Lower Member

1	Covered; sltst. predominates in float but ss. present locally.	47	172
2	Sandstone; buff to gn-gry; cliff former; inter-bedded sltst.	15	125
3	Covered; sltst. predominates in float, but ss. present locally.	30	110
4	Sandstone; lt. to m. gry.; f. grn.; f. w. srtd. Sets of cross-strata indicate current directions of 22° and 325°.	10	80
5	Sandstone; lt. brn.; f. grn.; sltst. interbeds.	25	70
6	Siltstone; gn-gry.; thin bedded. Thin gyp. layers present locally.	10	45
7	Sandstone; lt. brn.; f. grn.	2	35
8	Dolomite; slty.; brn. to m. gry. Conodonts were found (<i>Neoprioniodus</i> sp.).	1	33
9	Siltstone, calc.; brn. to gn-gry.; w. std. Qtz. grains are rd. to sbrd. (60% of rock).	2	32
10	Limestone; sdy.; buff; m. xln. Qtz. grains are rd. to sbrd.; fgrn.; w. srtd.	1	30
11	Sandstone; cal.; buff; m. to c. grn.; w. srtd. Qtz. grains are rd. to sbrd. (60% of rock).	2	29

12	Conglomerate; m. to dk. gry.; c. grn.; p. srted. Chert clasts are ang. to subang. Basal most chert is bedded and resembles paleosoil observed in section 2.	2	27
	TOTAL Lower Moenkopi Thickness	147	
Unconformity			
<i>Kaibab Formation</i>			
1	Limestone; sdy.; dolmitic; gry.; c. xln. Qtz. grains are rd. to sbrd.; c. grn.; w. srted. Unidentifiable conodont fragments were found.	5	25
2	Sandstone; calc.; gry.; m. grn.; p. srted. Qtz. grains are rd. to sbrd. Unidentifiable conodont fragments were found in upper 5 feet.	10	20
3	Dolomite; calc.; bioclastic; buff to m. brn.; f. to m. xln. Qtz. clasts are rd. to sbrd. (15% of rock). Fossil debris includes bivalves, brachiopods, gastropods (?), and algae (?).	5	10
4	Limestone; buff to m. brn.; f. xln. NOTE: The contact between the White Rim and Kaibab formations was observed approximately 20 feet below the beginning of the measured section. The contact was irregular, with small scale onlap observed, and was gradational.	5	5
Section 4			
	Location: C N/2, Sec. 23, T. 25 S., R. 9 E.		
Moenkopi Formation			
<i>Sinbad Member</i>			
	Limestone; dolmitic; m. gry. to brn.; c. xln. Hydrocarbon stain present in well-developed vugular porosity. Conodonts were found (<i>Parachiroganthus geiseri</i> Clark, and <i>Parachiroganthus</i> sp.).		
<i>Lower Member</i>			
1	Covered, sltst. predominates in float, but ss. present locally.	20	203
2	Conglomerate; lt. gry. to buff; f. gm.	15	183
3	Covered; sltst. predominates in float.	65	68
4	Siltstone; buff to gn-gray.; f. grn.; w. srted. Abundant gyp. interbeds. Current ripple marks indicate a current direction of 295°.	24	93
5	Conglomerate; calc.; chert pol.; dk. gry. to brn.; p. srted. Qtz. grains are rd. to sbrd. Chert clasts are subang. to sbrd. Outcrop is lenticular and represents a stream channel in Moenkopi. Current ripple marks indicate a current direction of 325°.	1	69
6	Sandstone; buff; w. srted., some interbedded sltst. ..	1	68
7	Siltstone; calc.; buff to m. brn.; f. grn.; w. srted. ..	1	67
8	Siltstone; arenaceous; lt. to m. gry.; biomodal; p. srted. Qtz. grains are rd. to sbrd. (1/4 mm). Chert clasts are ang. to subang. (1/2-1 mm).	2	66
9	Limestone; slty.; lt. to dk. gry.; f. xln.	7	64
10	Siltstone; buff to m. brn.; grades up into slty. ls. and laterally into chert peb. cgl.	1	57
11	Conglomerate; chert peb.; m. to dk. gry.; f. to m. grn.; p. srted. Qtz. grains are rd. to sbrd. Chert clasts are ang. to subang.	3	56
12	Siltstone; calc.; lt. gry. to brn.; mod. w. srted. Grades upward into calc. ss. Hydrocarbon stained.	1	53

13	Conglomerate; chert peb.; m. to dk. gry.; f. grn.; p. srted. Qtz. grains are rd. to sbrd. Chert clasts are ang. to subang. Carb. cement increases upward from 5% at base to 40% in upper foot. Hydrocarbon stained. Cross-strata indicates a current direction of 180°.	3	52
14	Sandstone; qtz.; m. to dk. gry.; f. grn.; w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained. Current ripple marks indicate a current direction of 180°.	1/2	49
15	Conglomerate; chert peb.; m. to dk. gry.; f. grn. p. srted. Qtz. grains are rd. to sbrd. (2 mm). Chert clasts are ang. to subang. (2 mm). Hydrocarbon stained.	1	48.5
16	Sandstone; qtz.; lt. to m. gry.; f. grn.; mod. w. srted. Qtz. grains are rd. to sbrd. Chert clasts are subang.	1/2	47.5
17	Siltstone; calc.; lt. to m. gry.; w. srted.	1	47
	TOTAL Lower Moenkopi Thickness	156	

Unconformity

White Rim Sandstone

1	Limestone; slty.; lt. to m. gry.; f. xln. Intensely bioturbated. Contains large chert nodules. Hydrocarbon stained.	1	46
2	Siltstone; sdy.; lt. to m. gry.; bimodal; mod. w. srted. Intensely bioturbated. Hydrocarbon stained.	2	45
3	Siltstone; lt. to m. gry.; mod. w. srted. Intensely bioturbated-decreases in intensity downward. Chert nodules abundant. Hydrocarbon stained.	8	43
4	Sandstone; dk. gry. to brn.; f. grn.; mod. w. srted. Grades upward into siltstone. Bioturbated. Secondary calcite xls. and limonite concretions abundant locally. Hydrocarbon stained.	15	35
5	Dolomite; dk. brn. to gry.; m. to c. xln. Large chert nodules comprise as much as 30% of the rock. Hydrocarbon stained.	6	20
6	Limestone; slty.; gry. to dk. brn.; f. xln. Chert nodules and sec. calcite slx. abundant. Hydrocarbon stained.	4	14
7	Sandstone; calc.; lt. to m. gry.; f. grn.; w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained. ..	5	10
8	Sandstone; qtz.; wh. to m. gry.; m. grn.; w. srted. Hydrocarbon stained.	5	5

Section 5

Location: SW NW Sec. 12, T. 25 S., R. 9 E.

Moenkopi Formation

Sinbad Member

Limestone; dolmitic; m. to dk. brn.; m. xln. Well-developed vugular porosity. Hydrocarbon stained.

Lower Member

1	Covered; the entire lower member is covered above the basal unit but float indicates the presence of interbed. sltst. & ss. Hydrocarbon staining was observed in some sands.	155	195
2	Conglomerate; chert peb.; calc.; lt. to m. gry.; f. to m. grn.; p. srted. Qtz. grains are rd to sbrd.		

	(1-2 mm). Chert clasts are ang. (2-16 mm). Un- identifiable conodont fragments were found.	4	40
3	Limestone; sdy.; lt. to m. gry.; c. grn.; w. srted. Chert clasts are subang. to sbrd. (1/2-3 mm).	1	36
4	Siltstone; calc.; lt. to m. gry.; w. srted. Qtz. grains are rd to sbrd. Hydrocarbon stained.	1	35
5	Sandstone; calc.; lt. to m. gry.; p. srted. Qtz. grains are rd. to sbrd. Chert nodules enclose Qtz. grains. Hydrocarbon stained.	1	34
6	Sandstone; qtz.; lt. to m. gry.; mod. w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained.	1	33
7	Sandstone; qtz.; m. to dk. gry.; f. to m. grn.; mod. w. srted. Qtz. grains are rd. to sbrd. Dol. clasts are w. rd. Hydrocarbon stained.	2	32
8	Calcarinite; dolmitic; sdy.; m. to dk. gry.; mod. w. srted. Qtz. grains are rd. to sbrd. (30% of rock) Dol. clasts are w. rd. (20% of rock). Hydrocarbon stained.	1	30
	TOTAL Lower Moenkopi Thickness	166	
Unconformity			
<i>White Rim Sandstone</i>			
1	Sandstone; qtz.; m. to dk. gry.; v. f. grn., w. srted. Intensely bioturbated. Hydrocarbon stained.	1	29
2	Siltstone; calc.; buff to m. gry.; f. grn. Bioturbated with locally abundant chert nodules.	3	28
3	Sandstone; calc.; lt. to m. gry.; m. grn.; mod. w. srted. Qtz. grains are rd. to sbrd. Hydrocarbon stained.	5	25
4	Sandstone; qtz.; lt. to m. gry.; m. grn.; w. to mod. w. srted. Hydrocarbon stained. Cross-strata indicate a current direction of 98°.	20	20
Section 6			
	Location: E/2 E/2 SE SE, Sec. 4, T. 21 S., R. 13 E.		
Moenkopi Formation			
<i>Sinbad Member</i>			
	Limestone; bioclastic; dk. brn.; m. to t. bed. Fossil representatives include bivalves, brachiopods, and gastropods.		
<i>Lower Member</i>			
1	Siltstone; gn-gry.; f. grn.; thin bed to lam. Nu- merous gypsum layers.	15	310
2	Siltstone; gn. to lt. red.; thin bed.	35	295
3	Siltstone; lt. red; thin bed.	25	260
4	Siltstone; interbed. red & gn.; thin bed.	5	235
5	Siltstone; dk. red; thin bed to lam.	50	230
6	Covered; sltst. predominates in float.	50	180
7	Siltstone; gn-gry.; lam.	30	130
8	Siltstone; interbed. red & gn.; f. lam.	5	100
9	Sandstone; lt. red; thin to m. bed.	5	95
10	Siltstone; gn.; lam.	5	90
11	Siltstone; dk. red; thin bed at base to lam. at top.	10	85
12	Siltstone; dk. red; w. srted.; thin bed.	5	75
13	Siltstone; sdy.; m. to dk. red; f. to m. grn.; mod. w. srted.; thin bed. Qtz. grains are rd. to sbrd.	5	70

14	Siltstone; lt. to m. gry.; w. srted.; lam.	5	65
15	Siltstone; lt. red; w. srted.; thin bed.	5	60
16	Siltstone; dk. red; c. grn.; w. srted.; lam. Qtz. grains are rd. to sbrd.	11	55
17	Limestone; sdy.; m. to dk. gry.; mod. w. srted.; m. bed. Qtz. grains are rd. to sbrd. (30% of rock). Abundant chert nodules (30% of rock).	1	44
18	Conglomerate; chert peb.; m. to dk. gry.; p. srted. thin bed. Qtz. grains are rd. to sbrd. Chert clasts are ang. to subang.	1	43
19	Sandstone; lt. to m. gry.; c. grn.; mod. w. srted. thin bed. Qtz. grains are rd. to sbrd. Chert clasts are subang.	1	42
20	Siltstone; dolmitic; lt. to m. gry.; mod. w. srted. m. bed. Qtz. grains are rd. to sbrd. Carbonate matrix comprises about 60% of the rock.	1	41
	TOTAL Lower Moenkopi Thickness	269	

Unconformity

Kaibab Formation

1	Dolomite; slty.; buff to lt. gry.; Hydrocarbon stain in well-developed vugular porosity.	5	40
2	Dolomite; buff to m. brn.; m. bed. Abundant chert nodules and limonite pseudomorphs after pyrity.	5	35
3	Dolomite; bioclastic; buff to m. brn.; m. xln.; m. bed. Hydrocarbon stained. Fossil representatives include bivalves, brachiopods, crinoidal debris and unidentifiable conodont fragments. Cross-bedding indicates a current direction of 315°.	5	30
4	Dolomite; slty.; buff to m. brn. Abundant chert nodules present. Fossil representatives include unidentifiable conodont fragments and the sponge <i>Actinocoelia maeandria</i> Finks.	5	25
5	Dolomite; bioclastic; buff to m. brn.; thick bed. Fossil representatives include bivalves, brachiopods, and crinoidal debris.	5	20
6	Limestone; bioclastic; buff to m. brn.; thick bed. Fossil representatives include bivalves, brachiopods, crinoidal debris and conodonts (<i>Apatognathus</i> (?), and <i>Hideoella</i> (?)).	5	15
7	Dolomite; slty.; buff to lt. gry.; thick bed. Abundant chert nodules are present. Conodonts (<i>Streptognathodus</i> sp.) were found.	5	10
8	Dolomite; bioclastic; buff to m. brn.; thick bed. Abundant chert nodules are present. Crinoidal debris is abundant.	5	5
	NOTE: The Kaibab continued for approximately 90 feet below the beginning of the measured section to where it overlies the White Rim Sandstone.		
	TOTAL Kaibab Thickness	130	

Section 7

Location: C W/2 NW, Sec. 5, T. 21 S., R. 12 E.

Moenkopi Formation

Sinbad Member

Limestone; dk. brn.; m. to thick bed.

Lower Member

1	Siltstone; buff to pale yel.; m. to thin bed. Thin interbeds of shale, gypsum, and limestone.	15	285
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2	Siltstone; buff to pale yel.; thin bed. Thin shale interbeds.	90	270
3	Siltstone; dk. red; thin bed. Oscillation ripple marks indicate currents trending 270° and 35°.	5	180
4	Siltstone; buff to lt. brn.; thin bed to lam. Numerous shale interbeds.	75	175
5	Siltstone; buff to lt. brn.; thin bed. A 6-inch limestone was noted in the center of the unit.	5	100
6	Siltstone; buff to lt. brn.; thin bed.	10	95
7	Siltstone; dk. gn-gry.; c. to m. grn.; thin bed. Qtz. grains are rd. to sbrd. Numerous ls. interbeds throughout unit.	10	85
8	Siltstone; calc.; buff to lt. gry.; w. srtd.; thin bed to lam. Qtz. grains are rd. to sbrd. Thin gyp. interbeds in upper 2 feet.	10	75
9	Covered; sltst. predominates in float.	30	65
10	Conglomerate; chert peb.; calc.; m. to dk. gry.; m. grn.; p. srtd.; thin bed. Qtz. grains are rd. to sbrd. Chert clasts are ang. to subang. Calcite cement comprises about 40% of the rock. Grades laterally into c. grn. ss.	3	35
	TOTAL Lower Moenkopi Thickness	250	

Unconformity

	<i>Kaibab Formation</i>	
1	Limestone; dolmtc.; lt. to m. gry.; m. bed. Abundant sec. calcite xls. present.	7 32
2	Limestone; bioclastic; buff to m. brn.; m. bed. Well-developed vugular porosity contains sec. calcite xls. Fossil representatives include bivalves, brachiopods and crinoidal debris.	5 25
3	Limestone; sdy. buff to m. brn.; m. bed. Abundant chert nodules are present.	5 20
4	Dolomite; bioclastic; buff to m. brn.; m. to thick bed. Qtz. grains are rd. to sbrd. and were observed in lower 3 feet. Abundant nodular chert was present throughout the unit.	15 15

Section 8

Location: SW NW NW, Sec. 3, T. 22 S., R. 12 E.

Moenkopi Formation

Sinbad Member

Limestone; bioclastic; m. to dk. brn.; c. xln.; m. bed. Fossil representatives include bivalves, brachiopods, and gastropods.

Lower Member

1	Sandstone; dolmtic.; lt. to m. brn.; f. to m. grn. Minor sltst. and sh. interbeds occur throughout the unit.	23	308
2	Sandstone; calc.; lt. brn. to gry.; f. grn. Local sltst. interbeds are present. Oscillation ripple marks indicate a current trending 345°.	45	285
3	Siltstone; dk. gry.; f. grn.; lam. Minor f. grn. ss. interbeds occur throughout unit. Hydrocarbon stained locally.	130	240
4	Siltstone; calc.; m. to dk. gn-gry.; thin bed to lam.	10	110

5	Covered; siltstone predominates in float.	25	100
6	Sandstone; qtz.; m. brn. to gry.; f. grn.; thin bed. Qtz. grains are rd. to sbrd.	3	75
7	Covered; siltstone predominates in float.	5	72
8	Siltstone; dk. brn.; thin bed to lam.; f. to m. grn. gyp. interbeds occur throughout the unit.	5	67
9	Sandstone; qtz.; dk. brn.; m. grn.; w. srted. Qtz. grains are rd. to sbrd. Cross-bedding indicates a current direction of 315°.	5	62
10	Siltstone; gry-grn.; lam. Minor ss. interbeds occur throughout unit. Cross-bedding indicates a current direction of 348°.	10	57
11	Covered; siltstone predominates in float.	25	47
12	Limestone; sdy.; m. to dk. gry.; c. grn.; p. srted. m. bed. Qtz. grains are rd. to sbrd. (35% of rock). Chert clasts are ang. to subang. (15% of rock).	2	22
13	Conglomerate; chert peb.; calc.; lt. to m. gry. f. grn.; p. srted.; m. bed. Qtz. grains are rd. to sbrd. Chert clasts are ang. to subang.	5	20
	TOTAL Lower Moenkopi Thickness	293	

Unconformity

Kaibab Formation

1	Dolomite; bioclastic; buff to m. brn.; m. xln. thin bed. Floating qtz. grains (5% of rock) are rd. to sbrd. and increase downward to a max. of 15% in the lower 10 feet.	15	15
	NOTE: The Kaibab is exposed for approximately 65 feet below the beginning of the measured section but the White Rim Sandstone is not exposed in the area.		
	TOTAL Kaibab Thickness	80+	

Section 9

Location: NE SW, Sec. 28, T. 22 S., R. 12 E.

Sinbad Member

Limestone; bioclastic; lt. to m. brn.; c. xln. m. to thick bed. Minor sandstone interbeds occur in basal unit. Fossil representatives include bivalves, brachiopods, and gastropods.

Lower Member

1	Siltstone; calc.; buff to m. brn.; thin bed. Local gyp. interbeds occur throughout unit.	3	140
2	Covered; sltst. predominates in float.	35	137
3	Siltstone; calc.; buff to gn-gry.; m. bed. Qtz. clasts are rd. to sbrd.	5	102
4	Covered; float indicates that underlying rocks consist of interbedded ss. and sltst.	75	97
5	Siltstone; calc.; lt. to m. yel. brn.; lam. Minor f. grn. ss. interbeds occur throughout unit. Qtz. grains are rd. to sbrd. and are set in calc. matrix comprising as much as 40% of the rock.	12	22
6	Sandstone; calc.; m. to dk. brn.; c. grn.; mod. w. srted.; thin bed. Qtz. grains are rd. to sbrd. and are set in a calc. matrix comprising about 20% of the rock.	3	10
	TOTAL Lower Moenkopi Thickness	133	

Unconformity

Kaibab Formation

- 1 Dolomite; slty; buff to m. brn.; f. xln.; thick bed. Chert nodules are abundant. 7 7

NOTE: A well-defined onlap relationship was observed between the Kaibab and White Rim formations with the Kaibab Formation thickening 40 feet within 500 yards from 0 on the south to 40 feet on the north.

Unconformity

White Rim Sandstone

The White Rim consists of a series of bioturbated poorly bedded siltstones and calcareous siltstones which are approximately 20 feet thick. This unit overlies a 7-foot thick horizontally bedded unit which truncates and overlies a cross-bedded unit.

Section 10

Location: S/2 N/2 SE, Sec. 28, T. 23 S., R. 11 E.

Moenkopi Formation

Sinbad Member

Limestone; dk. gry. to brn.; m. to c. xln.; m. bed.

Lower Member

1	Dolomite; silic.; buff; f. xln.; m. bed.	20	215
2	Siltstone; buff; thin bed to lam.	35	195
3	Covered; sltst. predominates in float.	35	160
4	Limestone; slty.; buff to m. brn.	5	140
5	Covered; sltst. predominates in float.	25	135
6	Siltstone; calc.; m. brn. to gn-gry.; c. xln.; lam.	5	110
7	Covered; float indicates that the underlying rocks are interbedded sltst. and ss.	30	105
8	Siltstone; calc.; dk. brn.; m. grn.; thin bed. Qtz. grains are rd. to sbrd. and are set in a calc. matrix comprising about 30% of the rock.	20	75
9	Covered; sltst. predominates in float.	5	55
10	Siltstone; slightly calc.; lt. brn. to gn-gry.; lam. Qtz. grains are rd. to sbrd.	5	50
11	Covered; sltst. predominates in float.	10	45
12	Conglomerate; chert peb.; calc.; m. to dk. gry.; f. grn.; p. srted.; thin bed. Qtz. grains are rd. to sbrd. Chert and dol. clasts are ang. to subang. Unit becomes more w. srted. downward as it loses its f. grn. sands.	10	35
	TOTAL Lower Moenkopi Thickness	190	

Unconformity

Kaibab Formation

1	Limestone; bioclastic; dolmitic; buff to m. brn.; f. xln.; m. bed.	5	25
2	Dolomite; bioclastic; buff to m. brn.; f. xln.; m. bed.	5	25
3	Limestone; dolmitic; m. to dk. brn.; c. xln.; thin bed.	5	15

4	Dolomite; slty.; buff to m. brn.; c. xln.; m. bed. Chert nodules present in lower portion of unit.	10	10
	NOTE: The White Rim-Kaibab contact was approximately 65 feet below the beginning of the measured section.		
	TOTAL Kaibab Thickness	90	

Section 11

Location: C N/2, Sec. 17. T. 24 S., R. 11 E.

Moenkopi Formation

Sinbad Member

Limestone; bioclastic; m. to dk. brn.; m. to c. xln.; m. bed. Overlies thin calcirudite.

Lower Member

1	Siltstone; buff to lt. brn.; thin bed to lam.	64	194
2	Siltstone; slightly calc.; buff to lt. gn-gry; thin bed.	5	130
3	Covered; sltst. predominates in float.	10	125
4	Siltstone; m. brn. to gn-gry.; thin bed to lam. Qtz. grains are rd. to sbrd.	5	115
5	Covered; sltst. predominates in float.	10	110
6	Limestone; slty.; buff to gn-gry.; f. xln.; thin bed.	5	100
7	Siltstone; m. to dk. brn.; c. grn.; lam. Qtz. grains are rd. to sbrd.	10	95
8	Covered; float indicates that underlying rocks consist of interbedded sltst. and f. grn. ss.	12	85
9	Siltstone; slightly calc.; dk. gn-gry.; lam. Hydrocarbon stained.	5	73
10	Conglomerate; chert peb.; m. to dk. gry.; f. grn.; p. srted.; thin to m. bed. Interbedded with c. grn. ss. in channel in Kaibab. Qtz. grains are rd. to sbrd. Chert clasts are ang. to subang.	10	68
	TOTAL Lower Moenkopi Thickness	136	

Unconformity

Kaibab Formation

1	Dolomite; calc.; lt. to dk. brn.; c. xln.	3	58
2	Limestone; slty.; m. to dk. brn.; c. xln.; m. to thick bed.	10	55

NOTE: Unit 2 pinches out on either side of a White Rim high composed of very calc. mdst.

TOTAL Kaibab Thickness

Unconformity

White Rim Sandstone

1	Mudstone; calc.; m. to dk. gry.; Forms elongate White Rim high (approx. 100 yds. long).	10	45
2	Siltstone; calc.; m. to dk. gry.; intensely bioturbated. Oil filled geodes and silic. burrows are prolific.	20	35
3	Sandstone; lt. to m. gry.; f. grn.; mod. to intensely bioturbated (<i>Ophiomorpha</i>). Hydrocarbon stained.	15	15

NOTE: The underlying White Rim consists of the normal qtz. ss. of the formation.

APPENDIX B

SUBSURFACE DATA

SECTION NUMBER	WELL NAMES AND LOCATIONS	THICKNESS DATA	
		LOWER MOENKOPI	KAIBAB FORMATION
12	Mt. Fuel Supply Co., Farnham Dm. Petr. Co. No. 1 SW NW SE-Sec. 12, T. 14 S., R. 11 E.	342	103
13	Shell Oil Co., No. 1-a Farnham Dome Unit C SW SW-Sec. 8, T. 15 S., R. 12 E.	370	75
14	Cities Service, Government No. 1 NE NW-Sec. 1, T. 16 S., R. 12 E.	322	138
15	El Paso Nat. Gas. Pack Saddle No. 1 NE SE NE-Sec. 12, T. 18 S., R. 12 E.	262	63
16	Utah Oil & Refin. Co., WM. Fitzhugh No. 1 SW SE-Sec. 12, T. 19 S., R. 13 E.	265	80
17	Tenneco. No. 5 Ferron Unit NW SE-Sec. 21, T. 20 S., R. 7 E.	257	139
18	Skyline Oil Co., No. 1 Green River Unit NE NW-Sec. 33, T. 21 S., R. 16 E.	151	46
19	Skelly Oil Co., No. 1 Emery Unit C SW SE-Sec. 34, T. 22 S., R. 5 E.	185	145
20	Amerada Petr. Co., No. 1 U.S.A.-Colman NW SW-Sec. 17, T. 23 S., R. 9 E.	263	0
21	Lion (Monsanto), No. 1 Federal-Hatt SE SE-Sec. 19, T. 23 S., R. 14 E.	159	0
22	Mobil Oil Co., No. 12-3 Jukeys Ridge E/2 SW NW-Sec. 3, T. 23 S., R. 16 E.	215	0
23	Amerada Petr. Co., No. 1-362 Strat NE SE-Sec. 7, T. 24 S., R. 9 E.	135	35
24	Superior Oil Et. Al., No. 23-2 Iron Wash C NE SW-Sec. 2, T. 24 S., R. 13 E.	128	0
25	Shell Oil Co., No. 1 Gruvers Mesa W/2 SW NE-Sec. 19, T. 24 S., R. 16 E.	212	0
26	American Liberty Oil Co., No. 1 Government Well C NE SW SW-Sec. 13, T. 25 S., R. 5 E.	137	140
27	Union Oil of Calif., No. 019-1 Temple Wash- Govrn. SW SE-Sec. 1, T. 25 S., R. 12 E.	146	0
28	AMOCO, No. 1 U.S.A. Brown NW NW-Sec. 24, T. 24 S., R. 12 E.	*	73
29	Delhi Oil Corp., No. 1 Russell SW SW-Sec. 34, T. 25 S., R. 12 E.	*	142
30	Texaco, Inc., No. 2 Temple Springs Unit SE SW-Sec. 22, T. 25 S., R. 14 E.	170	0
31	Stand. Oil of Calif., No. 1 Lookout Point SE SW-Sec. 29, T. 25 S., R. 16 E.	68	0
32	Texaco, Inc., No. 1 Govrn.-Stevenson-A SE NW-Sec. 14, T. 26 S., R. 8 E.	89	56
33	Amer. Metal Climax., No. 1 Govrn. Maroni Slopes E/2 NE NE-Sec. 13, T. 27 S., R. 8 E.	102	96
34	Carter Oil Co., No. 1 Blackburn Draw Unit NE NE-Sec. 9, T. 27 S., R. 12 E.	198	59

35	Superior Oil Co., No. 31-30 Hanksville Unit NW NE-Sec. 30, T. 27 S., R. 13 E.	37	13
36	Belco Petr. Co., No. 1 Henry Mt. Unit SE SE-Sec. 20, T. 31 S., R. 11 E.	382	44
37	Tenn. Gas, No. 1-A U.S.A. Poison Springs SW SW NE-Sec. 4, T. 31 S., R. 12 E.	233	0
38	Carter Oil Co., No. 1 Dugout Creek NE SE-Sec. 21, T. 24 S., R. 14 E.	*	0
39	Stand. Oil of Calif., No. 1 Bert Mesa Unit NE SW SE-Sec. 13, T. 31 S., R. 13 E.	*	0
40	Pure Oil Co., No. 1-A Washboard Wash- U.S.A. NE NW-Sec. 12, T. 16 S., R. 9 E.	*	186
41	Chev. Oil Co., No. 1 Willson (24-28) SE SW-Sec. 28, T. 16 S., R. 10 E.	327	177
42	AMOCO, No. 1 Federal-Mounds NW SE-Sec. 11, T. 16 S., R. 11 E.	345	117
43	Phillips Petr., No. 1 Huntington Unit SE NW-Sec. 15, T. 17 S., R. 8 E.	308	144
44	Pure Oil Co., No. 1 Desert Lake NW SE-Sec. 1, T. 17 S., R. 10 E.	*	181
45	Austral Oil Co., No. 1-27 Federal SW NE-Sec. 27, T. 18 S., R. 11 E.	328	45
46	Reynolds Mining Corp., No. 2 Sinbad Unit NW NE-Sec. 26, T. 22 S., R. 12 E.	223	82
47	AMOCO, No. 1 Anderson-Federal S/2 SW SE-Sec. 24, T. 23, S., R. 15 E.	*	10
48	Shell Oil Co., No. 1 Chaffin Unit NE NW-Sec. 21, T. 23 S., R. 15 E.	178	0
49	Tidewater Oil Co., Big Flat Top-Sweetwater Sec. 25, T. 26 S., R. 13 E.	58	0
50	Pacific Western, Unit No. 1-Teasdale Sec. 17, T. 30 S., R. 6 E.	117	184
51	Mt. Fuel Supply Co., So Last Chance Unit-1-A Sec. 18, T. 26 S., R. 6 E.	135	67
52	Ohio Oil Co., No. 1 Unit Sec. 22, T. 28 S., R. 8 E.	29	0
53	Mt. Fuel Supply Co., No. 1-A Sec. 18, T. 26 S., R. 7 E.	29	29
54	Hallgarth-1962 (measured section) Sec. 20, T. 23 S., R. 13 E.		28
55	M. M. Knechtel (Baker, 1946) (measured section) Sec. 26, T. 24 S., R. 11 E.	142	31

REFERENCES CITED

- Baars, D. L., 1962, Permian System of the Colorado Plateau: Am. Assoc. Petrol. Geol. Bull., v. 45, no. 2, p. 149-218.
- Baars, D. L., & Seager, W. R., 1970, Stratigraphic control of petroleum in White Rim Sandstone (Permian) in and near Canyonlands National Park, Utah: Am. Assoc. Petrol. Geol. Bull., v. 54, no. 5, p. 709-718.
- Baer, J. L., 1971, An occurrence of *Ophiomorpha* in Permian strata, southeastern Utah: Geol. Soc. Am. Abs. with Prog., Rocky Mt. Sect., Calgary, Alberta, Canada, p. 366-367.
- Baker, A. A.; and Reeside, J. B., Jr., 1929, Correlation of the Permian of southern

- Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petrol. Geol. Bull., v. 13, p. 1413-1448.
- Baker, A. A., 1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, & Garfield counties, Utah: U. S. Geol. Survey Bull. 951, 122 p.
- Bissell, H. J., 1964, Ely, Arcturus, & Park City Groups (Pennsylvanian-Permian) in eastern Nevada & western Utah: Am. Assoc. Petrol. Geol. Bull., v. 48, no. 5, p. 565-636.
- , 1970, Realms of Permian tectonism & sedimentation in western Utah & western Nevada: Am. Assoc. Petrol. Geol. Bull., v. 54, no. 2, p. 285-312.
- Clark, D. L., 1959, Conodonts from the Triassic of Nevada and Utah: Jour. Paleo., v. 33, no. 2, p. 305-312.
- Clark, D. L., & Ethington, R. L., 1962, Survey of Permian Conodonts in western North America: Brigham Young Univ. Geol. Studies, v. 9, pt. 2, p. 102-114.
- Dake, C. L., 1920, The pre-Moenkopi unconformity of the Colorado Plateau: Jour. Geol., v. 28, no. 1, p. 61-74.
- Dane, C. H., 1935, Geology of Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geol. Survey Bull. 863, 184 p.
- Dunbar, C. O., & Rodgers, J., 1957, Principles of stratigraphy; sixth printing: John Wiley & Sons, Inc., New York, (1966), p. 341.
- Fetzner, R. W., 1960, Pennsylvanian paleotectonics of Colorado Plateau: Am. Assoc. Petrol. Geol. Bull., v. 44, p. 1371-1413.
- Finks, R. M., 1960, Late Paleozoic sponge fauna of the Texas Region: Bull. Am. Mus. Nat. Hist., v. 120, article 1, New York, p. 160.
- Finks, R. M., Yochelson, E. L., & Sheldon, R. P., 1961, Stratigraphic implications of a Permian sponge occurrence in the Park City Formation of western Wyoming: Jour. Paleo., v. 35, no. 3, p. 564-568.
- Gilluly, J., & Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150.
- Gilluly, J., 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806-C, p. 69-130.
- Hallgarth, W. E., 1962, Upper Paleozoic rocks exposed in Straight Wash Canyon, San Raphael Swell, Utah: Am. Assoc. Petrol. Geol. Bull., v. 46, no. 8, p. 1494-1501.
- Hawley, C. D., *et al.*, 1968, Geology, altered rocks and ore deposits of the San Raphael Swell-Emery County, Utah: U. S. Geol. Survey Bull. 1239, p. 111.
- Herman, G., & Sharps, S. L., 1956, Pennsylvanian and Permian stratigraphy of the Paradox Salt Embayment: Intermtn. Assoc. Petrol. Geol., 7th Ann. Field Conf. Guidebook, p. 77-84.
- Hoyt, J. H., & Weimer, R. J., 1965, The origin and significance of *Ophiomorpha* (Halymenites) in the Cretaceous of the western interior: Wyo. Geol. Assoc. Guidebook, 19th Field Conf., p. 203-207.
- Kelley, V. C., 1955, Tectonics of the Four Corners region: Four Corners Geol. Soc. Guidebook, p. 108-117.
- Kunkel, R. P., 1958, Permian stratigraphy of the Paradox Basin: Intermtn. Assoc. Petrol. Geol. 9th Ann. Field Conf. Guidebook, p. 163-168.
- Longwell, C. R., 1921, Geology of the Muddy Mountains, Nevada, with a section to the Grand Wash Cliffs in western Arizona: Am. Jour. Sci., 5th ser., v. 1, 139-62.
- , 1925, Pre-Triassic unconformity in southern Nevada: Am. Jour. Sci., 5th Ser., v. 10, p. 93-106.
- McKee, E. D., 1938, The environment and history of the Toroweap and Kaibab Formations of northern Arizona and southern Utah: Carnegie Inst. Wash. Pub. 492, 268 p.
- , 1954, Permian stratigraphy between Price and Escalante, Utah: Intermtn. Assoc. Petrol. Geol., 5th Ann. Field Conf. Guidebook, p. 21-24.
- , 1954a, Stratigraphy and history of the Moenkopi Formation of Triassic age: Geol. Soc. Am. Mem. 61, 133 p.
- McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand, and San Juan Counties, Utah: U. S. Geol. Survey Bull. 908, 90 p.
- Mosher, L. C., 1968, Triassic conodonts from western North America and Europe and their correlation: Jour. Paleo., v. 42, no. 4, p. 895-946.
- Müller, K. J., 1956, Triassic conodonts from Nevada: Jour. Paleo., v. 33, no. 4, p. 818-830.
- Newell, N. D., 1967, Paraconformities: Essays in Paleo and Strat., Univ. Kansas, Dept. Geol. Spec. Pub. 2, p. 349-367.

- Ohlen, H. R., & McIntyre, L. B., 1965, Stratigraphy and tectonic history of Paradox Basin, Four Corners area: *Am. Assoc. Petrol. Geol. Bull.*, v. 49, p. 2020-2040.
- Pettijohn, R. J., 1949, *Sedimentary rocks*; second edition (1957): Harper and Row Publishers, New York, 701 p.
- Reeside, J. B., Jr., & Bassler, H., 1922, Stratigraphic sections in southwestern Utah, and northwestern Arizona: *U. S. Geol. Survey Prof. Paper* 129.
- Repenning, C. A., et. al., 1969, Stratigraphy of the Chinle and Moenkopi Formations, Navajo and Hopi Indian Reservations Arizona, New Mexico, and Utah: *U. S. Geol. Survey Prof. Paper* 521-B.
- Shimer, H. W., 1919, Permo-Triassic of northwestern Arizona: *Geol. Soc. Am. Bull.*, v. 30, no. 4, p. 471-497.
- Stewart, J. H., & Smith, J. R., Jr., 1954, Triassic rocks in the San Rafael Swell, Capitol Reef, and adjoining parts of southeastern Utah: *Intermtn. Assoc. Petrol. Geol.*, 5th Ann. Field Conf. Guidebook, p. 25-33.
- Stewart, J. H., 1956, Triassic strata of southeastern Utah and southwestern Colorado: *Intermtn. Assoc. Petrol. Geol. Guidebook, Geology and Economic Deposits of east-central Utah*, p. 85-92.
- Stewart, J. H., et al., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau: *U. S. Geol. Survey Bull.* 1946-q.
- Ward, L. F., 1901, Geology of the Little Colorado Valley: *Am. Jour. Sci.*, 4th ser., v. 12, p. 401-413.
- Weller, J. M., 1960, *Stratigraphic principles and practice*: Harper and Row Publishers, New York, p. 683.