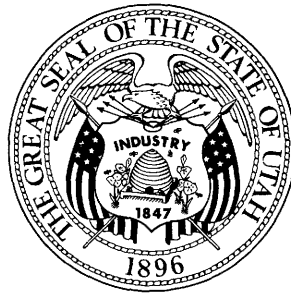


Stratigraphic and Depositional Analysis of the Moenkopi Formation, Southeastern Utah

by
R. C. Blakey



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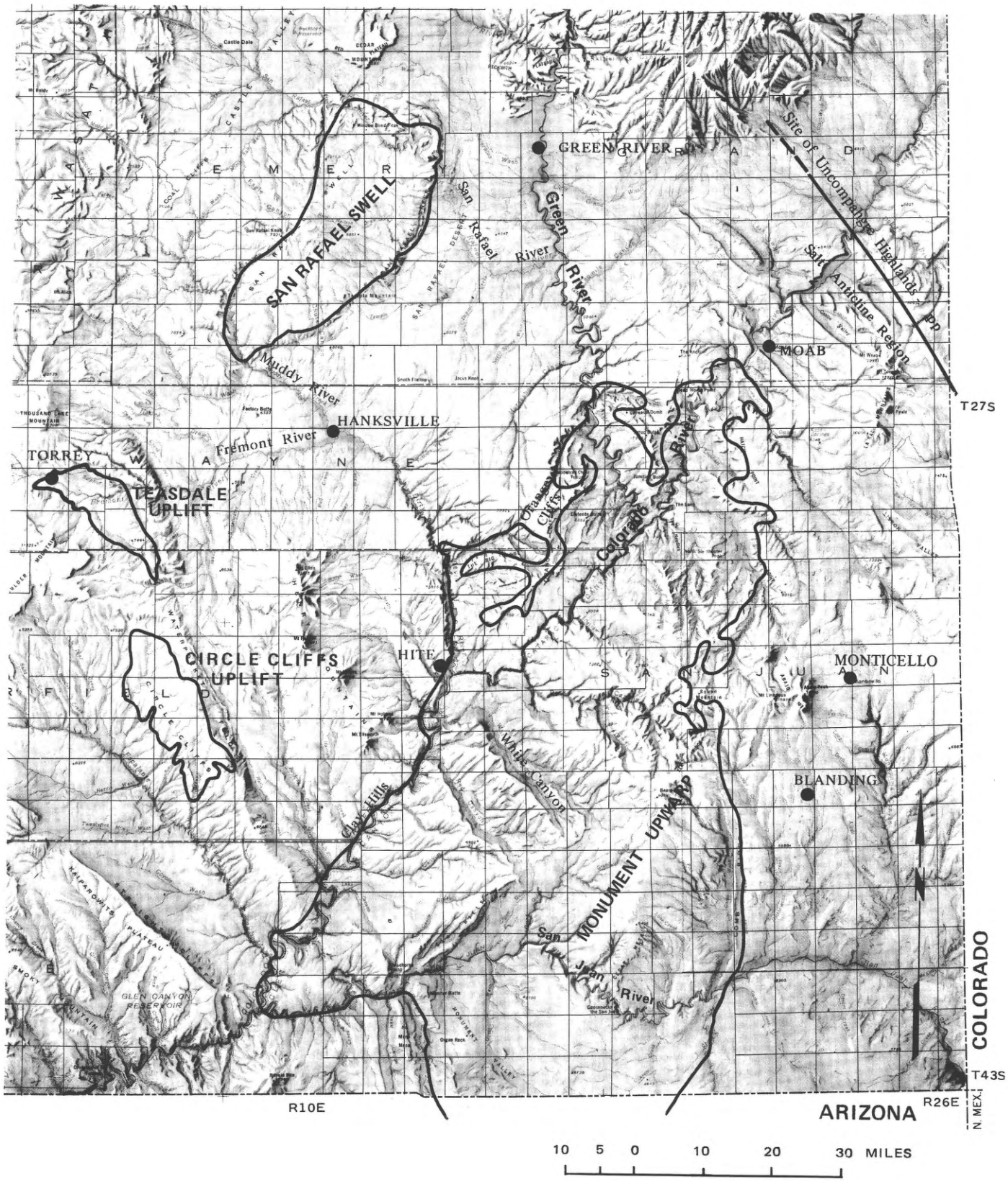


Figure 1. Map of southeastern Utah showing area of study.

STRATIGRAPHIC AND DEPOSITIONAL ANALYSIS OF THE MOENKOPI FORMATION, SOUTHEASTERN UTAH

by R. C. Blakey¹

ABSTRACT

The Triassic Moenkopi Formation of southeastern Utah comprises red and yellowish gray siltstone, sandstone, limestone, mudstone, and local conglomerate. Extensive exposures in the San Rafael Swell, Teasdale and Circle Cliffs Uplifts, and Monument Upwarp were studied for continuity of individual units and a number of key horizons to provide a basis for regional correlation and division of the Moenkopi into four members: (1) Black Dragon (new), (2) Sinbad Limestone, (3) Torrey (new), and (4) Moody Canyon (new).

Dark reddish brown, very poorly sorted sandstone and siltstone in regularly "bedded" sets and cosets constitute the Hoskinnini Formation; it is present over most of the Monument Upwarp area. The Black Dragon Member of the Moenkopi Formation consists of micaceous, platy to massive, ripple-marked and cross-stratified sandstone and siltstone with subordinate limestone and gypsum forming a westward-thickening wedge west of the Colorado River. The Sinbad Limestone Member is a generally fossiliferous unit containing the *Meekoceras* fauna and comprises a broad suite of limestone and dolomite as well as local quartz sandstone, siltstone, and conglomerate. Ledge- and cliff-forming, very fine-grained sandstone and siltstone are the diagnostic characteristics of the Torrey Member. Although present over the entire area of study, the ledgy units are most prominent in a lobe-shaped body extending throughout the eastern and central areas of study. Mudstone, sandy siltstone, and gypsum comprise the Moody Canyon Member which is present over the entire area of study, but thickest (400 feet) in the western portion.

The Moenkopi and Hoskinnini were deposited in several episodes related to transgression and regression of shallow seas across a moderately uniform and gentle west slope. The isolated nature of the Hoskinnini Basin as well as a lack of fluvial criteria suggest deposition of that unit in a lake or restricted arm of the sea. A lower marine and paralic episode deposited the Black Dragon and Sinbad Limestone Members of the Moenkopi in a variety of shallow marine and shoreline environments. The Torrey Member was deposited under deltaic conditions spreading westward into the Sinbad sea; horizontal distribution of ledgy sandstone and a vertical sequence of facies provide the evidence of deltaic deposition. The Moody Canyon Member was deposited

adjacent to or in a shallow sea. This upper marine and paralic episode was probably followed by a brief local fluvial episode preceding pre-Chinle erosion.

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A number of persons and organizations cooperated with me on this project and I wish to extend my appreciation to the following: Drs. William Furnish and Philip Heckel of the University of Iowa criticized the manuscript and provided numerous stratigraphic and environmental suggestions; Dr. W. L. Stokes of the University of Utah examined fossils and extended much advice concerning Triassic stratigraphy. Mr. Howard Ritzma of the Utah Geological and Mineral Survey directed general field operations and provided much other assistance; Sam Quigley served as field assistant. Clark Kiser of Energetics Incorporated and Dr. John Stewart of the U. S. Geological Survey provided subsurface data and preliminary manuscripts on the Moenkopi Formation respectively; Jim Minick of Atlantic Richfield Corporation accompanied me to the field and assisted with field interpretations. Much gratitude is extended to my wife Dee who served as a field assistant and typed the manuscript.

INTRODUCTION

The Moenkopi Formation forms part of a thick redbed sequence laid down over the Colorado Plateau and adjacent areas during the Pennsylvanian, Permian, Triassic, and Jurassic periods. Because of its distinctive color and its stratigraphic position between two major unconformities, it was one of the first units of this sequence to be recognized and formally named (Ward, 1901).

Methods and Scope

This study was initiated in the summer of 1970 with mapping of tar-impregnated sandstone bodies in the Moenkopi Formation of the San Rafael Swell, Emery County, Utah (figure 1; plate 1), under auspices of the Utah Geological and Mineral Survey. Data gained working in the Swell, combined with that obtained on field trips to the Moenkopi in adjacent areas of southeastern Utah, suggested the correlation of some of the units in the formation across much of the region.

Twenty-four complete sections and several partial ones were measured in southeastern Utah (table 1). The San Rafael Swell, Teasdale Uplift, and the northwest and

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Table 1. Names and locations of complete measured sections.

Area of Study

Number	Name	Location	
		Township	Range
SAN RAFAEL SWELL			
1	Black Dragon Canyon	21 S.	13 E.
2	Red Canyon	20 S.	12 E.
3	Cottonwood Draw- Windowblind Butte	21 S.	11 E.
4	Iron Wash	23 S.	11 E.
5	Temple Mountain	24 S.	11 E.
6	Chute Canyon	25 S.	10 E.
TEASDALE UPLIFT			
7	Torrey	29 S.	4 R.
8	Sulphur Creek	29 S.	6 E.
9	Pleasant Creek	30 S.	7 E.
CIRCLE CLIFFS			
10	Studhorse Peaks	34 S.	7 E.
11	Wagonbox Mesa	34 S.	7 E.
MONUMENT UPWARP			
12	Kane Springs Canyon	27 S.	21 E.
13	Shafer Trail	27 S.	19 E.
14	Stillwater Canyon	27 S.	17½ E.
15	Millard Canyon	28 S.	17 E.
16	Elaterite Canyon	31 S.	17 E.
17	Sunset Pass	31 S.	16 E.
18	Poison Spring Canyon	31 S.	14 E.
19	North Wash	33 S.	14 E.
20	Copper Point	34 S.	14 E.
21	Fry Canyon	37 S.	16 E.
22	Hideout Canyon	36 S.	17 E.
23	Bears Ears	37 S.	18 E.
24	North Long Point	34 S.	19 E.

central sections of the Monument Upwarp were the areas most intensively studied (figure 1). The Circle Cliffs Uplift and southern section of the Monument Upwarp received less attention. Nearly all the outcrop areas of the Moenkopi in southeastern Utah were visited. The Salt Anticline region was visited but is not directly involved in this report. Standard field methods were used. Several hundred samples were collected; about 100 thin-sections were made and studied, and many of the other samples were examined by hand lens or binocular microscope.

Continuity of individual beds and units combined with generally excellent exposures provided means of correlating and mapping members and facies. Gross stratigraphic relationships of the units suggested general environments of deposition later corroborated or modified by more detailed field and laboratory studies. The ultimate goal of this study is to achieve an understanding of the three-dimensional nature of the Moenkopi and to identify specific environments of deposition for the facies and members of the Moenkopi Formation of southeastern Utah.

Southeastern Utah is in the central part of the Colorado Plateau region. Most of the area is a high desert and canyonlands region which receives less than ten inches of rainfall per year and where local relief of 2,000 feet from the mesa tops to canyon bottoms is not unusual. Outcrop exposures are generally better closer to the canyons because the broader intercanion areas are mantled with thin desert soils, alluvium, or sand dunes.

The Moenkopi is exposed in and along the flanks of the San Rafael Swell, Teasdale, Circle Cliffs, and Monument Uplifts; in the interlying areas it is buried beneath Jurassic and Cretaceous rocks. Maximum distance between uplifts is about 40 miles. Because several units in the Moenkopi form ledges and benches, the outcrops are commonly many miles wide. The San Rafael Swell, Teasdale, and Circle Cliffs Uplifts are referred to as the western area of study; the Monument Upwarp constitutes the eastern area.

Definition of Moenkopi Formation and Previous Work

Ward (1901) proposed the name Moenkopi (originally "Moencopie") for a section of reddish-brown siltstone and sandstone about 300 feet thick, near the junction of Moenkopi Wash and the Little Colorado River in north-central Arizona, a few miles west of the town of Cameron. The type Moenkopi can be traced along outcrops northwestward into southwestern Utah, but about 50 miles separate this outcrop belt from equivalent rocks in southeastern Utah. Because of facies changes and pinchouts of underlying Permian strata, the first usage of the term, Moenkopi Formation, in southeastern Utah was incorrect. Woodruff (1912) and Gregory (1916, 1917) applied the term to strata now assigned to the Permian Organ Rock Formation. Longwell *et al.* (1923) included the Organ Rock, as well as strata now assigned to the Moenkopi, in their description of the Moenkopi Formation. Emery (1918) and Moore (1922) correctly used the term, Moenkopi, as it is now recognized. In a 1929 study of the stratigraphy of Permian rocks on the Colorado Plateau, Baker and Reeside also separated the Organ Rock from the Moenkopi and in addition, recognized and named an intermediate unit, the Hoskinnini, which they considered to be part of the Permian Cutler Group (or Formation). Later Stewart (1959) classified the Hoskinnini as an additional member of the Moenkopi Formation. McKee (1954) completed the first comprehensive report on the Moenkopi Formation emphasizing northern Arizona.

The U. S. Geological Survey Triassic paleotectonic project presented Lower Triassic lithofacies

and generalized paleoenvironments (McKee *et al.*, 1959). The Moenkopi and Chinle Formations of the Navajo Indian Reservation were the subject of a report by Repenning *et al.* (1969), emphasizing stratigraphy and correlation. Orgill (1971) discussed the Permian-Triassic unconformity and the lower portion of the Moenkopi Formation in the San Rafael Swell area. Irwin (1971) presented a regional stratigraphic synthesis based largely on subsurface data of Permian and Triassic rocks of southern Utah. A second comprehensive stratigraphic study of the Moenkopi Formation was completed in 1972 by Stewart *et al.* and is complementary to reports by Cadigan (1971, 1972) which cover the sedimentary petrology of the Moenkopi. Blakey (1972, 1973) presented preliminary conclusions concerning the detailed stratigraphic facies analysis and specific depositional environments of the Moenkopi Formation in southeastern Utah.

A number of areal geologic studies in southeastern Utah discuss local aspects of the Moenkopi Formation (table 2). These reports are important sources of local details often ignored in more comprehensive reports.

Terms and classifications used in this report follow standard usage as much as possible; any special usage or connotation is indicated when the term appears for the first time. Bedding and thickness terms follow those used by McKee and Weir (1953). Very little effort was made in this study to quantify exact rock color since, in most cases, the important distinction is whether the Moenkopi is red or nonred. When used, specific terms such as "pale reddish brown" roughly correspond to the names used in the Rock Color Chart (Goddard *et al.*, 1948).

STRATIGRAPHY

Regional Triassic Stratigraphy

The Moenkopi Formation was deposited in most of southern and eastern Utah, northern Arizona, west-central Colorado, and west-central New Mexico. In northwestern Colorado, the upper portion of the State Bridge Formation is equivalent to the Moenkopi Formation. Across much of central Wyoming the lower portion of the Chugwater Group, the Red Peak, Alcova, and Crow Mountain Formations, is equivalent to the Moenkopi. The Moenkopi and Chugwater inter-tongue westward with the Thaynes Formation in western Utah, eastern Nevada, southeastern Idaho, western Wyoming, and southeastern Montana (Kummel, 1954).

Stratigraphic Setting

The Uncompahgre Highland, an element of the Ancestral Rocky Mountains, was raised in Middle Penn-

Table 2. Areal studies of the Moenkopi Formation in southeastern Utah.

Author	Date	Area of Study
Baker	1933	Moab district
Baker	1936	Monument Valley-Navajo Mountain
Baker	1946	Green River Desert-Cataract Canyon
Davidson	1967	Circle Cliffs
Gilluly	1929	San Rafael Swell
Gilluly and Reeside	1928	San Rafael Swell
Gregory	1916	Navajo Country
Gregory	1917	Navajo Country
Hawley <i>et al.</i>	1968	San Rafael Swell
Hunt <i>et al.</i>	1953	Henry Mountains-Dirty Devil River
McKnight	1940	Island in the Sky
Müllens	1960	Clay Hills
O'Sullivan	1965	Cedar Mesa-Boundary Butte
Prommel	1923	San Juan and Grand Counties
Sears	1956	Comb Ridge
Smith <i>et al.</i>	1963	Capitol Reef (Teasdale Uplift)
Thaden <i>et al.</i>	1964	White Canyon

sylvanian time. It trended northwestward from southwestern Colorado into east-central Utah (figure 2). After sedimentary rocks were stripped off the highland, the exposed core of Precambrian granitic and metamorphic rocks served as a source of sediment from the Pennsylvanian through the Jurassic periods. Sediments forming the Moenkopi Formation were deposited on a gently dipping westward slope. This broad shelf area was some 400 miles long and 100 to 300 miles wide. To the north the shelf graded imperceptibly into the Wyoming Platform, on the east it was bordered by the Uncompahgre Highland and the slightly positive Defiance Uplift, and on the south it was bordered by the Mogollon Highland which also furnished sediment to the Moenkopi Formation of northern Arizona (figure 2). A slightly negative trough extended into west-central New Mexico between the Defiance Uplift and Mogollon Highland (Stewart *et al.*, 1972). West of a line extending from Salt Lake City, Utah, to Las Vegas, Nevada, was a miogeosyncline.

In southeastern Utah an important but less well-defined tectonic feature trended northwest from the Orange Cliffs through the San Rafael Swell and into central Utah. This positive area, the Emery Uplift, was most active tectonically during the Pennsylvanian and early Permian periods (Fetzner, 1960). Nevertheless, as will be demonstrated later in this paper, the Emery Uplift had subtle but important effects on Moenkopi deposition.

Most Lower Triassic rocks deposited adjacent to the highlands are of continental origin, whereas those deposited in, or adjacent to, the miogeosyncline are mostly of marine origin. The bulk of the Moenkopi Formation was deposited on a broad shelf between the

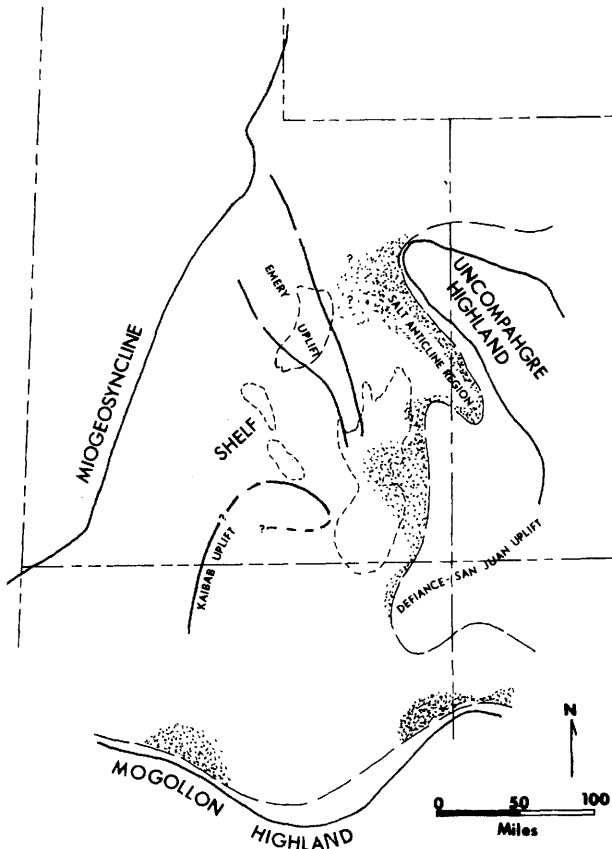


Figure 2. Early Triassic tectonic features of southeastern Utah. Stippled areas show major influxes of sediments.

highlands and miogeosyncline under a variety of marine and paralic conditions.

Age of Moenkopi Formation

In southeastern Utah, the *Meekoceras* fauna, medial Early Triassic (Smithian of Tozer, 1967), is found in the Moenkopi in the San Rafael Swell, Teasdale Uplift, and northwest Monument Upwarp areas. In all three areas the fauna occurs from 100 to 200 feet above the base of the formation. In southwestern Utah, however, the *Meekoceras* fauna occurs at the base of the Moenkopi. The *Tirolites* and possibly *Columbites* faunas, late Early Triassic (Spathian of Tozer, 1967), are found in southwestern Utah but not southeastern Utah (Stewart *et al.*, 1972). Kummel (1954) prefers the European series term Scythian. Probable Early Triassic fish and pelecypod remains are reported in the Moenkopi Formation of the Circle Cliffs area by Davidson (1967), and vertebrate remains from the Moenkopi Formation of northern Arizona and southwestern Utah are suggestive of Early and possibly Middle Triassic age (Welles, 1947; Peabody, 1956). Based upon the ammonite and vertebrate

faunas, the U. S. Geological Survey has assigned the Moenkopi an Early to Middle (?) Triassic age.

In many areas of southeastern Utah the Moenkopi Formation rests on underlying Permian rocks with erosional unconformity. However, in the Monument Upwarp area the Moenkopi rests on the Hoskinnini, the basal member of the Moenkopi according to Stewart *et al.* (1972), but given formational status in this paper (Appendix A). The age of the Hoskinnini may be Permian, Triassic, or Permo-Triassic. According to the U. S. Geological Survey its age is Triassic (?) (Stewart, 1959).

In the Uinta Mountains and central Utah the Permian-Triassic unconformity cannot be differentiated locally (Irwin, 1971; Stewart *et al.*, 1972). Permian fossils are reported in the Woodside Formation of the Uinta Mountains by Yochelson *et al.* (1961) and the Woodside can be traced in the subsurface into strata of the lower part of the Moenkopi Formation of southeastern Utah (Irwin, 1971). The base of the Woodside Formation is sometimes difficult to locate in the Uinta Mountain area and is commonly placed at the change in color from gray Dinwoody Formation below to red Woodside Formation above. According to W. M. Furnish and B. F. Glenister of the Department of Geology, University of Iowa (personal communications, 1973), no definite late Permian fossils have been found in the Western Interior. These findings only suggest "possible Permian" age for part of the Moenkopi Formation, but there is no conclusive evidence.

Nomenclature of Moenkopi Formation in Southeastern Utah

The Moenkopi Formation was divided into four members to facilitate location of stratigraphic position and simplify description in field notes while mapping the tar-impregnated sandstone bodies in the San Rafael Swell. The four members were readily correlated into the Teasdale and Circle Cliffs Uplifts and tentatively correlated to the northwestern Monument Upwarp (Blakey, 1972). These same divisions were recognized by Smith *et al.* (1963) in the Teasdale Uplift; Davidson (1967) recognized similar divisions in the Circle Cliffs area although he divided the upper unit into two members. Similar correlations were presented for most of southeastern Utah by Stewart *et al.* (1972). Therefore, the division and correlation of the members used in this report were similarly but independently developed by this observer and the U. S. Geological Survey reports mentioned above. Discrepancies between the correlations of Stewart *et al.* (1972) and this paper will be presented later. Because of the numerous informal descriptive names applied to the Moenkopi at various localities, nomenclature can be confusing. Three new

names are proposed in this paper so all the members in southeastern Utah can have formal names.

The four members in the San Rafael Swell, Teasdale, and Circle Cliffs Uplifts are, in ascending order: Black Dragon Member (new), Sinbad Limestone Member, Torrey Member (new), and Moody Canyon Member (new). All can be correlated into the Monument Upwarp where they overlie the Hoskinnini Formation (figures 3 and 4; plate 1).

The Black Dragon Member contains mainly red and nonred, laminated to thick-bedded sandstone and siltstone. Yellowish-gray limestone, dolomite, and siltstone in very thin to thick beds mark the Sinbad Limestone Member. Red and nonred ledge-forming sandstone and interbedded siltstone characterize the Torrey Member. The Moody Canyon Member is comprised of mostly red, thinly-laminated to thin-bedded mudstone and siltstone.

Permo-Triassic Boundary and Basal Conglomerate

Permian rocks are widely exposed over much of the Colorado Plateau, but abrupt facies changes and lack of fossils have hindered exact correlation. Local sequences are fairly well understood but regional correlation is still in doubt. Centers of nomenclature are the Grand Canyon and Mogollon Rim regions, Monument Upwarp, the Zuni-Defiance Upwarp, and central and southern New Mexico. Generally, each area has its own terminology.

The Permian rocks were laid down in several discrete but overlapping depositional areas, each containing several episodes of marine facies (Irwin, 1971). In southeastern Utah apparently three phases of Permian deposition are represented (figure 5). The first phase consisted of marine transgression and regression originating in the Oquirrh Basin near Salt Lake City (Irwin, 1971). Marine carbonates of the Elephant Canyon Formation were deposited as far southeastward as the north-central Monument Upwarp. Farther to the south and east they interfinger with paralic and continental redbeds of the Halgaito Formation. The regressive phase is represented in the overlying shallow marine and beach facies of the Cedar Mesa Sandstone which interfingers with the Elephant Canyon and Halgaito Formations (Baars, 1962).

The second episode of marine deposition was initiated west of the Grand Canyon in the miogeosyncline. The Torowearp Formation, the marine carbonate phase, reached the western edge of southeastern Utah. The shallow marine sand and beach facies is represented by the quartz sandstone, called the White Rim Sandstone, exposed across much of southeastern Utah. Somewhat intermediate, but perhaps

partially equivalent, to both of these phases is the red paralic and continental sandstone and siltstone of the Organ Rock Formation, present throughout the Monument Upwarp, and the pale-orange aeolian quartz sandstone of the DeChelly Sandstone, present on the southernmost Monument Upwarp.

A third phase also originated from the west. The "Kaibab" Formation, another marine carbonate, is present in the western area of study but pinches out in the subsurface west of the Monument Upwarp. Transgressive and nearshore sandstones may be represented in the upper White Rim Sandstone (Irwin, 1971), but regressive phases, if ever deposited, have been eroded from southeastern Utah west of the Monument Upwarp.

To further complicate the situation, northeast of the junction of the Green and Colorado Rivers, undifferentiated continental arkosic sandstone and conglomerate was deposited while the above-mentioned sequences were forming. This particular eastward-thickening wedge of sediment is called the Cutler Formation.

In areas where the Moenkopi Formation overlies the Permian "Kaibab" Formation, and in areas immediately east of the edge of the "Kaibab", basal chert-pebble conglomerates are common. The "Kaibab" contains several very cherty horizons and the chert pebbles in the basal conglomerate of the Moenkopi were most probably derived from this source. A maximum thickness of 42 feet of chert-pebble conglomerate was measured in the northeastern San Rafael Swell area in Black Dragon Canyon. Other thicknesses of the unit are: 24 feet where Poison Spring Canyon joins the Dirty Devil River, 10 feet near Hite, 12 feet in the southern Circle Cliffs, and 16 feet at Temple Mountain in the San Rafael Swell. This conglomerate varies greatly in thickness, is locally absent, and usually contains chert pebbles ranging up to 3 inches, but averaging about ½ inch in diameter. In the San Rafael Swell the unit displays prominent wedge-shaped, small-scale cross-stratification with consistent westerly dips, but in most areas the unit is crudely bedded. Orgill (1971) reports and describes cherty paleosoils within the basal conglomerate in the northeastern San Rafael Swell.

Where the Moenkopi overlies the White Rim, DeChelly, or Organ Rock Formations east of the edge of the "Kaibab", no basal conglomerate is present. Absence of the conglomerate is most likely due to the lack of suitable conglomerate-producing units in the underlying rocks.

Fossils were found in the basal conglomerate at one locality in the north-central San Rafael Swell.

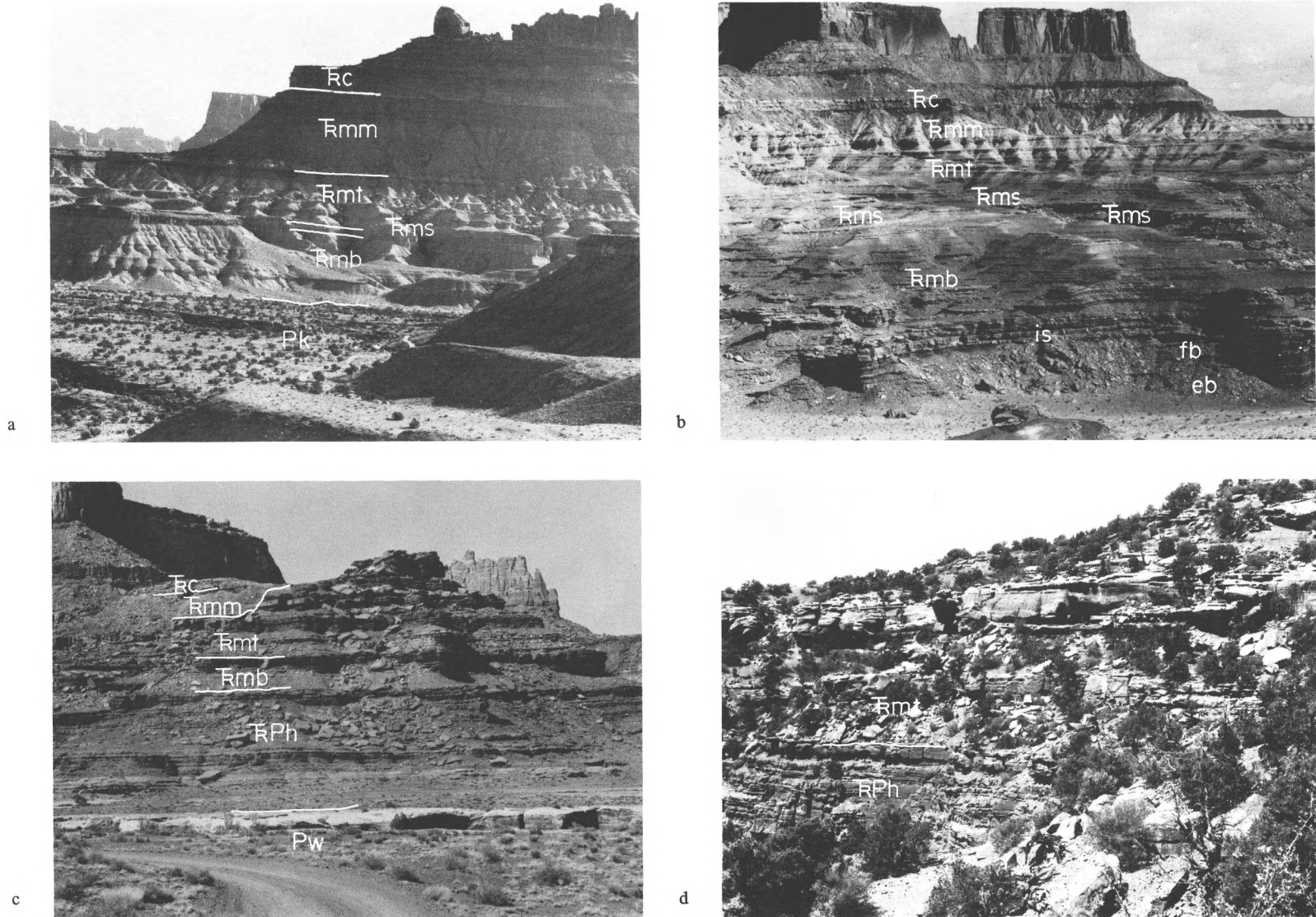


Figure 3. Photographs of Moenkopi Formation in southeastern Utah. (a) Black Dragon Canyon, San Rafael Swell (866 ft.), (b) Steer Mesa, Monument Upwarp (450 ft.), (c) Island in the Sky, Monument Upwarp (300 ft.), and (d) White Canyon, Monument Upwarp (200 ft.). Symbols used on this and succeeding photographs: **Rc** = Chinle Formation, **Rmm** = Moody Canyon Member, **Rmt** = Torrey Member, **Rms** = Sinbad Limestone Member, **Rmb** = Black Dragon Member, **Pk** = "Kaibab" Formation, **R-Ph** = Hoskinnini Formation, **Pw** = White Rim Sandstone, **Por** = Organ Rock Formation.

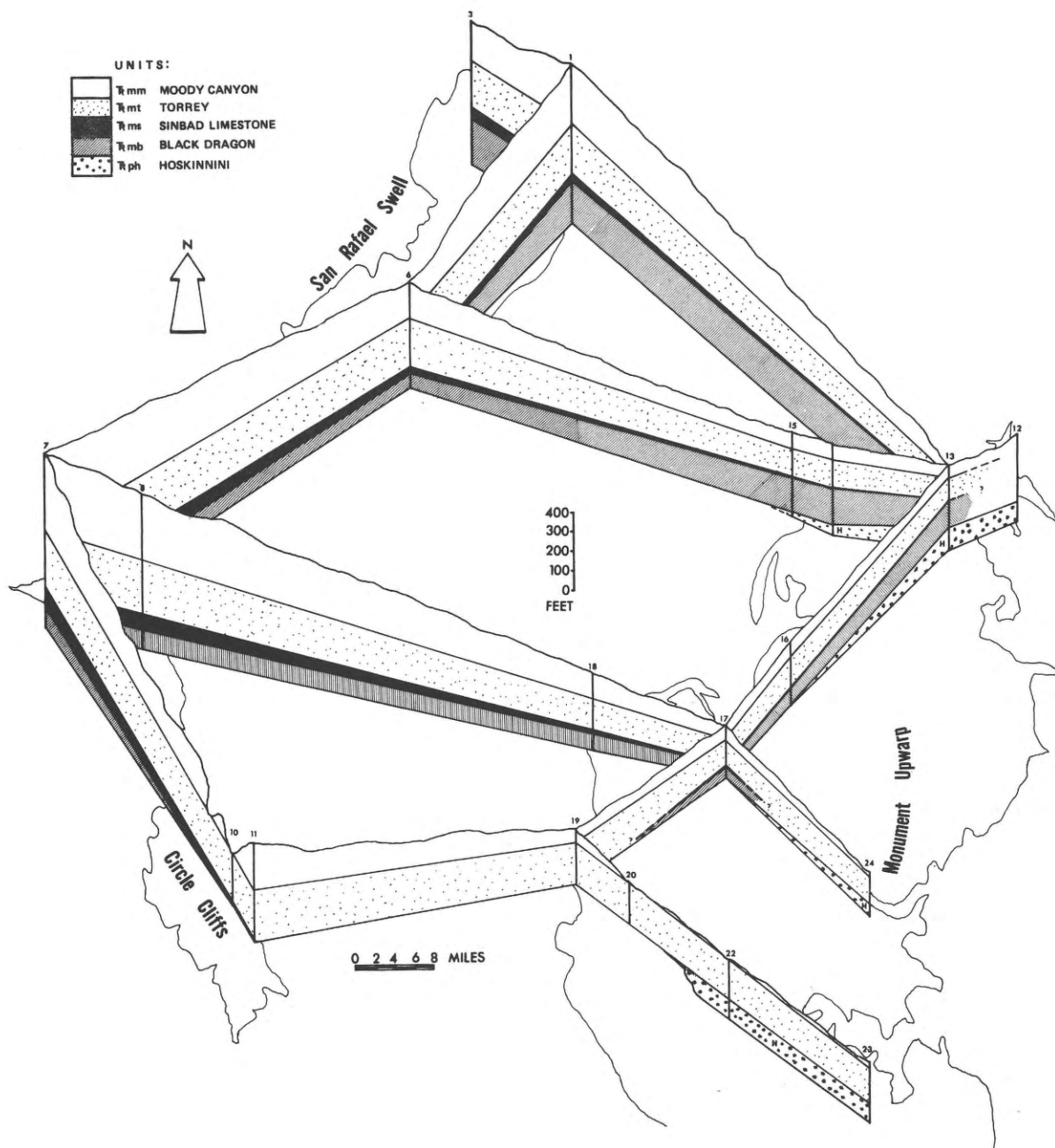


Figure 4. Fence diagram showing geometry of members of Moenkopi Formation and Hoskinnini Formation.

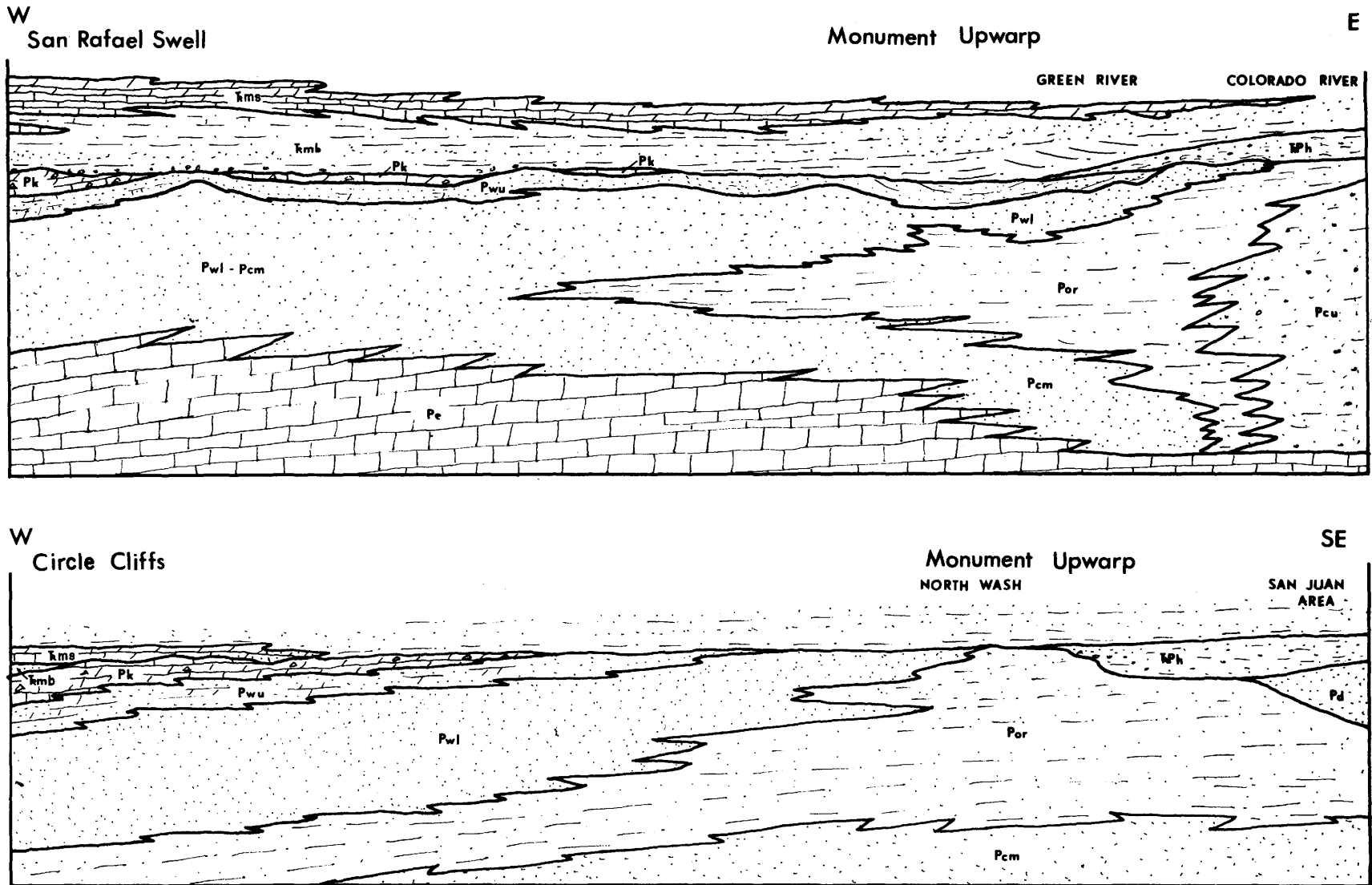


Figure 5. Diagrammatic sections of Permian rocks in southeastern Utah. Symbols: Rms = Sinbad Limestone Member, Rmb = Black Dragon Member, Pk = "Kaibab" Formation, Pwu = Upper White Rim Sandstone, Pwl = Lower White Rim Sandstone, RPh = Hoskinnini Formation, Pd = DeChelly Sandstone, Por = Organ Rock Formation, Pcm = Cedar Mesa Sandstone, Pe = Elephant Canyon Formation, Pcu = Cutler Formation, undivided.

They include the conodont *Ellisonia triassica* (?) and numerous bellerophonid and other gastropods, pelecypods, and ostracodes. Their significance will be discussed later.

In the western area of study the Permo-Triassic boundary is an irregular surface representing an unknown amount of time. In the western interior province, this boundary generally becomes more subtle towards the north. For example, in the western Grand Canyon region the basal Moenkopi, called the Timpoweap Member, is equivalent to the Sinbad Limestone Member. Here the *Meekoceras* zone overlies the type Kaibab Formation of Leonardian age and relief of several hundred feet is apparent on the contact (McKee, 1954). In the southern Circle Cliffs area (figure 6a), the Sinbad overlies the "Kaibab"; and a few miles northward a few feet of the Black Dragon Member separate the Sinbad from higher units. Relief approximating 70 feet was reported by Davidson (1967). In the Teasdale Uplift about 100 feet of the Black Dragon Member separate the Sinbad and the "Kaibab". In the San Rafael Swell (figure 6b), up to 250 feet of the Black Dragon Member are present between the Sinbad and "Kaibab" and much of the basal relief may be due to pre-"Kaibab" deposition rather than post-"Kaibab" erosion (Orgill, 1971). In the western area of study the "Kaibab" is apparently younger than type Kaibab and probably is partly or wholly of Guadalupian age (McKee, 1938; Irwin, 1971). Thus, the maximum amount of time represented by the unconformity is uppermost Permian (Chideruan of Kummel and Teichert, 1970) and an undetermined amount of pre-Meekoceran Early Triassic (Griesbachian and Dienerian of Tozer, 1967). In the Grand Canyon region the missing rocks represent Guadalupian, Chideruan, and all of Griesbachian and Dienerian time. In the Uinta Mountains of northern Utah, Stewart *et al.* (1972) suggest no major Permo-Triassic unconformity is present, but rather a number of small diastems occur throughout a sequence of relatively continuous sedimentation.

The amount of erosional relief formed during the period of nondeposition is difficult to determine. Baars and Seager (1970) and Orgill (1971) have demonstrated much of the relief results from depositional highs in the underlying White Rim Sandstone. In the San Rafael Swell some of these highs were probably islands in the "Kaibab" sea and locally contributed quartz sand to the limestone of the "Kaibab" (Orgill, 1971).

The author observed erosional channels at many locations in the western area of study. One typical channel exposed near Temple Mountain in the San Rafael Swell measures 6 feet deep by 15 feet wide and contains pebbles of chert up to 2 inches in diameter.

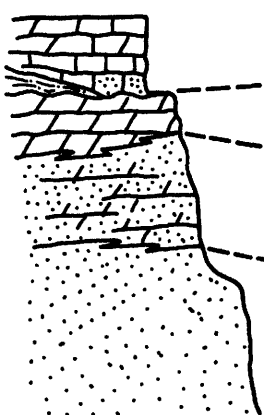
On the Monument Upwarp the position of the Permo-Triassic boundary is uncertain since the fossiliferous "Kaibab" does not extend into the area, and uppermost Permian rocks are generally unfossiliferous redbeds and sandstone of uncertain age. Although a few vertebrate and invertebrate fossils and plant fragments have been reported, most correlations and age assignments are based on stratigraphic position. According to Irwin (1971) the Organ Rock is late Wolfcampian to early Leonardian, the White Rim (= Toroweap) is middle to late Leonardian, and the DeChelly is middle Leonardian.

The age of the Moenkopi Formation is Medial and Late Early Triassic (Smithian and Spathian). The Hoskinnini Formation, however, may be Permian. At North Wash, along the Dirty Devil River, and in western White Canyon the Hoskinnini is absent and the Moenkopi overlies the White Rim Sandstone or the Organ Rock Formation (figure 6, c, d). The basal conglomerate of the Moenkopi is 10 feet thick at North Wash, 24 feet thick at Poison Creek Canyon, and 2 feet thick in western White Canyon. Farther north in the Orange Cliffs, the Moenkopi overlies the upper White Rim Sandstone with local angular unconformity (figure 7). Stewart *et al.* (1972), however, include the upper White Rim unit in the Moenkopi. Farther northeast in Stillwater Canyon, this same unit is present underneath the Hoskinnini Formation. Because of the uncertain affinities of the Hoskinnini, anything below it is not included in the Moenkopi Formation until further stratigraphic work is done. It is believed the unit referred to in this paper as the upper White Rim is part of the regressive phase of the White Rim-Toroweap sea or transgressive and nearshore phase of the "Kaibab" sea, and in the Orange Cliffs area it was probably deposited in a lagoonal environment (Baars and Seager, 1970). Westward the upper White Rim was deposited in a shallow marine and beach environment (Davidson, 1967).

Over the remainder of the Monument Upwarp the Hoskinnini is present, so the position and magnitude of the Permo-Triassic boundary hiatus are uncertain. Three possibilities exist for its position: (1) the base of the Hoskinnini, (2) within the Hoskinnini, and (3) the top of the Hoskinnini.

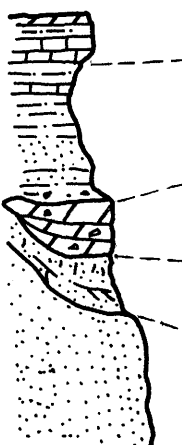
Little or no apparent relief is present at the top of the Hoskinnini Formation. In the White Canyon, Elk Ridge, and eastern Island in the Sky areas, the base of the Moenkopi contains a medium to coarse-grained, well-sorted, friable quartz sandstone 1 to 3 feet thick, locally separated from the top of the Hoskinnini by a 1 to 3-foot thick siltstone. Whether this unit can be correlated over the region is difficult to determine because several other similar units are present higher in the section. Mud-pebble conglomerate

A. CIRCLE CLIFFS



	McKee, 1938	Davidson, 1967	Irwin, 1971	Others	This paper
Ls; dol calc foss Siltstone; gray	Moenkopi Fm.	Sinbad basal unit	Sinbad Woodside Fm.		Sinbad Black Dragon
Dol; oolitic, cherty, foss	Kaibab Fm.	Kaibab Fm.	B Kaibab	Park City Fm. Toro- weap Fm.	"Kaibab"
Dol ss; foss		Upper Cutler Fm.	G Kaibab		Upper White Rim Ss.
Ss; qtz arenite	Cedar Mesa Ss.	Lower Cutler Fm.	White Rim- Toroweap	Coco- nino Ss.	Lower White Rim Ss.

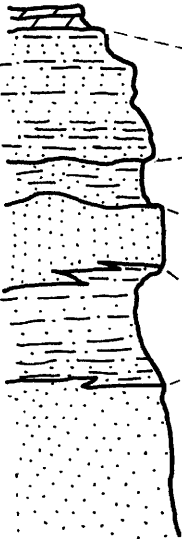
B. SAN RAFAEL SWELL



	McKee, 1938	Irwin, 1971	Orgill, 1971	Baars, 1962	Others	This paper
Ls; dol	Moenkopi Fm.	Sinbad	Sinbad	Moenkopi Fm.		Sinbad
Sltm; gry calc, ss foss		Woodside Fm.	Lower Moen- kopi Fm.			Black Dragon
Dol; cht foss	B Kaibab northern facies	B Kaibab	Kaibab Fm.	Kaibab Fm.	Park City	"Kaibab Fm."
Dol ss; bioturb		G Kaibab	bioturbated White Rim			Toro- weap
Ss; qtz	Cedar Mesa Ss.	White Rim Ss.	normal White Rim Ss.	Cedar Mesa Ss.	Coco- nino	Lower White Rim Ss.

Figure 6. Permian-Triassic nomenclature.

C. ORANGE CLIFFS

	Baker, 1946	Baars and Seager, 1970	Irwin, 1971	Stewart <i>et al.</i> , 1972	This paper	
	Dol; vug, foss	Sinbad	Moenkopi Fm.	Sinbad	Sinbad	
	Slt; red, sndy, even	Lower Moenkopi		Woodside Fm.	Lower Slope-Forming	Black Dragon Member
	Ss; slty calc	Upper Cutler	Cutler Fm.	unnamed	basal sss	Upper White Rim Ss.
	Ss; qtz, mass	White Rim		White Rim Ss.	White Rim	Lower White Rim Ss.
	Slt and ss; red	Organ Rock		Organ Rock Sh.	Organ Rock	Organ Rock Sh.
	Ss; qtz, mass	Cedar Mesa		Cedar Mesa Ss.	Cedar Mesa	Cedar Mesa Ss.

D. SHAFER CANYON

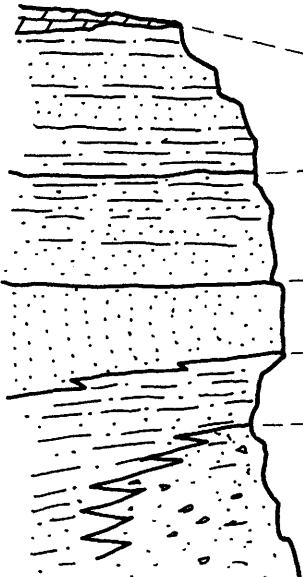
	General concensus
	Sinbad
Dol; vuggy, yel.	
Slt and ss; red	Lower Moenkopi Fm.
Ss and sltn; poorly sorted	Hoskinnini Fm.
Ss; wht, qtz, mass	White Rim Ss.
Slt; Sndy, red	Organ Rock Fm.
Ss, sltn, and cong; Red, arkosic	Cutler Fm. (undiv)

Figure 6. (continued)

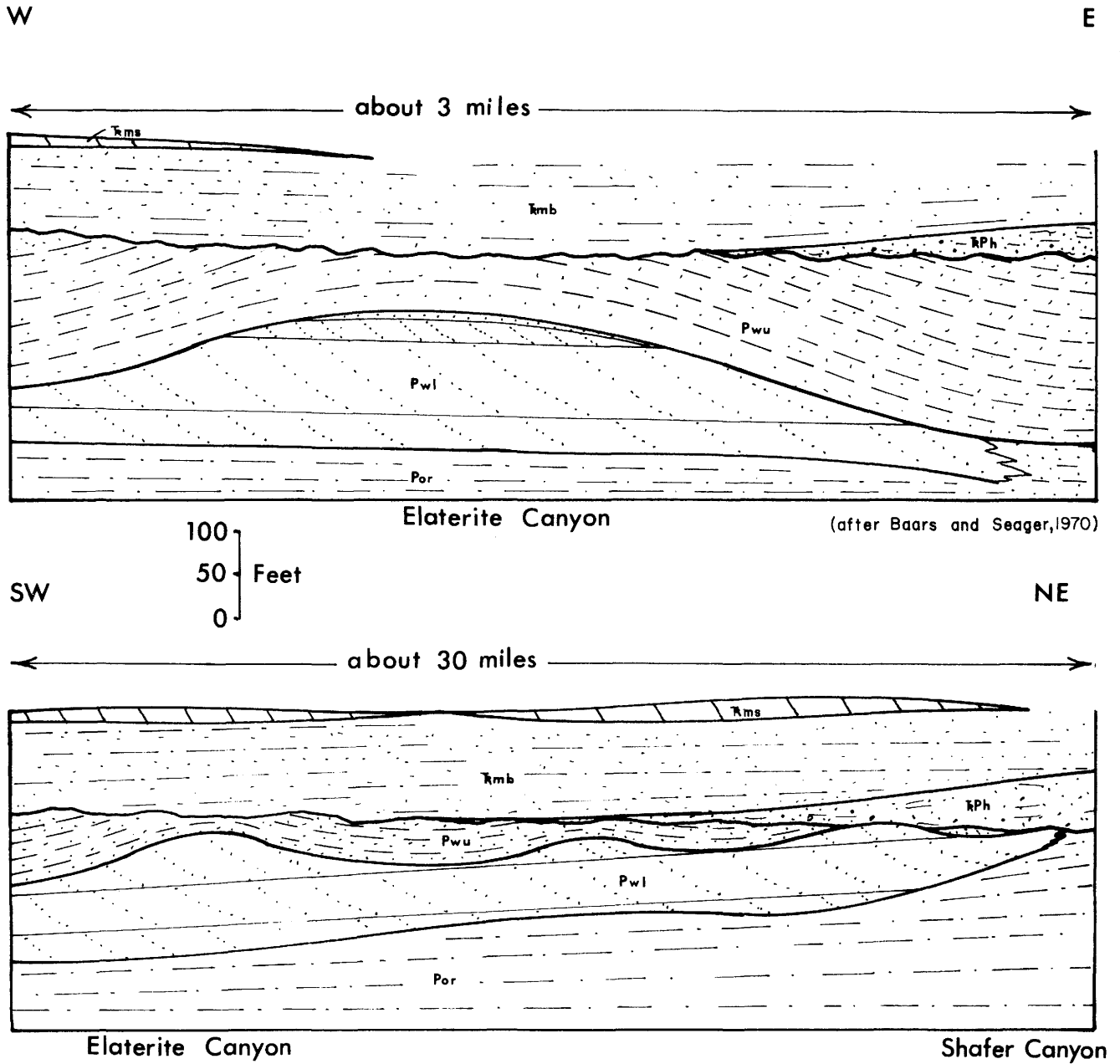


Figure 7. Sketches of Permian-Triassic boundary units on Monument Upwarp (see figure 5, page 8, for symbols).

near the base of the Moenkopi is probably unrelated to a possible post-Hoskinnini unconformity because this lithology is very common in the Torrey Member on the Monument Upwarp. There is no conclusive physical evidence for a major unconformity at the top of the Hoskinnini; however, at many places the time represented by the deposition of the Black Dragon and Sinbad Limestone Members must be represented by a hiatus. Thus, neither the Permo-Triassic boundary nor an unconformity can be located with any degree of certainty over most of the Monument Upwarp.

Black Dragon Member

Introduction

The Black Dragon Member of the Moenkopi Formation is named for a sequence of slope and ledge forming clastic and carbonate rocks exposed in Black Dragon Canyon in the northeastern section of the San Rafael Swell. The member is generally present between underlying Permian rocks and the overlying Sinbad Limestone Member of the Moenkopi Formation. Because it forms a distinct division of the Moenkopi Formation it has been recognized and referred to in many previous publications. Stewart *et al.* (1972) correlate the unit, referred to by them as the "lower slope-forming member," across most of the Monument Upwarp. Their recognition of the member, however, is more descriptive than generic and much of what they call lower slope-forming member east of the Colorado River is the basal unit of the Torrey Member as used in this report (figure 8).

In this study the Black Dragon Member (lower slope-forming member) is recognized only where the Sinbad Limestone Member or its correlative are present for two reasons: (1) the Black Dragon Member and Sinbad Limestone Member are probably related to the same phase of deposition, and (2) even if it does extend southeastward of the Sinbad or its equivalent, it cannot be separated from the base of the Torrey Member.

Stratigraphy and Lithology

The Black Dragon Member comprises many different lithologies including sandstone, siltstone, mudstone, limestone, dolomite, and gypsum. Regardless of lithology much of the member weathers flaggy, shaly, or fissile and thus forms smooth slopes or, where protected by overlying units, earthy cliffs. Typically the member consists of laminated to very thin-bedded siltstone and sandstone locally ripple-marked and intercalated with thin-bedded very fine-grained micaceous sandstone. The base of the member commonly contains chert or quartz pebbles and locally chert-pebble conglomerate. The upper portion of the

member contains lenses of interbedded limestone and dolomite which probably reflect intertonguing between the Black Dragon Member and Sinbad Limestone Member. Throughout the member calcareous and dolomitic sandstone and siltstone layers are present. Gypsum is also present in parts of the member but appears to be most abundant towards the top. Blocky and massive fine-grained sandstone forms ledges and cliffs in the northern San Rafael Swell and Stillwater Canyon areas.

Much of the Black Dragon Member consists of intercalated sandstone and siltstone in laminae and very thin beds forming sets of strata 1 to 6 inches thick, but which may range up to 3 feet in thickness. The boundaries between sets generally correspond to slight changes in sediment type from fine-grained sandstone to sandy siltstone. Thinner sets may be horizontally-stratified, ripple-laminated, ripple-marked, or ripple-cross-stratified, and thicker sets are commonly trough-cross-stratified with the scale of the cross-stratification generally dependent on the thickness of the set or coset (figure 9, a-f).

The dominant characteristics of the bedding in the member are regularity and continuity of the individual sets. The boundaries between adjacent sets or cosets are generally parallel planar surfaces but a few irregular or channeled boundaries can be observed. Within cosets, internal channeling is present, particularly in thicker sandstone units. Contorted bedding, though uncommon, is generally associated with poorly-sorted sandy siltstone. Relatively thick sequences (4 to 8 feet thick) of siltstone and mudstone display ball and pillow structure. Tracks, trails, and burrows were noted in the member in the northern San Rafael Swell, and mud-pebble conglomerate was present in a number of localities, but mud cracks are rare or absent.

On the northwestern Monument Upwarp a prominent angular unconformity within the Black Dragon Member is exposed in Stillwater Canyon and along the Orange Cliffs for a distance of 20 miles (figure 9d). The beds below the unconformity dip eastward at 5 to 15 degrees and flatten out at their bases. The exposed width of the angular beds is about 8 miles. The maximum exposed thickness of all the beds involved in the unconformity is about 70 feet at Steer Mesa, but this figure decreases to the south and is generally 20 to 40 feet along the Orange Cliffs. The bedding and the sedimentary structures are nearly identical to those of the normal flat-lying beds except that load casts and channeling are much more abundant in the angular units. Bedded gypsum up to 2 inches thick is present at several localities. The unconformity was noted by McKnight (1940) and Baker (1946). McKnight suggested that the angular beds were deposited as delta

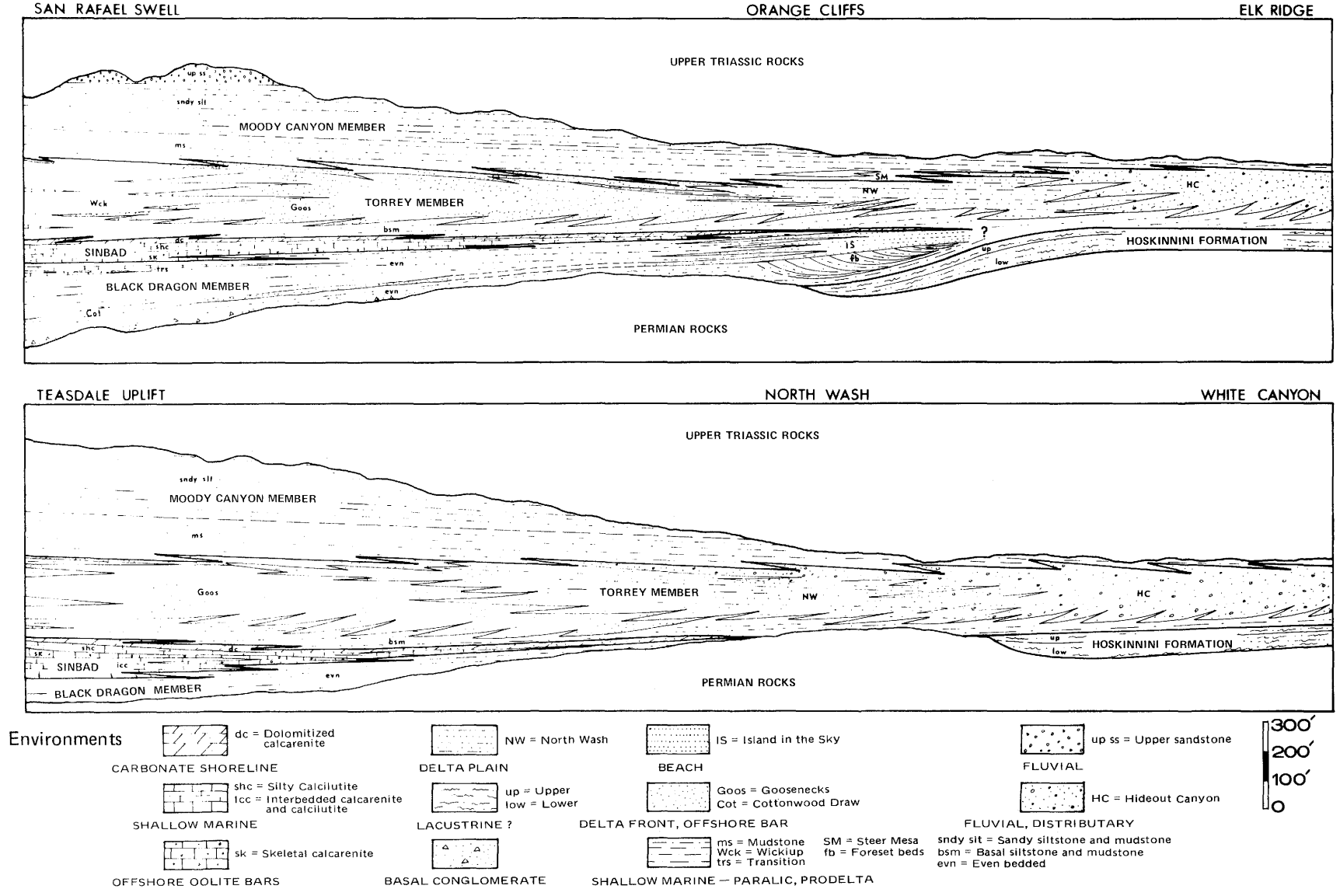


Figure 8. Cross-section of members of Moenkopi Formation showing facies relationships and inferred depositional environments. Facies symbols are as follows: up ss = upper sandstone facies, sndy silt = sandy siltstone and mudstone facies, ms = mudstone facies, SM = Steer Mesa facies (all in Moody Canyon Member); Wck = Wickiup facies, Goos = Goosenecks facies, NW = North Wash facies, HC = Hideout Canyon facies, bsm = basal siltstone and mudstone facies (all in Torrey Member); dc = dolomitized calcarenite facies, shc = silty calcilutite facies, sk = skeletal calcarenite facies, icc = interbedded calcarenite and calcilutite facies (all in Sinbad Limestone Member); evn = even-bedded facies, Cot = Cottonwood Draw sandstone, IS = Island in the Sky facies, fb = foreset beds (all in Black Dragon Member); up = upper unit, low = lower unit (both in Hoskinnini Formation).

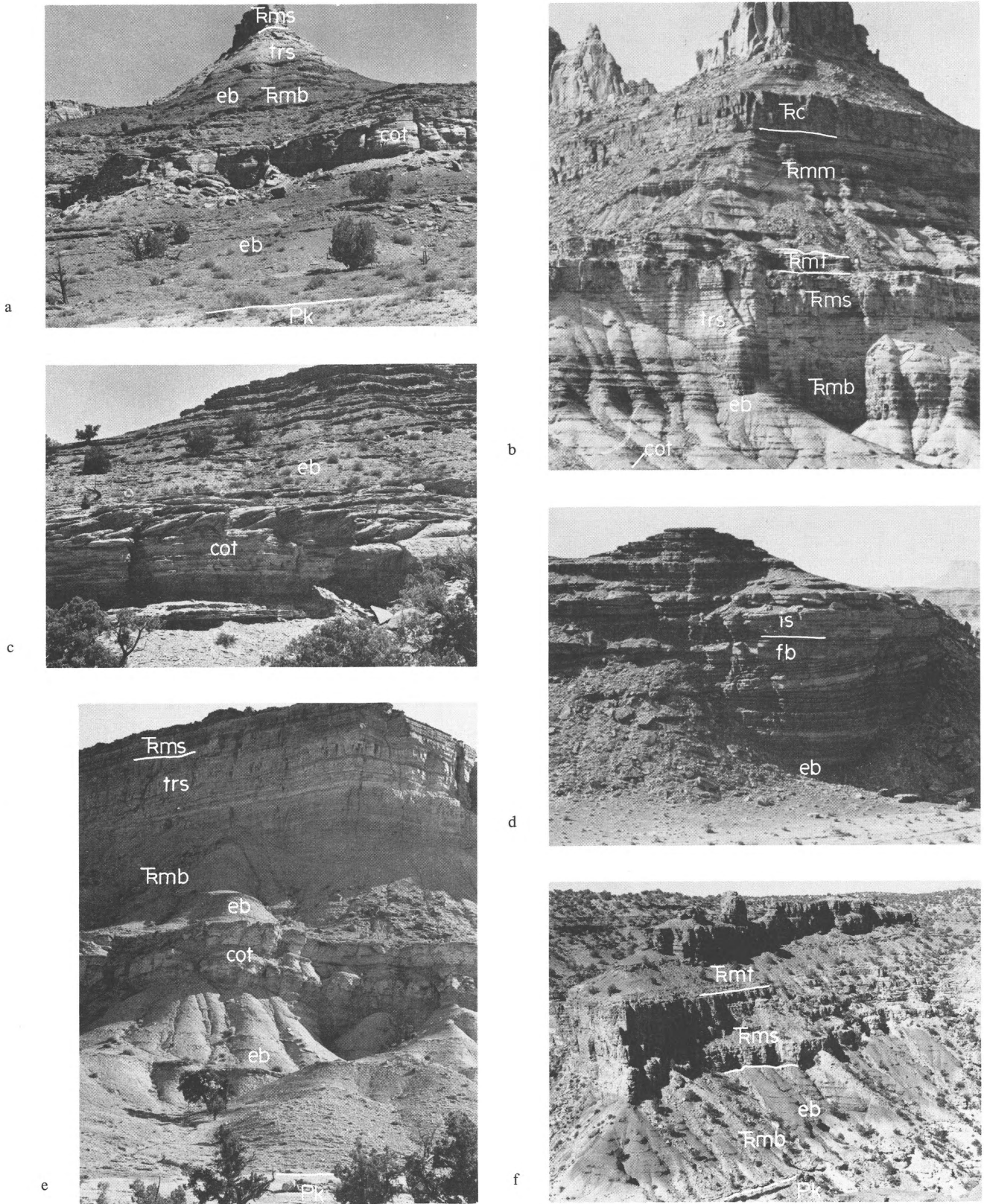


Figure 9. Photographs of Black Dragon Member. (a), (b), (c) Northern San Rafael Swell, (d) "foreset beds", Stillwater Canyon, (e) Cottonwood Draw, San Rafael Swell, and (f) Island in the Sky.

foresets; the unit is informally referred to in the present paper as the "foreset beds".

The zero isopach line of the Black Dragon Member follows the Colorado River southward across the Monument Upwarp (figure 10). With the possible exception of an area on the northeastern Monument Upwarp below Dead Horse Point, the member cannot be recognized east of the Colorado. Northwestward the member thickens in an irregular manner: the isopach lines show three prongs, or thins, and four intervening troughs, or thicks, all trending northwestward parallel to the Emery Uplift (Fetzner, 1960). Conglomerate at the base of the member appears to be thickest and most extensive on the flanks of the troughs (figure 10).

The southeastern margin of the Black Dragon Member is clearly defined in the north-central Circle Cliffs where it thins from about 60 feet in the southern Teasdale Uplift to less than 10 feet in the northern Circle Cliffs. It continues to thin southward until it wedges out between the carbonates of the "Kaibab" Formation below and Sinbad Limestone Member above. The margin is also known to be exposed in the canyon of the Dirty Devil River and southern Orange Cliffs area, but difficulty of access prevented study there; the member is 79 feet thick in Poison Spring Canyon, 51 feet thick at Sunset Pass, and absent at North Wash. It is unknown whether the Black Dragon pinches out in this area or intertongues with the higher Torrey Member. A detailed study in the southern Orange Cliffs area should reveal the answer.

In the area around Dead Horse Point (northern Monument Upwarp) the Sinbad Limestone Member pinches out. The Black Dragon Member can be traced east of Dead Horse Point along the cliffs bordering the Colorado River, but a few miles farther eastward the overlying units in the Moenkopi undergo a facies change rendering correlation of any members tenuous. Rocks equivalent to the Black Dragon Member probably are present in this area and in the Salt Anticline region to the east, but more detailed work is necessary in order to separate them from overlying units.

The nature of the basal contact of the Black Dragon Member in areas where it overlies the "Kaibab" and White Rim was discussed in the section concerning the Permo-Triassic boundary. Where it overlies the Hoskinnini, the two units can usually be separated without problem. Although both are reddish-brown, the Hoskinnini is more brilliantly colored. The slopes formed by the Black Dragon also contrast with the rounded ledges and rocky slopes of the Hoskinnini. The contact appears to be a planar surface and there is

no physical evidence for an unconformity; no paleontological evidence is available.

With the exception of the area near Dead Horse Point, the Black Dragon is overlain by the Sinbad Limestone Member. In the San Rafael Swell and Teasdale Uplift, the two members intertongue. In the other areas intertonguing may or may not be present, but the contact is believed to be conformable.

Divisions

The Black Dragon Member can be divided into a number of facies or units, some of which are given informal names in this report to simplify description.

Over much of the area of deposition the dominant lithology is even-bedded siltstone and sandstone and is referred to as the even-bedded facies. This facies comprises laminated to very thin-bedded sandstone, siltstone, and occasionally limestone with local concentrations of thin-bedded gypsum (figure 9). It may be red (pale reddish-brown to dark reddish-brown) or nonred (yellowish-gray to medium gray) and it forms smooth slopes or earthy cliffs. It increases in thickness to the west and proportionally constitutes more of the member until it composes nearly all of the Black Dragon Member in the Circle Cliffs, Teasdale Uplift and southern San Rafael Swell, and forms the lower portion of the member in the Orange Cliffs and Island in the Sky areas of the Monument Upwarp. The previously described angular beds or "foreset beds" of Stillwater Canyon are near the middle of the member. Lithologically they are similar to, and probably correlate with, the even-bedded facies.

In the northwest Monument Upwarp, near the top of the Black Dragon Member, are ledge-forming sandstone units referred to as the Island in the Sky facies. The basal sandstone in this facies can be traced continuously for over 24 miles along the Orange Cliffs and covers an area of over 288 square miles (figure 3b). Although it displays a wide variety of cross-stratification and varies slightly in color and thickness (6 to 18 feet), the persistence of the unit is the dominant characteristic. Cross-stratification readings consistently show that west to northwest-moving currents deposited the sandstone. This basal sandstone marker bed comprises very fine to medium-grained, fairly well-sorted sandstone. Southeast on the Island in the Sky Plateau the unit splits into slabby beds of sandstone and interbedded siltstone. Southwest along the Orange Cliffs it thins and becomes siltier until it cannot be traced with certainty south of Sunset Pass.

Other units in the Island in the Sky facies are similar but less widespread. The facies is generally 60 to 80 feet thick and forms ledges and cliffs which

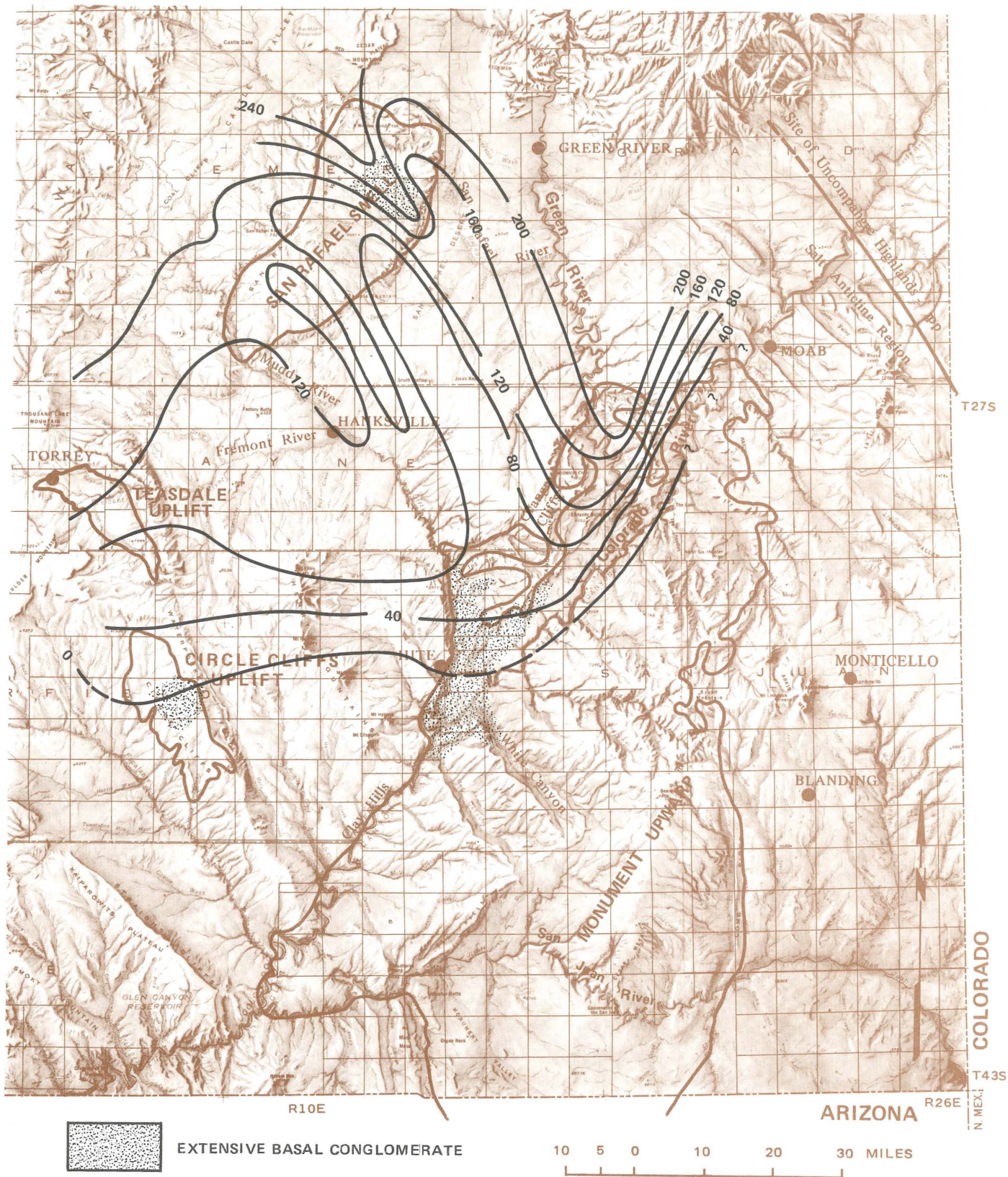


Figure 10. Isopach map of Black Dragon Member.

would be difficult to separate from the Torrey Member without the intervening Sinbad Limestone Member (figure 3, b, c). Outcrops of the Island in the Sky facies are limited to the northwest Monument Upwarp but it may correlate with sandy units of the Black Dragon Member in the San Rafael Swell.

In the San Rafael Swell slabby to massive-weathering sandstone units in the Black Dragon Member increase in number and thickness to the northeast. In Black Dragon Canyon, Cottonwood Draw, and along the San Rafael River several sandstone units are present, and one prominent oil-impregnated sandstone near the middle of the member can be directly traced throughout the area. Informally the oil-impregnated sandstone is referred to as the Cottonwood Draw sandstone (figure 9, a, b, c, e) and is similar to the basal sandstone in the Island in the Sky facies and may be a correlative. In places oil oozes from it on hot summer days. The Cottonwood Draw sandstone is 11-feet thick in lower Black Dragon Canyon, about 18 feet thick in the Jackass Bench area and southern Cottonwood Draw, 17 feet thick in northern Cottonwood Draw, 42 feet thick in Oil Well Draw, and 13 feet thick at Lockhart Box. South of Interstate 70 a few sandstone units are present in the same interval but none can be definitely correlated with the Cottonwood Draw sandstone. The Cottonwood Draw sandstone was deposited by west or northwest-flowing currents as indicated by prominent wedge and trough-cross-stratification.

The unit displays a vertical variability at many locations such as siltstone or sandy siltstone commonly interbedded with the sandstone. The base of the sandstone is gradational, coarsening upwards into slabby and flaggy-weathering sandstone and siltstone at the top. At one locality in Cottonwood Draw the sandstone displays boudinage-cross-stratification; the "sausages" are well-indurated sandstone in contrast to the poorly-cemented silty sandstone of the matrix.

Locally the consistently northwest-dipping cross-strata are interrupted by narrow, steepwalled channels several feet deep. They were not studied in enough detail to determine trends.

The Sinbad Limestone and Black Dragon Members intertongue in a zone in which terrigenous material increases to the east and carbonates increase to the west. In the San Rafael Swell this sequence is included in the transition facies of the Black Dragon Member; in the Teasdale Uplift it is included in the Sinbad Limestone Member and is discussed in detail later.

Carbonate rocks are not uncommon in other facies of the Black Dragon Member, especially the even-bedded facies, but they are not as thick, widespread, or pure as those in the transition facies. The

carbonates comprise fossiliferous and oolitic limestone and dolomite. One yellowish-orange limestone unit is traceable for at least 15 miles across the San Rafael Swell and contains beds of small-scale cross-stratification weathering to slabby or blocky units. This particular limestone averages about 5 feet thick, but most carbonates in the transition facies are much thinner. Siltstone and sandstone in this facies are similar to those in the even-bedded facies; gypsum is also present occurring as thin beds, cross-cutting veins, and cement.

Conglomerates at the base of the Black Dragon Member have been described in the section on the Permo-Triassic boundary. However, the lithology of one unit near the base of the member warrants additional attention. In the northern San Rafael Swell several well-sorted, medium to coarse-grained sandstones, generally less than 2 feet thick and with well-rounded grains, are present right above most of the conglomeratic units (figure 11). The extent or continuity of these beds cannot be determined because the lower portion of the member is commonly poorly exposed. The quartz grains are well-rounded but have prominent quartz overgrowths. Similar sandstone units were observed near the base of the "foreset beds" in Elaterite Basin and at the base of the Torrey Member on the Monument Upwarp.

Paleontology

Fossils are sporadically distributed in the Black Dragon Member. Nearly all the body fossils recovered for this study were from the San Rafael Swell but trace fossils were observed elsewhere.

Gastropods and pelecypods are the most abundant fossils in the limestones of the transition facies of the Black Dragon Member. They appear to be similar to, or identical with, those in the overlying Sinbad Limestone Member and are discussed with that member. A potentially important fauna of small bellerophontids and other gastropods and pelecypods composed mostly of phosphatic internal molds occurs at the base of the Black Dragon Member in Cottonwood Draw in the San Rafael Swell.

Ostracodes have been observed in thin-section in the limestone of the transition facies and less commonly in some of the sandstone units in the other facies. Whole-shell ostracodes were recovered from the basal unit in Cottonwood Draw in great abundance. None of the ostracodes were identified but several genera of smooth and ornate forms are thought to be present.

A single conodont fragment was tentatively identified as *Ellisonia triassica* by James W. Collinson of

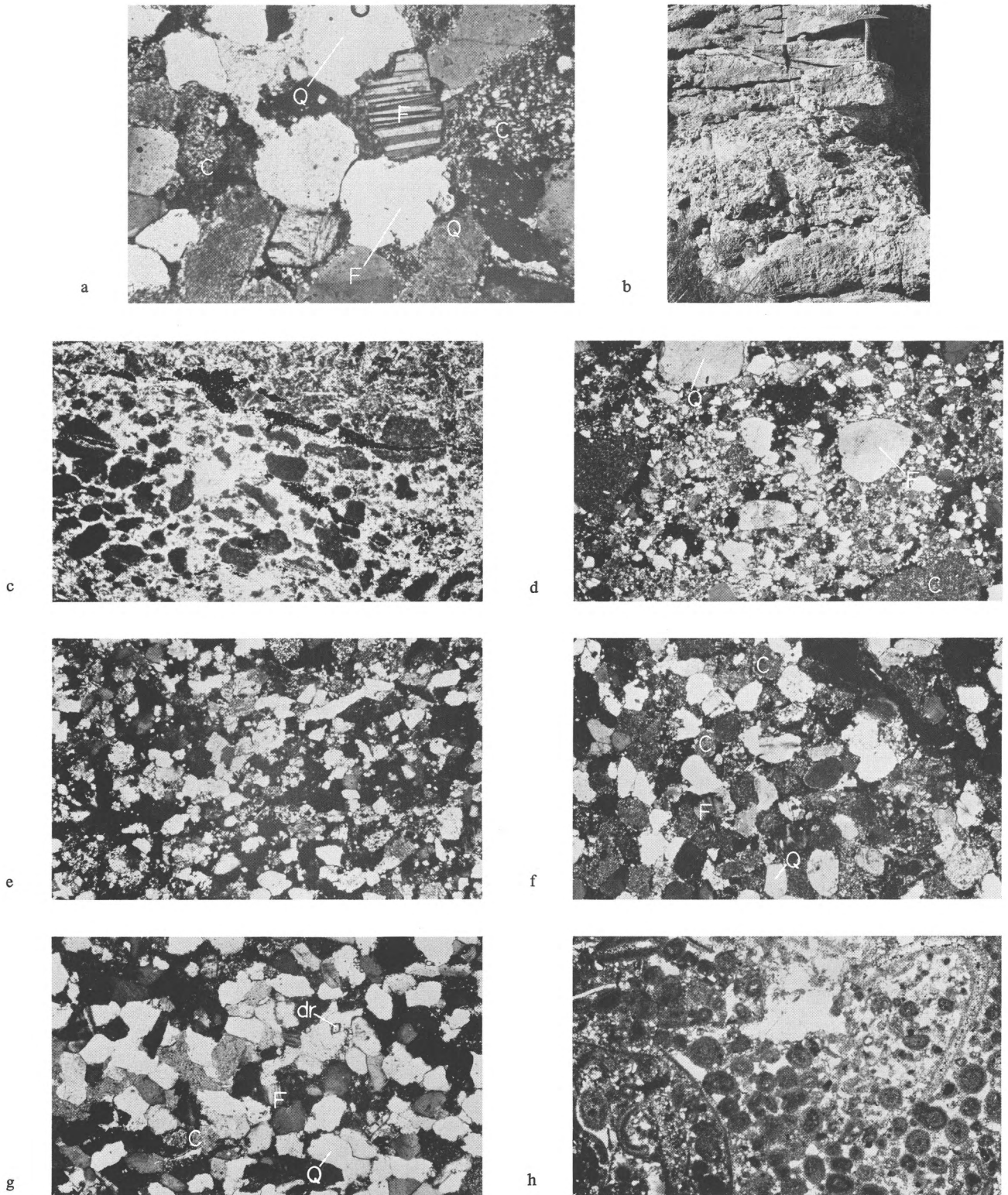


Figure 11. Photomicrographs and photograph of Black Dragon Member. (a), (d), (f), and (g) taken using crossed nichols. (a) Medium-grained, arkosic litharenite, northern San Rafael Swell, (b) basal conglomerate, Black Dragon Canyon, (c) gypsiferous micritic dolomite, transition facies, northern San Rafael Swell, (d) basal conglomerate, cherty litharenite, northern San Rafael Swell, (e) very fine-grained dolomitic subarkose, Cottonwood Draw sandstone, northern San Rafael Swell, (f) coarse-grained calcitic cherty subarkose, northern San Rafael Swell, (g) dolomitic arkose, "foreset beds", Stillwater Canyon, (h) bio-oosparite with ammonite fragment, transition facies, northern San Rafael Swell. Symbols used on these and other photomicrographs: q = quartz, f = feldspar, c = chert, g = gypsum, h = hematite, ff = fossil fragment, dr = dolomite rhombs, cal = calcite.

The Ohio State University (personal communication, 1973). Orgill (1971) also reported a number of conodont specimens from the Black Dragon Member belonging to *E. triassica*, but none were found in this study.

Bioturbation is most common near the top of the Black Dragon Member in the transition and Island in the Sky facies. Many different types of trace fossils were noted but not described. Rather unusual and well preserved "rooster tail" trace fossils which appear to be feeding marks of an organism that gathered food in a systematic fashion are present in the basal conglomerate in Cottonwood Draw.

A questionable ammonite was observed in a thin-section of a limestone in the transition facies. The thin-section was cut oblique to the plane of coiling, so no identification was possible (figure 11).

Correlation and Age

Similar lithologic character, stratigraphic position, and subsurface control serve to correlate the Black Dragon Member with the Woodside Formation of the Wasatch and Uinta Mountains. Irwin (1971) suggests using the term Woodside in southeastern Utah. Similar criteria suggest the member correlates with the lower part of the Ali Baba Member of the Moenkopi Formation in the Salt Anticline region. The State Bridge Formation of north-central Colorado contains Permian and Triassic rocks partially correlated with the Moenkopi Formation (Stewart *et al.*, 1972) and it is possible that part of the upper member of the State Bridge Formation is equivalent to the Black Dragon Member, although the two units were apparently deposited in different basins.

Correlation of the Black Dragon Member east of the Colorado River is difficult and somewhat controversial. East of Dead Horse Point in the area of Lockhart and Cane Springs Canyons, the Moenkopi is a rather homogeneous sequence of siltstone and silty sandstone and has not been satisfactorily divided into members or correlated with either the Salt Anticline region or the units of southeastern Utah. The area is apparently a transition zone between the above two areas. However, units equivalent to the Black Dragon Member are most likely present in this area.

Other than in the above area, the member is not recognized to the southeast of the margin as shown in figure 10. This interpretation conflicts with the correlations of Stewart *et al.* (1972) who recognize the Black Dragon (lower slope-forming member) over most of the Monument Upwarp. This discrepancy can be summarized as follows:

(1) Over most of the Monument Upwarp a 10- to 40-foot thick sequence of slope-forming siltstone, sandstone, and mudstone with local limestone separates the Torrey Member from the Hoskinnini Formation (plate 1).

(2) The lithology of this unit is similar to the Black Dragon Member and the basal unit of the Torrey Member which is always present in the western area of study (basal siltstone and mudstone facies).

(3) Because of erosion, nondeposition, or drastic facies change of this unit at North Wash, the key section in the controversy, direct physical correlation is not possible.

(4) Stewart *et al.* (1972) correlate this unit with the lower slope-forming member (Black Dragon) on the basis of lithologic similarity.

(5) Data presented in this paper suggest that the unit in question is related to the deltaic deposition in the Torrey Member; however, because of the time-transgressive nature of the Moenkopi, the unit may be partially time equivalent to the Black Dragon.

(6) In the present paper this unit is placed at the base of the Torrey Member; the southeastern edge of the Black Dragon Member is shown in figure 10. This interpretation is substantiated by the drastic thinning of the Black Dragon to the southeast in the Island in the Sky.

Evidence presented by McKee (1954) and Stewart *et al.* (1972) demonstrated that the Black Dragon Member is older than any of the units in the Moenkopi Formation of northern Arizona and southwestern Utah. Therefore, the member can be correlated with units only to the north, northwest, and northeast.

The Black Dragon Member is conformably overlain by rocks containing *Meekoceras* fauna and it overlies with erosional unconformity Middle or possibly Upper Permian rocks; therefore, its age has been assumed to be Early Triassic. This interpretation is supported by the fossil evidence of conodonts found near the base by Orgill (1971) reported by him to be probably Early Triassic; also, in a personal communication of January 27, 1973, James W. Collinson of The Ohio State University identified a single conodont fragment recovered from the basal conglomerate in Cottonwood Draw:

"Unfortunately the conodont fragment probably belongs to the long ranging multi-element species *Ellisonia triassica*, which can be either Permian or Triassic. From my field experience in the region I would concur with you that the basal beds are Moenkopi and that they are Triassic. It isn't unusual in western Utah and eastern Nevada to find *Meekoceras* beds a couple hundred feet above the base."

In the opinion of W. L. Stokes of the University of Utah (personal communication, 1973), the San Rafael Swell area was more positive than the miogeosyncline to the west, and thus would be an unlikely place to find any deposits very close to the Permo-Triassic boundary.

Roger L. Batten of the American Museum of Natural History (personal communication, 1973) examined the gastropods from this locality and states:

"I think one of the species is *Worthenia* which has a distinctive profile even as a steinkern. What really is interesting is that there are several bellerophontids present. There are two different types only one of which I can identify—*Euphemites* sp. Bellerophontids have been reported at two or three places in the world in the lower Triassic. But if the unit you obtained this sample from is Triassic, this would be the first report of *Euphemites* in the Triassic. Could the unit be very late Permian? More likely these forms could have been reworked from the Permian judging from the poor preservation. The other interesting form is *Glabrocingulum*, a very common upper Paleozoic genus which is unknown in the lower Triassic but does show up in the Ladinian of Europe. The unidentifiable steinkerns, in addition, give the whole sample a strong Permian component, with nothing to suggest Triassic."

Petrology

Thirteen thin-sections from the Black Dragon Member were studied. Because of the complexity of the member and its facies, representatives of the various rock types will be discussed rather than the petrology of an entire facies; most facies contain several lithologies which are very similar from one facies to another.

Quartz, feldspar, and chert in varying proportions comprise most of the grains of the basal conglomerate (figure 11). A few grains of chert are as large as 3 inches (75 mm) in diameter, but most of the grains are about 1 to 2 mm in size. Sorting is generally poor but in some localized areas it is very good. Most quartz grains larger than 0.1 mm are well-rounded and commonly display quartz overgrowths. Both strained and nonstrained quartz are present, but composite quartz grains are uncommon. Finer sand and silt-sized quartz is sub-angular to angular and frequently blade-shaped. Feldspar grains include microcline, perthite, albite, and orthoclase with a few overgrowths noted. Chert grains, some partially replaced by dolomite, were probably derived from the "Kaibab" Formation. Thin-section studies showed that chert in the "Kaibab" is similar to chert in the basal conglomerates of the Moenkopi. Mica is present in the basal conglomerate but is much less abundant than in overlying units. Occasional resistates such as tourmaline and rutile were noted in thin-section.

A phosphatic unit is present near the top of the basal conglomerate in Cottonwood Draw of the San Rafael Swell. Gastropods, pelecypods, and ostracodes are phosphatized in a matrix of moderately well-sorted,

coarse, quartz silt and very fine sand (figure 11). Cement is predominantly calcite with some dolomite, but insolubles such as phosphate or silica may also serve as cementing agents because the rock does not break down very well in formic acid. Cement in other units of the basal conglomerate includes silica occurring as quartz overgrowths on larger quartz grains; calcite, present as large crystals of spar up to several inches across, called "sand crystals"; and dolomite in silt-sized rhombs.

The most common lithology in the Black Dragon Member is quartz siltstone (figure 11) in which grains bridge the sand-silt range (0.25 mm to 0.03 mm). Quartz is the dominant detrital material, but feldspar commonly constitutes 20 to 30 percent of the detrital fraction. Both the quartz and the feldspar fragments are much more angular than the rounded detrital grains described in the conglomerate. Mica is very abundant in this lithology and mica flakes coat the bedding planes in hand specimen. In thin-section some mica grains appear twice as large as the average quartz grains.

The siltstone is cemented with dolomite in the form of silt-sized rhombs, some of which are zoned (figure 11). Ferric oxide also acts as a cement, forms discrete coatings on detrital grains, or stains and obscures finer-grained portions of the sediment. Field evidence suggests that clay is abundant in some of the siltstone units, but none of the thin-sections studied revealed very much clayey material.

The sandstone units in the member appear quite variable in the nature of their bedding and associated sedimentary structures, but are actually very similar in thin-section. In hand specimen most of the sandstone seems to display bi-modal sorting with very fine-grained sand and silt or clay matrix. In thin-section the matrix appears to be dolomite rhombs cementing a well-sorted sandstone (figure 11).

Detrital grains are mainly quartz and feldspar with minor amounts of muscovite and chert. The quartz grains are mostly subangular to subrounded although a number are very angular and blade-shaped and quartz overgrowths are prominent on grains larger than about 0.25 mm (medium sand) but are minor or absent on the finer material. Although a few sandstone units, especially those near the base, are composed of medium- or coarse-grained sand, the majority are fine- or very fine-grained sand. Some of the sandstone units contain abundant hydrocarbons appearing as very fine sand- or silt-sized particles disseminated throughout the rock. Apparently all the volatiles have been driven off.

Cementing agents in the sandstone include silica, dolomite rhombs, some calcite, and ferric oxide. The nature of the iron-bearing minerals is particularly

important in the relationship of red and nonred sandstones. Red units display ferric oxide as coatings on sand grains or as stain in dolomite cement. In nonred rocks the grains are rimmed with limonite or minor amounts of ferric oxide and the dolomite cement is pale-yellowish-orange (perhaps due to limonite within or between the dolomite crystals); authigenic pyrite grains are rimmed with limonite or hematite; little or no pyrite is present in red rocks. Frequently the nonred rocks also contain hydrocarbons. Other than the above differences, red and nonred rocks cannot be differentiated petrologically.

Although impure limestone and dolomite characterize many of the thinner-bedded units of the Black Dragon, fairly pure carbonate is common in the transition facies. One representative thin-section was studied and the grains observed included fossils, oolites, pellets, and detritus. Fossils constitute about 30 percent of the grains and are predominantly molluscan shell fragments; some can be identified as gastropods consisting of recrystallized shells up to 6 mm across. A single recrystallized parabolic mollusk fragment, possibly an ammonite, was observed (figure 11h), as were ostracodes.

Oolites are about 0.3 mm in diameter and constitute about 60 percent of the grains. They have nuclei of fossil fragments, or one to several quartz sand grains. Pellets occur in trace amounts and are mainly indistinct masses of dolomite about 0.1 mm in diameter that may originally have been oolites. Preservation of oolitic structure varies; some grains show detailed laminae and a nucleus, some show only a nucleus, and some show neither.

Detrital grains averaging about 0.06 mm in diameter include quartz, feldspar, chert, mica, and opaques. This material is subangular to angular and composes about 10 percent of the grain fraction.

Mineralogically the unit contains about 70 percent dolomite and 30 percent calcite. The dolomite forms the oolites, pellets, and some of the recrystallized shell fragments, and dolomite rhombs are also present between grains. The calcite is most commonly present in void fillings and in some shell structures. The grains are moderately packed and well-indurated, although many vugs or voids are present. Geopetal and umbrella effect structures are present. According to Folk (1959, 1962), the rock is a fossiliferous oosparite.

Gypsiferous units are relatively common at several horizons within the Black Dragon Member. One thin-section from the transition facies was studied. The gypsum generally forms the cement and fills voids in a dolomitic intraformational conglomerate. It also occurs as needles and as irregular "roses" but all these forms are

less than 50 percent of the rock. Silt-sized detrital material comprises less than 2 percent of the grains. The dolomitic intraclasts are aphanic. Although direct evidence is lacking, it is believed that much of the gypsum in the member was introduced at or shortly after deposition. Many of the gypsiferous horizons can be traced fairly long distances.

Sinbad Limestone Member

Introduction

The Sinbad Limestone Member of the Moenkopi Formation was named by Gilluly and Reeside (1928) for exposures in the Sinbad Country, San Rafael Swell, Emery County, Utah. The Sinbad is a conspicuous carbonate unit in a dominantly siliceous clastic sequence. During Early Triassic time, the western portion of the Colorado Plateau was adjacent to, and sometimes covered by, an epicontinental sea. To the east was an area of clastic deposition or erosion, and to the west was a shallow marine shelf where carbonates of the Thaynes Formation were deposited. The Sinbad represents the easternmost extension of extensive shallow marine carbonate during the Early Triassic; thus it is an eastward tongue of the Thaynes Formation into the Moenkopi Formation (figure 12).

The Sinbad crops out in the San Rafael Swell, Teasdale Uplift, northern Circle Cliffs Uplift, and northwest part of the Monument Upwarp. Although field work and subsequent laboratory studies of Sinbad samples were undertaken in all four areas, the most detailed areas of study were the San Rafael Swell and Monument Upwarp. In most areas the Sinbad is a yellowish-gray, tannish-gray, or pale orangish-brown weathering limestone and dolomite, generally a conspicuous cliff-former where it exceeds 20 feet in thickness (figure 13, b, c) or a bench-former where it is less than 20 feet thick (figure 3b).

Stratigraphy and Lithology

The major constituents of the Sinbad Limestone Member are limestone, dolomite, and calcareous siltstone. Accessory minerals include quartz, feldspar, muscovite, "limonite", hematite, and pyrite. Detrital carbonate grains include whole and abraded fossils, oolites, pellets, and intraclasts. Detrital quartz and feldspar are present in predominantly medium to coarse silt or very fine sand sizes, with a few medium-sized grains occasionally rimmed or replaced by limonite or hematite. Both limonite and hematite occur as impurities or void fillings. Solid or semifluid hydrocarbons commonly fill voids in coarser fractions of the Sinbad imparting a black color and a fetid odor to freshly broken samples, whether limestone or dolomite.

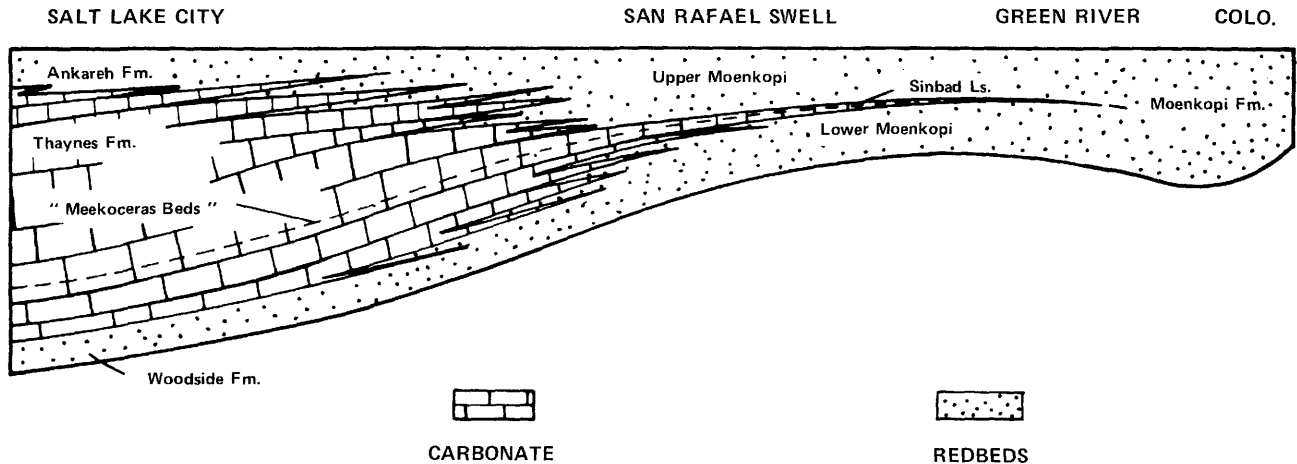


Figure 12. Sketch of the relationships of Lower Triassic rocks from Salt Lake City to the Utah-Colorado border showing relationships of Sinbad Limestone Member and Thaynes Formation.

Sedimentary structures in the Sinbad include trough and planar-wedge cross-stratification in sets up to 2 feet thick with both high and low angle dips. Herringbone cross-stratification, indicative of bimodal current directions, is present in the calcarenitic units. Ripple marks and mud cracks are locally common in various lithologies. Tracks, trails, and burrows are abundant at many locations as are disturbed, probably bioturbated units.

Beds of the Sinbad weather platy to massive depending upon lithologic variation and sedimentary structures. Most commonly the calcarenites and calcisiltites weather blocky to massive, whereas the calcilitites and calcareous siltstones weather platy. Many of the calcarenite units are somewhat wavy-bedded and some give the appearance of lenticular bedding, while the siltier units are more regularly bedded. In general, the well-indurated calcarenites form massive cliffs or resistant ledges and the silty units form ledgy slopes or broken cliffs.

From its southeastern margin (figure 14), the Sinbad thickens fairly regularly to the west and northwest attaining maximum exposed thicknesses of 103 feet north of Torrey, Utah, 86 feet in the southwestern San Rafael Swell (Stewart *et al.*, 1972), and 53 feet in the northwestern Circle Cliffs. On the Monument Upwarp (Orange Cliffs and Island in the Sky), the Sinbad is discontinuous and usually less than 10 feet thick. The geometry of the Sinbad is a carbonate wedge thickening to the northwest where it presumably merges with the Thaynes Formation (figure 12).

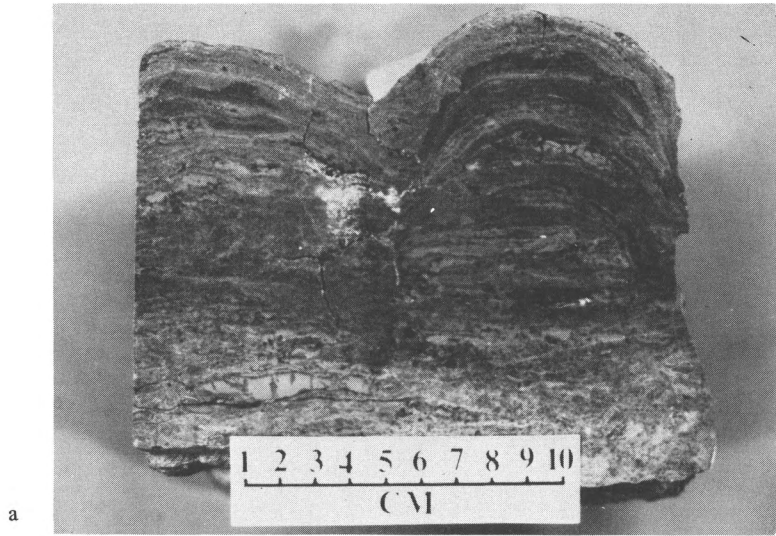
Because of intertonguing with underlying and overlying units, the boundaries of the Sinbad vary according to different authors. In this report the

boundaries of the Sinbad are placed at the maximum change from predominantly siliceous rocks to predominantly carbonate rocks, readily recognizable at most localities. At the southern and eastern depositional edges, however, the carbonate units become sandy or discontinuous, and the boundaries must be traced by careful field work.

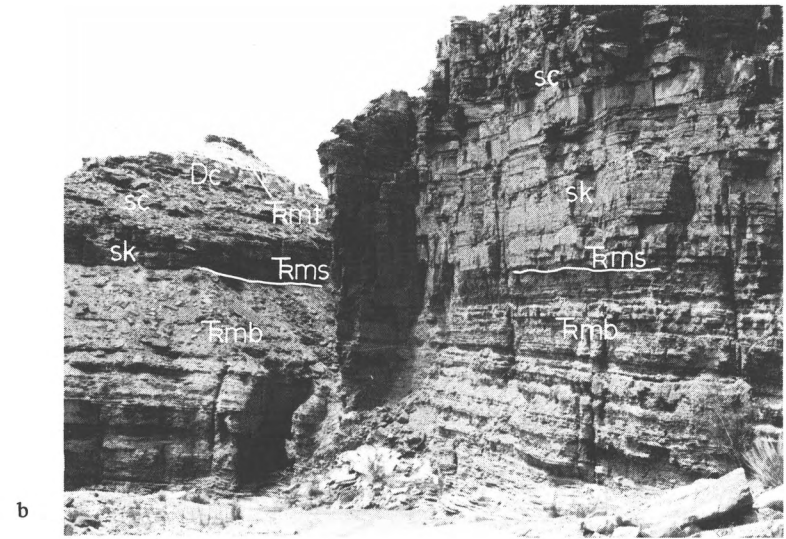
At most localities the Sinbad overlies the Black Dragon Member and underlies the Torrey Member of the Moenkopi Formation. Intertonguing of the Sinbad with the Black Dragon Member is evident throughout the San Rafael Swell (figure 9, a, b, e). Outcrops commonly display 20 feet or more of interbedded limestone, siltstone, and sandstone. The limestone units are fossiliferous and individual beds can be correlated 10 miles or more across the Swell while the intercalated siltstones and sandstones are generally unfossiliferous. In the San Rafael Swell area, this unit is included in the Black Dragon Member, but southward in the Teasdale Uplift area, limestone dominates the unit and it is included within the Sinbad. In the San Rafael Swell, the base of the Sinbad is a massive, cliff-forming skeletal calcarenite.

In the Teasdale Uplift the yellowish-gray Sinbad conformably overlies the reddish-brown Black Dragon Member in which the upper several feet are commonly yellowish-gray. The contact is easily recognized despite probable intertonguing. In the Circle Cliffs, the Black Dragon Member is thin or absent, and the Sinbad unconformably overlies the Permian Kaibab Formation.

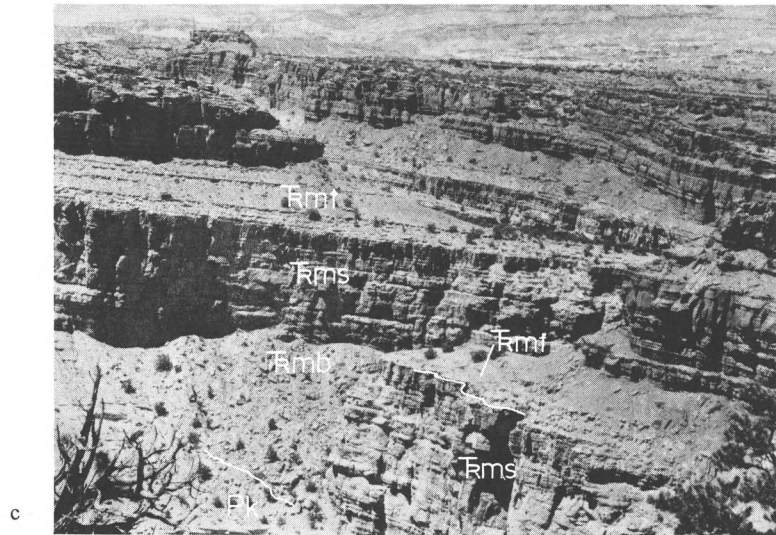
In the Orange Cliffs and Island in the Sky areas, the Sinbad overlies the reddish-brown Black Dragon Member. Near the southeastern margin of the Sinbad, the carbonate is generally discontinuous, sandy, or interbedded with sandstone and siltstone.



a



b



c



d

Figure 13. Photographs of Sinbad Limestone Member. (a) Stromatolites in Stillwater Canyon, (b) Black Dragon Canyon, San Rafael Swell, (c) near Torrey, Utah, (d) cliff 100 feet high along Fremont River south of Torrey, Utah.



Figure 14. Isopach map of Sinbad Limestone Member.

At all localities the Sinbad is conformably overlain by the Torrey Member of the Moenkopi Formation. The base of this member is believed to be a mixed prodelta and migrating shoreline deposit which diluted carbonate deposition (Blakey, 1973). A few thin limestone units occur in the base of the Torrey Member and may indicate limited intertonguing between it and the Sinbad.

Based upon the combined field and petrographic studies, four facies of the Sinbad are distinguishable (figure 15). Because genetic interpretations are subject to opinion, purely descriptive names are given to these units, and environmental interpretations will be presented later. In the San Rafael Swell a basal skeletal calcarenite, a middle silty, peloidal calcilutite, and an upper, dolomitized calcarenite are recognized. In each of the other three areas of study one or more of these facies units are recognized. The fourth facies, a thin, discontinuous, sandy dolomite in the Orange Cliffs, Island in the Sky, and central Circle Cliffs regions, probably correlates with the upper dolomite.

The Sinbad was not studied in enough detail in the Teasdale Uplift to accurately define the facies units, but a 12 to 20-foot thick skeletal calcarenite is tentatively correlated to the skeletal calcarenite of the Swell because it displays similar characteristics. In addition, Davidson (1967) reports pelecypod and gastropod "coquinas" in the northern Circle Cliffs, possibly the southeasternmost occurrence of the skeletal calcarenite. The uppermost unit of the Teasdale Uplift is "dolomitic and has a rough weathered surface on which dolomite rhombohedra may be observed with a hand lens" (Smith *et al.*, 1963). This unit is similar enough to the dolomitized calcarenite facies in the San Rafael Swell to be tentatively correlated to it. Also because of similar characteristics, the middle unit is tentatively included in the silty peloidal calcilutite.

These correlations leave as much as 58 feet of interbedded calcarenite and calcilutite at the base of the Sinbad in the Teasdale Uplift. This interval probably reflects the intertonguing and facies change between the Sinbad-Thaynes to the west and the Black Dragon Member of the Moenkopi Formation to the north and east (figure 15). In the Teasdale Uplift this facies unit is assigned to the Sinbad Limestone Member and in the San Rafael Swell its apparent equivalent is assigned to the Black Dragon Member.

Paleontology

Gastropods and pelecypods dominate the Sinbad fauna (figure 16) as published in a number of reports and most specimens represented are assigned to long-ranging Paleozoic and Mesozoic genera. According to Stewart *et al.* (1972) the most frequently mentioned gastropods are *Pleurotomaria*, *Naticopsis*, *Worthenia* (?), *Solariella* (?), *Neritaria* (?), and *Eucyclus* (?); pelecypods include *Aviculopecton*, *Myalina*, *Pseudomonotis*, *Monotis*, *Bakewellia*, *Pleurophorus*, and *Myophoria* (figure 17, i, j).

Some gastropods collected by the author were sent to Roger L. Batten who identified the following (personal communication, 1973): *Omphaloptycha anguliferous* White, *Naticopsis* sp., *Worthenia* sp., and ??? *Murchisonia* sp.

Ammonites from the Sinbad are reported by several authors. Stewart *et al.* (1972) summarized all ammonites reported from the Sinbad: *Meekoceras gracilitatis* (?), *Meekoceras* (?) sp., *Paranannites* sp., *Anasiberites* sp., *Xenocelites* sp., and *Hemiprionites* sp. The first three are characteristic of the *Meekoceras* zone and the last three are characteristic of the *Anasiberites* zone (Kummel, 1954).

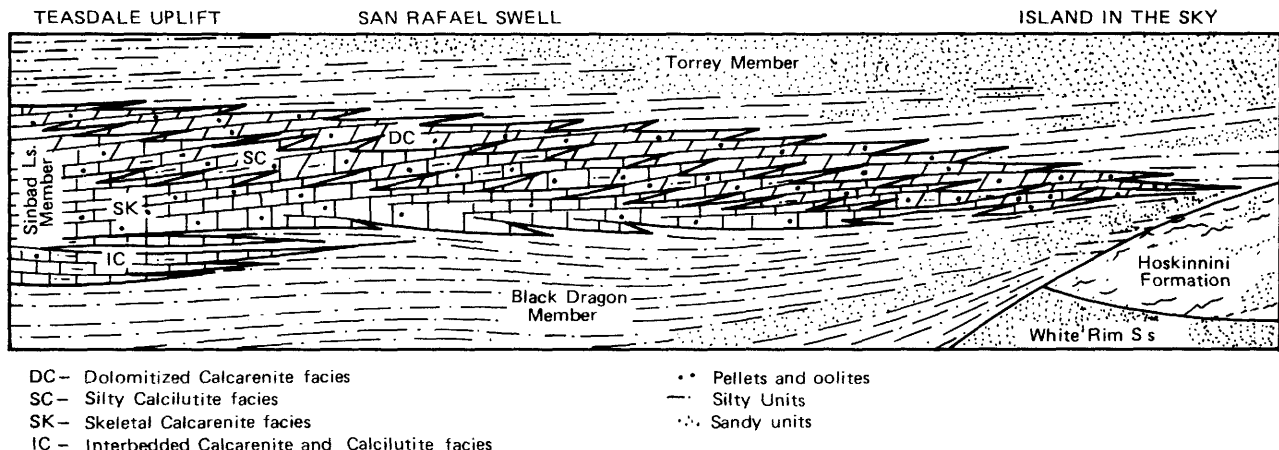


Figure 15. Cross-section of Sinbad Limestone Member showing facies relationships.

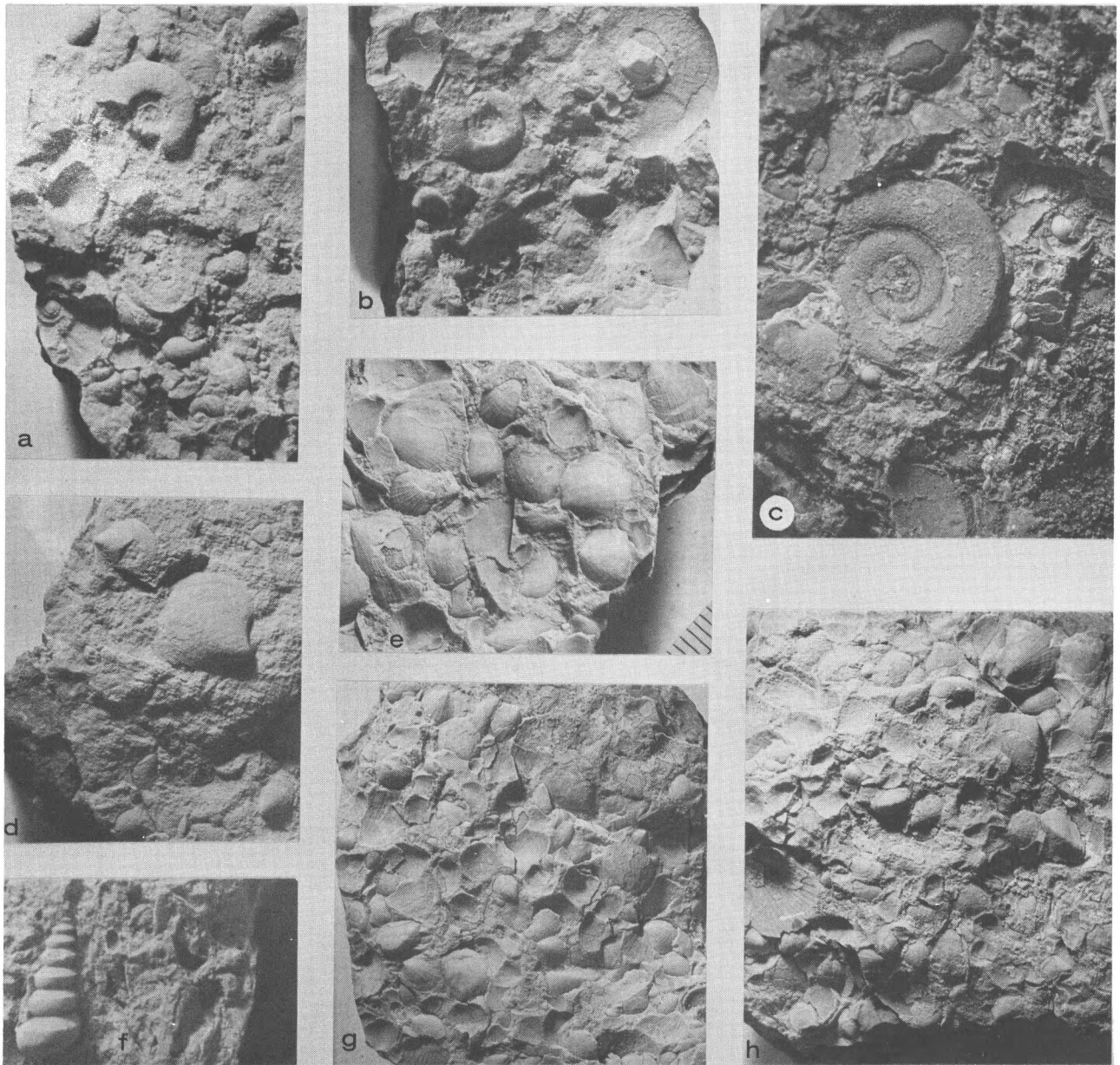


Figure 16. Fossiliferous rocks from Sinbad Limestone Member. (a), (b) Slab with molluscan fauna, ammonites are probably *Dieneroceras spathi* (Kummel and Steele), near Torrey, Utah, (c) slab with molluscan fauna including *Wyomingites*?, northern San Rafael Swell, (d) pectens, near Torrey, Utah, (e) pelecypods, northern San Rafael Swell, (f) gastropod, Black Dragon Canyon, (g), (h) pelecypods, northern San Rafael Swell.

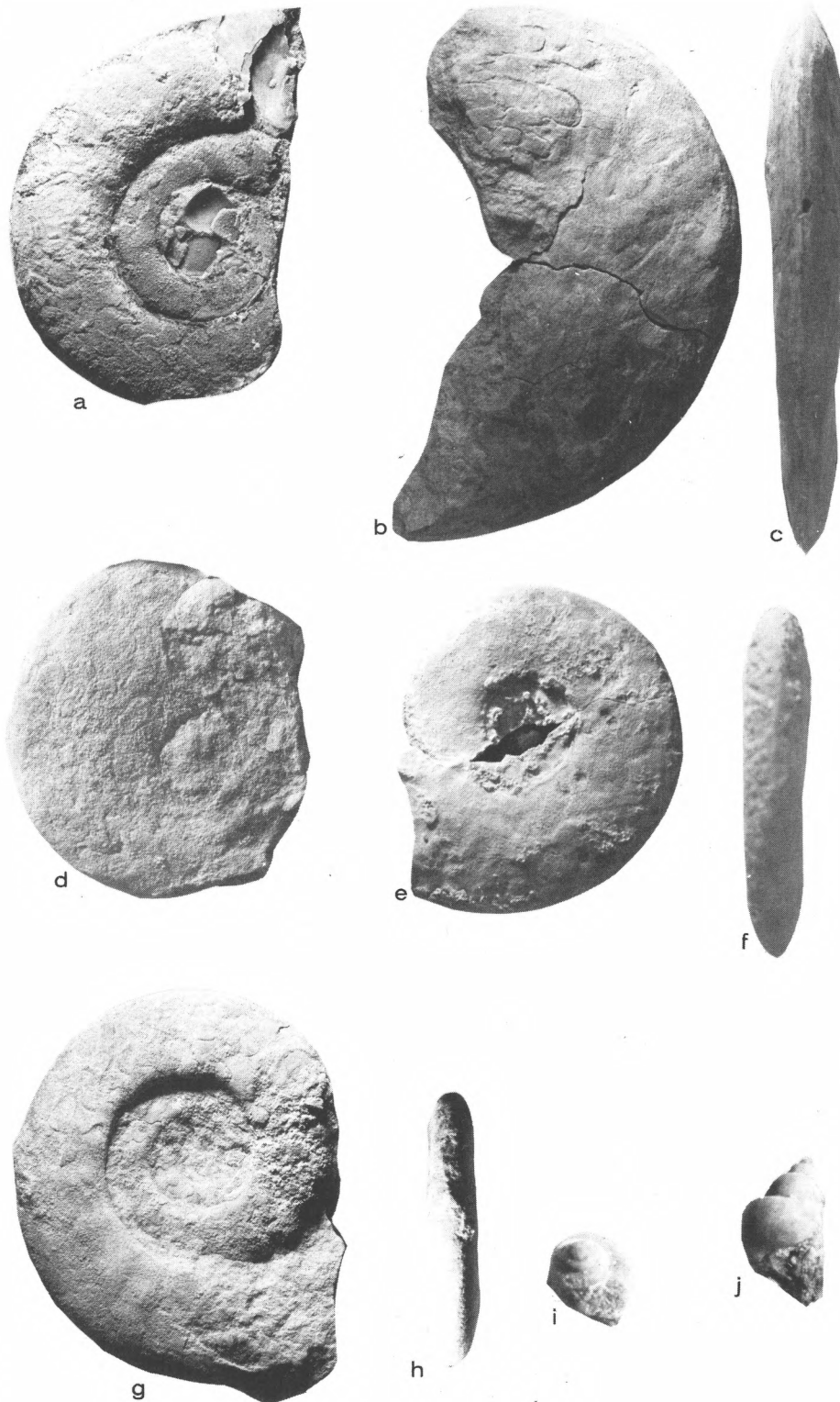


Figure 17. Fossils from Sinbad Limestone Member. (a) *Dieneroceras knechti* (Hayatt and Smith), (b)-(f) *Arctoceras tuberculatum* (Smith), (g), (h) *Wyomingites* cf. *W. whiteanus* (Waagen), (i), (j) unidentified gastropods. All specimens slightly reduced.

During this study, about two dozen ammonites were found at scattered localities in both the San Rafael Swell and Teasdale Uplift; identifiable specimens were assigned to: *Wyomingites* cf. *W. whiteanus*, *Dieneroceras knechti*, *D. spathi*, and *Arctoceras tuberculatum* (figure 17, a-h). These four species are reported from unit "a" of the *Meekoceras* zone, Thaynes Formation at Crittenden Spring, Elko County, Nevada (Kummel and Steele, 1962).

Scaphopods are relatively common in the San Rafael Swell. No attempt at identification was made, but *Laevidentalium* (?) and *Plagiogypta* are listed by Stewart *et al.* (1972).

Echinoderm fragments compose several percent of the grains in the skeletal calcarenite facies; probably both crinoid and echinoid parts are present. Ostracodes were observed in thin-section but no free, whole fossils were recovered.

Conodonts were not recovered from the Sinbad during this study, although several may have been observed in thin-section. However, Orgill (1971) reports *Parachirognathus geiseri*, *Lonchodina nevadensis* (?), and *Diplodella* sp. from the Sinbad of the Swell. He reports that all these species are characteristic of the *Meekoceras* zone and that *Parachirognathus geiseri* is restricted to it.

Correlation and Age

Stratigraphic relationships, subsurface control, and especially the contained fauna serve to correlate the Sinbad Limestone with the Thaynes Formation of western Utah, eastern Nevada, and southern Idaho. The Sinbad represents the farthest eastward position of marine carbonate rock at this level; in southwestern Utah the southern portion of this carbonate tongue is exposed and is classified as the Timpoweap Member of the Moenkopi Formation (McKee, 1954; Stewart *et al.*, 1972). Like the Sinbad of the south-central Circle Cliffs, the Timpoweap rests directly on the Kaibab Formation.

East and south of its pinchout the Sinbad lacks lithologic equivalents; however, the Sewemup Member (Appendix A) of the Moenkopi Formation in the Salt Anticline region contains small ammonites tentatively identified as *Meekoceras* (Stewart *et al.*, 1972).

The *Meekoceras* and *Anasiberites* zones are part of the Smithian stage as defined by Tozer (1967). Kummel and Steele (1962) and Kummel (1969, 1972) prefer to use the series name Scythian and refer the above zones to a position near its middle.

Petrology of Skeletal Calcarenite

The skeletal calcarenite facies is 11 to 24 feet thick in the San Rafael Swell and 10 to 12 feet thick in the Teasdale Uplift. Twelve thin-sections were analyzed from the Swell and one from the Teasdale Uplift. Mineralogically the skeletal calcarenite is dominantly calcite with minor amounts of dolomite in the form of secondary rhombohedra. Limonite, hematite, and pyrite are the dominant opaque minerals. Most of the pyrite displays rims or halos of limonite, or less commonly, hematite. Both limonite and hematite occur in void fillings, as grain coatings, and as stains in fine-grained material. Gypsum occurs as both thin vein fillings and void fillings.

Grains in the skeletal calcarenite are largely fossil material with both whole and abraded shells common in most samples (figure 18, a-d). Pelecypods, gastropods, and echinoderms dominate the samples; scaphopods, encrusting foraminifera, and phosphate grains, probable fish and conodont material are common in some samples. Pellets are generally less than 1.0 mm in diameter. Most fossil fragments smaller than 0.5 mm serve as nuclei for oolites (figure 18, b, c). Intraclasts are less common, occurring in only two samples, but are as large as 10 mm in diameter. Most intraclasts are micritic. Percentages of the various grain constituents are displayed diagrammatically in figure 19.

Terrigenous clastic grains 0.4 to 0.04 mm constitute five to ten percent of the grain fraction and are usually quartz, but feldspar and chert are locally abundant. Microcline, plagioclase, and orthoclase, respectively, are the common feldspars. Accessory minerals and grains in order of abundance include: muscovite, phosphate, igneous and metamorphic rock fragments, and rare ferromagnesian minerals.

Spar (greater than 20 microns), microspar (4-20 microns), and micrite (less than 4 microns) form the cement and matrix. Spar occurs as void-filling cement, blocky mosaic recrystallization of certain shell material, and neomorphic recrystallization of micrite (figure 18). Recrystallization is indicated by "floating" grains such as pellets and oolites in more than enough spar to have filled intergranular pores. Void-filling cement is most common in shell interiors, in protected areas under shells (umbrella effect), and in interstitial voids in grain-supported fabric (figure 18). Microspar and micrite are common inside shells, in portions of rock with nongrain-supported fabric, and in poorly-washed areas of rock. Clots (probably ghosts of pellets) are common in some large patches of micrite.

The fabric of the skeletal calcarenite is dominantly grain-supported. The rock is well-indurated and

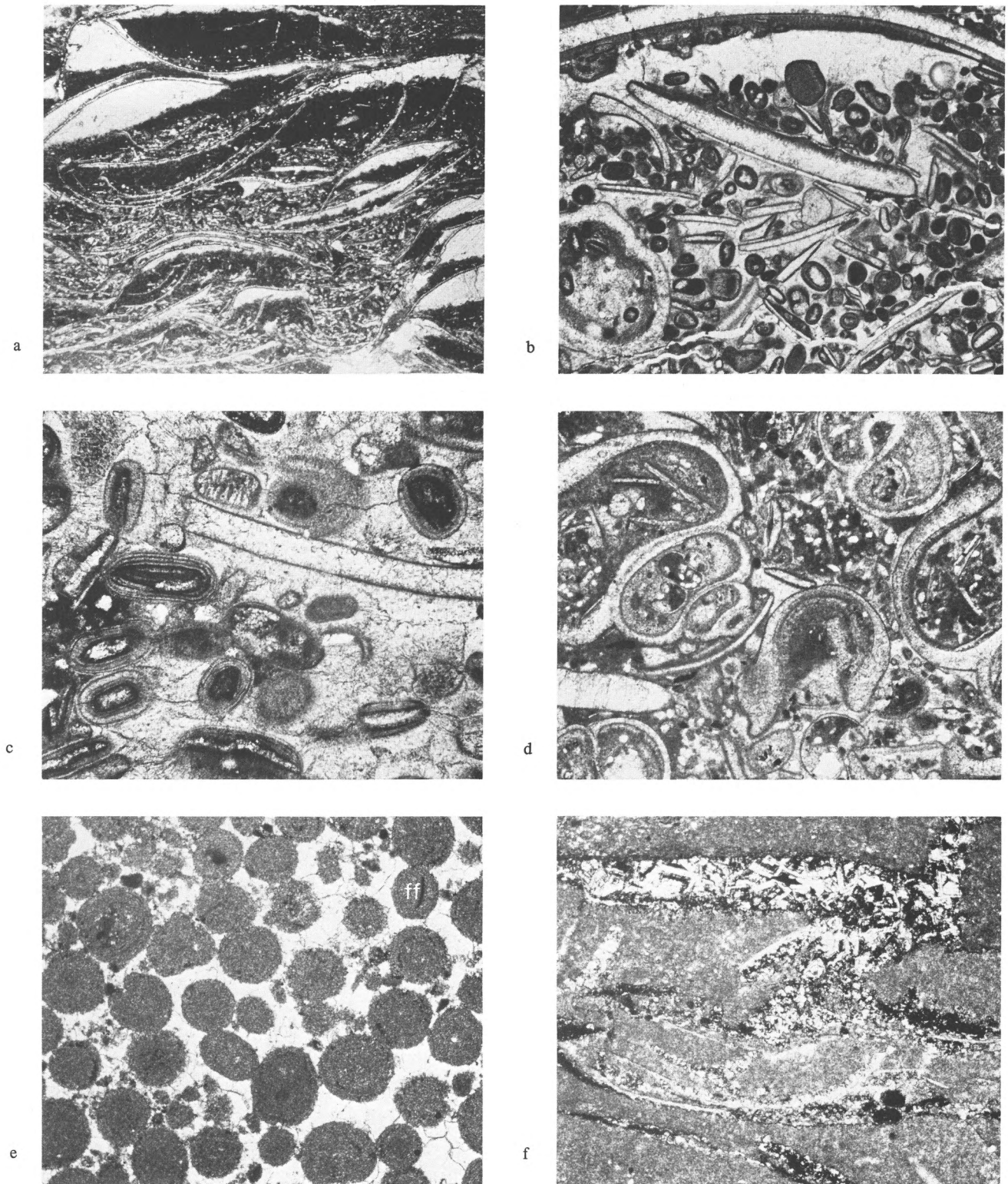


Figure 18. Photomicrographs of Sinbad Limestone Member. (a)-(d) Skeletal calcarenite facies showing oolites, fossils, and distribution of spar, San Rafael Swell, (e) silty calcilitite facies showing oolitic texture, San Rafael Swell, (f) silty calcilitite facies showing dolomitized mollusks, Teasdale Uplift.

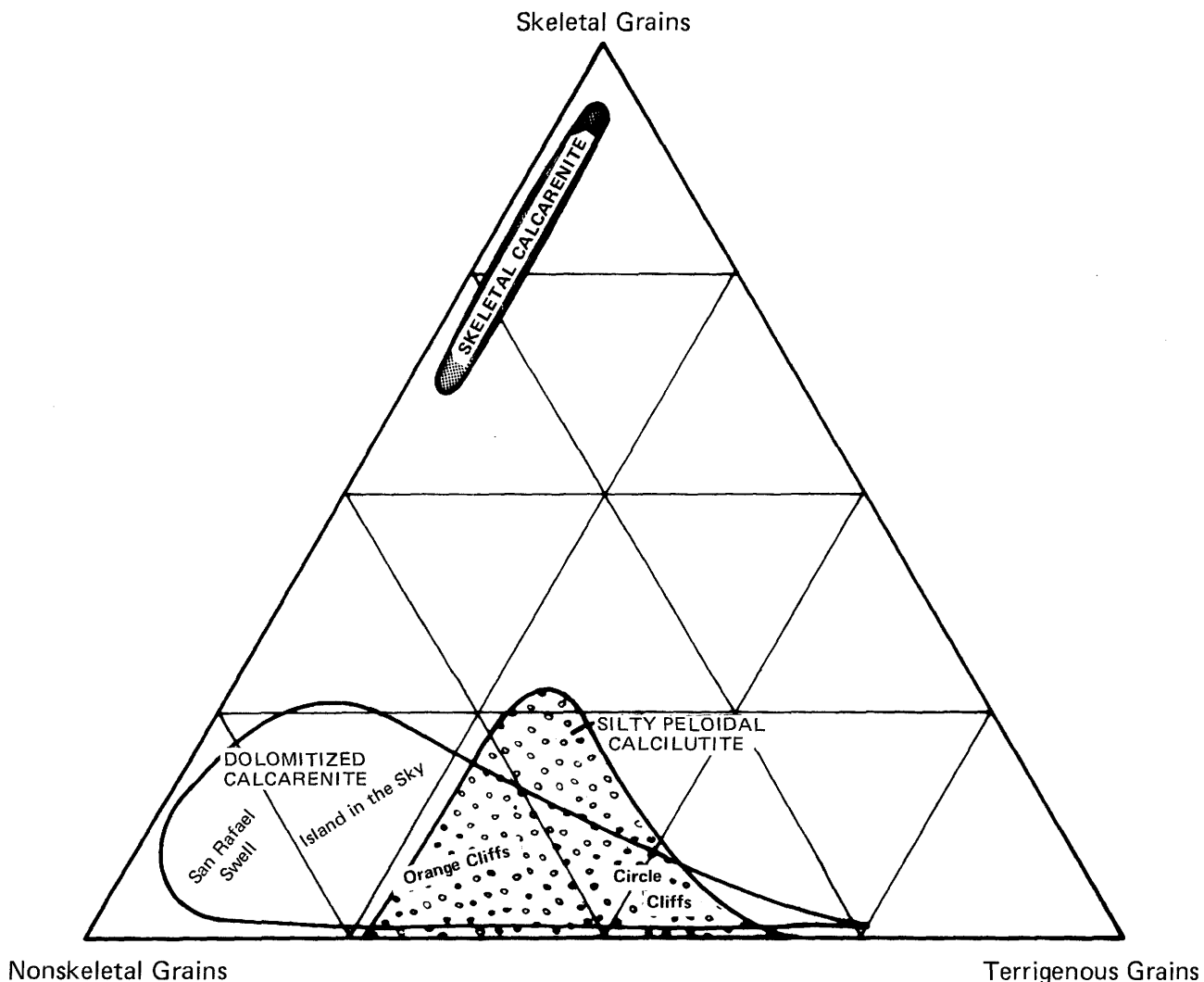


Figure 19. Triangular diagram showing grain constituents of the Sinbad Limestone Member. Composition of dolomitized calcarenite facies shown by location.

nearly all void space has crystal-like particles of hydrocarbons. Freshly broken rock commonly yields a petroliferous odor. Most common diagenetic features are authigenic dolomite rhombs, especially in areas of micrite or microspar, and neomorphic calcite spar, notably in pellet-rich rocks. According to Folk's (1959) classification most limestones in the skeletal calcarenite facies are oolitic biopelsparites.

Petrology of Silty Peloidal Calcilutite

The silty peloidal calcilutite facies is exposed throughout the San Rafael Swell where it ranges in thickness from 10 to 30 feet. Less precise data indicate approximate thicknesses from 15 to 40 feet in the Teasdale Uplift. The unit is thought to be present in the Circle Cliffs area, and locally present in the Northwest Monument Upwarp, although it was not studied

in these areas. The four thin-sections studied show both calcite and dolomite; the percentages vary greatly from rock to rock, but the dolomite fraction is greater than in the skeletal calcarenite facies. Limonite and hematite are common and occur as opaque grains, coatings on other grains, and locally as a cementing agent.

Oolites, pellets, and intraclasts are the dominant nonterrigenous grain types. Oolites range up to 0.7 mm, pellets 0.15 to 0.3 mm, and micritic intraclasts often exceed 10 mm. Skeletal grains were found in only two of the four samples and consist of poorly-preserved molluscan fragments constituting 5 to 10 percent of the grains (figure 18, e, f).

Terrigenous grains constitute 5 to 40 percent of the grain fraction of the rock, mostly in the fine sand

to silt-size range. Quartz is the dominant grain type, and feldspar, chert, and muscovite form the major accessories. In some samples very well-sorted dolomite rhombs, the same size as the quartz grains, form a major portion of the rock. According to E. A. Shinn (oral communication, 1972), similar silt and fine sand-sized dolomite rhombs occur as detrital grains in Recent shallow-water carbonate sediments in the Persian Gulf. Grains in the silty peloidal calcilitite are both internally-supported and floating in the matrix.

The micritic matrix is commonly clotted, dismicritic, or dolomitic and locally displays a mottled texture resulting from disturbed bedding. This may be caused by burrowing or desiccation. Spar is present both as void-filling cement and neomorphic recrystallization. Secondary dolomite rhombs are present in both the matrix and spar.

The silty peloidal calcilitite differs from the skeletal calcarenite by its decreased skeletal content and increased dolomite, nonskeletal, and terrigenous content. It is also more variable than the skeletal calcarenite with applicable rock names including sandy oosparite, silty pelleted intrasparite, and peldismicrite (Folk, 1959).

Petrology of Dolomitized Calcarenite

Because of its variability over a large area, the dolomitized calcarenite is described by region.

This well-indurated unit generally forms a yellowish-orange blocky-weathering bench at many localities in the San Rafael Swell where it is generally less than 8 feet thick. The three samples studied are nearly entirely dolomite with minor amounts of hematite.

Grains include skeletal, nonskeletal, and terrigenous types. The skeletal fraction, generally less than five percent, consists of mollusk fragments in varying states of preservation, including finely-prismatic ribbon-like shells that may be pinnid clams. The nonskeletal grains are pellets and peloid structures (micritized oolites?) about 0.2 mm in diameter (figure 20). Terrigenous material constitutes 5 to 20 percent of the grain fraction of the rock and is mostly fine or very fine sand-sized quartz, feldspar, and muscovite grains.

Packing of the grains is close, and much of the unit displays small-scale cross-stratification. The original fabric of one of the samples has been completely replaced by secondary dolomite (figure 20).

Matrix of the dolomitic calcarenite is generally sparry or microsparry dolomite, but it may have been

micrite at one time; hematite may act as a cementing agent in some of the samples. Most of the fossil fragments appear to have been micritized.

Rock types in the dolomitic calcarenite facies in the San Rafael Swell include dolomitic pelsparite and oomicrite (Folk, 1959).

Forty to fifty miles southeast of the San Rafael Swell in the northwest portion of the Monument Upwarp, the Sinbad Limestone is less than 13 feet thick everywhere, averages 2 to 4 feet thick, and is locally absent or difficult to recognize. In this area the Sinbad is a dominantly laminated, dolomitized calcarenite. Dolomite is the predominant carbonate mineral with calcite mostly confined to void fillings. Most of the 16 samples studied also contain gypsum in void fillings, veins, or shell linings. Limonite and hematite are present in all samples, and pyrite is locally abundant.

A complex suite of grains is present in the laminated dolomitized calcarenite (figure 21). Skeletal grains, although not abundant, were present in half of the samples. Generally, both the abundance and diversity of the skeletal material increase to the north. Pelecypods and gastropods occurring as whole shells and abraded grains are the most common skeletal traces, with ostracodes and probable algal structures locally present (figure 21).

Nonskeletal grains include intraclasts, some of which are greater than 10 mm in length, composed of laminated and clotted micrite, pellets, and oolites (figure 21). In the southern Orange Cliffs some of the intraclasts are ironrich and provide centers of hematite stain which color portions of the rock a brilliant red. Pellets and oolites are 0.2 to 0.3 mm in diameter and are often difficult to differentiate. Many oolites are micritized with only ghosts of oolitic structure present (figure 21) and some of the pellets are nearly destroyed; only a clotted structure in the matrix indicates their presence.

Terrigenous material constitutes 1 to 70 percent of the grains in the dolomitized calcarenite facies of the Monument Upwarp area, with 30 to 40 percent about average. Quartz and feldspar are the most abundant detrital minerals whereas chert, muscovite, and phosphate are accessories. A few ferromagnesian-mineral-bearing igneous rock fragments are locally present. Terrigenous grains are dominantly fine sand- to silt-sized, but some grains are as large as 0.5 mm and some of the quartz grains display overgrowths. Generally the relative percentage of terrigenous material in the unit increases southward.

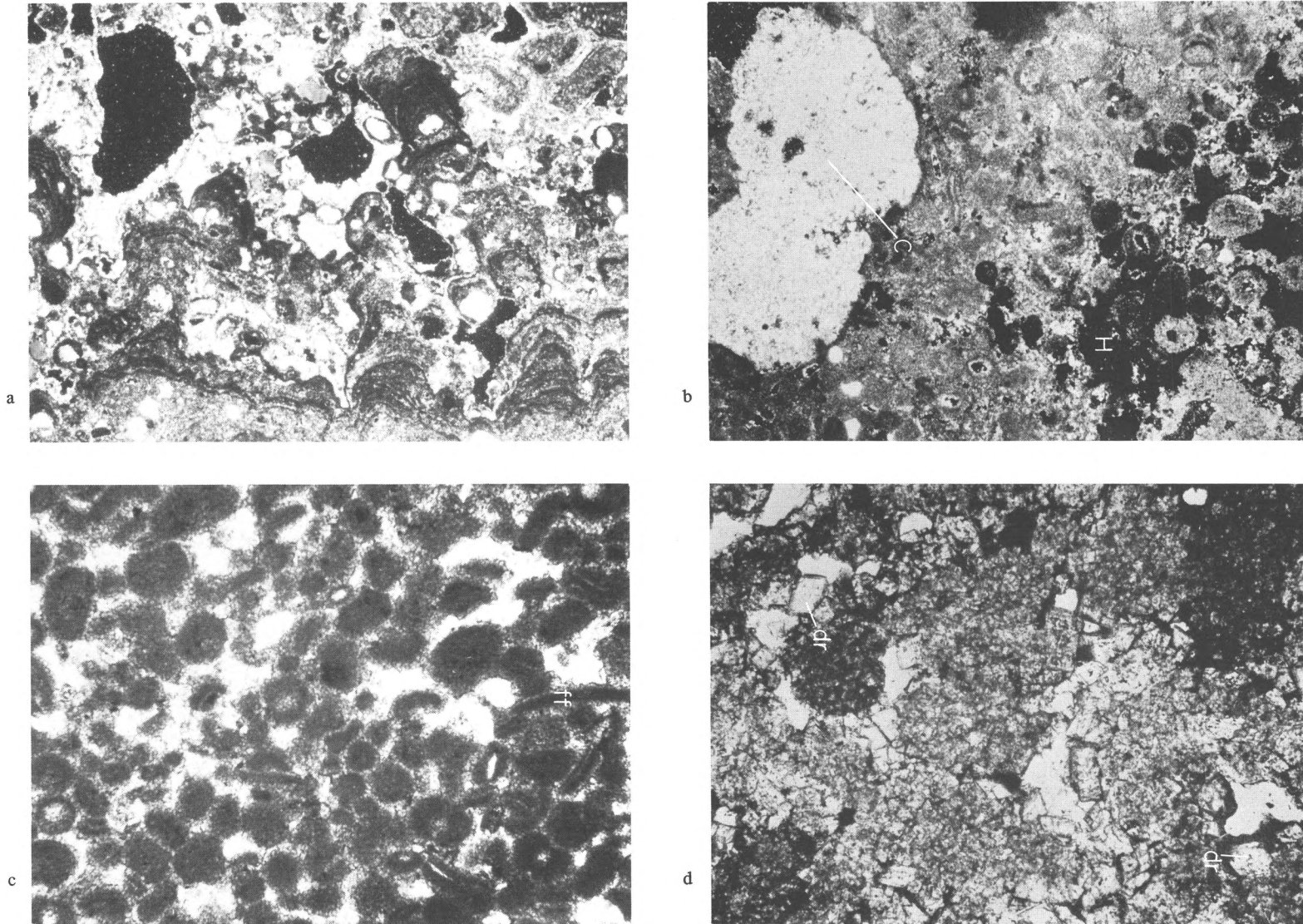


Figure 20. Photomicrographs of dolomitized calcarenite facies. (a) Microkarst structure, Circle Cliffs, (b) cherty unit, Circle Cliffs, (c) sandy dolomitized calcarenite with pellets and oolites, note fossil fragments (ff), San Rafael Swell, (d) dolomitized rock with evidence of former oolitic structure, Teasdale Uplift.

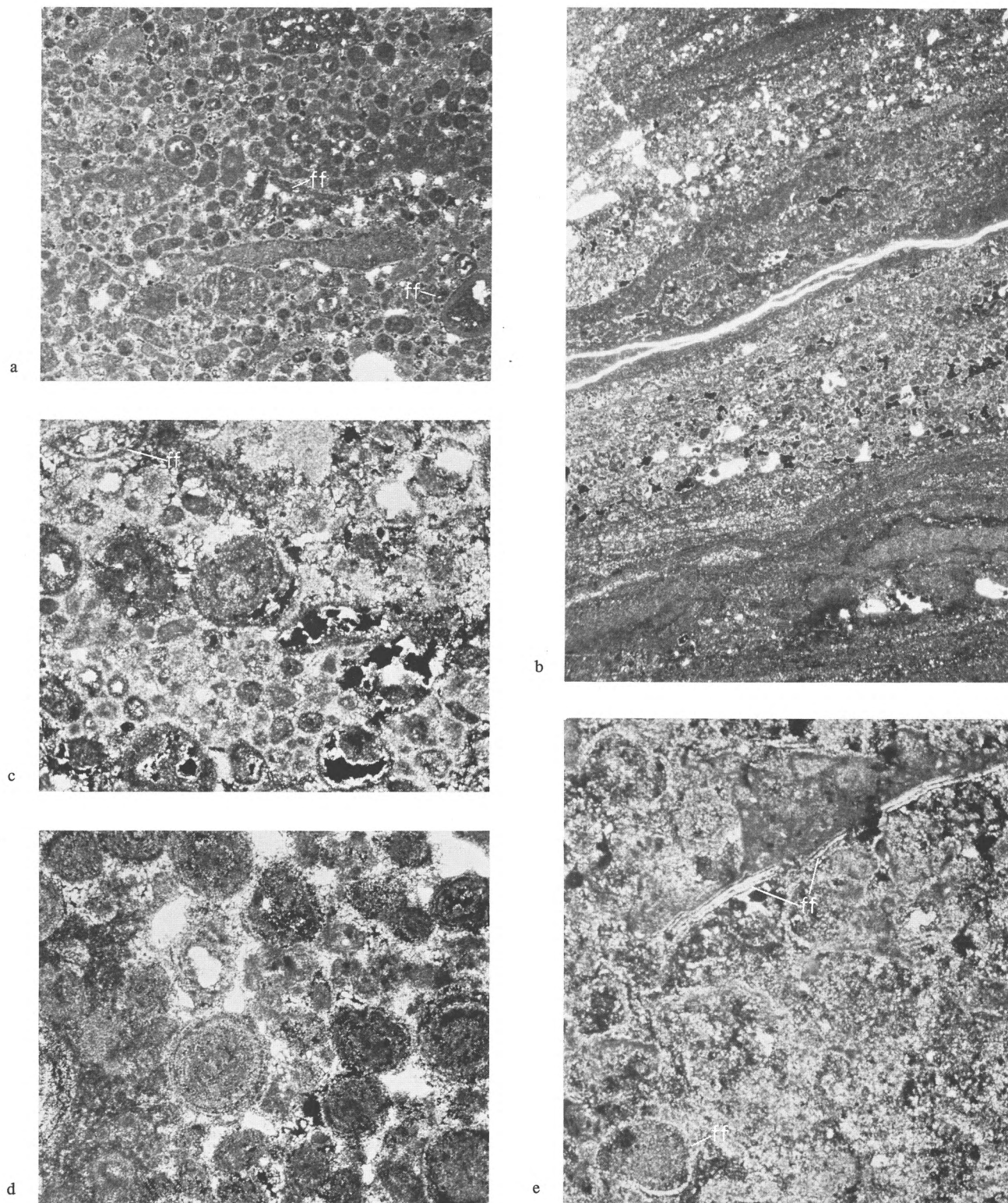


Figure 21. Photomicrographs of dolomitized calcarenite facies on the Monument Upwarp. (a) Dolomitized oolitic, pelleted intrasparite, note several fossil fragments, Stillwater Canyon, (b) algal structure, stromatolite unit, Stillwater Canyon, (c) dolomitized oosparite with possible ostracodes, Stillwater Canyon, (d) oosparite showing oolites in various stages of dolomitization, Poison Spring Canyon, (e) dolomitized biosparite with numerous ostracodes and an unidentified oyster-like shell (arrow), Orange Cliffs.

Close grain-packing is present in all but one sample. Most of the lamination, some of which is crinkly, probably was caused by the desiccation of algal mats which trapped and bound sediment (figure 21); many of the intraclasts appear to be composed of reworked algal mats. Stromatolites are common locally; a typical convex upward head measures 3 inches across and 4 inches thick, and displays laminae displacement of 1 to 2 inches (figure 13a). Although no evidence of algal skeletal remains has been found, the presence of blue-green algae is supported by the stromatolite heads and crinkly laminated mats. Birdseye structures occasionally filled with petroliferous material are also present.

Dolomite rhombs, perhaps formed by both secondary replacement and detrital reworking of dolomite mudflats, are common constituents of the dolomitized calcarenite. Most of the spar and micrite components are dolomite, and some of the matrix contains as much as 60 percent dolomitic microspar while calcite is mostly restricted to larger void fillings which probably precipitated later. Many of the structures of the unit have not been greatly altered by the dolomite. Rock names for the laminated, dolomitized calcarenite facies in the Monument Upwarp include sandy dolomitic pelsparite or oosparite and intramicrudite (Folk, 1959).

Southwestward in the Circle Cliffs the Sinbad Limestone is variable in lithology and thickness, locally discontinuous, and difficult to recognize. From an irregular margin in the southeastern Circle Cliffs, the member thickens considerably about 12 miles to the northwest to a maximum thickness of 120 feet reported by Davidson (1967), less than three miles from a maximum measured thickness of 53 feet observed by this author; the reason for this discrepancy is unknown. Most outcrops of Sinbad in the Circle Cliffs are sandy or conglomeratic dolomite, except to the northwest where the member is thicker and similar to the Sinbad of the Teasdale Uplift. Thus the dolomitized calcarenite facies is best developed in the southern Circle Cliffs.

Grains in the dolomitized calcarenite comprise a few skeletal grains (poorly preserved mollusk fragments) and numerous pellets, oolites, and terrigenous material (figure 20, a, b). Pellets and oolites are very similar to those found in the northwestern Monument Upwarp. The terrigenous fraction is generally coarser, ranging up to 0.3 mm for an average, and includes abundant chert fragments, some of which are conglomeratic in size (figure 20b). The chert was presumably derived from the underlying "Kaibab" Formation. Preliminary field observations seem to indicate that in areas where the Sinbad overlies cherty dolo-

mitic limestone of the Kaibab Formation, the terrigenous fraction is rich in chert, and where it overlies calcareous quartz sandstone of the White Rim Sandstone, it contains abundant quartz. Sorting in the Circle Cliffs is poorer than in other areas of Sinbad outcrop.

Matrix includes spar, micrite, and microspar, and in all but one slide, most of the carbonate is dolomite. Dolomite rhombs, some of which may be detrital, occur in replacement features and in void fillings.

Packing of the grains is generally close. Cross-stratification and wavy lamination are common in the dolomitized calcarenite facies. A particularly interesting and significant sample at the edge of Sinbad deposition displays probable microkarst structure. Quartz grains in the rock display laminar coatings of calcite which become thicker upward (figure 20a). Carbonate rock between the wavy layers is dominantly composed of pellets. The wavy sample is very porous and may represent cavity filling formed in exposed rock near the shoreline. In the Circle Cliffs the dolomitic calcarenite facies includes sandy dolomitic pelsparite or oosparite, oomicrite or sandy dolomite (Folk, 1959).

Interbedded Calcarenite and Calcilitite

Incomplete studies of this unit yield only sketchy information. The calcarenite is commonly skeletal and is similar to units in the overlying skeletal calcarenite facies. The calcilitite is commonly burrowed and contains scattered skeletal grains. Inter-calated within this facies is unfossiliferous calcareous and dolomitic siltstone and sandstone. The interbedded calcarenite and calcilitite facies displays crumbly- and wavy-bedding and trough-cross-stratification. The unit apparently grades into oolitic calcarenite southward; northward in the San Rafael Swell, the probable equivalent is predominantly siltstone and gypsiferous mudstone with interbedded pelleted or oolitic biosparite included in the Black Dragon Member of the Moenkopi Formation.

Torrey Member

Introduction

The Torrey Member was the most intensively studied unit for this report. The member is characteristically developed and well-exposed in Capitol Reef National Park and in the Torrey, Utah, area to the west. The type-section is a few miles south of Torrey. The amount of ledge-forming sandstone in the Moenkopi Formation of southeastern Utah, a relatively uncommon lithic type elsewhere, has attracted the attention of geologists working in the area for a long

time. Most previous authors have suggested fluvial, shoreline, or deltaic environments of deposition, but have not substantiated their interpretations. Most of the economic potential of the Moenkopi Formation lies within this member.

Stratigraphy and Lithology

Ledge and cliff-forming sandstone constitutes the diagnostic feature of the Torrey Member (figures 22, a-f and 23, a-f). Stewart *et al.* (1972) refer to the unit as the "ledge-forming member." Most of the ledges comprise very fine to fine-grained sandstone or silty sandstone; many of the units contain size fractions bridging the sand-silt size boundary. In hand specimen the units appear to be bimodal and contain abundant silty matrix. However, thin-section studies demonstrate the silty matrix is composed of silt-sized dolomite rhombs and the rock is fairly well-sorted with respect to quartz grains. Most of the units are well-indurated.

Intercalated with the ledgy sandstone is slope-forming siltstone and silty sandstone which is extremely micaceous, and flakes of muscovite coat many of the bedding planes. Colors of the lithologies range from red (pale reddish-brown to grayish-red) to nonred (pale yellowish-brown to tannish-gray). Locally both lithologies are red, but more often the siltstone is red and the sandstone is nonred or stained red on the surface by overlying siltstone. In parts of the San Rafael Swell and Circle Cliffs both lithologies are nonred.

Although characterized by the above lithologies, several other rock types are locally common in the Torrey Member; mud-pebble conglomerate with micritic dolomite intraclasts is especially prevalent in the eastern area of study. Sandy dolomite or dolomitic limestone is more common in the western area of study. So-called "structureless", concretionary-weathering siltstone or mudstone is common at many localities. Usually this lithology weathers massive at the base where the grains are coarse and becomes shaly at the top as the grain size becomes more fine. Lack of channeling at the base and continuity of individual sets, along with the above features, may indicate this lithology was rapidly deposited from a waning current or flood. Claystone is an important constituent in the northwestern San Rafael Swell although relatively rare at most other localities.

The Torrey Member contains a complex suite of sedimentary structures and bedding types. Continuity is a major character of the member in the western area where continuous units dominate most sequences. Lenticular units are common on the Monument Upwarp to the east and locally dominate the entire

member. Horizontal facies changes within any one sequence or unit are gradual, but vertical changes are commonly abrupt.

The ledgy sandstone units range in thickness from a few feet to 108 feet but most are 5 to 30 feet thick. They display laminar or cross-laminar-bedding (figure 24); the sets of cross-strata range from very small scale to large scale depending upon the thickness of the ledge. Planar and trough-cross-stratification are present with lenticular, tabular, and wedge-shaped sets. Dip of the cross-strata is generally low-angle or very low-angle, but high-angle dips are present in some units. Larger scale bedding features such as cut and fill structures, intraformational angular unconformities, and lenticular strata are also common in ledgy sandstone units (figures 22, 23, and 24). Most cross-stratification features are related to daily or annual variation in local fluid hydrodynamic sedimentation, whereas larger scale features are more likely related to semi-permanent, large-scale geomorphic features such as beaches, deltas, and river systems, or possibly catastrophic events such as floods and storms.

Nearly all ledgy-sandstone units display some form of structure at their base. Various types of load casts, flute casts, drag structures, and tool marks, and occasionally animal trails, were observed (figure 24f). They are best developed when the underlying lithology is mudstone.

Several different sequences of ledge-forming sandstone are present. The most abundant type comprises a sequence in which grain size becomes increasingly fine upwards from a sharp base, probably indicating erosion of the underlying strata (figures 22 and 23). Near the top the sandstone weathers slabby and becomes silty; usually the sequence grades into siltstone above. A few sequences coarsen upwards (figure 24h). Some sequences display combinations of the above or have both sharp bases and tops (figure 24c).

The slope-forming units between the ledgy-sandstone units comprise finely-laminated horizontal and cross-stratified siltstone and thin-bedded sandstone. Individual sets of strata range from fractions of an inch to several feet in thickness. Ripple-marked siltstone commonly one-half to two inches thick reflects burial of ripple marks on the upper surface of a siltstone by more argillaceous sediment (figure 24b). Internal structure of the rock is generally poorly developed or indistinctly cross-stratified but distinctly rippled in rare instances. Commonly several layers of ripple-marked siltstone form a sequence separated by layers of argillaceous sediment ranging from a thin film up to several inches in thickness. So-called ripple lenses or starved ripples are locally abundant within clay-rich sequences. Ripple marks and ripple lenses are most commonly

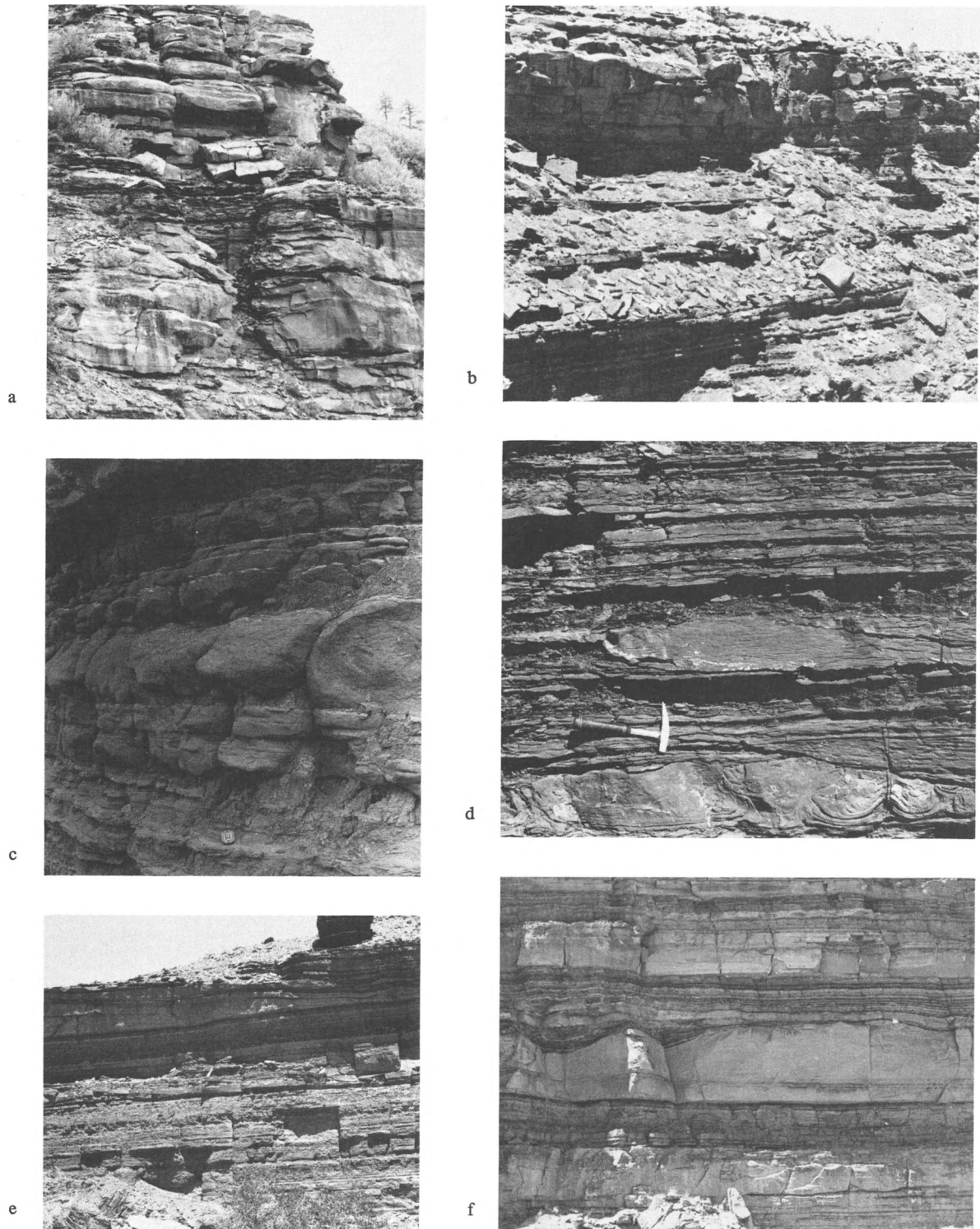


Figure 22. Photographs of Torrey Member in eastern area. (a) Hideout Canyon facies on Elk Ridge, (b) Hideout Canyon facies in western White Canyon (100 feet shown), (c) “massive” sandy mudstone (probably North Wash facies) on Teasdale Uplift, (d) detail of complex bedding in White Canyon, (e), (f) thin, lenticular strata of North Wash facies in Poison Spring Canyon (about 50 feet shown).

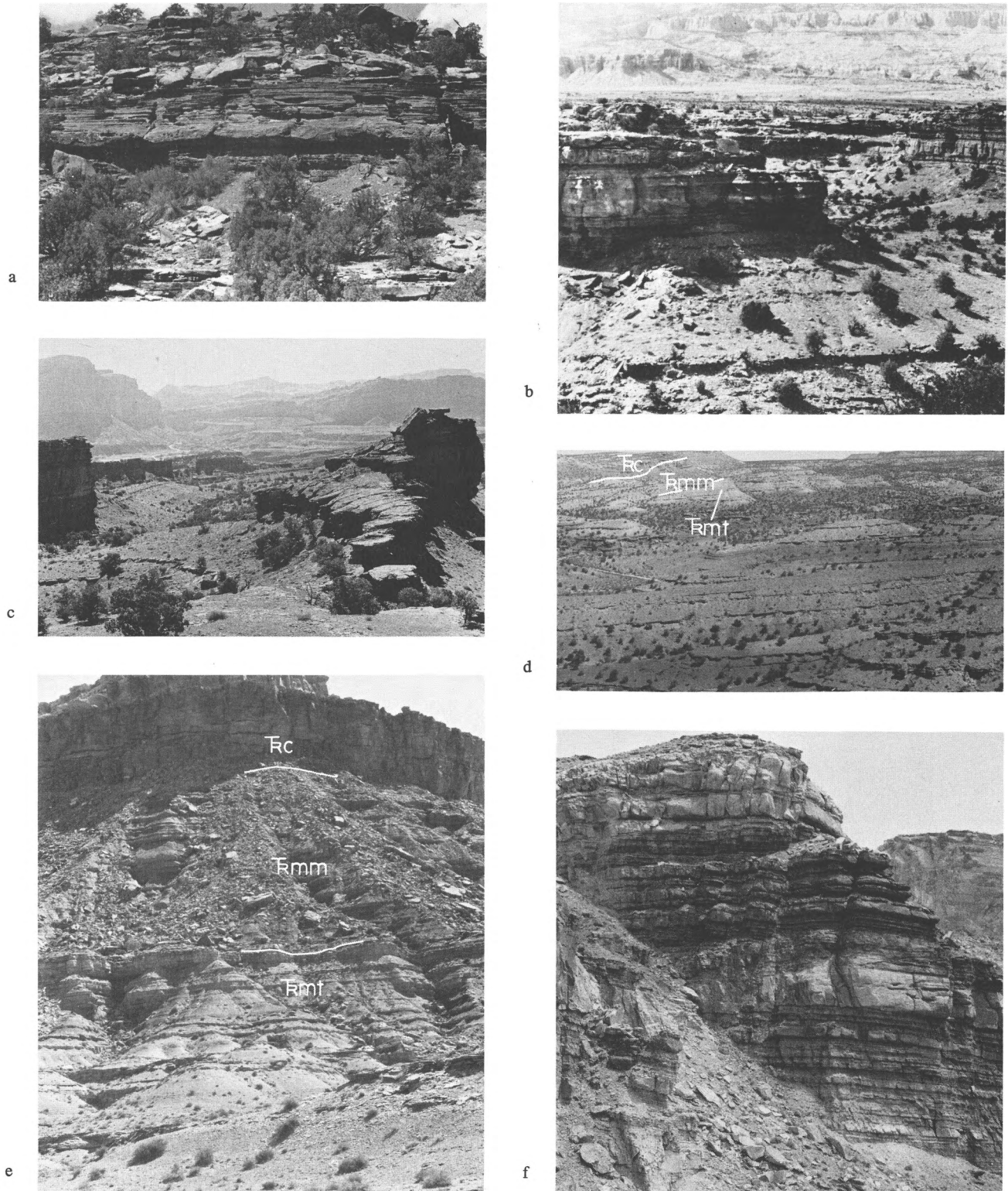


Figure 23. Photographs of Torrey Member in western area. (a) Type section (Goosenecks facies) at Torrey, (b), (c) Goosenecks overlook showing continuity of sandstone strata of Goosenecks facies, (d) transition from Goosenecks facies (right-center) to Wickiup facies (left) in the southern Circle Cliffs, (e) Wickiup facies in northern San Rafael Swell, (f) typical Goosenecks facies in southeastern San Rafael Swell.

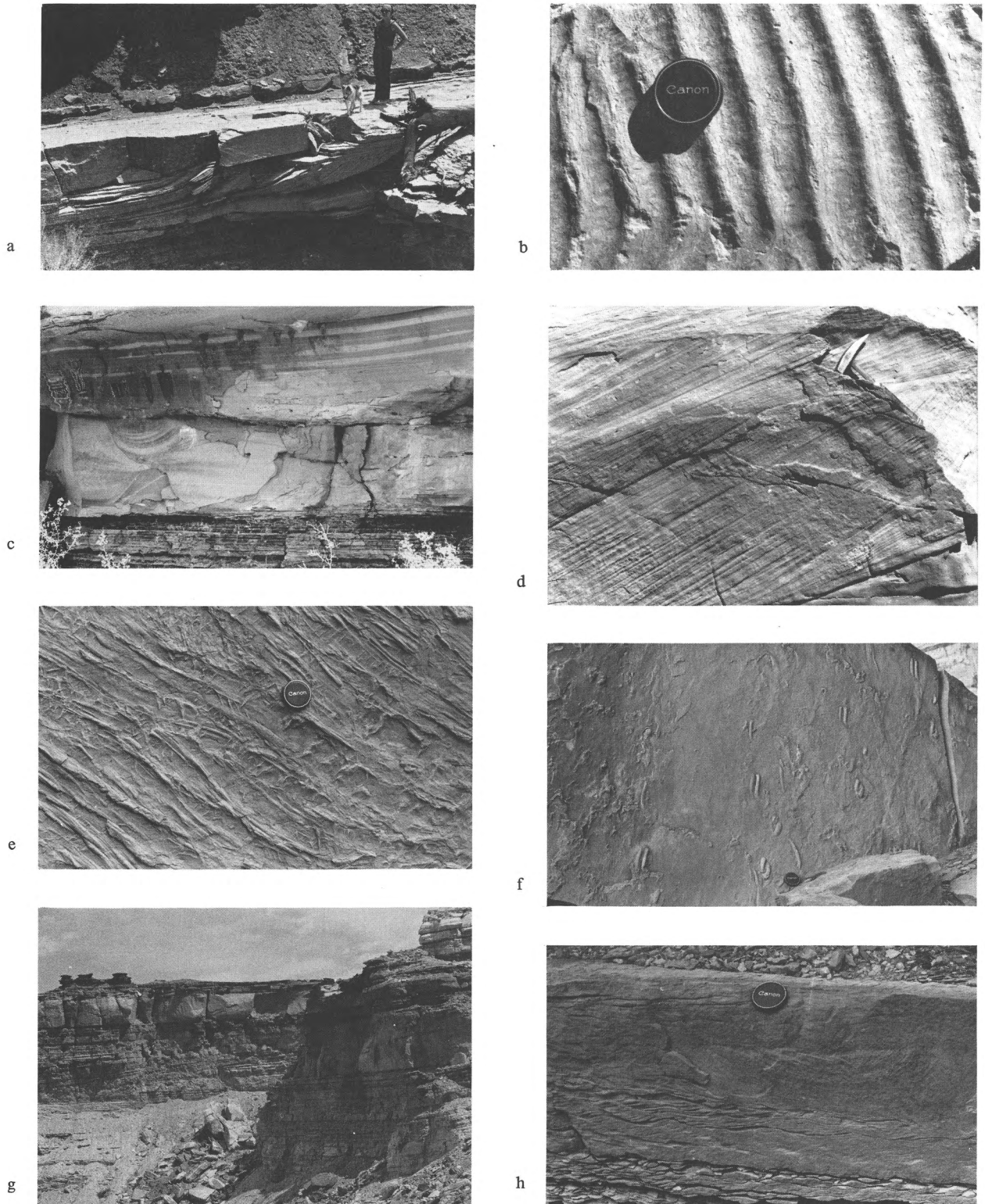


Figure 24. Bedding features of Torrey Member. (a) Small foreset beds along Capitol Reef, (b) ripple marks from Orange Cliffs, (c) low-angle cross-stratification (both base and top of units is diastem), (d) high-angle cross-stratification on Elk Ridge, (e) “sole” markings near Torrey, Utah, (f) geometrically arranged “footprints” near Torrey, Utah, (g) large-scale foreset beds in southern San Rafael Swell, (h) climbing ripple marks in a sequence that becomes coarser upwards, near Capitol Reef National Park Campground.

developed in areas with low sedimentation rates (McKee, 1965); when sediment is introduced, climbing ripples and ripple lamination develop (figure 24h). These latter structures are common in thicker sequences of siltstone ranging up to several feet in thickness. Ripple marks are seldom developed on the bedding-plane surfaces of rock displaying ripple lamination. Typically, massive, cross-stratified sandstone grades upward or downward into ripple-laminated, silty sandstone or siltstone.

Some siltstone and fine-grained sandstone units display primary current lineation as defined by Stokes (1968). This type of structure is commonly developed near the top of sequences that decrease in grain size upwards and is produced by the lineation of particles in flowing water, but some sequences are produced by rhythmic alternations of mudstone and siltstone (figure 22). Siltstone sequences containing primary-parting lineation are generally flaggy-weathering.

So-called "structureless siltstone" or mudstone is present in some of the sequences. Because of its weathering characteristics, it is only exposed in vertical cliffs such as along stream courses or where protected by overlying ledgy sandstone (figure 22c). Ball and pillow structure is associated with "structureless siltstone" and mudstone, and flaky or earthy mudstone is between the pillows. Upon close observation some of the "structureless" units display a wispy or poorly-developed small-scale cross-lamination. Individual units can be traced long distances where exposures permit.

Earthy and fissile mudstone and claystone are confined to thin units between the siltstone sequences described above, although a few thicker shaly sequences (up to 30 feet) are confined to the northern San Rafael Swell and the northern portion of Stillwater Canyon (figures 3, a, b, 23e).

Sedimentary structures associated with all or some of the above siltstone and mudstone sequences include ripple marks, ripple lamination, mud cracks, load casting, intraformational conglomerate, burrowing structures, disturbed bedding, tracks and trails, sole markings, and feeding marks. Commonly structures usually not preserved on the top of a siltstone are preserved as molds on the bottom of an overlying sandstone (figure 24, e, f). Raindrop prints and halite crystal casts have been reported by McKee (1954).

The Torrey Member is recognized at all outcrops within the study area. At most localities it ranges in thickness from 200 to 300 feet with extremes of 316 feet in the Teasdale Uplift and 139 feet at Shafer Canyon on the Island in the Sky Plateau (figure 25). Several internal features of the sedimentary facies of the Torrey Member provide clues for postulating the

origin; the 40 percent line on a plot of the percentage of the ledge-forming sandstone to non-ledge-forming units at each measured section reveals a distinct bilobed pattern (figure 25). This percentage is significant because the ledgy sandstone content drops off rapidly below the 40 percent figure (Blakey, 1973). Also, below this figure it becomes difficult at some localities to separate the Torrey Member from the Moody Canyon Member. Nearly coincident with this facies change is a color change from dominantly red deposits on the east and south to nonred deposits on the west and north; tar-impregnated sandstone deposits occur in the nonred strata. These relationships will be discussed in detail later.

Where the Torrey Member overlies the Sinbad Limestone Member, the lower boundary is easily recognized; slope-forming siltstone and interbedded sandstone overlie bench-forming dolomite. Where the Torrey Member overlies the Hoskinnini Formation the contact is easily recognized from a distance but at close range the contact may appear gradational; in some places the upper few feet of the Hoskinnini display some of the features of the Torrey Member.

In the San Rafael Swell the upper contact is placed at the top of a 5 to 10-foot thick, ledge-forming sandstone and siltstone unit which can be traced around the entire Swell. Similar, correlative units occur in the Orange Cliffs, Circle Cliffs, and Teasdale Uplift areas. In the Island in the Sky and Stillwater Canyon areas near Steer Mesa, the Torrey and Moody Canyon Members intertongue. Here, the stratigraphic relationship of the two members is complex, and the boundary between them is difficult to place.

Divisions

The Torrey Member is a very complex unit and does not lend itself to purely descriptive divisions, although at many localities the member can be divided into three general units: a basal slope-forming siltstone, a middle massive-ledge-forming sandstone sequence, and an upper sandstone and siltstone sequence, each unit apparently representing several environments. In addition, the regional variability is too great for the attachment of any stratigraphic significance to this rough sequence. Purely genetic subdivisions are inadvisable and purely descriptive terms are impractical because of the stratigraphic and sedimentological complexity of individual units and their similarity to other units. A lateral progression of four facies overlying a fifth is recognized (figures 8 and 26). These facies are given four geographic names and one descriptive name with the understanding that the geographic localities providing the names merely typify the facies.



Figure 25. Isopach map of Torrey Member. Dark line is drawn through points that contain 40% ledge-forming/non-ledge-forming sandstone.



Figure 26. Map showing distribution of facies, major sediment movement, and local current directions of the Torrey Member.

The facies occur elsewhere as well and commonly grade or intertongue into adjacent facies.

Starting from the southeast on the central Monument Upwarp, the Hideout Canyon facies is typically developed in White Canyon near the mouth of Hideout Canyon. The characteristic feature of the facies is lenticular, ledgy sandstone (figures 3d and 22, a, b). Lenticular strata are not confined to this facies, but are more common than in other facies. The size of the lenses varies considerably. Some lenses form individual lenticular ledges, whereas others occur in sets to form rather continuous ledges. The former probably represent single channel fills deposited over a rather short period of time in a limited area, and the latter represent widespread channel sandstone deposition. The sandstone units are massive to slabby-weathering and range to 108 feet, averaging 10 to 30 feet in thickness. They are sporadically conglomeratic and locally coarse-grained, display a variety of cross-stratification types, generally display erosional bases, and usually form sequences that become finer-grained upwards.

Two types of siltstone are commonly associated with the Hideout Canyon facies: (1) thin, even-bedded intercalated siltstone, mudstone, and fine-grained sandstone with primary current lineation, abundant intraformational conglomerate (dolomitic and argillaceous pebbles), and relatively few ripple marks (figure 22b); and (2) "structureless", knobby-weathering mudstone or sandy siltstone (figure 22c). The Hideout Canyon facies is the dominant unit of the Torrey Member in the White Canyon and Elk Ridge areas but probably extends into adjacent areas where it becomes difficult to separate from other sandstone bodies.

West of White Canyon ledgy-sandstone units 0.5 to 6 feet thick with interbedded flaggy, ripple-marked siltstone and sandstone constitute the main features of the North Wash facies (figure 22, d, e, f). Finely-laminated siltstone and mudstone with complex and varied sedimentary structures and "structureless" mudstone are also abundant; nearly every sedimentary structure present in the Torrey Member is found in this facies. The North Wash facies derives its name from North Wash, a tributary of the Colorado River about two miles south of the mouth of the Dirty Devil River. The facies is prominent in the Torrey Member in parts of the Orange Cliffs and Island in the Sky areas and is present, though not dominant, in the southeastern San Rafael Swell, Teasdale Uplift, and Circle Cliffs.

At the Goosenecks Overlook on Sand Creek, south of Utah Highway 24 in Capitol Reef National Park, on the Teasdale Uplift, the Torrey Member is characterized by several massive, continuous, cross-

stratified, ledge and cliff-forming sandstone units with interbedded thinner sandstone, siltstone, and mudstone (figures 23, a-c, f; 24, a, c, g). The sheet-like sandstone bodies are 5 to 20 feet thick with low to very low-angle cross-stratification in lenticular trough sets ranging from several inches to 10 feet thick. They display sequences that decrease in grain size upwards with or without erosional bases and coarsening upwards sequences with nonerosional bases. The sandstone bodies are locally cut by channels as much as 20 feet deep.

The intercalated thinner-bedded units are similar to those of the North Wash facies and probably represent intertonguing with that facies. The distal ends of the sandstone units in the Goosenecks facies are the hosts for "tar-sand" deposits. The Goosenecks facies is present over much of the Teasdale Uplift, south-central San Rafael Swell, and southern Circle Cliffs. It is present, though poorly developed, in parts of the Orange Cliffs.

The Wickiup facies, named after a prominent mammillary-shaped butte in the west-central San Rafael Swell, a few miles north of Interstate 70, is a transition unit that marks the distal edge of important sandstone deposition in the member. Thin sheet-sand bodies are intercalated in 30 to 50-foot thick sequences of slope-forming, thin-bedded to shaly siltstone, mudstone, and claystone (figure 23e). At most localities the facies is nonred; the color ranges from pale tannish-gray to pale grayish-orange.

The sandstone units are several feet thick and are extremely continuous. They contain prominently-weathering planar and trough-cross-stratification which demonstrates consistent local paleocurrent readings. The units appear to lack any channeling but commonly show evidence of post-depositional slumping. The siltstone and mudstone are commonly ripple-marked but lack mud cracks and intraformational conglomerate.

The facies outcrops prominently in the north-central San Rafael Swell, northern Stillwater Canyon, and northwestern Circle Cliffs. It may also be represented on the east side of the Monument Upwarp between Indian and Lockhart Canyons.

Throughout the area of study the basal unit of the Torrey Member is a slope-forming siltstone and thin-bedded sandstone sequence (figures 3, a, c, d; 9f; 13c; 23, b, c). The unit thickens very regularly to the west and is remarkably uniform in any given area. Throughout the eastern area it generally ranges in thickness from 9 to 30 feet with a maximum of 45 feet on northern Elk Ridge. In the Circle Cliffs it is 15 to 18 feet thick and in the rest of the western area it is 34 to 59 feet thick. The unit comprises very regular

and even-bedded, flaggy to platy-weathering siltstone and sandstone which is commonly intensely ripple-marked. Other common structures include small clastic dikes several inches long, and gypsum and dolomite are common at some localities. The unit is believed to be a transitional sequence from the Sinbad Limestone Member to the Torrey Member (figure 8).

Paleontology

Diagnostic fossils are uncommon in the Torrey Member. During the course of this study possible scouring rushes (*Equisetum?*) were found in the Elk Ridge area. Numerous casts and molds of possible mollusks occur sporadically throughout the member. None were identifiable, and some are probably load cast marks rather than fossils. Ostracodes can be seen in some thin-sections but no whole specimens were recovered. Tracks, trails, burrows, swim marks, and feeding marks are locally common but no attempt at classification or description was made.

Specimens of *Lingula* sp. were found and reported by Smith *et al.* (1963) from the Teasdale Uplift; Stewart *et al.* (1972) also reported *Lingula* sp. 51 feet above the Sinbad in this area. Fish scales and myalinid pelecypods characteristic of marine Lower Triassic strata elsewhere in the world were reported from the Circle Cliffs area (Davidson, 1967). Trackways of vertebrates were reported from the Teasdale Uplift and the Bears Ears on southern Elk Ridge, and fish and amphibian remains were recovered from the Bears Ears and Indian Canyon in southeastern Canyonlands National Park (McKee, 1954).

Correlation and Age

The Torrey Member generally lacks lithologic equivalents outside of the area of study, inasmuch as the member grades into siltstone, carbonate, and thin-bedded sandstone in the subsurface a few miles west of the San Rafael Swell (L. Clark Kiser, Energetics Incorporated, personal communication, 1973). These units correlate with the Thaynes and Ankareh Formations of the Wasatch Mountains. West and south of the Teasdale Uplift and Circle Cliffs, subsurface data indicates that the ledgy sandstone grades into siltstone, thin sandstone, and carbonate. Irwin (1971) correlates both the Lower Red Member and Virgin Limestone Member of the Moenkopi Formation of southwestern Utah with the Torrey Member. His correlations do not clarify which member of southwestern Utah correlates with what units of the Torrey Member, however. The Lower Red Member is lithologically similar and has the same stratigraphic position (overlying the Timpoweap = Sinbad) as the basal siltstone and mudstone unit of the

Torrey. This correlation is somewhat substantiated by what scattered subsurface information is available. Based on field work in the Paria area on the East Kaibab Monocline in south-central Utah, Blakey (1970) concluded that the Moenkopi Formation thins as it approaches the Kaibab Uplift suggesting this area was positive enough to keep the Lower Red-Virgin sea out of southeastern Utah and that, with the possible exception of the Moody Canyon Member, the Moenkopi of southeastern Utah does not directly correlate with the Moenkopi of southwestern Utah.

Similarly the Moenkopi of northeastern Arizona does not correlate readily into the study area. The Lower Red and Virgin Limestone Members are older than the Moenkopi of north-central Arizona (McKee, 1954; Stewart *et al.*, 1972). If the Torrey Member is the time equivalent of these two members of southwestern Utah, then it, too, is older than the Moenkopi in the type area.

Based upon a discussion in Stewart *et al.* (1972) and field observations during this study, the Torrey Member probably cannot be correlated into the Salt Anticline region. To the north in the Uinta Mountains and northwestern Colorado the Moenkopi and its equivalents lack abundant ledgy sandstone. Thus, from its apparent area of entry into southeastern Utah east of the Monument Upwarp, the Torrey Member is enclosed distally on three sides by siltstone, carbonate, and thin sandstone.

The Torrey Member was apparently deposited concurrently with the Virgin Limestone and with part of the Thaynes Formation. The upper portion of the Thaynes Formation and the Virgin Limestone, which are both post-Sinbad, contain the *Tirolites* and *Columbites* zones (McKee, 1954; Kummel, 1969; Stewart *et al.*, 1972). These zones are characteristic of the Late Scythian Series (Kummel, 1969) or Spathian Stage (Tozer, 1967).

Petrology

Most of the sandstone and siltstone units in the Torrey Member are similar to units in the Black Dragon Member and need not be redescribed. However, several regional trends either were recognized in thin section or supported trends noticed in the field. Grain size gradually decreases to the west. Medium- and coarse-grained sandstone and units with intraclasts are rare or absent west of the Colorado River. With some exceptions, sorting in ledgy-sandstone units is better in the western area of study. Photomicrographs of the Torrey Member are shown on figure 27.

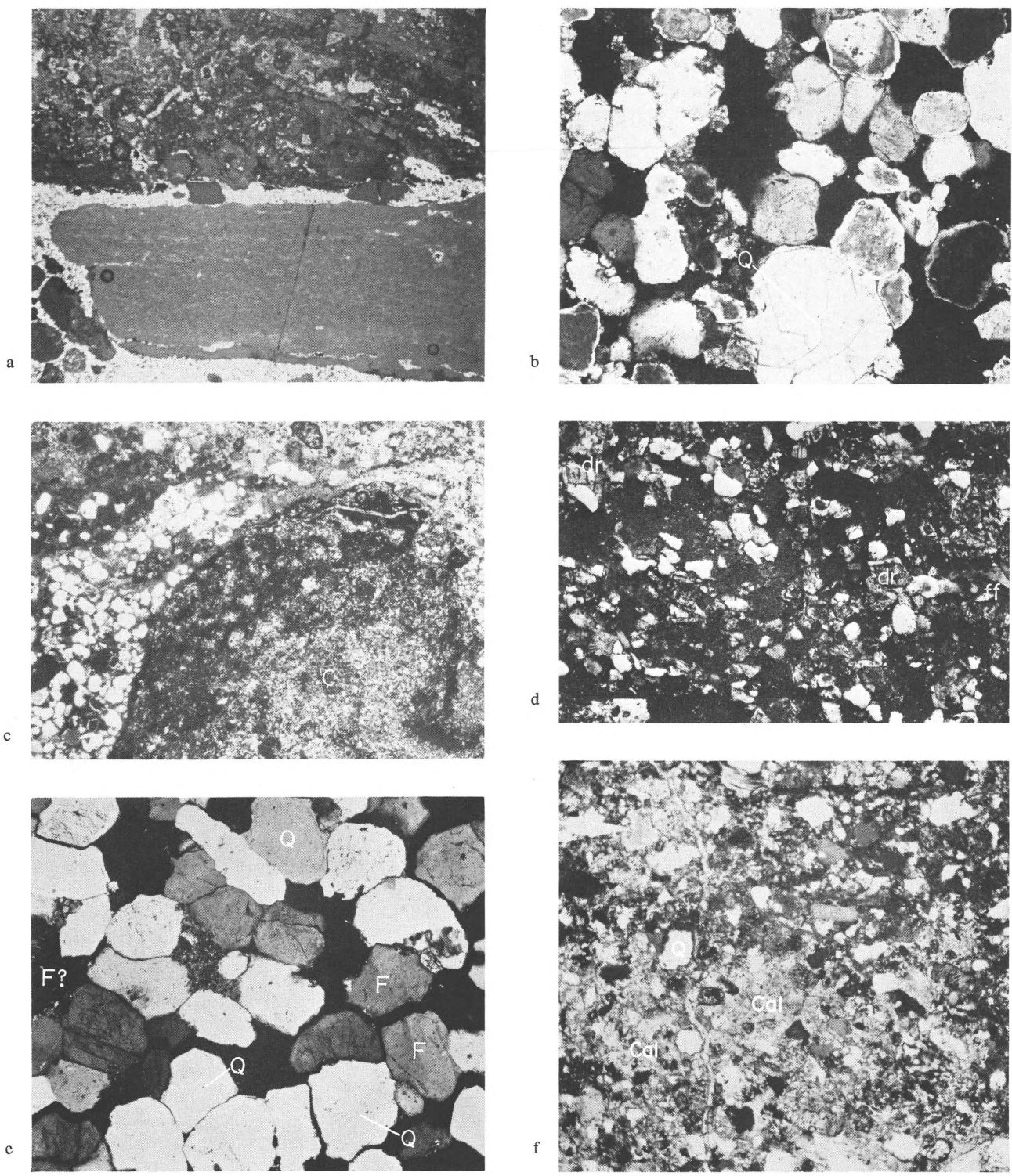


Figure 27. Photomicrographs of Torrey Member. (a) Dolomitized micritic and pelleted intraclastic mud-pebble conglomerate, North Wash or Hideout Canyon facies, western White Canyon, (b) medium- to coarse-grained feldspathic quartz arenite with prominent quartz overgrowths, Hideout Canyon facies, Elk Ridge, (c) chert-pebble conglomerate from base of member and formation, North Wash, (d) fine-grained dolomitic subarkose with fossil fragment (arrow), Wickiup facies, northern San Rafael Swell, (e) medium-grained, fairly well-sorted subarkose with authigenic quartz and feldspar, Hideout Canyon facies, Hideout Canyon, (f) fine-grained micaceous subarkose with prominent calcite “sand crystals”, Goosenecks facies (?), southwestern Circle Cliffs.

Moody Canyon Member

Introduction

The type section of the Moody Canyon Member is located in the southwesternmost Circle Cliffs along Moody Creek about two miles north of the head of Moody Canyon (figure 28e). As recognized in this paper, the unit includes the upper slope-forming and cliff-forming members of Davidson (1967) and Stewart *et al.* (1972). Although there are some sedimentological and stratigraphic criteria for recognizing two rather than one member, at many localities the difference in landforms (the reason for the two names) between the two units is closely related to the nature of the overlying Chinle Formation (figure 28, a, d, e).

Stratigraphy and Lithology

The Moody Canyon Member comprises intercalated siltstone, mudstone, dolomite, gypsum, and sandstone. The first two compose over 90 percent of the member, with red mudstone the predominant lithology in the lower portion. It is finely- to poorly-laminated, but is generally nonfissile and weathers into a partly-covered, earthy slope. Where protected or excavated, however, the mudstone breaks into irregular, angular lumps or nodules (figure 28) which then break cleanly into smaller pieces lacking any orientation, or preferred direction, other than a crude exfoliation tendency. The broken pieces have a porcellaneous surface.

Interbedded with the mudstone in the lower portion of the member are continuous beds of micaceous, greenish-gray siltstone one-eighth to one inch thick. Near the base of the member these siltstones are separated by fairly regular 6 to 12-foot intervals, but become closer higher in the sequence where several closely spaced siltstones commonly form ledges (figure 28). The nonred siltstone beds form conspicuous, light-colored, thin bands on the red slopes. At most localities about 70 feet above the base, a third lithology, ledge-forming sandy mudstone (1 to 4 feet thick), joins the mudstone and siltstone (figure 28). The bases are nonerosional and the units contain poorly-sorted, micaceous, sandy mudstone which is generally "structureless" or displays poorly-developed stratification. The units decrease in grain size upward, become more micaceous, and are commonly ripple-marked or ripple-laminated. They weather to sheer-faced ledges or knobby ledges. The ledgy-sandy mudstones increase in frequency toward the top of the Moody Canyon Member becoming closely spaced; this lithology forms a vertical, commonly earthy cliff (figure 28), especially if protected by the overlying Chinle Formation.

Bedded gypsum, as much as 6 inches but more commonly 1 to 2 inches thick, is abundant in the middle and upper portions of the member. Both nodular, orange-colored gypsum and white, evenly-bedded gypsum are present. Where the gypsum becomes abundant it also fills cross-cutting veins. Bright yellowish-orange dolomite is present in conjunction with the bedded gypsum. The dolomite is extremely fine-grained and contains very fine, well-preserved current lamination, but no fossils were found.

In the extreme northeastern and southwestern San Rafael Swell a lithologic sequence apparently unique to the Moody Canyon is present at the top of the member. The sequence consists of irregular, lenticular, cross-stratified, fine to coarse-grained, cliff-forming sandstone units 1 to 7 feet thick and interbedded mudstone and siltstone (figure 28c). This sequence is not present elsewhere in the member. It may be a local channel sandstone sequence or a remnant of a more extensive sequence later removed by pre-Chinle erosion.

The single most impressive feature of the Moody Canyon Member is the continuity and regularity of the beds. Possibly no other unit on the Colorado Plateau displays such continuity and regularity. Except for the uppermost units found in the San Rafael Swell, no lenticular units or channel structures were noted.

Most cross-stratification in the coarser units is poorly-developed, of fairly small scale, and probably related to ripple marks. Crests of the parallel ripples are generally less than 1 inch apart and trough to crest-amplitudes are one-quarter inch or less. Ripple marks associated with thicker, ledgy units are somewhat larger and also display parallel crests. Many of the other structures occurring in the Moenkopi Formation such as mud cracks, load casts, cut and fill structures, and minor slumping are rare or absent in the Moody Canyon Member.

Many of the sandy mudstones display crude graded-bedding. It is possible that further work will show a vertical or cyclic pattern to the sedimentary sequence with respect to the ledgy, sandy mudstone, ripple-marked siltstone, gypsum, and dolomite.

The Moody Canyon thickens regularly to the west-northwest (figure 29). West of the Colorado River the rate of thickening is approximately 100 feet per 12 to 15 miles. Except where removed by pre-Chinle erosion, it is present throughout the area of study. Maximum measured thicknesses are 367 feet in the San Rafael Swell, 426 feet in the Teasdale Uplift, 276 feet in the Circle Cliffs, and 114 feet in the Monument Upwarp. This regular pattern is broken by several

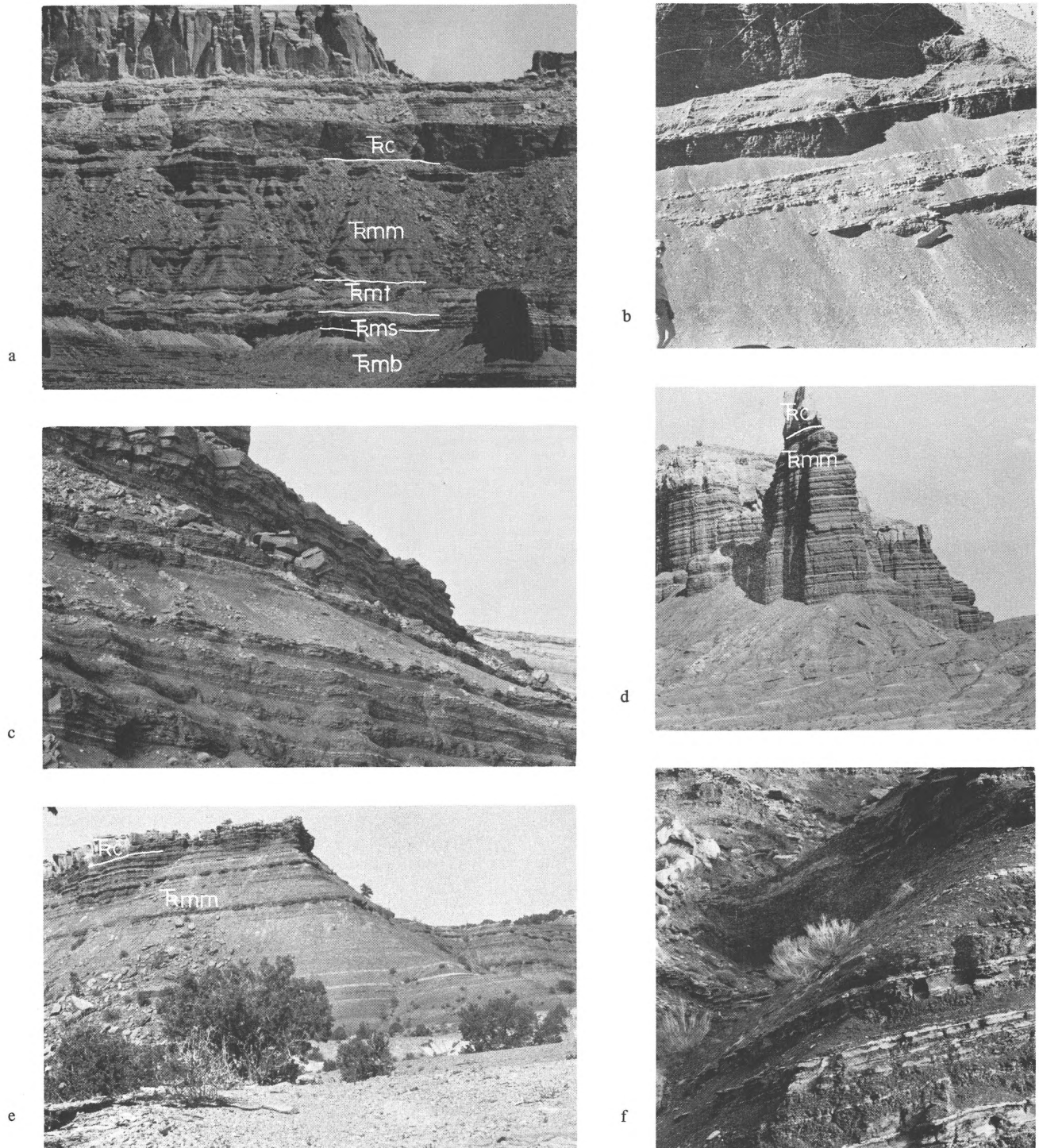


Figure 28. Photographs of Moody Canyon Member. (a) Ledge-forming sandy siltstone and slope-forming mudstone with three facies present, northern San Rafael Swell, (b) nodular and cross-cutting gypsum in mudstone facies, Campground, Capitol Reef National Park, (c) upper part of member in Black Dragon Canyon showing sandy siltstone and mudstone facies and upper sandstone facies (arrow), (d) 400-foot section at Chimney Rock, Capitol Reef National Park, showing sheer cliffs where capped by Shinarump Member of Chinle Formation, (e) mudstone facies and ledge- and cliff-forming sandy siltstone and mudstone facies in southern Circle Cliffs near type section (Two prominent ledges are present throughout Circle Cliffs. Note how upper portion forms cliffs where protected by the Shinarump Member of the Chinle Formation.), (f) detail of bedding of upper portion of member in Black Dragon Canyon.



Figure 29. Isopach map of Moody Canyon Member. Shaded areas show distribution of significant erosion between Chinle and Moenkopi Formations. The Moody Canyon is locally absent in these areas. Also, the distribution of uranium in the Chinle appears to be related to these areas.

“thins” in the isopach patterns. The most prominent “thin” trends northwestward across the San Rafael Swell. Another is present in the central Circle Cliffs and a third broad but poorly-defined “thin” follows White Canyon. However, these are probably not “thins” but rather areas of significant channeling at the base of the Chinle Formation. This possibility is enhanced by stratigraphic data inasmuch as most of the major uranium deposits in the Chinle Formation in southeastern Utah are in or adjacent to these areas (Hawley *et al.*, 1968; Davidson, 1967; Thaden *et al.*, 1964).

The lower boundary of the Moody Canyon Member is placed at the top of the highest ledgy sandstone in the Torrey Member. This corresponds to a fairly conspicuous change in landforms from ledges below to slopes above. In the San Rafael Swell the same ledge can be correlated throughout the area and similar, perhaps correlative, units are present in the Circle Cliffs and Teasdale Uplift and portions of the western Monument Upwarp. It should be noted that in some areas the boundary is more difficult to place. Even where the ledgy sandstone bed is present, the nature of the change is gradational. Intertonguing between the two members is present in Stillwater Canyon and, perhaps, White Canyon. The Moody Canyon Member is overlain with distinct erosional unconformity by the Chinle Formation. This unconformity is discussed in detail later.

Divisions

Unlike the other members which show distinct horizontal facies changes, most of the variation in the Moody Canyon Member is apparently vertical. The only lateral variation is in the northern and eastern San Rafael Swell and in Stillwater Canyon where the member contains more sandy ledge-forming units than in other areas. Both areas may reflect local sand sources to the northeast.

The sandy units in Stillwater Canyon probably reflect intertonguing between the Torrey and Moody Canyon Members. Because this sequence is well-exposed near Steer Mesa in Canyonlands National Park it is informally called the Steer Mesa facies. The following description of the intertonguing is based upon three traverses made along the White Rim Jeep Trail in and adjacent to Canyonlands National Park along the west edge of the Island in the Sky Plateau in Stillwater Canyon. North of the national park boundary the Moody Canyon Member is entirely red, slope-forming siltstone and mudstone about 50 feet thick. Southward at the park boundary the member becomes mostly nonred within a distance of one mile or less, and a massive-weathering, cliff-forming sandstone similar to those that occur in the Torrey Member

is present about 50 feet below the top of the Moody Canyon Member. It is underlain by at least 30 feet of siltstone and clay typical of the Moody Canyon Member (figure 3b). This sandstone and several similar but thinner units in the area appear to provide evidence of intertonguing between the two members.

The overall geometry of the largest sandstone body in the zone of intertonguing is blade-shaped. The long axis is parallel to depositional strike. The area of nonred Moody Canyon in Stillwater Canyon is closely related to the position of this sandstone.

The other divisions of the Moody Canyon Member are vertically divided. The basal slope-forming mudstone and thin, interbedded, ripple-marked siltstone are referred to as the mudstone facies. With few exceptions the facies lacks resistant units and forms smooth slopes and badlands. In the western area of study the mudstone facies forms the basal 70 to 100 feet of the member (figure 28).

With the exception of the topmost units in portions of the San Rafael Swell, the upper one-half to two-thirds of the Moody Canyon Member in the western area of study is composed of mudstone, gypsum, and dolomite intercalated with ledgy, sandy siltstone. This unit roughly corresponds to the Cliff-Forming Member of Davidson (1967) and Stewart *et al.* (1972).

The ledgy units weather very prominently at most localities and can be traced long distances (figure 28). For example, a set of two closely-spaced ledges overlain by another set of three closely-spaced ledges can be traced in outcrops around the entire San Rafael Swell. Similar correlations are possible in the Circle Cliffs and Teasdale Uplift areas. This facies is generally not present on the Monument Upwarp, where it either was not deposited or was removed by erosion. However, in northern Stillwater Canyon three ledges are generally present at the top of the member and they may correlate with the sandy siltstone and mudstone facies.

The lenticular, cliff-forming sandstone at the top of the Moody Canyon Member at the two localities in the San Rafael Swell is referred to as the upper sandstone facies (figure 28, a, c). Unfortunately the unit is relatively inaccessible and so the description given earlier represents most of the information available on the facies.

Paleontology

No fossils were found in the Moody Canyon Member during this study and few, if any, have been

definitely reported in the literature. Tracks of the reptile, *Chirotherium*, have been reported 40 feet below the top of the Moenkopi Formation in the Orange Cliffs (Stewart *et al.*, 1972). Because the Moody Canyon Member is about 80 feet thick in most of the Orange Cliffs, the above locality presumably would be in the middle of the member.

Correlation and Age

Because of the lack of fossils, correlation of the Moody Canyon Member outside of the area of study is based solely on stratigraphic and lithologic criteria. The maximum extent of Moenkopi deposition is represented by rocks near the top of the formation (table 3). Therefore the member probably has equivalent stratigraphic units at nearly all locations of the Moenkopi Formation and equivalent strata. In the Salt Anticline region the Sewemup Member is lithologically similar to the mudstone and the sandy mudstone facies. The Pariott Member which is exposed for several miles along the Colorado River east of Moab may correlate with the upper sandstone facies of the

San Rafael Swell. To the northwest the member correlates with part of the Ankareh Formation. Without fossil evidence it is not possible to determine if any of the Moody Canyon correlates with part of the Thaynes Formation.

The Upper Red and Shnabkaib Members of southwestern Utah are probably both time and lithologic correlatives although the sources of the clastic material possibly differed. In north-central Arizona the Moody Canyon Member probably correlates with the upper portion of the Moenkopi at Lees Ferry. Farther east and south in the Little Colorado River Valley, the Holbrook and possibly the upper portion of the Moqui Member of the Moenkopi Formation are probable correlatives of the member. A portion of the Moenkopi Formation can be questionably traced into northwestern New Mexico (Stewart *et al.*, 1972); this portion may correlate with the Moody Canyon Member. Finally, the Upper Member of the State Bridge Formation of northwestern Colorado likely contains units equivalent to the member although the two units were probably deposited in separate basins.

Table 3. Nomenclature of Moenkopi Formation in adjacent areas.

Northwestern Colorado	Salt Anticline region	Possible correlation to southeastern Utah	Southwestern Utah	North-central Arizona (Lees Ferry)	Northeastern Arizona (Little Colorado River Valley)
Upper State Bridge Formation	Pariott Member	Moody Canyon Member	Upper Red Member	Upper Member	Holbrook Member
	???		Shnabkaib Member	Lower Massive SS	Moqui Member
			Middle Red Member	Lower Member	Wupatki Member (contains Lower Massive SS)
	??	Torrey Member	Virgin Limestone Member		
		Sewemup Member	Sinbad Limestone Member	Timpoweap Member	
Lower State Bridge Formation	Ali Baba Member	Black Dragon Member			

None of the above correlative units contains fossils diagnostic of age. Stewart *et al.* (1972), quoting Kummel (1954) stated the possibility that the Shnabkaib Member may contain the *Columbites* zone, the highest recognized Lower Triassic ammonite zone in the Western Interior. Other evidence provided by McKee (1954) and Stewart *et al.* (1972) suggests that the upper portion of the Moenkopi Formation may be Middle Triassic. However, in southeastern Utah the Moody Canyon Member overlies rocks that are correlated with the *Tirolites* zone (Torrey Member) without apparent major disconformity and the member itself contains no apparent major disconformities. The age is regarded as Lower Triassic, with the possibility that the uppermost portion may be Middle Triassic.

Petrology

The consistent fine-grained nature of the Moody Canyon Member limited the amount of petrologic information gathered in this study. The mineralogy of the sand and silt fraction is similar to that of other members, but as might be expected, the percentage of clay-sized material is greater. In a section titled "Sedimentary Petrology" by R. A. Cadigan in Stewart *et al.* (1972), the clay minerals of the Moenkopi Formation were noted to include kaolinite, chlorite, and sparse montmorillonite. Red, semiopaque matrix and grain coatings comprise mica clays impregnated with red iron oxide and extremely small crystals of calcite and dolomite. This description appears to be substantiated in thin-sections examined in this study.

The Moody Canyon appears to contain the greatest amount of mica in the Moenkopi Formation. Mica flakes coat the bedding planes in siltstone units and in thin-section appear both as long, fibrous, highly birefringent grains and less commonly as fibrous bundles. Cadigan (in Stewart *et al.*, 1972) reported that biotite also is present.

One thinly laminated dolomite thin-section from a 2-inch thick bed was examined and was found to be composed of silt-sized dolomite and quartz material. Feldspar, mica, and traces of ferromagnesian minerals and phosphate also are present and the grains appear to be packed. Whether the dolomite is penecontemporaneous or secondary is unknown.

INTERPRETATIONS AND DEPOSITIONAL ENVIRONMENTS

No single set of criteria can be used to postulate the origin of the Moenkopi Formation although previous authors have cited color, sedimentary structures, and lithology as evidence for marine or non-marine origin. Only when all the data is assessed and

compared can meaningful interpretations be made. The data gathered in this study indicate several episodes of deposition throughout southeastern Utah. These episodes, defined in a previous paper (Blakey, 1973), will be discussed in more detail in the rest of this paper. The episodes are: lower marine and paralic episode (Black Dragon and Sinbad), deltaic episode (Torrey), upper marine and paralic episode (Moody Canyon), and a probable fluvial episode as represented by the sandstone remnants preserved in several areas of the San Rafael Swell. Another episode, the Hoskinnini, was defined by Blakey (1973), but is not discussed in the present paper. In addition, a period of erosion represented by the unconformity at the base of the Chinle Formation is discussed.

Lower Marine and Paralic Episode

Previous Interpretations

The lower marine and paralic episode includes both the Black Dragon and Sinbad Limestone Members of the Moenkopi Formation. Previous authors have cited a marine fauna as evidence of normal marine deposition in the Sinbad Limestone although no facies analysis or specific environments of deposition were presented. The Black Dragon Member was interpreted as a continental deposit laid down on a mud flat or flood plain (McKee, 1954; Smith *et al.*, 1963). Gilluly (1929) and Orgill (1971) suggest that red units are continental and grayish units are marine and deltaic.

Paleogeography

Following Permo-Triassic erosion and the deposition of the Hoskinnini, southeastern Utah was part of a broad shelf extending from the foothills of the Uncompahgre Highlands westward to the miogeosyncline. This relatively flat, though locally irregular, surface was influenced by two features: post-Permian depositional topography related to offshore bars (Orgill, 1971; Baars and Seager, 1970), and structural warping apparently associated with the Emery high. One fairly important feature of the paleogeography was that no barrier was present to keep the Lower Triassic sea out of southeastern Utah; the position of the shoreline was dependent on eustatic sea level and rates of subsidence and sedimentation. Once Lower Triassic sediments covered an area and buried the eroded post-Permian landscape, the shelf provided a nearly featureless plane for further sedimentation.

Black Dragon Member

The regularity and continuity of individual units indicate uniform deposition over a large area but the alteration of lithologies indicates conditions changed

periodically. Most of the sandstone and siltstone units display cross-stratification, primary current lamination, or ripple marks indicating deposition by currents. Except for the few units displaying channel structures, most of the sediment was deposited by sheet-flow currents. Some of the mudstone and claystone was deposited from suspension. The thin, alternating sets of sandstone, siltstone, limestone, and gypsum probably indicate rapid influxes of sediment followed by periods of carbonate and evaporite deposition.

Thicker cross-stratified sandstone was probably deposited in areas of higher sediment input and greater water energy. The beds with erosional bases in which grain size decreased upwards perhaps were deposited in tidal, fluvial, or deltaic channels and those with non-erosional bases with grain size increasing upwards were probably deposited in prograding beaches and offshore bars (Visser, 1965). Local evaporites and unweathered feldspars indicate an arid environment. An arid climate would also tend to lessen the sedimentation rates, particularly limiting land-derived detritus.

Paleocurrent readings from this and other studies indicate strong northwesterly tendencies for current directions (Orgill, 1971; Stewart *et al.*, 1972). Extensive thick cross-stratified sandstone is limited to the northern Monument Upwarp and northern San Rafael Swell. Although this may indicate a local northeasterly source of sediment, more likely it indicates areas of greater water energy where sand tends to accumulate, such as beaches where waves break or areas where shore currents winnow out the finer sediment.

The provenance of the sand and silt in the Black Dragon Member was apparently the Uncompahgre Highland. There is no evidence that a larger river system flowed directly across southeastern Utah from the east, so much of the sediment may have come from the north or northeast, and was transported by currents across the sea bottom.

The conglomerate at the base of the Moenkopi was probably deposited in a variety of environments. Orgill (1971) presented evidence that some of it is a residue from soil formation. The presence of marine fossils at the top of the conglomerate in Cottonwood Draw indicates the sea transgressed there during earliest Moenkopi deposition. It is probable that rivers deposited some of the conglomerate.

In the San Rafael Swell both the basal and topmost units in the Black Dragon Member contain normal marine faunas and Orgill (1971) reported conodonts at various levels throughout the member; therefore, the Lower Triassic Sea was in the vicinity

throughout the period of deposition. The marine faunas are not particularly diverse but this is characteristic of many Lower Triassic marine deposits of western North America. Many units contain numerous tracks, trails, and burrows.

Ostracodes were the only fossils observed in thin-section in some of the thicker sandstone units. They may indicate a more restricted or brackish environment. The overall sparsity and low diversity of fossils in most of the units in the member suggest an environment unfavorable to diverse life, probably because of turbidity and high salinity due to evaporation.

The facies of the Black Dragon Member were deposited in different but gradational environments of deposition. The even-bedded facies was dominated by sheet-flow conditions; few if any channel deposits have been detected in this facies. The sparse fauna and associated gypsum suggest a very shallow, restricted shoreline and associated salt-pan lagoonal conditions. Gypsum, mudstone, and claystone were probably deposited in associated lagoons and sabkhas. Such shoreline deposits are best preserved in regressive sequences.

The origin of the angular surface of deposition on which the "foreset beds" were deposited is uncertain. The beds are probably foresets, but whether they were deposited at the front of a delta, in fresh water such as an estuary, lagoon, lake, or in a large-scale channel, cannot be determined without more data. As discussed in the next section, the sequence is overlain by a probable beach, bar, and shallow marine sandstone complex. Interbedded gypsum up to 1 inch thick indicates a warm arid condition.

The Island in the Sky facies was probably deposited in a beach and shallow marine offshore bar complex. The continuity of the sandstone units and the local variation in thickness, different types of cross-stratification, and various textures suggest several different adjacent environments. A northwestward progradation of the environments is indicated by persistent northwest current indicators. Local areas of silty and muddy sandstone and the intercalated red siltstone indicate less agitated environments, probably lagoonal and backshore deposits. It is possible that the Island in the Sky facies is part of a delta complex, but detailed facies mapping has not been extensive enough to substantiate this hypothesis.

The possible correlation of the Cottonwood Draw sandstone with the Island in the Sky facies would substantiate the progradation of the shallow marine sandstone. The Cottonwood Draw sandstone is

thought to have been deposited in a northwestward migrating offshore bar complex, as suggested by the sedimentary structures present: (1) a nonerosional base with coarsening upward sequence, (2) consistent northwest-dipping cross-strata with the thickness of the cross-stratification proportional to the thickness of the unit, (3) continuity of the unit but high variability in thickness, (4) boudinage cross-stratification and other signs of subaqueous slumping and sliding, and (5) the stratigraphic sequence. The basal part of the sandstone overlying the even-bedded facies is probably offshore shallow marine deposits, and is overlain by slabby-weathering sandstone and siltstone typical of backbar and lagoonal deposits. The local deep narrow channels are probably tidal and inlet channels cutting across and between bars. The sequence is very similar to a model proposed by Davies *et al.* (1971).

The deposition of the transition facies during a period of time in which clastic sedimentation was waning and carbonate sedimentation was increasing in a marine environment is suggested by the gastropods, pelecypods, ostracodes, and possible ammonites present. The alternating clastic and carbonate layers suggest either: (1) alternation of transgressive marine carbonate and regressive clastic shoreline deposits, or (2) shallow marine sedimentation with periodic influxes of clastic sedimentation. Both clastic and carbonate deposits were apparently deposited above wave base as the siltstone and other clastics display current bedding and the limestone is an oolitic cal-

carenite. The gypsum present was probably deposited in restricted arms of the sea, in lagoons, or on sabkhas.

Many authors have suggested that redbeds imply continental deposition and at least two have directly related color to depositional environments in the Moenkopi Formation (Gilluly, 1929; Orgill, 1971). Walker (1967) demonstrated that Pleistocene and Recent deposits in the Gulf of California were post-depositionally altered from nonred to red by oxidation and dehydration of nonred iron-bearing minerals. Some of the rocks now red were deposited in a variety of environments: fluvial, bajada, playa, tidal flat, and sub-tidal. The important criteria are, therefore, post-depositional oxidation and dehydration, not primary environment of deposition.

Therefore, red-nonred boundaries were not seriously regarded as criteria of original continental *versus* marine environments of deposition in this paper. In fact, much of the evidence gathered for this study implies that the nonred siltstones were previously red and have been altered by migration of hydrocarbons. Table 4 lists evidence that supports the above conclusions; figure 30 shows the distribution of red-nonred clastic rocks.

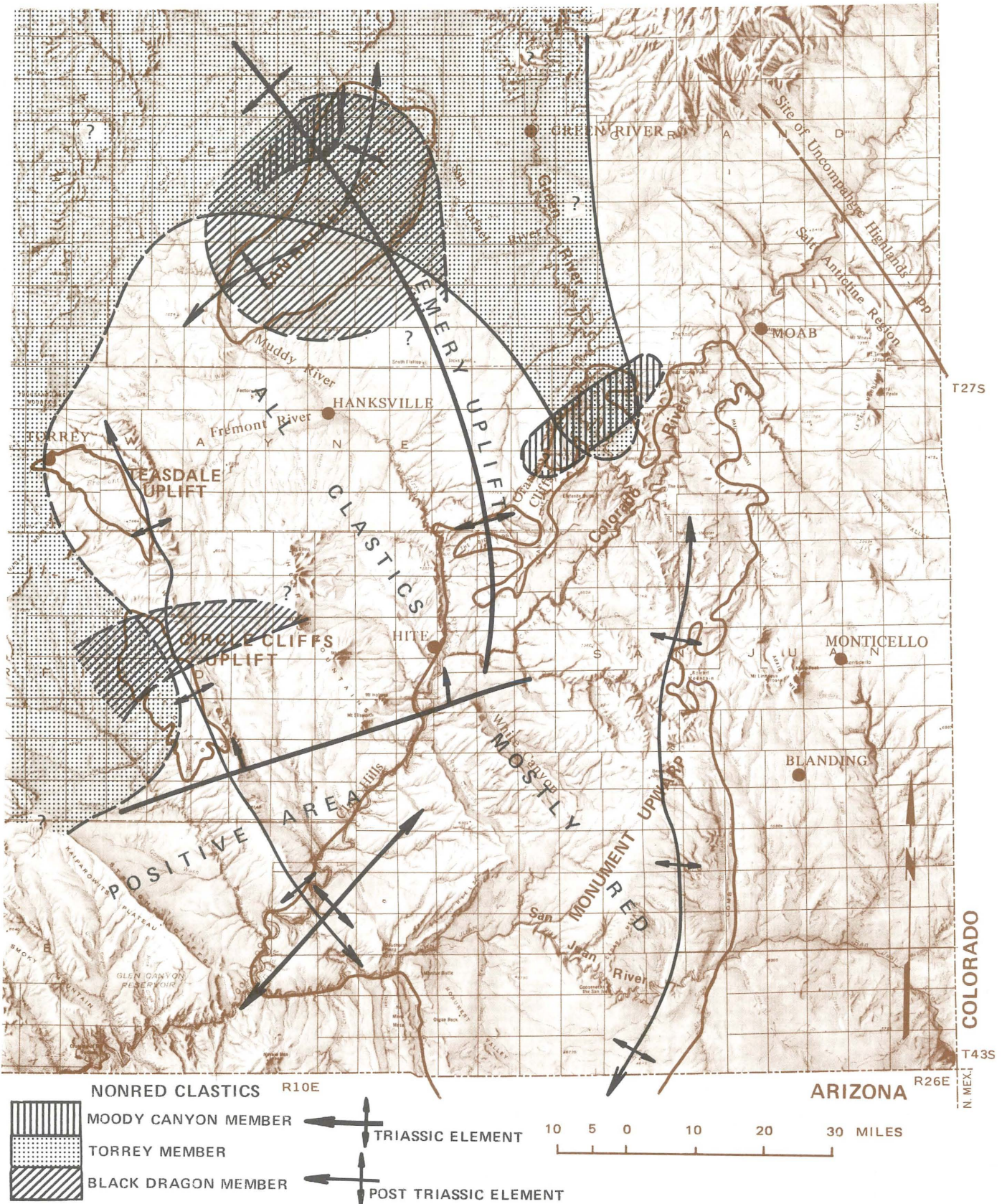
Sinbad Limestone Member

A diverse suite of lithologies and sedimentary structures indicates that the Sinbad Limestone was deposited in a variety of depositional environments.

Table 4. Evidence suggesting red-nonred relationships in the Moenkopi Formation of southeastern Utah are post-depositional and not necessarily related to primary environment of deposition.

Criteria	Member(s)	Location(s)
1. Red-nonred boundaries cross bedding planes	All but Sinbad	Many
2. Nonred rocks commonly associated with "massive" sandstone units (e. g. porosity of sandstone allowed reducing fluids to move through rocks)	Moody Canyon Torrey Black Dragon	Steer Mesa Others
3. Commonly the lower and upper several feet of a red member are nonred (e. g. fluids migrated from adjacent unit or along boundary)	All but Sinbad	Many
4. Nonred rocks are commonly associated with tar sand deposits (e. g. petroleum products bleached red rocks)	Black Dragon Torrey	San Rafael Swell San Rafael Swell Circle Cliffs
5. Nonred rocks are related to position of Emery Uplift (e. g. this structure helped direct migration of fluids)	All but Sinbad	San Rafael Swell Orange Cliffs Stillwater Canyon
6. Other red rock formations have same distribution of nonred rocks as that of Moenkopi Formation	Wingate Sandstone and Moss Back Member of Chinle Formation	San Rafael Swell
7. Red-nonred boundaries are complex spotted or mottled pattern	Especially Torrey	Teasdale Uplift, others

Figure 30. Distribution of red-nonred rocks in the clastic members of the Moenkopi Formation. Note relationship of nonred clastics to tectonic elements.



Large-scale cross-stratification, oolites, mud-pebble conglomerate, and herringbone structure were deposited in environments of turbulent water. Small-scale cross-stratification, ripple marks, mud cracks, fine horizontal laminations, burrows, and mottling were deposited, or preserved, in relatively calm environments. Layers of sediment displaying higher levels of turbulence enclosing a sequence of quiet-water deposition may be attributed to storms or large waves.

The skeletal calcarenite facies contains the most diverse and abundant fauna and thus suggests normal open marine conditions. The interbedded calcarenite and calcilitite and the equivalent transition facies of the Black Dragon Member contain beds with diversity of fauna ranging from diverse to restricted indicative of fluctuating or temporally unstable conditions. The dolomitized calcarenite and silty peloidal calcilitite contain faunas of low diversity including ostracodes, gastropods, and pelecypods suggestive of restricted marine conditions. In addition, the dolomitized calcarenite locally contains stromatolites and possible algal mats which would support a theory of intertidal and supratidal conditions (Heckel, 1972).

Field studies supported by thin-section petrology differentiate four different facies based on constituent composition in the Sinbad Limestone of southeastern Utah (figure 19). Intertonguing between shallow marine carbonates at the base of the Sinbad in the Teasdale Uplift, and shallow marine, paralic, and possible continental clastic rocks of the transitional top of the Black Dragon Member in the San Rafael Swell (Blakey, 1973), suggests periods of transgression and regression, or lessening of clastic influx from the west and increased carbonate dominance through time. Lack of more detailed stratigraphic and petrologic data precludes a more detailed discussion of this facies.

The dolomitized calcarenite constitutes all or most of the thin Sinbad at the southern and eastern margins, while to the west it forms the top of the member. This pattern suggests shoreline or nearshore deposition with westward progradation of this environment over offshore facies. The skeletal calcarenite reaches maximum development to the west and north away from the thin edge of the Sinbad suggesting offshore deposition in the direction of the thick marine Thaynes carbonate sequence. The silty peloidal calcilitite is transitional upward from the skeletal calcarenite facies to the dolomitic calcarenite facies above, which indicates an intermediate position of deposition farther offshore than the dolomitized calcarenite but closer to the shore than the skeletal calcarenite. Furthermore, it extends farther east than the skeletal calcarenite but not as far as dolomitized calcarenite.

The skeletal calcarenite was the most intensively studied facies. The nature of the skeletal material

indicates at least two subenvironments of deposition: (1) Well-sorted sand-sized abraded skeletal grains with abundant oolitic coating suggest turbulent water perhaps on offshore lime-sand bars. Whole unabraded gastropod, scaphopod, and pelecypod shells, including pectens with delicate auricles (ears) preserved, also occur with the abraded fragments. Clearly the whole shells did not suffer the same history of turbulence as the abraded grains with oolitic coatings. (2) Commonly pockets of these whole, unabraded shell fossils contain mud between the grains, indicating poorly-washed conditions; also some gastropods are filled with mud, silt, or glauconite. However, most or all of the grains are closely packed. Probably the whole shells were preserved in troughs between bars or in quiet environments on the lee side of bars. Mud accumulated in and around the shells while abraded grains from the bars periodically were washed in. Tidal processes were probably active on the margins of wide bars as indicated by herringbone cross-stratification. Some of these bars are thought to have been subaerially exposed to form islands because mud cracks occur with the more argillaceous units of the skeletal calcarenite in the San Rafael Swell.

The dolomitized calcarenite facies was deposited in a variety of shoreline and nearshore environments. In the Island in the Sky area, stromatolite heads, oncolites, and laminated mats of algal origin are common. These features are composed of intraclasts, pellets, and oolites with subordinate terrigenous material and gypsum in veins and pockets. A restricted marine fauna is present. According to Logan *et al.* (1964), flat to crinkly-laminated algal mats are suggestive of the supratidal or high intertidal zone, while discrete "cabbage heads" like those in the Sinbad suggest an intertidal environment with a substantial tidal range, and algal balls or oncolites suggest low intertidal or subtidal zones with more constant agitation. The small amount of sand and silt is attributed to low relief and absence of a nearby terrigenous source and distributing agents (rivers) in an arid climate. The above characteristics suggest marine carbonate shoreline sedimentation in an arid climate. The Trucial Coast of the Persian Gulf (summarized by Heckel, 1972) appears to be a reasonable Recent analogue. An ancient example of carbonate shoreline sedimentation similar to that of the Sinbad was reported by Textoris and Carozzi (1966) from the Silurian of Ohio.

The increase of clastic fraction to about 30 percent in the Orange Cliffs probably reflects a local source of terrigenous material. The apparent absence of stromatolite heads, along with presence of algal mats, suggests that this section is supratidal (Logan *et al.*, 1964). Farther south along the Dirty Devil River carbonate and clastic units are interbedded, probably reflecting sporadic clastic influx.

Increased percentage of clastic grains (40 to 80 percent) in the Circle Cliffs may suggest that the dolomitized calcarenite of this area was deposited at or near the shoreline. The previously mentioned specimen displaying possible microkarst structure was probably deposited as "beach rock" which substantiates the above statement. Locally abundant, rounded chert-pebble conglomerate apparently derived from the underlying "Kaibab" Formation indicates a nearby source, a shoreline with high turbulence, or adjacent areas of moderate relief.

In the San Rafael Swell and Teasdale Uplift where the dolomitized calcarenite forms the top of the Sinbad, the unit is believed to be a carbonate shoreline deposit prograding seaward over offshore deposits. The grains are pellets and oolites with subordinate terrigenous clastic material and a restricted fauna similar to that in the Monument Upwarp. Because pellets are commonly preserved in shallow lagoons (Heckel, 1972), the abundance of pellets in the dolomitic calcarenite facies in the San Rafael Swell along with the restricted fauna may indicate deposition in lagoons or restricted shallow-water embayments. Dolomite in the Sinbad is closely associated with shoreline and nearshore deposits suggesting an early diagenetic or "penecontemporaneous" origin for most of the dolomite in the Sinbad.

The quartzose, silty calcilutite facies is intermediate between the dolomitized calcarenite and the skeletal calcarenite. Grains include abraded and non-abraded mollusk shells, intraclasts, pellets, oolites, and terrigenous material. The unit was deposited under conditions with varying degrees of turbulence on a shallow marine shelf between the shoreline and the offshore calcarenite bars. The energy of waves was probably dampened by the calcarenite bars but periods of greater turbulence occurred during storms or shifts in position of the bars.

Depositional Analysis

The Black Dragon and Sinbad Limestone Members were deposited in a variety of shallow marine and paralic environments. During the Permo-Triassic hiatus, weathering and local fluvial and piedmont processes dominated most of the western area of study. As the Early Triassic Sea advanced into southeastern Utah, probably from the northwest or north, it encountered the depositional highs of the Permian offshore bars and the slightly positive elements of the Emery Uplift. As shown on the isopach map (figure 10), the thickest, and perhaps oldest, pre-Sinbad rocks are in the northern San Rafael Swell and Stillwater Canyon area. As the sea transgressed across the Swell it reworked Permian sandstone and cherty carbonate and scattered soil and fluvial units. In the Stillwater

Canyon area the underlying Hoskinnini and Permian sandstone and siltstone were not resistant enough to produce basal conglomerate. The sea eventually covered most of southeastern Utah northwest of the zero isopach line of the Black Dragon Member. As suggested by the phosphatic material in the San Rafael Swell, deposition was probably slow; the abundant cherty material derived from underlying Permian rocks suggests that much of the initial deposits was derived from local sources.

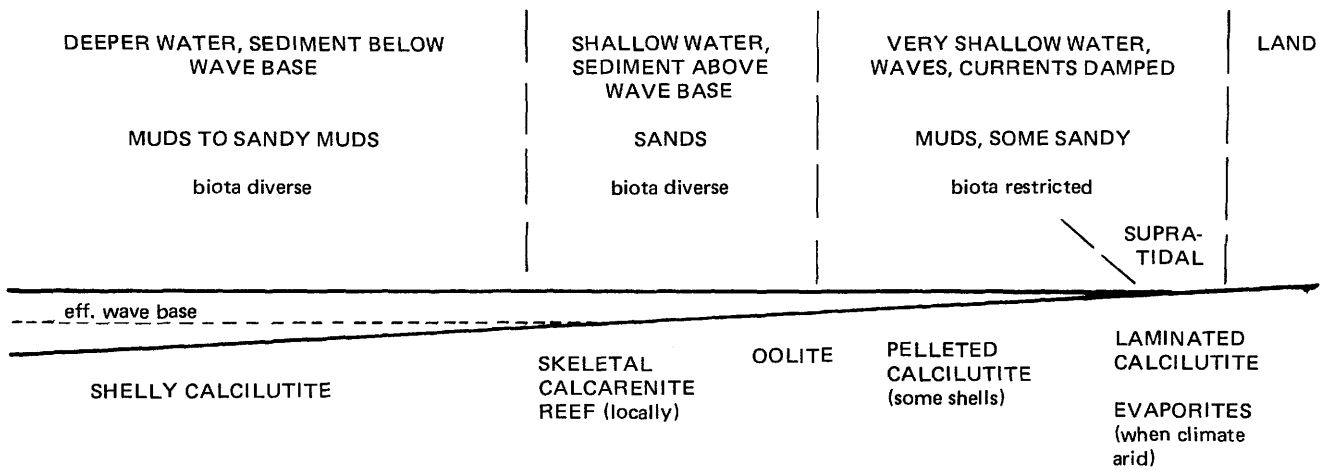
A change in climate in the source area, renewed uplift of the Uncompahgre Highland, or change in current direction of the Early Triassic Sea created an influx of terrigenous clastic material into the area. Periods of higher clastic influx caused local or widespread regression of the sea; during periods of regression tidal, lagoonal, beach, and offshore-bar deposits were preserved. During periods of transgression, deposits were extensively reworked and individual environments were incorporated into the general transgressive sequence. Carbonate and gypsum were deposited during periods of lower clastic influx. Fossils in some carbonates indicate shallow marine environments; the gypsum was probably deposited on supratidal flats and in lagoons.

In general, shoreline deposits predominated in the southeastern portion of the basin and offshore deposits were more frequent in the northwestern San Rafael Swell.

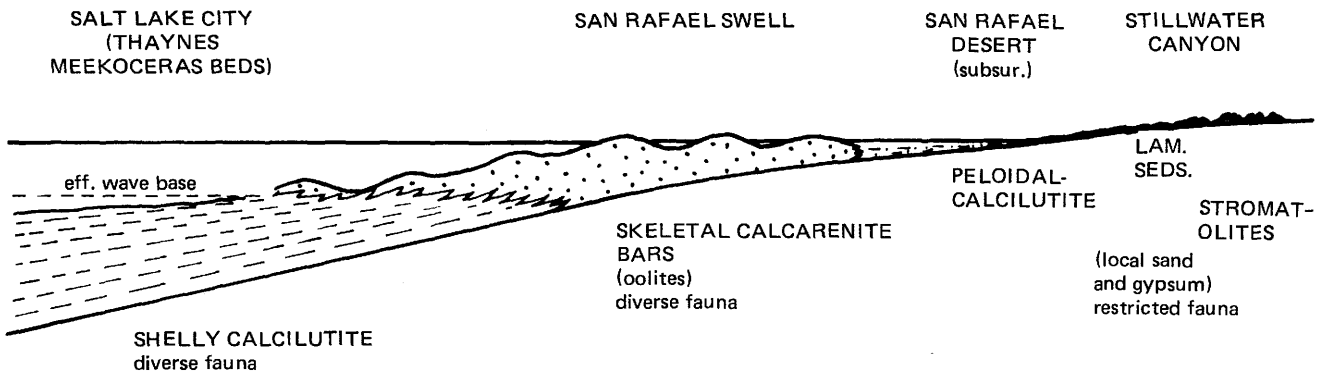
During the deposition of the Sinbad Limestone, clastic deposition waned and a period of extensive carbonate deposition was initiated. Geographic environments may have changed slightly, if at all, as carbonate sediment replaced terrigenous detritus. For example, the skeletal calcarenite facies of the Sinbad Limestone was probably deposited on offshore calcarenite shoals whereas the Cottonwood Draw sandstone facies was probably deposited on offshore sandstone bars. Similarly the dolomitized calcarenite facies is probably a carbonate shoreline deposit; units in the Island in the Sky facies probably represent a clastic shoreline complex. The Sinbad Limestone presents a clearer picture of shallow marine deposition, because carbonate deposits tend to be lithified much more rapidly than clastic deposits and preserve their structures better.

At the time of maximum transgression, the Sinbad Limestone closely fits the model proposed by Irwin (1965) for clearwater sedimentation on a gentle slope (figure 31, a, b). The dolomitized calcarenite facies represents the shoreline facies. Most wave and tidal energy was dissipated far offshore because of the gentle slope, but large waves and/or tsunamis provided sporadic periods of turbulence at the shoreline and

A. Theoretical (Irwin, 1965 as modified by Heckel, 1972)



B. Sinbad Limestone



C. Black Dragon Member

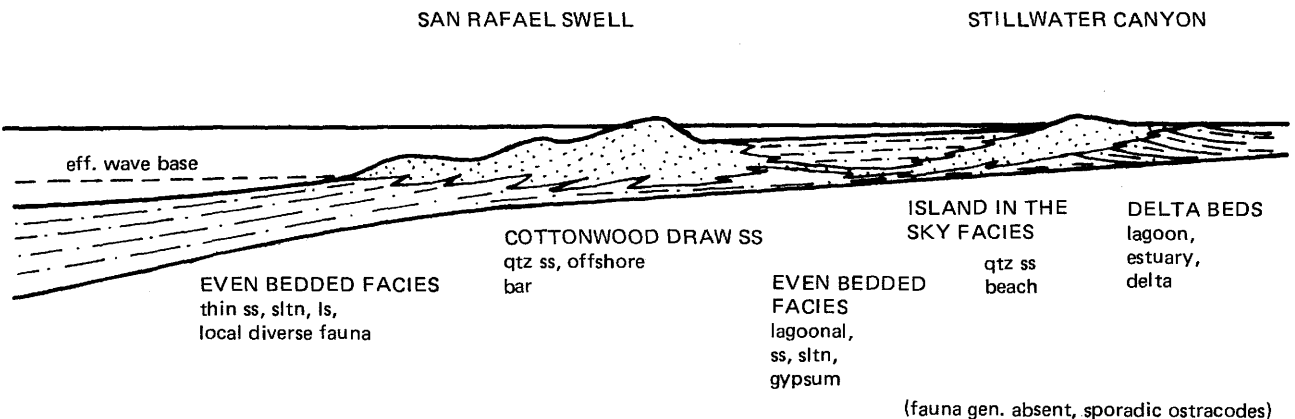


Figure 31. Sedimentation models for the lower marine and paralic episode compared with theoretical model.

promoted formation of mud-pebble conglomerate. Because this environment lacks abundant burrowing organisms, most of the shoreline deposits are horizontally laminated. Local sources provided terrigenous sandy or conglomeratic sediment. Offshore, where wave base affected the bottom, the skeletal calcarenite facies was deposited. Maximum development of calcarenite was probably at the point where waves broke on offshore bars. Areas of less turbulence where whole shells were preserved in a mud matrix were present in troughs between the bars and in the lee of the bar complex. The silty, peloidal, calcilutite facies was deposited in quieter water between the shoreline and offshore calcarenite bars. Although generally an area of low hydrodynamic energy, it may have been subjected periodically to intense storms or locally to strong currents. The geomorphology of this area probably varied regionally and may have included open shallow-shelf, bay, and lagoonal environments.

The Irwin model includes a deeper-water environment farther offshore from the skeletal calcarenite and below effective wave base. Here less well-sorted shelly calcilutite would accumulate. This environment has not been found in the Sinbad probably because none of the area now in southeastern Utah was far enough offshore. In the westward equivalent of the Sinbad, the "Meekoceras beds" of the Thaynes Formation sampled at two localities in the Wasatch Range near Salt Lake City, the predicted poorly-sorted, shelly calcilutite was present. Heckel (1972) suggests that, "this zone with reduced deposition probably also would be a site of formation of authigenic minerals, such as glauconite, as well as of deposition of fine detrital organic material to form dark-colored sediment and rock". If one ignores the petroliferous units of the Sinbad Limestone, the Thaynes is considerably darker than any of the units of the San Rafael Swell and contains organic material. After maximum development of the Sinbad Limestone, the shoreline prograded westward across the farther offshore units and deposited the dolomitic calcarenite facies across the top of the member (figure 15). Heckel (1972) also suggests that although the Irwin model was proposed for carbonate sedimentation, it can also apply to terrigenous sedimentation such as the Black Dragon Member (figure 31c).

A number of structures in the dolomitized calcarenite facies of the Sinbad, such as stromatolite heads, algal mats, and birdseye structures, compare favorably with the Trucial coast of the Persian Gulf (Evans *et al.*, 1964). The postulated calcarenite bars and associated tidal flats of the skeletal calcarenite facies are similar to Recent deposits on Andros Island in the Bahamas (Purdy, 1963).

Modern barred, clastic shorelines are rather uncommon; most of these are present on the Atlantic

and Gulf Coasts. Parts of these coastlines could serve as modern counterparts for the clastic shoreline of the Black Dragon Member.

Deltaic Episode

Previous Interpretations

The deltaic episode constitutes the rocks of the Torrey Member. The anomalous amount of ledgy sandstone in southeastern Utah has been mentioned by many authors. McKee (1954) attributed most of the sandstone to fluvial environments, although he pointed out that some characteristics of marine deposition also are present. Most authors have suggested one or more paralic environments of deposition for the Torrey Member: beach, delta, prograding shoreline, and others (Mullens, 1960; O'Sullivan, 1965; Davidson, 1967). Stewart *et al.* (1972) suggested a deltaic and shoreline environment and compared Moenkopi deposition with modern sedimentation in the Gulf of Pechili and at the mouth of the Hwang Ho River in China.

Paleogeography

The paleogeography of southeastern Utah during the deltaic episode probably was similar to that of the lower marine and paralic episode, except the sedimentary plain in the western area of study was probably much flatter than the post-Permian landscape that preceded Early Triassic deposition. In the eastern area of study the deltaic episode probably was initiated during the same time the lower marine and paralic episode was occurring to the west. It is even possible an arm of the lower marine and paralic sea may have extended a considerable distance across the Colorado River in the Stillwater Canyon and Orange Cliffs areas and left deposits equivalent to the Black Dragon and Sinbad Limestone Members. Because of statements made previously in this paper the basal siltstone and mudstone facies of the Torrey Member is believed to be related to a rapid transgression of the sea following the regression of the Sinbad sea. After this postulated transgression the sea then retreated as the deltaic complex prograded across southeastern Utah.

Sedimentological Evidence—Comparison with Modern Deltas

Two major sets of criteria are necessary for the recognition of ancient delta deposits: (1) a fairly distinct vertical facies progression of marine to non-marine rocks signifying a prograding shoreline, and (2) a horizontal pattern, usually documented by a lobate pattern of sandstone distribution, indicating deposition of most sediment was outward from the mouth (or mouths) of a stream complex. Unless exposures are

fairly fortuitous, only major delta systems can be recognized in the ancient record.

Nearly all deltas are composed of several distinct facies. These facies vary in extent and form and have been assigned different terminology by various authors. For this study the fluvial and delta distributary, delta plain, delta front, delta slope, and prodelta facies are recognized. Each of these facies can be subdivided, but the present study has not progressed far enough to discuss subdivisions in detail.

The lower reaches of a stream may be braided, straight, or most commonly, meandering. Typically, flood plains are present, some up to tens of miles wide. As the stream reaches the active delta, it usually breaks into two or more channels which, in turn, may divide again. The channel sands are characterized by their lenticular nature and by channeling at the base; considerable relief (up to many tens of feet) is common in large streams, but smaller or sediment-laden stream channels may exhibit considerably less relief. When a channel is abandoned, or as it migrates laterally, the sediments will become finer upwards and form suspension or flood plain deposits within the channel body; the bases may contain lag-gravel concentrates. High-angle trough-cross-stratification as well as other types is very common.

Flood plain deposits are predominantly suspension deposits interbedded with coarser flood-traction deposits and, in large, mature river systems, they may be widespread and fairly uniform. A variety of sedimentary structures such as ripple marks, mud cracks, fine lamination, animal tracks, and raindrop prints is common. The flood plain deposits should grade laterally into channel deposits. Both may contain fresh water or terrestrial biotas.

The Hideout Canyon facies of the Torrey Member matches the above description and is believed to have been deposited in these environments. A traverse from the Bears Ears to the mouth of North Wash through White Canyon typically illustrates the facies. For example, a large channel-sandstone complex can be traced for 20 to 30 miles reaching a maximum thickness of 108 feet at Cooper Point at the mouth of White Canyon (plate 1). Seven miles to the west at North Wash it breaks up into a sequence of thinner sandstones and interbedded siltstone. This is believed to be the transition from dominantly fluvial rocks to rocks deposited in the delta distributary and flood plain systems.

Not all the sandstone present in the Elk Ridge and White Canyon areas is fluvial. At least one sandstone at the Bears Ears and one or more in the Clay

Hills (Mullens, 1960) display low-angle cross-stratification, nonchanneled bases, and higher continuity than other sandstone units, and probably were deposited in a beach environment.

The delta plain deposits are similar to fluvial flood plain facies except that the former tend to be broader and may cover several thousand square miles. An alternate name for this facies is subaerial topset facies. In prograding deltas they tend to be reworked by fluvial processes; if subsidence and sedimentation are rapid they will be overlain by fluvial deposits. In the nearshore marine environments produced by retreating deltas they tend to be reworked into extremely regular and continuous sand and silt bodies; if subsidence is rapid and sedimentation slow they will be overlain by marine sediments.

Coleman and Gagliano (1964) and other recent workers have demonstrated that crevasse splays are a major factor in delta plain growth. When a levee breaks, crevasse deposits are deposited by both traction and suspension processes and may contain graded bedding. Depending on the complexity and extent of the delta plain, nearly all types of sedimentary structures may be present. A cross-section through a delta plain reveals many different sequences. Generally sedimentation rapidly shifts laterally across the plain and individual units or sequences tend to be comparatively thin; crevasse deposits rarely exceed 40 feet in thickness (Coleman and Gagliano, 1964). Biota is generally brackish, and vegetation is dominant near the distributaries.

The North Wash facies was probably deposited on a delta plain. This conclusion is supported by its wide distribution, the complexity of the facies, the thin, regular to irregular strata, the variety of sedimentary structures, such as ripple marks, mud cracks, graded bedding, and load casts, and its location in both a horizontal and vertical sense (figures 8 and 26). Complex cut and fill structures and flaser bedding at North Wash and Poison Spring Canyon probably are indicative of tidal processes.

The delta front or foreset facies varies considerably depending on the type of delta. In fluvial-dominated deltas, delta front bars build perpendicular to the delta front. As they build distally, a long digital sand body, the bar-finger sand, is formed (Fisk, 1961; Gould, 1970).

In marine-dominated deltas, the bar-finger sands are immediately reworked into accretion bars or delta front sheet sands parallel to the front of the delta. These large sand bodies are of economic significance: "... delta front sands, by virtue of being well sorted and clean and being adjacent to potential high-organic

source beds, make the best oil and gas reservoirs in the delta system" (Scott and Fisher, 1969). If further reworked, especially by marine processes transgressing a foundering delta, a well-sorted, widespread, blanket sand body may result.

Delta front sands grade distally into siltier and thinner-bedded deposits. With hyperpycnal or homopycnal flow true delta foresets can form, but in most marine deltas the entering fresh water is lighter than the salt water and hypopycnal flow restricts the development of true foresets. However, the original low seaward dip of the delta front causes some beds to be deposited at an angle.

Because of the rapid deposition and influx of fresh water, the biota is commonly restricted or absent in the delta front sands; linguloid brachiopods and, in post-Triassic deltas, oysters, are the most common fauna.

The Goosenecks facies of the Torrey Member is believed to have been deposited in a delta front environment. The continuity of individual sandstone units is demonstrated in the San Rafael Swell and the Teasdale Uplift (figure 32). The distal edge of these sandstone units contains the tar-sand deposits. Angular bedding is common within this facies (figure 24g).

On a small mesa about 2 miles east of Torrey, Utah, across Utah Highway 24 from the Rim Rock Motel near the western border of Capitol Reef National Park, excellent three-dimensional exposures show where a distributary probably entered marine waters on the delta front. The following traverse covers an outlier of rock about three-eighths of a mile east-west, several hundred yards north-south, and about 50 feet thick. At the western edge of the mesa a 20 to 30-foot thick, pale orangish-brown, massive sandstone overlies 15 or more feet of red siltstone and massive mudstone. The base of the sandstone displays thousands of parallel load casts or linguloid ripples about 1 inch long, one-quarter inch wide, and one-half inch deep; all show westward-flowing currents. Also on the base are several elongate troughs, 2 to 5 inches deep, several feet long, and 4 to 10 inches wide, that parallel the load casts. The basal 4 to 6 inches of the sandstone is ripple-laminated but the main body of sandstone consists of horizontal or very low-angle cross-stratification. Primary current lineation indicates east-west orientation of the depositing currents. In the middle portion of the mesa the massive sandstone displays several sets of planar-cross-stratification. The base of the sandstone contains molds of weathered-out mud pebbles up to 4 inches in diameter.

In the eastern portion of the mesa, mud pebbles up to 6 inches across are abundant at the base of the

sandstone. Few load casts are present; instead, scours 2 feet wide and 1.5 feet deep parallel the east-west current. The massive sandstone displays lenticular trough-cross-stratification in sets up to 6 feet thick. All display westward-flowing current direction.

The eastern edge of the mesa is believed to be the distal edge of a delta distributary or perhaps a prograding bar-finger sand. Near the middle of the mesa it encountered the standing water of the sea and the deposition mechanism was changed. At the west edge of the mesa the sand was spread out and reworked by marine processes. The mudstone underlying the sandstone was deposited in quiet water: either farther offshore or in a lake or bay on the delta plain.

The delta slope facies is a transition zone between the delta front and prodelta facies. It may contain both foreset and bottomset beds. Units are both thinner and siltier than those in the delta front facies. Both suspension and tractional processes operate but the latter probably dominate. Sandstone, if present, tends to be thin and ripple-marked.

The Wickiup facies was probably deposited in this environment. The stratigraphic position (figures 8; 23, d, e), thin regular bedding, and abundant ripple marks, combined with the absence of thick sandstone and most other sedimentary structures, support this contention.

The prodelta is dominantly a suspension deposit at the distal margins of a delta. It may be deposited in bays and lagoons or, more commonly, in open seawater. It is predominantly mud, but in shallower water, waves impinging on the bottom may produce some ripple-marked siltstone.

Part of the basal siltstone and mudstone facies was probably deposited in a prodelta environment. In a prograding delta complex the prodelta should be the basal facies. Also at the distal margins of a delta complex the prodelta commonly thickens and encloses the other facies (figures 8 and 32).

Perhaps the most convincing evidence of the above facies relationships can be shown by means of photographs and a sketch across the San Rafael Swell (figure 32). In the southern Swell at Reds and Chute Canyons, the Torrey Member consists of several massive, continuous ledgy-sandstone units, the Goosenecks (delta front) facies. Northward fewer of these sandstones are present, and as each one grades into the Wickiup (delta slope) facies it contains a tar-sand deposit. North of Interstate 70 the Wickiup facies dominates the entire member and it becomes increasingly difficult to separate the Torrey Member

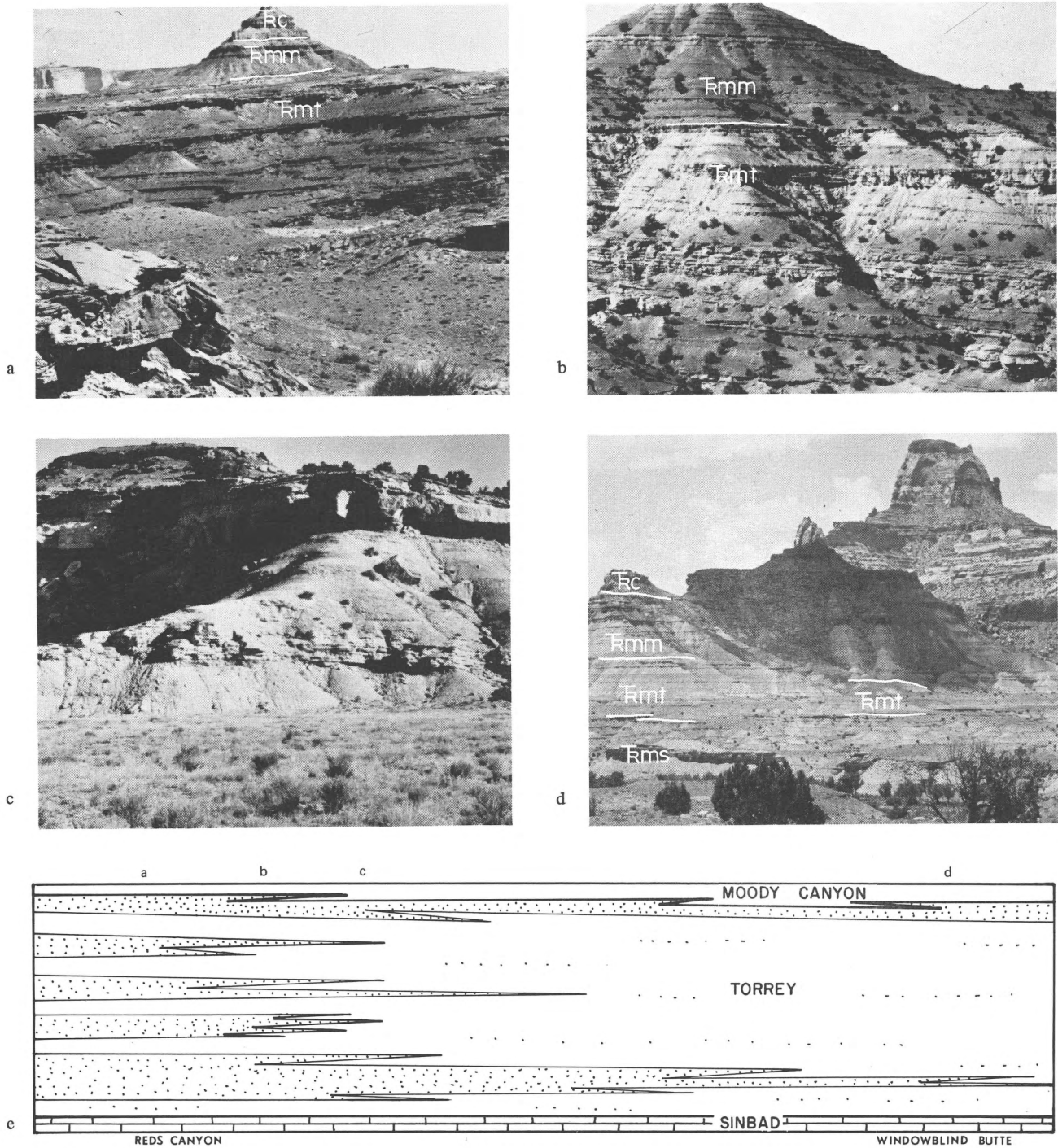


Figure 32. Photographs and section of Torrey Member on the San Rafael Swell showing evidence of deltaic deposition. (a) Goosenecks (delta front) facies in southern Reds Canyon showing continuous ledge-forming sandstone, (b) six miles north at head of Reds Canyon showing intertonguing of Goosenecks and Wickiup (delta slope) facies. Nonred color of some rocks due to presence of tar sand deposits in permeable sandstone beds. (c) Pinchout of delta front sandstone into siltstone and mudstone of delta slope facies six miles farther north. Most of the member is nonred. (d) Thin sandstone and mudstone of Wickiup (delta slope and prodelta) facies on northern San Rafael Swell at Windowblind Butte. The prodelta is enclosing the other facies. Due to diagenetic alteration by petroleum, the entire formation is nonred. (e) Cross-sectional diagram showing locations of photographs.

from the Moody Canyon Member. Near Windowblind Butte the Wickiup facies grades as well into the basal siltstone and mudstone facies; here the prodelta encloses the delta system.

Paleontological Evidence

Fossils are uncommon in the Torrey Member but the few present support the above conclusions. Vertebrate remains indicating terrestrial conditions are most common in the eastern area of study. Myalinids, fish scales, and linguloid brachiopods indicating a shoreline marine regime occur in the western area. Other than the above generalities, fossils are too sparse to be used as environmental indicators.

Depositional Analysis

Following the retreat of the carbonate shoreline at the top of the Sinbad Limestone, dominantly clastic sedimentation returned to southeastern Utah. The sea apparently advanced into the area and local limestone deposition took place as indicated by the few thin carbonates in the basal siltstone and mudstone facies. Although only one of these carbonate units was analyzed, it proved to be a dolomite mud-pebble conglomerate and is similar to some of the rocks in the Sinbad shoreline sequences. As the influx of clastic sediments intensified in extreme southeastern Utah, the shoreline and prodelta deposits of the basal siltstone and mudstone facies prograded westward across the area of study. Apparently during the initial phase of deltaic deposition fluvial processes dominated in the Hideout Canyon facies. With time the deltaic system began to establish equilibrium and a mature delta plain developed. Most of the deposition was directed towards the west as shown by the amounts of ledgy sandstone in the southern San Rafael Swell, Teasdale Uplift, and southeastern Circle Cliffs (figures 25 and 26). Relatively less sandstone is present northward in the Orange Cliffs and Island in the Sky areas. What effect, if any, the positive areas of the Emery Uplift had on deltaic sedimentation is not well known. However, the apparent absence of the basal siltstone and mudstone facies at North Wash probably indicates the area was slightly positive until buried by the delta plain deposits of the North Wash facies.

At least two strong pulses of sediment input are registered on the Teasdale Uplift; two massive sandstone units of the Goosenecks facies can be correlated across most of the area (plate 1; figures 13c, 23, b, c). In the San Rafael Swell at least five, and perhaps seven or eight, massive sandstone units are present in the southern extremities (figures 23f, 24g, 32a). Further work is necessary in this area to provide detailed correlation of the units.

The sea surrounding the delta complex was probably very shallow; possibly some of the prodelta deposits were deposited in shoal areas. Perhaps at times the sea withdrew from local areas and the delta front and delta plain deposits were laid down under subaerial conditions; also the probable arid conditions may have dried up the streams at times, adding to subaerial deposition. McKee (1939) described a possible analogue on the Colorado River delta in the Gulf of California. Since the 1930's most of the sediment and water of the Colorado has been retained by man-made dams and the Colorado redistributes what is left of its sediment load subaerially in the form of small fan-shaped deltas back on the delta plain. These delta "foresets" dip about 10 degrees down-stream in sets averaging 10 feet in length. Similar structures are present in the southern San Rafael Swell.

In the northwest Monument Upwarp marine processes apparently dominated and a number of thin, continuous sandstone bodies were deposited. The thick, ledgy sandstone in the southeastern Circle Cliffs probably indicates that a lobe of the delta was deposited in that direction.

The southernmost Monument Upwarp was not well studied for this report but the possible beach sandstone units in the Clay Hills may indicate beaches and tidal flats lying to the south of the main delta. Farther south in north-central Arizona (Lees Ferry and Echo Cliffs areas), equivalent units in the Moenkopi were deposited in beach, tidal, and sabkha environments (Baldwin, 1973).

As deltaic sedimentation waned, the latest deposits were reworked by marine and paralic processes into extremely continuous sheets of sandstone and siltstone. These are the marker beds at the top of the Torrey Member arbitrarily forming the upper boundary.

A number of models and classifications have been proposed for deltaic deposition. Curtis (1970) proposes three simple but useful models based on the ratio of the rates of deposition and subsidence. If deposition exceeds subsidence the delta progrades and generally has a lobate form with the long axis perpendicular to the shoreline. If the two are equal the delta stagnates and exhibits a more equi-dimensional form. If subsidence is greater the delta retreats or is reworked and delta morphology is elliptical with the long axis parallel to the shoreline.

During the early and middle stages of the deltaic episode of the Moenkopi Formation, the delta advanced and assumed a lobate form similar to the first model of Curtis, but at the close of deltaic deposition the complex probably compared with the third

model as the deposits were reworked by marine processes.

Scott and Fisher (1969) relate deltaic classification and models to dominant processes. Marine-dominated deltas tend to be compressed and parallel to the shoreline whereas fluvial-dominated deltas are lobe-shaped and prograde perpendicular to the shoreline. Classification of the Moenkopi delta within the Scott and Fisher (1969) system is difficult. Although both prograding and retreating systems are present, the overall lobate shape of the sand bodies resembles the fluvial-dominated lobate delta of Scott and Fisher. Other criteria used by Scott and Fisher, however, suggest much of the delta was marine dominated. These include the sheet-like nature and continuity of the sandstone bodies, high proportion of sand to silt and mud, medium size of the drainage basin (the Four Corners region), lack of straight, deep, and narrow delta distributary channels, a postulated arid climate that would tend to reduce the discharge of the river system, and widespread indication of tidal deposits (especially at North Wash and Poison Spring Canyon).

Of the number of modern deltas described in the volume edited by Morgan (1970), most have some aspects closely resembling deposits in the Moenkopi delta. Each example also has some major feature contrary to the conditions that prevailed during Moenkopi time; thus no single modern delta can serve as a model.

The Colorado River delta in the Gulf of California in some ways compares favorably with the Moenkopi. It is a marine-dominated delta in an arid climate. The following description is after Sykes (1937) and L. D. Meckel (unpublished oral presentation, 1972). Because of the tidal dominance by the Gulf, nearly all the sediment is eventually trapped on tidal flats. Sand dominates the estuary at the river mouth and is deposited in elongate bars perpendicular to the shoreline. Mud is deposited in the troughs. Many of the sand bodies are sheet-like and sand is present in nearly all the environments. Prograding cheniers commonly trap flood waters behind them to form lagoons having gypsum and other salts deposited in them. Much of the river sediment is deposited directly on the flood plain and then reworked by tidal processes.

A great variety of sedimentary structures is present in the Colorado River delta complex. Widespread sheetwash creates ripple marks and primary current lineation on the tidal and mud flats. The supratidal zone is dominated by mud cracks and local salt pans. Cheniers, marine bars, distributary channels, and tidal channels form cross-stratified bodies. The geometry and stratigraphic position, as well as internal

sediment characteristics, serve to separate these sand bodies.

Although the sedimentary processes, climate, and size of the Colorado River delta are comparable to the deltaic deposition of the Torrey Member, the overall paleogeographical characteristics are rather poor. Instead of a narrow, deep, tectonic basin, the Moenkopi was deposited on a gently subsiding uniform slope. The mouths of the Hwang Ho River and adjacent Gulf of Pechili of eastern China perhaps provide a better geographic model as proposed for the Moenkopi deposition by Stewart *et al.* (1972). Dunbar and Rodgers (1957) describe the Gulf of Pechili:

“The delta of the Hwang Ho or Yellow River forms the plains of north China and floors the Gulf of Pechili and nearly the whole Yellow Sea. The subaerial surface forms a great triangle with its apex at least 250 miles inland where the Hwang Ho leaves the mountains; its base, more than 350 miles long, is interrupted by the island-like mass of the Shantung Peninsula. The seaward slope of the delta averages only one and one-third feet per mile and the repeated floods over its surface have long been the scourge of China . . . It may be noted that a relative lowering of sea level by 100 feet would transform the whole floor of the Gulf of Pechili into land and move the shore south of the Shantung Peninsula as much as 50 miles seaward. On the other hand, a rise of 100 feet would bring the sea far in over the subaerial plain and transform the Shantung Peninsula into an island.”

Jim Minick of Atlantic Richfield Oil Company accompanied the author to the field and comparisons were made between the Torrey Member of the Moenkopi Formation and the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale. The overall comparison between the two units, especially in the vertical facies distribution, was remarkably similar. Other units on the Colorado Plateau, which are familiar and probably have similar depositional histories, are the Permian Supai Formation, parts of the Jurassic Carmel Formation, and the Cretaceous Straight Cliffs Sandstone.

Upper Marine and Paralic Episode

Paleogeography

Following the reworking of deltaic deposits, southeastern Utah must have been an extremely flat, low-lying shelf. As indicated by the probable inter-tonguing between the Torrey and Moody Canyon Members in the Island in the Sky and White Canyon areas, deltaic sandstone deposition probably persisted locally.

The shelf upon which the Moody Canyon Member was deposited may have had a westward slope of less than one-half foot per mile. On such a slope, a change in sea level of 5 feet would cause the shoreline to migrate ten miles.

Regional sedimentological and tectonic evidence suggests that sometime between the end of the Early Triassic and the beginning of the Early Cretaceous part of the miogeosyncline in Nevada was uplifted (McKee *et al.*, 1959). This prevented direct connection between the Pacific Ocean and the western interior. All marine basins from the end of the Early Triassic to the Cretaceous opened to the north or southeast. If this barrier was significant during the deposition of the Moody Canyon Member, it may have provided a western source for some of the sediment and may have restricted the basin of deposition. No petrological or sedimentological evidence for this source was found in this study and the paleogeography presented by Stanley *et al.* (1971) suggests the major uplift was post-Lower Jurassic. However, a slightly positive area may have been an effective barrier to the western seaway during late Moenkopi deposition.

Sedimentological Evidence

Sedimentary structures indicate that the Moody Canyon Member was deposited by westward-flowing currents. The source of the clastic material may have been from the east during the waning stages of the deltaic episode. It is also possible that a substantial amount of material was brought in by the sea. An increase in sandstone percentage (not including the upper sandstone facies) in the San Rafael Swell may indicate a source from the north or northeast (figure 28, a, c, f).

The thin, regular bedding, high degree of continuity, and abundant ripple marks indicate the member was deposited under widespread, uniform, low hydraulic-energy conditions. Thin gypsum and dolomite indicate evaporative conditions were present. The extremely continuous, sandy-siltstone deposits with the crude graded bedding may indicate rapid deposition from waning currents.

Paleontological Evidence

The lack of fossils suggests the entire sequence was deposited under restricted conditions. Very shallow water in areas of high evaporation potential tends to have higher salinities and thus restricts biota.

Depositional Analysis

In northern Stillwater Canyon enough sand was present during the initial stages of the upper marine and paralic episode to permit the formation of a beach or offshore bar. This particular facies is fairly local and can easily be recognized by its nonred color. The area of nonred color closely follows the distribution of massive sandstone. Apparently the sandstone allowed petroleum, gas, or other fluids to migrate through the

facies and cause reduction of any preexisting red color. Following the deposition of the Steer Mesa facies, about 50 feet of mudstone facies were deposited in the area.

The mudstone facies was deposited in extremely quiet water, but the lack of well-preserved laminations in the mudstone may indicate extensive bioturbation. The thin ripple-marked siltstone was deposited by slightly stronger currents. These latter units are probably the product of sorting rather than coarser sediment influx. Several methods of deposition are possible. The ripple-marked siltstones could reflect shallower water due to lowering of sea level, the migration of shoreline deposits by a slight change in sea level across a very flat plain, or locally higher turbulence caused by strong winds or storm currents. It is likely that beach sands were not well-developed because the gentle slope of the bottom probably dampened waves and tidal currents (Irwin, 1965).

The sandy-siltstone and mudstone facies indicates a moderate change in deposition of the upper marine and paralic episode. Although the mudstone and ripple-marked siltstone are still abundant, the addition of gypsum, dolomite, and ledge-forming sandy siltstone indicates a change in depositional environment. The gypsum and dolomite indicate an increase in aridity, less of an influx of terrigenous sediment, or deposition of some of the units in more restricted shoreline environments. Some of the gypsum is nodular which, according to Lucia (1972), suggests deposition by groundwater springs on supratidal mud flats. His hypothesis for gypsum formation of supratidal flats proposes that sheets of gypsum result from periodic flooding due to storms, perhaps every 20 years; the remainder of the time gypsum and other salts form by reflux action (capillary action of groundwater due to evaporation) of sea water or groundwater springs. The thin clastic sequences were brought in by sheetwash or wind from the land and by periodic storms from the sea.

The origin of the ledge-forming sandy siltstone is uncertain. The units apparently cover hundreds, or even thousands, of square miles and appear to have been deposited rapidly without appreciable basal channeling. Perhaps the deposits are the results of severe storms depositing huge quantities of sand, silt, and mud, most of which was transported landward from the sea. The widespread turbid water may inundate several otherwise different environments and leave homogeneous extensive deposits (Ball *et al.*, 1967).

In review, the mudstone facies was deposited in a variety of quiet, shallow, marine shoreline environments. Intensity of hydraulic energy fluctuated throughout deposition. The sandy-siltstone and mud-

stone facies was generally deposited more landward in sabkhas and lagoons. Periodic storms probably affected the area and deposited continuous ledge-forming sandy siltstone.

Not much data is available on the upper sandstone facies exposed in a few localities of the San Rafael Swell. Neither the original extent nor thickness is known. Cross-bedding and sedimentary structures suggest a fluvial origin, but sources or current directions are unknown.

The regular, even, and thin units of the Moody Canyon Member suggest deposition on, and adjacent to, a protected shoreline. Gypsum, and possibly dolomite, suggest evaporite conditions. As previously stated, the paleogeography to the west of southeastern Utah is uncertain. It is possible the withdrawal of the Lower Triassic Sea coupled with the slight emergence of central Nevada isolated an arm of the sea.

The sabkha environment (Kinsman, 1969; Kendall and Skipwith, 1969; and Amiel and Friedman, 1971) may provide a model for the upper marine and paralic episode. Two major types of sabkhas have been defined: marine supratidal and continental (Kinsman, 1969). Unfortunately, most modern sabkhas contain a higher percentage of carbonate and evaporite rocks than the Moody Canyon, but the probably equivalent, more marine Shnabkaib Member of the Moenkopi Formation of southeastern Utah (Stewart *et al.*, 1972) may fit the sabkha model fairly closely. The Moody Canyon may have received a higher influx of terrigenous sediment than the Shnabkaib.

Clastic sabkhas are uncommon in the Recent. However, Kinsman (1969) reports that a clastic sabkha is present on the edge of the Colorado River delta near San Felipe, Mexico. The source of most of the clastic material is the Colorado River. Some evaporites are deposited in landward salt pans. Stromatolites and algal mats, characteristic of the Persian Gulf sabkhas, are absent.

Pre-Chinle Erosion

A significant change in climate and depositional environment took place following Moenkopi deposition. The Upper Triassic Chinle, Wingate Sandstone, and Kayenta Formations were deposited in a variety of fluvial, lacustrine, and aeolian environments. Perhaps the local upper-sandstone facies of the Moody Canyon Member of the Moenkopi Formation is the initial deposit in the new sedimentation sequence. Because the sandstone of this facies is interbedded with "normal" units of the Moody Canyon, the change toward fluvial conditions apparently took place gradually.

A considerable amount of the Moenkopi Formation was removed by pre-Chinle erosion in places. The lateral continuity of the ledgy sandy-siltstone units of the Moody Canyon Member provides a means of determining the amount of Moenkopi that was removed; local variations of more than a few feet are probably related to post-depositional erosion. In the San Rafael Swell marker beds show over 240 feet of upper Moenkopi has been removed locally (figure 33b). Because of the breadth of the missing rock, it cannot be determined if the material was removed by fluvial channeling, or broad uplift and erosion of a portion of the Swell preceding Chinle deposition. Hawley *et al.* (1968) favor the latter theory.

In the northeast and southwest Circle Cliffs the Shinarump Member of the Chinle Formation rests locally on the Torrey Member of the Moenkopi (figure 33a). The narrow width of the channeled unconformity and the irregular distribution of this feature suggest that this portion of the Moenkopi was removed by pre-Chinle channeling. As the maximum measured thickness of the Moody Canyon Member in the Circle Cliffs is 295 feet (Davidson, 1967) the channels must have been at least that deep. Local relief of 50 to 120 feet, mostly due to channeling, can be observed at numerous locations. With the exception of the San Rafael Swell where the basal Chinle unit is the Moss Back Member, or mudstone, the greatest erosional relief occurs where the Shinarump Member is the basal unit.

Conclusions—Hypothetical Paleogeography

Recognition of certain genetic bodies of sediment such as beaches, delta fronts, offshore bars, and carbonate shorelines in sedimentary sequences allows fairly accurate paleogeographic reconstructions to be made. Based on the previous discussion of criteria and the lateral and vertical distribution of the sediment bodies, the conclusions of this paper are presented in the form of a number of paleogeographic sketches representing various periods of deposition during the Lower Triassic of southeastern Utah (figures 34-38).

As suggested in previous papers (McKee, 1954; Repenning *et al.*, 1969), and substantiated in this paper, the Moenkopi is a highly time-transgressive unit. With the exception of the Sinbad and the conodont-bearing beds of the Black Dragon, time correlations are difficult to establish. A number of sedimentological controls are responsible for the overall pattern. Tectonic activity in the Uncompahgre Highlands related to isostatic adjustment, along with possible climatic changes, controlled the rate at which sediment entered southeastern Utah. Assuming subsidence to be fairly uniform during Moenkopi deposition, when sediment

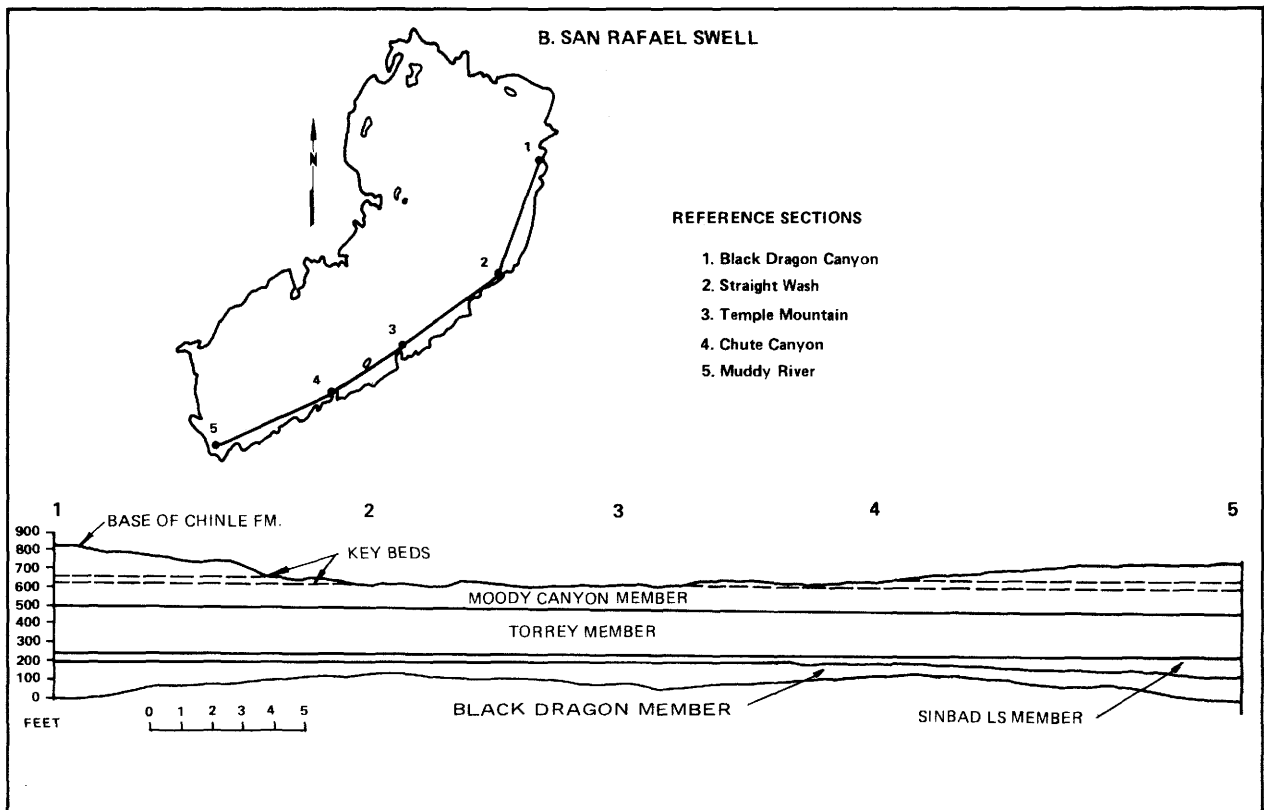
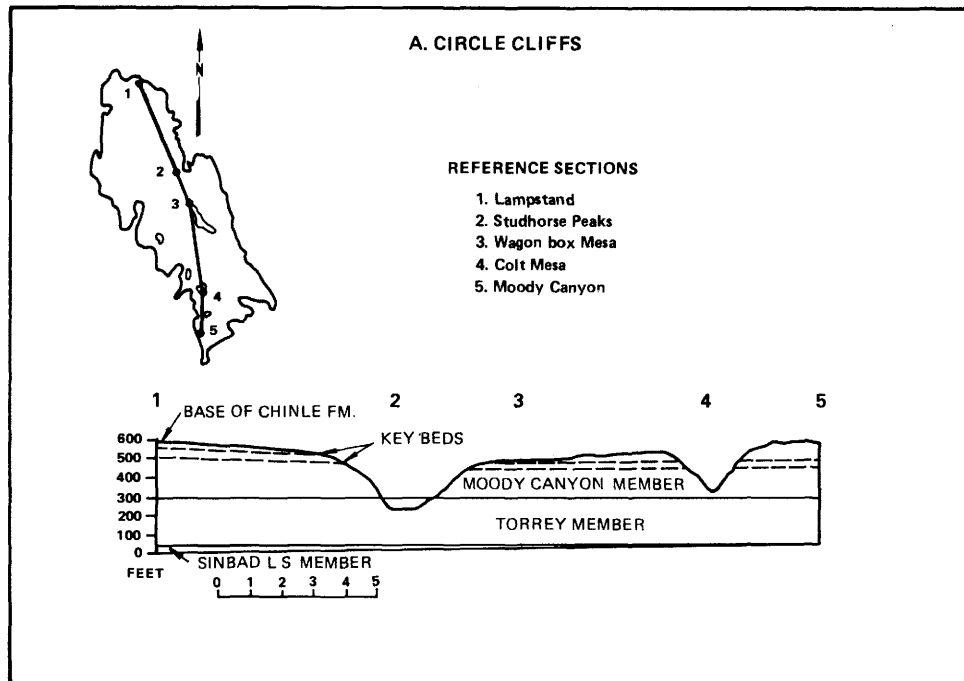


Figure 33. Cross-sections of Moenkopi Formation showing amount of material removed by pre-Chinle erosion. Note that in San Rafael Swell area the Black Dragon Member mirrors the Moody Canyon Member. This suggests minor activity across the Emery Uplift during the Triassic.

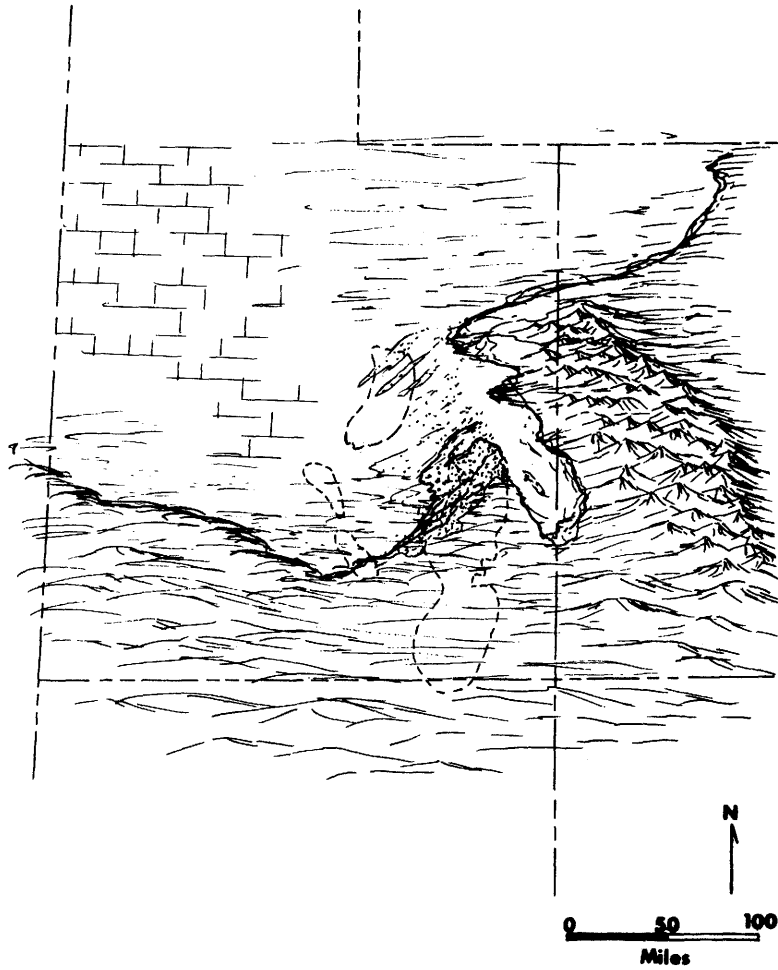


Figure 34. Hypothetical paleogeography of southeastern Utah during lower marine and paralic episode (Black Dragon Member). Thaynes and Woodside Formations were deposited to the northwest.

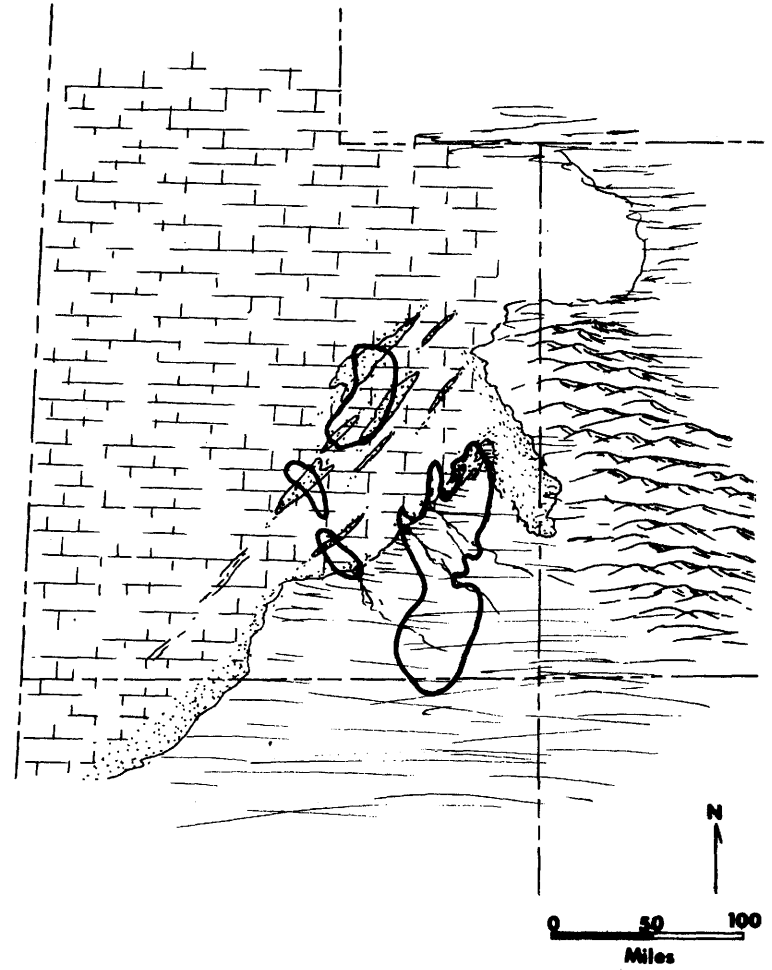


Figure 35. Hypothetical paleogeography of southeast Utah during lower marine and paralic episode (Sinbad Limestone Member). Thaynes Formation was deposited to the northwest and the Timpoweap Member of the Moenkopi Formation was deposited to the southwest.

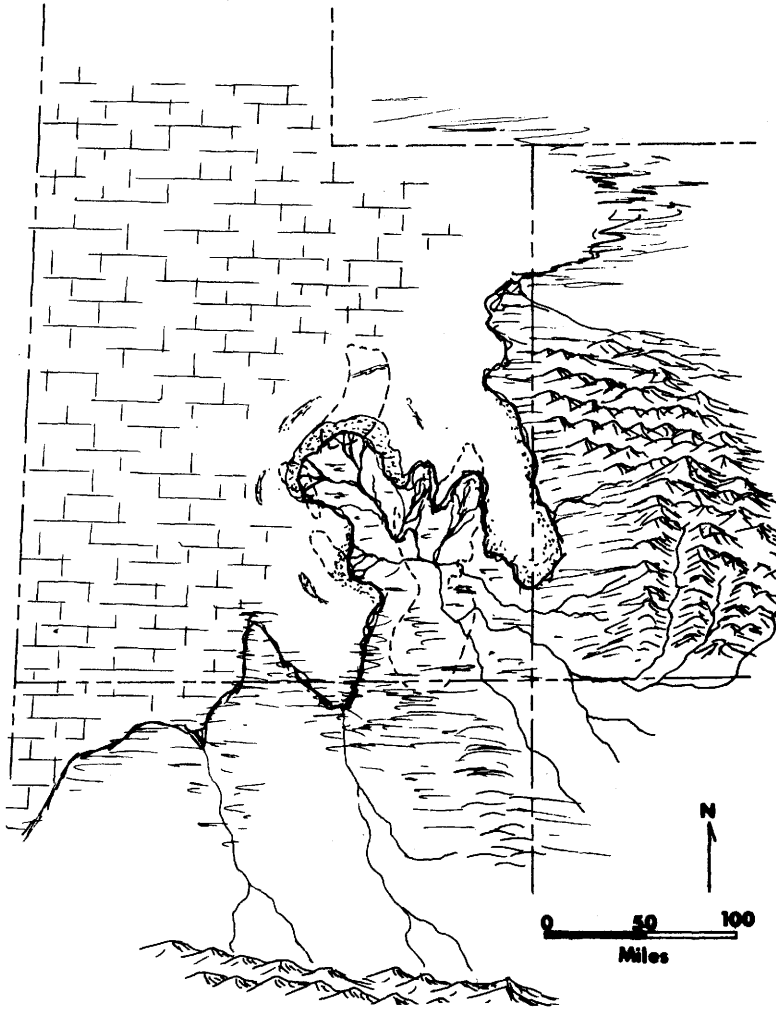


Figure 36. Hypothetical paleogeography of southeastern Utah during early deltaic episode (Torrey Member). Thaynes Formation was deposited to the northwest and Virgin and Lower Red Members of Moenkopi Formation were deposited to the southwest.

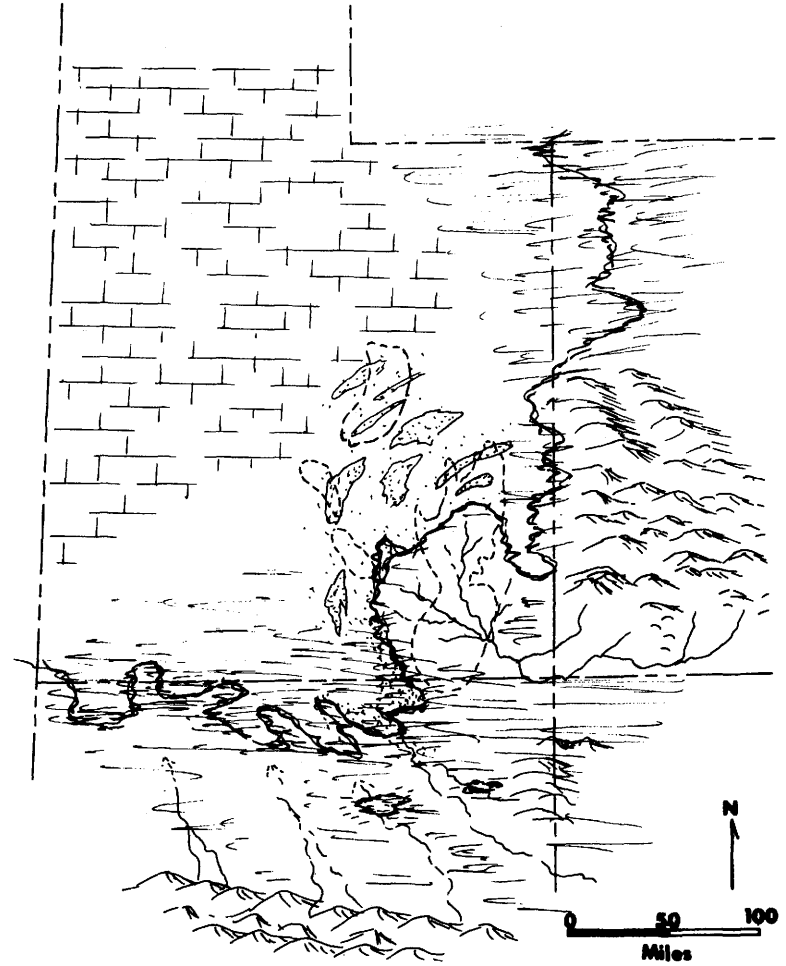


Figure 37. Hypothetical paleogeography of southeastern Utah during late deltaic episode (Torrey Member). Thaynes Formation was deposited to the northwest and Middle Red Member of the Moenkopi Formation was deposited to the southwest. "Type" Moenkopi deposition was initiated in northern Arizona.

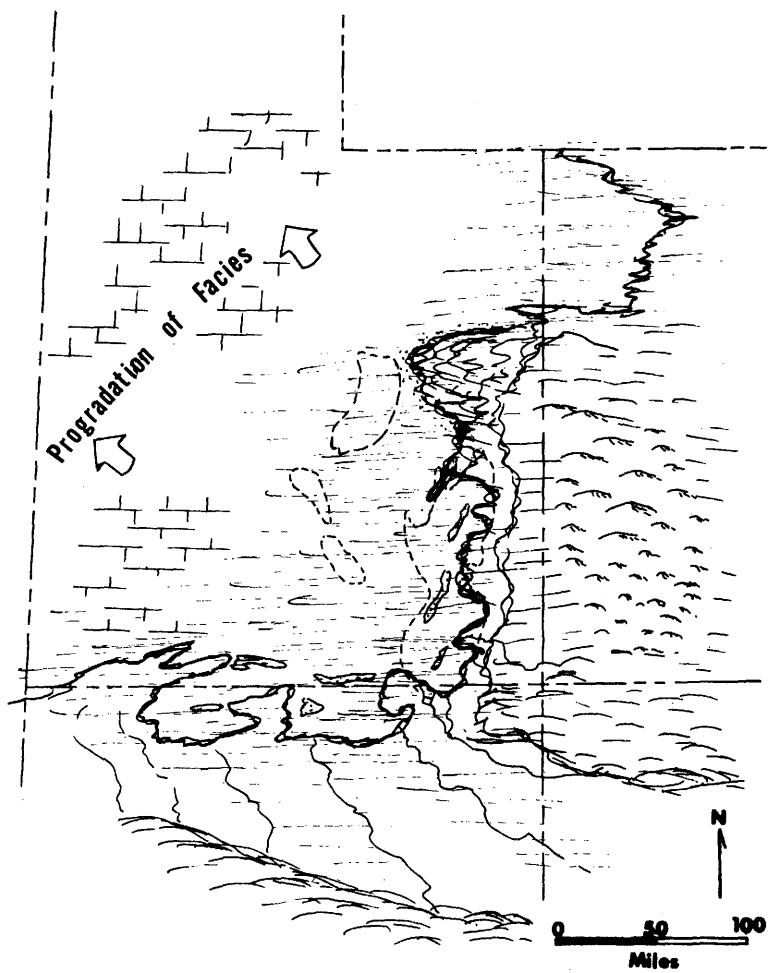


Figure 38. Hypothetical paleogeography of southeastern Utah during the upper marine and paralic episode (Moody Canyon Member). Thaynes Formation was deposited in the early stages and the Ankareh Formation was deposited in the later stages, both to the northwest. The Shnabkaib and Upper Red Members of the Moenkopi Formation were deposited to the southwest and "type" Moenkopi was deposited in northern Arizona.

output was relatively great the shoreline prograded westward and deltaic and continental sandstone and siltstone were deposited. When sediment output was somewhat less, the shoreline fluctuated gradually and regularly-bedded siltstone and mudstone were deposited. When sediment output was minor, the shoreline transgressed eastward and carbonates and reworked clastic sediments were deposited. Because of the irregular nature of deltaic deposition, the above events took place at different times in different parts of southeastern Utah, making time correlation very difficult.

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APPENDIX A

Nomenclature of the Hoskinnini, Moenkopi, and Related Units

HOSKINNINI FORMATION

The Hoskinnini was originally defined as a tongue of the Cutler Formation (Baker and Reeside, 1929). Although this usage was questioned by later authors, it was generally followed until work by Stewart (1959) demonstrated that the Hoskinnini was correlative with the Tenderfoot Member of the Moenkopi Formation in the Salt Anticline region. Following Stewart's recommendation, the Hoskinnini was assigned to the Moenkopi Formation. This usage is not entirely satisfactory either and, as admitted by Stewart (1959), was questioned by some of his co-workers. The age of the Hoskinnini may be Permian and/or Triassic as no diagnostic fossils have ever been reported from the unit. Also, various authors have disagreed as to whether an unconformity is present at the base or top of the unit.

Although the Hoskinnini was studied during this project and preliminary hypotheses were presented (Blakey, 1973), enough discrepancies remain to prohibit additional interpretations in this paper. However, data obtained in this study indicate that the Hoskinnini does not belong in the Moenkopi any more than it did in the Cutler. Rather, it apparently represents deposition in an isolated basin and is transitional from underlying Permian rocks to overlying Triassic rocks. Hence the Hoskinnini is considered to be a formation of Permo-Triassic age. Additional work and future publication by this author will hopefully substantiate this.

NOMENCLATURE OF MOENKOPI FORMATION IN ADJACENT AREAS

The comprehensive report on the Moenkopi Formation by Stewart *et al.* (1972) discusses the nomenclature of the formation in areas outside of southeastern Utah. Although a discussion of the stratigraphy and lithologies of these units is beyond the scope of this paper, table 3 presents a summary of this nomenclature for the convenience of the reader.

SUGGESTIONS CONCERNING FUTURE NOMENCLATURE OF MOENKOPI FORMATION

In an excellent summary of Permo-Triassic stratigraphy, Irwin (1971) suggests the following: (1) The Sinbad and Timpoweap be called the Sinbad and designated a formation; (2) The pre-Sinbad Moenkopi be called the Woodside Formation; (3) The post-Sinbad Moenkopi be referred to a reference section in the Virgin River Valley of southwestern Utah (the informal members would be given formal names). All three suggestions could very easily be followed if the Moenkopi on the Monument Upwarp were neglected;

however, the complex stratigraphy associated with the deltaic episode make the last two suggestions impractical. This study strongly suggests that the most complete Lower Triassic interval on the Colorado Plateau is found in the northern San Rafael Swell and northwestern Monument Upwarp. Unfortunately these areas lack the fossiliferous units present in the Virgin Limestone of southwestern Utah. So the northern section has a more complete interval along with excellent fossiliferous units in the *Meekoceras* zone and the southwestern section has fossiliferous units in the *Columbites* and *Tirolites* zones. In addition, excellent Lower and perhaps Middle Triassic vertebrate fossils have been recovered from the type Moenkopi of northern Arizona (Welles, 1947; Peabody, 1956).

Rather than discuss the merits of each section as a standard reference for the Moenkopi, this author will present some observations and suggestions concerning Moenkopi nomenclature.

(1) Lower Triassic rocks on the Colorado Plateau were deposited in a number of environments in several separate but overlapping basins. Tectonic elements controlling and separating the basins included the Kaibab and Emery positive areas, the sag in the Salt Anticline area, and the miogeosyncline to the west.

(2) Surface and subsurface work has not been able to satisfactorily correlate the Moenkopi from area to area. Like underlying Permian rocks, each area has its own nomenclature. This statement is supported by Stewart *et al.* (1972).

(3) Each area apparently has some unique event or fossiliferous sequence. These events are difficult or impossible to correlate over the Colorado Plateau.

(4) The separate areas of nomenclature should be retained. Detailed stratigraphic analyses should be made in each area to determine depositional environments. This study and one by Baldwin (1973) in north-central Arizona represent attempts to start this process.

(5) Formal names should be proposed for the units of each area, especially southwestern Utah. This will eliminate confusion over much of the descriptive terminology being used at present.

(6) Several papers have proposed that Moenkopi be raised to group status (Poborski, 1954; Smith, 1969; Irwin, 1971). All the members proposed in this paper could easily be raised to formational status. Although a tempting proposition, this idea awaits further study.

APPENDIX B

Stratigraphic Sections

1. Black Dragon Canyon

(Measured by R. C. Blakey, June, 1971, along bottom of Black Dragon Canyon and up slope on east flank of San Rafael Swell, Emery County, Utah).

Top of section; not top of exposure.

Chinle Formation:

Temple Mountain Member (unmeasured):

Siltstone and mudstone, varicolored, flaky to massive, partly mottled; basal several feet grade into Moenkopi Formation and contact cannot be accurately placed.

Moenkopi Formation:

Moody Canyon Member:

(Note: See figure 28, c, f for photographs of section.)

85. Mudstone, dark reddish-brown, flaky to massive, very micaceous; grades into Chinle Formation above; forms slope	5.0
84. Sandstone, dark reddish-brown, poorly-sorted, cross-stratified, micaceous; unit thins and thickens irregularly and contains lenticular strata; forms ledge	7.0
83. Siltstone and mudstone, same as unit 70	15.0
82. Sandstone, same as unit 74	2.0
81. Siltstone, same as unit 56	3.3
80. Sandstone, same as unit 74	1.0
79. Mudstone, same as unit 57	10.0
78. Sandstone, same as unit 74	1.0
77. Siltstone and mudstone, same as unit 70	18.0
76. Sandstone, same as unit 74	3.2
75. Siltstone and mudstone, same as unit 70	7.0
74. Sandstone, reddish-brown, cross-stratified, fine-grained, irregularly bedded, channeling at base with coarse quartz grains in basal few inches; thins and thickens irregularly along outcrop; forms cliff	8.0
(Note: units 74 through 85 are assigned to the upper sandstone and siltstone facies.)	
73. Sandstone and siltstone, pale reddish-brown, thin-bedded, micaceous, forms slope	7.0
72. Mudstone, same as unit 57	10.5
71. Siltstone, light yellowish-gray, ripple-marked, thin to platy-bedded	2.6
70. Siltstone and mudstone, reddish-brown, micaceous, thin to fissile-bedded; contains few thin sandstones and nodular gypsum beds up to 3 inches tk.; unit forms smooth slope	37.0
69. Mudstone, same as unit 57	32.0
68. Siltstone, pale reddish-brown, sandy, massive, micaceous; forms extremely continuous ledge	7.0
67. Mudstone, same as unit 57	4.0
66. Siltstone, sandy, same as unit 56	5.5

Feet

65. Mudstone, same as unit 57	1.8
64. Siltstone, sandy, same as unit 56	4.0
63. Mudstone, same as unit 57	24.0
62. Siltstone, sandy, same as unit 56	2.7
61. Mudstone, same as unit 57	7.0
60. Siltstone, sandy, same as unit 56	3.8
59. Mudstone, same as unit 57	6.2
58. Siltstone, sandy, same as unit 56	3.5
57. Mudstone, reddish-brown, micaceous, weathers into irregular nodules, flakes, and lumps; contains light-colored ripple-marked siltstone beds ¼-½ inch tk. at 2 to 8 ft. intervals; unit weathers to form smooth, striped slope	24.0
56. Siltstone, sandy, reddish-brown, micaceous, "structureless" to ripple-laminated; unit weathers to extremely continuous, rounded ledge	4.0

(Note: units 56 through 73 are assigned to the sandy siltstone and mudstone facies.)

55. Mudstone, micaceous, pale reddish-brown, and thin ripple-marked micaceous siltstone, pale yellowish-gray; siltstone occurs as single beds ½ to 1 inch tk. separated by 4 to 12 feet of mudstone; mudstone weathers flaky, earthy, fissile or lumpy; unit forms smooth regular slopes interrupted by thin ledges	88.0
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(Note: unit 55 is assigned to mudstone facies.)

Total Moody Canyon Member 355.1

Torrey Member:

(Note: see figure 3a for photograph of section.)

54. Siltstone, pale reddish-brown, micaceous, "structureless" at base grading into ripple-marked beds at top; forms extremely continuous ledge	5.0
53. Siltstone and mudstone, pale reddish-brown, ripple-marked, micaceous, thin-bedded; forms irregular earthy slope	20.0
52. Siltstone, sandy, pale reddish-brown, "structureless" with ball and pillow structure, micaceous, forms continuous ledge cliff	3.9
51. Mudstone, same as unit 25	13.8
50. Siltstone, same as unit 26	8.0
49. Mudstone, same as unit 25	5.3
48. Siltstone, same as unit 26	1.0
47. Mudstone, same as unit 25 but with more siltstone	5.1
46. Sandstone, yellowish-gray, same as unit 42 but with numerous signs of bioturbation	0.5
45. Mudstone, pale reddish-brown, same as unit 25	3.6
44. Sandstone, same as unit 42	3.0
43. Mudstone, same as unit 25	11.0
42. Sandstone, pale tannish-gray, very fine-grained, dolomitic, micaceous, ripple-marked to cross-stratified; forms cliff	2.7
41. Mudstone, bioturbation, same as unit 25	10.0
40. Sandstone, very fine-grained, with thin bed of ripple-marked siltstone in middle	4.0
39. Siltstone, mudstone, and sandstone complexly interbedded, ripple-marked, micaceous, gypsiferous; generally composed of	

fining-upwards sequence; unit forms ledges and slopes	42.0
38. Sandstone, same as unit 36	2.0
37. Mudstone, same as unit 25	1.6
36. Sandstone, pale tannish-brown, ripple-marked, very fine-grained; forms continuous ledge	1.0
35. Mudstone, same as unit 25	4.5
34. Sandstone, same as unit 27 but siltier	5.3
33. Mudstone, same as unit 25	5.4
32. Sandstone, siltstone, and mudstone, same as unit 28	8.0
31. Mudstone, same as unit 25	15.8
30. Sandstone, siltstone, and mudstone, same as unit 28	8.0
29. Mudstone, same as unit 25	13.0
28. Sandstone, siltstone and mudstone, pale tannish-gray, micaceous, ripple-marked and laminated, thin to fissile-bedded, gypsiferous, petroliferous; forms ledgy slope	13.9
27. Sandstone, yellowish-gray, very fine-grained, ripple-laminated, thin to medium-bedded, micaceous; forms ledge	11.0
26. Siltstone, yellowish-gray, thin-bedded, ripple-laminated, fissile to thin-bedded, micaceous; forms ledgy slope	11.8
25. Mudstone, light gray, gypsiferous, micaceous, fissile; forms weak slope	9.0
24. Sandstone, siltstone and mudstone, light gray, micaceous, ripple-laminated, thin- to platy-bedded; max. sandstone thickness 1 ft.; unit forms ledgy slope	16.0

(Note: the Torrey Member at this locality is assigned to the Wickiup facies; the three lowest units correlate with the basal siltstone and mudstone facies.)

Total Torrey Member 265.2

Sinbad Limestone Member:

23. Dolomite, light yellowish-gray, dense, traces of mica; intraclasts, pellets, and oolites; thin- to medium-bedded, forms bench	3.0
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(Note: above unit assigned to dolomitized calcarenite facies.)

22. Limestone, dolomitic, medium-gray, petroliferous; trough-cross-stratification, irregular bedding, some beds ripple-marked; probably pelleted; forms ledgy cliff	5.6
21. Siltstone, calcareous, light gray, petroliferous, micaceous; platy-bedded with trough-cross-stratification; contains carbonate intraclasts; forms ledgy cliff or irregular slope	7.5
20. Siltstone, limestone, and gypsum, medium-gray; thin to thick-bedded with low-angle trough-cross-stratification; forms ledgy slope	4.1
19. Limestone and siltstone, grayish-brown, vuggy; thin to platy-bedded with low-angle trough-cross-stratification; calcite crystals in vugs; unit forms ledge	2.3

(Note: units 19 through 22 are assigned to the silty peloidal calcilutite facies.)

18. Limestone, same as unit 16	1.5
17. Limestone, grayish-brown, skeletal calcarenite with "depauperate" fauna of gastropods, pelecypods, scaphopods; trough-cross-stratification, thin to platy-bedded; forms ledge	4.4
16. Limestone, gray, skeletal calcarenite, calcite crystals in vugs, thick to massive beds; forms cliff	1.3

15. Limestone, bluish-gray, skeletal calcarenite with intraclasts; platy-bedded with trough-cross-stratification; forms ledge	1.9
14. Limestone, medium gray, skeletal calcarenite, oolitic micaceous; thin to thick-bedding; contains ammonites; forms massive cliff	3.3

(Note: units 14 through 18 are assigned to the skeletal calcarenite facies.)

Total Sinbad Limestone Member 34.9

Black Dragon Member (type section):

13. Siltstone and limestone, yellowish-gray, siltstone like unit 12; limestone fossiliferous, skeletal calcarenite; thin interbedded sandstone; unit contains regular, even beds; forms ledgy cliff	46.0
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(Note: unit 13 assigned to transition facies.)

12. Siltstone, mudstone, and sandstone, yellowish-gray, micaceous; even-bedded, thin to platy beds, ripple-marked and laminated; some units petroliferous; tracks, trails, and bioturbation very evident; few thin gypsum beds; unit forms ledgy slope	24.0
11. Mudstone and siltstone, micaceous, petroliferous; ripple-laminated and marked, platy to thin regular-bedding; forms ledgy slope	16.0
10. Mudstone, siltstone, and sandstone, micaceous, petroliferous; sandstone is in regular beds ½ to 4 inches tk. that are ripple-marked and laminated; mudstone and siltstone thin to fissile; unit forms ledgy slope	19.0

(Note: units 10 through 12 are assigned to the even-bedded facies.)

9. Sandstone, gray, micaceous, very petroliferous, fine-grained; lower portion cross-stratified and locally cut by narrow channels; upper portion thinner-bedded and ripple-marked; sandstone fines both upwards and downwards; forms ledge	11.0
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(Note: unit 9 is Cottonwood Draw sandstone.)

8. Sandstone, siltstone, and mudstone, light to dark gray, micaceous, petroliferous; irregular complex bedding, trough-cross-stratification; hematite and pyrite concretions up to 1 inch; platy to thick-bedded; mudstone weathers to ball and pillow structure; forms ledges and slopes	27.7
7. Sandstone and siltstone, same as unit 2	3.3
6. Sandstone and siltstone, same as unit 2 but sandstone is coarser-grained	1.3
5. Mudstone, same as unit 3	7.1
4. Sandstone and siltstone, same as unit 2	0.8
3. Mudstone, gypsiferous, varicolored yellow, gray and tan; platy to fissile; weathers to ball and pillow structure	3.3
2. Sandstone and siltstone, yellowish-gray, micaceous, few gypsum seams; trails and burrows common; thin- to platy-bedding, ripple-marked, unit thins to 1 ft. few yards to west	6.0

(Note: units 2 through 8 assigned to even-bedded facies.)

1. Chert-pebble conglomerate interbedded with sandstone and mudstone, light yellowish-gray; chert pebbles up to 2 inches occur in beds 1 to 4 ft. tk. that are separated by sandstone and mudstone units 2 to 9	
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ft. tk.; unit cross-stratified, ripple-marked, thin to medium-bedded; forms ledges 42.6

(Note: unit 1 is basal conglomerate.)

Total Black Dragon Member 208.1

Total Moenkopi Formation 863.3

Kaibab Formation (unmeasured):

Limestone and dolomite, cherty, locally fossiliferous; generally in massive beds.

8. Sulphur Creek

(Measured by R. C. Blakey, June, 1971, along bottom of Sulphur Creek Canyon and up slope of Capitol Reef, Capitol Reef National Park, Wayne County, Utah).

Top of section; not top of exposure.

Feet

Chinle Formation:

Petrified Forest Member (unmeasured):

Sandstone, siltstone, and mudstone, mottled, variegated, bentonitic; contact with Moenkopi sharp color change from dominantly reddish-brown below to purple and gray above.

Moenkopi Formation:

(Note: see figure 23, b, c for photographs of section.)

Moody Canyon Member:

38. Mudstone and sandy siltstone alternating in units about 6 in. to 2 ft. tk.; mudstone and sandy siltstone similar to unit; nodular pale orange gypsum up to 6 in. tk. common, increase in abundance towards top of section; few thin dolomitic (?) beds present; unit forms pinnacles, castles, knobby cliff 210.0

(Note: unit 38 tentatively assigned to sandy siltstone and mudstone facies).

37. Mudstone, pale reddish-brown to dark brown, micaceous, interbedded with ripple-marked micaceous siltstone beds ¼ to 1 in. tk.; possible tracks and trails present on some siltstone beds; towards top unit contains "structureless" dark reddish-brown sandy siltstone strata ½ to 2 ft. tk.; these beds form continuous ledges traceable for many miles along Capitol Reef; thin white gypsum seams occur with the mudstone units and pale orange nodular gypsum beds 2 in. tk. occur with the sandy siltstone; unit forms striped slope 216.0

Total Moody Canyon Member 426.0

Torrey Member (in vicinity of type section):

36. Sandstone, same as unit 28 3.6
 35. Mudstone, reddish-brown, micaceous, fissile to platy with several thin ripple-marked siltstone beds; unit forms slope 4.0

34. Sandstone, same as unit 28 2.8
 33. Sandstone, thin-bedded with interbedded micaceous mudstone 3.5
 32. Sandstone, same as unit 28 4.0
 31. Siltstone and mudstone, same as unit 19 9.0
 30. Siltstone, dark reddish-brown, sandy, massive, micaceous; weathers to rounded ledge 4.0
 29. Siltstone and mudstone, same as unit 19 10.0

(Note: units 29 through 36 are tentatively placed in the Wickiup Facies.)

28. Sandstone, very pale reddish-brown to pale grayish-orange, very fine-grained, dolomite cement; contains trough-cross-stratification sets up to 3 ft. tk.; unit thinner-bedded and ripple-marked near top; some sets are lenticular but unit forms prominent cliff that can be traced throughout the Teasdale Uplift 60.0
 27. Sandstone, siltstone, and mudstone, same as unit 23 . . . 19.0
 26. Sandstone and siltstone, reddish-brown; three cross-stratified sandstones interbedded with two ripple-marked micaceous siltstones 5.0
 25. Sandstone, siltstone, and mudstone, same as unit 23 . . . 29.0
 24. Sandstone, pale orangish-gray; bedding complex and variable with cross-stratification, ripple marks, and interbedded silty units; forms cliff 58.0
 23. Sandstone, siltstone, and mudstone, reddish-brown, micaceous, ripple-marked; thin to fissile bedding with regular and irregular sets; some units lenticular; forms slopes and ledges 20.0
 22. Sandstone, reddish-brown, ripple-marked, with thin to thick sets; unit somewhat lenticular; forms ledge 17.0
 21. Siltstone, sandy, reddish-brown, thin to thick sets; forms rounded ledge 8.0

(Note: units 21 through 28 are assigned to Goosenecks and North Wash facies.)

20. Siltstone, dark reddish-brown, and thin micaceous sandstone, pale reddish-brown; complex bedding and stratification; ripple marks; unit forms slope or protected cliff 37.0

(Note: unit 20 probably represents intertonguing between basal siltstone and mudstone and the North Wash facies.)

19. Siltstone and mudstone, dark reddish-brown, fissile to platy; micaceous, ripple-marked; contains few thin sandstone and dolomite beds; forms slope 22.8

(Note: unit 19 assigned to basal siltstone and mudstone facies.)

Total Torrey Member 315.9

Sinbad Limestone Member:

18. Limestone and dolomite, yellowish-gray, thin- to thick-bedded, with interbedded quartz siltstone; some carbonate beds contain poorly-preserved pelecypods; limestone and dolomite form ledges, siltstone forms slopes 15.0
 17. Dolomitic limestone, dense, massive, crystalline; forms ledge 2.7
 16. Siltstone, calcareous, thin-bedded, forms slope 2.0
 15. Dolomitic limestone, gray, dense, medium- to thick-bedded; burrowed structures common; forms cliff 9.0
 14. Siltstone, calcareous, medium-bedded; forms ledgy slope 6.9

13. Limestone, probably skeletal calcarenite; dense, massive, yellowish-gray; forms cliff 9.5
 12. Limestone and siltstone, grayish-yellow; thick to massive, cross-stratified; forms ledgy cliff 31.0
 11. Limestone and siltstone; wavy bedded; similar to unit 8 8.0
 10. Limestone and siltstone, same as unit 8 5.0
 9. Siltstone and calcareous siltstone, grayish-yellow; thin to fissile, "structureless", micaceous; forms notch between two cliffs 5.4
 8. Limestone and calcareous siltstone, pale yellowish-gray, medium- to thick-bedded; displays numerous trails and burrows; forms ledgy cliff 9.0
 Total Sinbad Limestone Member 103.5

Black Dragon Member

7. Sandstone and siltstone, dark reddish-brown, micaceous, medium to thin strata in parallel, regular sets; forms slope or protected cliff 25.0
 6. Siltstone, reddish-brown, thin-bedded to laminated, micaceous, ripple laminations; forms slope 13.9
 5. Siltstone, reddish-brown, sandy; medium-bedded; forms slope 3.4
 4. Siltstone, reddish-brown; thin-bedded, micaceous; forms slope 11.7
 3. Siltstone and mudstone, thin to laminar bedding, micaceous; siltstone is ripple-marked; forms slope 9.8
 2. Siltstone, yellowish-brown, micaceous; thin-bedded, ripple-marked; forms slope 0.9
 1. Siltstone and mudstone, yellowish-gray, platy, micaceous; forms slope 10.0

(Note: units 1 through 7 are assigned to the even-bedded facies. The basal contact is mostly concealed but little or no conglomerate is present. About 2 feet of relief is apparent.)

Total Black Dragon Member 74.7
 Total Moenkopi Formation 920.1

Kaibab Formation (unmeasured):

Limestone and dolomite, cherty, pale yellowish-brown, massive- to thin-bedded.

14. Stillwater Canyon

(Measured by R. C. Blakey, August, 1971, along White Rim Jeep Trail, below Steer Mesa in Canyonlands National Park, Island in the Sky, San Juan County, Utah).

Top of section; not top of exposure.

Feet

Chinle Formation:

Moss Back Member (unmeasured):

Sandstone, tannish-gray, conglomeratic, contains small petrified wood fragments.

Moenkopi Formation:

(Note: see figures 3b and 9, d, f for photographs of section.)

Moody Canyon Member:

19. Siltstone, 3 massive "structureless" units interbedded with thin, fissile mudstone;

unit micaceous, reddish-brown; the siltstones can be traced for miles throughout the area; unit forms knobby cliff 12.0

(Note: unit 19 may correlate with the sandy siltstone and mudstone facies.)

18. Mudstone and siltstone, same as unit 17 but pale reddish-brown 23.0
 17. Mudstone and siltstone, yellowish-gray, micaceous, very even-bedded, gypsiferous; forms slope 50.0

(Note: units 17 and 18 are assigned to the mudstone facies.)

16. Sandstone, same as unit 13; forms prominent sandy ledge in slope-forming sequence; distribution of nonred rocks in Moody Canyon Member closely related to distribution of this unit 9.0
 15. Siltstone, sandy, and mudstone, yellowish-gray, micaceous, gypsiferous, fissile; forms ledgy slope 3.0
 14. Mudstone, medium gray, fissile, gypsiferous, micaceous; forms slope 3.0
 13. Sandstone, yellowish-gray, micaceous, ripple-laminated, massive; forms ledge 4.0

(Note: boundary between Torrey and Moody Canyon Members is very uncertain. Units 13 through 16 are assigned to the Steer Mesa facies of the Moody Canyon Member.)

Total Moody Canyon Member 104.0

Torrey Member:

12. Siltstone and mudstone with platy sandstones, medium gray to yellowish-gray, gypsiferous, micaceous; thin to fissile; weathers to smooth slope or protected cliff 67.0
 11. Sandstone, same as unit 9 5.0
 10. Siltstone and sandy siltstone, mostly reddish-brown; some strata ripple-marked or ripple-laminated; some "structureless" siltstone present; unit micaceous, platy to massive; weathers to ledgy slope 47.0
 9. Sandstone, yellowish-gray, ripple-laminated, very fine-grained, micaceous, probably dolomitic; forms ledge 3.0

(Note: the units in the Torrey Member are assigned to the Wickiup facies; units 9 through 11 probably correlate with the basal siltstone and mudstone.)

Total Torrey Member 122.0

Sinbad Limestone Member:

8. Dolomite, yellowish-orange, petroliferous, vuggy, platy-weathering; contains gastropods, pelecypods, and ostracodes; stromatolite mounds and thin "algal mats" are present; dolomite grains comprise pellets, oolites, intraclasts, and fossils; unit is locally silty (quartz); unit weathers to form prominent yellow bench in red clastic sequence 2.5

(Note: this unit is assigned to the dolomitized calcarenite facies.)

Total Sinbad Limestone Member 2.5

Black Dragon Member:

- 7. Sandstone, pale reddish-brown; very fine-grained and interbedded dark reddish-brown micaceous siltstone; siltstone strata commonly ripple-marked; most sandstone units about 2 to 5 ft. tk.; unit forms ledgy cliff65.0
- 6. Sandstone, pale grayish-orange, medium- to fine-grained; unit variable along strike but can be traced throughout the western Island in the Sky Plateau and along the Orange Cliffs; a variety of cross-stratification types and bedding thickness is present; generally the base is more highly cross-stratified; base of unit marks the top of a prominent angular discordance with underlying strata; unit forms conspicuous ledge or cliff18.0

(Note: units 6 and 7 are assigned to the Island in the Sky facies.)

- 5. Siltstone and mudstone, dark reddish-brown, micaceous; mudstone finely-laminated and displays ball and pillow structure; siltstone commonly ripple-laminated; forms protected cliff22.0
- 4. Siltstone and mudstone; same as unit 2 but with several medium-grained sandstones up to 2 ft. tk. with load casting on the bases; forms slopes and ledges24.0
- 3. Siltstone and mudstone, same as unit 220.0

(Note: units 3 through 5 dip eastward about 10 degrees; this sequence can be correlated southward more than 20 miles and is assigned to the "Foreset Beds".)

- 2. Siltstone and mudstone, dark reddish-brown, micaceous, even-bedded; strata weather fissile to platy; forms slope34.0

(Note: unit 2 assigned to the even-bedded facies).

Total Black Dragon Member183.0
 Total Moenkopi Formation411.5

Hoskinnini Formation:

- 1. Sandstone and siltstone, dark reddish-brown, very poorly-sorted; lower part of unit is dominantly sandstone in sets or cosets up to 12 ft. tk.; top of unit is micaceous and contains dominantly siltstone and very fine-grained sandstone in sets less than 3 ft. tk.; unit is very poorly- to well-cemented and lower portion weathers to form rounded ledges and top portion forms slopes and rounded ledges50.0

Total Hoskinnini Formation50.0

Total Moenkopi and Hoskinnini Formations461.5

White Rim Sandstone:

Upper Member (unmeasured):

Sandstone, yellowish-gray, medium-grained, sugary textured, very poorly-cemented.

22. Hideout Canyon

(Measured by R. C. Blakey, August, 1971, along jeep road to uranium mine on the south wall of White Canyon opposite the mouth of Hideout Canyon, San Juan County, Utah).

Top of section; not top of exposure.

Feet

Chinle Formation:

Shinarump Member (unmeasured):

Sandstone, medium- to coarse-grained, cross-stratified; conglomeratic at base; small irregular channels or swales cut into underlying formation.

Moenkopi Formation:

(Note: Moody Canyon Member locally absent due to pre-Chinle erosion; see figures 3d and 22, a, b for photographs of similar section).

Torrey Member:

- 21. Siltstone and thin sandstone, pale reddish-brown; sandstone is generally 6 in. to 1 ft. tk. and is cross-stratified; siltstone platy to fissile and is ripple-marked; unit forms ledgy slope19.0
- 20. Sandstone, massive, same as unit 149.0
- 19. Siltstone and mudstone, same as unit 53.0
- 18. Siltstone, "structureless", same as unit 105.0
- 17. Siltstone, reddish-brown; thin-bedded, ripple-marked; contains mud cracks; forms slope6.0
- 16. Siltstone, "structureless", same as unit 103.0
- 15. Siltstone, reddish-brown; thin to fissile, ripple-marked, micaceous; forms ledgy slope12.0
- 14. Sandstone, pale grayish-orange, massive, intensely cross-stratified in low-angle sets 6 in. to 1 ft. tk.; contains internal channeling and base erodes underlying strata; unit thickens and thins along strike; contains lenses of mudstone; forms cliffs20.0
- 13. Siltstone, massive, dark reddish-brown; weathers to irregular-shaped mudchips; forms protected cliff7.0
- 12. Sandstone, grayish-orange, very fine-grained, cross-stratified; unit is massive at base but becomes ripple-laminated upward; forms persistent cliff15.0
- 11. Siltstone and sandy siltstone, reddish-brown, fissile to massive; ripple-marked and cross-stratified; complexly bedded and variable; forms ledges, slopes, and protected cliff18.0
- 10. Siltstone, reddish-brown, "structureless" to thinly laminated; locally cross-stratified; part of unit contains abundant dolomite and mud-pebble conglomerate; unit forms rounded ledge7.0
- 9. Siltstone, pale reddish-brown; forms complex sequence with ripple marks, cross-stratified units, mud cracks and mud-pebble conglomerate; forms slopes and ledges27.0
- 8. Sandstone and siltstone; sandstone 4 in. to 1 ft. tk. with small-scale cross-stratification; siltstone fissile, micaceous; forms slope or protected cliff6.0
- 7. Siltstone and silty sandstone; poorly exposed5.0
- 6. Sandstone, white, sugary textured, very coarse-grained, mud-pebble conglomerate; thins and thickens along strike; forms ledge1.0

(Note: units 6 through 21 are assigned to the Hideout Canyon facies.)

- 5. Siltstone and mudstone, reddish-brown; ripple-marked, fissile to platy-weathering, micaceous; contains few thin cross-stratified sandstones; unit forms slope 18.0
- 4. Sandstone, white, sugary, coarse-grained, vitreous quartz grains; unit cross-stratified, forms ledge 1.0
- 3. Sandstone, very fine-grained, tan; contains complex convolute laminations and micro-cross-stratification; forms ledge 1.5

(Note: units 3 through 5 are assigned to the basal siltstone and mudstone facies.)

Total Torrey Member 183.5

(Note: Black Dragon Member absent in this area.)

Total Moenkopi Formation 183.5

Hoskinnini Formation:

- 2. Sandstone and siltstone, dark reddish-brown; cosets 1 to 3 ft. tk.; cosets contain complex laminations; basal unit is "crinkly bed"; unit forms ledge 21.0
- 1. Sandstone, orangish-brown to reddish-brown; in cosets with parallel bases and tops, 3 to 12 ft. tk.; contains well-rounded quartz grains up to 2 mm in diameter; unit well-cemented and complexly internally laminated; unit forms cliff 56.0

(Note: unit 2 is assigned to the upper unit and unit 1 the lower unit.)

Total Hoskinnini Formation 77.0

Total Moenkopi and Hoskinnini Formations 260.5

Organ Rock Formation (unmeasured, undescribed):

(Note: contact between Hoskinnini and Organ Rock appears to be conformable; contact placed at base of lowest unit that contains well-rounded coarse quartz grains.)

7. Torrey (in part)

(Measured by R. C. Blakey, June, 1971, on west side of prominent mesa south of Torrey, Utah, in the center of Sec. 30, T. 29 S., R. 5 E., Wayne County, Utah. This is the type section of the Torrey Member.)

Top of mesa; top of exposure. Remainder of section (not published here) is several miles to north.

Feet

Moenkopi Formation

(Note: see figure 23a for photograph of section.)

Moody Canyon Member:

Mudstone, dark reddish-brown, micaceous, forms isolated hills on top of mesa (unmeasured).

Torrey Member:

- 16. Sandstone, reddish-brown, horizontally-stratified, fine to medium-grained, forms ledge that caps mesa 18.0

- 15. Siltstone, same as unit 3 18.0
 - 14. Sandstone, grayish-white, fine to medium-grained, displays prominent trough-cross-stratification in cosets 1 to 4 ft. tk.; unit forms massive cliff or ledge 24.0
 - 13. Siltstone and mudstone, reddish-brown to tannish-gray, locally gypsiferous, thin to fissile-weathering, forms irregular slope 56.0
 - 12. Sandstone and siltstone, reddish-brown, in alternating sequence, some units cross-stratified or ripple-marked, forms thin ledges and slopes 36.0
 - 11. Sandstone, silty, same as unit 6 6.0
 - 10. Siltstone, same as unit 3 9.0
 - 9. Sandstone, silty, same as unit 6 4.0
 - 8. Siltstone, same as unit 3 22.0
 - 7. Sandstone, yellowish-gray, horizontal to low-angle cross-stratification, contains clay intraclasts near base, micaceous, weathers to massive cliff in lower portion, becomes finer-grained and weathers flaggy towards top 25.0
 - 6. Sandstone, silty, pale reddish-brown, micaceous, ripple-marked, abundant tracks and trails, platy to medium-bedded, forms ledgy slope 15.0
 - 5. Siltstone, same as unit 3 12.0
 - 4. Dolomite, yellowish-brown, dense, forms ledge 1.0
 - 3. Siltstone, reddish-brown, ripple-marked, micaceous, abundant tracks and trails, weathers to flaggy slope . . . 12.0
 - 2. Siltstone, sandy, pale reddish-brown to yellowish-gray, intensely ripple-laminated, micaceous, tracks and trails, platy to flaggy-weathering, forms irregular slope 9.0
 - 1. Siltstone and mudstone, yellowish-gray, very gypsiferous, platy to fissile-weathering, forms slope or protected reentrant 15.0
- Total Torrey Member 272.0

Sinbad Limestone Member (not described)

Base of section; base of exposure

(Note: Sinbad Limestone Member measured to southeast on Fremont River, not published here.)

2P. Moody Canyon

(Measured by R. C. Blakey, June, 1971, along southwest side of Circle Cliffs about 1 mile north of where Moody Creek enters Moody Canyon, Garfield County, Utah. This is the type section of the Moody Canyon Member.)

Top of section; not top of exposure.

Feet

Chinle Formation:

Shinarump Member (unmeasured):

Sandstone, pale tannish-gray, medium to coarse-grained, locally conglomeratic, lenticular bedding, forms prominent cliff. Generally the Shinarump channels into the Moody Canyon Member but locally a mottled mudstone forms the base of the Chinle. Where this unit is present, apparent channeling is absent and the Chinle-Moenkopi contact is covered over an interval of several feet. This unit may represent a pre-Chinle soil or weathering horizon.

Moenkopi Formation:

Moody Canyon Member:

(Note: see figure 28e for photograph of section.)

- 20. Siltstone and mudstone, dark reddish-brown, micaceous, flaky to massive-weathering, mudstone forms fissile weathering slopes and siltstone forms "massive" rounded ledges16.0
- 19. Siltstone, same as unit 7 1.8
- 18. Mudstone, same as unit 1 2.5
- 17. Siltstone, same as unit 7 0.8
- 16. Mudstone, same as unit 1 8.0
- 15. Siltstone, same as unit 7 2.0
- 14. Mudstone, same as unit 1 3.8
- 13. Siltstone, same as unit 7 1.0
- 12. Mudstone, same as unit 1 3.0
- 11. Dolomite, pale yellowish-orange, micaceous, clayey, extremely fine-grained, finely-laminated, forms thin ledge 2.0
- 10. Mudstone, same as unit 110.0
- 9. Siltstone (key bed), same as unit 7 4.5
- 8. Mudstone, same as unit 136.0
- 7. Siltstone (key bed), dark reddish-brown, very micaceous, crudely ripple-laminated, "massive" but weathers to exfoliated fissile or

platy layers that do not parallel bedding, forms prominent rounded ledge that can be traced throughout Circle Cliffs 6.0

(Note: units 7 through 20 assigned to sandy siltstone and mudstone facies.)

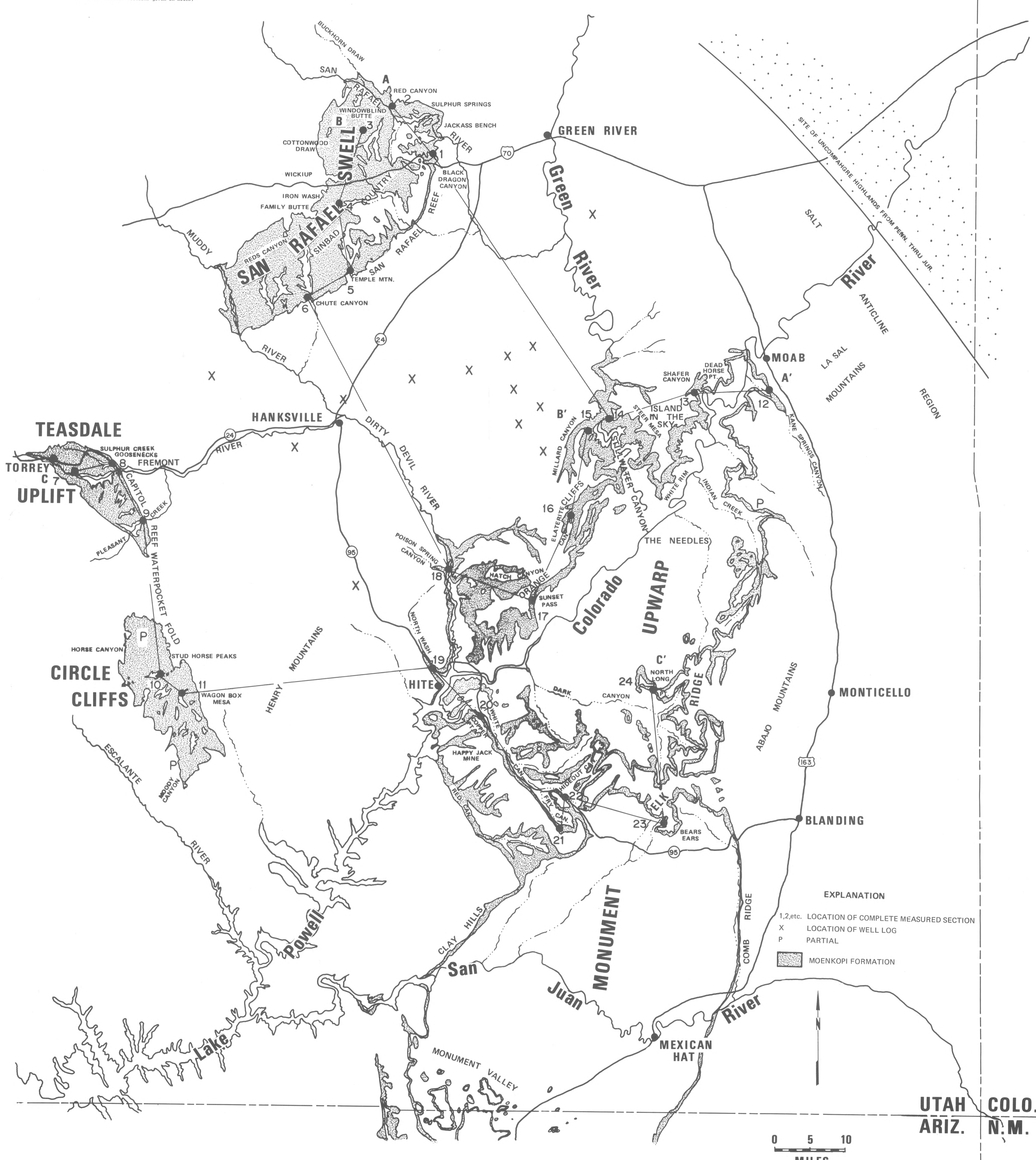
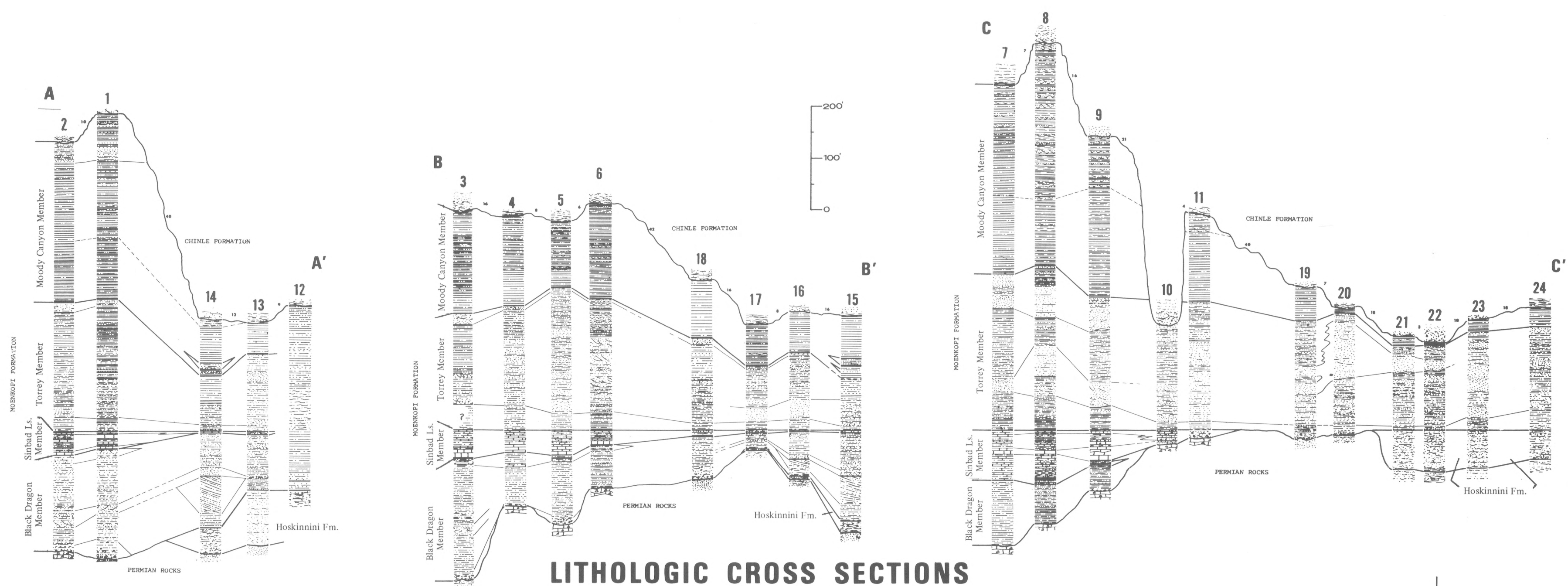
- 6. Mudstone, same as unit 316.0
- 5. Mudstone, same as unit 1 except siltier towards top . . .41.0
- 4. Siltstone, same as unit 2 2.0
- 3. Mudstone, dark reddish-brown, micaceous, fissile-weathering, contains abundant grayish-green, ripple-marked, micaceous siltstones at 6 to 12 ft. intervals, unit forms smooth striped slope102.0
- 2. Siltstone, reddish-brown, platy-weathering, forms platy ledge 1.2
- 1. Mudstone, reddish-brown, micaceous, flaggy to platy-weathering, locally ripple-marked, forms partly covered slope17.0

(Note: units 1 through 6 assigned to mudstone facies).

Total Moody Canyon Member276.6

Torrey Member (unmeasured, undescribed)

Base of section; not base of exposure.



INDEX MAP AND LITHOLOGIC CROSS-SECTIONS OF MOENKOPI FORMATION, SOUTHEASTERN UTAH