Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

NOTES ON THE MOENKOPI FORMATION IN THE SALT ANTICLINE REGION OF COLORADO AND UTAH*

By

Eugene M. Shoemaker and William L. Newman

October 1957

Trace Elements Investigations Report 681

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

USGS - TEI-681

GEOLOGY AND MINERALOGY

Distribution	No. of copies
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Austin.	1
Division of Raw Materials, Casper.	1
Division of Raw Materials, Denver.	1
Division of Raw Materials, Rapid City.	1
Division of Raw Materials, Salt Lake City.	1
Division of Raw Materials, Spokane	1
Division of Raw Materials, Washington.	3
Exploration Division, Grand Junction Operations Office	6
Grand Junction Operations Office	1
Technical Information Service Extension, Oak Ridge	6
U. S. Geological Survey:	
Foreign Geology Branch, Washington	1
Fuels Branch, Washington	1
Geochemistry and Petrology Branch, Washington.	1
Geophysics Branch, Washington.	1
Mineral Deposits Branch, Washington.	2
P. C. Bateman, Menlo Park.	1
A. L. Brokaw, Grand Junction	2
N. M. Denson, Denver	1
R. L. Griggs, Albuquerque.	1
W. R. Keefer, Laramie.	1
E. M. MacKevett, Menlo Park.	1
L. R. Page, Washington	1
P. K. Sims, Denver	1
Q. D. Singewald, Beltsville.	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver.	2
TEPCO, RPS, Washington, (including master)	2
	44

CONTENTS

ILLUSTRATION

NOTES ON THE MOENKOPI FORMATION IN THE SALT ANTICLINE REGION OF COLORADO AND UTAH

By Eugene M. Shoemaker and William L. Newman

ABSTRACT

The Moenkopi formation of Triassic age is widely exposed in the salt anticline region in southeastern Utah and southwestern Colorado. The distribution of the Moenkopi is that of a blanket of irregular thickness with several large holes worn in it, due chiefly to pre-Chinle erosion.

Four members of contrasting lithology have been mapped in the Moenkopi in the salt anticline region. In ascending order these members are: 1) the Tenderfoot member, composed dominantly of muddy or silty poorly sorted sandstone; 2) the Ali Baba member, composed of interstratified arkosic conglomeratic sandstone and fissile siltstone; 3) the Sewemup member, composed dominantly of fissile siltstone with minor beds of conglomeratic sandstone and gypsum; and 4) the Pariott member composed of interstratified sandstone and siltstone.

Part of the Tenderfoot member of the Moenkopi formation correlates with the Hoskinnini member of the Moenkopi formation of southeastern Utah, a unit which may be either Permian or Early Triassic in age or possibly both. If equivalents of the type Moenkopi of northeastern Arizona are present in the salt anticline region, they may include the upper part of the Sewemup member and part or all of the Pariott member.

The Moenkopi formation of Triassic age, a unit long recognized on the Colorado Plateau (Ward, 1901, p. 403-404; Gregory, 1917, p. 23-31; and McKee, 1954) was first delimited in the salt anticline region of southeastern Utah and southwestern Colorado (fig. 1) by Baker and others (1927, p. 796-798). It was subsequently mapped in the Utah part of the region by Baker (1933) and by Dane (1935), who extended stratigraphic observations on the Moenkopi into adjacent parts of Colorado. Dane (1935, p. 51) noted and called attention to an unusually thick section of the Moenkopi formation in Sinbad Valley, Colorado.

In 1948, mapping was begun in the vicinity of Sinbad Valley, Colo., by the senior author under a program of mapping undertaken by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. In order to determine the nature of the unusual lateral changes in thickness of the Moenkopi formation, three members were distinguished and mapped in Sinbad Valley, where the formation is composed of three major units of contrasting lithology (Shoemaker, 1955 and 1956). Subsequently the units were traced northward (by the senior author) to the vicinity of Gateway, Colo. (Cater, 1955a), southward into Paradox Valley, Colo. (Shoemaker, 1956), and westward into the areas previously mapped by Baker and Dane in Utah (Shoemaker, 1952). A fourth member was recognized in Utah. In 1952, additional field and laboratory work was undertaken in collaboration with the junior author to complete a study of the Moenkopi throughout the salt anticline region. The purpose of these notes is to set forth the salient features of the stratigraphy of the Moenkopi formation of this region and to supplement new

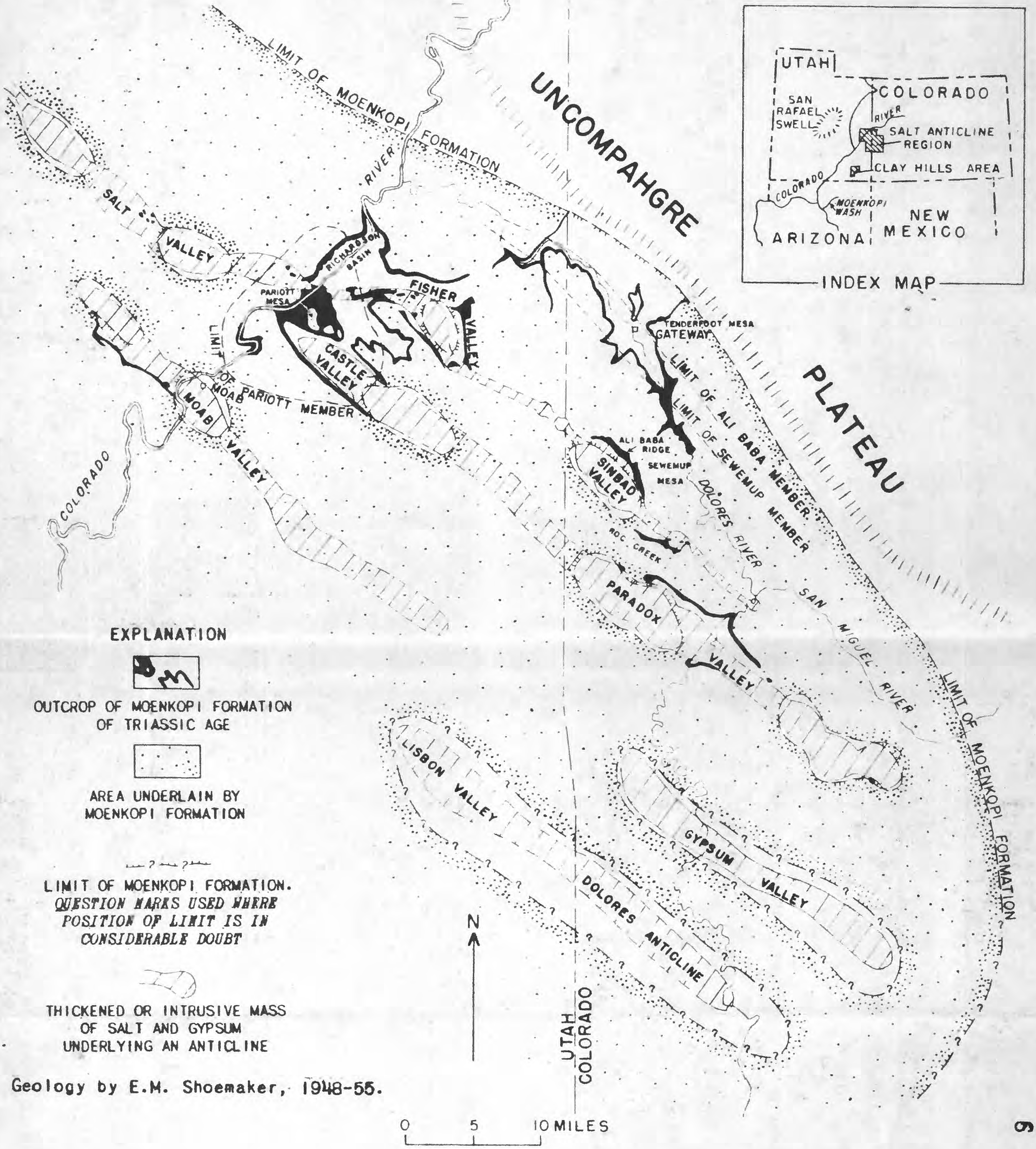

Figure 1.--SKETCH MAP SHOWING OUTCROPS OF THE MOENKOPI FORMATION IN THE SALT ANTICLINE REGION OF COLORADO AND UTAH. (Salt structure after Shoemaker, 1954, Pl. 1.)

stratigraphic observations on the Hoskinnini member of the Moenkopi formation (John H. Stewart, written communication). A more comprehensive report on the Moenkopi in the salt anticline region is in preparation by the senior author.

The salt anticline region comprises a series of northwest-trending faulted anticlines (fig. 1). From northeast to southwest the major folds are the Salt Valley-Fisher Valley-Sinbad Valley anticlinal system, the Castle Valley-Paradox Valley system, the Moab Valley system, the Gypsum Valley anticline, and the Lisbon Valley-Dolores anticlinal system (Shoemaker, 1954, p. 51-54 and Pl. 1; Cater, 1955b, p. 125 and Pl. 1). The anticlines occupy the axial or deep part of the late Paleozoic Paradox Basin (Baker, Dane, and Reeside, 1933; Borden, 1952; Wengerd and Strickland, 1954), and each major fold is underlain by a complex intrusive or thickened mass of salt, gypsum, and clastic sedimentary rocks, all derived from the Paradox member of the Hermosa formation of Pennsylvanian age (Shoemaker, 1954, p. 51-55; Cater, 1955b). Most of these intrusive masses had been almost fully formed by the beginning of Moenkopi time, though some of them continued to rise as sediments were deposited around them until Late Jurassic or possibly Early Cretaceous time (Stokes, 1948; Shoemaker, 1954; Cater, 1955b).

The salt anticline region and the Paradox Basin are bounded on the northeast by the Uncompahgre Plateau, a rejuvenated element of the ancestral Rockies. The ancestral Uncompahgre highland was a major source of clastic detritus in the formations of Pennsylvanian, Permian, and Triassic age deposited in the adjacent Paradox Basin (Dane, 1935, p. 37-39, 52 and 64; Baker, 1935, p. 1495; Shoemaker, 1954, p. 61; Cater, 1955a) and may have supplied nearly all of the clastic sediments in the Moenkopi formation in the salt anticline region.

The Moenkopi formation underlies a large part of the salt anticline region. It is exposed principally along the walls of several large valleys excavated in the crests of the salt anticlines and in deep canyons carved by the Dolores and the Colorado Rivers, the major streams draining the region (fig. 1). Toward the Uncompahgre Plateau the Moenkopi thins to a feather edge and is absent over the Plateau, where younger beds of Triassic age rest directly on Precambrian crystalline rocks. Over most of the salt anticline region basal beds of the Moenkopi lie unconformably on the Cutler formation of Permian age, but locally over the salt anticlines the Moenkopi rests with sedimentary contact directly on upthrust beds of the Paradox member of the Hermosa formation of Pennsylvanian age. The Moenkopi is everywhere overlain by the Chinle formation of Triassic age. Like the basal contact, the upper contact is an unconformity, and locally over the salt anticlines the Moenkopi is cut out entirely, principally by angular unconformity at the base of the Chinle. The distribution of the Moenkopi in the salt anticline region is that of a blanket of irregular thickness with several large holes worn in it, due chiefly to erosion prior to deposition of the Chinle (fig. 1). No Moenkopi is exposed over the Gypsum Valley or Lisbon Valley- Dolores anticlines even though rocks older than the Moenkopi formation come to the surface. The Moenkopi formation is tentatively interpreted to be present in this part of the salt anticline region but eroded away over the crests of the anticlines.

The Moenkopi formation, a part of the Permian-Triassic "red-bed" sequence of the Rocky Mountain region, is composed mainly of brown and red-brown sandstone, siltstone, and shale. One of the most distinctive features of the Moenkopi, found throughout its extent on the Colorado Plateau, is small-scale sharply defined ripple marks, which are best developed in fine-grained sandstone beds. Two principal lithologic characteristics distinguish the beds of the Moenkopi formation from the enclosing "red beds" in the salt anticline region. With the exception of some conglomeratic sandstone beds, the bedding in the Moenkopi is even and continuous, in some cases over distances of miles, whereas the bedding in the underlying Cutler and overlying Chinle formations is largely irregular and lenticular, individual beds rarely being traceable for distances of more than a few hundred feet. In addition, pale-colored mica is an ubiquitous and abundant constituent of nearly all beds in the Moenkopi; in the underlying Cutler formation mica is a fairly abundant constituent but commonly consists of both light- and dark-colored varieties; and in the overlying beds of the Chinle mica is only rarely a conspicuous constituent.

In the salt anticline region the Moenkopi formation is made up of four main lithologic units. In ascending sequence they are: 1) a basal unit composed dominantly of muddy or silty poorly sorted sandstone, 2) a unit of interstratified arkosic conglomeratic sandstone and fissile siltstone, 3) a unit composed dominantly of fissile siltstone with minor beds of conglomeratic sandstone and gypsum, and 4) an upper unit composed of interstratified sandstone and siltstone. These four units are here named, in ascending order, the Tenderfoot member, the Ali Baba member, the Sewemup member, and the Pariott member. The following type section for the three lower members was measured by E. M. Shoemaker and W. L. Newman on the east side of Sinbad Valley in sec. 15, T. 49 N., R. 19 W., Mesa County, Colo. (Shoemaker, 1955):

Section of the Moenkopi formation in Sinbad Valley,
Mesa County, Colo.

	Feet
Chinle formation:	
Conglomerate, pale-lavender, friable; consists of pebbles and granules of quartz and crystalline rocks set in a white claylike matrix.	----
Unconformity: Contact sharp but not noticeably channelled or angular	----
Moenkopi formation:	
Sewemup member:	
Shale and sandstone interbedded. Shale, chocolate-brown. Sandstone, reddish-brown to light-brown, fine-grained, ledge-forming, ripple-bedded and cross-laminated; contains pods of granules. Unit contains scattered beds of granule conglomerate 1 to 6 inches thick	38.6
Sandstone, light-brown and purplish-brown, fine-grained, forms prominent ledge; consists of alternating massive, cross-laminated layers 1 to 4 feet thick and thin and ripple-bedded, somewhat shaly layers 0.1 to 4.0 feet thick. A massive 2-foot thick bed in the middle of the unit contains lenses and pods of granule conglomerate	21.5

Moenkopi formation--Continued:
Sewemup member--Continued: Feet

Sandstone and mudstone interbedded. Sandstone, light reddish-brown, very fine- to fine-grained; beds in upper part of unit contain lenses and pods of rounded quartz and crystalline rock granules. Mudstone, dark reddish-brown. Unit consists of about equal parts of sandstone and mudstone in beds 0.1 to 0.3 foot thick. . . . 41.2

Mudstone, chocolate-brown, poorly sorted; contains thin interbeds of light reddish-brown very fine-grained sandstone. Unit breaks up into small angular chunks. . . . 57.5

Sandstone, light reddish-brown, fine-grained, ledge-forming; cross-laminated on a very small scale; calcareous cement; contains numerous thin stringers of gypsum subparallel to bedding. Mica flakes, chiefly biotite, coat bedding planes. 3.4

Shale, chocolate-brown with small irregular gray-green patches; contains interbeds of light-brown and reddish-brown, fine-grained sandstone 0.2 to 1.0 foot thick. Abundant gypsum in upper part occurs as nodules and thin stringers. 42.7

Sandstone, light-brown to light reddish-brown, fine-grained, ripple-bedded and cross-laminated on a small scale, forms indistinct ledge. Contains thin interbeds of chocolate-brown shale and scattered pods and lenses of purplish granule conglomerate. Predominant micaceous mineral is biotite. 20.1

Moenkopi formation--Continued:
Sewemup member--Continued: Feet

Shale, chocolate-brown; lamination paper thin; minor interbeds of very fine- to fine-grained brown to light-brown sandstone. Individual beds range from 0.2 to 1.5 feet in thickness. Ratio of shale to sandstone about 4:1. Some gypsum occurs as thin stringers and veinlets. Beds are locally altered to greenish-gray or gray. 89.0

Sandstone, light-gray to greenish-gray and light-brown, very fine- to fine-grained; some beds are flaggy and very argillaceous; one bed prominently cross-laminated; the rest are massive and range up to 1.5 feet thick. Grayish color due to alteration that cuts across bedding planes. Gray material is more friable than unaltered brown material. Unit forms marker that may be traced for several miles 21.8

Mudstone, chocolate-brown, micaceous 1.0

Interval covered by soil and boulder mantle. 34.6

Sandstone, light-brown, fine-grained; contains thin interbeds of chocolate-brown shale that range up to 1.0 foot thick and thin veinlets of gypsum. Unit weathers to fluffy gypsiferous soil. 18.5

Shale, chocolate-brown; contains interbeds of chocolate-brown siltstone and light-brown fine-grained sandstone. Shale beds have average thickness of about 5 feet. Sandstone layers 1 foot thick make up about one-fourth of unit. Some ripple bedding in sandstones. Gypsum moderately abundant, [illegible] 28[illegible]

Moenkopi formation--Continued:
Sewemup member--Continued — Feet

Sandstone and shale interbedded. Sandstone, light-brown, fine- to very fine-grained; forms beds 0.1 to 0.5 foot thick; sandstone makes up about 75 percent of unit. Sandstone beds are separated by 0.1 foot thick beds of chocolate-brown, micaceous, thinly laminated shale. Unit contains scattered beds that range from 0.3 to 1 foot in thickness of friable sandstone consisting of coarse angular fragments of quartz and feldspar set in a gypsum matrix. Gypsum is abundant throughout and occurs as thin stringers and dense sugary nodules; some veinlets of satin spar. Biotite and chlorite are common in both sandstone and shale. Unit weathers to a fluffy sandy soil. 77.9

Total of Sewemup member. 496.3

Ali Baba member:

Mudstone and sandstone interbedded; mudstone, chocolate-brown; sandstone, reddish-brown to purple, medium- to coarse-grained, argillaceous and poorly sorted, thinly and evenly bedded; some ripple-bedded, micaceous sandstone beds tend to form long dip slopes on which current lineation is plainly visible. Sandstone beds are closer spaced at top of unit and uppermost beds contain pods of granules and lumps of gypsum that characterize the gradational contact zone between the Ali Baba member and the overlying Sewemup member. 62.1

Moenkopi formation--Continued:
Ali Baba member--Continued:

	Feet
Sandstone, light-brown, conglomeratic, arkosic, cross-laminated, ripple marked on upper surface.	0.5
Shale and mudstone interbedded; shale, chocolate-brown; mudstone, reddish-brown, sandy. Unit poorly exposed.	5.2
Sandstone, light-brown, conglomeratic, arkosic, ledge-forming .	0.8
Shale, sandstone, and siltstone interbedded; slope-forming; shale, chocolate-brown; sandstone, reddish-brown, medium-grained, argillaceous, forms thin interbeds, ripple-bedded. Beds of coarse sandstone grading to granule conglomerate occur at base and top of unit	30.6
Sandstone, yellowish-gray to light yellowish-brown, medium- to coarse-grained. Forms beds about 1.0 foot thick. Beds somewhat conglomeratic at base; grades to fine-grained material at top.	4.8
Conglomerate, reddish-brown to purple; yellowish-gray at top; persistent ledge-former that caps hogback on east side of Sinbad Valley; very poorly sorted; material ranges in size from sand particles to pebbles 2 inches across. Pebbles consist of granitic rocks, gneiss, mica schist, quartzite, perthite, and chips of reddish-brown sandstone; unit is essentially one bed, but a vague stratification is apparent due to alinement of sandstone chips and variation in abundance of muddy matrix; locally cross-laminated.	5.4

Moenkopi formation--Continued:
Ali Baba member--Continued: Feet

Shale, chocolate-brown; contains thin reddish-brown ripple-marked siltstone beds; slope forming. Unit poorly exposed.	10.8
Conglomerate, light-brown, crossbedded; consists largely of granules.	1.4
Sandstone, reddish-brown, micaceous and argillaceous, rather evenly bedded; cross-lamination rare; sand grains range from medium to coarse, some beds weather to a warty surface.	15.5
Conglomerate, light-brown, crossbedded; bench-forming; consists largely of fairly well rounded granules of granite, quartz, and perthite	1.3
Sandstone, mudstone, and sandy shale interbedded; sandstone, reddish-brown, medium-grained; forms beds generally less than half an inch thick. Some conglomeratic sandstone at base. Unit is evenly bedded and ripple-bedded	46.6
Sandstone, reddish-brown and purplish-brown, medium-grained, very evenly bedded, ledge-forming; contains thin laminae of argillaceous sandstone. Forms overhanging slabs on weathering	9.4
Shale, reddish-brown, sandy; slope-forming; contains scattered layers of coarse-grained sandstone 0.5 to 1.0 inch thick; mud cracks and compression features at base of one sandstone layer.	21.7

Moenkopi formation--Continued:
Ali Baba member--Continued:

	Feet
Sandstone, and sandy shale interbedded, reddish-brown; sandstone, thin-bedded, medium- to coarse-grained; some is cross-laminated, ripple-bedded; unit is ledge-forming.	5.4
Shale, reddish-brown, sandy, evenly bedded and ripple-bedded; contains interbeds of medium-grained to conglomeratic sandstone up to 4 inches thick. Under surfaces of sandstone beds are marked by compression features; slope-forming.	15.8
Sandstone and shale, interbedded; sandstone conglomeratic, highly cross-laminated; beds range from 0.5 to 1.0 foot thick; unit contains thin beds of reddish-brown shale; the under surface of each sandstone bed is marked by ropy ridges due to compression and flowage of subjacent shale; lowermost bed contorted.	8.0
Mudstone, reddish-brown, sandy, micaceous, ripple-marked.	11.8
Sandstone, conglomeratic, purple, strongly cross-laminated; ledge-forming; unit consists of numerous interfingering lenses. Pebbles consist of quartz, granite, and perthite. Upper part contains scattered thin beds of red shale	26.5
Total of Ali Baba member.	283.6
Unconformity, contact fairly even but basal sandstone of Ali Baba member cuts out upper 2 to 3 feet of underlying mudstone in places	---

Moenkopi formation—Continued:
Tenderfoot member (following section is offset about 50 yards to south along unconformity):

	Feet
Mudstone and siltstone interbedded, chocolate-brown, micaceous, well-developed bedding; beds are 0.1 to 1.0 foot thick, some beds irregular to nodular shaped.	12.7
Sandstone, reddish-brown, muddy, ledge-forming; upper part contains chips of mudstone and sandstone; basal bed of unit contorted due to squeezing of underlying mudstone . .	22.1
Mudstone, chocolate-brown, sandy, rather massive, slope-forming; contains thin interbeds of sandstone at base and top; upper part of unit contorted; irregular zone of greenish-gray altered material a half foot thick occurs at top	22.6

Moenkopi formation--Continued:
Tenderfoot member--Continued: Feet

Sandstone, light brick-red, silty, very poorly sorted, nearly massive. Unit is essentially homogeneous from top to bottom and forms a smooth cliff grading off in rounded steps at top; crops out prominently for several miles on east side of Sinbad Valley. Stratification is indistinct in cliff face, but wide-spaced even bedding planes can be seen under favorable conditions of slope. Sandstone consists largely of a muddy matrix with scattered coarse-rounded grains of amber to pink stained quartz up to 2 mm across. The matrix includes a moderate proportion of feldspar and mica. Poorly defined beds and lenses of coarse grains are scattered throughout. Many beds that contain a high proportion of coarse grains show slump folds up to 1 foot in amplitude. Three poorly exposed interbeds of chocolate-brown sandy mudstone occur within 15 feet of the top of unit. 227.8

Arkose and mudstone; arkose, purple, medium-grained, soft; appears to be reworked material from Cutler formation. Mudstone, reddish-brown 3.8

Gypsum, white, massive, fine-grained, sugary; contains contorted lavender and gray streaks. 3.3

Total of Tenderfoot member 292.3

Total of Moenkopi formation. 1,072.2

Moenkopi formation--Continued:
Tenderfoot member--Continued: Feet

Unconformity, angular, major stratification planes of Cutler formation are truncated to the west at angle of 15° . . . . ----

Cutler formation:

Arkose, conglomeratic, crossbedded; pebbles and granules are chiefly granitoid rocks, fragments of quartz and perthite, and minor amounts of schist. Unit contains many thin seams and veinlets of gypsum. Arkose immediately beneath contact appears as fresh as material lower in the formation. . . . . 5.0 exposed

The following section, measured by E. M. Shoemaker and W. L. Newman on the south side of Pariott Mesa in sec. 5, T. 25 N., R. 23 E., Grand County, Utah, is the type section for the Pariott member (Baker, 1933, Pl. 1; and Dane, 1935, Pl. 1):

Section of the Moenkopi formation at Pariott Mesa, Grand County, Utah

Chinle formation: Feet

Sandstone, white, coarse-grained, tightly cemented. . . . . . . ----

Unconformity. . . . . ----

Moenkopi formation:
Pariott member:

	Feet
Mudstone, reddish-brown, sandy, massive, weathering to chips and blocks; contains interbeds of purplish-brown shaly cross-laminated and ripple-bedded sandstone particularly in lower part of unit and chocolate-brown mudstone near base. Mica flakes coat bedding planes.	81.4
Sandstone, purplish-brown to reddish-brown, medium-grained and conglomeratic, with scattered coarse quartz grains and granules; cross-laminated; ledge-forming; contains stringers of clay pellets	6.0
Siltstone and sandstone interbedded, reddish-brown, crudely bedded, slope-forming; sandstone, very fine-grained, argillaceous; contains some chocolate-brown shale	14.4
Sandstone, reddish-brown, fine-grained, silty, slope-forming; ripple-bedded, contains scattered thin limy gray zones. . .	7.4
Shale, chocolate-brown; contains thin interbeds of reddish-brown fine-grained and platy sandstone and gray limy fine-grained sandstone	9.9
Sandstone, reddish-brown, argillaceous, massive to crudely bedded; contains scattered coarse quartz grains and granules near top of unit	6.7
Shale, chocolate-brown	2.5
Sandstone, reddish-brown to purplish-brown, fine-grained, ledge-forming; contains prominent shaly partings. Channel surface at base of unit	6.6
Total Pariott member	134.9

Moenkopi formation--Continued:
Sewemup member: Feet

Sandstone and siltstone interbedded; light-brown slope-forming. Sandstone, very fine-grained and silty; some sandstone beds highly gypsiferous. Unit contains scattered thin beds of chocolate-brown mudstone and beds of sugary white gypsum 0.1 to 1 foot thick spaced from 3 to 6 feet apart. Gypsum beds become closer spaced toward top of unit. Massive and well-cemented sandstone beds and gypsum beds form thin ledges in slope .	150.4
Shale and mudstone interbedded, chocolate-brown; slope-forming; contains light-brown siltstone and very fine-grained sandstone in beds 0.5 to 3 feet thick spaced from 4 to 5 feet apart. Spacing gives subdued tread and riser character to slope. Beds of white gypsum, sugary and nodular or selenitic, ranging from less than an inch to 2 inches thick are spaced from 6 to 10 feet apart. Unit poorly exposed due to cementation of surface rubble by gypsum.	98.3
Shale, chocolate-brown.	2.0
Sandstone and siltstone interbedded, light-brown to orange-brown. Unit contains interbeds of fine-grained sandstone and chocolate-brown shale, gypsiferous	4.5
Shale, chocolate-brown.	4.5

Moenkopi formation--Continued:
Sewemup member--Continued:

	Feet
Sandstone and siltstone interbedded, light-brown to orange-brown; unit contains interbeds of fine-grained sandstone and chocolate-brown shale; gypsiferous.	4.0
Shale, chocolate-brown	2.5
Sandstone and siltstone interbedded, light-brown to orange-brown; contains interbeds of fine-grained sandstone and chocolate-brown shale; gypsiferous.	31.3
Shale, chocolate-brown	2.5
Sandstone and siltstone interbedded, light-brown to orange-brown; contains interbeds of fine-grained sandstone and chocolate-brown shale; some veinlets of gypsum. Unit is poorly exposed due to cementation of surface rubble by gypsum	79.4
Total Sewemup member	379.4

Ali Baba member:

Sandstone, light-brown to orange-brown, silty; forms indistinct ledge; bedding planes 0.5 to 1 foot thick marked by highly argillaceous sandstone layers. Unit distinctly lighter in color than underlying beds.	15.4
Sandstone and mudstone interbedded; sandstone, reddish-brown, fine- and very fine-grained and silty, ripple-bedded; mudstone, chocolate-brown, contains gypsum veinlets	5.5

Moenkopi formation--Continued:
Ali Baba member--Continued: Feet

Mudstone and sandstone interbedded; mudstone chocolate-brown; sandstone, dark reddish-brown, fine-grained; contains 0.1 foot conglomerate layers at top and base.	34.7
Sandstone and mudstone interbedded; sandstone, reddish-brown, fine- and very fine-grained; mudstone, chocolate-brown. . .	11.4
Conglomerate, red, brown and gray granules of chert and limestone	0.1
Sandstone and mudstone interbedded; sandstone, reddish-brown, fine- and very fine-grained; mudstone, chocolate-brown. . .	10.9
Conglomerate, red, brown and gray granules of chert and limestone	0.2
Sandstone and mudstone interbedded, slope-forming; sandstone, reddish-brown, fine- and very fine-grained, ripple-bedded; mudstone, chocolate-brown. Unit contains scattered gypsum veinlets.	55.1
Sandstone, reddish-brown, medium- to fine-grained; cross-lamination and ripple-bedding well developed; ledge-forming. Unit contains discontinuous mudstone and shaly sandstone partings. At the base unit grades to conglomeratic arkose which rests on a channel surface . . .	39.7
Sandstone and mudstone interbedded; sandstone, reddish-brown, fine-grained and silty; mudstone, chocolate-brown. Unit has well-developed bedding with beds ranging from 1 inch to 1 foot thick	15.5

Moenkopi formation--Continued:
Ali Baba member--Continued:

	Feet
Conglomerate, granules of chert and sandstone set in a matrix of arkose	1.0
Sandstone and mudstone interbedded; sandstone, reddish-brown, fine-grained; mudstone, chocolate-brown.	11.9
Conglomerate, granules of chert and sandstone set in a matrix of arkose	1.0
Sandstone and mudstone interbedded; sandstone, reddish-brown, fine-grained; mudstone, chocolate-brown.	9.4
Sandstone, reddish-brown, medium- to fine-grained, arkosic, ripple-bedded. Forms indistinct ledge; contains irregular discontinuous seams of chocolate-brown mudstone. Base of unit is channel surface with 0.5 foot of relief.	11.9
Total of Ali Baba member.	223.7
Unconformity.	----

Tenderfoot member:

Sandstone, light-brown, well-developed bedding with beds ranging from 1 to 8 inches thick; some beds contain granules of chert and sandstone, other beds are well sorted and ripple bedded. Unit is intensely fractured and contains abundant veinlets of gypsum about 0.25 inch thick	39.4

Moenkopi formation--Continued:
Tenderfoot member--Continued:

	Feet
Conglomerate, gray; contains angular to subrounded fragments of chert, limestone, and gypsum set in a matrix of gypsum. Size of fragments generally less than 10 mm. across	0.6
Sandstone, orange-brown to dark-brown, poorly sorted, unit contains interbeds of chocolate-brown mudstone near top	16.7
Sandstone, orange-brown to dark-brown, conglomeratic; contains scattered granules and pebbles of gray chert, sandstone, limestone, and angular fragments of sugary gypsum	5.5
Sandstone, orange-brown to dark-brown, very poorly sorted; grains range from clay size to 1.5 mm across. Coarse grains are both scattered and clustered in thin seams and pods less than 1 inch thick and several inches long; indistinctly bedded; arkosic granule conglomerate at base of unit grades upward into unsorted sandstone. Unit is highly fractured and contains abundant veinlets of gypsum. Lower part of unit poorly exposed	143.4
Gypsum, white, fine-grained, sugary; bedding planes marked by gray streaks, locally contorted	6.7

Moenkopi formation--Continued:
Tenderfoot member--Continued:

	Feet
Arkose, orange-brown, gypsiferous; resembles underlying Cutler formation in texture and composition of constituent grains but unit contains more silt in matrix; abundant seams of gypsum	7.4
Total of Tenderfoot member.	219.7
Total of Moenkopi formation	957.7
Unconformity.	----

Cutler formation:

Arkose, purple to lavender; contains fresh angular fragments of quartz, feldspar and mica, and scattered boulders and cobbles of biotite schist, granite, and granite gneiss	----

The Tenderfoot member of the Moenkopi formation is named for Tenderfoot Mesa, Colo., where it constitutes the whole of the formation on the north side of the mesa (Cater, 1955a). The Tenderfoot member overlies the Cutler formation and locally the Paradox member of the Hermosa formation with angular unconformity. Over much of the area the angular discordance is only a few degrees, or so slight as to be detectable only by tracing of individual beds in the underlying Cutler; but in some areas, notably Richardson Basin, Utah, the angular discordance is several degrees and easily discerned over distances of miles. Locally, near the margins of the salt intrusions the discordance is as much as 90°.

The beds of the Tenderfoot member may be grouped into four general units of different lithology or bedding characteristics. Commonly at the base, generally directly overlying the Cutler formation, is a sequence of beds up to 20 feet thick composed of weathered coarse arkosic detritus. This material is thought to be reworked sediment derived from the underlying Cutler formation. In some places where the deposit of reworked material from the Cutler is absent, the upper few feet of undisturbed Cutler are distinctly weathered. A bed of gypsum up to about 7 feet thick overlies the deposits of reworked Cutler at many places in the region (Dane, 1935, Pl. 9B) but is present in less than half of the outcrops of the basal beds. Locally, as in Sinbad Valley, Colo., the gypsum bed rests directly on upturned beds of the Cutler, and coarse reworked material from the Cutler overlies the gypsum.

Above the discontinuous basal units of arkose and gypsum lies a unit of brick-red or orange-brown to dark-brown poorly sorted sandy mudstone to silty sandstone, which at most localities makes up more than half of the Tenderfoot member and at the type section comprises nearly 80 percent of the member. This unit is exceptionally homogeneous in lithology, both laterally and vertically, and is characterized by the presence of scattered coarse rounded grains of quartz commonly stained a pink or amber color. It commonly crops out as a vertical or very steep smooth cliff on which bedding is only indistinctly discernible but which can be seen from a distance to be generally even, continuous, and uniformly spaced at about 1- to 5-foot intervals. Within beds a vague wavy lamination can be seen in places. Locally the bedding is contorted in peculiar slump structures described for the Hoskinnini tongue of the Moenkopi formation by John H. Stewart (written communication). This is the unit correlated by Stewart with the Hoskinnini member of the Moenkopi formation.

At most localities the massive unit is succeeded by a sequence of beds that consists primarily of material similar to that of the massive unit but is more distinctly bedded, the bedding planes being marked by partings of fissile siltstone or shale. In places the upper sequence includes thin beds of well-sorted fine-grained sandstone with well-developed ripple marks, and in a few places it also includes a bed of gypsum or gypsiferous conglomerate. The relative thicknesses of the lower massive unit and the upper unit with well-developed beds, in places, differ considerably over short distances along the outcrop, but the total thickness of the Tenderfoot member over short distances is fairly uniform. This change is considered by the authors to be due mainly to abrupt lateral transition of the upper part of the massive unit into sequences with well-developed beds, though abrupt swelling and pinching of beds are also known to occur locally.

At three localities, one in Sinbad Valley, Colo., one near Roc Creek, Colo., and one at the southeastern end of Paradox Valley, Colo., the Tenderfoot member contains coarse detritus, mainly angular fragments of limestone, derived from immediately adjacent intrusive masses of the Paradox member of the Hermosa formation.

The Tenderfoot member ranges in thickness from about 290 feet to a feather edge, and it extends farther to the northeast than the other members. In the vicinity of Gateway, Colo., it thins toward the Uncompahgre Plateau. The thinning is due to both overlap and the truncation of the top of the member by the overlying Chinle formation. The Tenderfoot is locally cut out over the salt intrusions by angular unconformity at the base of the overlying Ali Baba member in Sinbad and Paradox Valleys, Colo., and probably also in Fisher Valley, Utah.

The Ali Baba member of the Moenkopi formation is named for Ali Baba Ridge in Sinbad Valley, a hogback underlain by conglomeratic sandstone of this member. Over most of the salt anticline region the Ali Baba unconformably overlies the Tenderfoot member, and locally in Sinbad Valley, Paradox Valley, and around Fisher Valley the unconformity is sharply angular. In Paradox Valley the Ali Baba member rests in places on the Cutler formation, and in Fisher Valley the Ali Baba rests locally on the Cutler and on the Paradox member of the Hermosa formation. In Moab Valley the contact of the Ali Baba with the underlying Tenderfoot appears to be conformable.

The Ali Baba member consists mainly of red-brown to purplish ledge-forming beds of conglomeratic arkosic sandstone separated by interbedded red-brown and chocolate-brown silty shale and thin layers of fine- and coarse-grained sandstone. Thicker beds of sandstone are generally cross-laminated on a small scale, and, at the base, the sandstone fills channels cut into underlying shales. Current lineation is common on cross-lamination surfaces. The under surfaces of the thicker beds of sandstone are marked by convoluted small ridges and knobs due to compression of the underlying shales, and these features are a distinctive and diagnostic feature of the Ali Baba member. In the beds of shale, mud cracks are locally abundant; the beds of fine-grained sandstone are generally ripple bedded.

The Ali Baba member exhibits a marked facies change from northeast to southwest. Near the Uncompahgre Plateau, to the northeast, the ledge-forming beds of sandstone are highly arkosic, heavily conglomeratic, and constitute the dominant part of the member. To the southwest, the sandstones become progressively finer grained, better sorted, and less abundant. Southwest of Moab Valley the Ali Baba virtually converges in lithology with the overlying Sewemup member.

The Ali Baba member ranges in thickness from about 290 feet to a feather edge. It is cut out toward the Uncompahgre Plateau in the vicinity of Gateway, Colo., and locally over the salt anticlines by angular unconformity at the base of the Chinle formation.

The Sewemup member of the Moenkopi formation, named for Sewemup Mesa which forms the east wall of Sinbad Valley at the type section, overlies and in part intertongues with the Ali Baba member conformably. The contact is gradational and was selected for purposes of mapping at a change in color from dark-brown beds below to light-brown beds above. This color change is due mainly to an abrupt increase in amount of gypsum in the beds of the Sewemup member and generally occurs slightly above the highest prominent ledge-forming sandstone of the Ali Baba member. Over most of the salt anticline region this contact appears to be relatively continuous and serves well as a stratigraphic datum, but in the vicinity of Richardson Basin, Utah, it is locally difficult to follow. It probably cannot be traced southwest of Moab Valley.

The Sewemup member consists mainly of chocolate-brown fissile siltstone or shale with subordinate interbedded light-brown fine-grained sandstone. Gypsum is present throughout the member, mainly as an interstitial cement or as crosscutting veinlets near the base, and in discrete thin nodular beds near the top. The spacing of gypsum beds generally becomes progressively closer toward the top of the member. The relatively abundant gypsum gives rise to a fluffy soil or encrustation that mantles the slopes and gives the whole member a light-brown color when viewed from a distance. Thin beds of light-maroon coarse-grained sandstone are scattered through the member. Locally, at one place on the northwest side of Richardson Basin, the beds of sandstone become highly conglomeratic and increase in thickness and in number to the extent that the lithology of the Sewemup becomes nearly identical with that of the underlying Ali Baba member. Except for the conglomeratic sandstone, the bedding in the Sewemup member is generally very uniform and continuous; ripple marks are abundant. The Sewemup member thus exhibits prominently those features which are characteristically associated with the Moenkopi formation throughout the Colorado Plateau.

In thickness the Sewemup member ranges from a feather edge to about 500 feet. It is cut out toward the Uncompahgre Plateau, and locally over the salt anticlines and small folds peripheral to Fisher Valley by angular unconformity at the base of the overlying Chinle formation. Most of the change in thickness is due to truncation of beds at the top of the member, but some change is due to pinching out of beds within the member as well.

The uppermost unit of the Moenkopi formation in the salt anticline region, the Pariott member, is named for Pariott Mesa on the north side of Castle Valley, where the type section was measured. Outcrops that may be assigned with certainty to the Pariott member are limited to Castle Valley and Richardson Basin, and the intervening area, and to an isolated belt of outcrop along the Colorado River. It is possible that the uppermost 60 feet of beds assigned to the Sewemup member in Sinbad Valley are correlative with the basal beds of the Pariott member, but this correlation is difficult to substantiate because of the isolated nature of the outcrops resulting from erosion and truncation of the member in pre-Chinle time and from the partly isolated distribution of outcrops at the present. The uppermost beds of the Moenkopi formation in Sinbad Valley were all mapped as Sewemup member. The contact of the Pariott and the Sewemup members is generally a disconformity, but evidence is lacking to indicate whether or not the disconformity represents a significant or regional break in sedimentation.

The Pariott member consists of red-brown to purplish-brown sandstone and chocolate-brown, orange, and red mudstone, siltstone, and shale. It is more heterogeneous in lithology than any of the other members. Like the Ali Baba the Pariott is characterized by a relatively high proportion of sandstone, some of which is conglomeratic and some ledge-forming. In contrast with the alternate light- and dark-brown colors of the lower members, the Pariott exhibits a variety of colors, in some ways similar to the variegated appearance of the overlying Chinle formation. Orange and red mudstone units of the Pariott are particularly distinctive. The lithologic affinity of the Pariott to the Moenkopi formation is demonstrated, however, by the abundance of mica and the presence of well-formed ripple marks that are characteristic of other members of the formation.

From the type section on Pariott Mesa the Pariott member thickens abruptly to the west and is several hundred feet thick where it dips beneath the surface just beyond the northwest end of Castle Valley. At this locality the Pariott is overlain by a lens of mottled purplish-gray silty conglomeratic sandstone assigned by Baker (1933, p. 37-38) to the Shinarump conglomerate and by Dane (1935, p. 56) to the Chinle formation. The gray sandstone also thickens to the west and reaches a maximum exposed thickness of about 200 feet at the large bend of the Colorado River (fig. 1), about 2 miles downstream from the last Moenkopi outcrop. The unusual thicknesses of both the Pariott member and overlying gray sandstone are probably related to the same structural causes; and, if so, the thickest section of Moenkopi in the salt anticline region should be found beneath the central part of the gray sandstone lens. Here the total Moenkopi formation is probably at least 1,300 feet thick.

Away from the large bend in the Colorado River the Pariott member is truncated by an angular unconformity at the base of the Chinle formation and thins to a feather edge along the northwest wall of Richardson Basin and in the southeastern end of Castle Valley. The basal bed of the Chinle formation, lying unconformably on the Pariott and Sewemup members in Richardson Basin and Castle Valley, is a white gritty to conglomeratic, generally friable, sandstone described by Dane (1935, p. 55-56) and is commonly marked by a line of springs.

The lateral equivalent of the white grit bed also truncates the bedding of the mottled gray sandstone lens, which lies between the Pariott member and the white grit bed northwest of Castle Valley. Major bedding planes in the gray sandstone dip generally northwestward toward the apparent center of the lens and at the large bend in the Colorado River are truncated at angles greater than 10°. The inclination of the gray sandstone strata was interpreted by Baker (1933, p. 37-38) and by Dane (1935, p. 56) to be mainly an initial feature of the sediment, and the bedding to be foreset bedding. Foreset or cross-stratification can be seen within major bedding units, but the major bedding planes are interpreted by the present writers to have been initially horizontal, and the truncation of the beds to be a true angular unconformity as originally believed by Cross (1907, p. 654-655 and fig. 8).

No unconformity has been found between the Pariott member and the overlying gray sandstone lens where the contact is exposed northwest of Castle Valley and along the large bend of the Colorado River, but the areal extent of the contact is so limited that a significant unconformity is difficult to detect or demonstrate. Downstream from the large bend of the Colorado River the exact position of the top of the Pariott member is, in fact, difficult to place.

The thickness of the Moenkopi formation as a unit at any one locality is related to the position of the section with respect to the salt anticlines and, in particular, with respect to the major intrusive salt units in the cores of the anticlines (Shoemaker, 1951; 1954, p. 51-55). The thickest known sections of the Moenkopi are peripheral to major intrusive masses of the Paradox member of the Hermosa formation, and the Moenkopi is locally completely cut out over the adjacent intrusions. As the intrusions rose, the peripheral areas subsided, probably because of the withdrawal of plastic evaporites in the Paradox member, to form synclines partly encircling the intrusions similar to the ring synclines obtained in model experiments by Nettleton (1934, p. 1189). The unusual thickness of the Moenkopi formation northwest of Castle Valley at the large bend in the Colorado River, may be related to withdrawal of underlying plastic evaporites into both the Castle Valley and adjacent Salt Valley intrusive masses. The local development, at the bend of the Colorado River, of the lens of mottled gray sandstone, which may be as much as 600 or 800 feet thick in its central part, can probably be attributed to the same mechanics. Movement of the salt masses took place both during deposition of the Moenkopi and in post-Moenkopi-pre-Chinle time, as shown by the presence of an angular unconformity within the Moenkopi formation, by sympathetic internal thickening and thinning of the members of the Moenkopi, and by truncation of the members at the unconformity at the base of the Chinle formation.

The age of the Moenkopi formation in the salt anticline region is known only from rather indirect evidence. Fossils collected by G. A. Williams in company with the senior author from isolated outcrops of the Moenkopi in Salt Valley were identified by J. B. Reeside, Jr., of the U. S. Geological Survey as follows:

> "The specimen from the Salt Valley anticline in T. 22, 23 N., R. 19, 20 E., Grand County, Utah (USGS Mesoz. loc. 23869) contains an abundance of juvenile ammonites and gastropods. The ammonites appear to me to be Meekoceras, though too small for certain determination. This combination is widespread in the Sinbad member of the Moenkopi formation and not known at any other level in the region. I would place it with great confidence in the Lower Triassic."

The locality is evidently the same, and the material similar to that collected by McKnight (Dane, 1935, p. 43). At the locality from which the material was collected the Moenkopi underlies low rounded hills in the center of Salt Valley where the exposures are, unfortunately, poor. In addition the formation is badly broken by faults, and nearly all the beds are altered to a light yellowish-brown color. Here the Moenkopi probably rests directly on the Paradox member of the Hermosa formation. The exact position of the fossiliferous zone in the Moenkopi formation cannot be determined, but all beds exposed at the locality can be assigned with fair certainty to the Sewemup member. If the fossiliferous zone is at about the same stratigraphic position in the Moenkopi as a fossiliferous limestone described by McKnight (1940, p. 55) farther to the west, the fossils probably came from near the base of the Sewemup member.

The fossiliferous limestone described by McKnight is generally considered (Baker and others, 1927, p. 797; McKnight, 1940, p. 58; Dane, 1935, p. 43; Baker, 1946, p. 55) the equivalent of the Meekoceras-bearing Sinbad limestone member of the Moenkopi formation described by Gilluly and Reeside (1928, p. 65) (Gilluly, 1929, p. 83-87), in the San Rafael Swell, Utah. If the suggested position of the fossiliferous horizon in the Sewemup member is correct, and if this horizon correlates with the Sinbad limestone member of the San Rafael Swell, then the Sewemup member probably correlates in a general way with the upper member of the Moenkopi in the San Rafael Swell, and the Ali Baba member probably correlates approximately with the lower member of the Moenkopi in the San Rafael Swell. All of the Tenderfoot and Ali Baba members and at least the lower part of the Sewemup member are evidently older than the Moenkopi formation at the type section in Moenkopi Wash, Ariz., if the type Moenkopi correlates with beds overlying the Tirolites-bearing Virgin limestone (Reeside and Bassler, 1922, p. 59-61; McKee, 1954, p. 11; Poborski, 1954) member as indicated by McKee (1954, p. 20-24).

Part of the Tenderfoot member of the Moenkopi formation has been correlated by John H. Stewart (written communication) with the Hoskinnini member, formerly considered a tongue of the Cutler formation and therefore assigned to the Permian (Baker, 1936, p. 38-40). No fossils have been found in either the Hoskinnini or Tenderfoot, however, and the age of these units must be considered unknown. In the Clay Hills area, San Juan County, Utah, the Hoskinnini conformably overlies the Organ Rock tongue of the Cutler formation according to Thomas E. Mullens (written communication). The Organ Rock has been dated on the basis of plant and vertebrate remains as Permian (Baker, 1936, p. 35). Over most of its extent in Utah, on the other hand, the Hoskinnini is conformable with the overlying beds of the Moenkopi according to John H. Stewart (written communication). At the present time it must be admitted that part or all of the Hoskinnini and the Tenderfoot could be either Permian or Triassic. It seems likely that these units lie very close to or perhaps even straddle the Permian-Triassic systemic boundary.

If any of the beds in the Moenkopi in the salt anticline region are time equivalents of type Moenkopi they are probably in the Pariott or upper part of the Sewemup member. The evidence of the vertebrate faunal assemblage obtained from members of the Moenkopi traceable to the type section in Arizona (Welles, 1947, p. 285-286) and the recent additions to the known marine fauna of the Moenkopi in southwestern Utah (Poborski, 1954, p. 993) together with the regional correlations made by McKee (1954, p. 10-11 and 20-24) indicate the type Moenkopi is of late Early Triassic and possibly of Middle Triassic age. It is possible that part of the Pariott member could also be as young as Middle Triassic. Indeed, there is no clear-cut evidence that deposition was not continuous from the Pariott member to the local mottled-gray sandstone which forms the thick lens northwest of Castle Valley.

The age of the local gray sandstone lens must be considered indefinite for the present. This sandstone is not correlative with the type Shinarump of the Shinarump Cliffs of southern Utah as shown by the regional stratigraphic investigations of Stewart (1957). It may not be inappropriate to consider the gray sandstone a basal unit of the Chinle formation, following the usage of Dane (1935), if it is borne in mind that the gray sandstone is not necessarily of Late Triassic age, as all strata of the Chinle have heretofore been assigned (Gregory, 1917, p. 46-47; Baker, 1933, p. 46; Camp, 1930, p. 4-6) by most authors. The gray sandstone in the lens northwest of Castle Valley is probably related in a general way to similar mottled-gray sediments that occur as thin lenses or as relatively continuous thin units between the top of the Moenkopi formation and the base of the Chinle formation at widely scattered localities in southeastern Utah and northern Arizona (Warren I. Finch, Edward S. Davidson, Raymond C. Robeck, and John H. Stewart, written communications). These deposits may represent local accumulations of weathered and reworked detritus from the Moenkopi formed during a general period of erosion that intervened between the end of deposition of the Moenkopi and the beginning of deposition of the Chinle. The thick sequence of mottled gray beds in the unusual structural setting northwest of Castle Valley may be a sedimentary record of a mid-Triassic time interval represented at most places on the Colorado Plateau by a regional unconformity between the Moenkopi and Chinle formations.

LITERATURE CITED

Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841, 95 p.

__________1935, Geologic structure of southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 1472-1507.

__________1936, Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U. S. Geol. Survey Bull. 865, 106 p.

__________1946, Geology of the Green River-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U. S. Geol. Survey Bull. 951, 122 p.

Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., Jr., 1927, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., v. 11, p. 785-808.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1933, Paradox formation of eastern Utah and western Colorado: Am. Assoc. Petroleum Geologists Bull., v. 17, p. 963-980.

Borden, J. L., 1952, Paradox member of the Hermosa formation, in Four Corners Geol. Soc., Geological symposium of the Four Corners Region, p. 27-35.

Camp, C. L., 1930, A study of the phytosaurs with description of new material from western North America: California Univ. Mem., v. 10, 174 p.

Cater, F. W., Jr., 1955a, Geology of the Gateway quadrangle, Colorado: U. S. Geol. Survey Geol. Map GQ 55.

Cater, F. W., Jr., 1955b, The salt anticlines of southwestern Colorado and southeastern Utah, <u>in</u> Geology of parts of Paradox, Black Mesa and San Juan Basins: Four Corners Geol. Soc. Guidebook, Field Conference 1955, p. 125-131.

Cross, C. W., 1907, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, v. 15, p. 634-679.

Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geol. Survey Bull. 863, 184 p.

Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806-C, p. 69-130.

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150-D, p. 61-110.

Gregory, H. E., 1917, Geology of the Navajo country, a reconnaissance of parts of Arizona, New Mexico, and Utah: U. S. Geol. Survey Prof. Paper 93, 161 p.

McKee, E. D., 1954, Stratigraphy and history of the Moenkopi formation of Triassic age: Geol. Soc. America Mem. 61, 133 p.

McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 908, 147 p.

Nettleton, L. L., 1934, Fluid mechanics of salt domes: Am. Assoc. Petroleum Geologists Bull., v. 18, p. 1175-1204.

Poborski, S. J., 1954, Virgin formation (Triassic) of the St. George, Utah area: Geol. Soc. America Bull., v. 65, p. 971-1006.

Reeside, J. B., Jr., and Bassler, Harvey, 1922, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129-D, p. 53-77.

Shoemaker, E. M., 1951, Internal structure of the Sinbad Valley-Fisher Valley salt anticline, Colorado and Utah [abs.]: Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1478.

__________1952, Preliminary geologic map of part of the Sinbad Valley-Fisher Valley anticline, Colorado and Utah: U. S. Geol. Survey open file.

__________1954, Structural features of southeastern Utah and adjacent parts of Colorado, New Mexico, and Arizona, _in_ Uranium deposits and general geology of southeastern Utah: Utah Geol. Soc. Guidebook no. 9, p. 48-69.

__________1955, Geology of the Juanita Arch quadrangle, Colorado: U. S. Geol. Survey Geol. Map GQ 81.

__________1956, Geology of the Roc Creek quadrangle, Colorado: U. S. Geol. Survey Geol. Map GQ 83.

Stewart, J. H., 1957, Proposed nomenclature of part of upper Triassic strata in southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 441-465.

Stokes, W. L., 1948, Geology of the Utah-Colorado salt dome region with emphasis on Gypsum Valley, Colorado: Utah Geol. Soc. Guidebook, no. 3, 50 p.

Ward, L. F., 1901, Geology of the Little Colorado Valley: Am. Jour. Sci., 4th ser., v. 12, p. 401-413.

Welles, S. P., 1947, Vertebrates from the upper Moenkopi formation of northern Arizona: California Univ. Dept. Geol. Sci. Bull., v. 27, p. 241-294.

Wengerd, S. A., and Strickland, J. W., 1954, Pennsylvanian stratigraphy of Paradox salt basin, Four Corners Region, Colorado and Utah: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2157-2199.