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STRATIGRAPHY OF TRIASSIC AND ASSOCIATED FORMATIONS IN PART OF THE COLORADO PLATEAU REGION*

By

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SEDIMENTARY PETROLOGY by Robert A. Cadigan

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By John H. Stewart, George A. Williams, Howard F. Albee, and Omer B. Raup

With a section on

Sedimentary petrology

By Robert A. Cadigan

ABSTRACT

Stratigraphic studies of the Triassic and associated formations have been made in southeastern Utah and adjoining parts of Colorado and Arizona. These studies have followed five principal lines of investigation: regional stratigraphy, sedimentary petrology, pebble studies, sedimentary structure studies, and lithofacies studies.

The formations studied are the Cutler formation, Coconino sandstone, and Kaibab limestone of Permian age; the Moenkopi formation, Chinle formation, and Wingate sandstone of Triassic age; the Kayenta formation of Jurassic(?) age; and the Navajo sandstone of Jurassic and Jurassic(?) age.

The Cutler formation grades from a conglomeratic facies in southwestern Colorado to a unit containing alternating reddish siltstone tongues and light-colored sandstone members in southeastern Utah. The reddish siltstone units comprise the Halgaito, Organ Rock, and Hoskinnini tongues. These alternate with the light-colored sandstone members, the Cedar Mesa, White Rim, and DeChelly.

The conglomeratic facies of the Cutler is classified as an arkose that was deposited by streams flowing westward from a rising granitic area in southwestern Colorado. The reddish siltstones were deposited by quiet waters in basins of accumulation on a slowly sinking continental margin and were also derived from a source area in southwestern Colorado. The Organ Rock tongue is part graywacke and part arkose, whereas the Hoskinnini tongue is an arkose. The light-colored sandstones were deposited by winds blowing to the southeast and probably were derived from a source area to the northwest. The Cedar Mesa sandstone member is a feldspathic orthoquartzite and the DeChelly sandstone member is a tuffaceous feldspathic orthoquartzite.

The Coconino sandstone and Kaibab limestone crop out in the western part of southeastern Utah. The Coconino is laterally equivalent to part of the Cutler formation and is an eolian deposit formed by southeastward blowing winds. The Kaibab is a marine deposit.

The Moenkopi formation of Triassic age consists of reddish horizontally and ripple-laminated siltstone that is classified as arkose and some moderately sorted cross-stratified sandstone that is classified as feldspathic orthoquartzite. The Sinbad limestone member crops out in central and south-central Utah and overlaps to the south the underlying part of the Moenkopi. The Moenkopi is 900 feet thick in the Capitol Reef area and thins to a depositional wedge-edge along the Utah-Colorado boundary.

The Moenkopi formation in southeastern Utah is predominantly a tidal-flat deposit containing some stream-deposited material. The streams flowed to the west from a highland in southwestern Colorado. The Sinbad limestone is a marine deposit. The sea of Moenkopi time transgressed from the northwest and west across Utah.

The Chinle formation in southeastern Utah and in Monument Valley, Arizona, is divided into seven members, which are, in ascending order, the Temple Mountain, Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock members.

The Temple Mountain member is composed of mottled purple and white siltstone and claystone and minor amounts of light-colored sandstone and conglomerate. It averages about 20 feet in thickness and is restricted to the San Rafael Swell area, central Utah.

The Shinarump member is a fine- to coarse-grained poorly to moderately sorted sandstone which contains conglomeratic lenses composed dominantly of siliceous pebbles. The Shinarump is a feldspathic orthoquartzite with regional and local variations ranging from tuffaceous feldspathic orthoquartzite to an arkose. It ranges in thickness from a wedge-edge to about 250 feet.

The Monitor Butte member consists of greenish bentonitic claystone and interstratified grayish very fine-grained poorly sorted sandstone and ranges in thickness from a wedge-edge to 250 feet. The sandstone in the Monitor Butte member is a feldspathic orthoquartzite with local and regional variations that range from tuffaceous feldspathic orthoquartzite to arkose.

The Moss Back member is composed of grayish very fine- to medium-grained poorly sorted sandstone and averages about 60 feet in thickness. The Moss Back ranges in composition from an orthoquartzite to an arkose and contains some graywacke.

The Petrified Forest member consists of variegated bentonitic claystone and poorly sorted clayey sandstone and ranges in thickness from a wedge-edge to 700 feet. The sandstone in the Petrified Forest member is orthoquartzite tuff.

The Owl Rock member is composed of reddish siltstone and moderately sorted limy sandstone interstratified with thin limestone beds and ranges in thickness from a wedge-edge to 450 feet. The detrital units in the Owl Rock are tuffaceous arkoses.

The Church Rock member consists of reddish siltstone and minor moderately sorted reddish sandstone and ranges in thickness from a wedge-edge to 350 feet. The Church Rock member has two compositional classifications: the sandstones are arkose and the siltstones are graywacke.

The Chinle formation is a continental deposit formed under alluvial plain and lake or lagoonal environments. The Shinarump, Monitor Butte, Moss Back, and Petrified Forest members contain much volcanic debris. Cross-stratification studies indicate that the Chinle sandstones of southeastern Utah were derived from a source to the south and southeast.

The Glen Canyon group in southeastern Utah consists of the Wingate sandstone, Kayenta formation, and Navajo sandstone. Preliminary studies indicate that the sedimentary structures dip in a southeasterly to a southwesterly direction in this area. The Wingate sandstone is a moderately to well-sorted very fine grained sandstone that ranges in composition from a tuffaceous arkose to a feldspathic orthoquartzite. The Kayenta formation is a well-sorted very fine to medium grained sandstone and is a feldspathic orthoquartzite or an arkose, depending on the amount of kaolin present. The Navajo is a well-sorted very fine to medium grained sandstone that is a feldspathic orthoquartzite.

Most of the uranium deposits in the Triassic rocks are in the Shinarump, Monitor Butte, and Moss Back members of the Chinle, and in the base of undifferentiated Chinle. The deposits are generally near the base of the Chinle regardless of the unit that lies in that position. The deposits lie in broad northwest-trending belts near the northern limit of the respective units.

Many determinations have been made of the type of clays in the sandstones in the Triassic and associated formations. Evidence supports the hypothesis that much of the hydromica in the Chinle is the result of alteration of montmorillonite in the presence of soluble potassium salts.

Results of a thin-section study of the composition of ore-bearing sandstone and barren sandstone in the Shinarump and Moss Back members of the Chinle formation suggest that uranium ore occurs predominantly in sandstone that contains 20 percent or more kaolin. Strata containing 15 to 35 percent kaolin are more favorable for the occurrence of uranium than strata containing less than 15 percent kaolin.

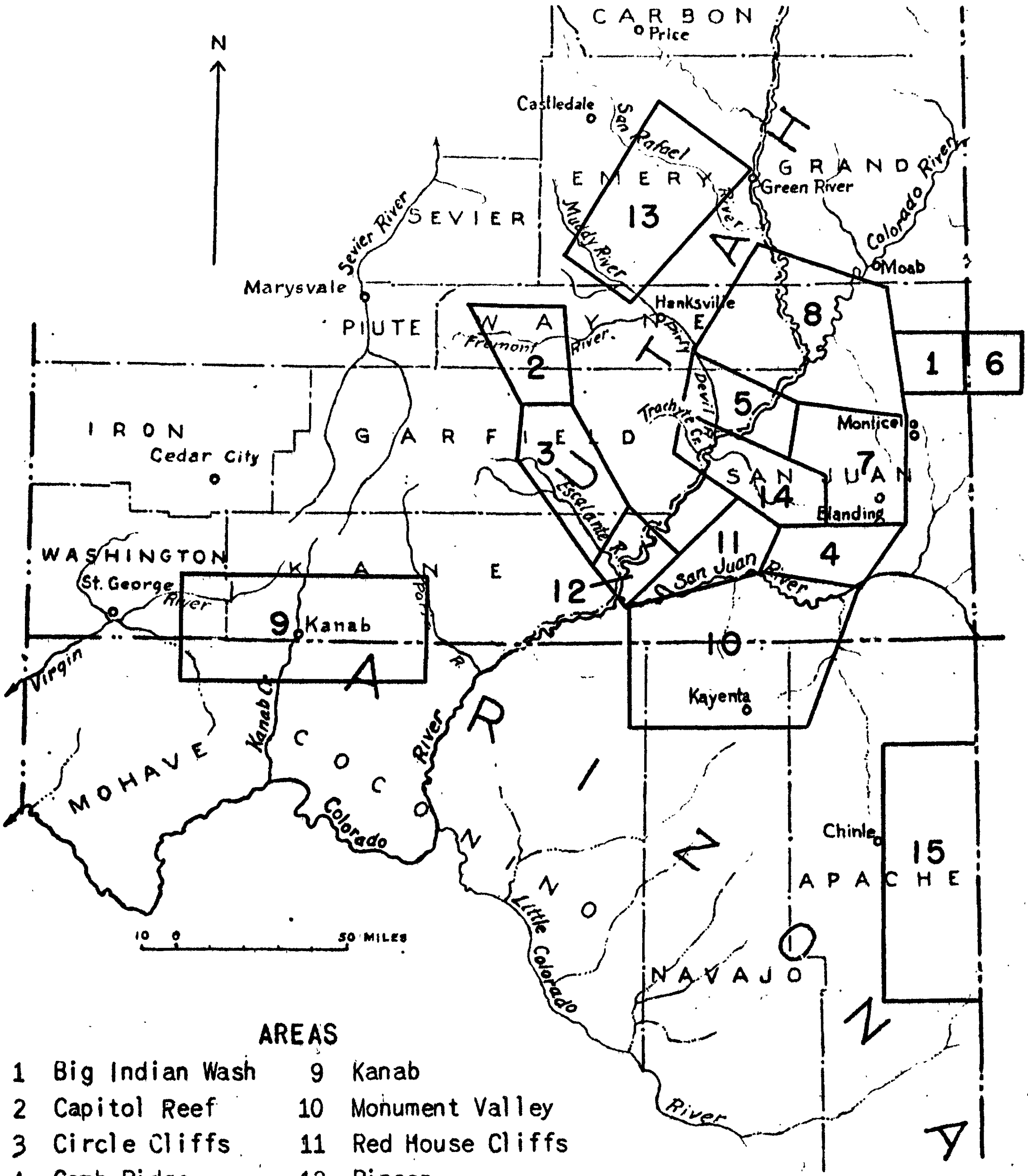
INTRODUCTION

Stratigraphic studies of the ore-bearing Chinle formation and associated formations of the Colorado Plateau region are being made to obtain information regarding their areal distribution, local and regional differences in lithology, sources and character of constituents, and conditions of deposition. Because of the regional variations in lithology, it has been necessary to study numerous sections to analyze the stratigraphic relation of the Chinle formation to associated formations. This report is based on work done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Field work was essentially completed in the northern part of the Monument Valley area (fig. 1) in 1951; in the Circle Cliffs, Capitol Reef, White Canyon, and Red House Cliffs areas in 1952; and in the Comb Ridge, Dirty Devil River, San Rafael Swell, Elk Ridge. and junction of the Green and Colorado River areas in 1953. Preliminary work has been done in the Big Indian Wash, Egnar, and Kanab areas. Although compilation and evaluation of field data collected in these areas is essentially finished, results of laboratory studies are preliminary.

The rock units studied are: the Cutler formation, Kaibab limestone, and Coconino sandstone of Permian age; the Moenkopi formation, Chinle formations, and Wingate sandstone of Triassic age; the Kayenta formation of Jurassic(?) age; and the Navajo sandstone of Jurassic and Jurassic(?) age. The rocks studied represent as much as 7,000 feet of strata (fig. 2).

The report summarizes the stratigraphy of the Triassic formations and associated units in southeastern Utah and adjoining parts of Arizona and Colorado, as well as the stratigraphy of the Chinle formation in the Kanab



AREAS

1	Big Indian Wash	9	Kanab
2	Capitol Reef	10	Monument Valley
3	Circle Cliffs	11	Red House Cliffs
4	Comb Ridge	12	Rincon
5	Dirty Devil River	13	San Rafael Swell
6	Egnar	14	White Canyon
7	Elk Ridge	15	Defiance uplift
8	Junction of the Green and Colorado Rivers		

Figure 1.--INDEX MAP OF PART OF THE COLORADO PLATEAU SHOWING AREAS OF STRATIGRAPHIC STUDIES.

area. Correlations are not made beyond the areas in which work has been done and the paleontology of the units is not discussed in detail.

Scope

Five principal lines of investigation are followed: regional stratigraphy, sedimentary petrology, pebble studies, sedimentary structure studies, and lithofacies studies.

Regional stratigraphy is designed to establish a background in the interpretation of the stratigraphic sequences. Regional correlation of stratigraphic units is based on physical continuity and primary and secondary lithologic characteristics.

Sedimentary petrology studies are designed to determine regional differences in composition and texture of the formations by means of statistical analyses of grain-size distributions, heavy mineral studies, and thin-section studies.

Pebble studies are designed to determine the regional and stratigraphic differences of pebble suites found in conglomeratic units. Composition, average and maximum size, color, roundness, and sphericity are studied. Fossiliferous pebbles in addition to lithologic characteristics are studied as an aid to identify possible source beds.

Sedimentary structure studies are designed to determine direction of movement of the depositing agent by detailed studies of the orientation of cross-stratification, ripple marks, and current lineation. These studies lead to interpretations of regional drainage patterns, of possible source areas, and of the validity of some stratigraphic correlations.

The lithofacies study of the lower part of the Chinle formation has two general objectives; to determine regional variations of lithology and thickness, and to compare parts containing uranium deposits with barren parts.

<u>Terminology and methods used in the classification of sedimentary rocks</u>

Two methods of sedimentary rock classification are used: 1) a field textural classification and 2) a laboratory petrographic classification.

In the field, classification is based on the estimated average grain size of the detrital components of a rock. The Wentworth (1922) size classification is used (table 1) in conjunction with the rock names given in table 2.

The petrographic classification is discussed in the sedimentary petrology section of this report.

The methods of determining average grain size in the field and in the laboratory often produce different results. Field grain-size determinations are visual and the average grain size is the grain size which is most abundant--the modal grain size. Laboratory grain-size determinations are made with the aid of graduated sieves and pipette, and the computed mean-grain diameter is used as the average grain size. In most detrital sediments, the modal-grain size is coarser than the mean-grain size. The difference may be 1 or 2 Wentworth grade sizes in a poorly sorted sedimentary rock less than half a grade size in a well-sorted sedimentary rock. Thus, average grain sizes based on field observations are generally coarser than those based on laboratory determinations.

Table 1.--Size classification (after Wentworth 1922).

Rock type	Variety	Grade limit (diameter in mm.)
Conglomerate	Gravel	
	Boulder	Above 256
	Cobble	256 - 64
	Pebble	64 - 4
	Granule	4 - 2
Sandstone	Sand	
	Very coarse	2 - 1
	Coarse	1 - 1/2
	Medium	1/2 - 1/4
	Fine	1/4 - 1/8
	Very fine	1/8 - 1/16
Siltstone	Silt	1/16 - 1/256
Claystone	Clay	Below 1/256

Table 2.--Field classification of detrital sedimentary rocks.

The fragments in a detrital sedimentary rock are divided into four consitiuents for the purpose of a field classification--clay, silt, sand, and gravel.

The constituent with the largest percentage is the major constituent and the constituents with smaller percentages are minor constituents.

Case I. No minor constituent greater than 20 percent.

Classification: Named after major constituent.

Example: 85 percent sand, 10 percent silt, and 5 percent clay.

Designation: Sandstone.

Case II. One minor constituent greater than 20 percent.

Classification: Modification of major constituent name.

Example: 75 percent silt, 25 percent sand.

Designation: Sandy siltstone.

Case III. Two or more constituents greater than 20 percent.

Classification: Double modification of major constituent with second largest minor constituent as first modifer and largest minor constituent as second modifier.

Example: 40 percent gravel, 35 percent sand, 25 percent silt.

Designation: Silty sandy conglomerate.

Case IV. Gravel comprises 10 to 20 percent.

Classification: Modification of major and minor constituent name with modifier granuly, pebbly, cobbly, or bouldery. The modifier is the largest class size in the gravel and precedes all other modifiers.

Example: 75 percent sand, 9 percent pebbles, 6 percent granules, 10 percent silt.

Designation: Pebbly sandstone.

Terminology and methods used in sedimentary structure studies

The methods used in sedimentary structure studies are slightly modified from those developed by Reiche (1938). Descriptive terms are those recommended by McKee and Weir (1953).

The amount and direction of dip is measured on a number of individual cross-strata in the unit being studied. The number of measurements that are necessary for adequate sampling depends on the diversity in dip directions of the cross-stratification. The results of many field tests show that 150 measurements are adequate in sediments such as the Shinarump conglomerate which contains medium-scale cross-stratification. Fifty measurements are sufficient in sediments such as the Navajo sandstone which contains large-scale cross-stratification. Only one measurement is made in a single set of cross-strata.

A basic assumption in the study of the orientation of cross-stratification is that a component of the dip direction of the cross-strata is in the down-current direction. If each dip direction reading is considered a vector, a resultant of the readings can be obtained by mathematical or graphical methods. This resultant is the average down-current direction from which a transportation direction and a source direction can be inferred.

The spread of the readings in a study is measured in terms of a consistency ratio which is expressed numerically from 0.00 to 1.00. In a study in which all the readings are in the same direction the consistency ratio would be 1.00, whereas in a study in which the readings are equally distributed through 360°, the consistency ratio would be zero. A consistency ratio below 0.20 indicates little if any tendency toward dominant trend.

STRATIGRAPHY

Permian rocks

The Permian rocks in southeastern Utah consist of the Coconino sandstone, Kaibab limestone, and Cutler formation. The Rico formation is considered to be of Pennsylvanian and Permian(?) age and is not described here. The Coconino sandstone, Kaibab limestone, and Cutler formation are all closely related and are marked by abrupt and prominent facies changes. The interrelation of these formations and of members within the Cutler are too complex to describe in detail here and an outline of only the major stratigraphic features of the Permian rocks is presented.

In southeastern Utah, the Coconino sandstone of Permian age (named by Darton, 1910, p. 21, 27) is exposed in the Capitol Reef and San Rafael Swell areas. It overlies the Hermosa limestone of Pennsylvanian age and underlies the Kaibab limestone of Permian age. Most, if not all, of the Coconino is equivalent to the Cutler formation in the areas to the south and east of the Capital Reef and San Rafael Swell areas. In southeastern Utah, the practice of geologists has been to use the term Cutler in areas where the Permian sequence contains reddish siltstone members and to use the term Coconino in areas where these reddish siltstone members are absent. A recent drill hole in the Circle Cliffs area shows the presence of a thick reddish siltstone unit in the Permian sequence (Steed, 1954) that has led to a reassignment to the Cutler of rocks formerly assigned to the Coconino sandstone by Gregory and Moore (1931).

McKee (1954a) has suggested that the Coconino of the type area of northern Arizona may not be physically continuous with the Coconino sandstone of southeastern Utah. Possibly further work might show that the term Coconino is not appropriate in southeastern Utah.

The Coconino sandstone is a yellowish-gray, fine-grained well-sorted sandstone composed of rounded clear quartz and rare black accessory minerals. It is composed of thick to very thick trough sets of medium- to large-scale cross-strata. The Coconino attains a thickness of 685 feet in the San Rafael Swell area (Baker, 1946, p. 49) and at least 550 feet is exposed in the Capital Reef area. The Coconino is interpreted to be an eolian deposit. The cross-strata in the Coconino dip dominantly to the southeast indicating that the winds that deposited the Coconino blew southeast.

In southeastern Utah, the Kaibab limestone of Permian age (named by Darton (1910, p. 21, 28, 32) crops out in the San Rafael Swell, Capitol Reef, and Circle Cliffs areas. Between these areas and outcrops of Permian rocks along the Colorado River to the east the Kaibab either pinches out or grades laterally into the White Rim sanstone member. The Kaibab overlies the Coconino sandstone of Permian age in the San Rafael Swell and the Capitol Reef areas and the Cutler formation of Permian age in the Circle Cliffs area. It underlies the Moenkopi formation of Early and Middle(?) Triassic age.

The Kaibab is composed of yellowish-gray and light greenish-gray thin to thick horizontally bedded limestone and dolomite. Abundant gray and brown chert occurs as beds and nodules in the limestone and dolomite. Thick sets of yellowish-gray fine-grained cross-stratified sandstone are interstratified with the limestone in some places. The Kaibab ranges in thickness from a wedge-edge to 360 feet. Invertebrate fossils such as brachiopods, pelecypods, and gastropods are common. Based on fossil evidence, the Kaibab limestone is interpreted to be a marine deposit.

The Cutler formation of Permian age (named by Cross and Howe, 1905, p. 5) extends over all of west-central and southwestern Colorado, east-central and southeastern Utah, and in the Monument Valley area, Arizona. It is absent in the San Rafael Swell and Capitol Reef areas, but the Coconino sandstone of Permian age in these areas is probably equivalent to part or all of the Cutler. The Cutler is underlain by the Rico formation of Pennsylvanian and Permian(?) age and is overlain by the Moenkopi formation of Early and Middle(?) Triassic age or by the Chinle formation of Late Triassic age in extreme east-central Utah.

The Cutler formation in southwestern Colorado and east-central Utah is composed of grayish-red and pale reddish-brown arkosic sandstone, conglomeratic sandstone, and minor quantities of sandy siltstone and will be referred to as the conglomeratic facies of the Cutler. The sandstone is very fine to coarse-grained and locally includes conglomeratic sandstone lenses containing granitic pebbles. The sandstone is cross-stratified but may contain horizontal laminae and thin beds. The sandy siltstone units commonly contain minor amounts of very fine grained sand and are composed of horizontal laminae to thin beds.

The conglomeratic facies of the Cutler extends throughout southwestern Colorado and into east-central Utah. In southeastern Utah and in Monument Valley, Arizona, the Cutler is composed of alternating reddish siltstone tongues and light-colored sandstone members. The units are in ascending order: Halgaito tongue, Cedar Mesa sandstone member, Organ Rock tongue, White Rim sandstone member, DeChelly sandstone member, and Hoskinnini tongue. Not all these units are found in the same area.

The Organ Rock tongue and possibly the Halgaito tongue, both reddih siltstone members, are finer grained westward-extending tongues of the conglomeratic facies of the Cutler. The Hoskinnini tongue, also a reddish siltstone member, has recently been found to be present in a large part of southeastern Utah and west-central Colorado (Stewart, and others, 1954) and is not a tongue of the conglomeratic facies of the Cutler. The Cedar Mesa sandstone and White Rim sandstone members are lithologically similar to the Coconino sandstone and are probably tongues of the Coconino extending to the east and south of the San Rafael Swell and Capitol Reef areas, where the Cocinino is exposed. The Cedar Mesa and White Rim grade to the east across southeastern Utah into the reddish siltstone members and eventually pinch out to the east in the conglomeratic facies of the Cutler. The DeChelly sandstone is also lithologically similar to the Coconino sandstone and may be equivalent to the White Rim sandstone.

The Halgaito, Organ Rock, and Hoskinnini tongues are composed mainly of pale reddish-brown horizontally laminated and bedded sandy siltstone and siltstone. The Cedar Mesa, White Rim, and DeChelly sandstone members are composed of very pale-orange and yellowish-gray very fine to fine-grained sandstone which is cross-stratified on a large scale.

More detailed descriptions of the lithology, distribution, and interrelations of the members of the Cutler are given by Baker and Reeside (1929), Baker (1933, 1936, and 1946) and Hunt and others (1953).

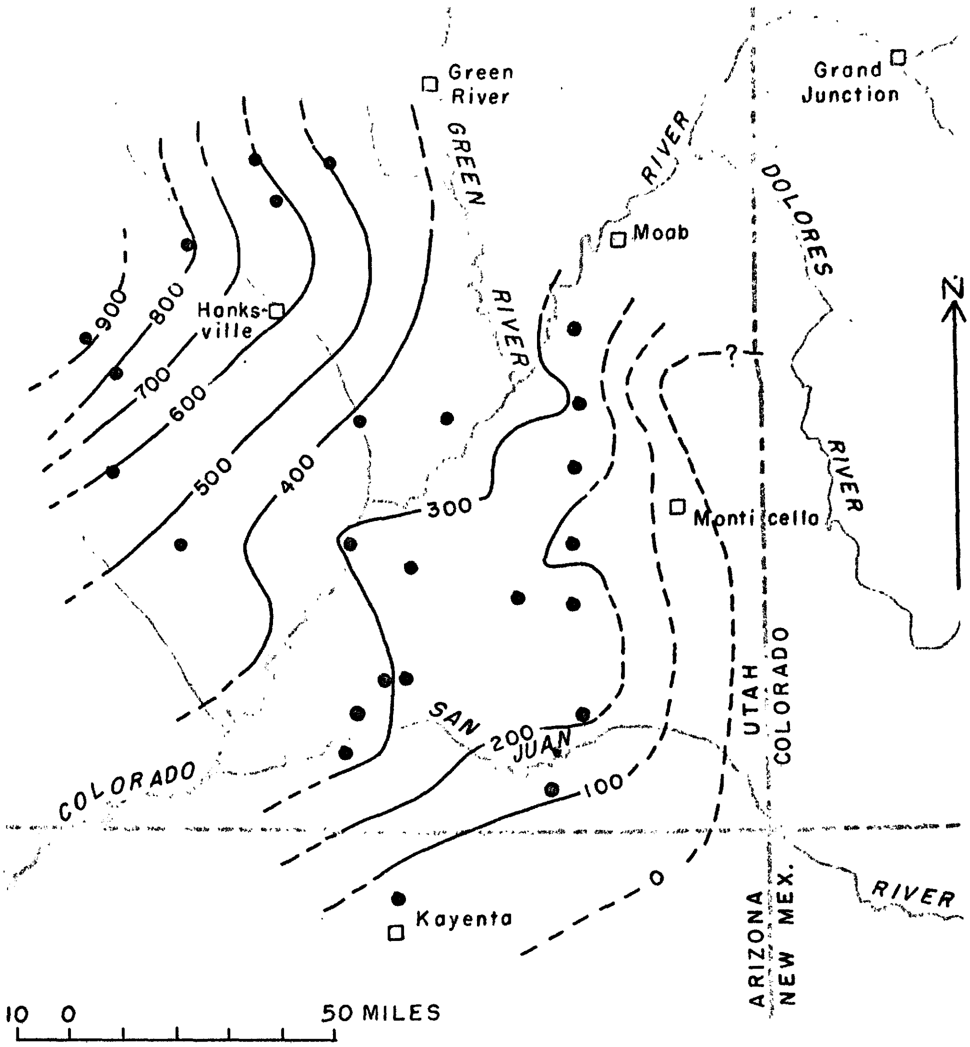
The rocks in the conglomeratic facies of the Cutler probably were deposited in streams. Field evidence indicates that this facies of the Cutler was derived from a rising granitic area in southwestern Colorado--the Uncompahgre highland--and that the streams flowed west from this highland.

The rocks in the reddish siltstone members and light-colored sandstone members of the Cutler are interpreted as deposited in two main environments. The reddish-siltstone members--the Halgaito, Organ Rock, and Hoskinnini tongues--were probably deposited in quiet waters in slowly sinking marginal continental basins. The light-colored sandstone units--the Cedar Mesa, White Rim, and DeChelly sandstone members--are probably eolian deposits formed under quiescent conditions in subaerial basins. The cross-strata in the light-colored sandstone members dip dominantly southeast indicating southeast blowing winds and a source area lying to the northwest of southeastern Utah.

Triassic rocks

Moenkopi formation

General characteristics.--The Moenkopi formation of Early and Middle(?) Triassic age was named by Ward (1901, p. 403) for exposures in northeastern Arizona. It extends over most of southeastern Utah and all of Monument Valley, Arizona (fig. 3). The eastern limit of the Moenkopi



EXPLANATION

LOCATION OF MEASURED SECTION

ISOPACHOUS LINE
DASHED WHERE INFERRED
INTERVAL 100 FEET

Figure 3.--ISOPACHOUS MAP OF THE MOENKOPI FORMATION IN SOUTHEASTERN UTAH.

in southeastern Utah is covered by younger rocks but further study of drill-hole information may locate the limit. The Moenkopi and equivalents are absent in the Big Indian Wash and Egnar areas. The absence of the Moenkopi in these areas may represent the eastward margin of the Moenkopi or these may be local pinchouts related to movement of salt in anticlines in these areas during Moenkopi time.

The Moenkopi formation overlies the Cutler formation in most of southeastern Utah, the Kaibab limestone in the San Rafael Swell and Capitol Reef areas, and locally the Coconino sandstone in the San Rafael Swell. The Moenkopi is overlain by the Chinle formation.

The Moenkopi formation in southeastern Utah is composed of pale reddish-brown, micaceous, ripple- and horizontally laminated siltstone and sandy siltstone and minor pale reddish-brown and yellowish-gray very fine grained cross-stratified sandstone. The trend of the ripple marks as developed in the siltstone is northeast-southwest with steepened side to the southeast. The cross-stratified sandstone, which comprises less than 10 percent of the Moenkopi, occurs in channel filling cosets from about 5 to 40 feet thick that weather to form ledges. The cross-strata in these sandstones dip to the northwest.

In the San Rafael Swell, Capitol Reef, and Dirty Devil River areas, and in the western part of the White Canyon area, the basal part of the Moenkopi consists of a conglomeratic sandstone ranging in thickness from a wedge-edge to 30 feet. The rock is light gray and yellowish gray and is composed of white and gray earthy angular rough-surfaced nonfossiliferous granules, pebbles, and cobbles of chert in a medium-grained sand matrix. This conglomerate at the base of the Moenkopi is composed of small-scale cross-strata that in places fill channels. The granules, pebbles, and cobbles closely resemble the chert pebbles found in the Hoskinnini tongue of the Cutler formation and may have had the same source.

The Moenkopi formation is unconformable on the underlying rocks in some areas of southeastern Utah. The unconformity is well developed in the San Rafael Swell where Baker (1946, p. 51) reported that pre-Moenkopi erosion removed the Kaibab limestone over large areas, and that the pre-Moenkopi surface probably had a relief of 100 feet or more. The Moenkopi conglomerate that fills channels cut into the underlying units suggests an unconformity in the areas where the conglomerate is present. In the eastern part of White Canyon and to the south in the Monument Valley area, however, the boundary between the Permian and Triassic rocks exhibits no signifacant break in deposition.

The Moenkopi formation is over 900 feet thick in the Capitol Reef area and thins to a wedge-edge in southeastern Utah (fig. 3). Locally the Moenkopi may be anomalously thin due to deep channels cut into the Moenkopi formation and filled with Shinarump.

The Moenkopi formation does not appear to be separable into distinctive members in southeastern Utah except in the areas where a limestone unit--the Sinbad limestone member--is present. However, there is a poorly defined interval, as much as a few hundred feet thick, near the middle of the Moenkopi in southeastern Utah that commonly contains more resistant strata and more cross-stratified units than the rest of the Moenkopi.

The Sinbad limestone member of the Moenkopi formation crops out in the San Rafael Swell, Capitol Reef, and the northern part of Circle Cliffs areas. In addition, thin limestone beds with a lithology and stratigraphic position similar to those of the Sinbad limestone have been found at two localities near the junction of the Green and Colorado Rivers. A limestone at one of these localities (McKnight, 1940, p. 58) contains Meekoceras(?) sp. In southeastern Utah Meekoceras is restricted to the Sinbad limestone member. The fossil evidence and the similarity of the lithology and stratigraphic position suggest that these thin limestone beds are correlative with the Sinbad limestone member.

The Sinbad limestone member is composed of limestone and minor amounts of siltstone. The limestone is yellowish gray, pale yellowish orange, or light olive gray. It is dense but may be partly composed of medium to coarse oölites and is horizontally laminated to thinly bedded. Minor amounts of thin trough sets of low-angle small-scale cross-laminae occur in the limestones. Siltstone in the Sinbad limestone member comprises 5 to 20 percent of the unit. The siltstone generally has the same color as the limestone and appears as thin to very thick horizontally laminated sets interstratified with the limestone. The Sinbad limestone member weathers to form a vertical cliff.

The Sinbad limestone member in the San Rafael Swell and the Capitol Reef areas ranges in thickness from about 12 feet (Baker, 1946, p. 55) to 150 feet. In the northernmost part of Circle Cliffs, the Sinbad is about 40 feet thick. In the southern part of Circle Cliffs, the Sinbad is thin and locally absent (E. S. Davidson, oral communication) and is inferred to be near a border of deposition.

The Sinbad limestone member becomes nearer, although irregularly, to the base of the Moenkopi to the south from the San Rafael Swell and finally overlaps that part of the Moenkopi formation underlying the Sinbad.

The part of the Moenkopi underlying the Sinbad ranges in thickness from 90 to 200 feet (Gilluly, 1929, p. 83; Baker, 1946, p. 55) in the Swell and from 50 to 100 feet in the Capitol Reef area. At one place in the northern part of the Circle Cliffs area, this part of the Moenkopi is only 8 feet thick. A few miles south of this place the part of the Moenkopi underlying the Sinbad has pinched out and the Sinbad limestone member rests directly on the Kaibab limestone.

Interpretation.--The Moenkopi formation is interpreted as dominantly a tidal flat deposit. This interpretation is based on the abundance of ripple laminae, shrinkage cracks, casts of salt cubes, and reptile tracks. The cross-stratified sandstone cosets are interpreted to be stream deposits. The direction of dip of the cross-strata in these sandstone cosets indicate that the Moenkopi streams flowed in a westerly direction from an eastern source. The Moenkopi formation in western Colorado contains arkosic coarse-grained and conglomeratic sandstone which suggests that the Moenkopi was derived from the granitic Uncompahgre highland of southwestern Colorado and partly from the conglomeratic facies of the underlying Cutler formation. The chert granules, pebbles, and cobbles that are found in the conglomerate at the base of the Moenkopi in the White Canyon, Dirty Devil River, and San Rafael Swell areas probably were derived from nearby western sources as is indicated by their angularity and rough surfaces. Reworking of the chert nodules of the Kaibab limestone probably was the source of these pebbles.

The Sinbad limestone member is a marine deposit, based on fossil evidence. The seas in which parts of the Moenkopi were deposited probably transgressed to the southeast and east across Utah as is shown by the thinning of the Moenkopi to the east, by the onlapping of the Sinbad limestone on older rocks to the southeast, and by the eastward asymmetry of the ripple marks. In addition, the Sinbad limestone, which is about 90 to 200 feet above the base of the Triassic rocks in the San Rafael Swell, contains the Meekoceras faunal zone which lies 1,000 feet above the base of the Triassic rocks in northern Utah (Newell and Kummel, 1942, p. 938). Considerable Triassic deposition may have taken place in northern Utah before deposition started in the San Rafael Swell. McKee (1954b) has described the transgression of the Moenkopi sea in detail.

At the end of Moenkopi deposition, a regional emergence occurred, as shown by the erosion that preceded the deposition of the Shinarump member of the Chinle formation.

Chinle formation

The Chinle formation (named by Gregory, 1947, p. 42) of Late Triassic age is present in outcrops throughout southeastern Utah. It unconformably overlies the Moenkopi formation or the Cutler formation in extreme east-central Utah where the Moenkopi is absent. The unconformity at the base of the Chinle is the most conspicuous and widespread break in the sequence of the Permian and Triassic rocks and is marked by many channels that cut from a few feet to several tens of feet into the Moenkopi surface. The Chinle is unconformably overlain, or perhaps conformably overlain in some areas, by the Wingate sandstone. The Chinle is composed of variegated claystone and siltstone, sandstone and conglomerate, and minor amounts of limestone and limestone-pebble conglomerate.

In southeastern Utah and in the Monument Valley area, Arizona, the Chinle is divided into seven members, which are in ascending order: the Temple Mountain, Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock members. The Temple Mountain member is a thin unit largely composed of siltstone and is restricted to the San Rafael Swell. The Shinarump and Moss Back members are widespread sandstone and conglomerate units. The Monitor Butte and Petrified Forest members are composed mostly of bentonitic claystone and clayey sandstone. The Monitor Butte member contains some lenses of sandstone. The Owl Rock and Church Rock members are largely composed of reddish siltstone. Minor amounts of limestone are present in the Owl Rock member.

In most areas, Shinarump and Moss Back members are distinctive units. The differences between the Monitor Butte, Petrified Forest, Owl Rock, and Church Rock members, however, are small in some areas, and locally separation is extremely difficult. These members of the Chinle intertongue and intergrade, making it necessary in some places to raise or lower defined contacts as much as 100 feet in a lateral distance of a few thousand feet. Because of these large local vertical shifts in the contacts, an individual measurement of thickness may not be typical for a restricted area. In some areas, contacts between members must be redefined in order to preserve consistent recognizable units.

The outcrop pattern of the Chinle formation in southeastern Utah and adjoining areas is shown in figure 4. Some of the gaps between outcrops are large and correlations are correspondingly less certain.

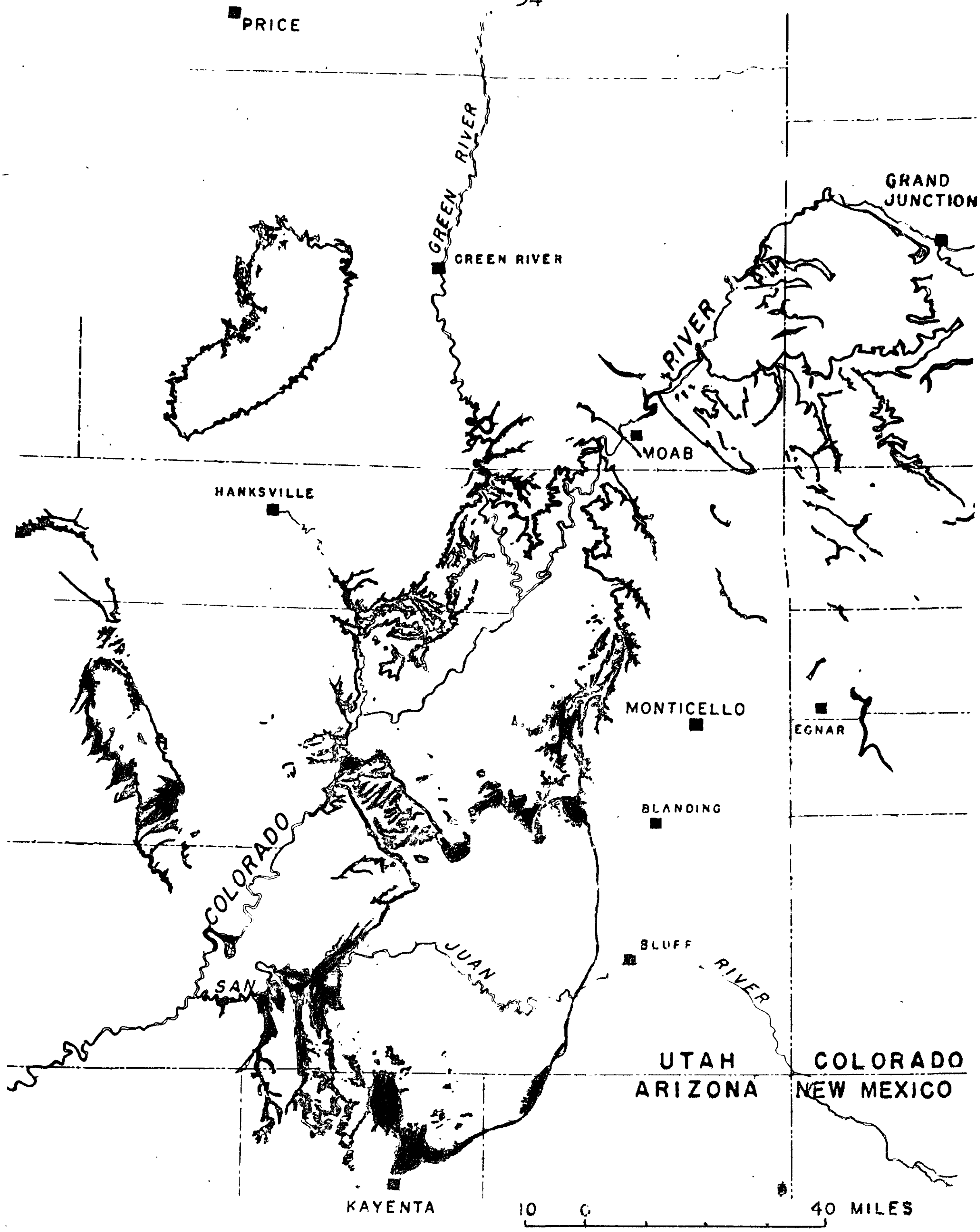


FIGURE 4.--INDEX MAP OF PART OF COLORADO PLATEAU SHOWING OUTCROPS OF THE CHINLE FORMATION.

Temple Mountain member.--The Temple Mountain member of the Chinle formation has been named and defined by Robeck[1] in the San Rafael Swell

[1] Roebeck, R. C., in preparation, The Temple Mountain member--a new member of the Chinle formation in the San Rafael Swell, Utah.

and is restricted by the authors to that area. The member is a thin unit that unconformably overlies the Moenkopi formation. It underlies the Monitor Butte member in the southern part of the Swell and the Moss Back in the northern part of the Swell beyond the limit of the Monitor Butte (fig. 5). The upper contact is considered by some geologists to be an unconformity. The authors believe, however, that the depositional break may be minor and that the contact may not be an unconformity.

The Temple Mountain member consists mostly of mottled purple, reddish-brown, and white, structureless siltstone. The siltstone generally contains some scattered well-rounded medium to very coarse quartz grains. In places, mottled purple and white claystone interfinger and intergrade with the siltstone. Locally light-gray, light greenish-gray or, rarely, reddish-purple sandstone is present in the Temple Mountain member. The sandstone is generally medium to very coarse grained although it is very fine grained in places. It locally contains conglomeratic lenses with granules and pebbles mostly of quartz and is cross-stratified. The sandstone is most commonly present at the base of the Temple Mountain member but may occupy any position in the member. Lenses of jasper and carbonaceous plant material are commonly present in the member.

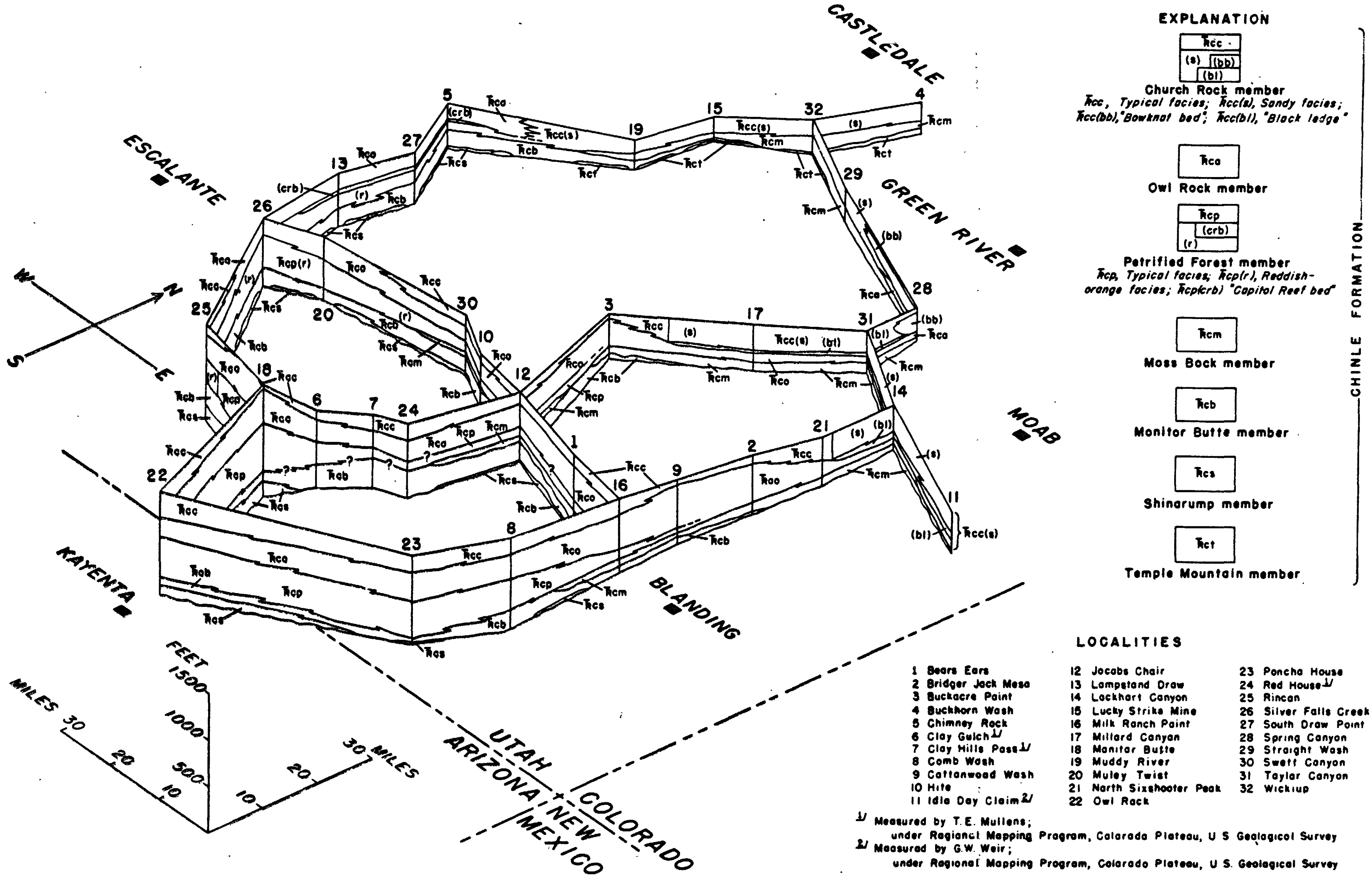


Figure 5.--CORRELATIONS OF THE CHINLE FORMATION.

Some of the sandstone lenses in the Temple Mountain member are lithologically similar to the Shinarump member, and possibly they are outlying lenses of the Shinarump. The term Shinarump, however, is not used in the Swell because of uncertainties of correlation of the Shinarump to the Swell and because these lenses form an integral part of the larger more inclusive Temple Mountain member that is lithologically unrelated to the Shinarump.

The Temple Mountain member is distinguished from the overlying and underlying strata by several lithologic characteristics, including the distinctive mottled purple and white coloration, the presence of medium to coarse quartz sand grains disseminated in the siltstone, the presence of sandstone containing coarse quartz pebbles, and the presence of iron oxide pebbles, carbonaceous material, and lenses of jasper (Robeck_/). The lower contact of the member is located in many places at the change

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_/ Robeck, R. C., in preparation, The Temple Mountain member-- a new member of the Chinle formation in the San Rafael Swell, Utah.

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from siltstone of the Moenkopi to sandstone of the Temple Mountain member. Where siltstone of the Temple Mountain member rests on siltstone of the Moenkopi formation, the contact is difficult to locate but generally can be selected by the distinctive coloration and presence of medium to coarse sand grains in the siltstone of the Temple Mountain member. The upper contact is located in most areas at the change from the mottled siltstone or claystone of the Temple Mountain member to the very fine to fine-grained sandstone at the base of the Monitor Butte member or the fine- to medium-grained sandstone of the Moss Back member. Locally siltstone and claystone of the Monitor Butte rest directly on the siltstone and claystone of the Temple Mountain and in these places the Temple Mountain can be distinguished from the Monitor Butte by the presence, in the Temple Mountain, of the purple and white color, jasper, and pebbles of quartz and iron oxide (Robeck—/).

_/ Robeck, R. C., in preparation, The Temple Mountain member—a new member of the Chinle formation in the San Rafael Swell, Utah.

The Temple Mountain member averages about 5 feet in thickness in the southwest third of the Swell and is not present in several exposures. The member averages about 20 feet in thickness in the central portions of the Swell and about 30 feet in thickness in the northern portion. Locally in the northern portion of the Swell the member attains a maximem thickness of 101 feet in a channel fill Robeck—/).

_/ Roebeck, R. C., in preparation, The Temple Mountain member—a new member of the Chinle formation in the San Rafael Swell, Utah.

Mottled purple and white siltstone strata lithologically similar to the Temple Mountain member are found in other parts of southeastern Utah, and perhaps they correlate with the Temple Mountain member. These strata rest directly on the Moenkopi formation and are overlain by the Shinarump, Monitor Butte, Moss Back, or some other part of the Chinle formation, whichever is present. The strata are present in parts of many areas throughout southeastern Utah, but their distribution is extremely spotty and perhaps they originally covered less than 10 percent of southeastern Utah. The strata are in most places less than 20 feet thick. The spotty distribution and thinness of these strata and the presence of lithologically similar mottled siltstone higher in the Chinle make precise correlation of these strata difficult. Possibly the mottled siltstone strata represent a deposit formed by a repetition of similar environments in different areas at different times rather than one widespread unit representing one time of deposition. In places, the mottled colors of the unit extend down into the top part of the Moenkopi formation, and part, or perhaps all, of the mottled siltstone strata in some areas is an altered zone at the top of the Moenkopi. In most areas, however, the unit probably represents an interval of reworked and altered Moenkopi sediments at the base of the Chinle.

Shinarump member

General characteristics.--The unit that constituted what has previously been called the Shinarump conglomerate was first noted by Powell (1873, p. 458). Powell selected the type locality and applied the name Shinarump Cliffs to the topographic feature of the unit, but did not apply the name Shinarump conglomerate to the unit. Gilbert (1875, p. 176) was the first to use the name Shinarump conglomerate. Stewart and others (in preparation) have redefined the Shinarump as the Shinarump member of the Chinle formation and have restricted the name, Shinarump, to strata correlative to the type Shinarump of southwestern Utah.

The restriction of the name Shinarump to strata correlative to the type Shinarump has led to a new classification of units previously included in the Shinarump conglomerate in southeastern Utah. The strata, previously called Shinarump conglomerate, included part or all of the Temple Mountain, Shinarump, Monitor Butte, and Moss Back members of the Chinle formation. In the Monument Valley, Circle Cliffs, and Capitol Reef areas the Shinarump member of this report is the same as the Shinarump conglomerate of Gregory and Moore (1931), Baker (1936), and Gregory and Anderson (1939). In most of the White Canyon and Elk Ridge areas, and in the area near the junction of the Dirty Devil and Colorado Rivers, the Monitor Butte and Moss Back members, and the Shinarump member where it is present, collectively form what was previously mapped as Shinarump conglomerate by Gregory (1938) and Hunt and others (1953). In the area near the junction of the Green and Colorado Rivers, the Shinarump and Monitor Butte members are absent, and the unit mapped as Shinarump conglomerate by Baker (1933 and 1946) and McKnight (1940) is the Moss Back member. In the San Rafael Swell, the Shinarump conglomerate of Gilluly (1929), (Baker, 1946) and Hunt and others (1953) consists mostly of the Moss Back and Monitor Butte members, or of the Moss Back member where the Monitor Butte is absent. In some parts of the San Rafael Swell these authors included the Temple Mountain member in their Shinarump; in other places, they included it partly in their Shinarump and partly in their Moenkopi; and in still other places, included it entirely in their Moenkopi.

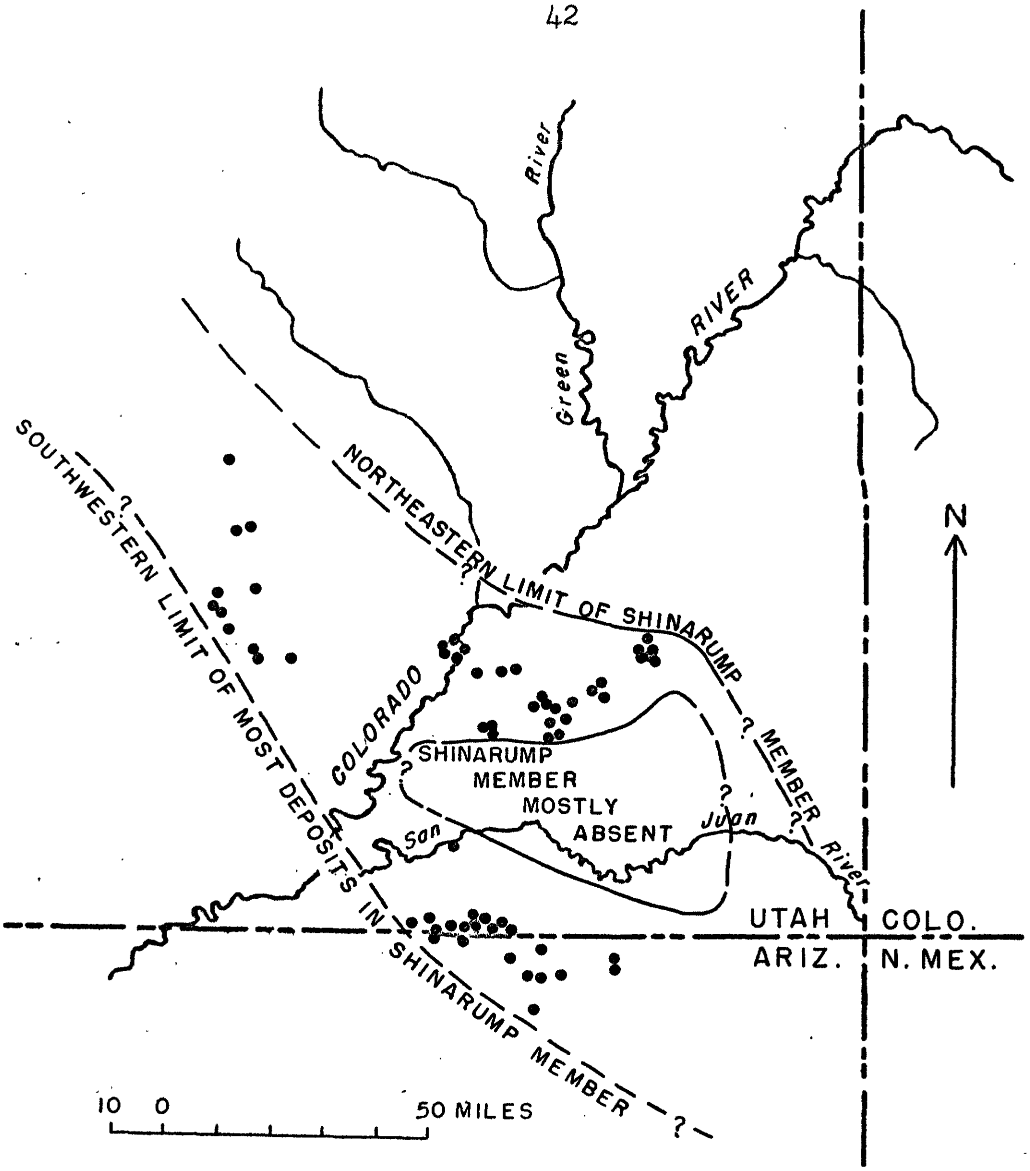
The northeastern limit of the Shinarump member is shown in figure 6. The limit is difficult to locate, as the strata correlative to the Shinarump form thin, small scattered lenses near the northern limit and detailed work may find lenses north of those now known.

The Shinarump member is composed typically of yellowish-gray and pale yellowish-orange, medium- to coarse-grained sandstone composed of subangular clear quartz. Lenses of conglomeratic sandstone and conglomerate containing granules and pebbles predominantly of quartz, quartzite, and chert are common. The Shinarump consists of thin trough sets of medium-scale cross-strata and contains abundant silicified and carbonized wood. It weathers to form a vertical cliff.

The Shinarump member can be differentiated in many places from other sandstone units in the Chinle formation on the basis of the range of grain sizes. The sandstones in the Shinarump generally range from medium to coarse grained, whereas the sandstone units in the overlying part of the Chinle generally range from very fine to medium grained. In addition, the proportions of pebble types are different in the Shinarump from those in the rest of the Chinle.

The contact of the Shinarump member and the Moenkopi formation is sharp and unconformable and is placed at the change from the reddish-brown, micaceous, ripple-laminated siltstones of the Moenkopi to the yellowish-gray cross-stratified medium- to coarse-grained sandstones of the Shinarump.

The contact of the Shinarump member and the Monitor Butte member is conformable and is placed at the change from the generally medium- to coarse-grained, cross-stratified sandstone beds of the Shinarump to the ripple-laminated sandstone or the structureless claystone of the Monitor Butte.



EXPLANATION

URANIUM DEPOSIT

FIGURE 6.--DISTRIBUTION OF THE SHINARUMP MEMBER OF THE CHINLE FORMATION AND LOCATION OF URANIUM DEPOSITS IN THIS MEMBER IN SOUTHEASTERN UTAH AND NORTHEASTERN ARIZONA.

The Shinarump member ranges in thickness from a maximum of about 250 feet to a wedge-edge, and at many places in southeastern Utah, and northeastern Arizona the Shinarump is locally absent within the depositional basin. These gaps in the Shinarump extend a few thousand feet to a few miles along the outcrops. In a fairly large area, including the Red House Cliffs and outcrops to the east, the Shinarump is absent (fig. 6) except for a few very thin conglomeratic sandstone lenses.

The general thickness, depth of channels, and continuity of the Shinarump vary from area to area in southern Utah and northern Arizona. In the Kanab area the Shinarump is continuous, consistently 50 to 100 feet thick, and fills channels cut only a few feet into the underlying Moenkopi. In the Monument Valley, Circle Cliffs, and Capitol Reef areas, the Shinarump is discontinuous, ranges in thickness from a wedge-edge to 200 feet, and fills deep channels. In the White Canyon and Elk Ridge areas, the Shinarump is discontinuous, less than 20 feet thick, and fills channels cut only a few feet into the underlying Moenkopi.

Pebble studies.--The pebbles in the Shinarump are composed almost entirely of quartz, quartzite, and chert (table 3).

Types of quartz pebbles differ markedly among the areas. In the Kanab area the quartz is mostly either transparent or translucent white. In the Circle Cliffs and Capitol Reef areas the quartz pebbles are dominantly transparent; pink and smoky quartz are common. In the White Canyon area, transparent quartz and a distinctive pink variety are dominant, and smoky varieties of quartz pebbles are common.

Table 3.--Average percent composition of pebbles in the Shinarump member of the Chinle formation of southern Utah.

Area	Vitreous quartz	Quartzite	Chert	Other
Kanab	17	47	36	--
Rincon	30	36	33	1
Circle Cliffs	41	20	35	4
Capitol Reef	60	16	13	11
Red House Cliffs	84	14	2	--
White Canyon	89	9	1+	--

A pronounced change in the color of the chert pebbles occurs eastward from the Kanab area. In the Kanab area red, pink, and orange colors comprise about 10 percent of the chert pebbles and the balance are gray, brown, black, and white. In the Capitol Reef area gray chert is dominant; brown, black, and white chert are common; and red chert is rare.

A change in the color of the quartzite pebbles occurs northward and eastward from the Kanab area. In the Kanab area red and pink colors make up about 30 percent of the quartzite pebbles. Gray, tan, and brown comprise most of the remaining 60 percent. In the Capitol Reef and White Canyon areas, the red and pink colors are uncommon, and white, gray, and tan colors comprise most of the remainder.

Silicified limestone constitutes about 5 percent of the gravel in the Circle Cliffs and Capitol Reef areas. It was identified in only one other collection--a collection near Fredonia, Ariz., in the Kanab area.

The maximum size of the gravel varies regionally. The maximum size decreases from about 4-1/2 inches in the Kanab area to about 1-1/2 inches in the Capitol Reef area and from about 8 inches in the Monument Valley area to about 4 inches in the White Canyon area.

Fossiliferous pebbles from the White Canyon area indicate a source from Mississippian, Pennsylvanian, and Permian rocks. Most of the fossil-bearing pebbles from the Kanab, Circle Cliffs, and Capitol Reef areas indicate a source from the Permian Kaibab limestone. The Kaibab or its lateral equivalents have not yielded fusulinids, which indicates that some pebbles containing fusulinids probably had another source. Areas that contain rocks of these ages surround the Colorado Plateau, and many of the areas could have been sources for the pebbles.

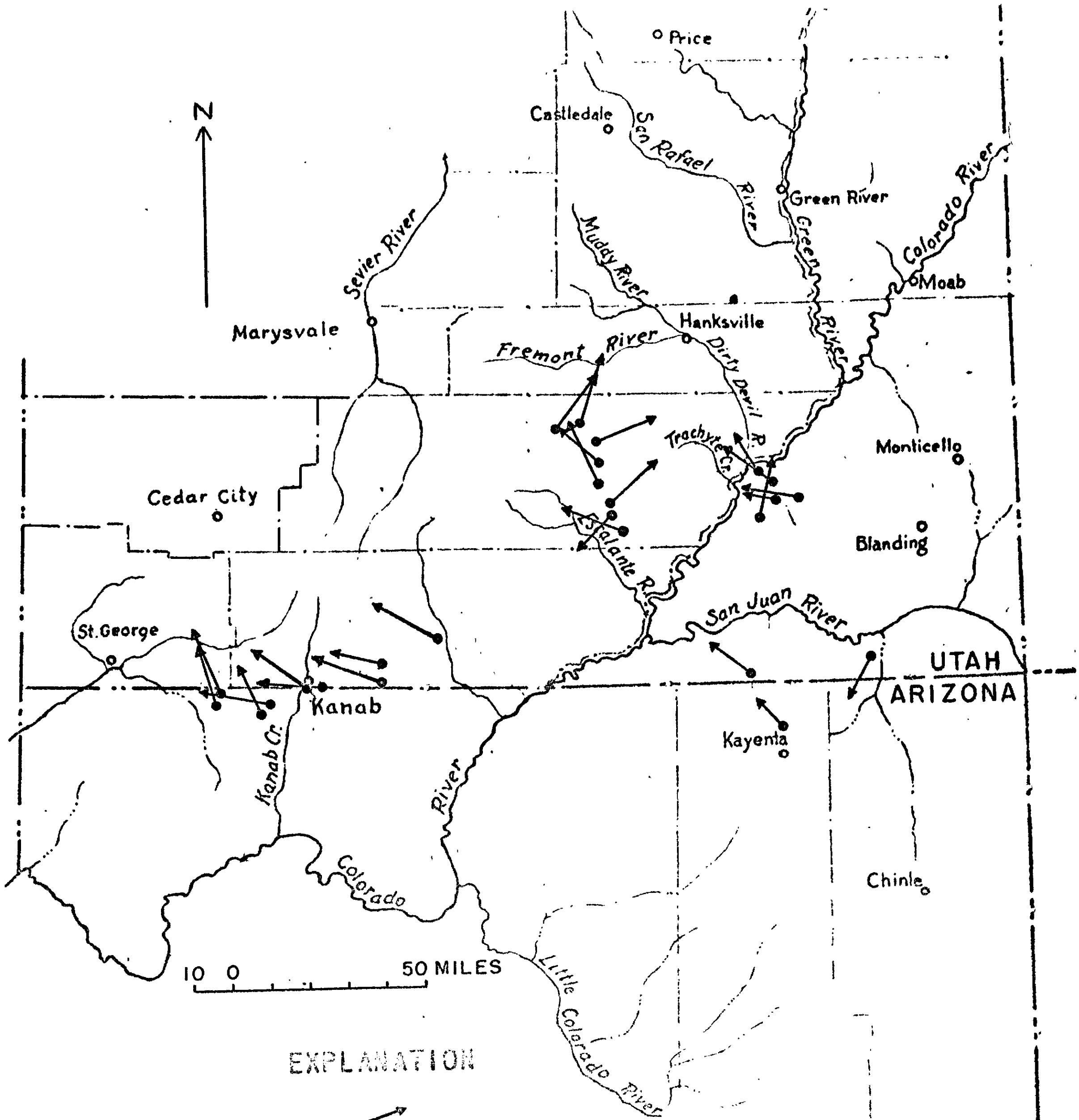
Sedimentary structure studies.--The cross-strata in the Shinarump member, based on the resultants of 30 studies (fig. 7), have an average dip of N. 54° W. The consistency factors among readings in individual studies are quite variable and range from 0.46 to 0.95 and average 0.63.

Monitor Butte member.--The Monitor Butte member of the Chinle formation has been named and defined by Witkind and Thaden (TEI-204, in preparation)for exposures in the Monument Valley area, Arizona.

The Monitor Butte member is present in Chinle outcrops throughout the Monument Valley area, Arizona, and most of southeastern Utah. Its limits in southeastern Utah are shown in figure 8. Recognition of the member is difficult in many areas and some of the correlations are tentative.

The Monitor Butte member consists dominantly of greenish-gray and minor amounts of pale reddish-brown, bentonitic claystone or clayey sandstone that weathers to form a "frothy" appearing slope. The clayey sandstone is fine grained and consists of milky, and minor orange and green grains. The claystone and clayey sandstone commonly contain as much as 1 to 3 percent dark-green, medium- to coarse-grained mica (probably biotite). Stratification is poorly exposed, but the rocks are either cross-stratified or structureless. Carbonized and silicified wood is common.

Interstratified with the claystone and clayey sandstone are sandstone lenses that are mostly 1 to 10 feet thick and about 1,000 feet wide. The lenses comprise about 5 to 20 percent of the member. Locally these



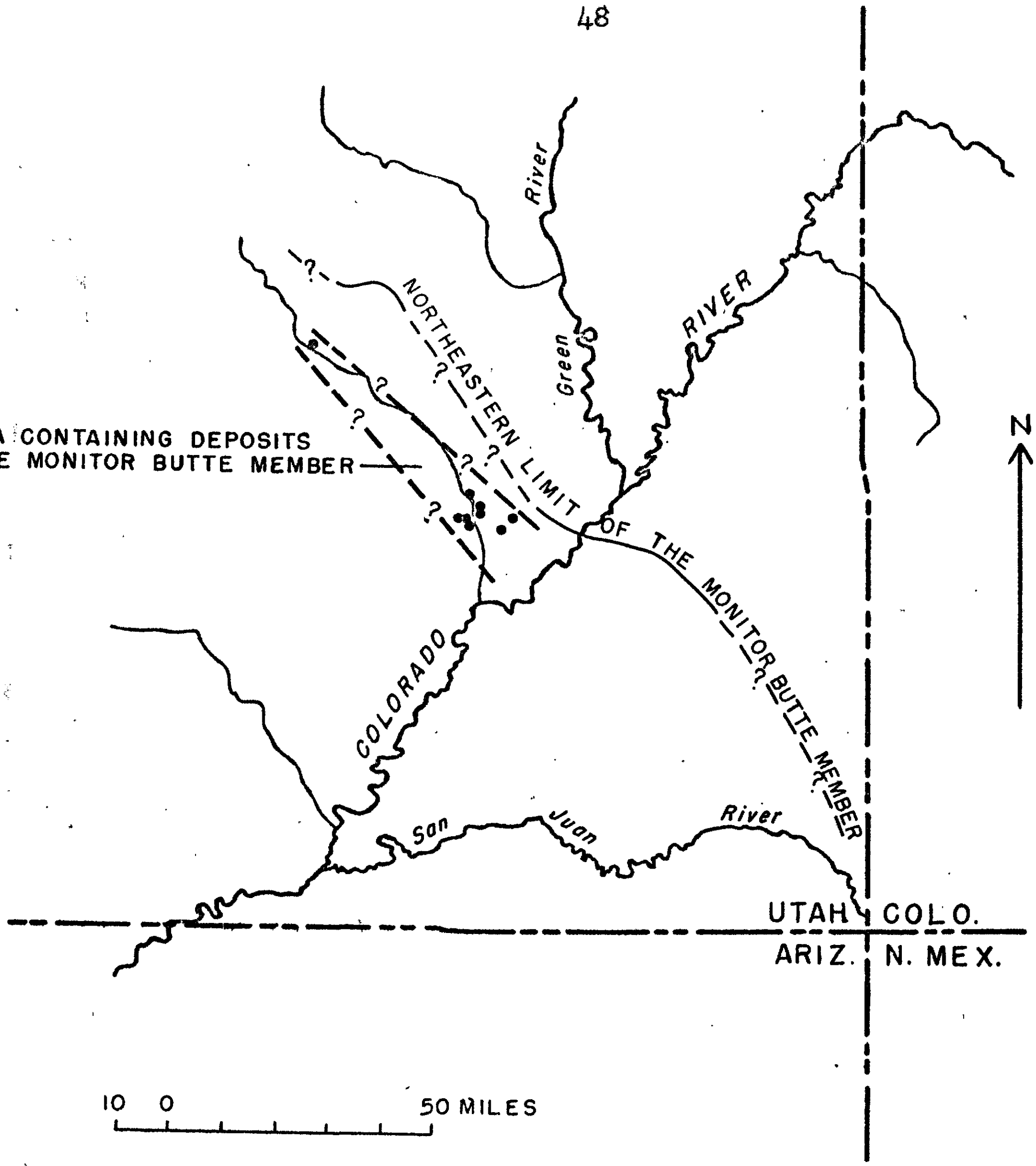
EXPLANATION

Direction of arrow is resultant dip of cross-strata
Tail of arrow marks location of cross-stratification study
Length of arrow is proportional to consistency factor

0 1

Unit consistency length

FIGURE 7.--MAP OF RESULTANT DIP DIRECTIONS OF CROSS-STRATA IN THE SHINARUMP MEMBER OF THE CHINLE FORMATION.



EXPLANATION

• URANIUM DEPOSIT

— —?— — —?— — —?— — BOUNDARY OF AREA CONTAINING DEPOSITS IN THE MONITOR BUTTE MEMBER

Figure 8.--DISTRIBUTION OF THE MONITOR BUTTE MEMBER OF THE CHINLE FORMATION AND LOCATION OF THE URANIUM DEPOSITS IN THIS MEMBER IN SOUTHEASTERN UTAH.

sandstone lenses may be absent. The sandstone is very fine grained, micaceous, well cemented, ripple-laminated or rarely cross-stratified, and platy splitting. A few of the sandstone lenses are conglomeratic with pebbles of limestone, siltstone, and minor weathered chert pebbles. The sandstone lenses are commonly highly contorted by many small-scale folds and faults.

The Monitor Butte member has several lithologic characteristics that distinguish it from associated units. Lenses of greenish-gray micaceous well-cemented ripple-laminated sandstone strata are the main distinguishing characteristics of the member. Sandstone of this type is present in a few areas in other members of the Chinle, but these can be recognized as stratigraphically distinct from the Monitor Butte member. Although lenses of cross-stratified sandstone are to some extent diagnostic, similar sandstones occur in the overlying Moss Back member. In many places, however, these sandstones in the Monitor Butte member do not contain quartzose pebbles, whereas quartzose pebbles are common in the Moss Back member. Other characteristic features of the member that in places distinguish it from overlying rocks are: 1) contorted stratification of sandstone lenses, 2) greenish-gray clayey sandstones composed of milky and minor orange and green grains and containing an abundance of coarse-grained dark mica, and 3) flakes of carbonaceous material in thick units of claystone or clayey sandstone.

The contact between the Monitor Butte and Shinarump members is conformable and placed at the change from the generally medium- to coarse-grained, cross-stratified sandstone beds of the Shinarump to the ripple-laminated sandstone or structureless claystone of the Monitor Butte member.

The contact is well defined in some localities and transitional in others. Intertonguing between the Shinarump and Monitor Butte members has been noted in several places in southeastern Utah. Where the Monitor Butte member directly overlies the Moenkopi formation, the contact is sharp and unconformable and is placed at the change from the reddish-brown, micaceous, ripple-laminated siltstone beds of the Moenkopi to the greenish-gray bentonitic claystone or clayey sandstone and ripple-laminated sandstone beds of the Monitor Butte.

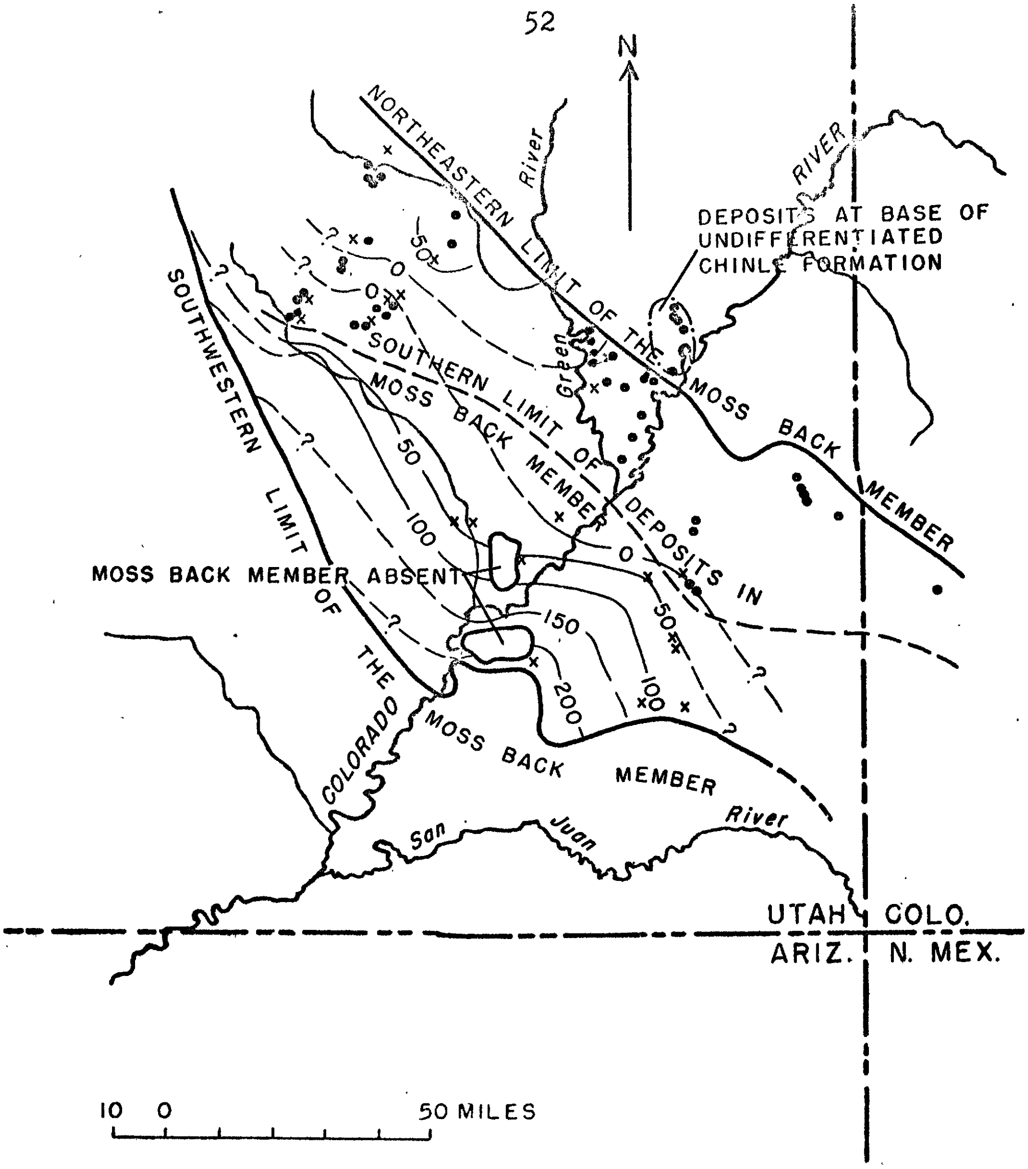
The upper contact of the Monitor Butte member is placed, in most areas, at the top of the highest unit in the Chinle formation containing distinguishing lithologic features (see above) of the Monitor Butte member, which is generally the top of the highest ripple-laminated or cross-stratified sandstone lens. The contact, as defined, abruptly rises or falls depending on the local variations in the position of the lenses. Locally the sandstone lenses that are typical of the Monitor Butte are absent and the Monitor Butte is separated from the rest of the Chinle by distinguishing characteristics of the member other than the sandstone lenses. Where the sandstone lenses are absent, however, separation of the Monitor Butte from the rest of the Chinle is difficult or even impossible.

The Monitor Butte member in southeastern Utah and in the Monument Valley area, Arizona, ranges in thickness from a wedge-edge to 250 feet thick. It thins from 200 feet in White Canyon to a wedge-edge along an east-west line passing about 15 miles north of White Canyon. In the San Rafael Swell it ranges in thickness from a wedge-edge to as much as 100 feet.

The Monitor Butte member is confined to the Monument Valley area, Arizona, and to southeastern Utah but may correlate with defined members of the Chinle in western Utah and northern Arizona. In the Defiance uplift area, Harshbarger (oral communication) has recognized a lower member of the Chinle. This member corresponds with a unit that Gregory (1917, p. 43) called the "D" division on the Chinle. This lower member of the Chinle is similar lithologically to the Monitor Butte member and is probably physically continuous with it. In the Zion Park region, Gregory (1950, p. 67) recognized a lower sandstone member of the Chinle formation which may be physically continuous with the Monitor Butte member.

Moss Back member.--The Moss Back member has been named by Stewart and others (TEI-447, in preparation) for exposures in the eastern part of White Canyon, San Juan County, Utah, The distribution of the Moss Back member is shown in figure 9. The northern and southwestern limits are probably limits of deposition. The extension of the Moss Back to the southeast into Colorado is tentative. The northwest and southeast limits of the Moss Back are not known.

The Moss Back member is typically a yellowish-gray and very pale-orange, fine- to medium-grained, well-sorted sandstone. The sandstone is composed of subround clear quartz and rare black accessory grains. The stratification is dominantly thin to thick, trough to planer sets of medium-scale cross-strata, but horizontally stratified sets are common. Carbonaceous material and silicified wood are abundant. The Moss Back typically weathers to form a vertical cliff.



EXPLANATION

• URANIUM DEPOSIT

× LOCATION OF MEASURED SECTION

—50— ISOPACHOUS LINE
Dashed where inferred
Interval 50 feet

FIGURE 9.--DISTRIBUTION OF THE MOSS BACK MEMBER OF THE CHINLE FORMATION; LOCATION OF URANIUM DEPOSITS IN THE MOSS BACK AND AT THE BASE OF UNDIFFERENTIATED CHINLE; AND A GENERALIZED ISOPACHOUS MAP OF THAT PART OF THE CHINLE FORMATION UNDERLYING THE MOSS BACK MEMBER.

Conglomerate and conglomeratic sandstone lenses are common. The pebbles in the conglomerate lenses generally occur in two suites which are composed of either light-brown and gray siltstone and limestone or vitreous quartz, quartzite, and chert. These two pebble assemblages are not always found in the same lens; however, different lenses containing these lithologies are generally found in the same outcrop. Where the limestone and siltstone pebbles occur with the quartzose pebbles, they generally exceed the quartzose pebbles in number by as much as 15 or 20 times. Where they occur as the only pebbles present, they may comprise more than 50 percent of the rock by volume.

The Moss Back member has a different facies in a belt about 10 miles wide along its northern limit in the areas near the junction of the Green and Colorado Rivers. This facies of the Moss Back contains abundant interstitial greenish silt and clay and interstratified thin lenses of greenish siltstone and claystone and contains few, if any, quartzose pebbles.

The Moss Back member can be distinguished lithologically from the Shinarump member and other sandstone units in the Chinle on the basis of grain size and pebble types. The Moss Back is generally fine to medium grained, whereas the Shinarump is medium to coarse grained and the other sandstone units in the Chinle are generally very fine to fine grained. In addition, the Moss Back contains a different pebble assemblage than the Shinarump member. A study of about 2,000 pebbles from the Moss Back at five localities show quartzite to average 43 percent, chert 40 percent, quartz 13 percent, and other types 4 percent. In contrast, a study of about 1,000 pebbles from the Shinarump at 19 localities show quartzite to average 25 percent, chert 18 percent, quartz

52 percent, and other types 3 percent. In addition, the Moss Back commonly contains conglomeratic sandstone lenses composed almost entirely of siltstone and limestone pebbles, whereas the Shinarump does not contain these conglomeratic lenses. The conglomerates in other parts of the Chinle formation contain few, if any, quartzose pebbles.

The lower contact of the Moss Back member is placed at the break between the channel-filling cross-stratified, cliff-forming sandstone of the Moss Back and the siltstone and claystone of the underlying Chinle or the siltstone of the underlying Moenkopi.

The upper contact of the Moss Back is in most places well defined but in some places may be gradational with the overlying part of the Chinle. The top of the Moss Back is placed at the top of the highest fine- to medium-grained cross-stratified sandstone. This contact corresponds to a change from sandstone below to siltstone and claystone above. In places where the upper part of the Moss Back is gradational with the overlying part of the Chinle, the contact is arbitrarily placed at the most conspicuous change in the strata.

The Moss Back averages about 60 feet thick but may be as much as 150 feet thick where it fills channels. The Moss Back member overlaps the Monitor Butte member to the north in east-central Utah. In White Canyon, the Moss Back is about 200 feet above the base of the Chinle formation; north of White Canyon the Moss Back is lower in the Chinle section, and north of a line trending northwest, about 15 miles north of White Canyon, the Moss Back is at the base of the Chinle (fig. 9).

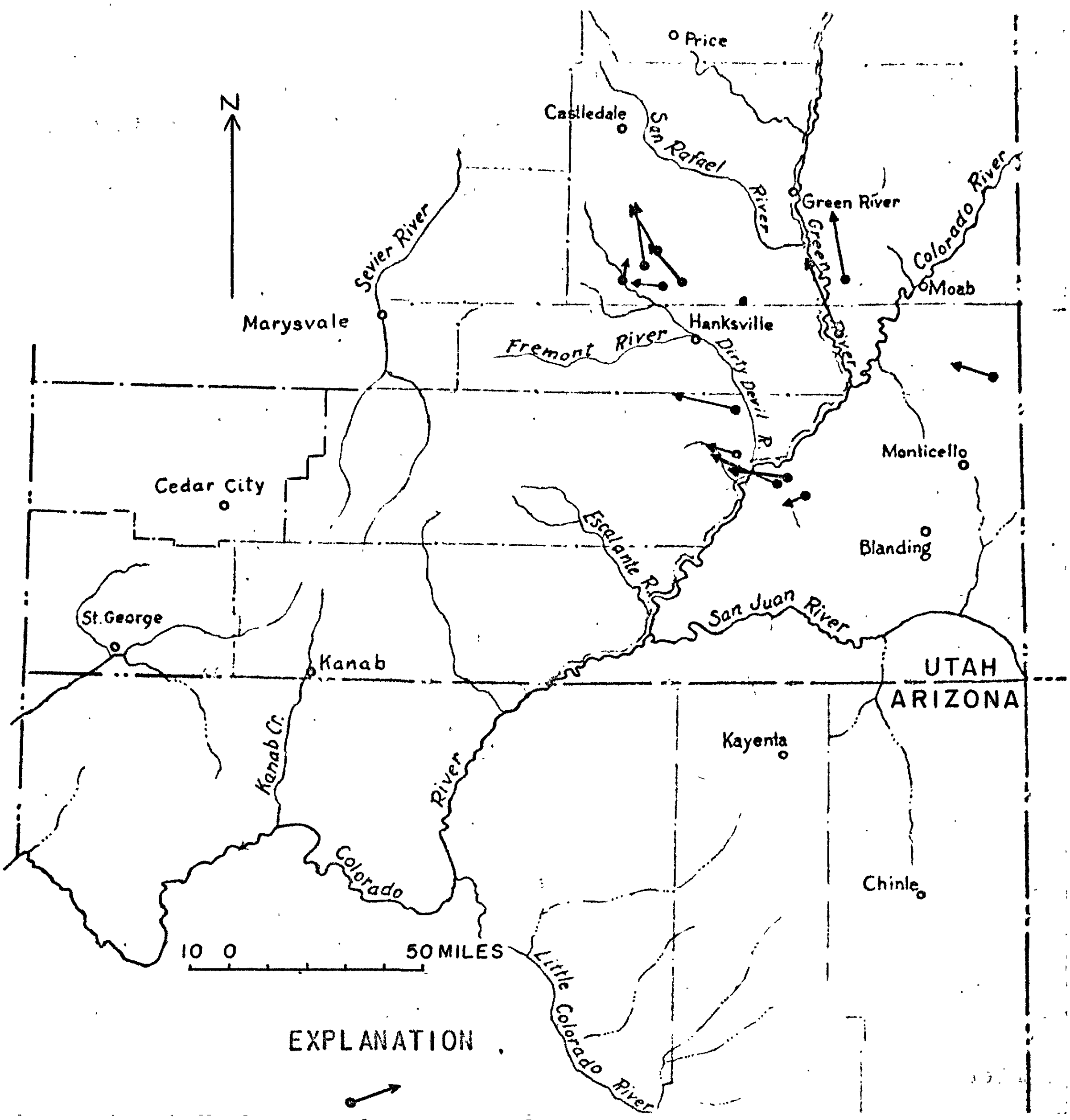
Pebble studies.--The percent of quartzose pebble types in the Moss Back at various localities, based on detailed studies, is shown in table 4. Not enough information is available to determine any systematic regional variations.

Table 4.--Percent of quartzose pebble types in the Moss Back member of the Chinle formation in part of southeastern Utah.

Areas		Quartzite	Quartz	Chert	Other
White Canyon		46	9	41	4
San Rafael Swell	1)	22	13	63	2
(Localities 1, 2,	2)	31	9	60	0
3, and 4 are from	3)	56	19	17	8
south to north)	4)	62	15	18	5

Sedimentary structure studies.--The cross-strata in the Moss Back member, based on the resultants of 16 studies, have an average dip of N. 59° W. (fig. 10). The consistency factors among readings in individual studies are quite variable and range from 0.46 to 0.97 and average 0.58.

Petrified Forest member.--The Petrified Forest member of the Chinle formation was named by Gregory (1950, p. 67) for exposures in the Zion Park region, although he derived the name from the Petrified Forest in northeastern Arizona. The Petrified Forest member has been correlated from the Zion Park region into northeastern Arizona by Gregory (1950, p. 68).



Direction of arrow is resultant dip of cross-strata
il of arrow marks location of cross-stratification study
Length of arrow is proportional to consistency factor

0 1

Unit consistency length

Figure 10.--MAP OF RESULTANT DIP DIRECTIONS OF CROSS-STRATA IN THE MOSS BACK MEMBER OF THE CHINLE FORMATION.

The member is present throughout northeastern Arizona and extends north into southeastern Utah nearly as far as White Canyon. A reddish-orange facies of the Petrified Forest member extends into Circle Cliffs and Capitol Reef areas but cannot be recognized in the San Rafael Swell area.

The Petrified Forest member typically consists of bentonitic claystone and clayey sandstone. The rocks are variegated with red, purple, green, and yellow colors. The sandy parts of the rocks are very fine to fine grained, are composed of silky grains and as much as 10 percent orange and green grains, and contain abundant very coarse flakes of dark mica (probably biotite). The claystone and clayey sandstone beds in the Petrified Forest member are mainly structureless, but a few cross-stratified units crop out. The member weathers to form a "frothy-surfaced"slope which results from the weathering of swelling clays. It contains some limestone-pebble conglomerate lenses.

The reddish-orange facies of the Petrified Forest member of the Chinle formation consists dominantly of pale reddish-brown, light-brown, moderate reddish-orange, and grayish-red siltstone and minor amounts of pale-red and light greenish-gray sandstone. The sandstone is fine grained and composed of clear and milky quartz, minor amounts of colored graines, and common amounts of dark-grown mica. It is composed of trough sets of small- to medium-scale cross-strata. A persistent and conspicuous bed--the "Capitol Reef bed"--is present at the top of the reddish-orange facies in the Capitol Reef area and the northern part of the Circle Cliffs area (fig. 4). This reddish-orange unit weathers to form a characteristic reddish-orange slope containing conspicuous reddish ledges.

The basal contact of the Petrified Forest member is placed at the top of the stratigraphically highest rocks that distinguish the Monitor Butte member or the Moss Back member where it is present. The top contact of the Petrified Forest member is placed in most areas at the base of the lowest dense limestone beds of the Owl Rock member.

In the Monument Valley area the Petrified Forest member ranges from about 500 to 700 feet in thickness. North from the Monument Valley area it thins to about 100 feet just south of the White Canyon area and the southernmost part of the Elk Ridge area. North of these areas it loses identity by intertonguing with the Owl Rock member.

Owl Rock member.--The Owl Rock member has been named by Witkind and Thaden (TEI-204, in preparation) for exposures in the Monument Valley area, Navajo County, Ariz. The Owl Rock member is present in most of southeastern Utah (fig. 4). J. W. Harshbarger (oral communication) has traced the Owl Rock member over most of northeastern Arizona. It grades laterally into the Church Rock member to the north in the area near the junction of the Green and Colorado Rivers. A similar lateral gradation probably takes place between the Capitol Reef and the San Rafael Swell areas. The Owl Rock member is the "B" division of Gregory (1917, p. 42).

The Owl Rock member typically is composed of pale-red and pale reddish-brown structureless siltstone interstratified with thin to thick sets of limestone that comprise about 5 to 10 percent of the member. The limestone is pale red and light greenish gray, dense, and commonly grades to limy siltstone. The limestone occurs as horizontal beds which average about a foot in thickness and are in part horizontally laminated. Limestone-pebble conglomerate lenses are common. The member weathers to form steep slopes with alternating small ledges of limestone.

The only distinguishing feature of the Owl Rock member is dense limestone beds. At a few places limestone beds occur in other parts of the Chinle formation, but these limestone beds are in most places separated from those of the Owl Rock member by at least 100 feet of strata.

In most areas, the bottom contact of the Owl Rock member is placed at the base of the lowest limestone and the top contact is placed at the top of the highest limestone. Locally, however, the contacts are raised or lowered to include strata that laterally contain limestone.

The base of the Owl Rock member marks the most significant break in the lithologic characteristics of the Chinle. This horizon is the change from light-colored, variegated partly cross-stratified bentonitic claystone and clayey sandstone below to reddish horizontally stratified nonbentonitic siltstone above.

In southeastern Utah the Owl Rock member is generally 150 to 250 feet thick. Intertonguing of the Owl Rock member and the overlying and underlying members causes its thickness to vary greatly. The member has an abnormal thickness in the White Canyon and Elk Ridge areas where it is 350 to 450 feet thick. Near the northern limit the member is 50 to 100 feet thick (fig. 4).

<u>Church Rock member</u>.--The Church Rock member has been named by Witkind and Thaden (TEI-204, in preparation) for exposures in the Monument Valley area, Navajo County, Ariz. The Church Rock is present in most of southeastern Utah and all of the Monument Valley area, Arizona. It is absent in the Capitol Reef area and in most of the Circle Cliffs area, probably because of both wedging out of strata and intergrading of the Church Rock and the Owl Rock members.

Typically the Church Rock member is composed of pale reddish-brown and light-brown very fine grained sandy siltstone. The sandy siltstone may be structureless, composed of thin to very thick horizontal beds, or, in a few cases, ripple-laminated. The sandy siltstone fractures into pebble-sized angular fragments and weathers to form a slope.

Over a large part of southeastern Utah the top 10 to 50 feet of the Chinle formation is composed of a cross-stratified sandstone. This sandstone is well developed at exposures about 2 miles south of Hite, San Juan County, Utah, and is referred to there as the "Hite bed." This bed is tentatively assigned to the Church Rock member because of lithologic similarities of the bed to other units in the Church Rock member. It is composed of pale-red and light greenish-gray very fine grained sandstone and of many lenses of pale reddish-brown siltstone. The sandstone is composed of trough sets of medium-scale cross-strata and contains a few conglomeratic sandstone lenses of granules, pebbles, and a few cobbles and boulders of reddish siltstone. The siltstone is structureless but contains minor amounts of horizontally laminated or ripple-laminated rocks. The "Hite bed" weathers to form a vertical cliff that is continuous with the overlying cliff of the Wingate sandstone.

The "Hite bed" is correlated over most of southeastern Utah north of the San Juan River. A sandstone bed that appears to be similar to the "Hite bed" is at the top of the Chinle formation in part of the Monument Valley area. Not enough detailed work has been done to correlate this bed definitely with the "Hite bed." To the west the "Hite bed" has been tentatively correlated with a prominent local sandstone at the top of the Chinle in the southeastern part of the Circle Cliffs area. The "Hite bed" is absent in Capitol Reef and cannot be correlated through the area between the Green and Colorado Rivers.

The Church Rock member contains many sandstone units in the San Rafael Swell and in the areas near the junction of the Green and Colorado Rivers (fig. 4), and in these areas it will be referred to as the sandy facies of the Church Rock member. The sandstone units are few, but form fairly thick and conspicuous ledges. They are generally interstratified with the reddish sandy siltstones typical of the Church Rock member in the Monument Valley area. The sandstone is pale red, very fine grained and composed of trough sets of low-angle medium-scale cross-laminae. The southern limit of one of these units--referred to as the "Black ledge"--arbitrarily marks the southern limit of the sandy facies of the Church Rock member. A unit referred to as the "Bowknot bed" forms a conspicuous sandstone unit in the northeastern part of the area near the junction of the Green and Colorado Rivers (fig. 4).

The contact of the Church Rock member and the Owl Rock member is placed in most areas at the top of the highest limestone or limy siltstone in the Chinle. The contact of the Church Rock member and overlying rocks in most of southeastern Utah is between the "Hite bed" and the Wingate sandstone. This contact is well defined and disconformable. The contact marks the change from pale-red and light greenish-gray, purplish-weathering sandstone in the Chinle to the light-brown, brownish-weathering sandstone of the Wingate. The contact also marks the change from well-cemented sandstone in the Chinle formation composed dominantly of subangular milky minerals and clear quartz and commonly containing clay galls and interstitial clay to the poorly cemented Wingate sandstone composed of subrounded grains of clear quartz and containing no clay galls of interstitial clay. A highly characteristic feature of the contact is the abundant frosted and rounded, medium to coarse grains in the basal part of the Wingate.

In places where the "Hite bed" is not present the contact between the Church Rock member and the Wingate sandstone is placed at the disconformity between the reddish horizontally stratified siltstone of the Chinle and the light-brown cross-stratified sandstone of the Wingate.

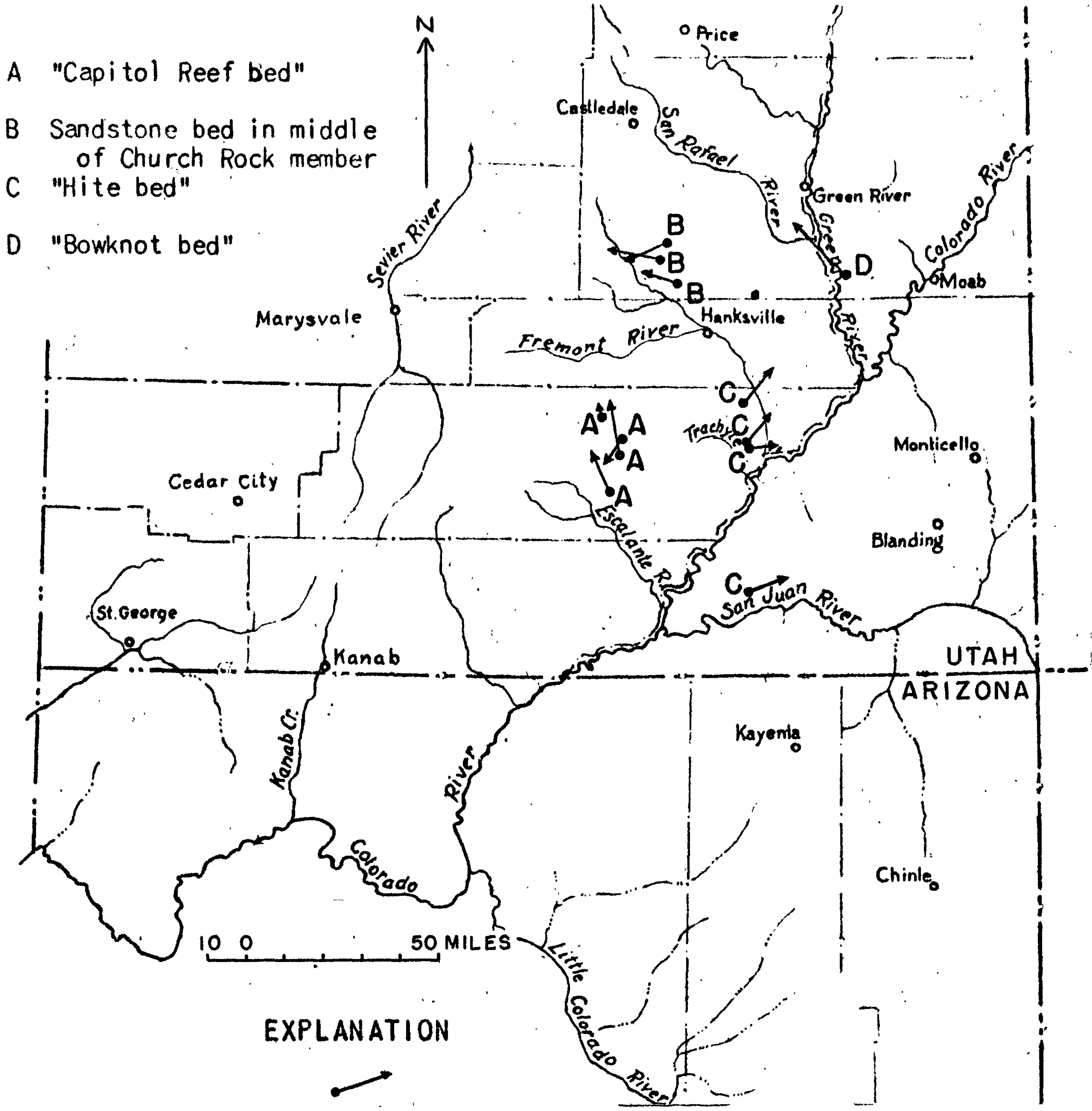
The Church Rock member in most of southeastern Utah ranges in thickness from 50 to 350 feet. The Church Rock thickens north of the Elk Ridge area (figs. 1 and 4), probably by incorporating strata which are equivalent to the Owl Rock farther south.

The Church Rock member in Monument Valley is probably physically continuous with at least part of the Rock Point member(J. W. Harshbarger, C. A. Repenning, and J. H. Irwin, in preparation) of the Wingate sandstone in northeastern Arizona. The Rock Point member corresponds to Gregory's "A" division (Gregory, 1917, p. 42) of the Chinle. Harshbarger has placed the Rock Point member in the Wingate sandstone because of lithologic similarities and of intertonguing between the Rock Point and the overlying Wingate.

<u>Sedimentary structure studies</u>.--Sedimentary structure studies have been made in three units in the Church Rock member (fig. 11): 1) the "Bowknot bed," 2) a prominent sandstone bed in the middle of the Church Rock member in the San Rafael Swell, and 3) the "Hite bed." The resultant dip direction of the cross-strata in the "Bowknot bed," based on one study, is N. 45° W. with a consistency among readings of 0.87. Three studies in a prominent sandstone bed in the middle of the Church Rock member in the San Rafael Swell area have an average resultant dip direction of N. 85° W. and have a consistency among the readings that ranges from 0. 41 to 0.61. Three studies in the "Hite bed" give an average resultant dip direction of N. 60° E. and have a consistency among readings that ranges from 0.34 to 0.55. The greatly different resultant dip direction of the studies in the "Hite bed" from those in the other two units suggests that the "Hite bed" may not be related to the other units and that it may not properly belong in the Church Rock member.

Some characteristics of the Chinle formation

<u>Thickness.</u>--The thickness of the Chinle formation in the areas studied is shown in figure 12. In three places in southeastern Utah--the Red House Cliffs area, the central part of the Dirty Devil River area, and the southeastern part of the San Rafael Swell area--the Chinle is slightly thinner than in adjoining areas. In these same areas the Shinarump and Moss Back members are thin or mostly absent. Possibly these three areas were relatively high in the continental basin in Late Triassic time and caused diversion of Chinle streams, resulting in thinner deposits than in adjoining areas.

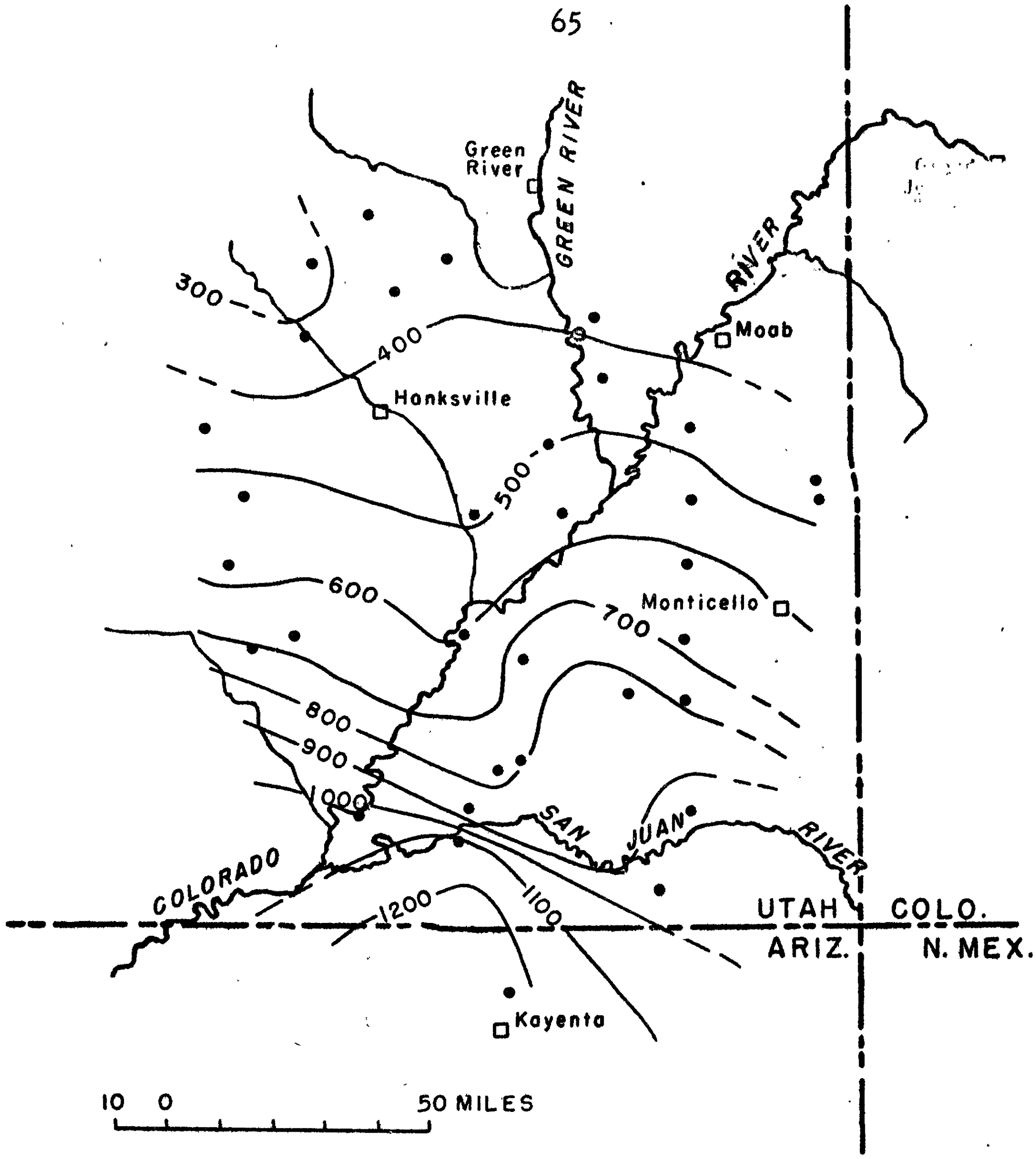


Direction of arrow is resultant dip of cross-strata
Tail of arrow marks location of cross-stratification study
Length of arrow is proportional to consistency factor

0 1

Unit consistency length

Figure 11.--MAP OF RESULTANT DIP DIRECTIONS OF CROSS-STRATA IN VARIOUS SANDSTONE UNITS IN THE CHINLE FORMATION.



EXPLANATION

LOCATION OF MEASURED SECTION

ISOPACHOUS LINE
Dashed where inferred
Interval 100 feet

Figure 12.--ISOPACHOUS MAP OF THE CHINLE FORMATION IN SOUTHEASTERN UTAH.

Paleontology.--Fossils in the Chinle formation consist of plants, pelecypods, gastropods, and vertebrates. The palecypods are mostly fresh water Unios, and the gastropods are small nonmarine forms. Vertebrate remains consist of amphibians, fish, and reptiles. Phytosaurs are the most numerous reptiles, particularly common in Arizona, and have been described in detail by Camp (1930). Assignment of the Chinle to the Upper Triassic is based on vertebrate fossil evidence. Various types of fossil plants have been described by Daugherty (1941) from east-central Arizona.

Interpretation.--A continental environment of deposition is indicated for the Chinle formation by the type of sedimentary structures, the presence of nonmarine vertebrate and invertebrate fossils, and the presence of fossil wood. Both fluvial and lacustrine environments probably existed.

The Temple Mountain, Shinarump, Monitor Butte, Moss Back, and Petrified Forest members of the Chinle formation were probably deposited in an alluvial plain environment including stream and flood plain deposits. The Temple Mountain, Shinarump, and Moss Back members are interpreted to be stream deposits. The association of the cross-stratified conglomeratic sandstone, channels and fossil wood as found in these members is similar to that found in present-day stream deposits.

The Monitor Butte and Petrified Forest members probably include both stream and flood plain deposits. The cross-stratified sandstone lens of the Monitor Butte and possibly some of the claystone and clayey sandstone of the Monitor Butte and Petrified Forest members are probably stream deposits. The crescentic ripple-laminated sandstone lenses in the Monitor Butte member indicate current action and possibly these sandstone lenses were deposited on a flood plain. In addition, the structureless claystone of the Monitor Butte and Petrified Forest may be flood plain deposits. Possibly the Monitor Butte and Petrified Forest members contain some swamp and lake deposits.

The Moss Back member is composed mostly of cross-stratified channel-filling sandstone and conglomerate which contains carbonaceous material, indicating that it is a stream deposit. The scarcity of clay and the presence of moderately well-sorted sandstone indicates considerable reworking of the sand during deposition. The persistency of the Moss Back in southeastern Utah suggests that it was deposited in a fairly quiescent time in the Chinle basin of deposition and on an alluvial plain with little relief, so that the streams could migrate freely.

The Owl Rock and Church Rock members are probably, in large part, lake or lagoonal deposits. A lake or lagoonal environment is suggested by the presence of limestone beds, horizontal stratification,and nonmarine gastropods. The limestone beds in the Owl Rock member represent times of slower deposition of clastic material than those of the overlying and underlying rocks, and clear water conditions more favorable for the existence of animals and for the preservation of fossils. The type of cross-stratification and channels in the sandy facies of the Church Rock member suggest stream deposits. The limestone pebble conglomerates in the Owl Rock and Petrified Forest members may have been produced during periods of slow deposition by wave action in a lake environment.

The Monitor Butte and Petrified Forest members contain a considerable amount of volcanic debris. This is suggested by the presence of bentonitic clays, the reported presence of altered glass shards

(Waters and Granger, 1953, p. 6) and the presence of coarse flakes of dark mica (probably biotite). The claystone in these members may have been derived from volcanic ash by alteration and devitrification.

Studies of the orientation of cross-strata in the Chinle formation indicate the direction of stream currents. The cross-strata in all the studied units of the Chinle formation except the "Hite bed" have a resultant dip direction to the northwest which indicates northwest-flowing streams. The northeast resultant dip direction in the "Hite bed" indicates northeast-flowing streams. The consistency of most of the resultant directions of dip suggests that the various units of the Chinle were deposited under similar conditions of regional slopes and had similar source areas.

The source areas for the Chinle, suggested by sedimentary structure studies, lie southeast of southeastern Utah. A similar direction for the source area of the volcanic debris in the lower part of the Chinle is suggested by the thickening of the bentonitic units to the south and the reported presence of coarse volcanic debris (Allen, 1930) in the Chinle of east-central Arizona. Regional relations suggest that a source area may have been present in southern Arizona and New Mexico.

The disconformity at the top of the Chinle formation in most of southeastern Utah probably represents a period of erosion of varying intensity in different areas caused by a slight upwarping of the region of Chinle deposition.

Triassic and Jurassic rocks

Glen Canyon group

The Glen Canyon group in southeastern Utah consists of three formations which are, in ascending order, the Wingate sandstone of Triassic age, the Kayenta formation of Jurassic(?) age, and the Navajo sandstone of Jurassic and Jurassic(?) age. Study of these formations has been confined mostly to sedimentary petrology and sedimentary structures.

Wingate sandstone.--The Wingate sandstone was named and defined by Dutton (1885) for exposures near Fort Wingate, McKinley County, N. Mex. The Wingate was correlated into southeastern Utah (Gregory, 1917) where the name was extensively used. Later work (Baker and others, 1947) showed that most of the Wingate sandstone at Fort Wingate, N. Mex., correlated with the Entrada sandstone of Late Jurassic age and that the Wingate of Utah was for the most part not equivalent to the Wingate at Fort Wingate. The name, Wingate sandstone, however, because of its extensive use, was retained for the unit in southeastern Utah and the name Entrada sandstone was applied to most of the original Wingate sandstone at Fort Wingate.

The Wingate occurs in all of southeastern Utah and adjoining parts of Arizona and Colorado. It is composed of very pale-orange and light-brown, very fine to fine-grained well-sorted sandstone. The sand grains are dominantly rounded to well-rounded quartz. The lower few feet, and in places as much as the lower third, of the Wingate contains abundant frosted and rounded, medium to coarse grains. The sedimentary structures of the Wingate are composed of trough sets of large-scale cross-strata that are tangential to the lower contact of the set. These cross-strata, as is indicated by nine sedimentary structure studies, dip dominantly southeast.

The basal contact of the Wingate in southeastern Utah is sharp, but the top part of the Wingate intertongues with the overlying Kayenta formation.

The Wingate in most of southeastern Utah ranges in thickness from 200 to 350 feet but is generally about 300 feet thick.

Kayenta formation.--The Kayenta formation (Baker and others, 1947) extends throughout southeastern Utah but pinches out to the east in western Colorado and northeastern Arizona. It is composed of pale-red and very pale orange sandstone and some siltstone and weathers with a purplish tinge. The sandstone is very fine to medium grained, fair to well sorted, and composed of subangular to rounded grains. Field observation suggests that in central and south-central Utah the Kayenta is largely composed of quartz grains but that to the east the content of feldspar in the Kayenta increases. In western Colorado it may, in places, be an arkose. The sandstones of the Kayenta are composed of interstratified cosets of horizontal laminae and cosets composed of thin trough sets of medium-scale, very low angle cross-strata. These cross-strata, based on six sedimentary structure studies, dip dominantly to the southwest. The sandstone commonly contains angular fragments of reddish siltstone that were undoubtedly derived from underlying siltstone lenses.

The Kayenta intertongues with both the overlying and underlying units. In many places a transition interval as thick as 50 feet is present between the Kayenta and the overlying Navajo sandstone.

The Kayenta is about 250 feet thick in southeastern Utah.

Navajo sandstone.--The Navajo sandstone (Gregory, 1915) occurs in most of southeastern Utah and adjoining parts of Arizona and Colorado. It pinches out to the east in western Colorado and northeastern Arizona. The Navajo is a very pale-orange, fine- to medium-grained, fair- to well-sorted sandstone composed dominantly of subrounded- to rounded-quartz grains. The structures are composed of thin to very thick trough sets of medium- to large-scale cross-strata. Twelve sedimentary structure studies indicate that the cross-strata dip dominantly to the southeast.

The Navajo intertongues with the underlying Kayenta formation and in places a transitional interval is present between the two units. The contact of the Navajo with the overlying Carmel formation of Late Jurassic age is disconformable at most places; a beveling surface overlain by reworked Navajo sandstone is characteristic of the contact. However, recent work by L. C. Craig (oral communication) indicates that strata included in the Carmel in some areas grade laterally into beds included in the Navajo in other areas. These relations suggest that deposition may have been continuous from the time of Navajo deposition into the time of the Carmel deposition in these areas.

Interpretations.--The formations in the Glen Canyon group are all of continental origin. Sedimentary structures indicate that the Wingate and Navajo sandstones are probably eolian deposits formed by southeast-blowing winds and that the Kayenta formation is, in large part, a stream deposit formed by southwest flowing streams.

Relation of uranium deposits to the stratigraphy of the Triassic and associated formations

Studies of the relations of uranium deposits to the stratigraphy of the Triassic and related formations permit broad generalizations which may not conform in detail to specific deposits.

The deposits in the Triassic and associated formations in southeastern Utah are found mostly in five stratigraphic units: 1) the conglomeratic facies of the Cutler formation; 2) the Shinarump, 3) the Monitor Butte, and 4) the Moss Back members of the Chinle formation; and 5) near the base of undifferentiated Chinle. A few deposits have been found in the Moenkopi formation and the Wingate sandstone.

Distribution of ore deposits

Permian rocks.

Cutler formation.--A large number of small weakly mineralized uranium occurrences in the Cutler formation occur in the area near the junction of the Green and Colorado Rivers. These deposits are in the conglomeratic facies of the Cutler and are near the area where the conglomeratic facies changes to the light-colored sandstone and reddish siltstone facies. The deposits may be related to this facies change, or to particular lithologic rock types associated with the margin of the conglomeratic facies.

The ore-bearing strata are light-colored arkose beds as compared with the nonmineralized reddish arkose beds. The ore-bearing arkose is at different stratigraphic levels from place to place and always has well-developed cross-stratification and small channel fills.

Triassic rocks

Moenkopi formation.--Mineralized material in the Moenkopi formation is confined to relatively few areas. The two known ore deposits are in the Capitol Reef and Elk Ridge areas. No relation is indicated between the ore deposits and regional stratigraphic features. The Moenkopi in many places has a middle sandy interval that contains channel-filling cross-stratified conglomeratic sandstone lenses that may be favorable host rocks for uranium. Prospectors may tend to bypass the Moenkopi in favor of units that contain many known deposits, and the lack of systematic prospecting may account for the small amount of reported mineralized material.

Chinle formation.--The distribution of the known deposits in the Shinarump member of the Chinle formation in southeastern Utah and an adjoining part of Arizona are shown in figure 5. The Shinarump contains a few occurrences of mineralized material in northwestern, central, and east-central Arizona and southwestern Utah, but most of the deposits and all of the important ones are in an area that lies near the northern limit of the Shinarump. The limits of this area can be only crudely located because of large gaps between outcrops. This area appears to be more favorable for finding new ore deposits than other areas.

Uranium deposits in the Monitor Butte member of the Chinle formation (fig. 8) are known in two-areas--the Dirty Devil and San Rafael Swell areas (fig. 1). Between these two areas, across a gap in exposures, a belt of ground containing deposits is inferred. This belt is suggested by a similarly oriented belt of deposits in the Moss Back member.

The uranium deposits in the Moss Back member of the Chinle formation are present in a belt about 30 to 40 miles wide that parallels the northern limit of the member (fig. 9). No deposits are known south of this belt. Deposits in the Moss Back occur where the Moss Back lies less than 50 feet above the base of the Chinle formation.

A few uranium deposits occur in the Chinle formation in southeastern Utah at or above the stratigraphic position of the Moss Back member. The most important of these deposits are in sandy siltstone or very fine grained sandstone that lie near the base of the undifferentiated Chinle formation (fig. 13). Several deposits are known in the area near the junction of the Colorado and Green Rivers in a unit that appears to be equivalent to the "Black ledge."

The uranium deposits in the Chinle formation lie near the base of the Chinle regardless of the unit that lies in that position (fig. 13). Northward across southeastern Utah as various units onlap on the Moenkopi and pinch out, the ore deposits occur in progressively higher stratigraphic units. In progressing northward in southeastern Utah the deposits first lie in the Shinarump member, then in order, the Monitor Butte member, the Moss Back member, and finally near the base of the undifferentiated Chinle formation.

The location of the deposits near the base of the Chinle may have been caused by the damming of vertically rising ore-bearing solutions by the bentonitic rocks of the Chinle. Open fractures that provided passageways for solutions below the Chinle may not have continued through the Chinle because the bentonitic beds were either not strong enough to support open fractures or were closed by the swelling of the clays when the ore-bearing solutions arrived. At the present time the Chinle rocks appear to be less permeable than those of the Moenkopi, but at some time in the past the Chinle formation may have been composed largely of beds of volcanic material such as glass shards. This

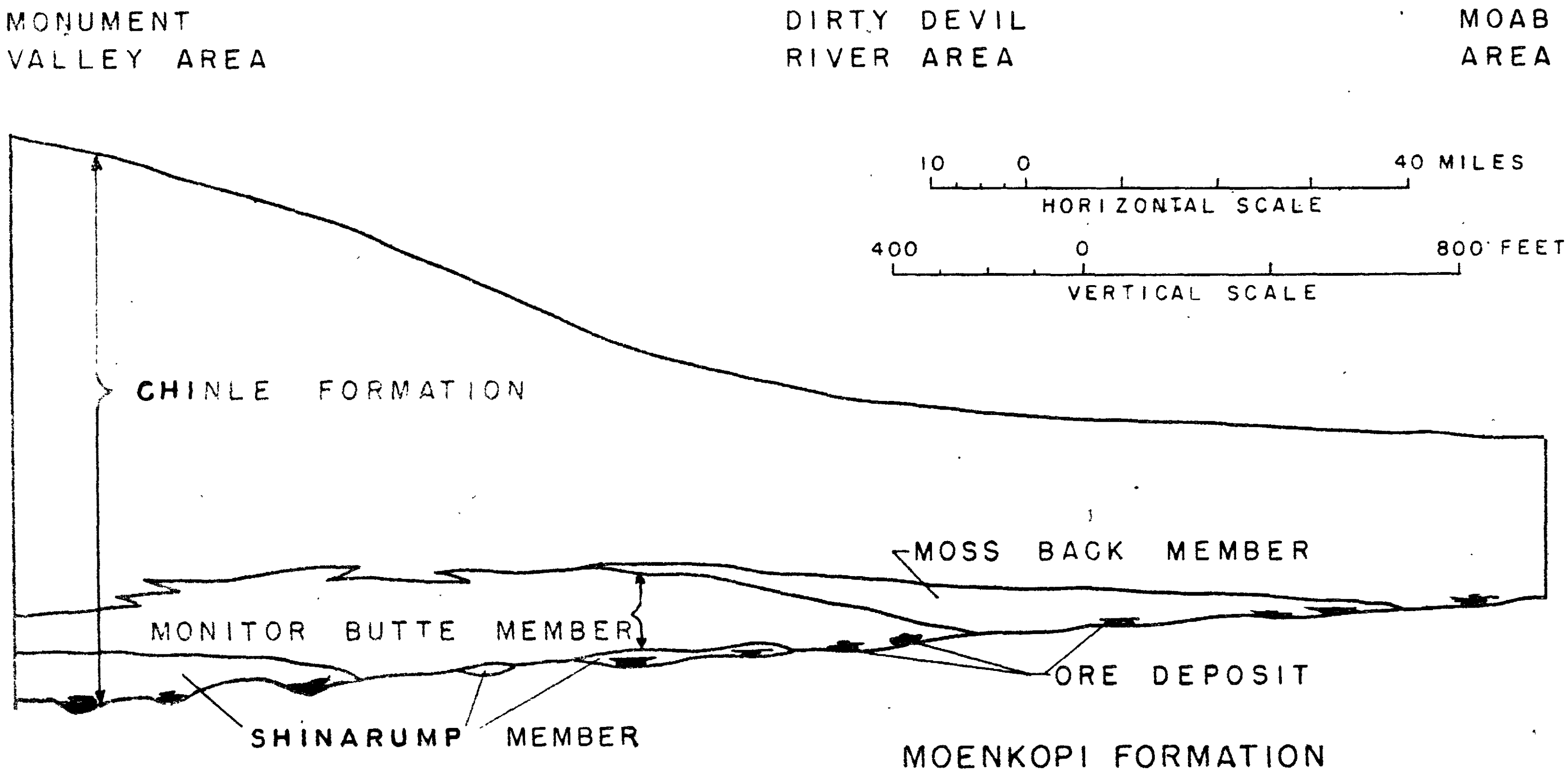


FIGURE 13.--GENERALIZED CROSS SECTION SHOWING DISTRIBUTION OF ORE DEPOSITS IN THE CHINLE FORMATION.

volcanic material may have made the Chinle more permeable than the Moenkopi, and vertically descending solutions were dammed and then migrated laterally on top of the Moenkopi.

The distribution of the deposits appears to have some relation to pinchouts and to continuity of the ore-bearing unit. The deposits in the Shinarump member occur near its northern limit where the Shinarump is discontinuous and are not as common to the south in Arizona and southwestern Utah where the Shinarump is more continuous. In addition, many of the deposits in the Moss Back member lie near its northern boundary in an area where the Moss Back is discontinuous.

The relation of the ore deposits to pinchouts may be caused by the traps that the pinchouts provide for the ore-bearing solutions. Solutions passing laterally thorugh the rocks would probably continue to a place close to a pinchout where reduced permeability might cause precipitation of the uranium. In areas where the Shinarump member or basal other Chinle sandstone is continuous, the ore-bearing solutions might continue through an area without being confined or delayed enough to form a deposit.

Wingate sandstone.--Only a few small deposits are known in the Wingate sandstone of southeastern Utah. No relation is apparent between these deposits and the regional stratigraphy. The deposits appear to be realted to secondary structural features such as faults and collapse structures.

Relation of ore deposits to local sedimentary features

The ore deposits in the Chinle formation appear to be related to at least two local sedimentary features: 1) channel fills and 2) lithologic features.

Channel fills

Almost all the ore deposits in the Chinle formation are related to channel fills (Finch, 1953; Witkind and others, 1953). Channel fills are probably the best guide to ore in these units. They range in size from 75 feet deep and several thousand feet wide to only minor scour fills less than a foot deep and only a few feet wide. The location of ore deposits does not seem to be related to the size or depth of the channel fills because deposits are found both in large and small channel fills.

Lithologic features

Most of the ore deposits in the Chinle formation appear to be associated with a host rock of specific lithologic characteristics. Rock of this character is considered favorable for the occurrence of ore and is distinguished by three features: 1) lenticular sandstone units that are bounded by mudstone lenses, 2) conglomerates composed both of quartzose and of siltstone or claystone pebbles, and 3) carbonaceous plant material.

In general, rock of this character occurs in channel fills or near pinchouts. It occurs near the bottom of channel fills and is associated with a more diversified direction of dip of the cross-strata than is usual in the unit (McKee and others, 1953).

The ore deposits can be related either to the physical presence of channels or pinchouts or to the presence of this rock type favorable for ore. As the channel fills, pinchouts, and this rock type are generally associated, an evaluation of their relative importance is difficult. Deposits are known in channel fills and near pinchouts that do not contain this favorable lithology, but deposits are also known that occur with this lithology and do not appear to be related to channel fills or pinchouts. These relations suggest, therefore, that both channel fills and pinchouts, as well as these favorable lithologic characteristics, acted independently in affecting the localization of ore.

SEDIMENTARY PETROLOGY

By R. A. Cadigan

Introduction

This section of the report contains the results of the petrological investigation of the Triassic and associated sedimentary rocks of part of the Colorado Plateau. Certain observed relations of petrographic features within uranium-ore samples are also reported with tentative interpretations. A discussion of petrographic terminology is included because it differs markedly from the field terminology used in the first part of the text.

Emphasis is placed on the fact that conclusions and interpretations presented here are based on incomplete data and are, therefore, subject to change.

Objectives

The petrographic study of the Triassic and associated sedimentary rocks has two general objectives: 1) to obtain evidence which will support some logical conclusions regarding the paleotectonic background of the accumulation of sediments during the late Permian, Triassic, and early Jurassic times, and 2) to detect relationships that may be present between the location of uranium-ore deposits and petrologic characteristics of the sedimentary host rocks.

Methods

To achieve the objectives, outcrop samples were collected from the Cutler formation of Permian age, the Moenkopi formation, Chinle formation, and Wingate sandstone of Triassic age, the Kayenta formation of Jurassic(?) age, and the Navajo sandstone of Jurassic and Jurassic(?) age. The samples were analyzed for measurable characteristics of texture and composition.

Texture was studied by disaggreating the samples and making a statistical analysis of the grain-size distribution. Composition was studied by obtaining volumetric mineral composition measurements of thin sections, by separating out representative loose mineral grains, concentrating samples of "heavy minerals," and having X-ray spectrographic analyses made of clay fractions.

Methods of textural analysis

Fine sediments are difficult to study in thin sections with ordinary equipment, and textural and compositional parameters of fine silts and clays raise many unresolved problems of interpretation. Thus, pertinent information can be obtained more easily from a study of sandstones and sandy siltstones than from claystones, shales, and fine-grained siltstones. Measured textural data presented in this report were arbitrarily restricted to sediments with a mean-grain size of 33 microns or larger.

Samples of 100 grams each were crushed to pass through a U. S. No. 5 sieve, digested in 400 ml of boiling 20 percent strength citric acid, cooled, acidified, with 20 to 50 ml of concentrated hydrochloric acid and washed 4 to 6 times to remove dissolved salts. The fines were separated and analyzed for size distribution by the pipette method. The sand-size material was analyzed for size distribution by sieving through a set of graduated sieves.

The statistical analyses of grain-size distribution produce measurements of a number of properties of the texture. Some of the measurements are familiar in a geologic sense and some, though common in statistics, are unfamiliar in geologic discussion.

Four textural concepts are used in this investigation of sedimentary rocks: 1) average or mean grain size, 2) sorting, 3) skewness, and 4) peakedness (or kurtosis). These properties may be said to define a grain-size distribution. They are derived from the first four statistical moments of the phi grain-size distribution. The term "phi" refers to a conventional scale obtained by translating sizes in millimeters into their respective negative logarithms to the base of two ($-\log_2$) (Krumbein, 1934).

To define the mathematical terms so that they may be applied in geologic discussion, it is necessary to impose connotations of meaning which are not strictly from the mathematical point of view, but which aid materially in their interpretation. Thus, the mean of the phi grain-size distribution may be interpreted as the average grain size of the rock. When the phi mean is converted to millimeters it approximates the geometric mean of the arithmetic distribution.

Average grain size of a rock is classified in terms of the Wentworth (1922) scale. Each size grade is represented by a range of mean-grain sizes. Part of the Wentworth scale with the range of mean-grain size for each grade is illustrated by table 5.

Table 5.--Phi mean and Wentworth grain-size classification

Wentworth grade	Phi mean in mm	Phi mean in phi units
Pebbles	64.000 to 4.000	-8.00 to -2.00
Granules	4.000 to 2.000	-2.00 to -1.00
Very coarse sand	2.000 to 1.000	-1.00 to 0.00
Coarse sand	1.000 to 0.500	0.00 to 1.00
Medium sand	0.500 to 0.250	1.00 to 2.00
Fine sand	0.250 to 0.125	2.00 to 3.00
Very fine sand	0.125 to 0.062	3.00 to 4.00
Silt	0.062 to 0.004	4.00 to 8.00
Clay	0.004 to 0.000	8.00 to infinity

The standard deviation is the second important parameter for describing the phi grain-size distribution of a sedimentary rock. The phi standard deviation may be interpreted as the measure of sorting.

As no common sorting classification based on the standard deviation is in general use, the system illustrated in table 6 has been adopted for this investigation.

The mean size and the standard deviation define a grain-size distribution if the distribution of sizes falls into a symmetrical bell-shaped frequency curve. The mean locates the center of the curve over the size scale and the standard deviation measures the spread or width of the curve.

Two other measurements-skewness and kurtosis--are used to define grain-size distribution which vary from the theoretical normal as defined by the mean and standard deviation. Skewness measures the lack of symmetry of the distribution and is generally marked by a spread of the size range on one side of the mean that is out of proportion to the spread on the other side of the mean. To express skewness in terms of sorting, one end is less well sorted than the rest of the distribution. The distribution is said to be skewed toward the end with the poorer sorting. Positive skewness in a grain-size distribution indicates a disproportional spread or poorer sorting in the finer sizes. Negative skewness indicates a disproportional spread or poorer sorting in the coarser sizes.

Table 6.--Classification of sorting.

Sorting	Phi standard deviation	The spread of the central 68 percent of the distribution nearest the mean in Wentworth grade sizes
Very well sorted	0 to 0.500	less than 1
Well sorted	0.500 to 1.000	1 to 2
Moderately sorted	1.000 to 2.000	2 to 4
Poorly sorted	2.000 to 4.000	4 to 8
Unsorted	4.000 to infinity	8 or more

Kurtosis is a measure of the peakedness of the distribution. In terms of sorting, kurtosis measures the relative degree of sorting that the center of a distribution bears to the two ends. A sand with a grain-size distribution which is better sorted in the center than on the two ends has a positive kurtosis. If it is poorer sorted in the center, it has a negative kurtosis.

The basis for comparison of sorting in various parts of a distribution is the theoretical normal distribution; skewness and kurtosis represent measurements of average deviations from the theoretical normal distribution defined by the mean and standard deviation.

For comparative purposes certain ranges of values of skewness and kurtosis are given verbal classifications as shown in tables 7 and 8.

Textural parameters that are used to describe stratigraphic or lithologic units are generally reduced to a system of verbal classifications. However, for regional comparisons of tabulations of data, numerical values are used.

Table 7.--Classification of skewness.

Description	Phi skewness coefficient
Slightly skewed	0.00 to 1.00
Moderately skewed	1.00 to 2.00
Highly skewed	2.00 to infinity
Negatively skewed	All negative values

Table 8.--Classification of kurtosis or peakedness.

Description	Phi kurtosis coefficient
Flattened distribution	Less than -1.00
Normal	-1.00 to 1.00
Moderately peaked	1.00 to 10.00
Highly peaked	10.00
Very highly peaked	20.00 or larger

Methods of compositional analysis

Mineral composition was determined from the study of thin sections made from selected fragments of each sample. The thin section was etched with hydrofluoric acid and stained with sodium cobaltinitrite in the method described by Chayes (1952). Potash feldspar and potassium-bearing clays were stained a canary to golden yellow by this process. The thin section was then covered with a conventional cover glass using cool rather tacky uncooked Canada balsam. The slide was allowed to air dry for 2 weeks or more before being trimmed. Xylol was used sparingly and only for cleaning purposes.

The proportion of mineral components was measured by means of a petrographic microscope in conjunction with a point-count stage and a cell counter similar to those described by Chayes (1949). Five hundred counts were made on each thin section to obtain a measure of the average proportional area of the thin section occupied by each mineral or mineral group being counted.

In this study it has been convenient to group the minerals in the rocks into 10 mineral groups. The mineral groups and their assigned minerals are listed below.

Mineral group	Assigned minerals or rock fragments
Quartz	Quartz, quartz overgrowths
Hydromica	Illite, sericite, chlorite, "heavy minerals," fragments of micaceous metamorphic rocks
Potash feldspar	Orthoclase, microcline
Kaolin	Kaolinite group of clays, and kaolin mud--a mixture of kaolinite clays, and ground-up quartz and feldspar with minor amounts of carbonate and other clays
Cements	Calcite, gypsum, chalcedony, dolomite, barite, iron oxides, interstitial ore minerals, other interstitial chemical deposits
Quartzite	Quartzite and quartz schist fragments
Tuffaceous material	Silicified tuff fragments, chert, montmorillonite, rhyolite fragments, other volcanic material
Mica	Muscovite, biotite
Plagioclase	Plagioclase feldspars
Miscellaneous	Minerals and mineral mixtures which are not readily identified or assigned to other mineral groups such as highly altered opaque heavy minerals or basic igneous rock fragments

A sedimentary rock that contains more than 50 percent cement is classified as a chemically deposited rock. A rock that contains more than 50 percent detrital components is classified as a detrital rock and the chemically deposited constituents are not considered in the classification of the rock.

For detrital rock classification purposes the detrital mineral groups are consolidated further into four general components as follows:

1. Quartz, (quartz, quartzite)
2. Tuffaceous material
3. Feldspar (potash feldspar, kaolin, plagioclase)
4. Micas (hydromica, mica, miscellaneous)

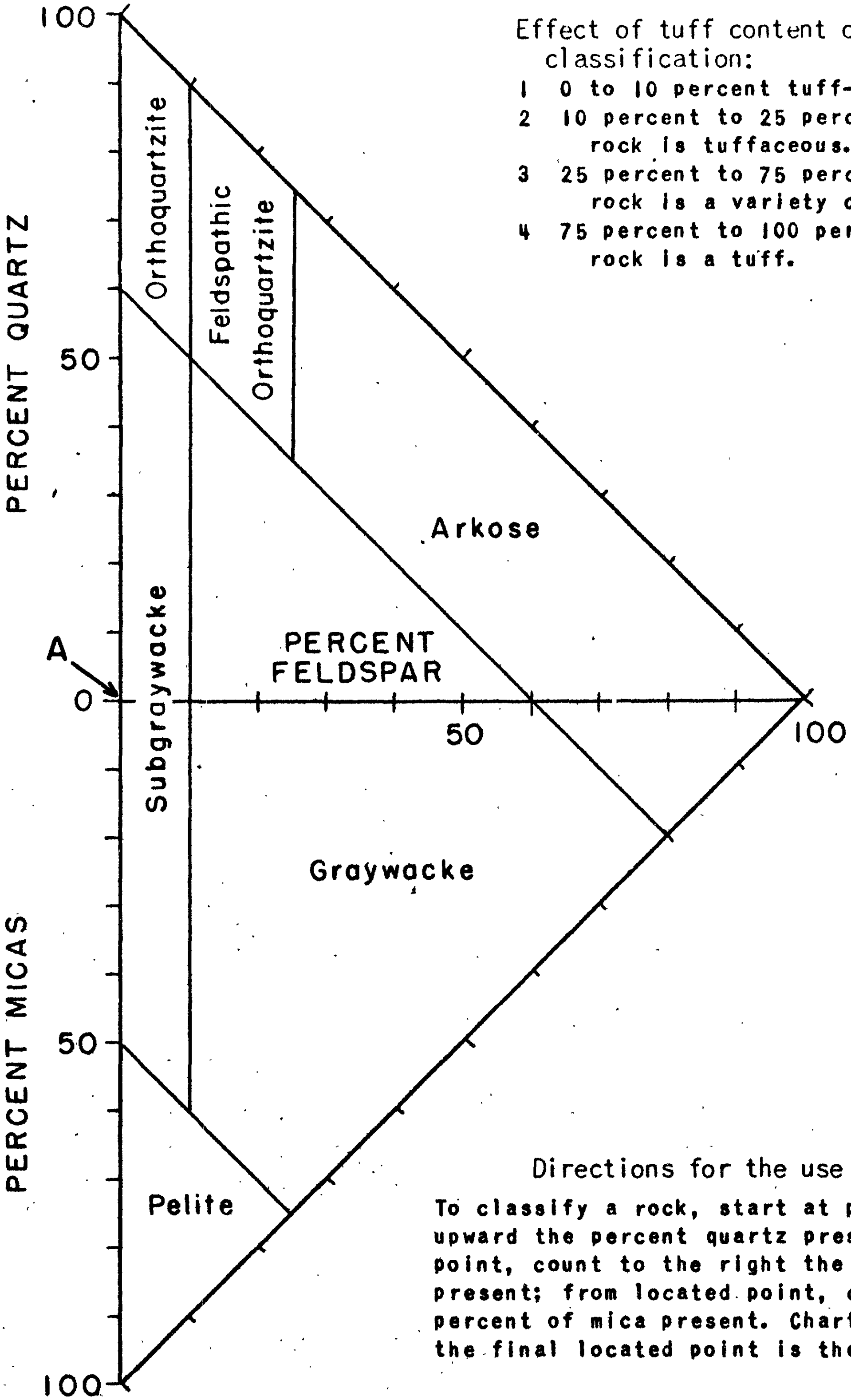
Rocks are classified according to table 9 or as illustrated in figure 14. This consolidation of minerals is patterned after that of Krynine (1948); however, the role of tuffaceous material is, as far as the authors know, unique to this paper. Tuffaceous material is combined with quartz in figure 14 for practical reasons. An isometric projection would be required to illustrate a four-dimensional classification; such a diagram is difficult to use and for most detrital sedimentary rocks would be unnecessarily complicated. In rocks where the separation of fragments of silicified tuff from chert is questionable the chert may be added in with quartz as proposed by Krynine (1948). In rocks where fragmental ruff is identified, it modifies the classification made with the tuff counted as quartz.

Table 9.--The petrologic classification of detrital sedimentary rocks.

(After Pettijohn, 1949, and Krynine, oral communication, 1952).

Classification		Quartz plus Tuffaceous material (percent)	Feldspar (percent)	Micas (percent)
Orthoquartzite	Range:_/	70 through 100	0 to 10	0 to 20
	Typical:	85	5	10
Feldspathic orthoquartzite	Range:	53 through 90	10 to 25	0 to 20
	Typical:	75	15	10
Graywacke	Range:	0 through 70	10 through 80	20 to 75
	Typical:	50	20	30
Subgraywacke	Range:	17 through 80	0 to 10	20 to 75
	Typical:	60	5	35
Arkose	Range:	0 through 75	25 through 100	0 to 20
	Typical:	50	40	10
Pelite	Range:	0 through 25	0 through 25	75 through 100
	Typical:	5	15	80

_/ The use of "through" implies inclusion of the upper limit; the use of "to" implies exclusion of the upper limit. Example: 70 through 100 implies that values of 100 percent are possible; 10 to 20 implies that a value of 20 percent is not possible without a change of classification.



Effect of tuff content on rock classification:

1 0 to 10 percent tuff--no effect.
2 10 percent to 25 percent tuff--rock is tuffaceous.
3 25 percent to 75 percent tuff--rock is a variety of tuff.
4 75 percent to 100 percent tuff--rock is a tuff.

Directions for the use of chart:

To classify a rock, start at point "A", count upward the percent quartz present; from located point, count to the right the percent feldspar present; from located point, count downward the percent of mica present. Chart area containing the final located point is the rock classification.

Figure 14.--ILLUSTRATION OF THE PETROLOGIC CLASSIFICATION OF DETRITAL SEDIMENTARY ROCKS(AFTER PETTIJOHN, 1949, AND

The amount of tuff present modifies the rock classification in the following manner:

1. If there is less than 10 percent tuffaceous material, the rock classification is not affected:

2. If there is 10 percent to 25 percent of tuffaceous material, the rock name is modified by the word "tuffaceous," i.e., tuffaceous arkose.

3. If there is 25 percent to 75 percent of tuffaceous material, the rock name designates a variety of tuff, i.e., graywacke tuff.

4. If there is 75 percent or more of tuffaceous material, the rock is an unmodified tuff.

Heavy mineral studies have not been completed and results are not presented in this report.

Results

For the purpose of this report preliminary estimates of the composition of some Permian and Jurassic formations are provided. These estimates have been made by selecting thin sections which were made from representative sandstones and siltstones, making a point count of mineral composition using 100 counts and classifying rock units on the basis of the information obtained. The classification is adequate for the one location. A more thorough study using many more samples will be necessary to determine regional variations. The classification of a rock unit may change completely from one area to another. An arkose may grade into an orthoquartzite.

Data, sufficiently complete to permit regional comparisons, have been obtained for the Shinarump and other lower Chinle sandstones only.

The genetic interpretations associated with the terms ortho-quartzite, graywacke, and arkose by Pettijohn (1949) and Krynine (oral communication, 1952) have been tested and found applicable with slight modification to the sediments of the Colorado Plateau.

The thick sequence of continental basin or structural trough sediments of Mesozoic and late Paleozoic age found in the Colorado Plateau region might be expected to contain sediments related to tectonic conditions that varied from extreme uplift to quiescence. Sediments of the type associated with deposition in deep marine basins would be expected to be rare.

Genetically, then, the sediments should range from orthoquartzites to arkoses. In contrast, graywackes which are related to subaqueous troughs or basins should be rare except in small localized deposits. Observations to date generally confirm this theoretical concept.

One feature casts some doubt on the genetic interpretations associated with the system of classification. This is the presence of hydromica clay, which is characteristic of the graywacke series, as the dominant clay mineral group in sediments which otherwise appear to have been derived from a granitic igneous source or silicic-alkalic volcanic debris. This problem is dealt with to some extent in the section on clays, but the final answer must come from the clay mineralogists.

Several charts and tables which contain data in summarized form, are assembled as appendices to this report. Appendix I is a summary of grain-size analysis data on geologic formations treated in this report. Appendix II is a set of tables giving the results of point-count analyses of thin sections of individual sandstone samples from the Shinarump member of the Chinle formation at certain geographic localities; appendix III gives the results for the Monitor Butte member of the Chinle formation; appendix IV gives the results for the Moss Back member of the Chinle formation; and appendix V gives the results for the Petrified Forest member of the Chinle formation.

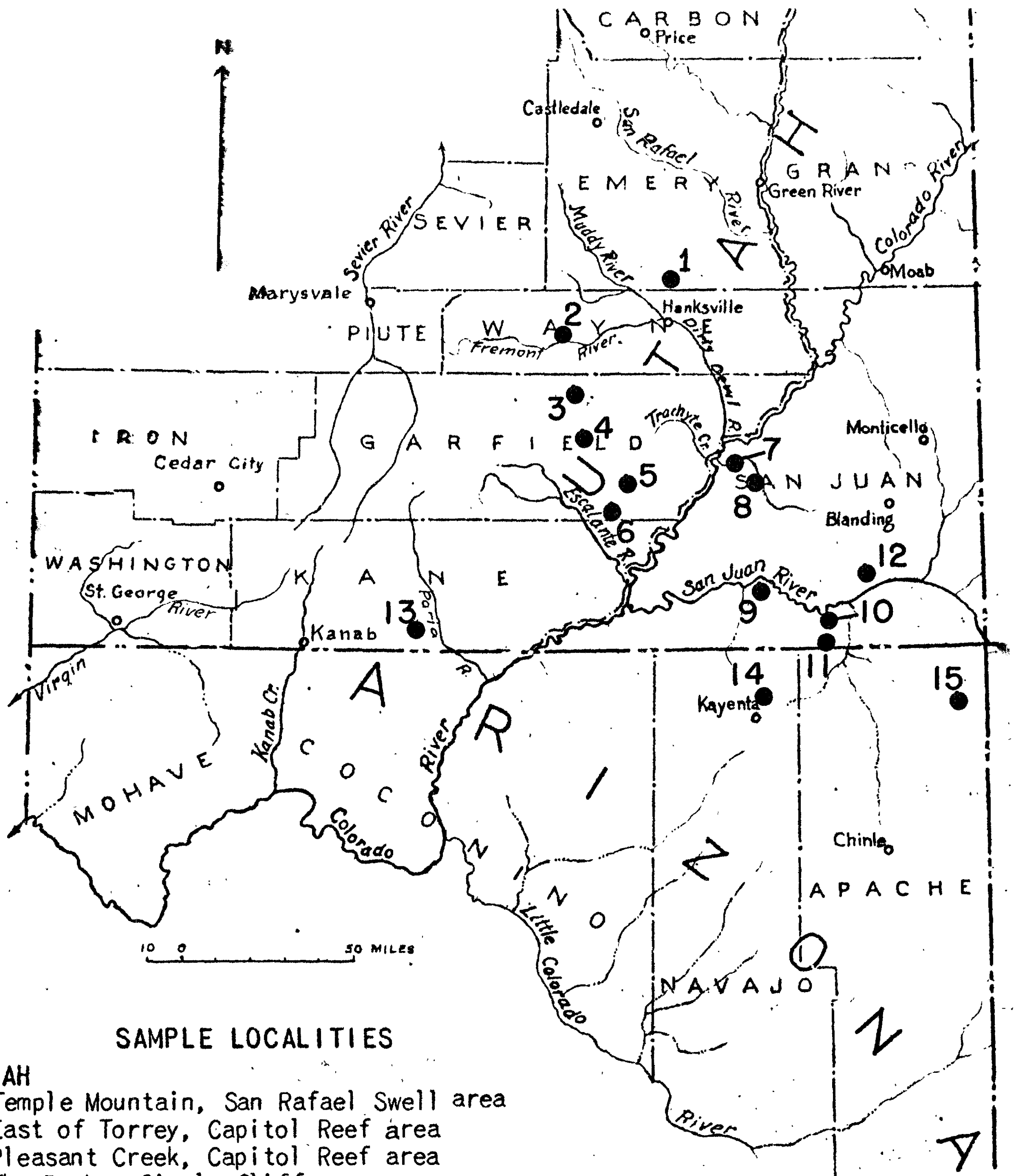
Permian rocks

Cutler formation

Cedar Mesa sandstone member.--The oldest rocks studied are those of the Permian Cutler formation and its various members. The lowest member, the Cedar Mesa sandstone, was examined in the field and in thin section, and grain-size analyses were completed on seven samples. The unit is a light- or reddish-colored massive appearing sandstone with conspicuous large-scale cross-strata. The Cedar Mesa is composed of sands that are, on the average, very fine grained and have moderately well-sorted, moderately skewed, and highly peaked grain-size distributions.

The Cedar Mesa sandstone is composed typically of very fine subangular to subrounded grains of quartz, feldspar, chert, and mica cemented with carbonate (predominantly calcite) cements. The variation in the samples collected suggests that the Cedar Mesa has zones of both highly cemented and friable sand.

Composition in terms of point-count mineral groups based on 100 counts from a thin section of Cedar Mesa sandstone from the northeastern corner of the Monument Valley (Poncho House) area (fig. 15) is shown below.



SAMPLE LOCALITIES

UTAH

1 Temple Mountain, San Rafael Swell area
2 East of Torrey, Capitol Reef area
3 Pleasant Creek, Capitol Reef area
4 The Peaks, Circle Cliffs area
5 Muley Twist, Circle Cliffs area
6 Silver Falls, Circle Cliffs area
7 Happy Jack mine, White Canyon area
8 Frey Canyon, White Canyon area
9 Monitor Butte, Monument Valley area
10 Poncho House, Monument Valley area
11 Monument No. 2 mine, Monument Valley area
12 Comb Wash area
13 Paria area

ARIZONA

14 Owl Rock, Monument Valley area
15 Carrizo Mountains area

Figure 15.--INDEX MAP OF PARTS OF ARIZONA AND UTAH SHOWING

Mineral group	Percent by volume
Quartz	49
Potash feldspar (orthoclase)	11
Quartzite fragments	1
Plagioclase (albite)	5
Mica (muscovite)	1
Cement (mostly calcite)	33

The classification of the rock is based on the following detrital components:

Component	Percent by volume
Quartz (quartz plus quartzite)	75
Feldspar (potash feldspar plus plagioclase)	24
Micas	1

The Cedar Mesa is a feldspathic orthoquartzite in the Poncho House area (fig. 15).

Organ Rock member.--The Organ Rock member of the Cutler formation overlies the Cedar Mesa sandstone member. Thin sections of the Organ Rock were examined and grain-size analyses were completed on 14 samples. The unit is a dark-colored reddish earthy-weathered sequence of alternating nonresistant siltstone and slightly resistant sandstone strata.

Based on the average grain-size distribution measurements (appendix I) the coarser-textured strata of the Organ Rock member are composed of coarse sandy siltstone and very fine grained silty sandstone with moderately well-sorted, moderately skewed, and moderately peaked grain-size distributions.

The Organ Rock siltstone and silty sandstone strata are composed typically of subangular to subrounded grains of quartz, feldspar, and heavy minerals and minor igneous or metamorphic rock fragments. The constituents are tightly bound together by interstitial reddish iron-oxide-stained hydromica clay, and isolated patches of carbonate (dominantly calcite) cements.

Composition in terms of point-count mineral groups based on 100 counts from a thin section of a representative Organ Rock sandy siltstone from the northeastern corner of the Monument Valley (Poncho House) area (fig. 15) is shown below:

Mineral group	Percent by volume
Quartz	48
Potash feldspar (orthoclase)	16
Hydromica (red iron-oxide-stained(?)	18
Quartzite	1
Plagioclase (albite)	10
Cement (mostly calcite)	4
Miscellaneous (leucoxene, opaque iron oxide pellets)	3

As an exception to the above, some Organ Rock strata contain kaolin as the dominant clay. The kaolin occurs interstitially.

The classification of the rock is based on the following detrital components:

Component	Percent by volume
Quartz	51
Feldspar	27
Micas	22

The Organ Rock is at most places a graywacke, but, at a few places, it is an arkose. Its classification as a graywacke is due to the high proportion of hydromica clay. The significant amount of rock fragments considered essential by Pettijohn (1949) and others is not present; however, the hydromica might be considered by some petrographers as being derived from shales or phyllites.

DeChelly sandstone member.--The DeChelly sandstone member of the Cutler formation lies above the Organ Rock in parts of southeastern Utah and northeastern Arizona. The DeChelly sandstone was examined in the field and in thin section, and grain-size analyses were completed on seven samples.

The unit is a light-colored to reddish massive sandstone unit with conspicuous large-scale cross-strata. Based on the average of the grain-size distribution measurements (appendix I), the DeChelly is composed of sands that are very fine grained and have well-sorted, slightly skewed, and highly peaked grain-size distributions.

The DeChelly sandstone is composed typically of very fine subrounded to subangular grains of quartz, feldspar, various heavy minerals, and grains of altered tuff loosely cemented by interstitial montmorillonite, hydromica or kaolin clay, reddish iron oxides, and isolated patches of carbonate cement.

Composition in terms of point-count mineral groups based on 100 counts from a thin section of a representative DeChelly sandstone in the Monitor Butte area (fig. 15) is shown below:

Mineral group	Percent by volume
Quartz	67
Potash feldspar (orthoclase)	11
Hydromica	2
Tuffaceous material	10
Plagioclase (albite)	5
Cement	4
Miscellaneous	1

The classification of the rock is based on the following detrital components:

Component	Percent by volume
Quartz	70
Feldspar	17
Micas	3
Tuffaceous material	10

The DeChelly sandstone member of the Cutler formation may be described as a tuffaceous feldspathic orthoquartzite in part, but examination of other thin sections indicates that the unit varies in classification through feldspathic to arkose in the Comb Wash area (fig. 15).

Hoskinnini tongue.--The Hoskinnini tongue of the Cutler formation lies above the DeChelly or above the Organ Rock where the DeChelly is absent. The Hoskinnini is the uppermost member of the Cutler and forms the top unit of the Permian system. The Hoskinnini tongue was examined in the field and in thin section, and grain-size analyses were completed on 13 samples.

The unit is a light- to reddish-colored assemblage of thin horizontally to irregularly bedded sandstone and siltstone strata. Some of the strata are resistant to weathering and others are weakly resistant. Due to the lack of conspicuous well-defined characteristics in the outcrop, recognition depends to a large extent upon the presence of medium or coarse sand grains anomalously present in the finer-grained sandstone strata.

Based on the average of the grain-size distribution measurements (appendix I) the sandy strata of the Hoskinini tongue are composed of very fine grained sands with moderately sorted, slightly skewed, moderately peaked grain-size distributions.

The Hoskinnini is composed typically of very fine to coarse subrounded grains of quartz and feldspar. In some samples the grains of quartz and feldspar occur in a matrix of kaolin in the presence of isolated patches of carbonate (mostly calcite) cements; in other samples they occur in a continuous red iron-oxide-stained carbonate cement, without matrix.

Composition in terms of point-count mineral groups based on 100 counts from each of three thin sections of representative Hoskinnini tongue sandstone in southeastern Utah and northeastern Arizona (Poncho House, Monitor Butte, and Comb Wash) (fig. 15) is shown below:

Mineral group	Percent by volume
Quartz	59
Potash feldspar (orthoclase, microcline)	8
Kaolin	10
Hydromica	1
Plagioclase (albite)	3
Cement	19

The classification of the rock is based on the following detrital components:

Component	Percent by volume
Quartz	73
Feldspar	26
Micas	1

The Hoskinnini tongue of the Cutler formation may be described generally as an arkose with some thin beds suggestive of what Pettijohn 1949, p. 259) refers to as a tectonic arkose, a coarse sediment derived from a rapidly eroding granitic land mass resulting from abrupt tectonic uplift.

Conglomeratic facies of the Cutler formation.--The conglomeratic facies of the Cutler formation, which is present chiefly along the flanks of the granitic and metamorphic crystalline rocks that comprise the Uncompahgre highland, has not been studied in thin section. The type Cutler has been observed in the field, however, and grain-size analyses have been completed on two samples.

The unit consists of reddish- to purplish-colored thick-bedded sandstone, pebbly sandstone, conglomerate, and fanglomerate strata.

Based on the average of the grain-size distribution measurements (appendix I) the sandy facies of the Cutler are made of medium-grained sands with moderately sorted, moderately skewed, and moderately peaked grain-size deistributions.

The composition has not been determined from point-count measurements, but field examination reveals the presence of coarse fragments of pink feldspar, quartz mica, and a kaolin-like clay matrix; these features identify the Cutler as an arkose.

Triassic rocks

Moenkopi formation

The oldest of the Triassic series of sedimentary rocks in the Colorado Plateau region is the Moenkopi formation. The Moenkopi was studied in the field and in thin section. Grain-size analyses were completed on 21 samples of the sandstone or sandy siltstone facies.

The unit is a silty sandstone and siltstone unit with generally uniform pale reddish-brown color, weathering to "shaly" slopes which are littered with ripple-marked platy sandstone fragments. Based on the average of the grain-size distribution measurements (appendix I), the coarser strata of the formation consist of very fine grained sands with moderately sorted, moderately skewed, and moderately peaked grain distributions.

The Moenkopi siltstone and sandstone strata are composed of subangular to subrounded grains of quartz and feldspar, rounded heavy mineral grains, angular chert grains, and flakes of mica. The detrital grains are bound and cemented by an interstitial matrix of reddish iron-oxide-stained hydromica clay and carbonate (dominantly calcite and dolomite) cements which occur in isolated patches and as disseminated subhedral crystals. Siltstones vary from sandstones mostly in the increased angularity of the grains in the siltstones, as well as in the increased difficulty of identification of minerals and mineral relationships.

Composition of the siltstone and the sandstone facies in terms of point-count mineral groups based on 100 counts each from a thin section of representative Moenkopi siltstone in the Monitor Butte area (fig. 15) and a thin section of typical Moenkopi very fine grained sandstone in the Poncho House area in northeastern Arizona are as shown below:

Mineral group	Sandstone Percent by volume	Siltstone Percent by volume
Quartz	47	40
Potash feldspar	12	12
Kaolin	--	1
Hydromica	4	12
Plagioclase	8	12
Mica	--	1
Cement	29	21
Miscellaneous	--	1

The classification of the rocks is based on the following detrital components:

Component	Sandstone Percent by volume	Siltstone Percent by volume
Quartz	66	51
Feldspar	28	32
Micas	6	17

The typical very fine-grained sandstone and the typical siltstone of the Moenkopi are assigned to the arkose series.

Chinle formation.

Shinarump member.--The Chinle formation lies immediately above the Moenkopi in southeastern Utah. The Shinarump member is the basal unit of the Chinle over much of the southern part of the Plateau region.

It has been studied in the field and in thin section in greater detail than any of the previously described units. Grain-size analyses were completed on 83 samples.

Thin sections from 28 of the samples were analyzed by point-count method and 500 counts per section were made in 10 traverses of 50 counts each. Many of the slides were made from semifriable material which resulted in loss of material from the section during preparation. Because of losses of material and other damage to the thin sections, voids were not counted and volume was calculated on the basis of percent mineral volume rather than percent rock volume. One constituent which probably suffers a disproportionate loss in the damaged thin sections is the kaolinite group of clay minerals.

The Shinarump member is typically a light-colored sandstone, conglomeratic sandstone, or conglomerate. In field exposure it presents a strong color and texture contrast with the underlying dark-red siltstones of the Moenkopi but may grade upward into overlying sandstones of the Chinle. Based on the average of the grain-size distribution measurements (appendix I) the Shinarump contains fine-grained sandstones with poorly sorted to moderately sorted, slightly skewed, moderately peaked grain-size distributions.

The Shinarump sandstones are composed of subrounded to subangular grains and granules of quartz and feldspar and some altered tuffaceous material bound in a matrix of kaolin mud. The sands are commonly very loosely cemented with isolated patches of carbonate (predominantly calcite) and iron-oxide cements.

One or more samples from each of the numbered areas shown on figure 15 except 1, 14, and 15 were used in the composition analysis. The regional average composition based on 28 thin sections is as follows:

Mineral groups	Percent by volume
Quartz	71.0
Potash feldspar	4.6
Kaolin	12.5
Hydromica	1.5
Quartzite	0.5
Tuffaceous material	3.2
Plagioclase	0.4
Mica	0.3
Cement	6.0
Miscellaneous	0,0

The classification of the rock is based on the following average amounts of detrital components:

Component	Percent by volume
Quartz	76
Feldspar	19
Micas	2
Tuffaceous materials	3

The average Shinarump sandstone in the area sampled is a feldspathic orthoquartzite but composition varies from bed to bed and between areas (appendis II). Shinarump samples from the Paria River area (fig. 15) are tuffaceous feldspaathic orthoquartzites and contain an average of 15 percent altered tuffaceous material; this is suggestive of a southern or southwestern source of volcanic debris. Shinarump samples from southern Monument Valley (fig. 15) are arkoses, averaging 31 percent feldspar and kaolin; this is suggestive of a southeastern granitic source.

Further work will be necessary to substantiate these regional variations as evidence of contributions from differen source areas.

Table 10 summarizes the percentage composition of Shinarump sandstones for the different areas sampled (fig. 15).

Table 10.--Percent mineral components by volume (Shinarump member of the Chinle formation).

Area	Quartz	Feld-spar	Micas	Tuffaceous materials	No. of samples	Location (fig. 15)	Classification
Paris River	70	14	1	15	2	13	tuff. feld. orthoqzte.
S. Monument Valley	66	31	3	0	3	14	arkose
N. Monument Valley	81	14	4	1	7	10, 11	feld. orthoqzte.
Monitor Butte	75	15	3	7	2	9	feld. orthoqzte.
White Canyon	80	17	1	2	7	7	feld. orthoqzte.
Capitol Reef	73	22	1	4	2	2, 3	feld. orthoqzte.
Circle Cliffs	73	22	1	4	5	5, 6	feld. orthoqzte.

<u>Monitor Butte member.</u>--In different areas various units of the Chinle formation lie just above the Shinarump member. These units range from claystone to pebbly sandstone. The contact may be marked by either an abrupt or a gradational lithologic change. The Monitor Butte member overlies the Shinarump member of the Chinle over a large area of the Plateau region. Sandstones of the Monitor Butte have been examined in the field and in thin section. Grain-size analyses were completed on 12 samples of the sandstone or sandy siltstone facies.

The unit consists of greenish limy sandstone, siltstone, and claystone strata. The general appearance in outcrop is that of medium-bedded sandstone ledges separated by thicker intervals of siltstone and claystone. The sandstone ledges show horizontal, irregular, or rippled lamination with paper-thin micaceous clay laminae between the sand laminas. The sandstone fractures in a limestone pattern and splits easily along the horizontal laminae within each block.

Based on the average of the grain-size distribution measurements (appendix) the Monitor Butte sandstone is very fine grained with poorly sorted, slightly skewed, and moderately peaked grain-size distributions.

The Monitor Butte sandstones and sandy siltstones are composed of subangular grains of quartz, feldspar, mica, and tuffaceous materials. Hydromica clay or in some cases kaolinite or montmorillonite clays are present as a sparse matrix, or in pods, or thin laminae. The sands are usually well cemented with carbonate and iron-oxide cements. Two types of microscopic structure are seen in thin section; one is the quartz-grain-quartz-overgrowth mosaic (as seen with crossed nicols) interbedded with clay laminae; the other type is the heterogeneous arrangement of the components mentioned above, with the grains suspended in matrix and cement, with irregular spacing between grains. The thin sections that show the mosaic-type structure contain much less feldspar than those that show the heterogeneous-type structure.

Composition of the sandstone and sandy siltstone facies of the Monitor Butte member in terms of mineral groups based on the average of the results of standard point-count analysis of 17 thin sections (appendix III) is as follows:

Mineral group	Percent by volume
Quartz	62.5
Potash feldspar	5.0
Kaolin	8.9
Hydromica	3.2
Quartzite fragments	0.2
Tuffaceous material	5.3
Plagioclase	0.6
Mica	0.8
Cement	13.5

The classification of the Monitor Butte sandstone and sandy siltstone strata is based on the following average amounts of detrital components:

Component	Percent by volume
Quartz	74
Feldspar	16
Micas	4
Tuffaceous material	6

The average Monitor Butte sandstone is a feldspathic orthoquartzite, but the sandstones vary markedly both locally and regionally (appendix III). Like the Shinarump, Monitor Butte samples from the Paria River area (fig. 15) are tuffaceous feldspathic orthoquartzites averaging 20 percent altered tuffaceous material. Samples from the Capitol Reef area (fig. 15) are arkoses with an average feldspar and kaolin content of 34 percent by volume.

The composition of the Monitor Butte sandstone in the Paris River area (fig. 15), like that of the Shinarump, supports the hypothesis of a western or southwestern source of volcanic material. The changes in ratios of the detrital components may be interpreted as indicating the existence of multiple sources of sediment for the basal Chinle.

Table 11 is a summary of the composition of the Monitor Butte member for the different areas sampled (fig. 15).

Table 11.--Percent mineral components by volume (Monitor Butte member).

Area	Quartz	Feld-spar	Micas	Tuffaceous material	No. of samples	Classification
Paria River	56	21	3	20	2	tuff. feld. orthoqzte.
N. Monument Valley	85	7	6	2	2	orthoquartzite
White Canyon	87	7	3	3	5	orthoquartzite
Circle Cliffs	72	17	4	7	5	feld. orthoqzte.
Capitol Reef	57	34	6	3	3	arkose

Moss Back member.-- Another basal sandy unit of the Chinle formation is the Moss Back member which may overlie either the Moenkopi formation or the Monitor Butte member of the Chinle formation (fig. 13). The sandstone strata of the Moss Back member have been examined in the field and in thin section. Grain-size analyses were completed on 13 samples.

The unit contains light-colored sandstones, pebbly sandstones, and conglomerates. Generally an exposure of the Moss Back consists of one or more very thick sandstone beds which form a resistant massive or compound ledge in the less resistant units near the base of the Chinle. Gray to greenish strata of claystone or clayey siltstone occur between beds in some localities but are not typical. The unit is generally conspicuously cross-stratified and in places fills channels at the base in the same manner as the Shinarump member.

Based on the average grain-size distribution measurements (appendix I) the sandstones of the Moss Back are very fine to fine grained with moderately to poorly sorted, moderately skewed, and moderately peaked, grain-size distributions.

The Moss Back sandstones are composed of detrital grains, matrix, and cement arranged in a heterogeneous type of microscopic structure. The detrital components are subrounded to subangular grains of quartz, orthoclase, albite, chert, tuffaceous material, mica, and a few heavy minerals. Other components are represented by subhedral carbonate (mostly calcite) crystals and reddish iron oxide-type cements interspersed with interstitial wads of kaolin, montmorillonite, or hydromica. Only one of the sandstones studied in thin section was constructed in the mosaic type of arrangement with quartz and feldspar grains in a sparse interstitial montmorillonitic matrix. The heterogeneous arrangement of components is typical of the Moss Back sandstone units.

The composition of the sandstone of the Moss Back member in terms of point-count mineral groups based on the averages of the results of standard point-count analyses of six thin sections (appendix IV) is as follows:

Mineral group	Percent by volume
Quartz	68.3
Potash feldspar	3.9
Kaolin	9.7
Hydromica	6.0
Quartzite fragments	0.1
Tuffaceous material	4.8
Plagioclase	1.2
Mica	0.6
Cement	5.4
Miscellaneous	0.0

The classification of the sandstones of the Moss Back member is based on the following average amounts of detrital components:

Component	Percent by volume
Quartz	72
Feldspar	16
Micas	7
Tuffaceous material	3

Based on the above figures the average Moss Back sandstone is a feldspathic orthoquartzite; however, none of the individual samples fall into this classificiation. There are two arkoses from the Temple Mountain area, and three orthoquartzites and one graywacke (hydromica type) from the White Canyon area (fig. 15). Not enough samples of Moss Back have been studied to be certain of regional differences, but the

Moss Back arkoses at Temple Mountain, the Monitor Butte arkoses at Capitol Reef, and the high-feldspar feldspathic orthoquartzites of the Shinarump from Capitol Reef and Circle Cliffs suggest a high feldspar content for the basal Chinle sandstones in the northwestern part of the Colorado Plateau area.

Pertified Forest member.--The Petrified Forest member of the Chinle overlies the Moss Back member in many areas. The Chinle may be easily divided into an upper and lower part with the boundary at the top of the Petrified Forest member. The lower part is dominated by dark grayish-green colors, variegated bentonitic shales, and pale-brown sandstones. The upper part is dominated by pale reddish-brown siltstones and sandstones, and grayish-green limestone and limy siltstone beds. The Petrified Forest member has been studied in the field and in thin section. Grain-size analyses were completed on four samples of sandstone. The Petrified Forest member is essentially a bentonitic siltstone-claystone unit but contains scattered discontinuous thin-, medium- and thick-bedded, moderately to poorly resistant sandstone beds, many of which are conspicuously cross-stratified.

Based on the average grain-size distribution measurements (appendix I), the Petrified Forest sandstones are very fine grained with poorly sorted, moderately skewed, and moderately peaked grain-size distributions.

The Petrified Forest sandstones are composed of subangular to sub-rounded grains of quartz, feldspar, tuffaceous material, and a few scattered flakes of mica in a matrix of montmorillonite and hydromica clay minerals. They are slightly cemented by subhedral carbonate crystals, and much reddish- to purplish-iron(?)-oxide stain is present. The microscopic structure of the sandstones as seen in thin section may be classified as heterogeneous.

Composition of the sandstone facies of the Petrified Forest member of the Chinle in terms of point-count mineral groups based on the average of the results of standard point-count analysis of two thin sections (appendix IV) from the Comb Wash area (fig. 15) is as follows:

Mineral group	Percent by volume
Quartz	51.9
Potash feldspar	7.3
Kaolin	0.6
Hydromica	6.6
Quartzite fragments	0.0
Tuffaceous material	32.1
Plagioclase	0.4
Mica	0.7
Cement	0.4
Miscellaneous	0.0

The classification of the Petrified Forest is based on the following average amounts of detrital components:

Component	Percent by volume
Quartz	52
Feldspar	8
Micas	7
Tuffaceous material	33

The average Petrified Forest sandstone in the Comb Wash area is an orthoquartzitic tuff. This conforms with the general impression of volcanic origin for much of the material making up the Petrified Forest member of the Chinle formation.

Owl Rock member.--The Owl Rock member of the Chinle formation overlies the Petrified Forest member. As discussed above, the boundary between the two members may also be used to divide the Chinle into an upper and lower part.

The Owl Rock member has been examined in the field and in thin section. Grain-size analyses were completed on four samples of sandstone or silty sandstone.

The unit is generally a siltstone-sandstone-limestone unit, pale dark-green and pale reddish-brown in color. The general appearance in outcrop is that of several moderately to poorly resistant rounded rough-surfaced limestone ledges separated by intergraded poorly resistant units of limy siltstone; the unit forms a slope thinly covered with limestone pellets 1 mm to 10 mm in diameter.

Based on the average grain-size distribution measurements (appendix I), the sandstones and silty sandstones of the Owl Rock member are very fine grained, with moderately sorted, slightly skewed, moderately peaked grain-size distributions.

The rocks of the Owl Rock member are composed of calcite and dolomite pellets and crystalline masses which contain subangular to subrounded grains of quartz, orthoclase, albite, tuffaceous material, and in some cases, biotite and muscovite, and a matrix of interstitial montmorillonite and chlorite types of clays. The ratios of chemical material to detrital material (including carbonate pellets) probably form a series. Many of the "limestone" beds consist of carbonate-pellet conglomerate and appear as such in the field exposure, as well as in thin section.

Composition in terms of point-count mineral groups based on 100 counts from a thin section of representative Owl Rock member sandstone (53 percent allogenic detritals plus 47 percent carbonates) from the Monitor Butte area (fig. 15) is as follows:

Mineral group	Percent by volume
Quartz	20
Potash feldspar	13
Hydromica (mostly chlorite)	9
Tuffaceous material	8
Plagioclase	3
Cement (mostly calcite, dolomite, iron oxide)	47

The classification of the Owl Rock sandstone is based on the following amounts of detrital components:

Component	Percent by volume
Quartz	38
Feldspar	30
Micas	17
Tuffaceous material	15

On the basis of the above measurements, the average Owl Rock member sandstone in the Monitor Butte area has the detrital composition of a tuffaceous arkose. The average "limestone" unit varies in composition within the same bed from a true limestone to what would probably be called a dolomite; this conclusion is based on field tests using 10 percent strength hydrocloric acid. No data are available on the proportion of total calcium to total magnesium in these beds.

Church Rock member.--The Church Rock member of the Chinle overlies the Owl Rock member and forms the uppermost unit of the Chinle in southeastern Utah. The sandstones and sandy siltstones of the Church Rock have been examined in the field and in thin section. Grain-size analyses were completed on seven samples. The unit is generally a dark reddish-brown unit which appears as a sequence of moderately resistant alternating thick sandstone and siltstone beds at the top of the Chinle. Some of the sandstone beds are cross-stratified.

Based on the average grain-size distribution measurements (appendix I), the sandstones and silty sandstones of the Church Rock are very fine grained with moderately sorted, moderately skewed, and moderately peaked grain-size distributions.

The sandstones and silty sandstones of the Church Rock are composed of subangular to subrounded grains of quartz, orthoclase, albite, some heavy minerals, flakes of mica, iron-oxide-stained interstitial hydromica, disseminated subhedral crystals of carbonate (mostly calcite) cement, and interstitial blobs of iron oxides.

Composition in terms of point-count mineral groups based on 100 counts from thin sections of a representative silty sandstone and of a sandy siltstone of the Church Rock member from the Monitor Butte and Comb Wash areas (fig. 15) respectively are as follows:

Mineral group	Percent by volume	
	Sandstone	Siltstone
Quartz	44	33
Potash feldspar	11	14
Hydromica	3	20
Tuffaceous material	0	0
Plagioclase	7	8
Mica	6	3
Cement	27	20
Miscellaneous	2	2

The classification of the Church Rock silty sandstone and the sandy siltstone is based on the following amounts of detrital components:

Component	Percent by volume	
	Sandstone	Siltstone
Quartz	60	41
Feldspar	25	28
Micas	15	31
Tuffaceous material	0	0

On the basis of the above measurements the average fine-grained sandstone of the Church Rock member of the Chinle formation in the Monitor Butte area (fig. 15) belongs to the arkose series, but the average siltstone is of the graywacke series. The difference in classification between the two samples results from the increased amount of hydromica clay minerals in the siltstone.

The Chinle formation in southwestern Colorado resembles the Church Rock member superficially but may be better referred to as undifferentiated Chinle. Compositional data based on thin-section study have not been determined. Grain-size analyses were completed on seven samples of sandstones and coarse siltstones. The rocks were found to be, on the average (appendix I), very fine grained silty sandstones with moderately sorted, moderately skewed, moderately peaked grain-size distributions.

Triassic and Jurassic rocks

Glen Canyon group

Wingate sandstone.-- The Wingate sandstone lies above the Chinle formation and forms the uppermost part of the Triassic rocks in southeastern Utah.

The Wingate has been examined in the field and in thin section. Grain-size analyses were completed on 44 samples of sandstone or sandy siltstone.

The unit consists of light-colored very thick bedded, massive cliff-forming sandstone strata. The general appearance of the unit in the outcrop is that of a high vertical cliff at the top of the dark-reddish slope formed by the Chinle formation. The Wingate contains conspicuous large-scale cross-strata.

Based on the average grain-size distribution measurements (appendix I), the sandstone of the Wingate is very fine grained with moderately to well-sorted, moderately skewed, highly peaked grain-size distributions.

The sandstones of the Wingate are composed of subrounded grains of quartz, orthoclase, microcline, albite, altered tuffaceous material, quartzite fragments, and some rounded heavy mineral grains. The matrix consists of a sparse amount of kaolinite, hydromica, or montmorillonite clay. The cement consists of some subhedral interstitial carbonate crystals and reddish iron(?) oxides that stain the matrix. The base of the Wingate is often marked by coarse to very coarse spherical grains of quartz, feldspar, quartzite, and chert (silicified tuff) in a matrix of very fine grained sand.

The composition of the Wingate sandstone in terms of point-count mineral groups based on 100 counts in two thin sections of representative sandstone from the Poncho House and Carrizo areas respectively (fig. 15) is as follows:

Mineral groups	Percent by volume		
	Poncho House	Carrizo	Average
Quartz	37	58	48
Potash feldspar	17	11	14
Kaolin	1	0	1
Hydromica	6	10	8
Tuffaceous material	23	2	12
Plagioclase	16	11	13
Cement	0	6	3
Miscellaneous	0	2	1

The classification of the Wingate sandstone in extreme northeastern Arizona is based on the following amounts of detrital components:

Component	Percent by volume		
	Poncho House	Carrizo	Average
Quartz	37	63	49
Feldspar	34	23	29
Micas	6	12	9
Tuffaceous material	23	2	13

On the basis of the above measurements the Wingate sandstone in northeastern Arizona may be said to range from a tuffaceous arkose to a feldspathic orthoquartzite. To obtain a significant mean composition and an idea of the distribution of components more work must be done. From the inspection of several thin sections, the Poncho House sample appears to represent one extreme but also one of many of the same general classification. The typical or more common sandstone is more similar in composition to the Carrizo sample.

The unexpected presence of tuffaceous material suggests either the reworking of old tuffaceous material (from the Chinle?) or the occurrence of volcanic activity synchronously with the deposition of the Wingate. The fact that the tuffaceous material is abundant in some strata and nearly absent in others supports the hypothesis of intermittent contemporaneous volcanism as the explanation. Additional work may establish regional distribution of the tuffaceous material in the Wingate.

Kayenta formation.--The Kayenta formation of Jurassic(?) age overlies the Wingate sandstone in much of the Plateau area.

The sandstones of the Kayenta have been examined in the field but not in thin section. Grain-size analyses were completed on 19 samples.

The unit is generally a light- to dark-reddish or brownish medium- to thick-bedded sandstone unit which forms a moderately resistant slope above the massive vertical cliff of the Wingate sandstone. Some of the sandstone beds contain cross-strata.

Based on the average grain-size distribution measurements (appendix I), the sandstones of the Kayenta are very fine grained with moderately to well-sorted, moderately skewed and highly peaked, grain-size distributions.

No thin-section data are available on the Kayenta formation. Previous work done on loose grain mounts of disaggregated sands from seven samples taken in southwestern Colorado indicated that the detrital grains in the Kayenta consist, on the average, of 16 percent potash and sodic feldspar, 6 percent fragments of silicified tuff and chert, 78 percent quartz, and a trace of mica. The Kayenta would be classified as a feldspathic orthoquartzite or an arkose depending upon the amounts of kaolin clay and sodic-calcic feldspars present. The rock is composed on the average of 81 percent sand, 9 percent silt and clay, and 10 percent soluble cements.

Navajo sandstone.--The Navajo sandstone overlies the Kayenta in much of the Colorado Plateau region.

The sandstones of the Navajo have been examined in the field, but not in thin section. Grain-size analyses were completed on 22 samples.

The unit is generally a light-colored thick-bedded sandstone. The appearance in outcrop is that of a massive light-colored sandstone with convex weathering surfaces and in most localities with conspicuous large-scale cross-strata that have been brought into relief by differential weathering along the contacts of the cross-strata.

Based on the average grain-size distribution measurements (appendis I), the sandstones of the Navajo are very fine grained, with well-sorted, moderately skewed, highly peaked grain-size distributions.

No thin-section data are available on the Navajo sandstone. Previous work done on loose grain mounts of disaggregated sand from 9 samples taken about 30 miles north of the Temple Mountain area (fig. 15) indicates that the detrital grains consist, on the average, of 82 percent quartz, 12 percent potash and sodic feldspars, and 3 percent chert and fragments of tuff. The rock is composed of 94 percent sand, 3 percent silt and clay, and 3 percent soluble cements. The Navajo would be classified as a feldspathic orthoquartzite.

Study of the clay mineral groups in the Triassic and associated formations

Clay fractions obtained in the grain-size analyses of Jurassic, Triassic, and Permian sandstones were submitted to a U. S. Geological Survey laboratory for identification by X-ray spectrometer. Acknowledgment is made of the help and cooperation of Alice D. Weeks who expedited the service requests and Mary E. Thompson and Evelyn Cisney who made the clay mineral identifications.

The results of the clay analyses are shown in tables 12 and 13. The percentages given in table 12 refer to the number of samples that contain the particular clay mineral group as the major constituent in the clay fraction. In table 13, the percentages refer to samples that contain the particular mineral group as the minor constituent in the clay fraction.

As an example, in a group of 54 sandstone and siltstone samples from the Shinarump member of the Chinle formation (table 12), 85 percent of the samples have kaolinite as the major clay mineral group, 11 percent have hydromica as the major clay mineral group, and 4 percent have montmorillonite as the major clay mineral group. Of the original 54 samples, 29 contain 2 or more detectable clay mineral groups (table 13), of which 17 percent have kaolinite as the minor clay mineral group and 83 percent have hydromica as the minor clay mineral group.

Table 12.--The percent of the samples of sandstone which contain one of the three clay mineral groups as the major clay mineral.

Units sampled	Number of samples	Kaolinite group (percent)	Hydromica group (percent)	Montmorillonite group (percent)
Navajo sandstone	17	71	23	6
Kayenta formation	9	78	22	0
Wingate sandstone	28	50	29	21
Chinle formation (exclusive of Shinarump member)	25	11	81	8
Shinarump member	54	85	11	4
Moenkopi formation	18	28	72	0
Hoskinnini tongue	6	100	0	0
DeChelly sandstone	4	50	25	25
Organ Rock tongue	7	43	57	0

Table 13.--The percent of the samples of sandstone which contain one of the three clay mineral groups as the minor clay mineral.

Units sampled	Number of samples	Kaolinite group (percent)	Hydromica group (percent)	Montmorillonite group (percent)
Navajo sandstone	10	40	40	20
Kayenta formation	6	33	67	0
Wingate sandstone	19	32	63	5
Chinle formation (exclusive of Shinarump member)	13	85	15	0
Shinarump member	29	17	83	0
Moenkopi formation	14	64	29	7
Hoskinnini tongue	6	0	33	67
DeChelly sandstone	3	33	67	0
Organ Rock tongue	8	38	62	0

The typical clays in the sandstone and siltstone strata of the Shinarump member of the Chinle formation in order of abundance are kaolinite and hydromica. The microscopic study of thin sections of samples from the above rocks indicates that the kaolinite is mostly allogenic and detrital and was probably derived from potash and sodic feldspars during the weathering of granitic rocks or fanglomerates. The presence of kaloinite as the dominant clay supports other petrographic evidence that the Shinarump member is essentially an arkosic unit.

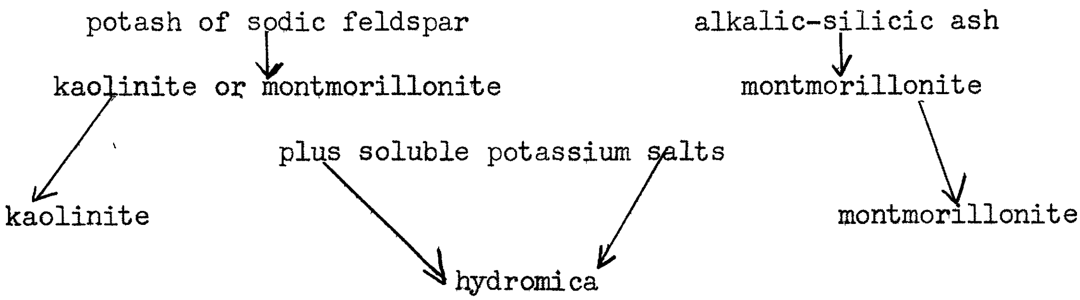
The hydromica may be allogenic detrital clay, but petrographic evidence suggests that the hydromica is authigenic and was derived from the alteration of montmorillonite or volcanic ash in the presence of soluble potassium salts. The potassium salts would originate from the breakdown of potash feldspar or during the alteration of alkalic-silicic volcanic glass, and other tuffaceous debris.

The Chinle has long been noted as a formation which contains much altered volcanic debris, yet from table 12 it may be seen that 81 percent of a group of 25 sandstone and siltstone samples contain hydromica as the major clay minerals and only 8 percent contain montmorillonites as the major clay minerals. The minor clay minerals in the 13 samples which contain a second clay mineral group are kaolinites in 85 percent of the cases and hydromicas in 15 percent of the cases.

Microscopic study of the same samples on which clay analyses were run showed hydromicas to occur as rims around grains even where the more conspicuous clay was kaolinite or montmorillonite. Hydromica clays also occur interstitially, or as wads or galls in which one part of the wad is montmorillonite and part is hydromica with a mixed layer transition between the two types.

Thus, evidence supports the hypothesis that much of the hydromica in the Shinarump member and in the Chinle formation generally is the result of the alteration of volcanic debris or montmorillonite in the presence of soluble potassium salts. Such an alteration is suggested by Grim (1953) with reference to Noll (1936), and others. The confirmation of such a hypothesis would explain the anomaly of tuffaceous sandstone interbedded with hydromica-rich claystone in the Chinle formation.

The following diagrammic arrangement of the materials involved illustrates the hypothesis of the formation of much of the hydromica.



Many of the interpretations in this report are based on certain expected occurrences and associations of clay-mineral groups. Kaolinite is assumed to be related most of the time to granitic source rocks and the formation of arkoses; montmorillonite is assumed to be related most of the time to sediments derived from alkalic-silicic source rocks of volcanic origin (ash, tuff, glass, felsite); hydromica was originally assumed to be related most of the time to sediments derived from sericitic sedimentary and micaceous metamorphic rocks. As discussed above, the conception of the role of the hydromicas as authigenic clay minerals has altered the original assumption.

Petrologic features observed in ore-bearing sandstones

During the petrographic study of thin sections of sandstone samples from the Shinarump and Moss Back members of the Chinle formation and the estimation of volumetric composition by the point-count method (based on 500 counts), nine thin sections from uranium-mineralized locations were studied. These thin sections represent samples that may be classified as 1 sample of high-grade ore-bearing sandstone designated L258 (appendix II) and 3 samples of medium- to low-grade ore-bearing sandstone designated

L260, L842 (appendix II), and L252 (appendix IV). Five samples can be classed as barren sandstone associated with ore-bearing sandstone; these were designated L261, L259, L883, L841 (appendix II), and L254 (appendix IV).

Study of the thin section from the high-grade ore sample (L258) and the thin section from the associated barren sandstone sample (L261) from the Happy Jack mine in White Canyon, San Juan County, Utah, suggests that kaolinite may have influenced the deposition of the ore minerals. Each of these thin sections contains quartz, potash feldspar, quartzite, tuffaceous material, plagioclase, cement (calcite, iron oxides, barite, etc.), and kaolin. In addition, the ore-bearing sandstone contains unidentified uranium minerals, chalcopyrite, azurite, barite, covellite, malachite, and pyrite; these minerals occur interstitially and comprise about 30 percent of the volume of the rock. The mine face at the point where the sample was reported by the owners to assay about 10 percent copper and 2 percent uranium.

Quartz grains in the associated barren thin section have euhedral authigenic overgrowths, whereas the quartz grains in the ore-bearing sandstone contain few overgrowths, most of which show corrosion by solution action which apparently occurred prior to or during deposition of the sulfide minerals.

Kaolin occurs in the two thin sections, primarily in a detrital interstitial material which is composed of ground up quartz; potash and sodic feldspar, kaolinite clays, and minor amounts of carbonates and micaceous clays, and secondarily as an alteration product along cleavage planes in some of the potash feldspar grains. A comparison of the two thin sections shows that they are similar in the proportions of all components with the exception of kaolin mud and ore minerals, The results of this comparison suggest that a lower content of kaolin mud is present in the ore-bearing sandstone becuse most of the original mud has been replaced or obscured by uranium and copper minerals; whereas, in the adjacent barren sandstone most of the kaolin has been unaffected.

Other data indicate some possible significance of the ore-kaolin relationship. At the mine face where samples L258 and L261 were taken the copper-uranium sulfide-bearing sandstone was surrounded by a halo of azurite-malachite-stained mineralized sandstone. A thin section from the halo (sample L260) contains euhedral crystals of azurite and malachite suspended in the interstitial kaolin matrix of the rocks.

A similar ore sand--associated barren sand relationship was studied in the Moss Back member of the Chinle at Temple Mountain, Emery County, Utah. The ore-bearing sandstone (L252) contained 19 percent interstitial kaolin and 5 percent asphaltoid residue containing ore minerals and pyrite in cryptocrystalline form. The associated barren sandstone L254 contains 24 percent interstitial kaolin and 1 percent pyrite. The implication may be that the kaolin and asphaltoid-ore-pyrite contents are complementary,--that the ore-bearing sandstone was originally of the same composition as the barren sandstone and the mineralization was effected at the expense of the interstitial kaolin.

To test further this apparent relationship a comparison of kaolin content was made between the nine sandstone samples containing or associated with known ore deposits and the average for all the Shinarump and Moss Back samples studied. The ore minerals of high grade sample L258 are combined with the kaolin to compensate for the supposed loss of kaolin by it and other ore-bearing samples.

The mean amount of kaolin for the ore-associated samples is 21 percent with a range from 5 percent to 35 percent. The mean amount of kaolin for all 34 samples is 12 percent with a range from 0 to 35 percent. By removing the ore-associated samples from the calculations the mean amount of kaolinite in barren samples becomes 9 percent with a range from 0 to 26 percent.

The three barren samples with the highest kaolin content away from known ore deposits came from one location, the Owl Rock section (appendix II) in southern Monument Valley.

The results of the study suggest that ore is localized in Shinarump and other lower Chinle sandstones containing 20 percent or more interstitial kaolin mud. The effect of the kaolin may be physical or chemical, or both, or the effective agent may be something contained in the kaolin.

Whatever the cause of localization may be, the recommendation is made that strata containing 15 to 35 percent interstitial kaolin be considered as more favorable for the occurrence of uranium ore than strata containing less than 15 percent kaolin.

Interpretations

The final objectives of the petrographic study of the Triassic and associated sedimentary rocks have been achieved in part. More progress has been made on reconstruction of the paleogeography; less progress has been made on the problem of associating the occurrence of uranium ore with measurable properties of the sedimentary host rocks.

Based on the thin-section study, the source areas of the rocks studied were dominantly granitic with minor quartzites and quartz-mica schist or gneiss. At least three separate areas were contributing sediments to the major continental basin of deposition during deposition of the Shinarump and other members of the lower part of the Chinle formation. Some volcanic activity occurred in all periods, but the greatest contribution of volcanic material to the sediments occurred during the deposition of the lower Chinle. The volcanic material appears to have had an alkalic-silicic composition. The main volcanic contribution takes the form of deposits of thick claystone and siltstone strata combined with a large volume of sand-sized altered tuffaceous material. The main loci of deposition were in the extreme northeastern part of Arizona and southeastern to south-central Utah. Many thin concretionary or banded cherty lenses in the Lower Chinle may have derived their silica from the alteration of volcanic glass.

The chief uranium-bearing units, the Shinarump, Monitor Butte, Moss Back, and Petrified Forest members of the Chinle formation, are distinguished from the other units by features that are both physical and chemical in nature. The uranium-bearing rocks are made up of generally coarser and generally more poorly sorted sandstone and siltstone than other rocks of the geologic column studied. The above units contain large amounts of sand-, silt-, and clay-sized materials, which have been derived from alkalic-silicic volcanic material. Due to the impervious nature of many of the montmorillonite and hydromica clays, much of the more soluble products of decomposition of the volcanic materials have probably been retained in the clayey strata or are still in the process of slow leaching, which makes possible a wide variety of chemical environments in the uranium-bearing units. Any one of these features mentioned, or a combination, may have been critical to the localization of the uranium ore.

Conclusions resulting from a petrographic study of sedimentary rocks fall into two categories. In one category are direct comparisons based on microscopic or megascopic measurements; for instance, the sandstones of the Moenkopi formation are finer grained on the average than the sandstones of the Shinarump member of the Chinle formation. (See appendix I for comparison of mean-grain size.) In the second category, hypotheses are put forward by the petrologist to explain why the sands deposited during Moenkopi time were finer grained than the sands deposited during Shinarump time.

Second category conclusions are handicapped by the fact that they are built on interpretations or assumptions which are open to question at all times, even when the assumptions are based on fairly well-accepted and often well-substantiated cause and effect relationships.

A logical course in presenting conclusions of the second category is to present the basic cause and effect relationships that are assumed to be true by the author.

The assumption is made that conditions in three loci determine the grain size and sorting of a sediment. The loci are the source area, the basin of deposition, and the particular environment within the basin. It is assumed that the gross controlling causes are the degree of differential tectonic uplift in the source area, the degree of differential subsidence or uplift in the basin of deposition, and the degree of region-wide subsidence or uplift.

The effect of these multiple causes on the mean-grain size and the sorting of the related sediments is assumed to be as follows:

1. With an increase in differential tectonic uplift in the source area, the mean-size increases and the sorting becomes poorer (standard deviation increases).

2. With an increase in the differential subsidence of the basin of deposition, the mean-grain size decreases and the sorting becomes poorer (standard deviation increases).

3. With region-wide uplift encompassing both source area and basin, grain size increases and sorting becomes better (standard deviation decreases). The same effect occurs if the cause in number two is reversed.

4. With general quiescence, grain size is determined by the texture of the material available for reworking; sorting steadily improves until the sediments are finally buried. Eolian sands are continental terrestrial sediments typical of this condition.

Any combination of the first three conditions is possible, with resulting modification of the sediments. When tectonic movements are relatively rapid, the resulting sediments change abruptly. When tectonic movements are slow but fast enough to change rates of erosion or deposition, the resulting sediments will indicate gradational change. Quiescence may result from a slight region-wide positive tectonic movement which tilts the lower end of the profile of equilibrium upward or may occur during a period when the basin is subsiding very slowly and erosion is proceeding at a diminishing rate in the source area.

If the above cause and effect relationships may be assumed for the overall picture and the minor modifications may be ignored, interpretation then becomes a matter of selecting a cause or causes for each effect.

Figure 16 is a graph showing mean grain size and sorting (as measured by the standard deviation of the phi grain-size distribution) for each formation and member studied in the investigation. Plotted points are connected by lines to emphasize the sense and degree of change. Data for the points are listed in appendix I.

Using figure 16 for reference, interpretations are made on the basis of changes that take place in the sequence. To interpret the texture of each unit without reference to adjacent units, would be similar to taking phrases out of context--some would make sense, others would be unintelligible.

The two curves present an interpretative summary of general tectonic activity during the period covered. The projection of the grain-size curve to the right may be read as an indication of movement of coarser material from the source areas into the basin of deposition. The projection of the sorting curve to the right is an indication of an increased rate of deposition, based on the assumption that the slower the rate of deposition is, the better sorted the sediments will be.

One other characteristic used is interpretation is the structure of the sedimentary unit as observed in the field. A massive, thick-bedded sandstone with large-scale cross-strata and fair regional extent is interpreted as eolian in origin, but it should be noted that even if the unit were of marine origin the tectonic significance would be the same. Units that have even, regular bedding suggest continuous deposition and little or no erosion or reworking. Units that have irregular bedding, cut and fill structure or local erosional disconformities suggest

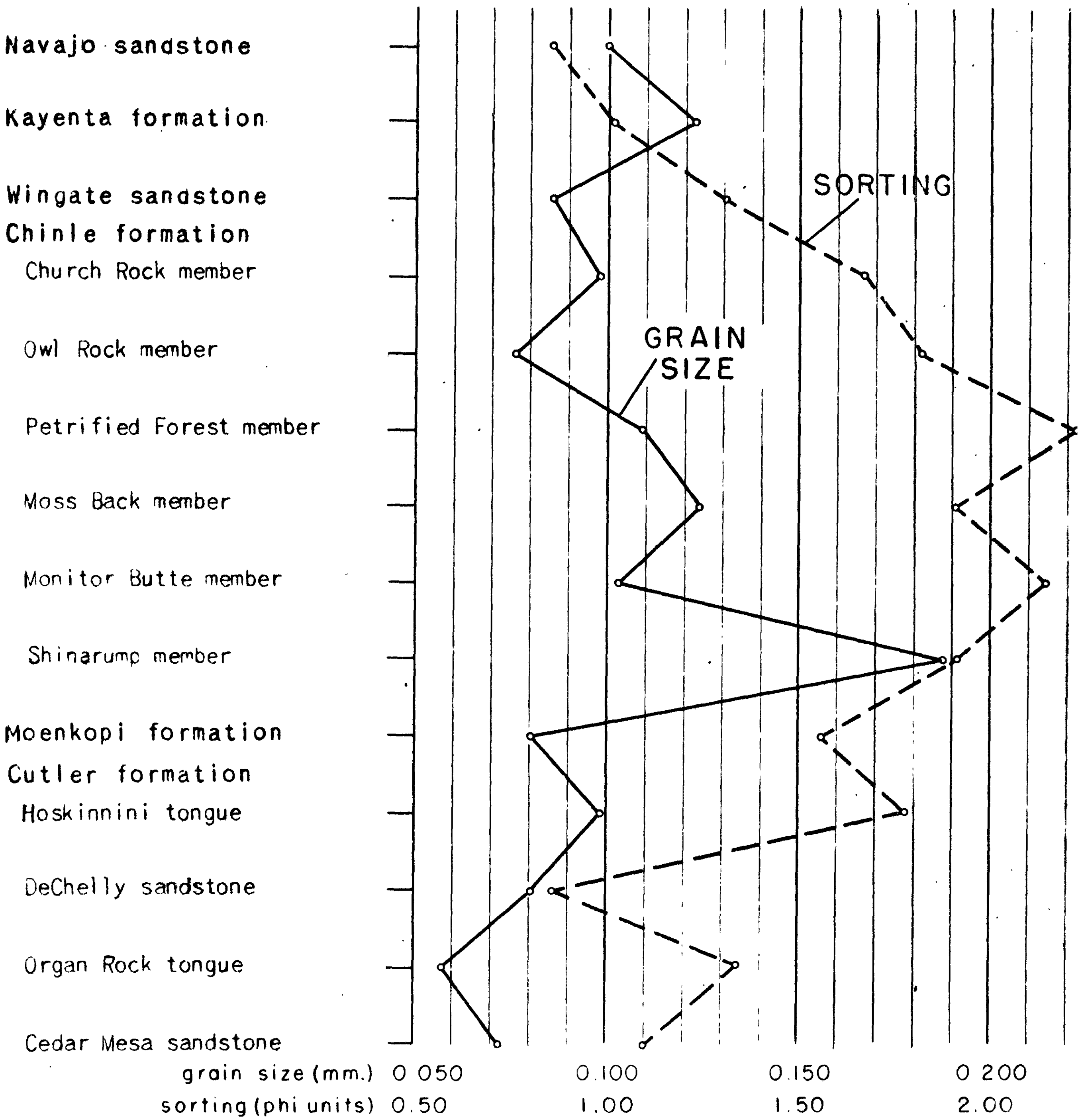


Figure 16.--CHANGES IN AVERAGE GRAIN SIZE AND AVERAGE SORTING FROM UPPER PERMIAN TO LOWER JURASSIC UNITS IN THE CENTRAL PART OF THE COLORADO PLATEAU.

discontinuous deposition accompanied by much erosion and reworking of deposits which in turn suggests deposition in a slowly subsiding basin where rate of burial is not fast enough to prevent reworking.

When interpreting change, certain reference points must be recognized. A reference point would be an interpretation attached to a particular type of sediment such as an eolian sandstone. An eolian sandstone or a unit resembling an eolian sandstone would suggest or be interpreted as evidence of quiescence in the basin of deposition.

Interpreting the changes illustrated on figure 16, the Cedar Mesa sandstone member of the Cutler formation has many of the criteria of an eolian sandstone and represents conditions of quiescence in the basin area and probably in the region, which resulted from an interval of time of decreased erosion in the source area and a very slowly subsiding basin of deposition. The unit is classified as a marginal terrestrial deposit.

The Organ Rock tongue of the Cutler formation is marked by a decrease in grain size and a decrease in the degree of sorting which, combined with the depositional structures, is interpreted as indicating a more rapid rate of deposition brought about by faster subsidence of the basin. The unit is classified as a marginal terrestrial deposit.

The DeChally member of the Cutler is marked by an increase in grain size and an increase in the degree of sorting which in view of the eolian characteristics of the unit is interpreted as a return to quiescent conditions brought about by a continued, slow rate of erosion in the source areas and a decreased rate of deposition in a very slowly subsiding basin. The DeChelly is classified as a marginal terrestrial deposit.

The Hoskinnini tongue of the Cutler formation is marked by an increase in the grain size and a decrease in the degree of sorting. This change combined with the irregular bedding suggests moderate tectonic uplift in the source area which resulted in an increased rate of erosion with some increase in the rate of deposition in a slowly subsiding basin. The Hoskinnini is classified as a marginal terrestrial deposit.

The Moenkopi formation, which has a decreased grain size and slightly improved sorting and regular bedding structure, is interpreted as representing a slightly decreased rate of erosion in the source area accompanied by deposition in a basin which was subsiding at an increased rate. The Moenkopi is classified as a marginal terrestrial-marginal marine deposit.

The Shinarump member of the Chinle formation is marked by an abrupt increase in grain size and a decrease in the degree of sorting. These changes in light of the irregular, discontinuous bedding features and large erosional cuts, are interpreted as indicating marked regional uplift, tectonic uplift in the source area--resulting in increased erosion--and little if any subsidence in the basin of deposition. The unit is classified as a terrestrial deposit. The occurrence of altered tuffaceous material in the unit indicates that the tectonic activity was accompanied by volcanic activity.

The Monitor Butte member of the Chinle formation is marked by a decrease in grain size and a decrease in the degree of sorting. These changes combined with the more regular bedding and amount of clay present are interpreted as indicating continued tectonic activity in the source areas, a high rate of erosion and an increased rate of deposition in a subsiding basin. Volcanic activity continued. The unit is classified as a terrestrial deposit.

The Moss Back member of the Chinle is marked by an increase in grain size and an increase in the degree of sorting. These changes combined with the irregular bedding and moderate erosional cuts within the deposit are interpreted as indicating continued tectonic activity in the source areas and a decreased rate of subsistence in the basin. Volcanic activity continued. The unit is classified as a terrestrial deposit.

The Petrified Forest member of the Chinle is marked by a decrease in grain size and a decrease in the degree of sorting. These changes combined with irregularly bedded sandstones and relatively large thicknesses of bentonitic claystones and siltstones are interpreted as indicating continued volcanic activity, continued tectonic uplift, a high rate of erosion in the source areas, and moderate to rapid subsidence in the basin of deposition with intervals, at least locally, when subsidence halted for short periods of time. The unit is classified as a terrestrial deposit.

The Owl Rock member of the Chinle formation is marked by a decrease in grain size and an increase in the degree of sorting. These changes viewed with respect to changes in lithology are interpreted as indicating a substantial decrease in tectonic activity in the source area, a reduced rate of erosion, minor volcanism, and a slower subsistence of the basin of deposition. The unit is classified as a marginal terrestrial deposit.

The Church Rock member of the Chinle formation is marked by an increase in grain size and continued increase in the degree of sorting. These changes and the combination of regular and irregular bedding are interpreted as indicating almost no tectonic activity and a continued low rate of erosion in the source areas, a decrease in the rate of deposition, and a slower subsidence of the basin of deposition. The unit is classified as a terrestial deposit.

The Wingate sandstone is marked by a decrease in grain size and a continued increase in the degree of sorting. These changes, the eolian structure of the Wingate, and the erosional contact at the base, are interpreted as indicating regional quiescence brought about by a minor uplift in the basin of deposition during a time of tectonic inactivity and a low rate of erosion in the source areas. The Wingate was deposited under conditions of gradual subsidence in the basin following the uplift which preceded deposition. The unit is classified as a terrestial deposit.

The Kayenta formation is marked by an increase in grain size and a continued increase in the degree of sorting. These changes, combined with irregular bedding and erosion surfaces in the unit, are interpreted as indicating minor uplift in the source areas, a resulting increase in erosion but continued decrease in the rate of deposition and little or no change in the slow rate of subsidence of the basin of deposition. The unit is classified as a terrestrial deposit.

The Navajo sandstone is marked by a decrease in the grain size and a continued increase in the degree of sorting. These changes combined with the eolian structure are interpreted as indicating general regional quiescence with a very slow rate of deposition and a very slow rate of subsidence in the basin of deposition. The unit is classified as a terrestrial deposit.

Such a scheme of interpretation explains the relatively thin, widespread, but discontinuous nature of the Shinarump member of the Chinle formation. The regional uplift with initial erosion of the Moenkopi plain followed by deposition of the Shinarump suggests that the conglomerates, sands, and clays were deposited on a "high" if not rising surface with few of the opportunities of burial found in a subsiding basin. However, the sands are only moderately sorted, which suggests that reworking was not extensive. Reworking probably failed to improve sorting because of a huge sediment load being carried most of the time across the alluvial plain.

Other parameters resulting from statistical analysis of the grain-size distributions such as the measure of peakedness may eventually be usable in the interpretation of the petrology of Triassic and associated sediments, but sufficient data has not yet been accumulated and further study is necessary.

Summary of stratigraphic and petrologic interpretations

Integration of the preliminary conclusions and interpretations derived from all lines of investigation in the stratigraphic and petrologic study provides an historical account of the paleogeology and tectonic background of the sediments deposited during part of Permian, Triassic, and Early Jurassic time. The part of the continental area where sediments accumulated, as discussed in this summary, includes the southeastern quarter of the state of Utah and adjoining 50-mile overlap into Colorado, New Mexico and Arizona.

In Permian time, the area east of what is now the Colorado Plateau region was marked by extreme tectonic uplift of granitic and metamorphic terrains--possibly the Uncompahagre-San Luis highlands. The rising highlands contributed thick wedge-shaped deposits of arkosic sediments along their western flanks. These deposits form the conglomeratic facies of the Cutler formation of western Colorado and eastern Utah; simultaneous with deposition they were reworked and the finer material transported by streams into a continental area of sedimentary accumulation in southeastern Utah. Conditions in the basin alternated between slow subsidence and quiescence, which resulted in the deposition of the reddish siltstone members and light-colored sandstone members of the Cutler. Slow subsidence brought in arkosic material from the east, which formed the reddish siltstone members--the Halgaito, Organ Rock, and Hoskinnini tongues of the Cutler formation. Quiescence resulted in the slow accumulation of eolian sands--the light-colored sandstone members--derived from the northwest of southeastern Utah; these light-colored sandstones are the Cedar Mesa, DeChelly, and White Rim members of the Cutler formation and the equivalent Coconino sandstone. Contemporaneous with the deposition of all or part of the reddish siltstone and light-colored sandstone members, limestones were being deposited in the sea to the west; these form the Kaibab limestone of central and north-central Utah and northern Arizona.

At the end of Cutler deposition, adjustments in the level of parts of the basin resulted in erosion in some areas while deposition continued uninterrupted in other areas. Parts of the Kaibab limestone, deposited in the western sea in central Utah were exposed to erosion and were redeposited as conglomerates at the base of sediments now assigned to the Moenkopi formation of Early and Middle(?) Triassic age.

Early Triassic time was marked by general subsidence and a gradual advance of the shallow sea from the west and northwest. Part of the sediments of the Moenkopi formation probably were derived from erosion of the conglomeratic facies of the underlying Cutler formation. Moderate uplift and erosion of the Uncompahgre-San Luis highlands may have continued to contribute sediments. Some coarse sediments accumulated along the flanks of the highland, and deposition of sediments of the Moenkopi formation occurred at a moderate rate in the subsiding basin. Tidal flats in advance of the shallow sea occupied the basin during much of early Triassic time and resulted in widespread ripple marking of the sandy siltstones of the basal Moenkopi. The advancing shallow sea deposited the Sinbad limestone in central Utah. Following the deposition of the Sinbad limestone the environment of deposition returned to predominantly that of a tidal flat. Minor adjustments in subsidence of the basin of accumulation or uplift in the source area resulted in thick cross-stratified very fine grained sand units being deposited far out in the basin. Following the adjustment in mid-Moenkopi time, deposition continued at a moderate rate in the subsiding basin, in a dominantly tidal flat environment.

At the end of Moenkopi time, regional uplift of the Triassic basin of deposition and associated highlands resulted in an interval of erosion which developed a stream-cut surface on the top of the Moenkopi sediments. Uplift of granitic and volcanic source areas, probably to the southeast of the Colorado Plateau, or subsidence of the basin, started deposition of Chinle sediments of Late Triassic age.

Chinle deposition probably took place on an alluvial plain of low relief. Initial Chinle deposits were probably composed mostly of reworked Moenkopi sediments. The Temple Mountain member and lithologically similar strata are probably such reworked sediments although they include some sandstone and conglomerate not derived from the Moenkopi.

After deposition of the initial reworked sediments, coarse material including granite wash, volcanic material, and quartzose pebbles spread out over the area and formed the wide-spread coarse-textured Shinarump member of the Chinle formation.

The sediments of the Monitor Butte member indicate conditions of continued rapid erosion in the source areas and increase in the rate of deposition due to the moderate rate of subsidence of the basin. Ripple laminations and generally horizontal bedding structures in the sandstones plus an increase in the amount of mudstone are evidence of gentler currents than those responsible for deposition of the Shinarump.

Interruption of the subsidence occurred, resulting in the deposition of slightly reworked coarser sediments with strong fluvial characteristics such as the Moss Back snadstone and similar sandstones in the lower part of the Chinle.

Volcanism increased in intensity, resulting in great quantities of volcanic debris being deposited in the southern part of the basin to form the Petrified Forest member of the Chinle. Deposition in the subsiding basin took place at a high rate with intervals of reduced subsidence which resulted in some reworking of the sediment under fluvial conditions to produce strata of coarser texture.

The long period of deposition in an alluvial-plain environment ended in late Triassic time as volcanism and uplift in the source areas decreased or ceased altogether. Subsidence in the basin continued at a reduced rate but was fast enough to keep the basin flooded with water. The decreased rate of deposition and a lake or lagoonal environment resulted in deposition of the limestone and limy-siltstone strata identified as the Owl Rock member.

Further decrease in the rate of subsidence of the basin combined with the slow rate of erosion in the source areas changed the environment to an emerging plain with mixed low velocity fluvial and shallow water "mud-flat" conditions to produce the flat-bedded, sometimes cross-stratified silty sands of the Church Rock member of the Chinle formation.

The deposition of the last Chinle sediments was interrupted by a slight uplifting of the basin, which was followed by a period of moderate erosion and moderate reworking of the sediments on the emergent plain. This resulted in some deposition in low or slightly subsiding areas and slight scouring in more positive areas. This short period of adjustment was followed by a quiescent period of some duration. Windblown sediments partly derived from underlying Chinle and from sources to the northwest accumulated to form the eolian strata of the Wingate sandstone.

This cycle of eolian deposition was interrupted by moderate uplift to the east, possibly in the Uncompahgre-San Luis highlands area which resulted in a movement of some granitic material into the basin and a substantial amount of erosion and reworking of eolian sands by westward-flowing streams to form the Kayenta formation. Little or no change occurred in the rate of basin subsidence, so that with the cessation of the uplift the continued stability of the basin area rapidly reinstituted conditions of quiescence. Eolian deposition of sand from the northwest resulted in the accumulation of the strata assigned to the Navajo sandstone.

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endix I.--Mean or average measures of the prcperties of the phi distribution of the grain size of some Permian, Triassic, and Jurassic sandstones and coarse siltstones from the Colorado Plateau. (Size properties are given in millimeters. Deviation properties are given in phi units, which correspond to Wentworth size grades.)

Formation	Location	Number of samples	Mean grain size (range)	Modal grain size (range)	Median grain size (range)	Standard deviation (range)	Skewness (range)	Kurtosis (range)
vajo sandstone	SE. Utah, NE. Arizona, SW. Colorado	22	0.100 (0.156 to 0.072)	0.099 (0.138 to 0.062)	0.107 (0.154 to 0.075)	0.854 (1.440 to 0.510)	1.298 (2.211 to -0.059)	12.883 (30.500 to -0.733)
venta formation	SE. Utah, NE. Arizona, SW. Colorado	19	0.123 (0.244 to 0.067)	0.137 (0.258 to 0.074)	0.140 (0.253 to 0.082)	1.005 (1.521 to 0.654)	1.474 (2.232 to 0.621)	13.506 (28.704 to 2.299)
ngate sandstone	SE. Utah, NE. Arizona, SW. Colorado,	44	0.086 (0.175 to 0.032)	0.093 (0.210 to 0.044)	0.098 (0.208 to 0.045)	1.031 (1.792 to 0.523)	1.404 (2.301 to 0.329)	13.154 (29.700 to 4.714)
inle formation ndifferentiated)	Western Colorado	7	0.059 (0.116 to 0.034	0.078 (0.149 to 0.044	0.075 (0.151 to 0.044)	1.254 (1.377 to 1. 099	1.114 (1.493 to 0.852	6.201 (10.248 to 2.781)
urch Rock member	SE. Utah	7	0.098 (0.209 to 0.039)	0.172 (0.353 to 0.044	0.145 (0.337 to 0.046	1.668 (2.507 to 1.119)	1.145 (1.641 to 0.607)	6.737 (12.386 to 0.719)
l Rock member	SE. Utah	4	0.076 (0.146 to 0.035)	0.123 (0.210 to 0.031	0.105 (0.210 to 0.044)	1.822 (2.287 to 1.478)	0.862 (1.359 to 0.365)	3.885 (8.296 to -0.170)
etrified Forest member	SE. Utah	4	0.089 (0.094 to 0.048)	0.186 (0.250 to 0.148)	0.168 (0.209 to 0.151)	2.225 (2.723 to 1.975)	1.014 (1.277 to 0.613)	3.604 (5.976 to 0.213)

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Formation	Location	Number of samples	Mean grain size (range)	Modal grain size (range)	Median grain size (range)	Standard deviation (range)	Skewness (range)	Kurtosis (range)
ss Back member	SE. Utah	13	0.124 (0.260 to 0.048)	0.228 (0.490 to 0.098)	0.195 (0.402 to 0.087	1.905 (3.173 to 1.113	1.075 (1.678 to 0.466)	5.493 (16.345 to -0.413)
nitor Butte member	SE. Utah	12	0.103 (0.331 to 0.050)	0.221 (0.557 to 0.096	0.188 (0.461 to 0.076)	2.145 (3.454 to 0.995)	0.945 (1.612 to 0.531)	4.119 (15.026 to 0.226)
inarump member	SE. Utah, NE. Arizona	83	0.188 (0.616 to 0.034)	0.275 (0.593 to 0.043)	0.251 (0.663 to 0.045)	1.914 (3.568 to 1.063)	0.959 (2.051 to 0.138)	6.281 (21.088 to -0.940)
oenkopi ormation	SE. Utah, NE. Arizona	21	0.080 (0.374 to 0.036)	0.111 (0.590 to 0.037)	0.109 (0.563 to 0.042)	1.560 (2.242 to 0.976)	1.145 (1.710 to 0.433)	7.140 (17.097 to 1.066)
utler formation (undifferentiated)	SW. Colorado	2	0.367 (0.553 to 0.181)	0.391 (0.553 to 0.229)	0.421 (0.623 to 0.218)	1.611 (1.962 to 1.260)	1.038 (1.383 to 0.693)	7.580 (11.302 to 3.858)
oskinnini	SE. Utah, NE. Arizona	13	0.098 (0.195 to 0.033)	0.131 (0.241 to 0.043)	0.124 (0.235 to 0.044)	1.777 (2.224 to 1.335)	0.921 (1.370 to 0.537)	4.957 (11.060 to 1.033)
eChelly member	SE. Utah	7	0.080 (0.116 to 0.057)	0.082 (0.139 to 0.062)	0.084 (0.130 to 0.062)	0.859 (0.990 to 0.689)	1.399 (1.780 to 1.000)	13.190 (17.747 to 9.478)

ppendix I.--Mean or average measures of the properties of the phi distribution of the grain size of some Permian Triassic, and Jurassic sandstones and coarse siltstones from the Colorado Plateau. (Size properties are given in millimeters. Deviation properties are given in phi units, which correspond to Wentworth size grades.).--Continued

ormation	Location	Number of samples	Mean grain size (range)	Modal grain size (range)	Median grain size (range)	Standard deviation (range)	Skewness (range)	Kurtosis (range)
rgan Rock tongue	SE. Utah	14	0.057 (0.122 to 0.033)	0.065 (0.109 to 0.044)	0.066 (0.104 to 0.044)	1.342 (1.703 to 0.982)	1.350 (2.782 to 0.783)	10.356 (28.279 to 3.561)
edar Mesa member	SE. Utah	7	0.072 (0.098 to 0.038)	0.076 (0.104 to 0.045)	0.083 (0.114 to 0.050)	1.103 (1.411 to 0.725)	1.533 (2.022 to 0.827)	12.406 (21.935 to 3.243)

Appendix II.--Percent mineral composition of samples of the Shinarump member of the Chinle formation as determined by point-count analyses of thin sections.

ocation	Sample No.	Percent detrital components								Percent components	
		Quartz	Potash feld-spar	Kaolin	Hydro-mica	Quartz-ite	Tuffaceous material	Plagio-clase	Mica	Total detrital	Total chemical
rizona											
Navajo County											
(Monument Valley)											
Owl Rock section	L-660	60.4	8.1	25.9	2.4	0.0	0.0	1.8	1.4	99.0	1.0
	661	70.9	8.4	17.9	0.8	0.4	0.2	1.0	0.4	98.2	1.8
	662	63.7	8.8	20.1	3.4	1.4	0.8	1.0	0.8	95.4	4.6
ah											
arfield County											
Circle Cliffs)											
uley Twist section	L-1012	88.5	3.6	4.7	0.2	0.0	2.6	0.2	0.2	94.0	6.0
he Peaks section	L-1017	70.9	10.9	13.1	0.4	0.0	2.7	1.6	0.4	97.4	2.6
	1019	74.2	8.1	14.1	0.0	0.8	1.6	0.8	0.4	99.2	0.8
ilver Falls section B	L-1007	62.9	6.2	19.7	0.2	0.2	10.0	0.4	0.4	94.2	5.8
	1009	70.5	3.4	21.0	1.3	0.0	3.4	0.4	0.0	95.0	5.0
ane County											
Paria	CD-794	73.1	9.8	9.0	0.2	0.2	7.1	0.0	0.6	96.0	4.0
	L-1098	68.4	5.7	2.6	0.0	0.0	23.1	0.0	0.2	98.0	2.0
an Juan County											
(White Canyon)											
Frey Canyon	L-1049	57.7	11.2	13.3	2.4	0.0	14.3	0.7	0.4	57.2	42.8
	1050	87.6	5.0	7.0	0.2	0.0	0.2	0.0	0.0	99.6	0.4

Appendix II.-- Percent mineral composition of samples of the Shinarump member of the Chinle formation as determined by point-count analyses of thin sections.--Continued

Location	Sample No.	Percent detrital components								Percent rock components	
		Quartz	Potash feld-spar	Kaolin	Hydro-mica	Quartz-ite	Tuffaceous material	Plagio-clase	Mica	Total detrital	Total chemical
ppy Jack mine nd area	L-258	90.2	2.1	3.7	0.0	3.1	0.0	0.0	0.9	65.6	34.4
	261	69.8	2.5	26.3	0.0	1.2	0.0	0.2	0.0	98.0	2.0
	259	82.1	1.0	13.9	0.0	1.8	0.6	0.6	0.0	99.6	0.4
	260	64.7	4.4	29.4	0.0	1.1	0.4	0.0	0.0	94.8	5.2
	1043	98.6	0.7	0.0	0.2	0.0	0.5	0.0	0.0	84.8	15.2
n Juan County Monument Valley)											
onument No. 2 area	L-841	75.1	2.8	11.8	4.9	1.0	1.4	1.4	1.6	98.6	1.4
	842	65.1	4.0	28.9	1.0	0.2	0.2	0.6	0.0	99.0	1.0
	871	78.1	0.6	8.4	9.9	0.8	2.0	0.2	0.0	99.6	0.4
	872	93.2	0.2	2.9	1.2	0.8	1.7	0.0	0.0	97.2	2.8
	873	84.3	0.4	11.6	2.5	0.8	0.0	0.0	0.4	98.4	1.6
	883	85.8	2.2	5.3	5.9	0.2	0.2	0.0	0.4	98.6	1.4
nitor Butte	L-906	76.3	7.2	5.2	0.7	1.1	9.5	0.0	0.0	88.4	11.6
	907	71.7	4.7	13.1	3.2	0.4	3.9	0.2	2.8	99.0	1.0
ncho House section	L-901	81.2	0.2	13.5	0.2	0.0	4.8	0.1	0.0	99.2	0.8
ayne County (Capitol Reef) Pleasant Creek section	L-1005	69.0	17.0	7.2	0.0	0.4	5.7	0.7	0.0	91.6	8.4
orrey section	L-1027	76.4	8.3	11.3	0.2	0.6	2.2	0.4	0.6	99.0	1.0

pendix III.--Percent mineral composition of samples of the Monitor Butte member of the Chinle formation as determined by point-count analyses of thin sections.

Location	Sample No.	Percent detrital components								Percent rock components	
		Quartz	Potash feld-spar	Kaolin	Hydro-mica	Quartz-ite	Tuffaceous material	Plagio-clase	Mica	Total detrital	Total chemical
tah											
Garfield County											
(Circle Cliffs)											
Muley Twist section	L-1119	71.8	4.6	10.7	10.3	0.0	0.8	1.0	0.8	95.6	4.4
	1120	72.0	5.1	14.5	0.9	0.2	3.1	1.3	2.9	89.6	10.4
he Peaks section	L-1126	57.2	10.9	10.1	1.7	0.0	18.5	0.4	1.2	97.2	2.8
	1128	73.4	8.6	9.6	0.5	0.7	6.7	0.0	0.5	83.4	16.6
ilver Falls											
ection B	L-1118	84.4	4.0	4.0	2.3	0.3	4.7	0.0	0.3	60.2	39.8
ane County											
Paria	CD-796	49.2	7.5	9.7	0.7	1.3	31.0	0.2	0.4	90.4	9.6
	798	61.3	9.4	15.5	2.6	0.0	9.4	0.4	1.4	98.2	1.8
an Juan County											
(White Canyon)											
Frey Canyon	L-1184	80.5	0.0	8.6	7.4	0.0	1.9	0.8	0.8	87.2	2.4
	1185	89.1	0.0	3.8	3.1	0.0	2 0	1.3	0.7	89.2	10.8
appy Jack mine											
nd area	L-1106	83.0	5.5	2.1	0.6	0.3	7.0	0.6	0.9	65.6	34.4

Appendix III.--Percent mineral composition of samples of the Monitor Butte member of the Chinle formation as determined by point-count analyses of thin sections.--Continued

Location	Sample No.	Percent detrital components								Percent rock components	
		Quartz	Potash feld-spar	Kaolin	Hydro-mica	Quartz-ite	Tuffaceous material	Plagio-clase	Mica	Total detrital	Total chemical
:appy Jack mine .nd area	L-1181	91.8	5.7	1.1	0.0	0.0	1.4	0.0	0.0	55.8	44.2
	1182	91.5	1.5	2.9	2.9	0.0	1.0	0.0	0.2	81.8	18.2
Monument Valley) ;onitor Butte	L-908	84.1	0.5	3.8	8.4	0.2	1.4	1.6	0.0	88.6	11.4
'oncho House	L-900	86.9	0.0	6.0	3.3	0.0	2.5	1.3	0.0	96.2	3.8
'ayne County (Capitol Reef) Pleasant Creek section	L-1112	57.1	13.3	17.4	5.3	0.0	2.3	2.0	2.5	97.4	2.6
	1113	65.5	11.2	13.8	1.4	0.0	6.7	0.2	1.2	98.2	1.8
	1114	47.8	9.6	32.9	8.1	0.2	0.2	0.5	0.7	85.8	14.2

Appendix IV.--Percent mineral composition of samples of the Moss Back member of the Chinle formation as determined by point-count analyses of thin sections.

Location	Sample No.	Percent detrital components								Percent rock components	
		Quartz	Potash feld-spar	Kaolin	Hydro-mica	Quartz-ite	Tuffaceous material	Plagio-clase	Mica	Total detrital	Total chemical
Utah											
Emery County											
Temple Mountain	L-252	67.4	7.8	20.2	0.0	0.0	0.8	3.4	0.4	95.2	4.8
	254	64.6	4.3	24.1	2.6	0.4	0.4	2.8	0.8	98.8	1.2
San Juan County (White Canyon)											
Frey Canyon	L-1107	63.5	1.4	5.6	27.1	0.0	1.0	0.2	1.2	97.4	2.6
	1108	78.5	1.0	6.0	8.2	0.0	4.6	0.5	1.2	83.0	17.0
Happy Jack area	L-1102	78.0	4.9	3.6	0.2	0.0	12.7	0.2	0.4	94.6	5.4
	1105	82.2	5.2	1.2	0.1	0.0	10.9	0.4	0.0	98.8	1.2

Appendix V.--Percent mineral composition of samples of the Petrified Forest member of the Chinle formation as determined by point-count analyses of thin sections.

Location	Sample No.	Percent detrital components							Percent rock components		
		Quartz	Potash feld-spar	Kaolin	Hydro-mica	Quartz-ite	Tuffaceous material	Plagio-clase	Mica	Total detrital	Total chemical
tah											
San Juan County											
Comb Wash	L-886	57.8	3.8	0.0	5.8	0.0	31.6	0.2	0.8	99.6	0.4
	945	46.4	10.9	1.2	7.4	0.0	32.9	0.6	0.6	99.6	0.4