Progress Report on the Stratigraphy of the Triassic and Associated Formations in Part of the Colorado Plateau Region

By G. A. Williams, R. A. Cadigan, H. F. Albee and J. H. Stewart

Trace Elements Investigations Report 313

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

By

George A. Williams, Robert A. Cadigan,
Howard F. Albee, and John H. Stewart

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By George A. Williams, Robert A. Cadigan, Howard F. Albee, and John H. Stewart

ABSTRACT

Stratigraphic studies involving regional stratigraphy, sedimentary structures, pebbles, and sedimentary petrology are designed to furnish information regarding areal distribution, stratigraphic relationship, source areas, and depositional environment of the Triassic Shinarump conglomerate. Because of regional changes in stratigraphy, it is necessary to study rocks ranging from Permian to Jurassic(?) in age in order to obtain this knowledge.

Field studies have been restricted to areas in northern Arizona and southern Utah, and conclusions made here will be subject to revision as the Triassic and associated formations are studied in other areas.

The four programs of study used are: (1) regional stratigraphic descriptions and correlation of units, (2) sedimentary structure studies, (3) pebble studies, and (4) sedimentary petrology.

The Permian Cutler formation consists of six members: the Halgaito tongue, the Cedar Mesa sandstone, the Organ Rock tongue, the DeChelly sandstone, the White Rim sandstone, and the Hoskinnini tongue. The Hoskinnini tongue was traced to its pinch out in White Canyon.

In the western part of the areas studied, the Kaibab limestone and Coconino sandstone make up the Permian section.

The Triassic Moenkopi formation thins from the west and northwest to the south and southeast. In the western parts of the areas studied, the Sinbad limestone member of the Moenkopi was traced to where it could no longer be recognized.

The Triassic Shinarump conglomerate lies unconformably on the Moenkopi formation. The Shinarump is thickest and most continuous in the Kanab area and in the western part of the Monument Valley area. To the north and northeast of these areas, the Shinarump is less continuous and in large areas is present only as sparse lenses. The ore-producing areas commonly are not in the most continuous Shinarump, nor where it is absent, but they seem to be localized where the Shinarump is moderately lenticular.

Distinctive lithologies have been recognized in the Triassic Chinle formation which will probably permit a detailed stratigraphic analysis of the Chinle. Six lithologic units were recognized and their relationships studied.

Orientation studies of the cross-stratified units in the Permian, Triassic, and Jurassic(?) rocks have been made with special emphasis on the Shinarump conglomerate. Cross-stratification studies in the Shinarump indicate that the sediment making up the Shinarump was derived from several directions with a southeast direction predominating.

Studies of the pebbles of the Shinarump conglomerate were made using composition, maximum pebble size, sphericity, and roundness. These studies indicate that the pebbles were derived from several directions.

A preliminary study of the petrology of sandstones in the northern Monument Valley area shows that the sandstones of the Permian Cutler formation, the Triassic Moenkopi and the Jurassic(?) Wingate are predominately feldspathic orthoquartzites. The Triassic Shinarump conglomerate and the Chinle formation are predominantly tectonic arkoses, with conspicuous amounts of interspersed volcanic tuffs and ash.

INTRODUCTION

Stratigraphic studies of the Triassic and associated formations in the Colorado Plateau region are planned to obtain information regarding the areal distribution, local and regional differences in lithology, sources and character of constituting material and conditions of deposition of the ore-bearing Shinarump conglomerate and adjacent strata. The studies are concentrated in the Shinarump, but because of regional changes in the lithology it is necessary to study a considerable thickness of rocks above and below the Shinarump to obtain a complete knowledge of depositional and post-depositional events. This report summarizes information accumulated before 1953, and outlines plans for future work. The stratigraphic studies are being made by the U. S. Geological Survey on behalf of the Division of Raw Materials of the Atomic Energy Commission.

Field studies are essentially completed in the Monument Valley, Kanab, Circle Cliffs, Capitol Reef, White Canyon, and Red House Cliffs areas in southern Utah and northern Arizona (fig. 1). These areas form only a small part of the total areal extent of the Shinarump conglomerate and conclusions made in this report will be subject to revision as more is learned by study of the Shinarump in other areas.

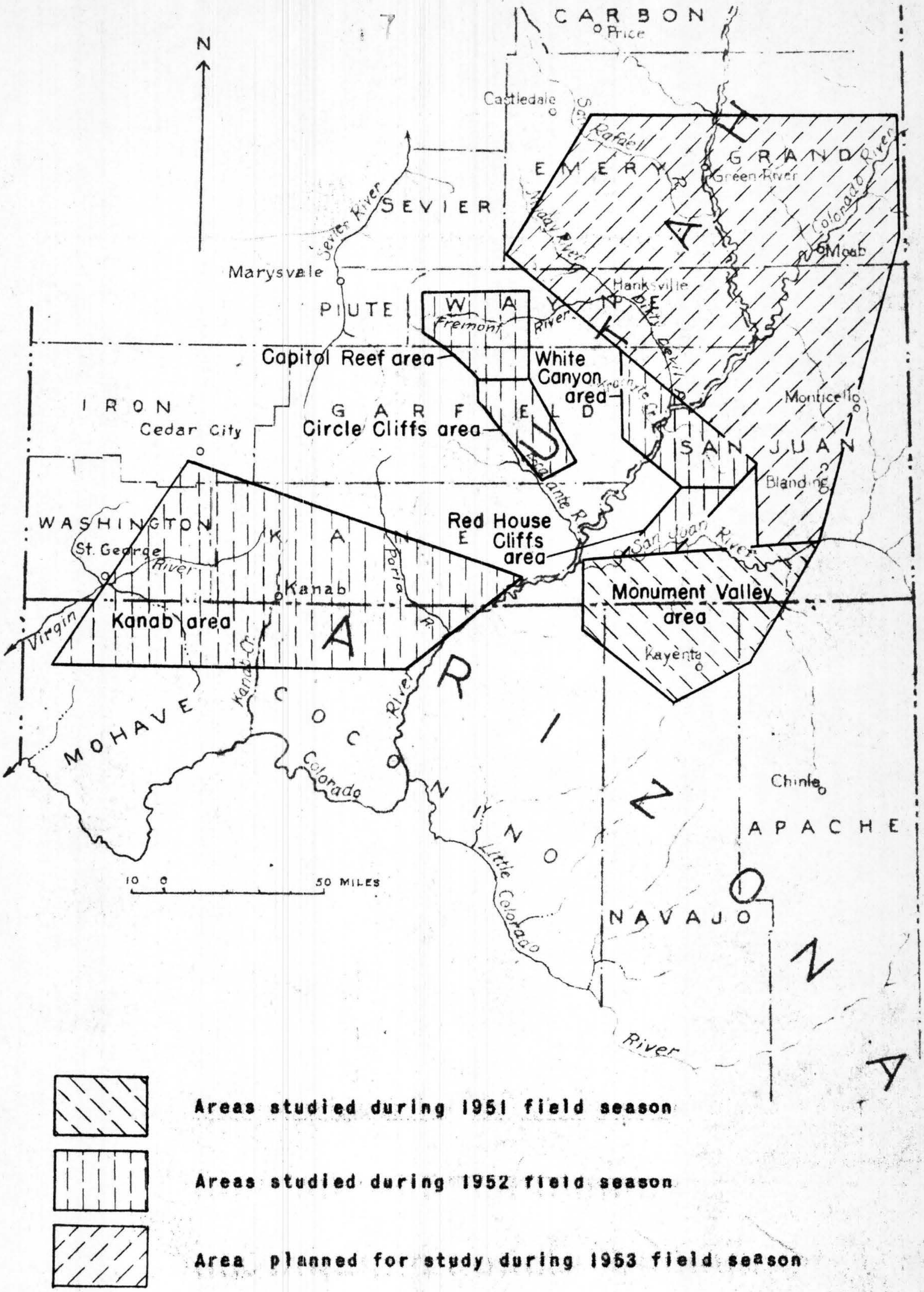

Figure 1. INDEX MAP OF PART OF ARIZONA AND UTAH SHOWING AREAS OF STRATIGRAPHIC STUDIES

The Triassic formations are in ascending order, the Moenkopi formation, the Shinarump conglomerate, and the Chinle formation (table 1). Associated formations are the underlying Cutler formation, Coconino sandstone, and Kaibab limestone of Permian age and the overlying Wingate sandstone of Jurassic(?) age.

The four principal programs of study are: (1) regional stratigraphy--the measurement and description of geologic sections and the tracing of formation contacts; (2) sedimentary structure studies--measurement and description of the orientation of cross-stratification, current lineation, and ripple marks; (3) pebble studies--the study of size, sphericity, roundness, and composition of pebbles found in conglomeratic strata; and (4) sedimentary petrology studies of the microscopic texture, structure, and composition of the sediments.

REGIONAL STRATIGRAPHY

Permian rocks

Part of the Cutler formation was studied in the Monument Valley, Red House Cliffs, and White Canyon areas (fig. 1). The Cutler formation is divided into six members which are from oldest to youngest: the Halgaito tongue, the Cedar Mesa sandstone member, the Organ Rock tongue, the DeChelly sandstone member, the White Rim sandstone member, and the Hoskinnini tongue. The Halgaito tongue was not studied. The Cedar Mesa sandstone member changes from sandstone and abundant interstratified red siltstone in the eastern part of the Monument Valley area to massive cross-stratified yellowish-gray sandstone in the western part of the Monument Valley, the Red House Cliffs and White Canyon areas.

Table 1. GENERALIZED SECTION OF PERMIAN, TRIASSIC, AND JURASSIC (?) ROCKS IN PART OF THE COLORADO PLATEAU

System	Formation		Thickness (feet)	Character and distribution
	Unconformity			
Jurassic (?)	Glen Canyon group	Navajo sandstone	0-1350	Sandstone, white to pale yellowish orange 1/, fine- to medium-grained, large scale cross-laminated. Thickens westward from featheredge in northeasternmost Arizona.
		Kayenta formation	0-300	Sandstone, yellowish orange and pale grayish red, fine- to medium-grained, thin to thick horizontally bedded and medium scale, low-angle cross-laminated. Contains minor reddish brown siltstone. Thickens westward from featheredge in northeasternmost Arizona.
		Wingate sandstone	250-350	Sandstone, very pale orange to moderate reddish orange, very fine- to fine-grained, large scale cross-laminated, cliff-forming, widespread.
	Local unconformity			
Triassic	Chinle formation		10-1200	Claystone and siltstone, pale red, grayish purple, greenish gray, variegated, sandy. Contains minor ripple-laminated or small to medium scale, cross-laminated sandstones and minor thin to thick interstratified beds of dense limestone. Thins northward.
	Shinarump conglomerate		0-350	Sandstone, grayish orange to pale yellowish orange, medium- to coarse-grained, small to medium scale cross-laminated; common thin to very thick beds of conglomeratic sandstone to conglomerate; locally highly variable in thickness; locally absent.
	Unconformity			
	Moenkopi formation		50-1000	Siltstone, pale reddish brown, horizontally and ripple-laminated; minor very fine-grained, cross-laminated sandstones, Formation thickens westward and northwestward. Sinbad limestone member present only in western part of southeastern Utah; 0-200 feet above base of Moenkopi formation; ranges in thickness from a featheredge to 150 feet; composed of pale yellowish brown, dense limestone and minor pale olive siltstone.
	Local unconformity			

System	Northeastern Arizona and central, east-central, and southeastern Utah				South-central Utah		
	Formation	Member	Thickness (feet)	Character and distribution	Formation	Thickness (feet)	Character and distribution
Permian	Cutler formation	Hoskinnini tongue	0-120	Siltstone to fine-grained sandstone, pale reddish brown, common medium to coarse, well-rounded grains, thin to very thick horizontally bedded. Not present in south-central, central, or east-central Utah.			
		Local unconformity					
		White Rim sandstone	0-230	Sandstone, very light gray to yellowish gray, fine- to medium-grained, medium to large scale cross-laminated, present only in east-central Utah.	Kaibab limestone	150	Dolomitic limestone, light greenish gray and yellowish gray, dense, commonly fine-grained sandy, cherty, widespread.
		DeChelly sandstone	0-825	Sandstone, moderate reddish orange, very fine- to medium-grained, medium to large scale cross-laminated, cliff-forming. Thins to the northwest and pinches out near the Arizona-Utah boundary.	Coconino sandstone	800	Sandstone, yellowish gray, fine-grained, medium to large scale cross-laminated. Contains minor limy sandstone and dolomitic limestone beds. Formation is cliff-forming.
		Organ Rock tongue	250-800	Siltstone, pale reddish brown, horizontally laminated to very thick bedded. Contains minor very fine- to fine-grained, cross-laminated sandstones. Thins to northwest.			
		Cedar Mesa sandstone	0-1250	Sandstone, yellowish gray, fine- to medium-grained, medium to large scale cross-laminated, cliff-forming. Thickens to northwest from inferred featheredge in northeastern Arizona.			
		Halgaito tongue 2/	0-470	Siltstone to very fine-grained sandstone, pale reddish brown, horizontally bedded. Contains minor limestones. Present only in northeastern Arizona and southeastern Utah.			
	2/ Rico formation		300-470	Siltstone to medium-grained sandstone, pale reddish brown, horizontally bedded. Contains minor greenish gray, thin to thick horizontal beds of limestone. Formation is widespread.			

1/ Colors according to Rock Color Chart, National Research Council, 1948.

2/ Baker, A. A., 1936, Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U. S. Geol. Survey, Bull. 865.

Gregory, H. E., 1938, The San Juan Country, a geographic and geologic reconnaissance of southeastern Utah: U. S. Geol. Survey Prof. Paper 188.

The Organ Rock tongue is a widespread unit of reddish-brown siltstone that thins northward from 450 feet in Monument Valley to a measured minimum of 300 feet in the White Canyon area. The middle part of the Organ Rock in the western part of the White Canyon area contains a prominent cross-stratified sandstone unit. This sandstone grades into siltstones of the Organ Rock in the Central part of the White Canyon area. The DeChelly sandstone, which overlies the Organ Rock in the Monument Valley area, thins to the north in the Monument Valley area and pinches out near the San Juan River. The White Rim sandstone, which overlies the Organ Rock tongue north of the White Canyon area grades laterally into siltstone of the Organ Rock tongue in the western part of the White Canyon area. The White Rim sandstone, the mid-Organ Rock sandstone unit or both may connect with DeChelly sandstone. This correlation can not be made positively for the two units are absent along the only continuous line of Permian rock exposures between Monument Valley and White Canyon. Either or both of these sandstones may connect and be a continuous sandstone unit with the DeChelly beneath areas where these rocks are deeply buried. The Hoskinnini tongue, previous to this study, had not been extended north of the pinch-out of the DeChelly sandstone near the San Juan River because it was thought that the Hoskinnini could not be differentiated from the Organ Rock where the DeChelly sandstone was not present (Baker, 1936). However, in the Red House Cliffs area (Mullens and Hubbard, 1952), the Hoskinnini has been recognized by its distinctive lithology of siltstone or very fine-grained sandstone containing abundant well-rounded, medium grains and by its distinctive smooth surface weathering. The Hoskinnini was traced north from the Red House Cliffs area to a pinch-out in the middle of the White Canyon area.

The Cutler formation was deposited in at least two depositional environments--eolian and marine or marginal marine. The light-colored sandstone members--the Cedar Mesa sandstone, DeChelly sandstone, and White Rim sandstone--are interpreted as eolian, whereas the reddish siltstone and sandstone members, such as the Organ Rock tongue, are interpreted as marine or marginal marine.

In the Circle Cliffs and Capitol Reef areas the Permian Coconino sandstone and Kaibab limestone are the lowest formations exposed and are presumably equivalent to the upper part or all of the Cutler formation. The Coconino sandstone is a fine- to medium-grained cross-stratified sandstone which is interpreted as eolian. The Coconino grades upward into the sandy dolomitic limestone of the Kaibab formation which was probably deposited in a marginal marine or near shore environment.

Triassic rocks

The Moenkopi formation, the lowest Triassic formation in the areas studied, is dominantly reddish-brown siltstone to sandy siltstone. It thins to the east from 1,600 feet (Gregory, 1950) in the Kanab area and about 900 feet in the Capitol Reef area to about 250 feet in the western part of the Monument Valley, Red House Cliffs, White Canyon, and Circle Cliffs areas, and to about 100 feet in the eastern part of the Monument Valley area.

The Moenkopi formation contains a limestone unit in the Capitol Reef area that has been tentatively identified by J. F. Smith and others (1952) as the Sinbad limestone member of the Moenkopi formation. In the central part of the Capitol Reef area the Sinbad limestone is about 150 feet thick and is underlain by about 100 feet of siltstone that forms the basal unit of the Moenkopi. Southward from the Capitol Reef are, the Sinbad limestone and underlying siltstone unit is thinner. In the northern part of the Circle Cliffs area, where the Sinbad has not been previously reported, the limestone is about 50 feet thick and the underlying siltstone unit is only a few feet thick. In the central part of the Circle Cliffs area the siltstone unit pinches out and the Sinbad limestone lies directly on the Kaibab limestone, but in the southern part of the Circle Cliffs area the Sinbad limestone has not been recognized.

The Moenkopi formation was deposited dominantly in a marginal marine or tidal flat environment in which current and wave action was active enough to produce abundant ripple marks. The Sinbad limestone member was deposited in a marine environment that encroached on a marginal marine environment from the west.

The Shinarump conglomerate of this report includes only the sandstone, conglomeratic sandstone, conglomerate, and gray-green lenses of claystone and siltstone that directly overlie the Moenkopi formation. The sandstone is grayish to pale yellowish orange, cross-stratified on a small to medium scale, and composed dominantly of medium- to coarse-grained subrounded clear quartz; the conglomerate is cross-stratified.

on a small to medium scale, and is composed dominantly of vitreous quartz, quartzite, and chert pebbles. The conglomerate beds in some places are as much as 40 feet thick but in other places form only thin stringers on planes of bedding and cross stratification. In the Red House Cliffs area where the Shinarump is absent, pebbles are present in the basal few inches of the Chinle shales. Lenses of gray-green claystone and silt-stone in the Shinarump are present in all areas and locally they comprise a large percentage of the Shinarump.

The Shinarump ranges from a continuous unit 150 to 350 feet thick in the Kanab and western part of Monument Valley areas to a discontinuous unit a few inches to 50 feet thick in the White Canyon, Red House Cliffs, and the eastern part of the Monument Valley areas. In many parts of Circle Cliffs, Capitol Reef, White Canyon, and Red House Cliffs areas the Shinarump is absent and the Chinle formation rests directly on the Moenkopi.

The discontinuity of the Shinarump is due mainly to a depositional wedging out of the individual lenses but in a few places is due to erosion prior to the deposition of the Chinle. In places in Capitol Reef, channels filled with claystones of the Chinle cut down through the Shinarump, with no intertonguing evident, into the top of the Moenkopi formation. In the Circle Cliffs, however, as well as in most of the areas, lenses of Shinarump conglomerate intertongue with Chinle shales.

Channels filled with Shinarump conglomerate are common along the erosional unconformity between the Shinarump and Moenkopi formations. The channels range from a few feet deep and a few feet wide to about 75 feet deep and 2,300 feet wide (Witkind and others, 1953) in the western part of the Monument Valley area. Channels are common in the Monument Valley, Circle Cliffs and Capitol Reef areas. In the White Canyon and Red House Cliffs areas channels are rare, and where present, they are small, both in depth and width. In the Kanab area channels that cut into the underlying Moenkopi are rare, but channels within the Shinarump are common.

The presence of channels, trough cross-stratification, and carbonaceous debris indicates that the Shinarump was deposited in a fluviatile environment.

The Chinle formation consists of variegated claystone and siltstone interbedded with minor sandstone beds. The formation thins northward from Monument Valley; the thickness averages 950 feet in the Monument Valley area, 800 feet in the Red House Cliffs area, 650 feet in the White Canyon and Circle Cliffs areas, and 500 feet in the Capitol Reef area. The Chinle is 1,400 feet thick in the Kanab area, but the significance of this large thickness has not yet been evaluated.

In the Navajo Indian Reservation, the Chinle formation was separated into four divisions by Gregory (1917, p. 42). These divisions in ascending order are "D", "C", "B", and "A". Although the lithology and thickness of these members (McKee, 1951, p. 89) differ from place to place away from areas where they are best developed, they have been tentatively correlated throughout northern Arizona and southern Utah. Correlation of these units has not been established in the Kanab area.

The "D" member in the Monument Valley area is predominately a reddish-brown silty claystone and interstratified miceacous and ripple-laminated sandstone. Throughout the area studied the "D" member is about 200 feet thick. Northward in the White Canyon, Circle Cliffs, and Capitol Reef areas, this member is a distinctive and persistent unit predominately of greenish-gray claystone and interstratified sandstone similar to the sandstone of the "D" member in Monument Valley. Throughout northern Arizona and southern Utah the interstratified sandstones in the "D" member commonly have strikes and dips anomalous to the regional strike and dip. Field evidence suggests that the unusual attitudes of these beds is due to penecontemporaneous deformation.

The "C" member is a variegated claystone unit about 450 feet thick in the Monument Valley area. This member intertongues with the overlying "B" member in the Red House Cliffs area. In the White Canyon area and northward, intertonguing of the "C" and "B" members has progressed to the point where the "C" member is replaced by the "B" member.

A reddish-orange claystone and siltstone unit about 150 feet thick which commonly contains a high proportion of sandstone is found in the Circle Cliffs and Capitol Reef areas and probably in the western part of the White Canyon area. This unit is probably equivalent to a part of the "C" member. The prominent mid-Chinle sandstone of the Capitol Reef and Circle Cliffs areas lies at the top of the reddish orange claystone and siltstone unit, whereas the prominent sandstone unit of the White Canyon area, easily mistaken for the Shinarump, lies at the base of, or immediately below the probably extension of this unit.

These two sandstone units are not believed to correlate because of their probable different stratigraphic positions.

The "B" member is composed of pale-red siltstone and commonly interstratified gray or pale-red, thin to thick limestone beds. It thins from 300 feet in the Monument Valley area to about 200 feet in the White Canyon and Circle Cliffs areas, and is about 150 feet thick in the Capitol Reef area.

The "A" member is composed of reddish siltstone and sandstone. It ranges in thickness from 40 to 200 feet and averages about 150 feet thick. In the Red House Cliffs and White Canyon areas the lower part of the "A" member is a reddish siltstone that intertongues and is replaced by the "B" member to the west in Circle Cliffs and Capitol Reef areas. The upper part of the "A" member in the Red House Cliffs and White Canyon areas and in the eastern part of the Circle Cliffs area is predominantly a reddish sandstone commonly containing granules to boulders of siltstone.

The Chinle formation is interpreted to have been deposited in a fluviatile and lacustrine environment. The "D" and "C" members are probably primarily fluviatile deposits composed in large part of volcanic ash. The "B" and "A" members are mainly deposited in a lacustrine environment and probably contain considerably less volcanic material than the "D" and "C" members. The upper part of the "A" member is predominately a fluviatile deposit.

Jurassic(?) rocks

The Wingate sandstone and the "A" member of the Chinle formation are lithologically similar, but have a recognizable contact between them in the areas studied. Generally the contact can be located by the distinctive well-rounded coarse grains in the lower few feet of the fine-grained Wingate sandstone. Locally a slight angular and erosional unconformity is present along this contact in the Circle Cliffs and Capitol Reef areas.

SEDIMENTARY STRUCTURES

Studies of the orientation of sedimentary structures in the Shinarump conglomerate and associated formations began in 1951 and continued during the 1952 field season. The methods used, with minor modifications, are the same as those developed in the Morrison study (Craig, and others, 1952). Descriptive terms are those recommended by McKee and Weir (1952).

The amount and direction of dip is measured on the cross-strata in the unit being studied. The number of dip measurements that are necessary for adequate sampling depends on the diversity in direction of dips of the cross-stratification. The result of many field tests show that 150 dip measurements are adequate in units that have channels that cut into underlying units and contain trough-type cross-strata such as the Shinarump conglomerate. In units which contain large-scale trough-type cross-strata, such as the Navajo sandstone, 50 measurements are sufficient. 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 one component of 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 taken in each study 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.

Permian rocks

The Cedar Mesa sandstone member of the Cutler formation was studied in the Monument Valley, Red House Cliffs, and White Canyon areas. The studies indicate a direction of transport of the material from the northwest. The cross-strata are generally large-scale (greater than 20 feet) and become tangential to the lower bounding surface of the set. Present practice is to identify such structures as eolian.

Orientation studies in the DeChelly sandstone member of the Cutler formation in Monument Valley indicate that the material was transported from the northwest. The DeChelly sandstone is composed of large-scale trough cross-strata and is interpreted as eolian.

The sandstone unit in the middle part of the Organ Rock tongue in the western part of the White Canyon and the White Rim sandstone member of the Cutler formation contain large-scale trough cross-strata and are interpreted as eolian. Orientation studies in both units indicate that the material was transported from the northwest.

Two studies were made in the Coconino sandstone--one in the Circle Cliffs area, and one in the Capitol Reef area. The direction of transport indicated by these studies was from the northwest. The sandstone contains large-scale trough cross-strata and is interpreted as eolian.

The similarity in direction of transport of the material and the type of cross-stratification in the sandstone members of the Cutler and the Coconino sandstone suggest that these units are related and probably derived the material from the same source.

Triassic rocks

The Moenkopi formation contains several cross-stratified sandy siltstone units that permit orientation studies. The cross-stratification is small-scale (less than 1 foot) to medium-scale (more than 1 foot to less than 20 feet) and is of a trough-type closely resembling the festoon-type described by Knight (1929, p. 56-74). Based on three orientation studies the transportation direction of these sediments was predominantly from the east.

The orientation of sedimentary structures was concentrated in the Shinarump conglomerate with 22 orientation studies completed in the areas examined (fig. 1).

Orientation studies of the Shinarump conglomerate indicate that the direction of transport of sediments was from the south and southeast in all areas studied except the Circle Cliffs and Capitol Reef areas, Utah. In these areas orientation studies indicate a source to the southwest in addition to a southeast source. The differences in direction found in the orientation studies support the concept of multiple sources for the Shinarump.

Structure studies of the prominent sandstone in the White Canyon area show the direction of transport of the sediment from the east and southeast. These directions are more westerly than the direction of transport found for the Shinarump conglomerate.

Structure studies in the prominent sandstone of the Chinle formation in the Capitol Reef and the Circle Cliffs areas show the direction of transport of the sediment to have been from the southwest.

The "A" member of the Chinle formation contains medium-scale trough cross-stratification. Orientation studies in this "A" member in the Red House Cliffs and White Canyon areas indicate the transport of material to have been from the southwest.

Jurassic(?) rocks

The Wingate sandstone commonly forms a vertical cliff, making sedimentary structure studies difficult, but where exposures permit, orientation studies indicate the sediment was transported from the northwest.

Structure orientation studies were made in the Kayenta and Navajo formations whenever time permitted. Studies in the Kayenta formation show that sediment was transported predominately from the north and northeast but sufficient differences in these directions occur to indicate a variation in current directions which is not thoroughly understood. Studies in the Navajo are consistent in showing that the sediment was transported from the northwest.

The eolian sandstones which occur in the Permian and Jurassic(?) rocks have a consistent transportation direction from the northwest, suggesting the same general source areas and conditions of deposition.

PEBBLE STUDIES

The purpose of the pebble studies is to determine the regional differences in composition, size, sphericity, and roundness of the pebbles found in the Shinarump conglomerate. Pebbles in the Shinarump are studied in each area visited, but in some areas pebbles are scarce and a uniform areal distribution of the pebble studies cannot be made.

The pebble studies at each sample locality are based on two collections of 50 pebbles each. One collection is sieved into several size groups which conform with the Wentworth size classification (Wentworth, 1922, p. 377-392), and each size group is studied for composition. The second collection of 50 pebbles is retained for laboratory determinations of sphericity and roundness. Considerable time is spent at each sample locality searching for the largest pebble, for fossiliferous pebbles, and for rare lithologic types.

The pebbles of the Shinarump are mainly well-rounded fragments of vitreous quartz, quartzite, and chert, but some silicified limestone and igneous pebbles occur. Chert and quartzite pebbles are dominant in the Kanab area. Eastward from the Kanab area there is a marked, though not progressive, decrease in the relative abundance of chert and quartzite pebbles, and in the Red House Cliffs area vitreous quartz pebbles are dominant. These vitreous quartz pebbles are mostly of a pink variety and appear to have had a different source than the colorless and milky varieties found in areas west of the Colorado River. Silicified limestone pebbles were found only in the Circle Cliffs and Capitol Reef areas and igneous pebbles were found only in the Capitol Reef area. The relative abundance of different pebble types in the areas studied is shown in table 2.

The west to east change in pebble composition coincides with a general, though not progressive, west to east increase in sphericity and roundness. Also, the maximum pebble diameter decreases from 4 1/2 inches in the Kanab area to about 1 1/2 inches in the Capitol Reef area (fig. 1). Eastward from Capitol Reef the maximum pebble diameter increases to 5 inches in the Red House Cliffs area.

Although the field and laboratory data are incomplete, some paleo-geologic interpretations seem justified. The direction of change in size and sphericity and the introduction of different lithologies suggests a multiple source for the Shinarump: (1) a source from the south or west of the Kanab area, (2) a source from the southeast of the areas studied east of the Colorado River, and (3) a suggestion of a possible contribution from somewhere north and west of the Capitol Reef area.

SEDIMENTARY PETROLOGY

The investigation of Triassic and related sediments on the Colorado Plateau was undertaken by the sedimentary petrology laboratory on a part-time basis during the field season of 1951. Systematic study and a regional sampling program were begun in the 1952 field season. Laboratory work includes grain-size analyses, heavy mineral separations, preparing samples for thin-sectioning, and otherwise processing for study the samples that were collected.

Table 2.--Average percentage composition of pebbles in the Shinarump conglomerate of southern Utah without regard to size

Area	Vitreous Quartz	Quartzite	Chert	Siliceous limestone	Igneous	Maximum Size (in.)
Western part of Kanab	18	34	48	--	--	4.5
Eastern part of Kanab	16	60	24	--	--	3.7
Circle Cliffs	41	20	35	4	--	2.5
Capitol Reef	60	16	13	9	2	1.7
White Canyon	89	9	1+	--	--	3.2
Red House Cliffs	84	14	2	--	--	5.0

A brief study of the general character of Triassic and related sandstones has been completed. The study consisted of a qualitative inspection of selected thin-sections of Shinarump conglomerate from five different areas, and an inspection of a suite of representative thin-sections of Permian, Triassic, and Jurassic(?) sandstones from the northern part of the Monument Valley area.

The recognition of the rock types into which the sandstones have been classified is based on a visual estimate of the composition in general and on the amount of sodium cobaltinitrite-stained orthoclase and microcline feldspars plus derived kaolinite present in the thin sections. The sandstones are highly quartzitic with varying amounts of potash feldspar, plagioclase feldspar, chert, and clay minerals. The cementing materials are chiefly calcium carbonate or secondary silica deposited in the form of optically continuous quartz overgrowths. Where feldspars are estimated to make up less than 10 percent of the detrital minerals, the sandstone is classified as an orthoquartzite; 10 percent to 25 percent feldspar defines a feldspathic orthoquartzite; 25 percent or more feldspar defines an arkose. The term feldspar as used in this system of classification includes the derived clay mineral, kaolinite.

Three general types of arkoses may be defined on the basis of texture and structure; these specific types are believed to occur under restricted conditions. Classified genetically these types are (1) residual arkose, or "granite wash" material which resembles weathered granite; (2) tectonic arkose which requires tectonic uplift of a granitic source area, extreme dissection, and torrential streams; and

(3) derived arkose which results from the reworking of a residual or tectonic arkose with a loss through winnowing of most of the kaolinite and the preservation of most of the feldspar. The terminology of rock classification used here with the exception of derived arkose is that presented by Pettijohn (1949).

Permian rocks

The sandstones of the Cutler formation are generally feldspathic orthoquartzites but there is some difference in composition between members. The Cedar Mesa sandstone and the DeChelly sandstone members are feldspathic orthoquartzites; the Organ Rock tongue is a feldspathic orthoquartzite characterized by poor sorting and angular grains. The Hoskinnini tongue is an arkose characterized by a conspicuous coarse fraction of well-rounded grains of quartz and potash feldspar.

Triassic rocks

Sandstones of the Moenkopi formation are feldspathic orthoquartzites.

The sandstones of the Shinarump conglomerate were found to vary in composition, texture, and structure from conglomerate arkoses of the type which are genetically classified by Pettijohn (1940) as tectonic arkoses, through coarse-grained feldspathic orthoquartzites to fine-grained feldspathic orthoquartzites. A substantial amount of altered rhyolitic tuff is present in most localitites. The amount of volcanic material may differ greatly between successive strata at the same location.

One or more of the source areas of the Shinarump is interpreted from the petrography of the sandstones to be dominantly a granitic terrain with some sedimentary cover undergoing extreme tectonic uplift with accompanying volcanic activity consisting of rhyolitic flows and ash falls. The parts of the Shinarump conglomerate which may be classified as arkose are probably directly derived from alluvial fans or possibly result from the overflow of nearby sedimentary basins. The better sorted and less feldspathic sandstones may be the result of reworking of the alluvial fan or basin material.

Petrographic work on the Shinarump has not progressed to the point where systematic regional differences in microscopic texture, structure, and mineral composition may be recognized.

The Chinle formation tends to be arkosic. The "D" member sandstones, which immediately overlie the Shinarump, are orthoquartzites with a tight mosiac arrangement of the grains; they contain much green chloritic clay in interlamellar seams, colorless mica, non-opaque heavy minerals, and altered volcanic ash. The basal sandstone of the Chinle "D" member often has been combined for mapping purposes with the Shinarump conglomerate. If the contrast between the two sandstones observed in the preliminary study is found to exist over the region as a whole, the two sandstones should be properly considered as separate lithologic units in future paleogeological interpretations. The "B" member sandstones are arkosic with layers of granule-size pellets of cryptocrystalline calcite which contain, as inclusions, clouds of angular microlites of quartz and feldspar possibly of volcanic origin. The "A" member sandstones are well sorted arkoses.

Jurassic(?) rocks

The Wingate sandstone is a feldspathic orthoquartzite which contains less-angular grains and is better sorted than the underlying Chinle sandstones.

INTERPRETATIONS AND RESULTS

The Cutler formation is a sequence of sediments which is believed to have been deposited in a complex of marginal marine and eolian environments. The sequence represents an intertonguing of sediments derived from two sources. The relatively high content of feldspar and the stratigraphic relationships of the Organ Rock and Hoskinnini tongues indicate that they probably received contributions from an actively rising landmass to the east, possibly the Uncompahgre and San Luis highlands, and that they were deposited in shallow water.

The Cedar Mesa, DeChelly, and White Rim sandstone members are interpreted as eolian sandstones. Orientation studies on the cross-stratification in these members indicate that the material was transported from the northwest.

The Hoskinnini tongue of the Cutler formation has been extended from the Red House Cliffs area into the White Canyon area where it pinches out. In these areas the Hoskinnini is an easily recognizable and mappable unit.

The Moenkopi formation is believed to be dominantly a tidal flat and shallow water marine deposit which derived material from the east, possibly from the granitic terrain of the Uncompahgre highland. Sandstone ledges that contain channels and trough cross-stratification are believed to represent an encroachment of stream deposits onto the tidal flat.

Field evidence indicates that the Sinbad limestone member of the Moenkopi formation in the Capitol Reef area extends into the Circle Cliffs area where it pinches out. The Sinbad limestone member is a marine limestone that represents an advance of a marine environment into a marginal marine environment.

The Shinarump conglomerate lies unconformably on the Moenkopi formation. The formation is thickest and most continuous in the Kanab area (fig. 1) and in the western part of the Monument Valley area. To the north and northeast of these areas the Shinarump is less continuous and over large areas is present only as thin and scattered lenses.

The presence of channels, trough cross-stratification, and carbonaceous debris indicates that the Shinarump was deposited in a fluviatile environment.

Preliminary data on the orientation of sedimentary structures indicate that the Shinarump was derived from several source areas, of which a source area to the southeast predominated. Similarly, incomplete pebble studies indicate that the Shinarump was derived from several sources; however, in contrast to the sedimentary structure studies, the pebble studies indicate a prominent southwesterly source. Since the Shinarump is an arkosic sediment, the source area probably was undergoing emergence and regional uplift which resulted in the dissection of granitic and sedimentary terrains. This uplift was accompanied by volcanic activity giving rise to rhyolitic flows and ash falls which were eroded and incorporated into the Shinarump sediments.

The ore-producing areas are generally not in the most continuous Shinarump conglomerate, nor where the Shinarump is absent, but they seem to be localized where the Shinarump is moderately lenticular.

The basal member of the Chinle formation is the "D" member that consists of thick altered volcanic ash and chloritic claystones, and minor orthoquartzitic sandstones. The overlying "C" member in the Monument Valley area consists of siltstone and claystone with minor arkosic sandstones.

A reddish-orange siltstone and arkosic sandstone unit which is believed to correlate, at least in part, with the "C" member of Monument Valley is found in the Circle Cliffs, Capitol Reef, and probably the western part of White Canyon area.

The prominent sandstone in the Chinle of Capitol Reef is probably at the top of the reddish-orange unit. Cross-stratification studies made in this sandstone indicate that the material was transported from the southwest.

The prominent sandstone in the Chinle of White Canyon probably is at the base of or immediately below the probable extension of the reddish-orange unit. Cross-stratification studies made in this prominent sandstone indicate that the material was transported from the east, and thus possibly derived from the Uncompahgre highland.

The overlying "B" member of the Chinle consists of claystone, limestone, dolomite, and calcareous arkoses.

The "A" member, the uppermost member, of the Chinle is composed of siltstones and arkosic sandstones. Cross-stratification studies in sandstones of this unit indicate that the sediment was derived from the southwest.

The sediments that make up the rocks of the Chinle are arkosic and quartzitic sands and silts interbedded and intermixed with varying amounts of volcanic ash and tuff. These sediments are believed to have been in a complex of stream, lake, swamp, and lagoon environments.

Recognition of distinctive lithologies in the Chinle will probably permit a detailed stratigraphic analysis of the Chinle.

The feldspathic orthoquartzites of the Wingate sandstone are believed to represent a widespread eolian deposit which accumulated on a flat low-lying plain formed on the upper surface of the Chinle. Cross-stratification orientation studies indicate that the material was transported from the northwest.

PLANS

In the 1953 field season the stratigraphic studies group will extend the regional study to central and east-central Utah (fig. 1). Several areas essentially completed will be revisited to collect additional data and to orient new personnel.

A special detailed study of the Shinarump conglomerate aimed at providing an analysis of the distribution and lenticularity as well as a better understanding of the relationships to the Chinle formation will be initiated in 1953. Many of the areas otherwise completed will be revisited to accomplish the detailed study.

A study of the distribution and character of volcanic debris in the ore-bearing rocks of the Triassic formations and the Morrison formation will be started by the sedimentology laboratory. The objective of this study is to determine the relation of the volcanic debris to uranium deposits and will include a study of volcanic debris as a precipitating agent or as a possible source of the metals.

In the winter of 1953-1954 a more detailed interim report will be prepared for transmittal to the Atomic Energy Commission.

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