A COMPARISON OF THE SHINARUMP CONGLOMERATE ON HOSKINNINI MESA WITH THAT IN OTHER SELECTED AREAS IN ARIZONA AND UTAH

by

Charles G. Evensen

A Thesis

submitted to the faculty of the

Department of Geology

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in the Graduate College, University of Arizona

1953

Approved: Edwin D. McKee, May 19-1953

Director of Thesis, Date

NC

TABLE OF CONTENTS

PLATES

INTRODUCTION

General Statement

The study presented in this paper is a comparison of the Shinarump conglomerate on Hoskinnini Mesa with that in a number of other localities in northern Arizona and southern Utah. Comparisons of mineralized with unmineralized areas are made in an effort to find some controls of mineralization which may be applicable in other areas. The months of June, July, and August, 1952 were spent in northern Arizona and southern Utah accumulating field data and gathering specimens for laboratory study which was done in Tucson, Arizona, during the following winter.

The early part of the field season was spent making a detailed study of the Shinarump conglomerate on Hoskinnini Mesa. This was followed by studies at Cameron, Lee's Ferry, Oljeto Mesa, Monument #2 Mine, and Canyon de Chelly (Fig. 1). Subsequently, the data accumulated and samples collected during the summer were tabulated and analyzed for the purpose of gaining further comparative material.

The Shinarump conglomerate consists of conglomerate, sandstone, and occasional lenses of mudstone. It underlies the Chinle formation (Upper Triassic) and overlies the Moenkopi formation (Lower Triassic) or De Chelly sandstone (Permian). The Shinarump conglomerate was deposited by a number of braided stream systems whose constant reworking caused the sheets of sand and gravel to advance across a relatively flat erosional surface. This constant process of reworking enabled the advancing sheets to cover a vast area with a relatively thin veneer of coarse material.

Locations and Accessibility

The geological field studies made in connection with this report were carried out at Hoskinnini Mesa, Oljeto Mesa, Monument #2 Mine, Cameron, Lee's Ferry, and Canyon de Chelly (Fig. 1).

Hoskinnini and Oljeto Mesas lie along the Arizona-Utah line approximately between 110°20' and 110°25' west longitude on the west side of Monument Valley. They extend nearly three miles north into Utah and four miles south into Arizona. The area involved is about 12 miles wide. The two mesas may be reached by traveling north on U. S. Highway No. 89 from Flagstaff, Arizona, to Route No. 1, Navajo Indian Reservation. Route No. 1 is a semi-maintained dirt road which passes through Tuba City, Tonalea (Red Lake), Kayenta, and continues on to Mexican Hat, Utah. About 12 miles north of Kayenta and several miles beyond Agathla, a prominent volcanic spire, the trail to Hoskinnini Mesa turns off to the west from the main road. This trail continues up onto the top of the mesa where several trails split off. About 20 miles north of

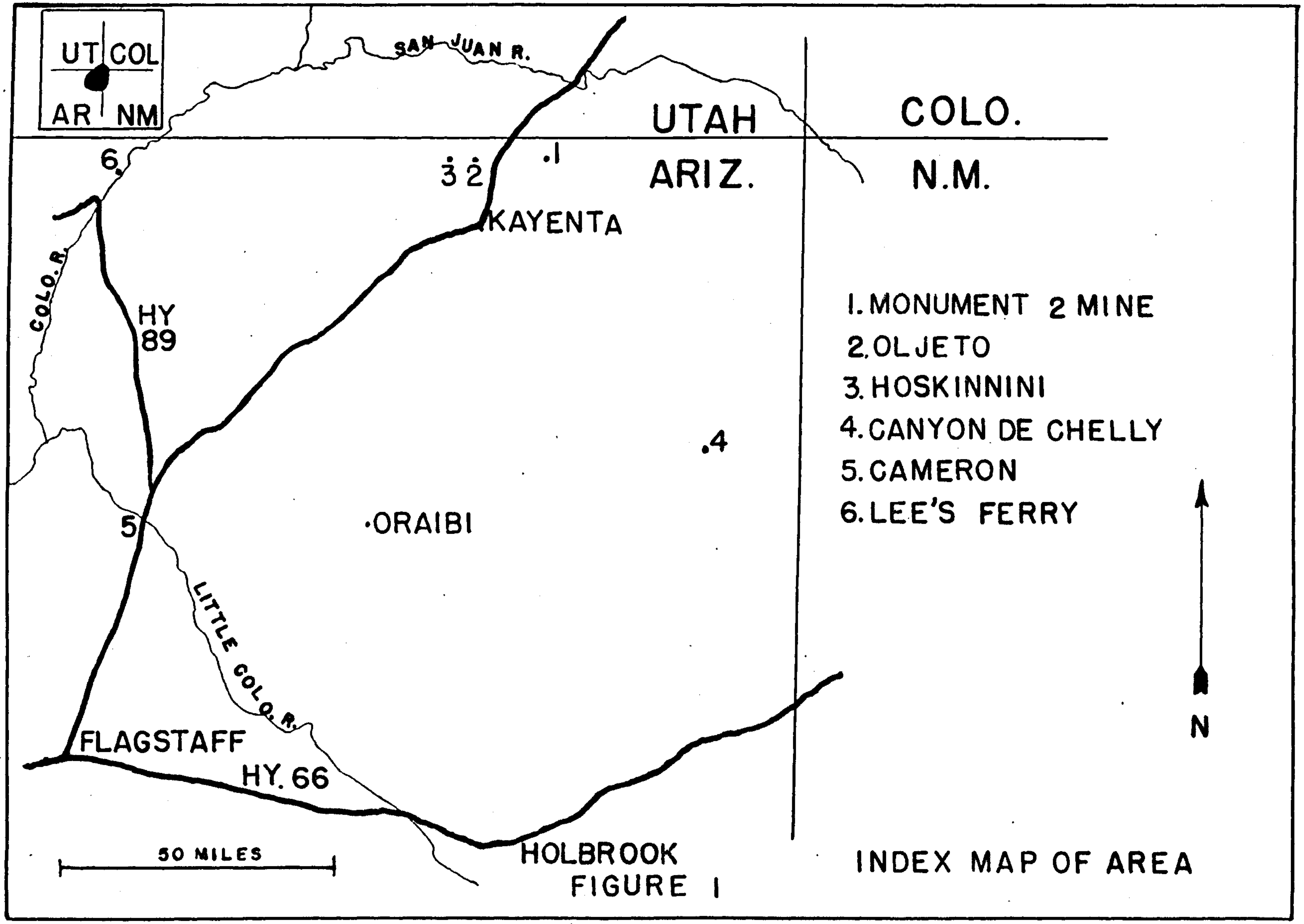


FIGURE 1

INDEX MAP OF AREA

Kayenta, the road to the Oljeto Trading Post turns off the main road in a northwesterly direction. The Trading Post lies at the western foot of Oljeto Mesa. No road to the top of the mesa is open at the present time.

Monument #2 Mine is located approximately at 109°50' west longitude and 37° north latitude, about two miles south of the Utah line and on the east side of Monument Valley. It may be reached by traveling north from Kayenta, Arizona, or south from Mexican Hat, Utah, on Route No. 1 Navajo Indian Reservation. A well marked road, the only other graveled road in the area, turns off a few miles south of the San Juan River. This road, built for the ore trucks from the mine, goes directly to the mine area.

The sections studied at Cameron are on both sides of the Little Colorado River about one half mile west of the Trading Post on U. S. Highway No. 89. The area is approximately at 111°25' west longitude and 35°50' north latitude.

Lee's Ferry is on the Colorado River at the head of Marble Canyon at 111°35' west longitude and 36°50' north latitude. The two localities studied in this area are on the north side of the river. One locality is about five miles upstream from the Marble Canyon bridge near the gauging station of the Surface Water Division of the U. S. Geological Survey. The second is on the east side of Beaver Creek and northwest of the Vermilion Cliffs Lodge, along the Vermilion Cliffs. These localities may be reached by foot trails from U. S. Highway No. 89.

Studies of the Shinarump conglomerate in the Canyon de Chelly area were made within the Canyon de Chelly National Monument which is on the east side of Black Mesa at approximately 109°25' west longitude and 36°10' north latitude. A well marked, graveled road extends to the Monument from the Chinle Trading Post, a distance of about ten miles.

Physiography

The areas discussed in this report, as indicated in Figure 1, lie within the Colorado Plateau province. The area, generally speaking, is a high, flat plateau cut in many places by deep canyons, as at Canyon de Chelly, Lee's Ferry and Cameron. In many areas, erosion has had greater effect than this and the table lands have either been maturely dissected or largely eroded away, leaving steep-sided mesas or rounded buttes rising out of the flat table land. The Monument Valley area is a classic example of this type of physiography. Here the mesas and buttes are mostly flat topped with steep cliffs forming the sides (Plate 2). The cap on most of the monuments is Shinarump conglomerate, and it protects the underlying more easily eroded Moenkopi, De Chelly, and Organ Rock formations whereas its upper surface is in most places stripped bare. Dunes, possibly the remnants of former climbing dunes, lie on the stripped upper surfaces on Hoskinnini and several other large mesas in the Monument Valley area.

Most of the drainage in the region studied is ephemeral, with dry washes becoming torrential streams following the summer cloudbursts. The various areas are drained by the Colorado, Little Colorado, and San Juan Rivers and thus ultimately all of the runoff reaches the Pacific Ocean by way of the Colorado River. Most of the areas covered in this report are drained by the San Juan River, but those at Lee's Ferry (Colorado River) and Cameron (Little Colorado River) are exceptions. The localities within the watershed of the San Juan are in turn served by a number of intermittent streams. Hoskinnini and Oljeto Mesas are drained by Copper Canyon and Oljeto Wash. Canyon de Chelly drains the Canyon de Chelly area and a small wash drains the Monument #2 Mine area.

The resistance to erosion of the Shinarump conglomerate, especially when compared to the weakness of the overlying and underlying formations, causes it to be an important factor in determining the topographic character of the areas in which it outcrops. Most of the sandstones and conglomerates of the Shinarump are well cemented causing them to form a cliff between slopes of the Chinle and Moenkopi formations. These cliffs are in many places impossible to scale. Erosion of the Chinle clays locally forms a stripped bench back of the Shinarump cliffs but elsewhere it is entirely eroded away, leaving the top of the Shinarump conglomerate entirely bare, as on Hoskinnini and Oljeto Mesas. The Shinarump in a few places forms overhanging cliffs as at Canyon de Chelly where undercutting is pronounced.

A feature of the upper surface of the Shinarump conglomerate, best exposed on the northwest side of Hoskinnini Mesa, is the occurrence of a large number of undrained basins (Plate 3). These basins, a few of which are greater than ten feet in depth and 25 feet in diameter, apparently were formed by solution of calcareous cement in the rock by slightly carbonated rain water. Calcium carbonate, leached from the rock, was deposited as a crust when the water evaporated. This powdery crust and the liberated sand grains were then removed by wind action. Examination of a number of these "potholes" indicates that this process stops only when one of two conditions prevails. Either the hole becomes too deep for wind deflation to be effective, leaving a bed of sand on the bottom of the basin, or the presence of pebbles in the rock causes a pebble pavement to form on the bottom. The two principal requirements of the rock, fineness of grain and lack of siliceous cement, apparently are the factors which limit this feature to a few scattered localities.

Desert varnish, composed of manganese and iron oxides, commonly coats Shinarump outcrops and residual pebbles on Shinarump surfaces. This characteristic desert feature is probably due to acid leaching by lichens (Laudermilk, 1931). Manganese dendrites are common on joint and fracture surfaces within the formation.

Structure

Structures within the Colorado Plateau consist almost entirely of highly asymmetrical anticlines (monoclines), high angle normal faults, and joints. The entire province is characterized by being relatively little disturbed structurally, whereas the surrounding areas show the effects of great tectonic movements. Most of the localities studied in connection with this report have been deformed, at least to some extent, by post-Triassic structural movements.

Two major structures, striking approximately north-south, occur in the area of Hoskinnini and Oljeto Mesas. They are the Organ Rock anticline to the west (Plate 1) and the Oljeto syncline to the east. The crest of the Organ Rock anticline is situated along the eastern margin of Hoskinnini Mesa. The east limb has dips up to 18 degrees with dips up to 3½ degrees on the west limb. Bradish (1952, p. 55) reports two closed domes on this asymmetrical fold with closures of 700 and 1500 feet on the north and south domes respectively. This structure is currently being drilled for petroleum by the Texas Company. To the east of the Organ Rock anticline, the Oljeto syncline (also known as the Moonlight syncline) controls the drainage of Oljeto Wash. The syncline is a broad, low-angle structure with dips of from 1 degree to 4 degrees on the flanks. The axes of these two structures are roughly parallel.

Monument #2 Mine is situated on the Comb Ridge monocline, a prominent regional structure which forms the eastern boundary of the Monument Valley upwarp. The Shinarump conglomerate, in the mine area, strikes North 10 degrees West and dips from 5 degrees to 8 degrees to the east.

Canyon de Chelly is incised into the De Chelly upwarp, a minor structure on the flank of the Defiance Uplift. Gregory (1917, pp. 111-2) states that the structure dips about 3 degrees to the west with the east side merging into the Defiance monocline. At all of the localities studied within the Cameron area the strata were horizontal. The Echo Cliffs monocline, striking North 5 degrees West and dipping 15 degrees to the east at this point, is a prominent structure in the Lee's Ferry area. The Paria River, a perennial stream which enters the Colorado River near Lee's Ferry apparently is controlled by the monocline.

A few high angle normal faults were noted in a number of the areas studied. Several, with displacements up to 15 feet, occur on Hoskinnini Mesa. One of these contains calcite mineralization, but none contained uranium, vanadium, or copper mineralization. Gouge zones from four inches to two feet thick occur in conjunction with these faults.

A fault showing horizontal movement, associated with monoclinal flexing, occurs on the northeast tip of Hoskinnini Mesa. The fault plane strikes North 75 degrees East, dips 16 degrees to the east, and visual inspection and "feel" of the slickensides indicate movement to the east by the southerly block.

These normal and shear faults on Howkinnini Mewa appear to be genetically related to the Organ Rock anticline. A similar occurrence of related folding and faulting in an area similar structurally to the Colorado Plateau, in central Montana, is described by Thom (1923). He believes that differential movement fractured the brittle basement rocks but in general merely flexed the more plastic younger sediments. Minor normal and shear faults are associated with these flexures.

Jointing in the Shinarump conglomerate is generally well developed. Within individual areas, the directions of the joint sets are remarkably uniform. The sets in the Monument Valley area ranged from North 55 degrees to 70 degrees East and North 50 degrees to 75 degrees West. These readings are characteristic of the areas studied east and northeast of Black Mesa. On the other hand, the joint sets at Lee's Ferry and Cameron ranged from North 20 degrees to 35 degrees East and North 25 degrees to 35 degrees West. Bleaching of red bed sediments, both within and below the Shinarump conglomerate, generally extends along these joints. No mineralization, other than thin films of secondary uranium and copper minerals, is associated with jointing.

Climate and Vegetation

The climate of the parts of northern Arizona and southern Utah covered by this report is semi-arid with moderate temperature variations. The average annual precipitation over most of the region is about ten inches, with Cameron having perhaps the least, averaging about five inches. About 50 per cent of this precipitation normally occurs during the months of July, August and September. Most of the remainder falls during the winter months as scattered showers and snow. The summer rainfall characteristically occurs during short but violent thunder storms which generally appear during the afternoons or early evenings. The resulting heavy runoff races down sloping surfaces and transforms flat desert country into a series of large puddles.

Temperatures, in general, vary from 0 degrees to 100 degrees Fahrenheit during the year in this portion of the Colorado Plateau. A notable exception to the temperate climate, encountered during the field investigations in early August, was in the area around Lee's Ferry. Here, during a period of five days, the maximum daily temperature was never below 100 degrees Fahrenheit. In contrast to this, in the Monument Valley area at an elevation of 6000 feet, the days were pleasantly warm and the nights cool enough to require blankets.

Vegetation, consisting of plants characteristic of arid and semi-arid climates, is generally sparse. A considerable amount of the area is covered by bare rock or dune sands which supports no vegetation.

Methods of Study

Field work: The field work covered in this study was done in the summer of 1952. Aerial photographs (scale 1" equals 20,000') furnished by the Atomic Energy Commission were used for the mapping and reconnaissance work in the Monument Valley area. The field studies in the other areas were carried on without the use of detailed maps or photos. This was done in recognition of the fact that the major contribution to this comparative study would be in the collection of samples and detailed data and not in the mapping of the aereal extent of the Shinarump in certain limited localities.

In order to draw valid conclusions regarding comparisons, the entire field study was carried on in as quantitative a manner as possible. This was done, not only to facilitate the presentation of results, but also to bring out detailed information which may not have been apparent at first.

The initial field work was done on Hoskinnini Mesa with primary emphasis placed on the accumulation of samples and data. The cross-strata, which are some of the most conspicuous features of the Shinarump conglomerate, lend themselves well to the quantitative approach. A considerable number of dips and dip directions was taken on cross-strata on Hoskinnini Mesa. A study made in the field of these data indicated that in certain areas the Shinarump conglomerate could be divided into definite zones. Following this discovery, an attempt was made to extend these zones laterally. Samples of pebbles occuring in a zone were taken in conjunction with the cross-strata measurements. The lower contact of the Shinarump was studied with considerable care because of its possible importance in the localization of uranium ore. Several columnar sections of the underlying Moenkopi formation were taken to aid in this study of the lower contact. Samples were taken of all materials that appeared to be of importance to the problem.

Following the detailed work on Hoskinnini Mesa, quantitative studies were carried on in other areas covered by this report. In each of these the emphasis was placed on the accumulation of data that might indicate similarities or differences between the individual areas. A comparison of mineralized and unmineralized localities within a limited area was made. Many of the data on mineralization accumulated in this connection proved to be qualitative rather than quantitative. A complete set of core samples from one hole, recovered by the Atomic Energy Commission during their drilling program on Hoskinnini Mesa, was taken for analysis during the winter.

Laboratory work: The laboratory work covered in this report was done during the school year of 1952-1953. Sedimentary analyses of surface and drill core samples were made in the manner outlined by Twenhofel and Tyler (1941) and included mechanical separations and heavy mineral studies. The composition of pebble samples was determined together with measurements on their roundness and sphericity. Cross-stratification data for the principal localities and zones were plotted on rosette charts. Measured sections of the Moenkopi formation were tabulated and described.

The drafting of maps, sections, and charts and the writing of the manuscript were done during the months of February, March, and April, 1953.

Acknowledgments

This investigation of the Shinarump conglomerate in selected localities of northern Arizona and southern Utah has been made possible under a fellowship granted by the United States Atomic Energy Commission. Thanks are given to Professor E. D. McKee for awarding the fellowship to the writer, thereby enabling him to conduct this comparative study.

Members of the faculty of the Department of Geology, University of Arizona, Doctors B. S. Butler, John F. Lance, and George A. Kiersch and Professors E. D. McKee, John W. Anthony, John Osmond, and Robert Dubois contributed valuable suggestions and helpful criticism in reviewing the manuscript. The time and invaluable ideas contributed by Professor McKee, both during the summer field season and the laboratory work which followed, are greatly appreciated.

The writer is much indebted to W. David Grundy, his field partner during the summer, whose hard work and stimulating discussions greatly aided in the accumulation and interpretation of the field data.

The writer is very grateful to Doctor H. S. Colton, Director of the Museum of Northern Arizona, for use of the facilities of the Museum and for housing and office space provided during the field season.

The advice and fresh points of view extended by Professor John J. Bigarella, University of Curitiba, Brazil during a number of days in the field are greatly appreciated. Thanks for the generous hospitality extended by Mr. and Mrs. Jay Ackers to the writer while working in the Lee's Ferry area, also are due.

Appreciative thanks are extended to Ralph A. Wilpolt, Robert J. Wright, Clare Gregg, John Hill, and other personnel of the United States Atomic Energy Commission whose cooperation and advice greatly aided in the field investigations.

GENERAL

Previous Work

The Shinarump conglomerate has been studied in connection with reconnaissance investigations of areas on the Colorado Plateau and reported on by a number of government geologists. In addition, several papers on the Shinarump conglomerate itself have been published by certain of these men.

Both Powell (1873) and Dutton (1880), in classic reports that covered large areas of western United States, mention the widespread occurrence of a conglomerate (Shinarump) containing fossil wood. Gregory (1916, 1917, and 1938) and Baker (1933 and 1936) mapped this conglomerate throughout wide areas during their field studies in northern Arizona and southern Utah. Descriptions of the formation in these areas are presented in the reports of these men.

Gregory (1913) published the first paper dealing exclusively with the Shinarump conglomerate. He discusses its lithology and presents theories of origin. Within recent years, Stokes (1950) has advanced a new theory of origin. He explains the Shinarump conglomerate as a pediment deposit and not the basal conglomerate of the Chinle formation.

A few small deposits of copper, vanadium, and uranium in the Shinarump conglomerate have been known for a number of years. These deposits and others of similar type have been described by Butler, et al (1920) and Fischer (1950). A recent paper by Waters and Granger (1953) discusses a number of theories on the origin of the Shinarump conglomerate and on the development of the mineral deposits within the formation.

The stratigraphy, structure, geomorphology, and general information on the Monument Valley area are covered by Baker (1936) in his paper on the Monument Valley-Navajo Mountain area.

The United States Atomic Energy Commission and the United States Geological Survey are investigating the Shinarump conglomerate in the Monument Valley area as a part of their mapping and uranium exploration programs on the Colorado Plateau. A study, similar to the one presented in this paper, is currently being made by W. D. Grundy, University of Arizona, Tucson, Arizona.

Origin of the Name

The "Shinarump formation", as defined by Powell (1873), included the entire Triassic section. Later workers split this heterogeneous unit into the Moenkopi, Shinarump, and Chinle formations. The word Shinarump, taken from the Shinarump Cliffs of southern Utah, is the name of the Wolf God of the Piute Indians who believed that the fossil wood represented his weapons.

Distribution and Thickness

In virtually every paper which discusses the Shinarump conglomerate, mention is made of its great areal extent and its uniformity of thickness. These features are especially remarkable when one considers that the Shinarump conglomerate is a continental deposit containing a large amount of coarse material. The areas studied in connection with this report (Fig. 1) represent only a small part of the total region covered by the formation.

Sedimentary rock identified as Shinarump conglomerate because of lithology and stratigraphic position, has been reported as occurring as far west as the Muddy Mountains of southern Nevada (Longwell, 1928, p. 53) and as far east as from Fort Wingate, New Mexico (McKee, 1951a, p. 58. Actual boundaries of its original areal extent are not precisely known, but the formation definitely occurs in the northern third of Arizona, the southern half of Utah, and extends short distances into northwestern New Mexico and southern Nevada. Gilluly and Reeside (1928, p. 67) estimate its original areal extent to have been about 100,000 square miles.

This figure assumes that the deposits were continuous across this vast area; however, at a number of localities in northern Arizona and southern Utah, Chinle clays rest directly on the Moenkopi formation, and in such places the Shinarump conglomerate never was deposited. Some of the areas where the Shinarump conglomerate is missing are relatively small as at Holbrook, Ganado, and Lee's Ferry. Where examined at Lee's Ferry, the advancing sheet of Shinarump sediments appears to have lapped against and to have been deposited around residual hills of Moenkopi material. Aggradation of the Shinarump sediments in these areas never progressed to the point where they covered the hills completely. Thus in a number of places the formation is absent owing to the relief of the pre-Shinarump erosional surface.

Control of the thickness of the Shinarump conglomerate by the relief of the surface on which it was deposited is apparent in the Monument Valley area. On the northwest side of Hoskinnini Mesa, a channel cuts to within five feet of the base of the Moenkopi formation. The Shinarump conglomerate at this point is at least 350 feet thick. Approximately ten miles to the southeast, a complete section of the Shinarump conglomerate was 54 feet thick. Some of this variation may have resulted from lateral changes in the lithology of the basal beds of the Chinle formation above. Such lateral gradation from Shinarump lithology to Chinle lithology locally changes the thickness of the Shinarump conglomerate as much as some tens of feet in relatively short distances. In general, however, the Shinarump conglomerate is quite uniform in thickness, varying from 50 to 100 feet across most of the entire region.

North of the San Juan River, in southern Utah, the thinning and absence of the Shinarump conglomerate apparently is caused by original deposition as a series of advancing sheets of sand and conglomerate. The sheets either did not reach the areas where the Shinarump conglomerate is missing before Chinle deposition began, or they failed to cover the areas during the time of deposition because of post-Moenkopi, pre-Shinarump uplift. If the latter explanation is correct, evidence concerning it may have been destroyed by post-Triassic deformation. Thus, these areas of non-deposition may have been caused by lack of time before Chinle deposition began, by lack of sedimentary material to form further advancing sheets, or by the presence of areas which were topographically higher than the base level of deposition.

Thus, both the distribution and the thickness of the Shinarump conglomerate are dependent on two factors. The distribution undoubtedly is dependent in some areas on the relief of the pre-Shinarump erosion surface. This factor together with the possibility that the advancing sheets may never have reached an area before Chinle deposition began, may explain the absence of Shinarump sediments in certain large areas of southern Utah. The thickness is dependent on processes affecting both the upper and lower contacts. The relief of the pre-Shinarump surface may cause the thickness in an area to vary from 50 to at least 350 feet. The lateral gradations which characterize the Shinarump-Chinle contact constitute a second factor which is rather difficult to evaluate quantitatively. These gradations will cause the contact to rise and fall depending on the lithology.

Age

The Shinarump conglomerate contains very little fossil material which can be used in determining its age. The continuous reworking, which the sediments were subjected to during the formation's depositional history, probably was a major factor in destroying any fossils which might have been preserved in a more stable environment. The underlying Moenkopi and overlying Chinle formations are both moderately fossiliferous and their ages have definitely been established.

Fossils contained in the Shinarump conglomerate are of two types. One of these consists of the remains of plants and animals which lived, died, and were preserved during the time of Shinarump deposition. The other includes fossils within rock fragments derived from older formations and the fossils are characteristic of earlier periods.

Fossils indigenous to the Shinarump conglomerate include bones of vertebrate animals, the shells of invertebrates, and petrified wood. Several water-worn bones of amphibians and reptiles have been reported from the Shinarump. These fragments have proven to be either nondiagnostic or too poorly preserved for age determination. Gilluly and Reeside (1928, p. 67) report the collection of a number of shell fragments identified as <u>Unio</u>. This pelecypod is valueless as an age indicator but it is characteristic of a fresh water environment. Poorly preserved logs and fragments of petrified wood are abundant in the Shinarump conglomerate. Daugherty (1941, p. 8) has identified the conifer *Araucarioxylon arizonicum* and states that it also occurs in the Chinle formation.

Examples of fossil materials derived from earlier formations are the fossil-bearing pebbles of the Shinarump conglomerate near Cameron, Arizona, described by McKee (1937, p.261). *Productus* (*Dictyoclostus*) *occidentalis* Newberry occurs in a limestone pebble. The fossil and lithology of the pebble indicate, according to McKee, that it was derived from the marine facies of the middle limestone member of the Kaibab formation. This gives no indication of the age for the Shinarump conglomerate itself, except that it is younger than the fossil represented in the pebble. Material such as this has its chief value as an indicator of possible source areas for the deposits.

Bones of amphibians and reptiles have been found in the Moenkopi formation at several localities in northern Arizona. Wells (1947) and Camp, Colbert, McKee, and Welles (1947) discuss the faunal assemblages in the Moenkopi formation near Holbrook and Cameron which they consider to have a definite lower and Middle Triassic aspect. The Chinle formation is particularly noted for its floral assemblage. Daugherty (1941) after a study of 35 genera of plants from this formation in east central Arizona, considers the formation to be

Upper Triassic.

The stratigraphic position of the Shinarump conglomerate limits its possible age to Middle Triassic or Upper Triassic. The Shinarump, however, is bounded below by an unconformity representing an unknown but apparently appreciable period of time. Its contact with the Chinle formation above is gradational both vertically and laterally. This would indicate little or no time break in any one area between Shinarump and Chinle deposition. Furthermore, similarity in the species of conifer in these formations indicates continuous deposition. Thus, it appears likely that both the Shinarump conglomerate and the Chinle formation are of Upper Triassic age. The formation is not the same age in all areas, however, as a study of its depositional history indicates that it was deposited as an advancing sheet.

Because of the uncertainty as to the age of the Shinarump conglomerate, precise correlation with other formations of the western United States is difficult. McKee (1951, p. 51) tentatively correlates the Shinarump with the Dockum formation of west Texas and the Popo Agie formation of Wyoming. Heaton (1950, p. 1679) considers the Higham grit of southeastern Idaho to be equivalent to the Shinarump conglomerate. Because of uncertainties as to the age of these formations, it appears likely that they have been correlated more on similarities of stratigraphic position and depositional history than on precise dating. As such, these tentative correlations are interesting in a consideration of the late Triassic history of the western United States.

Upper Triassic Climate

The Shinarump conglomerate was considered by all workers, prior to the 1930's, to have been deposited in a region having an arid or semi-arid climate. Since that time, detailed work on plant remains in Upper Triassic deposits of northern Arizona has suggested that such probably was not the case. Fossil plants, studied by Dougherty (1941, p. 35), indicate that subtropical to tropical temperatures existed during the time of Shinarump deposition and that sufficient moisture was present to maintain swamps in the lowlands. The plant growth rings are characteristic of climates that involve alternating wet and dry seasons. Dougherty, on the basis of his studies, envisions dense forests along perennial streams, together with open forests and grasslands on the slopes and uplands. The plants from these forests, particularly the conifers, are the source of the fossil wood which is so abundant in the Shinarump conglomerate.

STRATIGRAPHY

Basal Contact

The basal contact of the Shinarump conglomerate is one of the most conspicuous unconformities on the Colorado Plateau. In many places it is extremely irregular and in some areas the underlying erosional surface has a relief measured in hundreds of feet. This is in contrast to the statement made by Darton (1925, p. 119) stating "I have observed the Shinarump conglomerate in a wide area in northern Arizona and found no evidence of any notable unconformity or time break between it the the Moenkopi, except that in part of the Defiance uplift by pre-Shinarump erosion". Furthermore, a zone of bleaching, which occurs in the underlying formation in many places, makes the contact especially conspicuous (Plate IV). In most of the areas covered by this study, the Shinarump conglomerate is underlain by the Moenkopi formation. In the Canyon de Chelly area and in one locality of the Monument #2 Mine area, however, it immediately overlies the De Chelly sandstone (Permian).

In a number of localities, pre-Shinarump erosional channels have been cut tens and hundreds of feet into the underlying formations. Such channels are especially prominent features of the Monument Valley area, but they also occur at Canyon de Chelly and Cameron. A number of sections of the

Moenkopi formation were measured in the Monument Valley area in order to use the units within the formation as datum planes in determining the amount of downcutting involved in the pre-Shinarump erosion of this area. Fortunately, topographic development follows almost perfectly the lithology and structure of the various units within the Moenkopi formation. In many places, because of the lack of hand and foot holds for climbing, it was not advisable and, locally it was not possible, to examine the Shinarump-Moenkopi contact at the base of a channel. An estimate of the distance from the bottom of the channel to a distinct topographic unit then had to be made from a short distance away. Data on the relief of the pre-Shinarump erosional surface, acquired in this manner, will be discussed in a following paragraph.

The De Chelly sandstone underlies the lowest part of a large channel in the Monument #2 Mine and it underlies the entire Shinarump conglomerate in the Canyon de Chelly area. In general the De Chelly sandstone is a light tan to light gray, fine-grained, friable, cross-stratified rock. It contains no recognizable marker beds that can be used as horizon markers as in the case of the Moenkopi formation. Fortunately, in the areas studied, the channels carved in the De Chelly sandstone were not deep enough to require reference beds in determining their depth.

Relief of the Basal Contact

The basal contact of the Shinarump conglomerate is a gently undulating surface over much of the area covered in this study (Plate IV). In a number of places, however, the contact is a surface of considerable relief. Channels up to 250 feet in depth occur on Hoskinnini Mesa (Plate V). Uranium mineralization in the Shinarump conglomerate is restricted almost entirely to such channels and the localities studied in the Monument Valley area are no exception.

Several individual channels were traced and mapped on Hoskinnini Mesa where they intersect canyons along the rim (Plate I). A study of these cross-sections of individual channels reveals a number of points: (1) the base of a channel varies as much as 50 feet in depth between exposures (distances between exposures vary from $\frac{1}{4}$ to $1\frac{1}{2}$ miles) which indicates large scours were developed locally by the eroding streams; (2) the channels exhibit a meandering pattern over a distance of a few miles. This sinuous appearance in plan view (Plate I) is in contrast to the straight channels which have been inferred by workers in the past; (3) their cross-sectional profiles on cliff faces vary considerably, apparently depending upon the part of a meander exposed at any particular place; (4) the shape and character of a channel appear to depend, at least to some extent, on the type of lithology in the underlying Moenkopi formation. Mudstones form moderately low-angle slopes, whereas siltstones form steep slopes or locally, cliffs.

In the Canyon de Chelly area, the sides of most channels are vertical and in some places overhanging (Plate VI). This suggests that the De Chelly sandstone was as well indurated in post-Moenkopi time as it is today.

Alteration Zone

A striking feature of the basal contact of the Shinarump conglomerate is a zone of bleaching developed in the underlying Moenkopi formation (Plate IV). The alteration apparently is caused by a reduction of ferric to ferrous iron and its partial removal from the reddish-brown mudstones and siltstones (Keller, 1929). This changes the color of the Moenkopi sediments to shades of green, cream or pink. The zone of bleaching is in most places about one foot thick, but may be up to three or four feet thick, and in a number of local areas is absent. In a few places the alteration extends down into the Moenkopi formation a few inches below normal along joints and fractures. In general, the zone is somewhat thicker in the siltstones than in the mudstones. A few calcite veinlets occur in the alteration zone in several localities; most of them follow bedding, but some are along joints, or at random. No alteration occurs in the De Chelly sandstone due to the absence of iron.

Bleaching, where well developed, causes a definite color banding parallel to the formation contact. The colors in the bands exhibit a regular sequence though in few places does the entire sequence occur in one exposure. The arrangement of banding in mudstones is as follows: greenish- to yellowish-cream, yellowish-brown, and unaltered reddish-brown. The sequence in siltstones is as follows: light gray, light pink to pink, and unaltered reddish-brown. Contacts between color bands generally are sharper in the mudstones than in the siltstones.

Fragments of Moenkopi-like material, occurring as lenses, pellets, and blocks within the Shinarump conglomerate, exhibit bleaching effects similar to those at the contact. The smaller fragments generally are completely bleached, but many large masses contain cores of unaltered material. Bleaching may extend along fractures in the fragments, but banding of the colors is rare.

Possible causes of the variation in thickness of the alteration zone are the following: relief of the upper contact of the Moenkopi formation, thickness of the Shinarump, and lithology of the Shinarump conglomerate directly above the contact. In the present investigation no definite correlation could be recognized between the thickness of the bleached zone and any of these factors. In general, the zone of bleaching is especially thick at the bottoms of channels and thin where overlain by mudstone units of the Shinarump conglomerate. A considerable amount of bleaching occurs in several areas of mineralization. On the other hand, both mineralization and channels occur in several localities where there is no trace of alteration. Benson, Trites, Beroni, and Feeger (1952, p. 9) report the same situation in the White Canyon area of southeastern Utah.

The origin of bleached zones at the top of the Moenkopi formation and of the solutions which formed them is a subject of considerable controversy. The following are possible sources of these solutions: surface water prior to Shinarump deposition, primary mineralizing solutions, and ground water.

The alteration zones have a number of the general characteristics of a soil layer such as might have formed on the Moenkopi erosional surface prior to the deposition of the Shinarump conglomerate. However, Moenkopi-like material, occurring as lenses and fragments within the Shinarump conglomerate, have been bleached in the same manner as the contact zone. These masses have been altered since the Shinarump conglomerate was deposited, and presumably the underlying Moenkopi formation was bleached simultaneously.

The composition, age, and even the existence of primary hydrothermal mineralizing solutions are in doubt. Assuming that solutions responsible for depositing uranium, copper, and other minerals existed and could have caused the reduction and removal of ferric iron, their effect would have depended largely upon their composition and the composition of the connote waters within the Shinarump conglomerate itself. A theory involving such solutions, although entirely plausible, has one outstanding objection i.e., primary mineralization is restricted to a number of relatively small areas on the Colorado Plateau; whereas, alteration zones are almost universally present.

The remaining possible reducing agent is ground water. The relatively permeable Shinarump conglomerate undoubtedly was an important aquifer prior to the uplift and dissection which expose it today. The following are possible reasons for the reducing nature of the solutions: (1) redistribution by ground water of various mineralizing solutions containing hydrogen sulphide and/or other reducing agents or (2) contact of the ground water with plant material within the Shinarump conglomerate causing the ground water to become reducing in nature. Lack of an alteration zone in the Moenkopi formation in a few localities may possibly be explained by the following theory. Lenses and fragments of Moenkopi-like material within the Shinarump conglomerate are impermeable and contain ferric iron. The presence of this impermeable material near the Shinarump-Moenkopi contact may have tended to block the circulating solutions. Furthermore, reaction with the ferric iron would have decreased the reducing power of these solutions. Therefore, the clays of the Moenkopi formation at its upper contact may locally have been protected by similar clays of the Shinarump. Thus, although the origin of the alteration zone at the top of the Moenkopi formation is in doubt, ground water appears to be the most likely agent in its formation.

Upper Contact

The Shinarump conglomerate is overlain by the Chinle formation throughout the Colorado Plateau area. The upper contact of the Shinarump conglomerate is here defined as the uppermost unit of Shinarump-type lithology. Thus, in some places a few beds of Chinle clay may be included within the Shinarump.

The lowermost units of the Chinle formation consist in most places of alternating beds of mudstone and sandstone which are much channeled and cross-stratified. Due to its lack of resistance to erosion, however, the Chinle formation is locally absent, leaving a surface covered by residual material. This material in most places consists of sand, pebbles, fragments of silicified wood, and sand concretions.

Examination of the Shinarump conglomerate over the region studied and the descriptions of other geologists suggest that it is the basal conglomerate of the Chinle formation. The Shinarump probably never would have been recognized as a formation except that it is especially conspicuous because of its cliff-forming character and unique lithology. The upper contact of the Shinarump conglomerate is gradational into the Chinle in some areas but sharp in others. Gregory (1917, p. 39) regards the contact as generally unconformable. He bases this on differences in bedding and abrupt changes in lithology. Such conditions are characteristic throughout both formations and not merely at their contacts. Evidence of periods of non-deposition and of erosion within all portions of the Shinarump conglomerate is common and is to be expected because of its depositional history.

The hiatus between the Shinarump and Chinle deposits in areas of local unconformity probably is no greater than between certain units and lenses within the Shinarump itself. Baker (1946, p. 59) reports tongues of Shinarump conglomerate grading laterally into beds of Chinle clays, a situation to be expected in a gradational contact.

Thus, the Shinarump conglomerate is gradational both vertically and laterally into the Chinle formation. Minor variations in the relief of this contact may be expected from the mode of deposition of the units. The methods used in defining the contact are arbitrary which also explains local differences in character.

Sedimentary Structures

While cross-stratification is the most prominent structural feature within the Shinarump conglomerate, a number of other interesting sedimentary structures occur. These include sand concretions, ripple marks, mud cracks, current lineation, and unconsolidated rock deformation. Studies were made of these various sedimentary features for several reasons: (1) to gain information on the depositional history of the formation (2) to ascertain the importance of sedimentary structures in the localization of uranium ore (3) to gain general information on sedimentary structures of continental deposits which might be applicable elsewhere. An examination of cross-stratification, made in all areas covered by this report, consisted of descriptions of their appearance and a statistical study of dip directions. Characteristics and relationships of the other sedimentary features are described in detail.

Cross-Stratification

Cross-strata observed in the Shinarump conglomerate consist of three types; one of these is large- to medium-scale and the other two are medium-scale, after the classification of McKee and Weir (1953, p. 388). The large-scale type consists of lenses of sandstone and conglomerate in which cross-strata are bounded by surfaces of deposition. Such stratification is especially characteristic of channel fillings cut into the Moenkopi formation. The medium-scale cross-strata are either of the trough or planar type or combinations of these and occur largely within horizons above the channel-fill sediments.

Large-scale cross-stratification: The deposits of Shinarump conglomerate filling channels cut into the Moenkopi and De Chelly formations are characterized by elongate lenses, the contacts of which parallel the base of the channel in many places. These lenses may be tens of feet thick and, in several places, extend hundreds of feet across the channel fill. The lenses tend to feather out toward the margins of channels and most of them remain remarkably uniform in lithology throughout their length. Several were noted, however, with distinct changes in lithology roughly perpendicular to the course of the channel. Unfortunately, all of the lenses studied were visible only in two dimensions on the cliff faces, whereas a three dimensional analysis undoubtedly would have revealed more information on these changes in lithology.

A comparison of the lenses described above with the experimentally formed, asymmetrically filled trough deposits described by McKee (1953, p. 57) indicates similar conditions of deposition. The experimental deposits were formed by subaqueous filling of a trough from the side, the current traveling at an angle to the axis of the trough. This substantiates the field impression that the regularity of bedding and sorting are more typical of subaqueous than subaerial deposition. The existence of bodies of water in the areas of channel deposition may have been due to a generally higher base level or to ponding caused by uneven deposition of the advancing sheets of Shinarump sediment.

Medium-scale cross-stratification: Two types of medium-scale cross-stratification, planar and trough, as described by McKee and Weir (1953), were noted in the field studies. The planar type (Plate VIII), characterized by a planar lower surface, appears to have been deposited on a surface of erosion or beveling following a rise in base level. The trough type(Plate IX) differs from this in having a curved lower surface with cross-strata that conform roughly to this lower surface.

The sequence of events including erosion, rise in base level, and deposition is based on experimental work performed by the writer under the direction of Prof. McKee (McKee, 1953, p. 57-9). This work indicates that subaqueous deposits, in general, were formed as advancing foreset beds or were deposited by settling, so that beds conforming to the surface of deposition were formed. This appearance is in contrast to subaerial deposition which would have formed flat beds and sheet deposits. In trough-fill deposits, deposition in standing water forms perfectly symmetrical cross-strata as shown by experiment whereas deposition in water flowing parallel to the axis of the trough produces strata the thickness of which is somewhat greater at the base of the trough than on the flanks.

Perfectly symmetrical cross-strata occur at many places in the Shinarump conglomerate. A rise in base level, which apparently is necessary to form medium-scale cross-strata need only be a local ponding, such as commonly develops in a braided stream system. Cross-strata of the trough type vary somewhat in size in the several areas studied. Those on Hoskinnini Mesa range from two to three feet in width and two to four yards in length while at Monument #2 Mine they range from four to six feet in width and four to five feet in length. The ratio of length to width probably is a function both of the currents of erosion and of deposition.

Statistical Study of Cross-Stratification

Statistical studies of cross-stratification dip directions have been used by Knight (1929), Shotten (1937), Reiche (1938), and McKee (1940) to indicate the origin of sedimentary units and to determine the directions of movement of the agents of deposition. The methods used in the present investigation are those outlined by Reiche (1938) with modifications suggested by McKee (1940) and Gordon W. Weir (personal communication to E. D. McKee, 1952). These methods consist, in general, of recording the dip magnitude and direction of dip for at least 30 cross-strata surfaces which are scattered laterally across an area but are within the same zone vertically. The average dip direction, computed from these data, represents the direction of streamflow at that locality during the time of deposition. A considerable number of such averages, obtained across the region, should indicate the mean directions of movement of the various systems of Shinarump streams. A discussion of the application and accuracy of these methods is included in Reiche (1938) and McKee (1940).

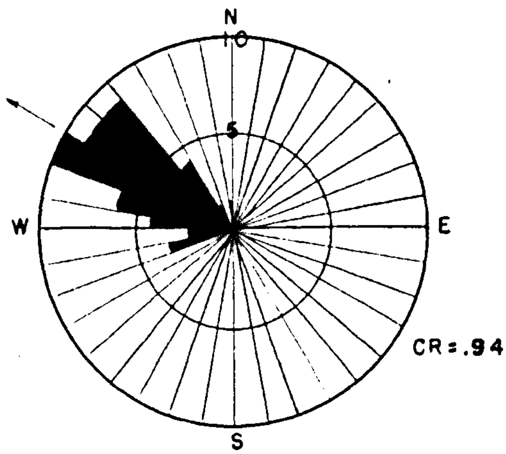
Rosette charts of representative sets of cross-stratification dip direction readings (Figs. 2 through 5) indicate the variety of dip directions studied. In addition, these data are tabulated (Table I) to facilitate comparisons between areas and between zones within an area. The tabulated data consist of the more reliable (i.e., higher consistency ratios) sets of readings. Figure 5 is an example of a possible source of error in interpretation due to poor consistency in data.

Examination of the data in Table I indicates the following: (1) no dip direction is common to any zone from one

Table I.- Cross-Stratification Data

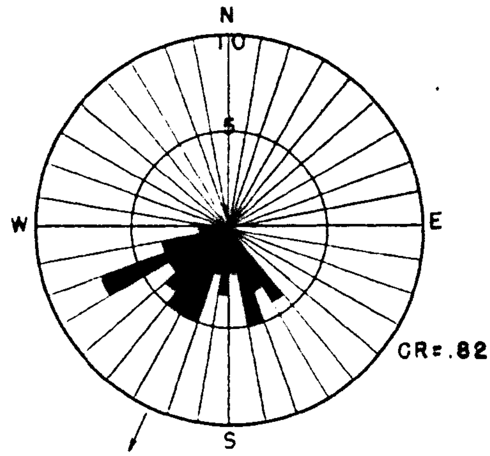
Area	Zone	Type*	Average Direction	Consistency Ratio	Maximum Dip in Degrees	Average Maximum Dip in Degrees
Monument #2 Mine	Ch. fill	P	N36E	.40	29	12
Monument #2 Mine	Lower	P	N26E	.70	30	12
Monument #2 Mine	Lower	P	S69E	.75	20	4
Monument #2 Mine	Lower (?)	P,T	S39E	.43	22	9
Monument #2 Mine	Upper	T	S18W	.92	27	14
Hoskinnini Mesa	Lower	T	S26W	.82	27	15
Hoskinnini Mesa	Lower (?)	P	S81W	.91	26	15
Hoskinnini Mesa	Lower (?)	P	S72W	.93	28	18
Hoskinnini Mesa	Lower (?)	P	S41W	.96	19	13
Hoskinnini Mesa	Upper	P	N60W	.94	21	10
Canyon de Chelly	Upper	T	S19E	.95	24	15
Canyon de Chelly	Upper (?)	T,P	S12W	.87	28	15
Canyon de Chelly	Lower	P	N75W	.94	29	17
Cameron	Lower	T	N50W	.85	20	15
Cameron	Upper	T	N60E	.69	22	13
Lee's Ferry	--	T	N37W	.93	24	11
Oljeto	--	P	N55E	.95	13	8

*P is planar, T is trough.



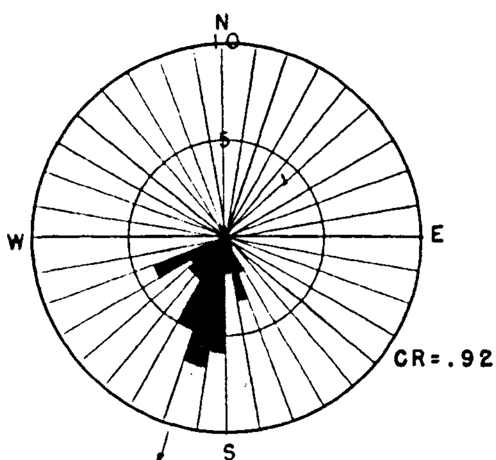
UPPER ZONE, HOSKINNINI MESA

FIGURE 2



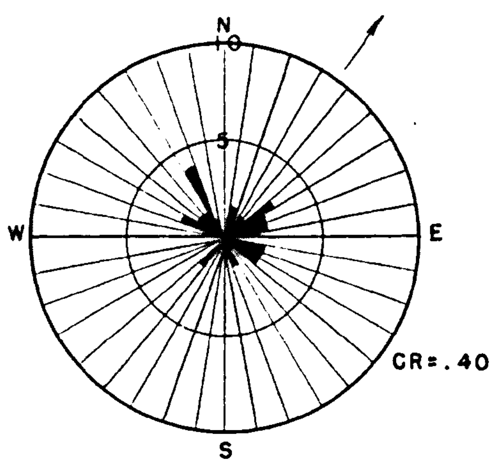
LOWER ZONE, HOSKINNINI MESA

FIGURE 3



UPPER ZONE, MONUMENT #2 MINE

FIGURE 4



CHANNEL-FILL ZONE, MONUMENT #2 MINE

FIGURE 5

CR = CONSISTENCY RATIO

→ = AVERAGE DIRECTION

area to another, nor is there any apparent relationship between zones within an area; (2) the average dip direction of the channel fill material in the Monument #2 Mine roughly parallels that of the lower zone; (3) all types of cross-stratification occur in all zones; (4) consistency ratios are generally very good (.50 is considered fair), but they are poor in the channel fill sediments and one lower zone locality at Monument #2 Mine; and (5) in general, the average maximum dip of the cross-strata is less in the upper than in the lower zone.

Zones of Cross-Stratification

During the statistical study of cross-stratification dip directions, a possible method of subdividing the Shinarump conglomerate vertically into lithologic units was discovered. On Hoskinnini Mesa the dip directions within certain areas are quite uniform laterally through the formation; whereas, with changes of level, vertically within the formation, radical changes in dip directions occur. At any particular level, the dip directions vary only slightly.

All of the areas included in this report were studied intensively in order to discover possible additional evidences of zoning. On Hoskinnini Mesa two well-defined zones have been delimited. In these, the dip directions of cross-strata within each zone are quite uniform, but the averages of the two zones vary widely (figs. 2 and 3). A still lower zone, comprising sediments of the channel fill, consists of a few poorly exposed cross-strata, dip directions of which are less consistent than those of the overlying zones. The channel-fill sediment probably was deposited contemporaneously with that of the lower zone.

A situation similar to that on Hoskinnini Mesa, with well-developed upper and lower zones and a poorly developed channel fill zone, occurs at Monument #2 Mine. Cross-strata dip directions also reveal the occurrence of two zones at Canyon de Chelly and at Cameron, but only one zone occurs at Oljeto Mesa and Lee's Ferry. Rarely can a sharp contact between zones be seen, but an exception is at Monument #2 Mine. A conglomerate lens marking the approximate contact between zones is conspicuous in several localities of the Monument Valley area.

Because of the rather unusual nature of the conditions necessary for the formation and preservation of these cross-strata, a zone probably cannot be traced for any appreciable distance by using dip directions of the cross-strata. Further studies of the zones, including features of lithology, grain size, sorting, cementing material, and heavy minerals have been made in an attempt to define the zones in such a manner that they could be recognized over considerable distances. The results of these investigations, discussed in the section of this thesis on Lithology, were for the most part unsatisfactory.

The lack of zoning at Oljeto Mesa and Lee's Ferry may be due to one or more of the following four factors: (1) the upper zone has been eroded away either recently or during Shinarump time, a possibility at Oljeto Mesa; (2) the area was topographically high and only the upper zone was deposited, a probability at Lee's Ferry; (3) the dip directions of the cross-strata of the two zones are so close, through coincidence, that the zones are indistinguishable, a possibility at Oljeto Mesa; and (4) Chinle deposition began earlier than in other areas, thus taking the place of the upper zone of the Shinarump conglomerate, a possibility at Lee's Ferry.

Small-Scale Sedimentary Structures

Small-scale sedimentary structures in the Shinarump conglomerate, not associated with cross-stratification, include the following: (1) sand concretions (2) ripple marks (3) mud cracks (4) current lineation (5) unconsolidated rock deformation.

Sand Concretions: A large number of sand concretions, varying from less than one inch to several inches in diameter, weather out of lenses in the Shinarump conglomerate at several localities on Hoskinnini Mesa (Plate X). The concretions, together with the lenses out of which they weather, consist of relatively well sorted, medium-to coarse-grained sandstone. Samples of the concretionary and nonconcretionary portions of a lens showed calcium carbonate content amounting to 2.6 per cent in the concretion and 1.6 per cent in the host rock.

The concretion, after soaking in acid, was quite friable, indicating that it contains little or no silica cement. In addition, the concretions contain a considerable amount of iron oxide, whereas the surrounding sandstone is very slightly iron stained. Thus, iron oxide, as well as calcium carbonate, appears to be a factor in the increased cementation which is characteristic of these concretions. The iron oxides, and possibly manganese oxides, form concentric bands within the concretions. In addition, a nucleus of iron oxide occurs in its center. The oxidation of pyrite probably explains the source of the iron oxide and the change of pH during oxidation may have induced a greater deposition of calcium carbonate by ground water. Limonite pseudomorphs after pyrite, ranging up to several inches in diameter, are numerous in the same general locality.

Ripple Marks: Casts of linear and cusp ripple marks occur both within and at the base of the Shinarump conglomerate in the Monument Valley area. Among the ripple marks within the formation, current directions, as indicated by the ripple marks, roughly parallel those indicated by cross-strata of the immediate vicinity. In addition, current ripple marks of the linear type occur at the top of the Moenkopi formation in several localities in the Monument Valley area. They generally are best exhibited on the underside of Shinarump conglomerate overhangs, but also are developed in the Moenkopi at the contact. These ripple marks appear to have been formed at the time of deposition of the initial Shinarump sediments. They indicate a lack of consolidation of the Moenkopi formation at the time of Shinarump deposition.

Mud Cracks: A mud crack, two feet deep, filled with Shinarump sand, occurs near a channel on the northwest side of Hoskinnini Mesa. The sand filling, with sediment identical to that of the overlying Shinarump conglomerate lens, reaches a maximum width of one inch near the top of the crack. Much of the contact between the Shinarump and Moenkopi in the immediate area is covered with talus, but exposed portions reveal no additional evidence of dessication.

Current Lineation: Casts of current lineation marks are clearly developed on the underside of a sandstone lens at Monument #2 Mine. They indicate a current direction roughly parallel to that shown by cross-strata in the immediate area.

Unconsolidated Rock Deformation: Examples of unconsolidated rock deformation within the Shinarump conglomerate occur in the Monument Valley area (Plate XI). The deformed sediments in a zone of well developed cross-strata are limited to a definite area and do not extend laterally for any appreciable distance. Similar exposures, discussed by Rettger (1935) and Fairbridge (1947), have been attributed to slumping at time of subaqueous deposition caused by over-steepening or overloading.

Lithology

The lithology of the Shinarump conglomerate is extremely variable in nearly all local areas, but relatively homogeneous from a regional viewpoint. Whereas all proportions of conglomerate, sandstone, and mudstone, occur in the Shinarump conglomerate in nearly all localities, these same lithologic types in varying proportions are characteristic of the formation throughout its extent. Differences in the lithology of pebbles in the conglomerates are characteristic.

Because of its heterogeneity, both vertically and laterally, the Shinarump conglomerate was not studied with a series of measured sections as is customary in stratigraphic work with most sedimentary units. During examination of exposures in the places studied, however, an approximation of the relative percentages of each lithologic type was noted. The average value for all areas is roughly 75 per cent sandstone, 20 per cent conglomerate, and 5 per cent mudstone. Thus, although the term conglomerate is part of the accepted name of this rock unit, the formation where examined is a slightly conglomeratic sandstone. This rough classification does not take into account considerable amounts of sand size particles in the conglomerates, scattered pebbles in sandstone units, and interstitial argillaceous material common in all units.

A comparison of the percentages of the lithologic types in the Shinarump conglomerate of the Monument Valley area with those in the other areas studied reveals a few moderate differences, but an amazingly great overall similarity. Percentages of conglomerate, sandstone, and mudstone exposed at Lee's Ferry are identical with those at Monument Valley except in the vicinity of certain ancient buried hills of Moenkopi mudstone that rise above the pre-Shinarump surface. Near these, probably because of protection from strong currents of ancient streams, the deposits of Shinarump conglomerate contain very little coarse material and include up to 25 per cent mudstone. The relatively small amount of Moenkopi sediment incorporated into the Shinarump conglomerate, and the fact that some hills of Moenkopi mudstone remained during the entire period of Shinarump deposition, indicate a lack of evidence of peneplane development.

The Shinarump is more conglomeratic at Cameron than in any other area studied. It contains very little conglomerate at Canyon de Chelly. Both of these areas are characterized by a lack of mudstone, but the explanation in each case is different. At Cameron, the streams which were capable of carrying coarse detrital material probably carried fine-grained material beyond, through the process of sorting. At Canyon de Chelly, the lack of mudstone in the Shinarump conglomerate probably is due to the absence or scarcity of Moenkopi deposits which constitute a possible source of fine detritals.

Lateral changes of lithology in the Shinarump conglomerate are abrupt in places and gradational elsewhere. Scouring and filling during deposition caused most of the abrupt changes. Lateral gradations in lithology are especially well developed in the lenses of channel-fill deposits.

A study of lithologic zones within the Shinarump conglomerate indicates that the upper zone is generally finer grained than the lower zone. In addition, the upper zone is, in most places, better sorted and contains less mudstone and fewer pebbles.

Conglomerate

The detrital sediment in the Shinarump conglomerate which is larger than sand size consists of two types: (1) resistent pebbles and a few cobbles, generally of siliceous composition, which apparently have been transported for long distances and (2) fragments of varying sizes of Moenkopi and De Chelly lithology which were deposited very near the point of their origin. The first type, generally referred to in the literature as quartz-pebble conglomerate, is the predominant type and occurs in all portions of the formation. Most of the second type is restricted to channel-fill deposits but in several localities occurs along flat-lying contacts.

Quartz-Pebble Conglomerate: Quartz-pebble conglomerates are somewhat more common in the lower portions of the formation than in the upper. Conglomerate beds occur also between the upper and lower zones in several localities. They may represent the basal material in a new series of deposits.

Table II is a presentation of statistical studies of pebble samples from various zones and localities of the Shinarump conglomerate within the areas studied. The study includes data on lithology, roundness, sphericity, and weight of the average pebble from each sample and largest pebble from each area. The pebbles are classified on the basis of lithology and color, using color groups which are as inclusive as practical. The roundness measurements were obtained visually by comparison with standard charts in the manner described by Krumbein (1941). The sphericity was obtained by measuring the lengths of the three axes of the pebble, computing the ratios of the axes, and using these ratios to determine the spericity as described by Krumbein and by Zingg (quoted by Payne, 1942).

A comparison of the average pebble weights from each locality studied indicates that the pebbles used in the computations were of about the same size except for those from Cameron which were larger. The largest pebble from a locality is a measure of the maximum transporting ability of the stream system. Such pebbles were not used in roundness and sphericity determinations. Because in some areas Tertiary terrace gravels are associated with residual gravels of the Shinarump conglomerate, extreme care was exercised in collecting samples.

The gravels collected in the various localities fall readily into the following four-fold classification: (1) chert (2) light-colored quartz and quartzite (3) gray, brown, and black quartzite (4) red and purple quartzite. In addition, granite and schist pebbles were collected in several localities. Chert, generally present in small amounts, comprises up to 68 per cent of samples collected on Hoskinnini Mesa. Many of these samples consist of chert nodules and fragments which are poorly rounded and a few of them include soft, calcareous masses within the pebbles. These characteristics, in contrast to the well rounded and highly abraided quartzite pebbles, suggest that the chert may have been derived from a source less distant than that of the quartzite. On the other hand, a scarcity of chert gravels in the Shinarump conglomerate at Cameron and Lee's Ferry indicates that local uplift and erosion of the underlying, cherty Kaibab formation (Permian) was of minor importance in supplying sediments to those areas.

Most of the gravels collected in the areas studied consist of quartz and quartzite of varying colors. A number of the light-colored gravels appear to be of vein quartz, rather than of quartzite. Such composition is in contrast to that of other gravel groups which appear to consist entirely of Quartzites. Many of the pebbles, because of their color and lithology, resemble types that occur today among Pre-cambrian and Paleozoic rocks of central Arizona. The red and purple quartzites, in particular, greatly resemble the Troy and Bolsa quartzites (Middle Cambrian) of central and southern Arizona, as well as certain other Cambrian formations of the southwestern United States. Other colors and lithologies less distinctive also resemble those of formations which crop out to the south in Arizona.

Several pebbles of granite and schist were collected both at Monument Valley and at Cameron. Pebbles of igneous and metamorphic rocks are noteworthy for their scarcity in the Shinarump conglomerate. This indicates either of two possible conditions: (1) the pebbles were largely derived from mountains which contained no igneous or metamorphic rocks or (2) they were derived from youthful mountain areas before erosion had breached the sedimentary cover over a crystalline core. The latter is suggested because the uplift had just occurred which ultimately caused the deposition of the Shinarump conglomerate.

Mud-Pellet Conglomerate: A conspicuous feature of the channel-fill deposits of the Shinarump conglomerate in the Monument Valley area is the quantity of subangular to rounded lumps or pellets of claystone and siltstone incorporated in the conglomerates and sandstones (Plate XII). These mudstone pellets comprise up to 20 per cent of the rock in several localities. Most of them range from pea size to several inches in diameter, but blocks of mudstone up to three feet in length and four inches thick also occur. In general, the small fragments are scattered rather uniformly throughout conglomerate lenses, whereas most of the large blocks (greater than one foot in length) are oriented parallel to the sides of channels as if they had slid down the slopes during deposition. Much of the mudstone probably was obtained from erosion of the underlying Moenkopi formation. Some may have

Table II.- Data on Pebble Samples

Area	Rnd.	Spher.	% of Sample					Weight (grams)	
			Chert	Light qtz. & qtzite	Brown, black, & gray qtzite	Red-purple qtzite	Schists*, granite#	Largest pebble	Average pebble
Hoskinnini Mesa:									
Upper zone over channel	.45	.75	6	46	30	18	--	42.0	6.2
Lower zone over channel	.59	.76	10	30	38	22	--	62.5	6.7
East of channel	.48	.74	30	28	14	28	--	40.5	15.1
West of channel	.53	.74	18	36	26	18	2*	128.0	13.8
Northeast part of mesa	.58	.78	68	6	14	12	--	226.0	13.3
Cameron:									
Upper zone	.54	.75	10	54	10	26	--	88.8	20.5
Lower zone	.52	.77	8	24	8	58	2#	101.0	51.2
Monument #2 Mine									
Over channel	.55	.74	--	6	78	16	--	Not available	
West of channel	.56	.74	--	14	82	4	--	"	"
East of channel	.57	.74	2	24	56	18	--	"	"
Oljeto	.52	.76	6	24	36	32	2#	56.2	13.3
Lee's Ferry	.54	.74	6	44	20	30	--	348.0	16.8
Canyon de Chelly	.52	.75	2	28	26	44	--	38.5	7.5

been derived from reworking of mudstones deposited during Shinarump time.

Deposits filling the small pre-Shinarump channels in the De Chelly sandstone of the Canyon de Chelly area contain rock fragments, up to two inches in diameter, similar in lithology to parts of the Moenkopi formation and to the De Chelly sandstone. Mudstone of the Moenkopi formation is exposed at Fort Defiance, but no Moenkopi is present in the Canyon de Chelly area. Thus, mud pellets may have been derived from former Moenkopi deposits of this area which were destroyed by erosion during Shinarump time. At Cameron a few fragments of Moenkopi mudstone occur in a pre-Shinarump channel.

A block of Moenkopi mudstone which has been compacted concordantly with undulating sand units above and below it occurs in the Shinarump conglomerate on Nokai Mesa (west of Hoskinnini Mesa). The perfect continuation of the undulations through the mudstone block indicate that it, and presumably the Moenkopi formation as a whole, had not been much lithified at the time of Shinarump deposition.

Most Moenkopi mudstone blocks that occur in channel-fill deposits have shapes dependent on lithology. Siltstones develop with square corners, whereas the claystone fragments have rounded edges. Similar characteristics prevail in recent unlithified sediments. Clay tends to round off and silts to break up.

Sandstone

Sandstones comprise approximately 75 per cent of the Shinarump conglomerate in the areas studied; yet they are rather inconspicuous where they occur with the more striking conglomerates and mudstones. Sand grains are composed of quartz and a little feldspar; they are subangular to subrounded and most of them range in size from medium to coarse. Most sandstone units contain less argillaceous material than do the conglomerates.

Statistical Study of Core Samples: Approximately 15 core holes were drilled by the U. S. Atomic Energy Commission on a Channel on the northwest side of Hoskinnini Mesa during a detailed investigation of uranium occurrences on the Mesa. The logs of ten of these holes and a complete core from one hole were obtained in order to study vertical changes in the Shinarump conglomerate at this locality. The holes were collared at or near the top of the lower zone of stratification, so the cores include only the lower zone and the channel-fill deposits. Sedimentary analyses were made of the core samples, and an attempt was made to correlate between core holes, using the logs.

Sedimentary analyses were made of all medium and coarse detrital units recovered in a 187-foot core hole on Hoskinnini Mesa. The results are tabulated in Table III. No sedimentary analyses have yet been attempted on the fine detrital units, both because of difficulties in size analysis, and

Table III.- Sedimentary Analyses of Drill Core Samples

Sample No.	Depth	Percent $CaCO_3$	Percent in sieve sizes							
			5	10	18	35	60	120	230	-230
1	8-10	2.6	1.9	14.0	36.7	28.8	8.0	4.8	2.6	3.2
2	10-35	.7	-	-	-	1.1	16.7	58.7	12.1	11.4
4	36-46	1.5	-	-	-	1.3	40.2	42.5	7.2	8.8
5	46-52	3.3	-	-	-	1.4	32.8	54.2	4.8	6.8
6	52-78	3.1	-	-	-	4.3	47.3	35.3	5.2	7.9
7	78-97	3.4	-	.7	3.6	15.6	46.3	24.6	3.8	5.4
9	100-167	10.9	-	.3	1.4	23.1	47.3	18.1	3.6	6.2
11	170-179	24.1	-	-	9.2	69.0	13.0	4.0	1.5	3.3
12	179-180.5	20.5	39.0	22.7	17.6	8.4	8.4	2.3	.8	.8
13 (Moenkopi)	180.5-187	7.3	*	*	*	*	*	*	*	*

* No size analysis performed on Moenkopi sample.

also because of difficulties in disaggregating the samples.

A number of statements may be made on the basis of results obtained from analyzing the core samples (Table III): (1) rocks from the upper portion of the core hole contain less than four per cent calcium carbonate, whereas those from deeper units, especially among the channel-fill deposits, contain at least seven per cent calcium carbonate. An exception to this is in units 11 and 12 which contain limestone pebbles; (2) a mudstone sample from the Moenkopi formation contained 7.3 per cent calcium carbonate; and (3) Although there are wide size variations throughout the entire core, individual units are fairly well sorted.

Lithologic logs of ten core holes drilled in one locality on Hoskinnini Mesa have been obtained and from them a lithologic facies block diagram of this limited area has been constructed. These logs, however, even where the locations and collar elevations of the holes accompany them, permit little more than very general correlations between the holes. Two characteristics of channel deposits that are cut into the upper Moenkopi surface are responsible for this: (1) lateral gradations in lithology within lenses and (2) the manner in which lenses change elevation laterally.

Mudstone

In addition to the mudstone pellets and lumps in many conglomerate lenses, a small amount of mudstone occurs as lenses and beds within the Shinarump conglomerate. These deposits probably were deposited in pools and backwash areas, protected from rapidly moving streams that formed the coarser beds. Most of the fine detrital sediment is either siltstone or silty claystone, but some claystone is present. Many of the beds are shaly, but some are structureless. A majority of the mudstone lenses occur near the base of the Shinarump conglomerate.

Accessory Features

Cement: The Shinarump conglomerate as a whole is well cemented, a partial explanation for its cliff-forming qualities. Three types of cement occur in the formation: (1) calcareous (2) siliceous (3) ferruginous.

In the areas studied, calcium carbonate is the most important cementing material. Table III indicates the amount of soluble material in a number of core samples from Hoskinnini Mesa. Reliable quantity values for cement range up to ten per cent. Specimens with higher values are the result, at least in part, of limestone pebbles being included in the cores.

Silica cement is moderately common in a number of localities studied. No evidence has been noted, however, to support the statement made by Gregory (1916, p. 79) that the cement is prevailingly siliceous in the Shinarump conglomerate of the Navajo country. Visual inspection and difficulties in disaggregation of a number of core samples from Hoskinnini Mesa indicate that the amount of siliceous cement is greater with depth. Whether this is due to greater deposition by ground water or to greater removal by weathering is not known. Waters and Granger (1953) discuss silica cement and secondary growth of quartz grains in the Shinarump conglomerate in considerable detail. They consider devitrification of volcanic ash in the Chinle formation as a likely source of large quantities of silica.

Ferruginous cement occurs in the Shinarump conglomerate in a few localities. Locally, together with calcareous cement, it forms sand concretions (Plate X). The iron probably is derived from the oxidation of pyrite within the formation. Limonite pseudomorphs after pyrite occur in masses up to two inches in diameter in the southwest portion of Hoskinnini Mesa.

Fossil Wood: Fossil wood within the Shinarump conglomerate consists of the following two types: (1) wood which has been replaced by silica forming silicified wood similar to that of the Chinle formation in the Petrified Forest and other areas and (2) black, powdery, charcoal-like carbonized wood. These two types of fossil wood do not occur together in single lenses in the areas studied. Most carbonized wood occurs in pockets filled with varying proportions of clay, sand, pebbles, and vegetable debris called trash pockets (Plate VII); whereas most silicified wood occurs in quartz pebble conglomerate lenses.

Silicified wood is common in the Monument Valley and Lee's Ferry areas, but is rare at Cameron and Canyon de Chelly.

Carbonized wood is restricted to the Monument Valley area, of the areas studied. Logs of silicified wood up to five feet in diameter occur on Hoskinnini Mesa, whereas carbonized wood fragments rarely are as large as two inches in diameter. One large silicified log, ten feet in length, apparently was derived from an exceptionally big tree as it had the same diameter at one end that it had at the other.

Most silicified logs are aligned parallel to the current direction of the streams that deposited the Shinarump conglomerate as indicated by cross-strata, scours, and current lineation. A statistical study of two groups of logs within limited areas was made on Oljeto Mesa. The average trend of eleven logs in an area southwest of Oljeto Trading Post is North 21 degrees East, whereas sedimentary structures in the immediate area trend North 15 degrees East. In a second locality, near the Skyline Mine on Oljeto Mesa, the logs have an average trend of North 46 degrees East which parallels the average trend of a number of nearby cross-strata. This parallelism apparently is due to the tendency of a linear object, when "grounded" in a stream, to align itself parallel to the current direction.

According to Daugherty (1941), vegetation was abundant during Shinarump time. Its incorporation and preservation by rapid burial in the Shinarump conglomerate is to be expected. The different factors which produced silicified wood in one place and carbonized wood in another are only partially understood. Waters and Granger (1953, p. 2) consider the carbonized wood to be charcoal, formed by burning prior to deposition, Both Bain (1952) and Stokes (1950) report the occurrence of abraded fragments of silicified wood where rounding included the silicified inner cell material. Both men believe that this indicates silicification of the wood during Shinarump time, before the wood was reworked and deposited for the last time. Thus, silicification may have been accomplished, at least in part, by silica-charged surface or near-surface waters rather than by ground water as is generally presumed.

Heavy Minerals: Heavy minerals were extracted from samples obtained from the upper, lower, and channel-fill zones of the Shinarump conglomerate on Hoskinnini Mesa. Zircon, tourmaline, rutile, and garnet (in descending order of abundance) occur in all zones. Significant differences in the heavy mineral content of the zones apparently does not occur in this locality and may not occur in the region.

Depositional History

Deposition of the Shinarump conglomerate probably resulted from uplift in areas adjacent to the margins of the present Colorado Plateau. Braided stream systems spread out the detrital material derived from these newly-formed or rejuvenated mountain areas. The history of the Shinarump conglomerate begins, after deposition of the Moenkopi formation, with the post-Moenkopi erosion and it includes uplift and erosion of the surrounding mountain areas, deposition of advancing sheets of conglomerate, and, finally, a change in type of deposition as shown by transition from coarse detritals to fine Chinle materials. The following sequence of events, many of which are necessarily inferred, is an attempt to bring field and laboratory data together into a reasonable depositional history.

Following the close of Moenkopi deposition in Middle Triassic time, a slight lowering of the regional base level occurred. Meandering streams began to drain the large area underlain by the unconsolidated Moenkopi silts and muds. This process caused slight erosion which probably continued to the close of Middle Triassic time. The Moenkopi formation, because of the lack of sedimentary cover, did not become indurated during this period of time but did become a fairly cohesive mass of muds and silts from compaction and cementation.

The period of relative crustal inactivity in the four corners region came to a close, probably near the beginning of Late Triassic time (McKee, 1951, p. 494), with the uplift of mountainous areas to the south and east of the margins of the present Colorado Plateau. Study of the Shinarump conglomerate in other areas has indicated additional uplifts to the north in Utah and Colorado (Dane, 1935). In the region of the present Colorado Plateau minor undulations and upwarps reflected these mountain-building disturbances. The warping and folding of Moenkopi beds prior to the deposition of the Shinarump conglomerate is reported by Camp, Colbert, McKee, and Welles (1947, p. 3). Such upwarps may well have been the cause of one of the most distinctive features in the areas studied. In the Monument Valley area, channels cut into the Moenkopi formation have the appearance of incised meanders. Possibly they were formed by local uplifting at this time, causing the meandering streams in the area to become entrenched. Furthermore, the absence of Shinarump conglomerate in large areas of southern Utah may have been caused by this same process. Upwarping of these areas, causing them to become topographically high, would have allowed the advancing sheets of Shinarump material to lap against them but never to be deposited upon them.

Canyon de Chelly, situated near the eastern margin of Moenkopi deposition, as well as Monument #2 Mine and Cameron are other areas of possible uplift and channel development. Channels have been cut into the De Chelly sandstone at Canyon de Chelly, into the Moenkopi formation at Cameron, and cut through the Moenkopi formation into the De Chelly sandstone to a depth of five feet at Monument #2 Mine.

Another area of probable uplift, southwest of those examined in this study, is indicated by the presence of chert nodules and rock fragments which resemble those in the Kaibab formation. McKee (1937, p. 261) reports a fragment of limestone from the Shinarump conglomerate at Cameron which contains Productus (Dictyoclostus) occidentalus Newberry and sections of crinoid stems. He believes that the pebble was derived from the marine facies of the middle limestone member of the Kaibab limestone and that it probably came from an area to the southwest.

Many of the Shinarump pebbles collected from Hoskinnini Mesa and from certain other areas studied in Arizona and Utah lithologically resemble rocks characteristic of central Arizona. Red and purple quartzite pebbles, common in most of the areas studied, are similar in appearance to rocks of the Cambrian Bolsa and Troy quartzites of central and southern Arizona.

As uplifted areas to the south and east of the present Colorado Plateau continued to be eroded, sheets of detritus apparently fanned out from their bases. To the south of these mountains, the sediments probably were contributed to the marine Upper Triassic deposits of northwestern Sonora (Cooper and Arellano, 1946, p. 611). To the north of these mountains, however, extended a region the surface of which was very near base level. Sheets of sand and conglomerate began to advance across this region from the mountainous areas.

The conditions under which at least some of the sediments of the Shinarump conglomerate probably were deposited, have been reproduced in the laboratory. Experiments, performed by the writer under the direction of Professor McKee, developed certain of the sedimentary structures of the Shinarump conglomerate. Briefly summarized, these experiments indicate that sedimentary structures involving channels and troughs are formed in a two-cycle process. The first cycle is one of low base level with erosion cutting the trough or channel. The second cycle is one of deposition, following a rise in base level, with the sediments being deposited subaqueously. Attempts to reproduce corss-stratification in a one cycle operation, either subaerially or subaqueously, using changes in gradient, volume of water, or volume of sediment available for deposition, failed to form cross-stratification structures characteristic of the Shinarump conglomerate. For instance, the lensing deposits which are characteristic of channel-fill material correspond in appearance to the experimentally formed, asymmetrically filled troughs described by McKee (1953, p. 58). These experiments indicate that there must have been either a rise in base level to fill the channels with water or a damming of the channels to form ponds, or possibly both.

Cross-stratification data, collected in scattered localities across the region (Table I), indicate that most of the streams that formed the Shinarump conglomerate in the areas studied, flowed in a general northerly to northwesterly direction. This is further evidence of high areas to the south and east of the Colorado Plateau.

Erosion of uplifted mountain areas beyond the basin of deposition apparently provided most of the Shinarump sediments. Variable amounts, however, were derived locally from hills and mounds of the Moenkopi formation and De Chelly sandstone, especially in the upwarped parts of the basin. Fragments of these rock types, especially common in channel deposits, probably were largely destroyed by the continual reworking in place where Shinarump sediments accumulated above the channels.

The end of Shinarump deposition resulted either from a change of material in the source areas or a lower topography of the mountains. Waters and Granger (1953, p. 3) believe that the mountainous areas were showered with volcanic debris that was carried and deposited in much the same manner as the Shinarump material. This change in type of sediment was not abrupt which explains the transitional nature of the contact between the Shinarump conglomerate and the Chinle formation.

Conditions similar to those that caused deposition of the Shinarump conglomerate were repeated several times during Chinle time, forming deposits of comparable lithology at several horizons within the Chinle. These deposits indicate that the Shinarump conglomerate was the result of a combination of conditions in the source areas and in the areas of deposition and was not formed as the veneer on a pediment surface as described by Stokes (1950, p. 95). Moreover, if the process had been one of pedimentation, the Shinarump streams would have cut down the high area in southern Utah and deposited conglomerate upon it. Most of the erosion of the underlying Moenkopi and De Chelly formations appears to have been completed before deposition of Shinarump sediments began. The process of advance by the sheets of Shinarump conglomerate was one of deposition, not pedimentation. The inclusion of fragments of Moenkopi and De Chelly sediment in the Shinarump conglomerate indicates that erosion occurred during deposition and the amount deposited indicates that the erosion was of minor importance. With subaqueous deposition going on in the channels, it is unlikely that the channels were being eroded simultaneously.

The last remnants of Moenkopi material in the Canyon de Chelly area may have been destroyed by the advancing streams that formed the Shinarump deposits. While no Moenkopi occurs in the area today, fragments of both Moenkopi- and De Chelly- type lithology are common in the Shinarump conglomerate that fills channels cut into the De Chelly sandstone.

MINERALIZATION

Deposits of uranium in the Shinarump conglomerate of the Colorado Plateau are an important source of uranium for the atomic energy programs of the Free World. The uranium occurs in conjunction with varying quantities of vanadium and copper, both in combination and as separate minerals. Carnotite, hewitite, malachite, azurite, and pyrite occur in one or more of the deposits studied. In addition, Gruner and Gardiner (1953) report the occurrence of uraninite, uvanite, gummite, and a number of other minerals in the Shinarump conglomerate deposits of the Monument Valley area. Carnotite, used in the broad sense, includes a number of similar minerals (including tyuyamunite) which are indistinguishable in the hand specimen.

History

Since the late 1800's, deposits in the Shinarump conglomerate on the Colorado Plateau have produced small quantities of vanadium and radium with uranium as a by-product. In the production of these elements, the Shinarump conglomerate was surpassed only by the Morrison formation (Upper Jurassic) in the United States. Since applications of atomic energy to various wartime and peacetime projects were discovered, a number of deposits in the Shinarump conglomerate have produced an appreciable amount of uranium, with vanadium, radium, and copper as by-products.

Descriptions of Mineralized Areas

Monument #2 Mine is the only operating uranium producer, at the present time, in the areas studied. Shipments of ore have been made from the Skyline Mine on Oljeto Mesa. In addition, mineralization occurs at Hoskinnini Mesa, Cameron, and Lee's Ferry. Much of the mineralization in the latter areas is due to recent redistribution by ground water depositing secondary uranium and copper minerals around pellets of mudstone and along joints and fractures on cliff faces. None of this material is of commercial grade so far as is known. An example of surface staining is exposed on a butte near Oljeto Trading Post. Carnotite is exposed along the wall of an adit driven into the side of the butte at the Moenkopi-Shinarump contact, but it is absent one foot from the cliff face and the amount of copper mineralization there is negligible.

Comparison of the mineralized localities at Monument #2 Mine, Oljeto Mesa, and Hoskinnini Mesa reveals the following: (1) mineralization is restricted to deposits in pre-Shinarump erosion channels cut into the upper surface of the Moenkopi formation; (2) most mineralization occurs in conjunction with clay and/or carbonized wood, with much of the remainder in relatively permeable pockets caused by "pinchouts" in mudstone beds; (3) most of the bleaching of the underlying

Moenkopi formation is somewhat more pronounced in the mineralized areas studied than is normal across the region; (4) mineralization extends several inches into the underlying Moenkopi formation on Oljeto Mesa and several feet into the underlying De Chelly sandstone at Monument #2 Mine; and (5) intensity of mineralization varies widely, being high at Monument #2 Mine, medium to low on Oljeto Mesa, and low on Hoskinnini Mesa.

Channels: The widespread occurrence of ore in pre-Shinarump erosion channels cut into the Moenkopi formation and its confinement to these channels are important features in the study of the mineralization of the Shinarump conglomerate. That this is due to chance seems extremely unlikely as channel deposits constitute only a minor portion of the total volume of the Shinarump conglomerate.

Channels vary considerably in size in the Monument Valley area. The channel at Monument #2 Mine is 400 feet wide and 40 feet deep, whereas those on Hoskinnini Mesa reach depths of 250 feet and are several thousands of feet in width. In addition, the channel at Monument #2 Mine is discontinuous (canoe-shaped) over a distance of about a mile, as indicated by drilling, whereas channels on the west side of Monument Valley apparently extend an unknown distance beyond the areas studied. These factors of size and discontinuity of channels may have been instrumental in forming a rich orebody at Monument #2 Mine and only meager mineralization on Hoskinnini Mesa.

Permeability: Permeability, especially variations in permeability, is apparently a second important factor in the mineralization of the Shinarump conglomerate. All theories on the origin of the mineralization in the Shinarump conglomerate recognize that solutions were active in the formation at some time prior to the final ore deposition. The passage of these solutions appears to have been controlled to a large extent by the wide ranges of permeability occurring within the formation.

Ore located above mudstone lenses, apparently deposited within a perched water table, occurs in several localities in the Monument Valley area and has been reported from White Canyon, Utah (Miller, oral communication 1952).

Much of the ore in the Monument #2 Mine is underlain by the De Chelly sandstone. Although the upper few feet of the sandstone are mineralized, the permeable sandstone appears to have been a barrier to the downward migration of the mineralizing solutions. A possible explanation is a lack of vertical permeability in the cross-stratified sandstone.

Lithology: A third factor in the control of mineralization in the Shinarump conglomerate is lithology. Most ore is segregated in pockets and lenses within sediment-filled channels along the Shinarump-Moenkopi contact. There is no apparent control by permeability changes. Most of the pockets and lenses contain clay and/or carbonized wood. A similar control occurs in the Shinarump conglomerate in other areas (Miller, 1952; Waters and Granger, 1953). Unmineralized clay occurs within a few feet of mineralization, however, in several localities of the Monument Valley area, and unmineralized carbonized wood occurs in conjunction with mineralized clay in the Skyline Mine on Oljeto Mesa.

A possible explanation of variations in clay mineralization is presented by Frederickson (1948, p. 184). His experiments indicate that uranyl ions are picked up by clays, such as montmorillonite, with base exchange properties, whereas kaolin, with no base exchange power, has no effect. Waters and Granger (1953, p. 10) consider this an adequate explanation for the selectivity in the mineralization of clays included within the various mudstones. Weeks and Riley (1952, p. 13), however, report that X-ray analysis of gray clay from five different Shinarump mines shows no montmorillonite.

A similarly confusing situation occurs in the study of carbonized wood. Field work indicates that selective mineralization occurs, but the cause is unknown. Waters and Granger (1953) suggest humic colloids and resins, derived from the wood, as possible precipitating agents.

<u>Structural Control</u>: Large- and small-scale tectonic structures are possible factors in the control of mineralization in the Shinarump conglomerate. In the areas studied, large-scale structures consist of monoclines and faults, whereas joints and fractures comprise the small-scale structures.

No mineralization has occurred in connection with faults, joints, or fractures in the areas studied, except for the deposition of secondary surface deposits by recent ground water movement. These observations agree with those of Miller (1952, p. 1280) at White Canyon, Utah.

Control of ground water movement within the Shinarump conglomerate by monoclinal flexing has been suggested by Bain (1953). He considers pre-Shinarump erosion channels on synclinal limbs, near the troughs of synclines, to be most favorably situated for mineralization. He conducted a number of laboratory experiments on ground water movement to corroborate his field observations. The areas studied, in connection with this report, tend to support this theory.

A suggested natural continuation of Bain's experiments would be a series studying the introduction and paths of movement of juvenile solutions in an area of monoclinal flexing. This would involve rising rather than descending solutions.

Origin of Mineralization

The origin of the Plateau-type ore deposits constitutes one of the most controversial problems in the field of economic geology. The two main theories consist of contemporaneous deposition, and later hydrothermal or ground water deposition. Contemporaneous deposition, moreover, may be divided into the following theories: (1) deposition in plant material along beaches and bars from sulphate-bearing waters in the Shinarump streams (Hess, 1933) and (2) deposition of detrital uranium minerals in the Shinarump conglomerate, as described by Bain (1953).

Theories of contemporaneous origin face certain definite objections. First, uranium deposits are concentrated in a number of areas and are not scattered uniformly throughout the region as might be expected. Second, Stieff and Stern (1952, p. 24) report that age determinations on uranium minerals from both the Shinarump conglomerate (Upper Triassic) and the Morrison formation (Upper Jurassic) indicate an age for mineralization of the magnitude of about 80 million years. The Upper Jurassic and Upper Triassic sedimentary units are approximately 130 and 160 million years old respectively, according to Zuener (1951, p. 310).

Uranium minerals are quite soluble under acid conditions and a uranium-bearing pebble in a stream load would probably be leached of its uranium before final deposition. An analagous situation is the leaching of uranium minerals from the dumps of old vanadium mines on the Plateau. Thus, pebbles of detrital uranium minerals probably were not deposited in the Shinarump conglomerate in appreciable quantities.

Post-Triassic age for the mineralization in the Shinarump conglomerate is postulated in the following theories: (1) introduction of hydrothermal mineralizing solutions, possibly during the Laramide orogeny and (2) concentration, transportation, and deposition by ground water of minute quantities of uranium scattered throughout the sedimentary rocks of the region.

The hydrothermal and ground water theories are both supported by the lead-isotope age determination of 80 million years for deposits in both the Shinarump conglomerate and the Morrison formation. Waters and Granger (1953) consider uranium-bearing volcanic ash in Upper Triassic and Upper Jurassic deposits as likely sources for uranium for ground water concentration. It has been suggested, however, that the grouping of uranium deposits in certain localities indicates a hydrothermal origin. Igneous dikes occur in the Oljeto area (Plate XIII) and near Monument #2 Mine. No known ore deposits occur in conjunction with the dikes.

The field studies of the Shinarump conglomerate presented in this paper produced no evidence to support any one of the previous theories. The study did, however, indicate that the mineralizing solutions traveled in a manner characteristic of ground water movement.

APPENDIX

Stratigraphy of the Hoskinnini Mesa Area

Four sedimentary units crop out in the Hoskinnini Mesa area. They are the Organ Rock tongue and the De Chelly sandstone member of the Cutler formation (Permian), the Moenkopi formation (Lower and Middle Triassic), and the Shinarump conglomerate (Upper Triassic). The following descriptions of these units are taken in part from Baker (1936).

Organ Rock Tongue

The Organ Rock tongue of the Cutler formation consists of reddish-brown mudstones and siltstones with a few lenses of red sandstone and gray limestone. It forms moderately steep slopes at the base of Hoskinnini Mesa.

The upper contact of the Organ Rock tongue is generally planar with irregularities in a few localities. The contact zone is bleached light gray with alteration extending downward along joints and laterally along bedding planes. The Organ Rock tongue is 540 feet thick near Hoskinnini Mesa.

De Chelly Sandstone Member

The De Chelly sandstone member of the Cutler formation consists of cross-bedded, gray to tan, medium- to fine-grained, subrounded to subangular, poorly cemented, quartz sandstone. The surface color of the formation is often reddish-brown due to wash from the overlying Moenkopi formation. The large-scale cross-bedding is typical of eolian deposits.

The De Chelly sandstone thins to the northwest and wedges out on the north side of the San Juan River. It has a thickness of 310 feet at Hoskinnini Mesa. The formation is not particularly resistant to erosion but forms cliffs with the protection of overlying sediments.

Moenkopi Formation

The Moenkopi formation consists of reddish-brown, ripple-marked mudstones and siltstones with a few beds of reddish-brown sandstone and gray limestone. The formation contains gypsum in thin lenses and crosscutting secondary veins. Mud cracks and rain pits are common.

The Moenkopi formation is a prominent slope-former below the Shinarump cap on Hoskinnini Mesa. It ranges from five feet to over 250 feet in thickness on Hoskinnini Mesa due to the extreme irregularity of the erosional contact with the overlying Shinarump conglomerate. In general, the formation decreases in thickness to the east. The upper contact is bleached with alteration extending along joints and bedding planes.

The basal portion of the Moenkopi formation (Lower and Middle Triassic) has been included, by Baker (1936), within the Cutler formation (Permian) as the Hoskinnini tongue. Differences in lithology and color, as seen by Baker, were used as criteria in making this change, whereas no faunal evidence has been reported to substantiate it. The writer was unable to find this "sharp lithologic boundary where both constituents and color change" on Hoskinnini Mesa, the type area of the unit. Similar difficulties have been reported by other workers (Bradish, 1952).

Shinarump Conglomerate

The Shinarump conglomerate consists of lensing deposits of gray, cross-bedded, medium- to coarse-grained sandstone with a number of conglomerate and mudstone lenses. The formation is resistant to erosion, cliff-forming, and caps many of the mesas and buttes in the Monument Valley area including Hoskinnini Mesa. The Shinarump conglomerate has a maximum thickness of about 300 feet on Hoskinnini Mesa and averages about 100 feet in thickness.

The upper contact of the Shinarump conglomerate, with the Chinle formation (Upper Triassic), is gradational both laterally and vertically. The Chinle formation, composed of claystone and siltstone, is easily eroded and does not occur on Hoskinnini Mesa.

Description of Measured Sections

SECTION ON NORTHWEST SIDE OF HOSKINNINI MESA

Feet

TRIASSIC:

SHINARUMP CONGLOMERATE:

9. Sandstone: light gray to light tan, medium- to very coarse-grained, lensing, cross-bedded, scattered quartzite pebbles, cliff-forming . . . . . .

CONTACT:

Erosional surface, undulating, maximum relief 3 feet.

MOENKOPI FORMATION:

8. Claystone: reddish-brown, beds up to 3 or 4 inches thick, generally shaly, alteration zone at top of unit is 18 inches thick with colors changed to shades of yellow and green, slope-forming 73
7. Siltstone: reddish-brown, beds up to 4 feet thick, several 2-inch to 6-inch shaly siltstone interbeds, abundant ripple marks, some cross-bedding, cliff-forming 13
6. Claystone: reddish-brown, bedding varies from 1 foot thick to shaly, lensing of beds in upper portion common, ripple marks abundant, scattered thin zones of bleaching parallel to bedding near top of unit, slope- and ledge-forming 40
5. Siltstone: reddish-brown, beds up to 8 feet thick, scattered thin lenses of shaly claystone, ripple marks abundant, cliff-forming 30
4. Claystone: reddish-brown, generally shaly, several 3-inch sandstone lenses just above middle of unit, bleaching along bedding planes, ripple marks common, slope-forming 41
3. Siltstone: reddish-brown, beds up to 5 feet thick, scattered sand grains, 3-foot gnarly bed at base of unit, scattered irregular bleached spots up to 3 inches in diameter common, slope-forming 10
2. Claystone: reddish-brown, bedding from 1 inch to several feet thick, cross-stratification and ripple marks abundant, scattered mud cracks, irregular bleached zones up to 3 inches in diameter common, slope-forming 36

Total Moenkopi 243

CONTACT:

Very sharp and flat, light-colored formation below stained by water from above.

PERMIAN: feet

DE CHELLY SANDSTONE:
1. Sandstone: light tan, very fine- to fine-grained, large-scale type cross-stratification with general southerly dip direction, poorly cemented, several nearly vertical sand dikes up to 3 inches thick, quartz grains subrounded to subangular, cliff-forming . . . .

SECTION FIVE MILES SOUTHEAST OF HOSKINNINI MESA

TRIASSIC:

SHINARUMP CONGLOMERATE:
9. Conglomerate: gray, pebbles up to 1 inch in diameter, medium- to coarse-grained sand matrix, abundant fossil wood, cliff-forming . . . .

CONTACT:
Undulating erosional contact with maximum relief of 1 foot.

MOENKOPI FORMATION:
8. Claystone: reddish-brown, shaly, abundant thin selenite seams near middle of unit, 2-foot yellow and green alteration zone, slope- to ledge-forming .160
7. Claystone: reddish-brown, shaly with a few 2- to 4-inch beds, ripple marks abundant, small selenite crystals common, ledge-forming 5
6. Claystone: reddish-brown, shaly, slope-forming . . . 34
5. Sandstone: buff to reddish-brown, prominently cross-bedded, ripple marks abundant, 2-inch beds of selenite in upper portion, cliff-forming 6
4. Claystone: reddish-brown, shaly, 1-foot siltstone bed near base, ledge-forming 19
3. Siltstone: reddish-brown, ripple marks common, 2-inch crust of rose quartz occurs near the top of the unit, upper portion of unit weathers nodularly, cliff-forming 8
2. Claystone: reddish-brown, shaly becoming somewhat massive toward upper contact, ripple marks common, occasional small irregular bleached spots, slope-forming 23

Total Moenkopi 255

CONTACT:
Flat surface, sharp in color and lithology.

PERMIAN:	feet
DE CHELLY SANDSTONE:	
1. Sandstone: light tan, very fine- to fine-grained, subrounded to subangular grains, cross-bedded, poorly cemented, cliff-forming	

SECTION TWO MILES SOUTHWEST OF OLJETO TRADING POST

TRIASSIC:	
SHINARUMP CONGLOMERATE:	
10. Conglomerate: gray, massive, pebbles up to 2 inches in diameter, silicified wood abundant, mud pellets common, cliff-forming	
CONTACT:	
undulating erosional contact with maximum relief of 5 feet.	
MOENKOPI FORMATION:	
9. Claystone: reddish-brown, shaly, several 2- to 4-inch light-gray siltstone lenses, ripple marks common, yellowish and greenish alteration zone up to 2 feet thick, slope-forming	100
8. Siltstone: reddish-brown, beds up to 4 feet thick, several thin shaly claystone interbeds, cross-bedding common, cliff-forming	20
7. Claystone: reddish-brown, generally shaly with a few nodular-weathering massive beds, cusp and linear ripple marks abundant, pseudo-bedding common, several 1-foot siltstone ledges, slope-forming	40
6. Siltstone: reddish-brown, alternately shaly and massive, scattered ripple marks, beds undulate slightly, cliff-forming	17
5. Claystone: reddish-brown, generally shaly with some massive, 2 cross-bedded siltstone ledges, ripple marks common, bleaching along bedding planes in upper part of unit, slope-forming . . .	35
4. Sandstone: light-gray; fine-grained; thin-bedded; beds undulate; several thin, reddish-brown, shaly mudstone interbeds; top of unit is a 1-inch bed of crystalline calcite and quartz; cliff-forming.	16
3. Claystone: reddish-brown, somewhat sandy toward base of unit, massive, scattered irregular bleached spots, slope-forming	41
Total Moenkopi	269

feet

CONTACT:
Contact appears planar, evidence of reworking of several inches of De Chelly sand and mixing with Moenkopi muds.

PERMIAN:

DE CHELLY SANDSTONE:
2. Sandstone: light reddish-brown, medium- to very fine-grained sand, subrounded to subangular grains, large-scale cross-stratification, unit is cut by several fairly continuous horizontal planes, scattered slump marks occur on bedding planes, cliff-forming with a few slopes 240

CONTACT:
Contact appears planar over considerable distances but has small-scale undulations on close examination.

ORGAN ROCK TONGUE:
1. Siltstone: light reddish-brown, shaly, 1-foot light-gray-bleached zone with alteration extending along bedding planes and joints, slope-forming . . . .

BIBLIOGRAPHY

Bain, George W. (1953) Experimental Simulation of Plateau Type Uranium Deposits, U. S. Atomic Energy Comm., R. M. O. 44, p. 1-210.

Baker, A. A. (1933) Geology and Oil Possibilities of the Moab District, Grand and San Juan Counties, Utah, U. S. Geol. Surv., Bull. 841, 95 pp.

_____ (1936) Geology of the Monument Valley-Navajo Mountain Region, San Juan County, Utah, U. S. Geol. Surv., Bull. 865, 106 pp.

_____, Dobbin, C.E., McKnight, E.T., and Reeside, J.B.,Jr. (1927) Notes on the Stratigraphy of the Moab Region, Utah, Am. Assoc. Pet. Geol., Bull., vol. 11, pp. 785-808.

Benson, W. E., Trites, A.F., Beroni, E.P., and Feeger, J.A. (1952) Preliminary Report on the White Canyon Area, San Juan County, Utah, U.S.Geol. Surv., Circ. 217.

Boutwell, J. M. (1905) Vanadium and Uranium in Southeastern Utah, U. S. Geol. Surv., Bull. 260, pp. 200-210.

Bradish, B. B. (1952) Geology of the Monument Upwarp, Geological Symposium of the Four Corners Region, Four Corners Geo. Soc., pp. 47-59.

Butler, B. S., Loughlin, F.G., Heikes, V.C., and others (1920) The Ore Deposits of Utah, U.S.Geol. Surv., Prof. Paper 111, 672 pp.

Camp, C.L., Colbert, E.H., McKee, E.D., and Wells, S.P. (1947) A Guide to the Continental Triassic of Northern Arizona, Plateau, vol. 20, pp 1-9.

Cooper, G. A. and Arellano, Alberto R.V. (1946) Stratigraphy near Caborca, Northwest Sonora, Mexico, Am. Assoc. Pet. Geol., Bull., vol. 30, p. 611 (abs).

Dane, C. H. (1935) Geology of the Salt Valley Anticline and Adjacent Areas, Grand County, Utah, U.S.Geol. Surv., Bull. 863, 184 pp.

Darton, N.H. (1910) A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona, U.S. Geol. Surv., Bull. 435, 88 pp.

_____ (1925) A Resume' of Arizona Geology, Univ. Ariz., Bur. Mines, Bull. 119, 298 pp.

Daugherty, L. H. (1941) The Upper Triassic Flora of Arizona, Carnegie Inst. Washington, Publ. 526, 108 pp.

Dodd, P. H. (1950) Happy Jack Mine, White Canyon, Utah, U.S. Atomic Energy Comm. Rept., R.M.O. 660, 23 pages.

Dutton, C.E. (1880) Report on the Geology of the High Plateau of Utah, U.S. Geog. and Geol. Surv., Rocky Mtns. Reg., pp. 1-307.

Eardley, A.J. (1949) Paleotectonic and Paleogeologic Maps of Central and Western North America, Am. Assoc. Pet. Geol., Bull., vol. 35, pp. 655-682.

Fairbridge, R.W. (1947) Possible Causes of Intraformational Disturbances in the Carboniferous Varve Rocks of Australia, Jour. and Proc. of the Royal Soc. of New South Wales, vol. 81, pp. 99-121.

Fischer, R.P. (1937) Sedimentary Deposits of Copper, Vanadium-Uranium, and Silver in Southwestern United States, Econ. Geol. vol. 32, pp. 906-951.

_____ (1950) Uranium Bearing Sandstone Deposits of the Colorado Plateau, Econ. Geol., vol. 45, pp. 1-11.

Frederickson, A.F. (1948) Some Mechanisms for the Fixation of Uranium in certain Sediments, Science, vol. 108, pp. 184-185.

Gilluly, James (1929) Geology and Oil and Gas Prospects of part of the San Rafael Swell, Utah, U.S. Geol. Surv., Bull. 806-C, pp. 69-130.

_____ and Reeside, J.B., Jr. (1928) Sedimentary Rocks of the San Rafael Swell and some Adjacent Areas in Eastern Utah, U.S. Geol. Surv., Prof. Paper 150 D, pp. 61-110.

Gregory, H.E. (1913) The Shinarump Conglomerate, Am. Jour. Sci. 4th ser., vol. 35, pp. 424-438.

_____ (1916) The Navajo Country, U.S.Geol. Surv., Water Supply Paper 380, 219 pp.

_____ (1917) Geology of the Navajo Country, U.S. Geol. Surv. Prof. Paper 93, 161 pp.

_____ (1938) The San Juan Country, U.S. Geol. Surv., Prof. Paper 188, 123 pp.

_____ and Moore, R.C. (1931) The Kaiparowitz Region, a Geographic and Geologic Reconnaissance of Parts of Utah and Arizona, U.S. Geol. Surv., Prof. Paper 164, 161 pp.

_____ and Williams, N.C. (1947) Zion National Monument, Utah, Geol. Soc. Am., Bull., vol. 58, pp. 211-244.

Gruner, John W. and Gardiner, Lynn (1952) Mineral Associations in the Uranium Deposits of the Colorado Plateau and Adjacent Regions with Special Emphasis on those in the Shinarump conglomerate, U.S. Atomic Energy Comm., R.M.O. 566, 36 pages.

Heaton, R.L. (1950) Late Paleozoic and Mesozoic History of Colorado and Adjacent areas, Am. Assoc. Pet. Geol., Bull., vol. 34, pp. 1659-1698.

Hess, F. L. (1933) Uranium, Vanadium, Radium, Gold, Silver, and Molybdenum Sedimentary Deposits, Ore Deposits of the Western States (Lindgren Volume), Am. Inst. Min. Eng., pp. 450-481.

Keller, W.D. (1929) Experimental Work on Red Bed Bleaching, Am. Jour. Sci., vol. 18, pp. 65-70.

Knight, S.H. (1929) The Fountain and the Casper Formations of the Laramie Basin, Univ. Wyoming Pub. in Sci., Geol. Vol. 1, pp. 1-82.

Laudermilk, J.D. (1931) Origin of Desert Varnish, Am. Jour. Sci., 5th ser., vol. 21, pp. 51-66.

Longwell, C.R. (1928) Geology of the Muddy Mountains, Nevada, U.S. Geol. Surv., Bull. 798, 152 pp.

_____, Miser, H.D., Moore, R.C., Bryan, Kirk, and Paige, Sidney (1923) Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona, U.S. Geol. Surv., Prof. Paper 132 A, pp. 1-22.

McKee, E.D. (1937) Triassic Pebbles in Northern Arizona Containing Invertebrate Fossils, Am. Jour. Sci., 5th ser. vol 33, pp. 260-263.

_____ (1940) Three Types of Cross-Laminae in Paleozoic Rocks of Northern Arizona, Am. Jour. Sci., 4th ser., vol. 238, pp. 811-824.

_____ (1951) Sedimentary Basins of Arizona and Adjoining Areas, Geol. Soc. Am., Bull., vol. 62 pp. 481-506.

_____ (1951) Triassic Deposits of the Arizona-New Mexico Border Area, New Mex. Geol. Soc., San Juan Basin Guidebook, pp. 85-92.

_____ (1953) Report on Studies of Stratification in Modern Sediments and in Laboratory Experiments, Office of Naval Research, Project Nonr 164(00), NR 081 123, p.1-61.

_____ and Weir, Gordon W. (1953) Terminology for Stratification and Cross-Stratification in Sedimentary Rocks, Geol. Soc. Am. Bull. vol. 64, pp. 381-389.

McKnight, E.T. (1940) Geology of Area Between Green and Colorado Rivers, Grand and San Juan Counties, Utah, U.S. Geol. Surv. Bull. 908, 147 pp.

Miller, L.J. (1952) Uranium Ore Controls in the Happy Jack Mine and Vicinity, White Canyon, Utah, Geol. Soc. Am., Bull., vol. 63, p. 1280 (abs)

Miser, Hugh D. (1924) The San Juan Canyon, Southeastern Utah, U.S. Geol. Surv. Water Supply Paper 538, 80 pp.

_____ (1925) Geologic Structure of the San Juan Canyon and Adjacent Country, Utah, U.S. Geol. Surv., Bull. 751 D, pp. 115-155.

Payne, Thomas G. (1942) Stratigraphic Analysis and Environmental Reconstruction, Am. Assoc. Pet. Geol., Bull., vol. 26 pp. 1697-1770.

Powell, J. W. (1873) Some Remarks on the Geological Structure of a District of Country lying to the North of the Grand Canyon of the Colorado, Am. Jour. Sci., 3rd ser. vol. 5, pp. 456-465.

Reiche, Parry (1938) An Analysis of Cross-Lamination, the Coconino Sandstone, Jour. Ceol., vol. 46, pp. 905-932.

Rettger, R.E. (1935) Experiments on Soft-Rock Deformation, Am Assoc. Pet. Geol., Bull., vol. 19, pp. 271-92.

Shotton, F.W. (1937) The lower Bunter Sandstone of Northern Worcestershire and East Shropshire, Geol. Mag., vol. 74, pp. 532-553.

Stieff, L.R. and Stern, T.W. (1952) Lead-Uranium Ages of Some Uraninites From Triassic and Jurassic Sedimentary Rocks of the Colorado Plateau, Geol. Soc. Am., Bull. vol. 63, pp. 1299-1300 (abs).

Stokes, W.L. (1950) Pediment Concept Applied to Shinarump and Similar Conglomerates, Geol. Soc. Am., Bull., vol. 61, pp. 91-98.

Thom, W.T.Jr. (1923) The Relation of Deep-Seated Faults to the Surface Structural Features of Central Montana, Am. Assoc. Pet. Geol., Bull., vol. 7, pp. 1-13.

Twenhofel, W. H. and Tyler, S.A. (1941) Methods of Study of Sediments, McGraw-Hill Book Co., New York, New York.

Waters, A.C. and Granger, H.C. (1953) Volcanic Debris in Uraniferous Sandstones, and its Possible Bearing on the Origin and Precipitation of Uranium, U.S. Geol. Surv. Circular 224, 26 pp.

Weeks, Alice and Riley, Leonard (1952) Summary of the Research Work of the Trace Elements Section, Geochemistry and Petrology Branch for the Period Oct. 1-Dec. 31, 1951, U.S.Geol. Surv., T.E.I. 218, pp. 12-15.

Zeuner, F. E. (1951) Dating the Past, Longmans, Green and Co. Inc., New York, p. 310.

Plate II

The Shinarump conglomerate caps most of the mesas and buttes in the Monument Valley area.

Plate III

Undrained basins on the upper surface of the Shinarump conglomerate. Note cross-strata in left center of photo.

Plate IV

Bleached zone in upper Moenkopi formation (Trm) at undulating Shinarump contact (Trs). Alteration extends along joints and bedding planes.

Plate V

Channel cut into the Moenkopi formation (Trm) and filled with Shinarump sediment (Trs) on Hoskinnini Mesa. Mud-pellet conglomerate lens occurs along the left (east) margin of the channel in left center of photo.


Ꞧs
Ꞧm


Ꞧs
Ꞧm

Plate VI

Channel cut into the De Chelly sandstone (Pdc) and filled with Shinarump sediment (Trs) seen in vertical section at Canyon de Chelly. Note the vertical walls and overhang in the pre-Shinarump channel.

Plate VII

Trash pocket in the channel-fill sediments of the Shinarump conglomerate. Trash pocket extends from upper right-hand corner to left center of photo.


TRs
Pdc

Plate VIII

Planar cross-strata in upper zone of the Shinarump conglomerate on Hoskinnini Mesa.

Plate IX

Trough cross-strata in lower zone of the Shinarump conglomerate on Hoskinnini Mesa. Pick handle approximately parallels direction of current during deposition.

Plate X

Iron-stained sand concretions weathering out of a sand lens in the Shinarump conglomerate.

Plate XI

Unconsolidated rock deformation in a cross-stratified sand lens in the Shinarump conglomerate. The exposed rock face is vertical.

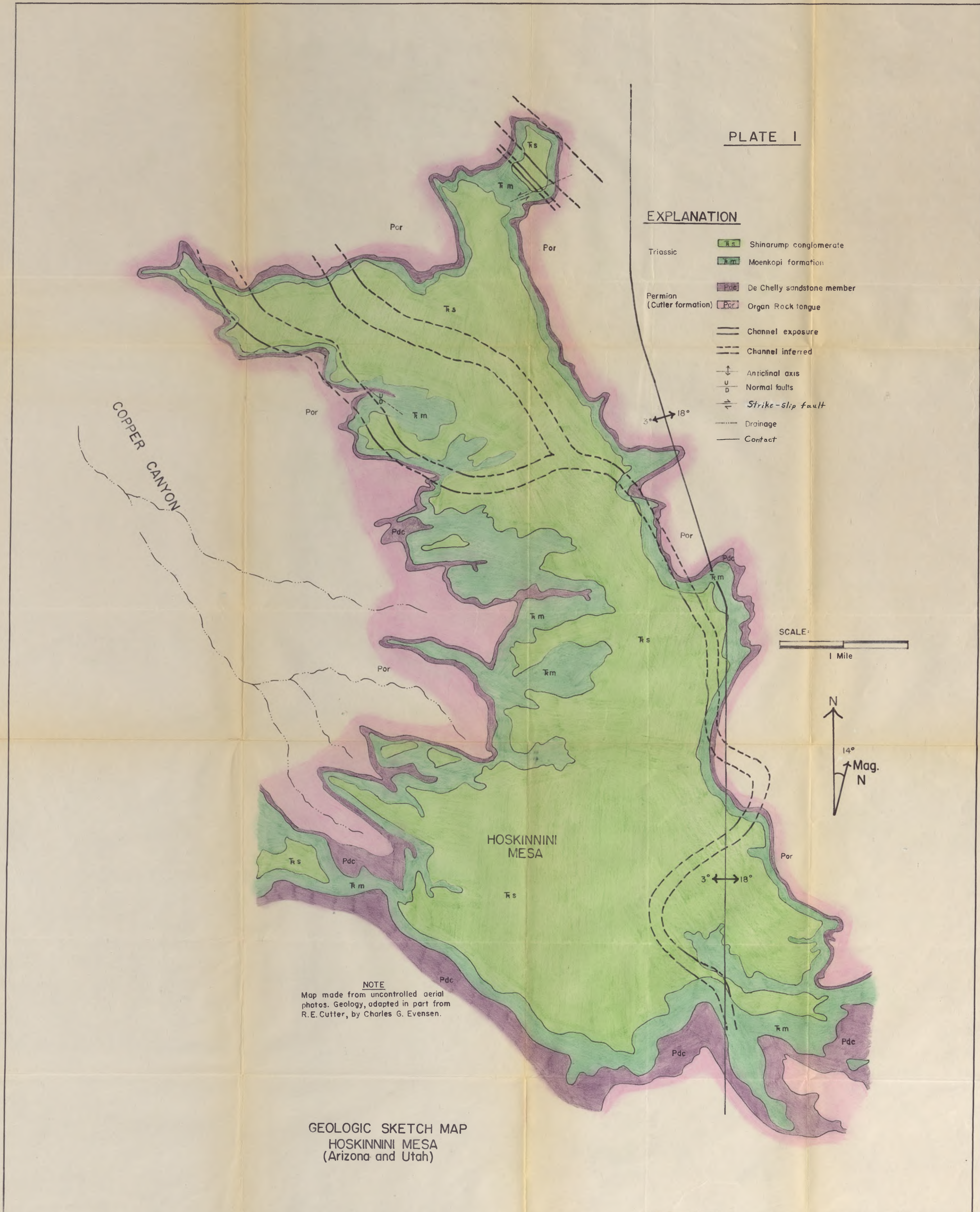
Plate XII

Mud-pellet conglomerate in Shinarump channel-fill sediment on Hoskinnini Mesa. Mud pellets weather out leaving disc-shaped or irregular cavities.

Plate XIII

Igneous dike intruding the De Chelly, Moenkopi, and Shinarump formations near Oljeto Mesa. The strike direction of the dike is toward Agathla, a prominent volcanic spire to the south, seen in the distance.

1 piece



GEOLOGIC SKETCH MAP
HOSKINNINI MESA
(Arizona and Utah)