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GENERAL GEOLOGY, CHANNELING AND URANIUM MINERALIZATION TRIASSIC SHINARUMP CONGLOMERATE CIRCLE CLIFFS AREA, UTAH

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ABSTRACT

The Circle Cliffs anticlinal upwarp lies just west of the Henry Mountains in Garfield County, Utah. It is an asymmetrical fold that has been breached by erosion and whose east limb passes into a major monocline called the Water Pocket fold. The sedimentary rocks in the Circle Cliffs area range in age from the Permian Coconino sandstone to the Jurassic Navajo sandstone.

The only known commercial concentrations of uranium minerals within the Circle Cliffs are found in stream channel-type deposits of the Triassic Shinarump conglomerate. The Shinarump conglomerate has as its base an erosional unconformity which is expressed by major and minor stream channels incised into the underlying Triassic Moenkopi formation.

Three general types of channels are recognized and artibrarily classified as: (1) the shallow, wide "flood plain" type, 15 to 60 feet thick and over one mile wide; (2) the wide, deeply incised "trunk" type, 60 to 245+ feet thick and from one-half to one mile wide; and (3) converging and diverging type, 60 to 100 feet thick and 500 feet to one-half mile wide.

Stream channels and their trends were recognized and plotted by direct observation of channel outlines, by variation of formational thicknesses, and by primary sedimentary structures such as cross-bedding and ripple marks. In the area studied the general direction of flow of the streams was toward the north-west and west. Some of the smaller stream patterns deviate from this general pattern.

Silicified, carbonized, and pitchy wood fragments are characteristic of the Shinarump channels. These wood fragments are usually concentrated in a "trash zone" at or near the bottom of the channels; log jams and high concentrations of wood fragments are found on the channel flanks, in channel lows, and in fringe areas. Lenses of carbonized wood fragments occur, however, in some amount throughout the channel deposits.

Uranium occurs as fillings and replacement bodies in the trash zones and as replacements and fillings in logs and larger fragments of wood. It is concentrated in channel sands saturated with hydrocarbons; in structural traps such as channel lows, slumps, and fault traps; and in stratigraphic traps formed by interfingering of sands, siltstones, and shales.

The uranium minerals present are torbernite, uraninite, autunite, with minor amounts of uranophane, and carnotite. Copper minerals found associated with the uranium minerals are azurite, malachite, chalcopyrite and chrysocola. Other minerals present are pyrite, arsenopyrite, and gypsum.

INTRODUCTION

Purpose and Scope of Report

The following thesis is the result of a research study on the general geology of the Circle Cliffs, and on the fluvial channeling within the Triassic Shinarump conglomerate and the associated uranium minerals within these channels. A study was made of the stratigraphic and structural features of the Circle Cliffs. The primary sedimentary features used by the writer in the field to trace the paleochannels of the Shinarump conglomerate are described in written and pictorial form. The uranium mineralized areas and the conditions favorable for uranium occurrence are similarly described.

Application of significant spatial relationships between uranium mineralization and various geologic features, (ore guides), of the Circle Cliffs area are shown. New concepts together with the compilation of previously described uranium ore guides of the Circle Cliffs area are outlined.

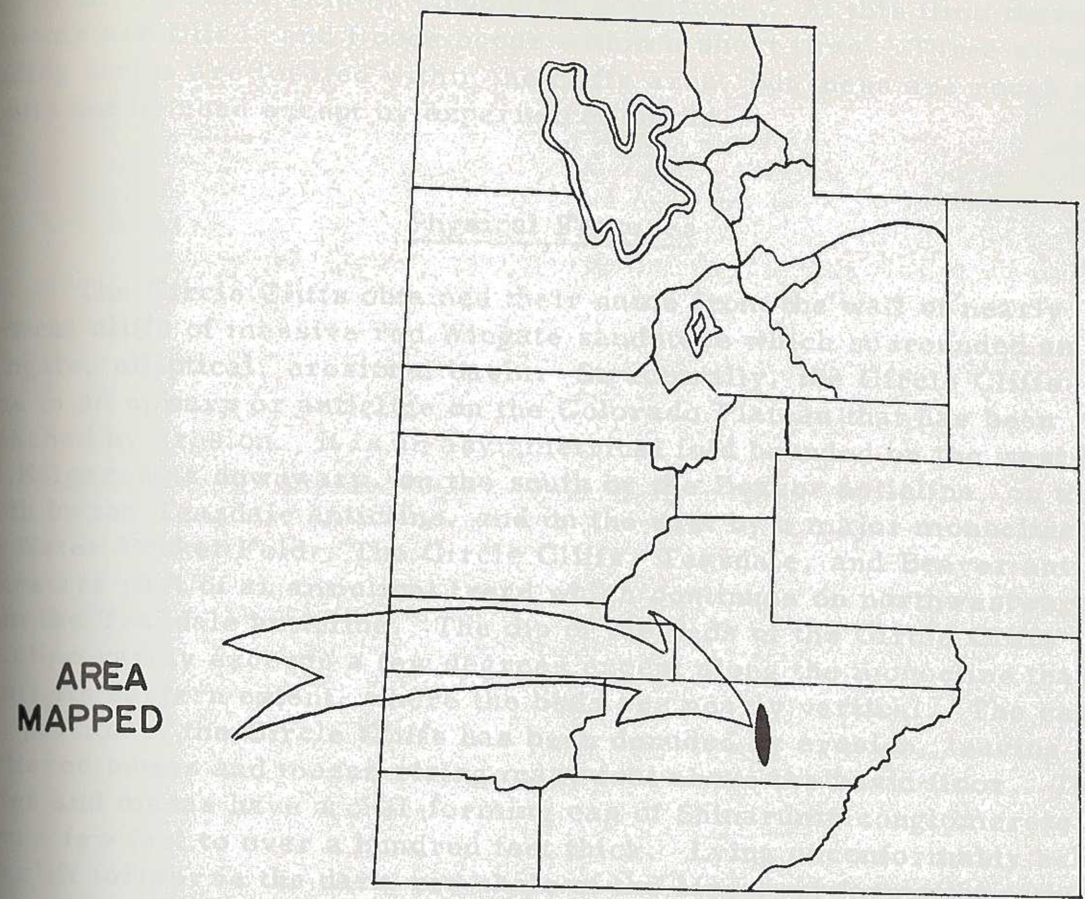
Several geologic corrections of the Atomic Energy Commission photo-geologic maps of the Circle Cliffs area were made by the writer. These corrections include both stratigraphic (deposition or non-deposition of the Shinarump conglomerate) and structural features (correction of fault trends and mapping of faults not previously shown).

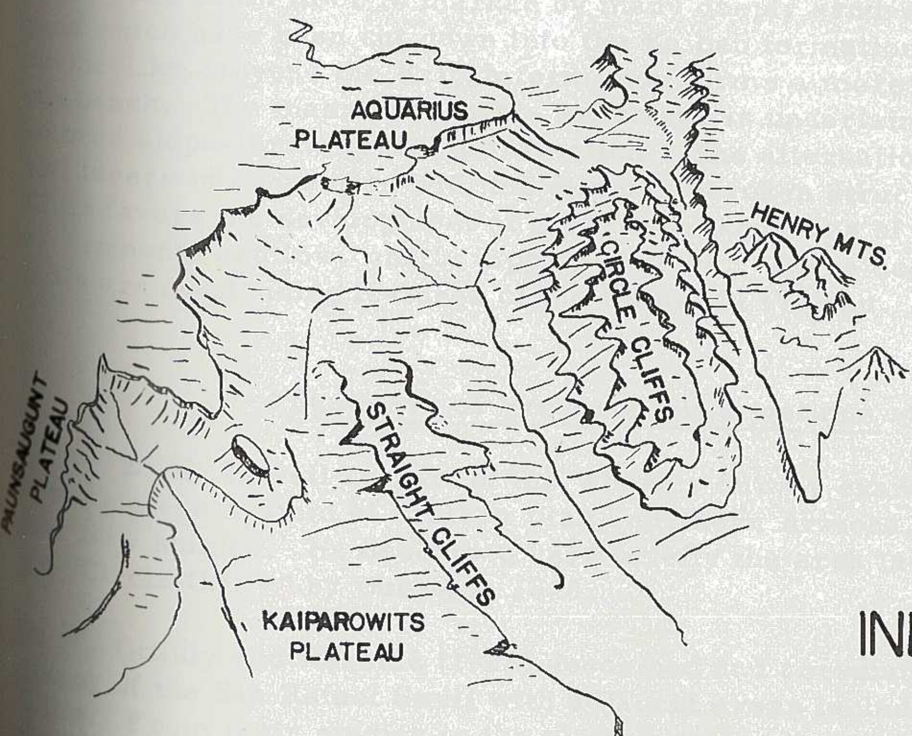
Location and Accessibility

The area examined by the writer lies in central-southern Utah in Garfield County. The Circle Cliffs anticline occupies an area approximately 15 miles wide and 30 miles long. It extends in a north-northwest direction through east-central Garfield county. Townships 32 South to 37 South, and Ranges 5 East to 9 East are the approximate boundaries of the Circle Cliffs structure. Southwest of the Circle Cliffs is the Straight Cliffs and Escalante Basin. On the east side of the Circle Cliffs are long, prominent hogback ridges formed by massive, uptilted sandstones which compose part of the Water Pocket Fold. Halls Creek, located at the base of the Water Pocket Fold, marks the eastern limit of the structure.

Access to the Circle Cliffs in conventional vehicles is afforded by a road from Boulder through Long Canyon into the Circle Cliffs, or by a dirt road through Capitol Reef across the Water Pocket Fold into the Circle Cliffs, following the Burr Trail. A third route leads from Escalante by way of Harris Wash into Silver Falls Canyon and Circle

PLATE 2





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Cliffs. All routes of entry into the Cliffs area should be used only during fair weather; these roads cross and follow stream beds which are dry except during heavy rain or cloudburst conditions. At this time these streams are filled, and floods occur within a short time. Three airplane landing strips are located within the cliffs area, but these are rough and should not be used except by experienced pilots.

Physical Features

The Circle Cliffs obtained their name from the wall of nearly vertical cliffs of massive red Wingate sandstone which surrounded an elongate, elliptical, erosional basin. Structurally, the Circle Cliffs area is an upwarp or anticline on the Colorado Plateau that has been breached by erosion. It is an asymmetrical fold bounded on the west by the Kaiparowits downwarp, on the south by the Beaver anticline, on the north by the Teasdale anticline, and on the east by a major monocline, the Water Pocket Fold. The Circle Cliffs, Teasdale, and Beaver anticlines are part of an anticlinal trend which continues on northwestward from the Teasdale anticline. The dip of the beds of the Circle Cliffs anticline rarely exceeds a few degrees except along the monocline that forms its eastern extent, where the beds are nearly vertical. The central portion of the Circle Cliffs has been denuded by erosion, leaving scattered buttes and mesas rising many feet above the basin floor. These buttes and mesas have a cliff-forming cap of Shinarump conglomerate from a few feet to over a hundred feet thick. Lying unconformably below this cliff former is the dark-red shale of the Moenkopi formation, which forms a slope to the floor of the basin and covers the depressional basin area. The basin floor is marked by many deeply eroded, youthful canyons which have been cut down into the Kaibab formation. Within these ravine-like canyons the Kaibab formation forms a more or less continuous bench. The massive Wingate sandstone is underlain by the vari-colored slope-forming Chinle formation. The alternation of hard and soft layers in connection with the simple unbroken structure of the Circle Cliffs favors the development of great unbroken lines of high, continuous escarpments and low, gently dipping shelves. These escarpments and cliffs are outstanding features of the Colorado Plateau.

Summary of Previous Investigations

E. E. Howell as part of the Wheeler Survey examined portions of the plateau system of eastern Utah, northern Arizona, and northwestern New Mexico. He described very briefly the area later to be named the "Circle Cliffs" by Dutton in 1880.

Gilluly and Reeside (1928) described and correlated the stratigraphy of the San Rafael Swell with adjacent areas including the Circle Cliffs. From their studies in the plateau region they defined and named the San Rafael group and the stratigraphic units within this group. Gregory and Moore (1931) applied the name "Glen Canyon group" to the Wingate sandstone, Kayenta formation, and Navajo sandstone. The type locality is the Glen Canyon of the Colorado River in Utah. A study of the Shinarump conglomerate by Stokes (1950) presents his theory as to the origin and nature of the Triassic Shinarump conglomeration.

Gilbert (1876) and Baker (1935) described the stresses forming the major uplifts and basins of the plateau region as vertical with major monoclines formed by draping of the layered sedimentary rocks over faulted edges of the Pre-Cambrian basement rocks. Baker (1935) made structural and stratigraphic studies of the Colorado Plateau area, and from these studies described the Colorado Plateau tectonic history. Spieker (1946), Hunt (1954), and Shoemaker (1954) each made studies regarding the folding and dating of the Circle Cliffs uplift. Steed (1954) prepared a geologic map of the Circle Cliffs Anticline upon which several faults and the structure and stratigraphy are shown.

The only recent work in the Circle Cliffs area has been done by the Atomic Energy Commission. This agency prepared photogeologic maps of this region for their use while evaluating a part of the area for possible uranium occurrence. Many uranium mineralization studies have been made on areas near or adjacent to the Circle Cliffs, but uranium mineralization studies of the Circle Cliffs, except by the A. E. C., are not known to the writer. The results of the work done by the A. E. C. in the Circle Cliffs area have not been completed or released to the public.

Field and Laboratory Studies

The field work upon which this report and accompanying maps are based was completed during the summers of 1954 and 1955. Photogeologic maps prepared by the A. E. C. were used as a base by the writer, since aerial photographs could not be obtained. All geologic mapping of formations, structure, channeling, and mineralized zones was done on these maps. Also field geologic corrections of these maps were made.

The writer followed standard techniques of field geologic mapping. The basic principles for the use of the telescopic plane table alidade, Brunton compass, and tape were adhered to in channel tracing and in measurement of stratigraphic sections. Basic principles in lateral tracing of formation boundaries and fault traces were used in the field by the writer.

Rock samples were taken at five and ten foot intervals along representative measured sections within the Circle Cliffs area. These rock samples were used by the writer for interpretation of stratigraphy and the environments of deposition. All samples taken were studied megascopically and microscopically.

STRATIGRAPHY

Permian System

Kaibab Limestone and Coconino Sandstone

The Permian Coconino sandstone and Kaibab limestone are the oldest formations exposed in the area studied by the writer. The type sections as named by Darton (1910) are located in the Grand Canyon area. The tracing of the Kaibab limestone and the Coconino sandstone from the type section area into the Circle Cliffs is not possible. There has been some question as to the validity of extending the Coconino sandstone from the type section to the Circle Cliffs area. Gregory and Moore, (1931) show scepticism in applying the name Coconino sandstone for the calcareous sandstone underlying the Kaibab limestone in the Circle Cliffs. From their studies in the Circle Cliffs they found that a gradation exists between the typical fossiliferous limestone of the Kaibab and the underlying calcareous and fossiliferous sandstone, and that the Kaibab limestone and Coconino sandstone "could" be only parts of a single widespread formation. Gregory and Moore (1931) also state that because of stratigraphic uncertainties the name Coconino for the calcareous sands that underlie the Kaibab limestone is of doubtful validity.

The unconformable contact between the Permian Kaibab limestone and the Triassic Moenkopi formation is readily apparent only in a few localities within the Circle Cliffs area. This unconformable contact is caused by erosion with partial or complete removal of the Kaibab limestone. Channels cut into the Kaibab limestone and filled with basal shales of the Moenkopi formation are present. A lensing basal conglomerate in the Moenkopi is also locally present at the base of the channels incised into the Kaibab limestone. Gregory and Moore (1931) show 37 feet of Permian strata removed locally. Drake (1920) shows 200 feet or more of Permian removed and complete removal in some places of the limestone beds of the Kaibab limestone.

The Coconino sandstone (an eolian type deposit) is considered a "clean" sandstone, whose quartz grains are fine and well sorted, and cemented with lime and silica (as compared with the siliceous cement of the type section in the Grand Canyon area). The Coconino sandstone shows large-scale cross-stratification, forms rounded and cliffed outcrops, and is creamy white to brown.

The Kaibab limestone is a marine deposit as shown by a marine invertebrate fauna of mulluscs and brachiopods in its upper limestone bed. It is composed of fine-and medium-grained, somewhat evenly bedded limestone, sandy limestone, sandstone, and locally thin shale and conglomerate beds. Dolomite lenses with nodular chert are present. The Kaibab limestone in the Circle Cliffs differs in marked contrast with the Kaibab limestone of the type section in being extremely sandy. Weathered outcrops are gray-white to brownish-yellow. Unweathered samples are usually almost white. The unit crops out and weathers as slopes and bench-like projections. Due to pre-Triassic erosion the Kaibab limestone in the Circle Cliffs area thins northward and eastward (Gregory and Moore, 1931).

The writer measured 45 feet of Kaibab limestone west of the Stud Horse Buttes in the Circle Cliffs. Moore measured 163 feet of Kaibab limestone and 73 feet of Coconino sandstone west of the Peaks, Circle Cliffs, Utah and 135 feet of Kaibab limestone north of the Peaks in the Circle Cliffs (1931, pp. 40-45).

Triassic System

Moenkopi Formation

The Moenkopi formation was named by Ward (1901), who studied and described the type locality in the Little Colorado Valley, Arizona. The formation is extensively developed in the area studied by the writer. The top of the formation is well exposed in the Circle Cliffs area, the base being exposed only in the more dissected portions of the basin floor.

The Moenkopi formation consists of interlaminated, reddish-brown, siltstone; sandy, micaceous shale; thin-bedded, calcareous, platy, fine-grained sandstone and siltsone; grayish-orange to yellow-orange, calcareous siltstone; fine-grained sandstone; and fine to medium grained, dark-gray to black sandstone. Locally a conglomerate is present at the base.

The thickness of the Moenkopi formation varies greatly from place to place. Gregory measured 390 feet at Lees Ferry and 514 feet at Kaibab Gulch, Utah. He also measured 456 feet on the west side of the Circle Cliffs, 425 feet on the east side of the Circle Cliffs near where Muley Twist road enters the canyon through the hogsback of the Circle Cliffs area, and 304 feet northwest of Wagonbox Mesa, Circle Cliffs. The writer measured 400 feet north of the Stud Horse Buttes area and 420 feet on the southeast side of the Pioneer Mesa, Circle Cliffs. This variation in thickness is attributed to deposition on an erosional surface, varying deposition rates, and an erosional unconformity at the top of the formation. The thickness of the Moenkopi increases westward, reaching a maximum in the Virgin River Valley where sections of 2135 and 1775 feet thick were measured.

Moenkopi sediments of the Circle Cliffs area are both marine and non-marine in origin. Sedimentary structures within the continental sediments of the Moenkopi formation indicate an eastern source for these sediments. Cross-bedding in the sandy siltstone lenses dips in a westerly direction as stated by Stewart and Smith (1954) and as found by the writer, and indicates westerly-flowing streams during Moenkopi time, and an eastern source for the continental sediments. The sea in which the marine Moenkopi sediments were deposited is thought to have transgressed from the northwest and west across southern Utah, and is indicated by the thinning of the Moenkopi to the east and by the onlapping of the Sinbad limestone member on older rocks to the southeast (Stewart and Smith, 1954) (McKee, 1954). Deposition of the Moenkopi formation is thought to have been in progress in northern Utah long before the first sediments were deposited in southern Utah.

The weathered hue of the Moenkopi formation in the northern Circle Cliffs area is reddish-brown. In the central and southern Circle Cliffs the reddish-brown color is subordinate and can be seen only in the upper half or upper few feet of the formation.* The color change is due to a prominent facies change within this formation. From the northern end of the Circle Cliffs to the southweastern end, the reddish-brown clays, siltstones and sandstones become increasingly calcareous and lighter in color. To the southwest and west the clays, siltstones, and sandstones give way to limestones and to the southeast and east the calcareous nature of the Moenkopi formation diminishes and the formation becomes entirely continental in origin.

At the base of the resistant sandstone cap of Shinarump conglomerate, the upper reddish beds of the Moenkopi formation form a vertical cliff that ranges in height from a few feet to over a hundred feet. Most of the formation, however, forms gentle slopes which are interrupted by small, discontinuous, step-like benches. Gentle rolling topography, breached by gullies and canyons, is typical in areas where the resistant Shinarump sandstone cap has been removed.

Shinarump Conglomerate

The Shinarump conglomerate was named by Gilbert (1875) who described the type section in the southern part of Kane County, Utah. The formation crops out as an inner bench and cliff-like escarpment around the periphery of the Circle Cliffs basin floor. This bench cliff lies between the friable shales of the Moenkopi and Chinle formations. Many isolated remnants of this resistant conglomerate are seen forming the cap of the mesas and buttes within the Circle Cliffs area. The top and base of the formation are everywhere exposed except where it plunges beneath the canyon floor on the western flank of the Circle Cliffs uplift.

The massive cross-bedded Shinarump conglomerate consists of gray, buff to white, medium to coarse-grained, lenticular quartzose sandstone and siltstone, well-rounded quartz-pebble conglomerate lenses which contain some chert and jasper, fine to medium-grained sandy-siltstones, and blue-green sandy claystones. Sandstones, siltstones, shales, and local conglomerates are cemented by ferruginous, siliceous, and calcareous cement. The sandstones are locally saturated

* (Fig. 6)

with hydrocarbons and gypsum. Many fluvial channel deposits of the Circle Cliffs area can be separated into three units: a lower soft sandstone unit, a middle greenish-gray blue shale unit, and an upper massive, cross-bedded sandstone unit. These divisions were also found and applied by Gregory and Moore (1931, p. 52). Primary intraformational structural features are cross-stratification, ripple marks, and contortion of strata.

The Shinarump conglomerate is generally conformable with the Chinle formation above, and disconformable with the Moenkopi formation below. The unconformity between the Shinarump conglomerate and Moenkopi formation was created by the fluvial streams which, during mid-Triassic time, removed portions of the upper Moenkopi surface and incised channels into the horizontal bedding of this formation. At the same time or soon after the erosional surface on the Moenkopi was completed, the streams became aggraded and migrated freely, incising and filling almost concurrently with fluvial deposition of the Shinarump conglomerate. The continuously flooding, aggradational streams covered interchannel areas, depositing the great sheet-like plane of sands and silts of the Shinarump conglomerate.

The sorted and mixed type lithologic character of the quartzose sands, silts, claystones, and local conglomerates of the Shinarump conglomerate is due to its fluvial origin. The lithologic variability and character of the Shinarump conglomerate will be discussed later in relation to the origin of three general types of channels studied and arbitrarily named by the writer.

Carbonized wood is abundant in the Shinarump conglomerate and may be found as lenses throughout the entire vertical extent of the formation and as wood fragment concentrations, "trash zones," at or near the bottom of the channels, on the channel flanks, in channel lows, and in fringe areas. Log jams in this conglomerate are more characteristically found associated with fringe and pinchout areas. Logs have been found which are forty feet long and two feet in diameter. The smaller fragments of carbonized wood are pitchy or of a soft, black charcoal form. A greater percentage of the larger (branches and limbs) carbonized wood fragments are of the above mentioned form, but some differ in having an outer zone of pitch-like coal and an inner core of silicified wood. All logs or tree trunks found were silicified.

The Shinarump conglomerate ranges in thickness from 245 feet (as proven by drilling at the head of Wolverine Canyon) to less than one foot and in some places is entirely absent, placing the Moenkopi in direct contact with the Chinle formation. To produce this effect either small structural or erosional highs on the Moenkopi erosional surface would necessarily be present, therefore, obstructing the Mid-Triassic fluvial deposition of the Shinarump conglomerate; or the Shinarump conglomerate has been partially or completely removed by erosion.

Chinle Formation

The type section of the Chinle formation is in Chinle Valley of northeastern Arizona. Gregory first studied, named, and described this formation in 1915. The Chinle formation is a continental deposit, as shown by its local extreme concentrations of silicified wood, freshwater fossil forms, various horizons of ripple-marked surfaces which indicate a west, northwest flowage of Moenkopi streams, and by its lithologic character. The Chinle formation is conformable with the Shinarump conglomerate below and the contact is gradational according to Stokes (1949, p. 81) and Gregory (1938, p. 49). The upper contact surface of the Chinle formation with the Wingate sandstone is unconformable and is quite well defined in the Circle Cliffs area, whereas in other areas little or no evidence of it can be found. The Chinle is well exposed in the Circle Cliffs area and it can be viewed and traced without termination for many miles. Its base and top are exposed with few exceptions over the entire area studied. The Chinle formation is very vulnerable to erosion and forms steep rounded slopes cut by numerous intersecting ravine-like gullies.

Several men who have studied and described the Chinle formation comment on the inconsistency of the beds within this formation in respect to rock type, color, and position in the section. Because of this inconsistency only general descriptions are given and detailed descriptions are shown only for measured sections. Gregory (1917, p. 53) described the Chinle formation as the group of shales, "marls", thin soft sandstones, and limestone conglomerates lying between the Triassic Shinarump conglomerate and the Jurassic Wingate sandstone. Stewart and Smith (1954, p. 25) described the Chinle formation as a heterogeneous unit of variegated claystone and siltstone, sandstone, conglomeritic sandstone, limestone, and limestone-pebble conglomerate. The writer describes the Chinle formation as multi-colored, calcareous, micaceous, claystone; orange-red, massive, friable, argillaceous limestone; light reddish-brown and grayish-white mottled shale; and hard, compact, or loose and poorly cemented, grit to pebble size limestone conglomerate that contain siltstone and shale in the form of mud balls and lozenges. Insoluble residues prepared of samples collected from sections measured by the writer show that limestone conglomerate and argillaceous limestone alternates with the calcareous siltstone and claystone throughout the vertical extent of the measured Chinle sections.

Two outstanding features that characterize the Chinle formation are the fossil wood and marls of this formation. The fossil wood which in some places constitutes a fossil forest of chips, blocks, and stripped tree trunks is found immediately above the lower calcareous bed of the Chinle formation. The writer found and measured in Wolverine and Death Canyons, logs and tree trunks that were from 50 to 150 feet long and three feet in diameter. These fossil trees seem to follow the outlines of the ancient paleostreams of the Shinarump conglomerate. The "Marl" unit, or bentonitic shale of the Chinle formation lies within the middle one-third of the Chinle formation. This marl unit shows deep, striking color tones. The marl surfaces are very soft and spongy and swell enormously, absorbing great quantities of water during rains and cloudburst conditions.

The thickness of the Chinle formation varies locally and regionally. Its greatest thickness is found in northeastern Arizona and southwestern Utah. Gregory measured 298 ≠ feet for a section of the lower part of the Chinle formation on the east side of Paria River at Lees Ferry; in the type section he measured 1182 feet; Moore measured 500 feet of Chinle on the east side of the Circle Cliffs northeast of Wagonbox Mesa, Utah and 593 feet of Chinle in an eastern tributary of Silver Falls Creek southwest of Wagonbox Mesa. The writer measured 475 feet in Horse Canyon, Circle Cliffs, Utah and 460 feet in Wolverine Canyon, Circle Cliffs. The range in thickness is due to the erosion of the Chinle before the Wingate sandstone was deposited or possibly to the original depositional thickness of the Chinle.

The Chinle formation extends over nearly all of the Colorado Plateau, as determined by outcrops in New Mexico, southeastern and southwestern Utah, Nevada, and Colorado. Gregory and Moore (1931) state that during most of Upper Triassic time, conditions of sedimentation were uniform over most of the Plateau Province.

JURASSIC SYSTEM

Glen Canyon Group

The Glen Canyon group includes the Wingate sandstone, Kayenta formation, and Navajo sandstone. The term Glen Canyon group was proposed by Gregory and Moore (1931). The type locality is Glen Canyon of the Colorado River in Utah. This group consists of three separable units, two of the units, the upper Navajo sandstone and the lower Wingate sandstone consists of cliff forming, massive, cross-bedded, aeolian sands. The Wingate has been transferred into the Triassic System by the United States Geologic Survey Committee on Geologic Names, but to prevent confusion it is here left in the Jurassic system. There is little variance in size and angularity of the quartzose sands of the two units, nor in their mineral composition. The third and middle unit of the Glen Canyon group is the Kayenta formation. It is a fluvial deposit and consists of calcareous sands and shales and thin-bedded limestones. It is believed that the source area of the sediments for this group was to the west.

As a result of little evidence for a break in sedimentation from the Triassic system into the Jurassic system, a gradational contact is postulated. The lower boundary of the Jurassic system is presently drawn at the base of the massive Wingate sandstone. Lack of fossils within this formation to support the Jurassic age now assigned to it has brought criticism by others who would show the formation as upper Triassic in age. The Glen Canyon group as a whole is lacking in fossils for confirmation of its Jurassic age.

Wingate Sandstone

In 1885 Dutton, while working on the Zuni Plateau, gave the name Wingate to some sandstone cliffs north of Fort Wingate, New Mexico. This original section has been later studied and correlated with the Entrada sandstone of Utah by Baker, Dane, and Reeside (1947).

As explained previously the units within the Glen Canyon group are gradational to each other and to the formations at their base and top. The Wingate, although lying unconformable upon the Triassic Chinle formation, forms a gradational contact with it. The origin of sediments for the Wingate sandstone and for the two other units of the Glen Canyon group is thought to be to the west. The thick sands of the Wingate accumulated mostly through the action of wind, but a partial fluvial type deposition is believed. The Wingate sandstone, as shown by microscopic study of thin sections, is composed of fine, somewhat frosted, angular- to subangular- to round, sorted quartz grains that are cemented by lime and silica. The prominent cross-bedding of the Wingate sandstone shows beveling or truncation by erosion in many of the individual sets of beds.

The weathered colors of the Wingate sandstone range from orange-red to pink or brown, to a cream-yellow where leached. At Long Canyon along the northwest wall of the Circle Cliffs the Wingate sandstone is cream-yellow. The light color is believed to be the result of leaching by underground waters following the more permeable areas within the massive sands of the Wingate. Strong vertical jointing is a prominent feature of the Wingate sandstone and huge slabs and blocks of this formation are continuously falling away as erosion attacks and removes the non-resistant underlying shales of the Chinle formation.

The thickness of the Wingate sandstone in the Circle Cliffs area ranges somewhat due to its lower unconformable surface. The writer measured 280 feet in Horse Canyon, 293 feet in Wolverine Canyon, and 370 feet near Long Canyon, Circle Cliffs. The average of 27 measured Wingate sandstone sections on the Colorado Plateau is 285 feet as computed by Gregory and Moore (1931, p. 62). Some of the thickest sections of Wingate sandstone measured are along the Water Pocket Fold and the San Rafael Swell area, Utah.

Kayenta Formation

The Kayenta Formation has its type locality one mile north of Kayenta, Arizona. This name was adopted by Baker (1936) to replace the Todilto limestone having shown the Todilto limestone at its type locality to be much younger than the Kayenta. The Kayenta formation of the Circle Cliffs area is present as a step-like, recessed horizon between the vertical cliffs of the Wingate and the vertical cliffed and domed outcrops of the Navajo sandstone. The contact between the Wingate sandstone and Kayenta formation is gradational.

The Kayenta formation can be separated from the underlying Wingate sandstone and the overlying Navajo sandstone by contrast in color hues and by resistance to erosion due to lithologic change. The Kayenta formation is a darker pink than the Wingate sandstone and has an unmistakable purplish cast to it. The Navajo sandstone is light to very light yellow-white, or brown in color. The lithologic change is accorded to the temporary change in conditions of deposition. The Kayenta formation represents a thin, irregularly stratified, water-laid deposit and the Wingate and Navajo sandstones represent massive, wind-blown deposits.

The formation consists of poorly cemented, calcareous, sandy, shale and calcareous sandstone that is cross-bedded and interlensing, thin limestone beds and limestone breccia. The sands are of the channel, scour-and-fill type, lensing into limestone, shale and mud. The shales are thin and contain mud balls and lozenges that are characteristic of reworked fluvial type deposits. The limestone beds are small, lensing, and impure, and show fragmental gradation into the shales and sands. Baker, Dane, and Reeside (1936, p. 5) described the Kayenta as a sandstone of varying grain size, grading into coarse grits and fine conglomerates. The sandstone contains subordinate lenses of shale and mudstone with localized beds of impure limestone and mud-pellet conglomerates.

The writer measured 140 feet of the Kayenta formation near Long Canyon, Circle Cliffs, Utah. Gregory and Moore (1931, p. 64) measured along the Waterpocket Fold 150, 160, 214, and 226 feet, in Circle Cliffs 175 feet, and in San Rafael Swell 40-180 feet.

Stokes and Holmes (1954, p. 36) give the areal extent of the Kayenta formation and Wingate sandstone, as the Zion Canyon area on the south; the eastern limit in southwestern Colorado; and a northern limit that lies beneath the Wasatch Plateau and Uinta Basin.

Navajo Sandstone

Resting on the fluvial Kayenta formation is the massive wind-blown Navajo sandstone. Gregory (1917) applied the name Navajo to outcrops in the Navajo Reservation of northeastern Arizona. The name now covers a greater part of the Colorado Plateau area. The Navajo sandstone is equivalent in part at least to the Nugget sandstone of northern Utah. In the type locality and in the Circle Cliffs area the base of the Navajo sandstone is transitional with the underlying Kayenta formation. The source of the Navajo sands of eastern Utah, as indicated by cross-bedding, is to the northwest (Stokes and Holmes, 1954, p. 34).

From the basin floor of the Circle Cliffs the Navajo sandstone can be seen as a massive, white, domed and cliffed unit atop the high, vertical, brightly colored cliffs of the massive Wingate sandstone. With few exceptions, only remnants of this white, finely cross-bedded sandstone remain near the rim of the great circling Wingate cliffs. A thick section is present locally in a few places. Farther back on the flanks of the Circle Cliffs uplift the Navajo sandstone shows its great thickness of section before passing under younger beds. At the Burr Trail on the east flank of the Circle Cliffs Gregory and Moore (1931, p. 47) measured 1260 feet of Navajo sandstone. The Navajo sandstone crops out over a large area, extending into Arizona, Colorado, and northern Utah. Its areal extent is greater than the other two units of the Glen Canyon group.

As observed the Navajo sandstone on the weathered surface is friable, the individual quartz grains in many cases being separate and devoid of cementation. It is eroded easily due to poor cementation. The weathered hue of the Navajo sandstone in the Circle Cliffs area is white to light-yellow or brown. Petrographic microscope study of thin sections prepared from picked samples of the sandstone show it to be composed of clear (in a few cases somewhat frosted), sub-round to round quartz grains cemented by lime. As minor constituent, grains of apatite, zircon, tourmaline, orthoclase, magnetite, titanite, and biotite or muscovite are found.

The Navajo sandstone forms narrow, deeply incised gorges with overhanging cliffs and alcoves. Its cliffed and domed faces are in many places pitted with potholes and "beehives".

STRUCTURE

General Features

The Colorado Plateau has acted in general as a buttress against the intensive deformational forces of the Larmide orogeny. Although the magnitude of the Larmide forces were extreme, the Colorado Plateau suffered only minor flexures and faults. The flexures resulting from the Laramide forces are in general broad upwarps that show parallelism and grouping; many are coaxial with each other and trend northerly. They are separated by small sags and plunge along their strike. Each is characterized by steeply, locally vertical, dipping beds on their east flank and gently dipping beds on their west flank. Although these flexures are truly anticlinal, many refer to them as monoclinal in nature; this error is due to the sharp plunge of the beds on the east side of each flexure. All are elongate parallel to their axial trend. Faults produced by the Laramide orogeny are normal and are numerous and prominent only along the western border of the Plateau area.

Folds

The Circle Cliffs Anticlinal Flexure

The Circle Cliffs structure is one of many small double-plunging, anticlinal flexures on the Colorado Plateau. It is asymmetric, elongated, and has an axial trend of northwest-southeast. The length and width of this structure vary in accordance with arbitrary boundaries drawn by men who have worked in the area, the length being drawn somewhat between 50 and 60 miles and the width between 8 and 30 or more miles. The Beaver, Teasdale, and Circle Cliffs anticlines are parts of a north-westward anticlinal trend. The Beaver anticline on the south is coaxial with the Circle Cliffs anticline while the Teasdale anticline on the north is considered as just part of the anticlinal trend in the area. The Teasdale anticline plunges beneath Tertiary sediments in Wayne County, and the Beaver anticline continues to the northeast flank of the Navajo dome where it dies out. The Kaiparowits downwarp borders the Circle Cliffs anticline on the west, and the Henry Mountains border it on the east. The beds of the Circle Cliffs anticlinal upward dip gently three or four degrees on the west and dip steeply 40 to 75 degrees on the east where it passes into, and is coincident with, the Waterpocket Fold.* The anticlinal closure is a little more than 1000 feet and the anticlinal plunge to the southeast is one-half to two degrees and to the northwest the plunge is a little greater (Steed, 1954, p. 102).

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* (Fig. 5.)

The Circle Cliffs anticlinal flexure has been breached by erosion, and high Wingate sandstone cliffs circle an erosional basin cut into the soft shales of the Moenkopi formation. A large domal high near the central portion of the basin floor is supported by the resistant Permian sands, which in some places are overlain by the Moenkopi shales and remnants of the resistant Shinarump conglomerate. The Stud Horse Buttes and the Pioneer Mesa are capped by the Triassic Shinarump conglomerate and form part of this domal high.

Faults

All faults in the Circle Cliffs area mapped and studied by the writer are vertical or near vertical. These faults seem to be the result of three different forces acting separately or together. These are: 1) incompetentcy of the formations during uplift, 2) relaxation of the uplift after the epirogenic forces were expended, and 3) by slumping of the weak shales that underlie the massive resistant sandstone formations. Of the three forces postulated to have been the cause of the faulting, the writer found best supporting evidence for slumping due to differential compaction of the underlying shales of the Moenkopi and Chinle formations.

The Horse Canyon fault is a vertical hinge fault with the down-dropped block on the north. The fault, as mapped by the writer, trends N 45° W. The fault as shown on the photogeologic map prepared by the Atomic Energy Commission, curves and trends more northerly. Displacement along the fault varies from 5 feet where it can be measured at the head of Horse Canyon to over 45 feet along its strike. The fault can be seen displacing the Shinarump conglomerate, the Moenkopi formation, and the Chinle formation. No apparent displacement could be found in the Wingate sandstone although a large fracture has developed where the fault would apparently pass. As the fault is traced northwestward along its strike the Shinarump conglomerate can be seen to become very thin and die out, placing the Moenkopi and Chinle formations in contact with each other.

The North Horse Head fault is a vertical fault with the down-dropped block on the south. The fault trends N 61° W and has a measured displacement of 65 feet. It can be seen to displace the Shinarump conglomerate and Moenkopi formations on the southeast and northwest sides of the outlier of Shinarump conglomerate called the Horse Head. From the Horse Head the fault continues northwestward into an area where the Shinarump conglomerate is absent and then back into an area where this formation is again present and can be seen displaced by the fault. Evidence for the fault disappears before reaching the Wingate sandstone cliffs farther north. The fault can be traced for over 10,000 feet northwestward along its strike.

The South Horse Head fault is also a vertical fault with 45 to 60 feet of displacement. The down-dropped block is on the north and the fault trends N 32° W where it can be seen displacing the Shinarump conglomerate just south of the Horse Head. It curves and becomes more northerly northwestward along its strike and can be traced for over 13,000 feet. Remants of the Wingate sandstone are displaced where intersected by the fault. This fault is believed to intersect the north Horse Head fault at some point along its strike. A block of Triassic sediment caught between the north and south Horse Head faults was dropped, producing a grabenlike structure. The faulting is believed due to the incompetentcy of the formations underlying this sunken block. The incompetentcy is shown as a differential compaction of the underlying shales in this area.

The Lamp Stand fault cuts a projecting point of the Shinarump conglomerate just northwest of the Lamp Stand and continues northwestward. It can be seen displacing the Shinarump conglomerate and Moenkopi formation again approximately 3000 feet to the northwest. The fault strikes N 40° W and can be traced for almost 7000 feet along its strike. The downdrop block is on the southwest, and the displacement is a little less than 15 feet.

The North Central Basin faults are shown on the photogeologic map used as a base by the writer and are not known to have been field checked. Two of the North Central Basin faults lie 5000 feet northwest of the Central Butte of the Stud Horse Buttes. These faults are vertical, parallel, and somewhat less than 2000 feet apart. They can be traced for over two miles along their strike which is N 13° W.

A third vertical fault lies 7500 feet due east from the mouth of Horse Canyon. This fault has a strike that varies only a few degrees from north. It can be traced for approximately 5000. The downdropped block is on the east and displacement from all indications is 30 to 40 feet.

At the head of Wolverine Canyon two faults, nearly vertical, show displacement of the Shinarump conglomerate. One parallels Wolverine Canyon, having a strike of N 20° E. It can be traced for more than one mile, showing a measured displacement in some places of 45 + feet. The down drop block is on the east. A canyon has been cut into the Moenkopi formation and partially filled along the almost entire traceable coarse of the fault. A second fault striking N 45° W, which is nearly at right angles to the first, cuts the northerly striking fault near its upper end. The down-dropped block of this fault is on the north. Displacement is small, indicating less than 30 feet of movement. From the mouth of Wolverine Canyon this fault can be traced along its strike for approximately 6000 feet to its northwestern observable extent which is near the mouth of Horse Canyon.

Summary of Geologic History

The Colorado Plateau emerged as a tectonic unit before Cambrian time and was adjacent to the westward lying Cordilleran geosyncline. During Cambrian time shallow seas covered what is now the Colorado plateau region, but in Ordovician and Silurian time the plateau must have been elevated slightly to produce the disconformity that represents Ordovician and Silurian time. Mild deformation began in late Mississippian and early Pennsylvanian time. Deformational forces that began in late Mississippian and early Pennsylvanian continued into the Triassic period. During this period of intermittent deformation of the plateau the Paradox basin formed and was filled, and the Uncompahgre and Zuni ranges were outlined and remained elevated until Triassic time when they were buried. Uplifts during Triassic and Jurassic time are indicated by the unconformities between the Kaibab limestone and the Moenkopi formation, between the Moenkopi formation and the Shinarump conglomerate, and between the Chinle formation and the Wingate sandstone. The major deformation of the Colorado Plateau began in late Cretaceous or early Paleocene or Eocene (the Laramide orogeny) and is represented by the monoclinal flexures, domes, and normal faults. The Circle Cliffs is one of the small monoclinal flexures that resulted from this late Cretaceous, Paleocene, or Eocene Laramide orogeny. During Cenozoic time, salt structures, laccolithic mountains, and lava flows formed on the plateau surface. It is believed that a maximum of 5000 feet of Paleozoic and 9000 feet of Mesozoic sediments were deposited on the Pre-Cambrian basement of the Colorado Plateau.

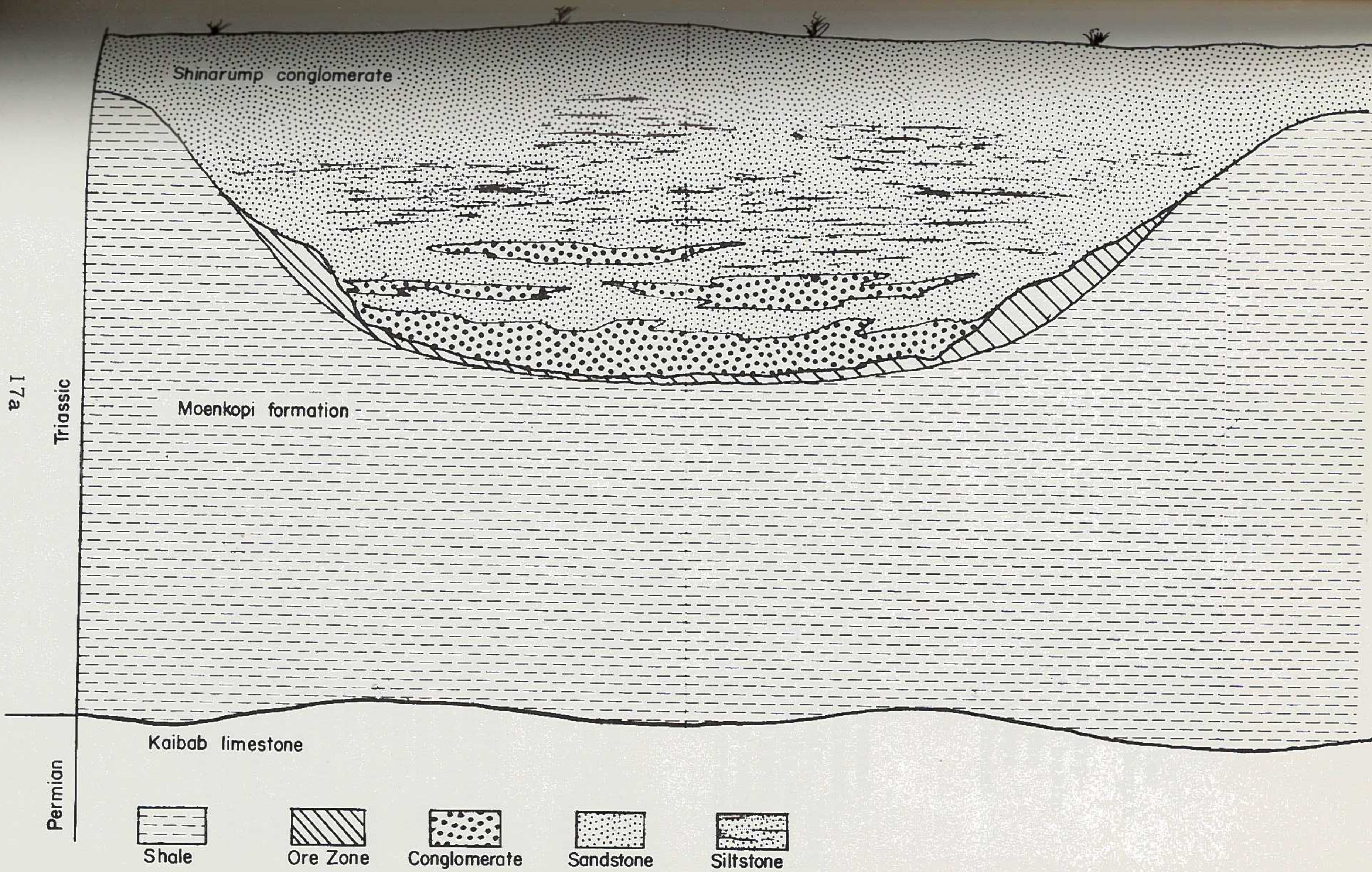

Fig. 1. Schematic cross section of a typical ore-bearing Shinarump channel in the Circle Cliffs area.

CHANNELING

General Statement

Soon after the termination of Moenkopi sedimentation the fluvial streams which deposited the Shinarump conglomerate began incising and filling channels on the Moenkopi surface.* The remnants of Shinarump conglomerate that form an inner escarpment around the basin flood and cap mesas and buttes on the basin floor are all that remain in the Circle Cliffs as evidence of the fluvial nature of the Shinarump conglomerate. These outcrops show the great lithologic variability so characteristic of a fluvial type deposit.

Channel Flow Direction and Size

A great flood plain with major meandering trunk streams, converging and diverging, carrying and depositing sediments, is believed to have covered the entire area of the Circle Cliffs. These streams show a general flow direction to the northwest. In the following paragraphs a description of these stream systems is given regarding their location (with reference to paleostream trend map), size, direction of flow, and as to their junctions with other streams.

Trunk-Type Streams

Three major trunk-type streams appear to have developed on the Moenkopi surface during Mid-Triassic time in the Circle Cliffs; namely, the Stud Horse channel, the McKensie channel, and the Wagon Box Mesa channel.

The Stud Horse Channel is the only one of the trunk-type stream channels that can be traced for any great distance across the area studied and mapped by the writer. Three large streams seem to converge (as shown on the channel direction map) to form the main Stud Horse channel. One of these paleostreams forms the cap for the Pioneer Mesa and shows a flow direction of north-northwest. A second large paleostream having a flow direction of north-northeast, can be seen on the cliffed face of the Shinarump conglomerate at the head of Wolverine Canyon. A third but somewhat smaller paleostream is located between the two larger ones and has a flow direction of almost north. The Stud Horse channel, so named because it forms the thick resistant cap of the Stud Horse Peaks, has a flow direction along these peaks to the northeast. The channel makes a meander curve upon leaving the Stud Horse Peaks area and changes to a general flow

* (Fig. 1)

direction of northwest with local changes in trend due to small meander curves. This channel forms the eastern escarpment of Shinarump conglomerate of the Circle Cliffs from the Stud Horse Peaks north.

The McKensie channel, although classified as a major trunk stream, converges into the Stud Horse channel approximately two and one-half miles northerly of the Stud Horse Peaks on the east flank of the Circle Cliffs. It has a general flow direction just north of west where it joins the Stud Horse channel.

The Wagon Box Mesa Paleochannel flows toward the Stud Horse Peaks area from Wagon Box Mesa. From flow trend indications this third trunk-type channel may converge into the Stud Horse channel. There are, however, no other remnants left of this channel.

The trunk-type Shinarump channels are usually over a mile in width and range in thickness from 100 feet to over 245 feet. These large channels are deeply incised into the Moenkopi sediments and have rather sharp channel boundaries. The great thickness of these large channels does not mean that the scour necessarily was 100 or 245 feet into the Moenkopi formation, for these trunk-type channels meandered, building levees and filling inter-channel floodplain areas almost continuously due to the flooding conditions.

The lithologic variation in these trunk-type channels is attributed to, 1) nearness to the source area, 2) the velocity of flow, and 3) position in the channel that sedimentation took place. The writer found only one location in the Circle Cliffs where a rather large thickness of true conglomerate had been deposited. This lies at the junction of the Stud Horse channel and the McKensie channel on the east side of the Circle Cliffs, where a well rounded quartzite and chert pebble conglomerate was observed, which in some places was over 20 feet thick. The matrix was very coarse to grit size quartz grains and contained very little sand, silt, or clay. It is believed that the source area for the sediments was to the southeast, and because of the nearness of the McKensie channel to the source area, its velocity was sufficient to carry the quartz pebbles. At the junction where it joined the meandering slow moving Stud Horse channel its velocity was diminished enough to unload the coarse sand, grit, and pebble sized sediments.

At many other locations along the major trunk streams, and even along the smaller streams, a basal quartz pebble conglomerate was found, but it was only a few inches to a few feet thick and mixed with silt and mud of the Moenkopi formation. In the large channels just above the basal conglomerate a soft friable coarse to fine grained sand is found, which grades upward into a siltstone of varying thickness. This in turn grades upward into a usually compact, fine grained sand. This upward gradation is not constant along the large channels, and changes in the relative amounts of silt and sand is everywhere present. The sand and silt at the flanks of these large channels mix and lens into each other, into the Moenkopi shales, and into the "Flood Plain" type channels.

Converging and Diverging Streams

Channels intermediate in size between the large trunk type and the small gullied type are common in the Circle Cliffs. These channels can be quite large and similar in lithologic character to the trunk-type channels, or they can be small and similar in lithologic character to the flood plain type channels. These converging and diverging streams are usually less than 100 feet thick and one-half to one mile in width. The larger channels usually show well outlined channel boundaries, upward gradation and lensing of the channel sand and silt, and lensing and mixing of the channel sand and silt with the Moenkopi formation. Small levees that developed along these intermediate channels also add to their thickness. These channels are similar to the large trunk-type channels, and grade into the sand, silt, and claystone of the floodplain type channel. During the final stages in the filling of these channels the streams seemed to have become smaller, and scours developed and were filled as the smaller streams migrated back and forth across the large, almost filled channel bed.

The smaller converging and diverging stream channels show a great difference in lithologic character when compared to the larger ones. The channel form and outline is also strikingly different and shows more similarity to the flood plain type. These small channels usually show one or more scours cutting into their flanks, but at different levels and usually offset. The first scour bottoms in the Moenkopi formation, but its flanks are usually cut by future scours whose left or right flanks grade into the Moenkopi formation or into the floodplain type channels. These scours show erratic and irregular lensing, the lenses being small and discontinuous. Channel lithology is different and closely resembles that of the floodplain type in that over half of the channel fill is fine silt and claystone. The channels lense into each other and into the shales of the Moenkopi formation. Weathering leaves the more resistant sand lenses projecting due to the removal of the silts and clays. These channels show more mixing and lensing of the channel sediments with the slumped or scoured Moenkopi muds than do the other types.

Paleostreams in the Circle Cliffs area have a general flow direction of northwest, but some flow west and even north and northeast. The streams seem to flow northwestward from the major trunk stream of the Stud Horse Peaks, and because of the stripped central basin only general conclusions can be reached. At the mouth of Wolverine Canyon there are three converging streams; one shows a flow direction at right angles to the mouth of Wolverine Canyon to the northwest, a second and third, seemingly smaller diverging streams of the first, have a flow direction of northeast with a curve back to the northwest into Horse Canyon where the flow direction becomes almost west. In Horse Canyon three more diverging streams were traced, one traced from Wolverine Canyon into Horse Canyon, a second coming from the east and flowing west into Horse Canyon where it apexes with the Wolverine Canyon flow trend, and a third coming from the northeast flowing southwest and west as it too, apexes into the other two flow trends in Horse Canyon. Approximately two miles north of Horse Canyon, just beyond a pinchout area in the Shinarump conglomerate, is a stream which shows northwest flow trends; and approximately one mile farther north a second stream with flow trends of northwest is also found. Flowing at right angles to the mouth of Long Canyon is a stream course with a flow trending approximately north. This channel continues to the Horse Head where it separates into two minor streams, one that curves sharply and flows west and another that continues northwest for less than a mile, then becomes almost west in flow trend. The left flank of the channel trend that continues from Long Canyon to the Horse Head is bounded by a Shinarump conglomerate pinchout on the west. At the north end of the Circle Cliffs two more stream channel trends are seen with a flow direction north of west.

A few diverging and converging streams within the Circle Cliffs are quite small and show a gullied form. A good example would be the Steam Boat channel. These small channels show well defined boundaries, and a sharp contact is present between the Moenkopi formation and the channel sands. The channel sands and silts do not seem to interlense into the Moenkopi muds, although slumping of the Moenkopi muds into the channel results in pods of intermixed sand, silt, and mud. The thickness of this channel, whose form is like that of a gully, depends upon how deeply it was incised into the Moenkopi formation before being filled with the channel sands and silts as compared to the trunk type channel, whose thickness depends to some extent on the heighth of the levees it formed. No basal conglomerate or soft friable coarse to fine sand was found in this channel. The channel contained only interlensing compact sand and silt.

Flood Plain Type

The "flood plain" type channels, into which all other types of channels grade, are regarded as the area where flooding waters from the main channels covered a depositional plain with a thin sheet of sediment laden water. Small, broad, and shallow scours were developed on this interchannel flood plain. These flood plain type channels cover great, broad, areas ranging from one mile to several miles wide, upon which are deposited fine sand, silt, and claystone, and sometimes even the coarser sand. The channel lithology changes from place to place, but the channel sands and siltstones are usually separated by broad lenses of blue to green claystone. The thickness of these flood plain deposits range from 15 to 60 feet in the Circle Cliffs area.

Methods of Identification of Paleostreams

The paleostreams and their flow direction can be identified by two major field observation criteria. These are: 1) observation of channel outlines and thicknesses, and 2) observation of primary sedimentary structures such as cross-bedding and ripple marks. To determine a channel and its direction of flow, both of the two field observation guides or principles must be used.

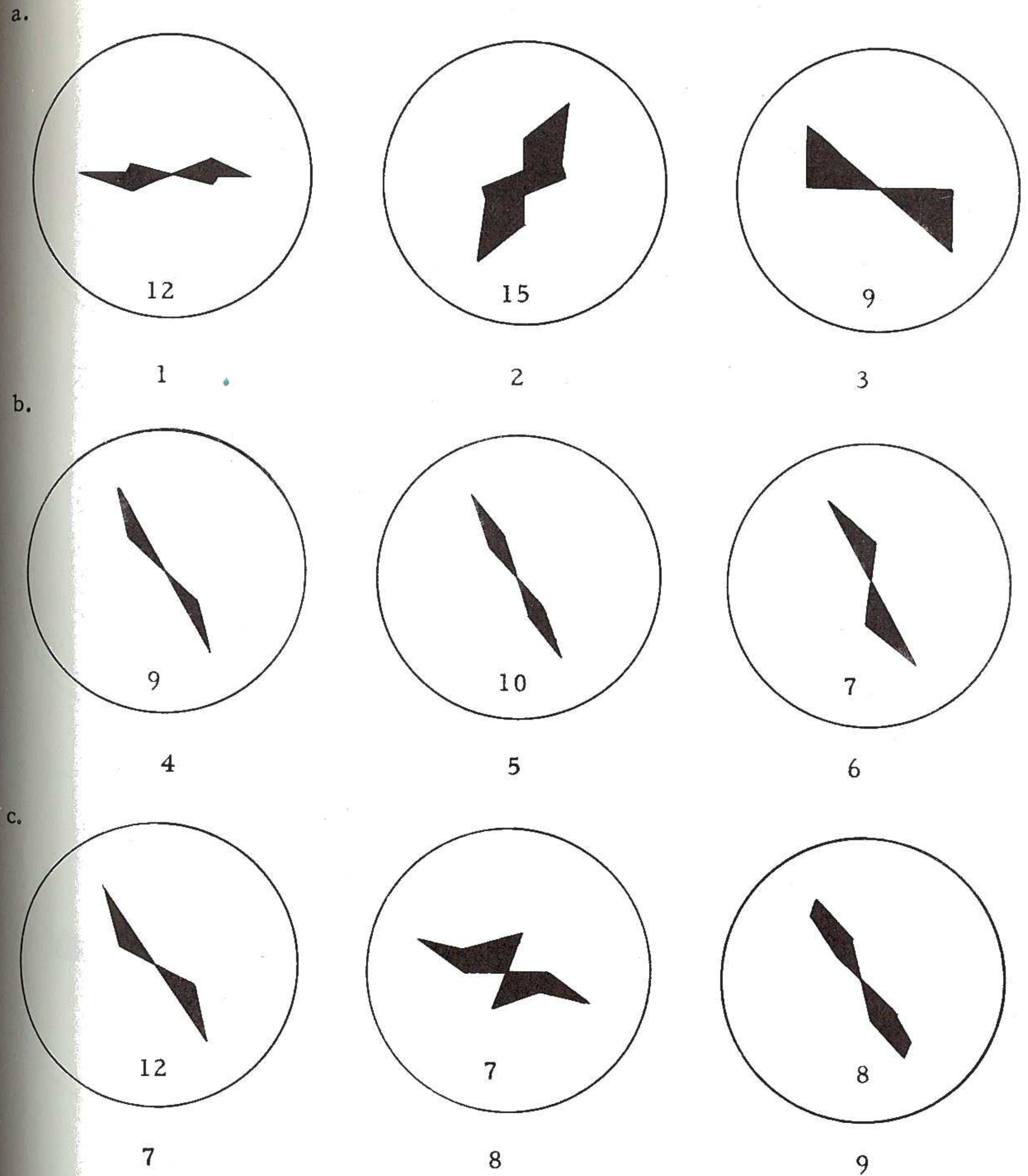

Fig. 2. - Analyses of the channel trends of (a) the Horse Canyon area, (b) the Pioneer Mesa area, and (c) the Horse Head area. The number in each circle represents the number of averaged flow direction readings used in determination of channel trends. The number under each circle corresponds with map number of channel trend area.

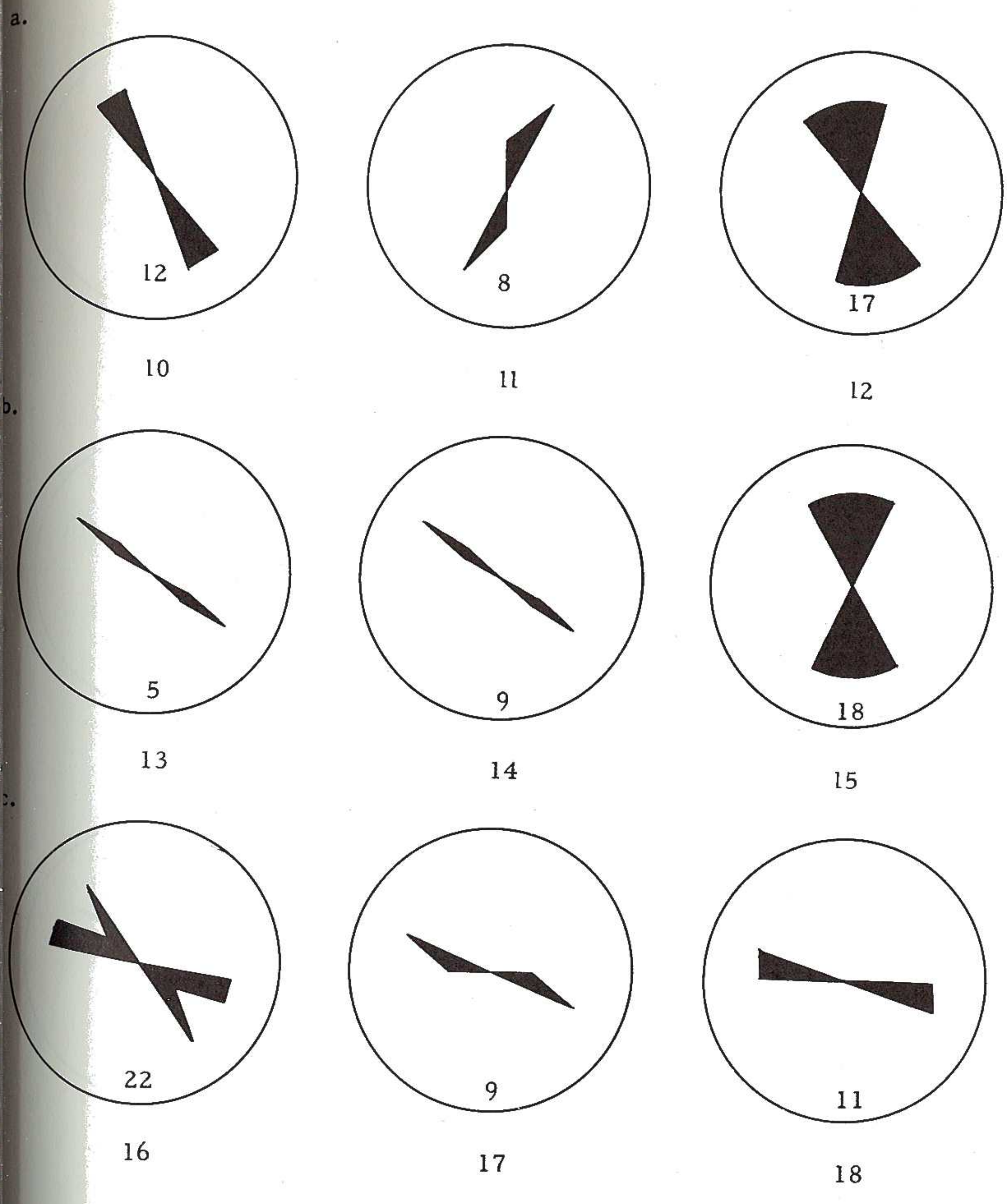

Fig. 3. - Analyses of the channel trends of (a) Wolverine Canyon area,) Blue Goose Mine area north to the Horse Head, and (c) area north of e Horse Head. The number in each circle represents the number of aver- ;ed flow direction readings used in determination of channel trends. The imber under each circle corresponds with map number of channel trend ea.

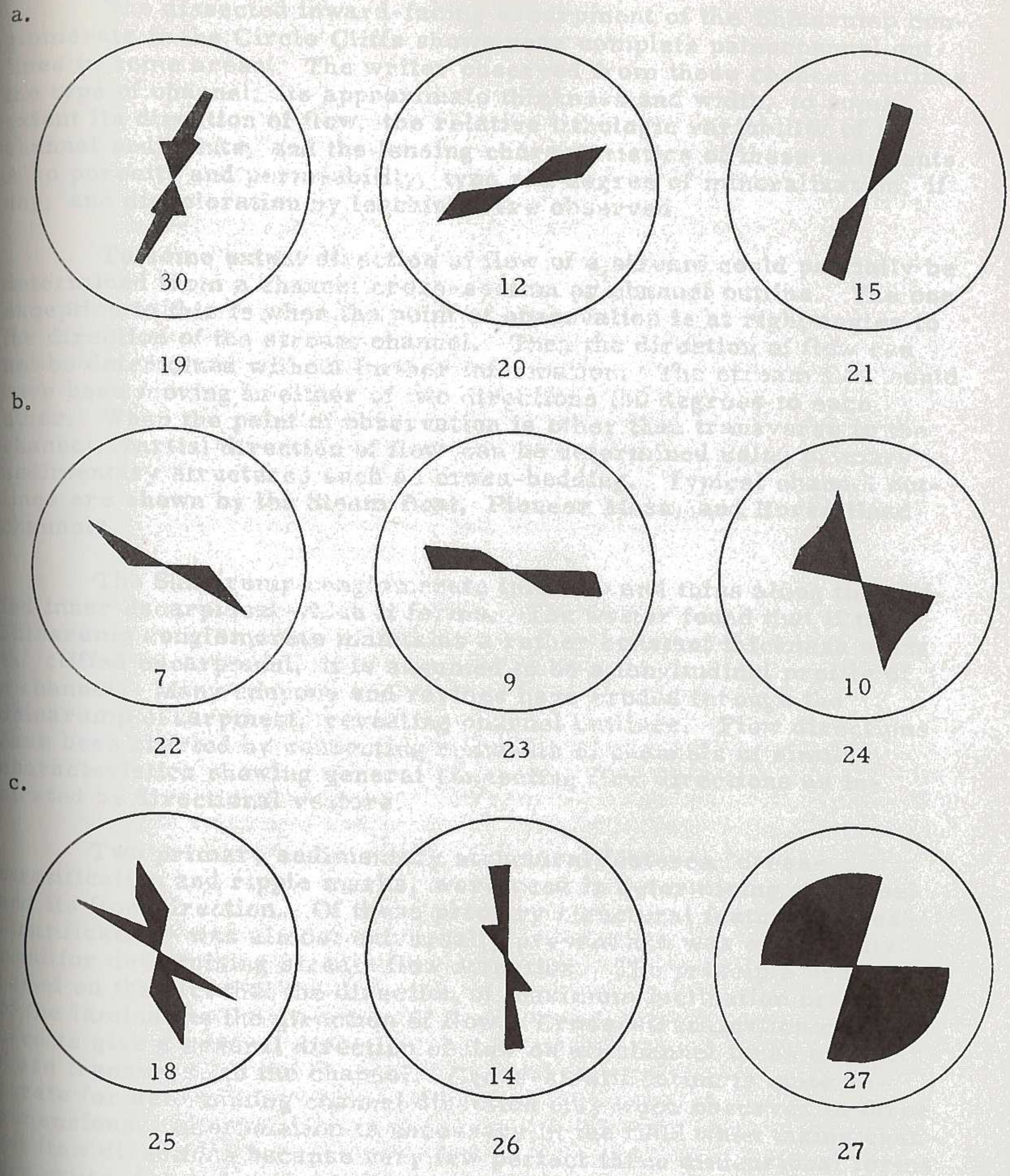

Fig. 4. - analyses of the channel trends of (a) Stud Horse Peaks area, (b) McKenzie channel area, and (c) North McKenzie Channel area. The number in each circle represents the number of averaged flow direction readings used in determination of channel trends. The number under each circle corresponds with map number of channel trend area.

The dissected inward-facing escarpment of the Shinarump conglomerate in the Circle Cliffs shows near complete paleochannel outlines in some areas. The writer observed from these channel outlines the type of channel, its approximate thickness and width, to some extent its direction of flow, the relative lithologic variability of the channel sediments, and the lensing characteristics of these sediments. Also porosity and permeability, type and degree of mineralization, if any, and discoloration by leaching were observed.

To some extent direction of flow of a stream could partially be determined from a channel cross-section or channel outline. The one exception to this is when the point of observation is at right angles to the direction of the stream channel. Then the direction of flow can not be determined without further information. The stream flow could have been moving in either of two directions 180 degrees to each other. When the point of observation is other than transverse to the channel, partial direction of flow can be determined using primary sedimentary structures such as cross-bedding. Typical channel outlines are shown by the Steam Boat, Pioneer Mesa, and Horse Head channels.

The Shinarump conglomerate thickens and thins along the cliffed inner escarpment which it forms. The writer found that if the Shinarump conglomerate maintains a rather constant thickness along the cliffed escarpment, it is assumed to be a longitudinal profile of a channel. Many canyons and ravines have eroded through the Shinarump escarpment, revealing channel outlines. Flow directions have been charted by connecting remnants of channels of similar characteristics showing general connecting flow directions as indicated by directional vectors.

Two primary sedimentary structural features, cross-stratification and ripple marks, were used in determining a channel and its flow direction. Of these primary structural features cross-stratification* was almost universally present and was extensively used for determining stream flow direction. The principle use is based on the fact that the direction of maximum inclination or dip of the laminae is the direction of flow. Cross-stratification can be used to give a general direction of flow on all channel faces except those transverse to the channel. Cross-stratification is quite accurate for determining channel direction only when observed in three dimensions. Interpolation is necessary in the field when taking channel flow directions because very few perfect three dimensional forms are exposed.

Cross-bedding is very useful in determining direction of stream flow. The writer found that in the Circle Cliffs area the best and most accurate method was by taking averages of many flow direction readings across and along the channel. These averages were

* (Fig 7 & 8)

then plotted and a directional vector was drawn.* Restriction of flow direction readings to the major channel course gave less divergency to individual readings. The channel flanks or edges gave flow directions divergent to each other and to the major channel course. Divergent current directions were also noted in the main channel course and those showing great directional difference were eliminated from average calculations of the stream flow direction. The several differing factors which attributed to the divergency of the cross-bedding within the major channel course are: 1) blocks or restrictions in the main channel course, 2) intersections with other channels, 3) undercutting, causing slumping restriction on channel bends or turns, and 4) small or minor structural displacements. Current ripple marks are formed by passage of a current of water over a surface of loose granular particles. Current ripples show asymetrical profiles with a short, steep down stream slope and a long gentle upst ream slope. It can thus be determined from these asymmetric profiles the direction of stream flow. It must be known whether or not there has been overturning if the flow determination is to be accurate.

Source of Sediments and Environmental Conditions of Deposition

During Mid-Triassic a broad flood plain developed on the Moenkopi surface. The incised channels that developed on the flood plain surface contain the greater amount of coarse, clean, channel sand and siltstone that show well developed cross-stratification. The channel stream and flood plain waters of the fluvial Shinarump conglomerate had a general flow direction to the northwest with a source then lying to the southeast, as indicated by the cross-stratification, ripple marks, coarseness of sediment, stream patterns, etc. The highland which was the source of sediments is thought to have been the then existent mountainous regions of the southern Ancestral Rockies and Zuni Mountains.

The environmental conditions of deposition for the Shinarump conglomerate were on a channeled flood plain under arid or semi-arid conditions. As seen today in arid to semi-arid climates the vegetation is more or less restricted to areas along the stream channels. This is thought to have been the case during deposition of the Shinarump conclomerate as shown by its channel lenses of wood fragments and by its log jams, which were washed into the channels by the erosive cutting of the flooding waters or brought in by the streams from other areas. Since the flood plain was cut by channels an interlensing and mixing of channel sand, silt, and claystone is common, whereas if the flood plain had not been cut with channels, deposits of silt and finer fractions would be recognized. The proportion of sand, silt, and clay, and local conglomerate, their mixing, and their interlensing depends upon the size of the channel and the time interval or duration of the channel before filling or destruction. The smaller channels are characterized by their fine to medium sands and silts with little or no clay, lack of a lower coarse sand fraction, rather sharp incised channel outline, and very small or

* Figures 2, 3, and 4 show an analyses of these vector channel trends.

non-existant flanking levies. During the aggradational period of the larger stream channels, three characteristic types of sediments were deposited. The basal depostis consist of coarse, friable sand, which is overlain by a middle unit of medium grained sands and siltstones. The upper unit consists of finer sands and silts, which grade into the fine sands, silts, and muds of the flood plain.

URANIUM MINERALIZATION WITHIN THE CIRCLE CLIFFS

General Statement

The Circle Cliffs has been one of the areas within the Colorado Plateau that has brought about much disappointment as a producer of commercial uranium ores. The Shinarump conglomerate and Chinle formation are the sedimentary deposits showing uranium mineralization. One horizon within the Chinle formation contains great numbers of petrified tree trunks and chips, constituting petrified forests in local areas. Uranium minerals seem to be confined to a few of these petrified trees and fragments within this formation. The uranium minerals occur as coatings on the outer edge of the petrified wood and as fillings within cracks. The Shinarump conglomerate was found to be mineralized locally along its lower contact and within its paleo-stream channels, and is more mineralized than the Chinle formation.

Occurrence

The uranium occurrences found and studied within the Circle Cliffs show very similar environments. With few exceptions these occurrences are in channels, particularly on the flank within the basal unit of the Shinarump conglomerate, and usually within sand lenses or within the sands mixed with muds near the channel boundary. On occasion, the uranium is found in mudstone at the contact with the Moenkopi formation. All occurrences show bleaching or discoloration of the Moenkopi formation at the contact and near the mineralized area. The uranium mineralized areas are peculiar in that nearly all occur at the flanks of the channels or within the lower portion or bottom of the channels. These mineralized areas or zones are elongate and convex, and are near that portion of the stream bed that would have formed the "bank" of the first incised river cut into the Moenkopi formation.

Mineralogy

The uranium minerals present are torbernite, uraninite, autunite, with minor amounts of uranophane and carnotite. Associated with the uranium minerals are copper minerals such as azurite, malachite, chalcopyrite, and chrysocola. Other minerals present are pyrite, arsenophyrite, and gypsum. Large quantities of carbonized wood fragments and some asphaltite are present. Many of the uranium prospects contain abundant wood fragments in the mineralized area, but this was not universal in all prospects and mines. The mineralized trash zones contain uranium minerals in the pitchy, carbonized, or silicified wood. It occurs as selective replacement of portions of the wood cell walls. Pyrite also fills the wood cells or occurs as crystal coatings between growth layers of the wood fragments. However in the Black Widow and Blue Goose mines it was found that uranium minerals were not associated with the trash zone, although it was present in the channel. The writer believes that it is not necessary for trash wood material to be present for accumulation of uranium minerals, but that under favorable conditions uranium minerals in contact with trash zones will be dropped or precipitated from solution.

There are several conditions which must prevail before the uranium minerals can go into solution, be deposited, and be restrained from further solution and removal. First, uranium is very soluable and can be taken into solution by very weak acids. Once taken into solution the uranium can be transported only if there is sufficient porosity and permeability within the host rock for the uranium bearing solution (in most cases ground water) to pass freely. Second, there must be present a controlled transporting medium (channels). Third, a trap either stratigraphic, structural, or a combination of the two, must be present within the channel to stop or precipitate and hold from further solution and removal these uranium minerals. Fourth, and of great importance, is the need for a continuous supply of uranium bearing solutions for concentration in the trap area.

Stratigraphic Controls

The action of aggradational streams constantly changing flow patterns caused cutting and undercutting of the Moenkopi banks, resulting in slumping and mixing of the channel sands and Moenkopi muds. These areas of mixed sand and mud form elongated pods which constitute stratigraphic traps. These pods occur on the flanks or near the base of the channel and may be mineralized. Lensing and mixing of the Moenkopi mud with channel sands form nearly all of the known stratigraphic traps. This mixing and lensing is found on the flanks of the channel, at its base, or within a low on the channel bed. Also it occurs at the pinchout of the Shinarump into the Moenkopi or Chinle formations, at a turn of the channel, or at its intersections with or into other channels. As a rule these stratigraphic traps formed of mixed mud and sand contain abundant trash wood material partially replaced with uranium minerals.

Structural Controls

Structural controls observed in the Circle Cliffs area are faults, slumps, and channels. Faults displaced the channel sands of the Shinarump conglomerate against the Chinle and Moenkopi muds, thus producing a structural trap by damming (due to the faulting) the uranium bearing ground water solutions circulating through the Shinarump channel sands. In two cases studied, faults are seen to displace the Shinarump channel sands against the Moenkopi and Chinle muds; but in both cases determining concentration of uranium minerals would require drilling.

A slump block of Moenkopi (?) sand containing mud galls slumped during the final stages of Moenkopi deposition into the

Moenkopi muds. Ground water uranium bearing solutions flowing through the Shinarump conglomerate found passage through this zone of weakness down into the slumped Moenkopi sand block. The uranium solutions in part mineralized the Moenkopi sand and in part followed the bedding planes of the Moenkopi muds depositing uranium minerals along in these bedding planes.

Channels of the Shinarump conglomerate have been described in detail within the preceeding unit of this paper, but here paleo-channels will again be briefly mentioned as constituting structural traps for the concentration of uranium minerals. The permeable sands of the Shinarump conglomerate deposited against muds of the Moenkopi formation in an incised channel on the Moenkopi surface create a structural trap by confining ground water solutions that will pass through this formation.

Genesis of Uranium Mineralization

There are two uranium theories which prevail regarding the origin of uranium. These are: 1) the hydrothermal theory, and 2) the concentration by ground waters. Within the Circle Cliffs there is little evidence for hydrothermal activity, and uranium minerals found and studied by the writer were all secondary. It is therefore assumed by the writer that the uranium minerals were carried into the area by circulating ground waters. Due to the fact that nearly all rocks contain around .0001 to .0003% uranium, ground waters could have leached and concentrated this minute fraction of uranium from a large surface area and transported it into the Circle Cliffs area. The uranium minerals could have been leached from primary or other concentrated secondary deposits of uranium and carried into the Circle Cliffs area. The writer believes that the uranium minerals carried by the channel solutions or waters were leached from such primary and secondary deposits and disseminations. It is also believed by the writer that hydrothermal solutions entering the circulating ground waters added to them concentrations of uranium minerals.

Possible Sources of Uranium Bearing Solutions

The streams of the fluvial Shinarump conglomerate flowed from the southeast to the northwest. Thus a possible source of the uranium minerals lay to the southeast. Several highlands bordered the Circle Cliffs area during the interval between Post-Triassic Shinarump conglomerate and Pre-Late-Cretaceous, Paleocene, and Eocene time. These highlands were possibly the source of the uranium minerals carried from them in ground water solutions.

The writer examined and explored many prospects within the Circle Cliffs area and was present on many occasions when drilling operations were under way. At all prospects and at all drill sites where uranium minerals were found no large ore bodies were discovered to the knowledge of the writer. It would seem reasonable to conclude that a sufficient amount of uranium minerals was supplied within the solution channelways at every location where uranium minerals were found, but on each occasion the trap formed was insufficient to localize the necessary amount to form an ore body of economic size.

The presence of such a large number of uranium-mineralized areas within the channels of the Circle Cliffs, and the fact that each locality was mineralized where some form of trap was found to be present within the channel, leads the writer to believe that the Circle Cliffs is still a very likely area for large production of uranium ore.

URANIUM MINES AND PROSPECTS

In all areas of the Colorado Plateau producing uranium from the Shinarump conglomerate channeling seems to be the major ore control. Only on rare occasions are ore bodies found not associated with channels. It is because of this association of uranium ore with the Shinarump conglomerate channels that many thousands of dollars have been spent in search of uranium within the Circle Cliffs. There are many uranium prospects in the base of the Shinarump channels, and in the upper few feet of the Moenkopi formation. Of all prospects studied, only a few seem worthy of mention and description.

Horse Head Mine

The Horse Head channel consists of three scours at different levels.* The first scour, which bottoms in the Moenkopi formation, has been prospected with a 40 foot adit. The contact of the Moenkopi and Shinarump channel sands is just above the floor of the adit. The Moenkopi muds are leached for approximately two feet below the upper contact. Channel sands above the contact for 2 to 3 feet contain a high percentage of Moenkopi mud galls and a few small lenses of wood fragments. Above this zone is a trash zone lensing from inches to 3 or more feet thick. The lower part of this trash zone contains pyrite in the wood fragments and a little in the sand. The upper part of the trash zone is oxidized and leached and the channel sands are iron stained. Uranium minerals present are uraninite, torbernite and autunite. The Horse Head mine is located immediately north of a projecting part of the Shinarump escarpment called the Horse Head.

Blue Goose Mine

The Blue Goose mine is located approximately one mile south of the mouth of Long Canyon on a northwest trending paleochannel. A 75 foot drift has been made along the partially mineralized zone at the base of the Shinarump channel. The mineralized zone lies at the base of the lower of three "rolls" or scours on or near the channel flank. The lower scour is at the contact with the area of leached Moenkopi mud. The two other scours are in a basal Shinarump mudstone.** The mineralized zone is approximately 75 feet along the lower scour, and is present within a narrow contact zone of mixed sand, silt, and Moenkopi mud. The uranium minerals present are autunite and torbernite. Associated minerals are azurite,

* (Fig. 9)

** (Fig. 10)

malachite, and gypsum which occur locally along the contact area. Above this mineralized zone is a 12 inch zone of medium grained mud-galled sand which grades into a zone of oxidized and leached iron stained, friable, and coarse, quartz sand. This sand grades upward into fine sand and silt. Wood fragment lenses occur throughout the entire vertical extent of the channel with the exception of the mineral-ized zone.

Lone B Mine

The Lone B mine is located in Wolvering Canyon on a north-east trending channel that continues into Horse Canyon. The mine is in a small canyon formed by a fault trending nearly parallel to the channel flow direction. The upthrown side of the fault has exposed the channel base, and it is here two 40 to 50 foot drifts have been developed. T e uranium minerals are in an 8 to 12 inch trash zone at the contact with the leached Moenkopi muds. The trash zone is composed of coarse channel sand, mud, and wood fragments lenses which are almost completely replaced by pyrite and some uranium minerals. An 18 to 24 inch reworked and leached Moenkopi mud zone lies at the lower contact with the trash zone. This mud contains wood fragment lenses, abundant pyrite seams, and individual pyrite crystals. The unoxidized and non-leached trash zone grades into a leached and oxidized, iron stained, coarse sand zone containing wood fragment lenses. The coarse sand and wood fragments contain some pyrite. The wood fragments are present in a sooty-carbon and hard pitchy form with pyrite coatings, and pyrite and uranium fillings and replacements. The coarse iron stained sands grade upwards into fine sands and silts.

Acme Mine

The Acme mine is located at the mouth of Horse Canyon on the right flank of a westward flowing channel. There are two drifts 30 feet long, at the channel base. The uranium mineralized zone is within the upper few inches of leached Moenkopi muds and the lower few inches of a contact trash zone which consists of intermixed mud, coarse friable channel sand, and lensing carbonized and pitchy wood fragments. The uranium minerals are autunite and torbernite, which occur as replacements of the sand and mud cement, as replace-ments of the cells and cell walls of the wood fragments, and as a coating on the leached muds of the Moenkopi formation. Other min-erals are azurite, malachite, pyrite and gypsum. The copper minerals occur as dissiminations of nearly pure azurite and mala-hite, coatings on the bedding planes of the leached Moenkopi muds, oloration within and on the gypsum, and as a coating on the quartz rains of the channel sands. The pyrite occurs as a partial replace-ent of the wood fragments. Gypsum is found as small parallel and itersecting stingers in the mineralized channel sands and along the oenkopi bedding planes in the leached area. Above this mineralized one is a one to three foot zone of friable medium to fine grained sand d siltstone, light to dark brown in color. This grades into an eight twelve inch leached and oxidized iron stained trash zone, which ades into the finer sands and silts of the channel deposits.

Black Widow Mine

The Black Widow mine lies on the Stud Horse channel approximately half way between Horse and Wolverine canyons. A few hundred tons of ore have been shipped from this mine. The mine is within a leached zone of the Moenkopi at the base of a 50 foot Shinarump Cliff. This zone is 100 feet long and over 20 feet thick. Uranium and associated minerals are within a slumped block of the Moenkopi formation consisting of reworked asphaltic mud, sand, and channel gravel. They are also found to be disseminated out from the slumped block along the bedding planes of the leached Moenkopi mud. The uranium minerals present are uraninite, torbernite autunite. Uraninite occurs within the slumped block in association with the asphaltite, while torbernite and autunite are disseminated into the Moenkopi muds. Other minerals associated with the uranium minerals are azurite, malachite, and gypsum. Copper minerals occur as coatings along the bedding planes of the leached Moenkopi muds and as coating on, and coloration within gypsum stringers. The gypsum here occurs as bedding plane stringers 1/4 to 3/4 inch thick in the leached Moenkopi muds.

Steam Boat Mine

The Steam Boat mine lies just north of the Horse Head mine on a northwest trending "gulley form" diverging channel. A cross-sectional area of the channel is exposed and there is a small 20 foot adit into its face. The adit is low on the left flank in a mixed channel sand and mud zone. This zone of mixed sand and mud contains uranium minerals and forms a small mineralized pod. The coarse sands on the right flank of this channel are mineralized a few hundred feet northwest of the adit along the channel trend. The uranium minerals present are torbernite and autunite. Associated minerals are azurite, malachite, and gypsum. The copper minerals occur as an oxide stain in the reworked sand and mud zone. Gypsum occurs as small stringers and disseminations in the leached zone of the Moenkopi muds and in the reworked zone. There is little wood trash within this channel.

Stud Horse Mine

The Stud Horse mine is located on the west side of the central peak of the Stud Horse peak. Three adits approximately 100 feet deep cut the channel at right angles to the direction of channel flow. Uranium minerals occur within a blackish gray silty mudstone which contains abundant carbonaceous material, and which forms a lens shaped pod which pinches out as the adit extends to its face. On the weathered channel face the ore occurs as secondary minerals, torbernite and autunite. Within the adits the uranium ore is uraninite. Above the ore zone is an exceptional inch thick blanket-like pyrite lens which contains some chalcopyrite. This pyrite blanket thickens towards the face of all adits.

Rocky Mountain Mine

The Rocky Mountain mine is located near the Muley Twist Canyon on the Water Pocket monocline. There are three incline shafts approximately 500 feet deep. The mine is on a northwest trending channel. This mine has produced many hundreds of tons of uranium ore. This ore occurred on the weathered cliff face as torbernite, autunite, and other minor secondary uranium minerals. Away from this weathered face the ore occurs as uraninite in an asphaltic carbonaceous silty mudstone. Associated with uranium minerals are chalcopyrite, pyrite, arsenopyrite, and gypsum.

CONCLUSIONS

The fluvial Shinarump channels within the Circle Cliffs are well developed as determined by observation of outcrops. Three types of channels can readily be distinguished. These are: (1) Stream Trunk-type, 60 to 245+ feet thick and from one-half to one mile wide; (2) Converging and diverging type, 60 to 100 feet thick and 500 feet to one-half mile wide; and (3) Flood plain type, 15 to 60 feet thick and over one mile wide. The type channels are quite large and show channeling within channels.

The streams flowing across the Shinarump flood plain had a general flow direction of northwest to west. These streams were aggrading and developed a diverging-converging system showing three remnants of major trunk streams.

The variation in size from fine mud to pebble size of the fluvial Shinarump channel deposits is believed to be the result of differential velocities of the aggrading streams, the size and form of these streams, and their nearness to the source area. The dominant channel lithology of the Shinarump deposits is coarse to fine channel sand, silt, and claystone, with local, true, basal quartz pebble conglomerate.

During the mid-Triassic period highlands were present to the south and east of the Circle Cliffs area, and are believed to be the source of the fluvial Shinarump sediments.

Faulting within the Circle Cliffs is very minor. The faults show small vertical displacements and are not of great length. The faults are believed due to differential compaction and slumping of the underlying incompetent shales. The above assumption is based on three facts. These are: (1) the fault contacts cannot be traced, in most cases, more than a few feet into the underlying shales, (2) the faults are associated in almost every instance with channels (the faults being located on or near the channel boundary), and (3) the faults are vertical and of small displacement.

Concentrated uranium minerals occur with few exceptions within the Triassic Shinarump conglomerate channels. The exceptions are small mineralized areas in and around petrified logs of the Chinle formation. In most occurances, the uranium minerals are found within the basal unit of the channel deposits, and usually within lens shaped pods of mixed channel sand and Moenkopi mud that are found at or near the contact of the Moenkopi muds and the Shinarump channel sands. The Moenkopi muds, into which the channels are scoured, generally show a thin, uranium soaked mud at the contact with the fluvial Shinarump channel deposit. Without exception the Moenkopi muds are discolored or bleached when associated with channel deposits containing concentrated uranium minerals.

Although carbonacious materials were found present in the majority of mineralized areas, its association is not essential for uranium mineral concentration. Minerals found consistently associated with the uranium are pyrite, gypsum, copper sulfides and copper carbonates. In many areas friable rust laden, iron stained channel sand zones remain as evidence of pyrite lenses. Gypsum, although seemingly not important to the uranium mineralization is present at all mineralized areas in large amounts.

Near surface uranium minerals are secondary torbernite and autunite with minor amounts of uranophane and carnotite. Uraninite is found in areas of little or no leaching. Asphaltic material was found associated with uranium minerals in a few instances.

This problem, although regional in nature, has as its objective a better understanding of the channel deposits and related uranium minerals of the fluvial Shinarump conglomerate in the Circle Cliffs area, Utah.

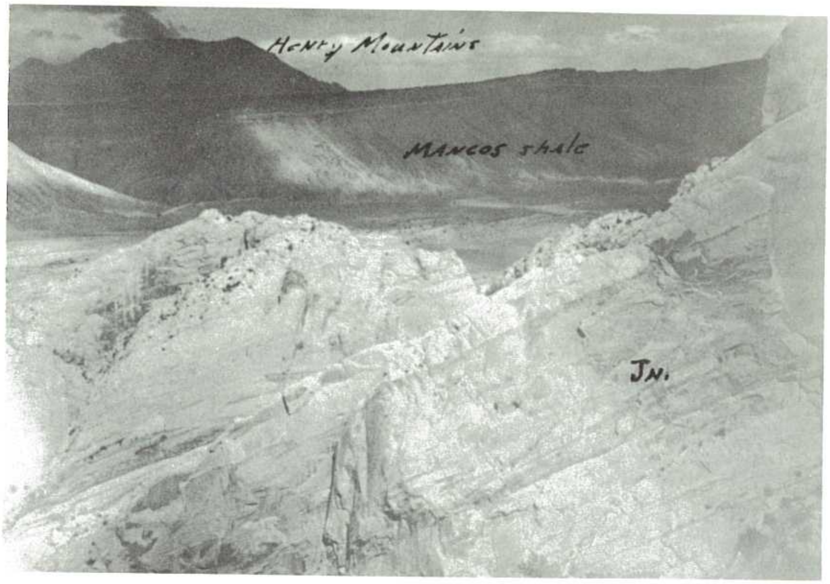

Figure 5. East dipping Navajo sandstone on east flank of the Waterpocket Fold, Circle Cliffs. In the distance are Mancos shale and Henry Mountains.

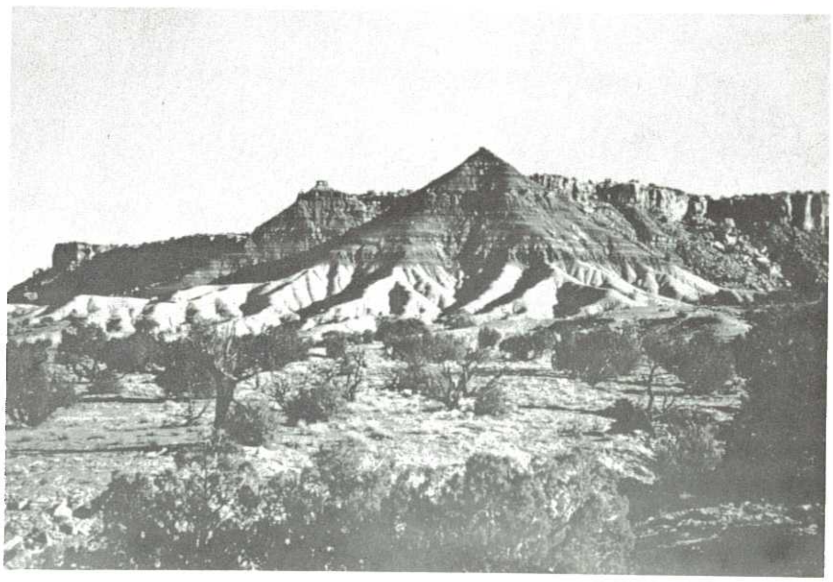

Figure 6. Facies and color changes in Moenkopi formation west side of the Pioneer Mesa.

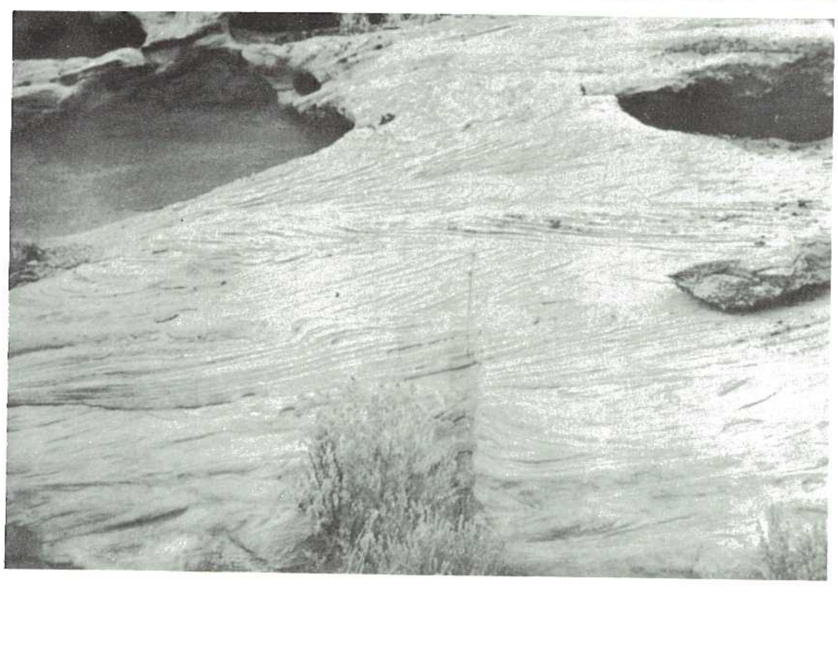

Figure 7. Cross-stratification in Shinarump Conglomerate.

Figure 8. Cross-stratification in Shinarump Conglomerate

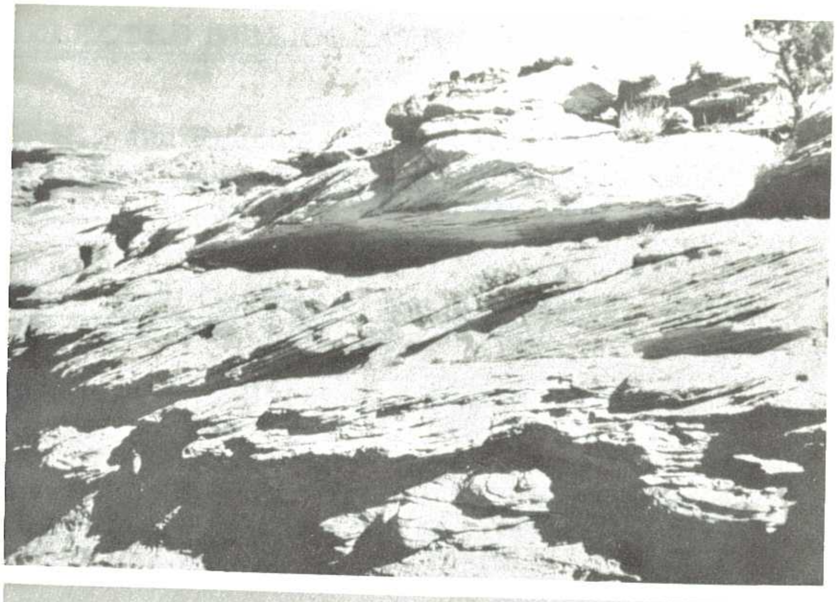

Figure 9. Small distributary type channel showing three levels of scouring, Horse Head channel, at Horse Head mine.

Figure 10. "Roll" of mixed channel sand and mud in Shinarump mudstone, Blue Goose mine area.

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