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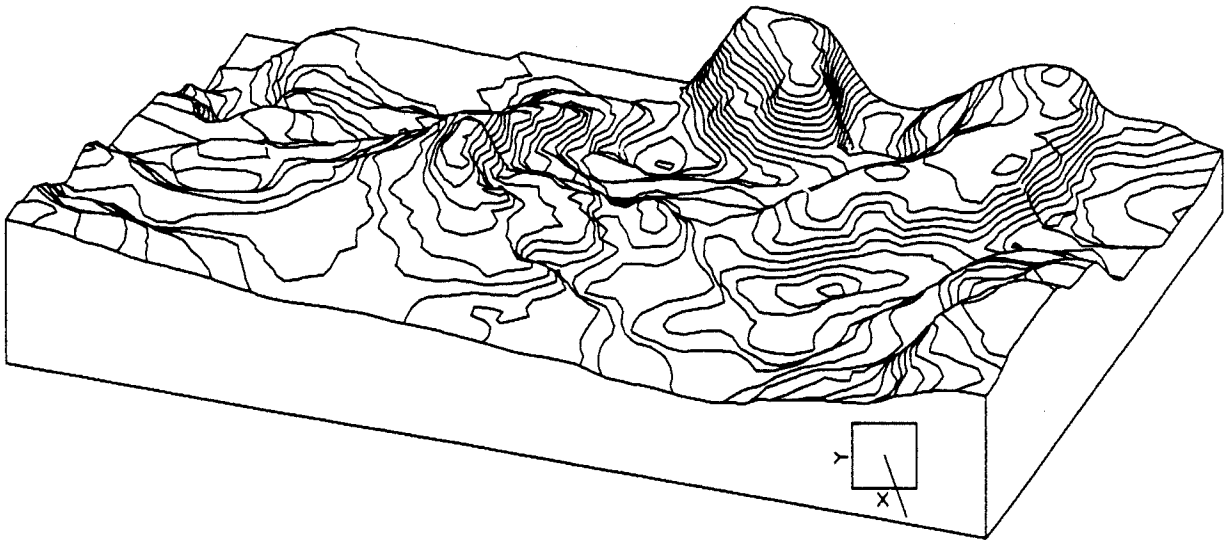
# Distribution of Proterozoic Hydrocarbon Source Rock in Northern Arizona and Southern Utah

Steven L. Rauzi

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Cover figure: Three-dimensional representation of the Precambrian structure and subcrop map, as generated on Surfer. The view direction is to the north-northwest; the view angle is 45°.

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PLATE 1. Precambrian subcrop and structure map, northern Arizona and southern Utah . . . . . in pocket

## ABSTRACT

Good to excellent source rocks are present in the Late Proterozoic Chuar Group of northern Arizona. Chuar mudstones contain up to eight percent total organic carbon, average three percent, and are within the principal oil-generating window. Chuar Group strata accumulated in a basin which extended from north-central Arizona into south-central Utah, and possibly into north-central Utah. The southern margin of the basin was influenced by the Mesa Butte fault in northern Arizona. Its eastern margin was influenced by a north-trending fault on the western flank of Monument uplift. Uplift across the area of the Grand Canyon ended deposition in the marine or lacustrine Chuar basin at about 800 Ma. The Chuar Group subcrop extends northward from outcrops in Grand Canyon into south-central Utah. There, the Tidewater Kaibab Gulch Unit #1 well penetrated 1,128 feet of Chuar Group strata. Rollover anticlines, sand pinchouts, and stratigraphic traps may be present in northern Arizona between the Tidewater well and the Grand Canyon. In structurally depressed terrane in the Grand Canyon, the Chuar is overlain by the continental Sixtymile Formation. Elsewhere, the Tapeats Sandstone overlies the Chuar Group probably throughout much of the extent of the Chuar subcrop. Oil was reported from the Tapeats Sandstone in the Collins Cobb Navajo #1-X well in Coconino County, Arizona. This oil may have migrated from Chuar Group source rocks. Structural closure on the pre-Cambrian unconformity is mapped east of the Cobb well beneath Kaibito Plateau in northern Arizona.

## INTRODUCTION

Reynolds and others (1988) described the petroleum source rock potential of the Late Proterozoic Chuar Group of northern Arizona and suggested that Chuar Group strata preserved in pre-Paleozoic graben may have served as source rock for commercial accumulations of oil and gas in lower Paleozoic or Proterozoic units. Their work inspired the current study which describes the location of the ancient Chuar basin and maps the distribution of Chuar Group rocks in northern Arizona and southern Utah (Figure 1).

Distribution of the Chuar Group on the subcrop map (Plate 1) is based on outcrop and well control in northern Arizona and southern Utah. Chuar Group rocks are exposed only in the eastern part of the Grand Canyon and have been penetrated by a single well in Kane County, Utah. Structural contours on the pre-Cambrian unconformity are a downward projection of Paleozoic structure modified to incorporate Proterozoic elevation data from outcrops and widely spaced drill holes in Arizona and Utah (Plate 1). The contours define closure on the Chuar Group subcrop beneath Kaibito Plateau in Coconino County, Arizona.

The northern boundary of the structure and subcrop map (Plate 1) is near the north edge of Township 36 South in Utah and the southern boundary is near the south side of Township 24 North in Arizona. Grand Wash fault marks the western edge of mapped Proterozoic rocks and the eastern limit is defined by the east edge of Utah and Arizona. The study area comprises about 38,700 square miles.

## PROTEROZOIC SETTING

A broad depositional trough has long been recognized on the western margin of what is now the North American continent (Schuchert, 1923; King, 1959; Clark and Stearn, 1968; Miall, 1984). The Proterozoic strata now exposed in Grand Canyon

accumulated in this trough, which extended over most of Arizona and merged with the ocean to the southwest and west, and may have extended northward to include Uinta Mountain and Beltian rocks in the northern Rocky Mountain region and northeastward to include Keweenawan rocks in the mid-continent region. The Middle to Late Proterozoic sedimentary rocks exposed in the Grand Canyon are mostly of shallow marine origin but include some fresh-water deposits. The latter are more prevalent in the Late Proterozoic due to uplift in the western part of Grand Canyon, which restricted and eventually ended marine deposition in the trough.

Late Proterozoic uplift (about 950 Ma) restricted deposition to less extensive basins in which organic material flourished. The Chuar Group exposed in the eastern Grand Canyon accumulated in such a basin which extended from north-central Arizona into south-central Utah and perhaps into north-central Utah and beyond. The depositional environments identified in the Chuar Group include a sediment-starved, possibly non-marine basin rich in organic material, a coastal or alluvial plain, and mixed coastal or fresh-water swamp and alluvial plain environments (Reynolds and Elston, 1986). Reynolds and others (1988) noted that these depositional sequences of aqueous and subaerial settings were markedly cyclic.

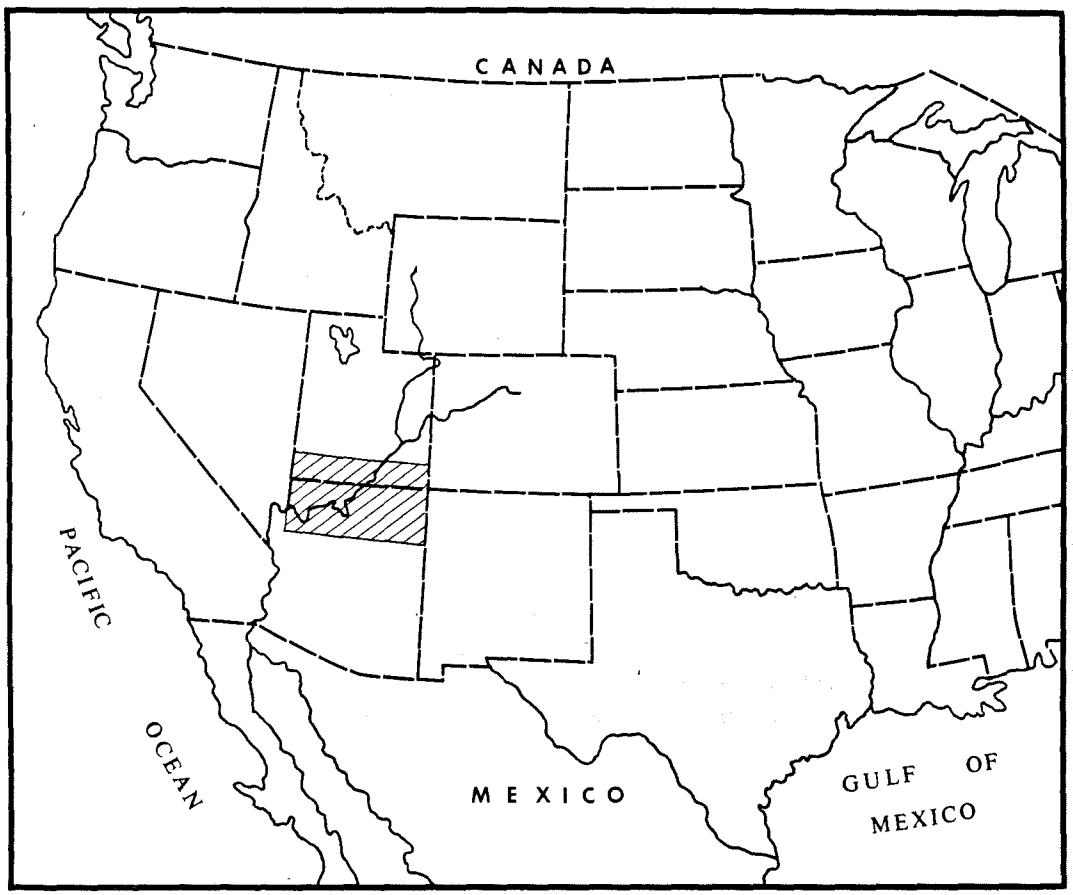


**Figure 1.** Location map showing area under investigation in northern Arizona and southern Utah.

## PROTEROZOIC STRATIGRAPHY

The Precambrian stratigraphy of the Grand Canyon consists of an Early Proterozoic basement of nearly vertical metamorphic crystalline rocks overlain by about 14,000 feet of unmetamorphosed Middle to Late Proterozoic sedimentary and subordinate volcanic rocks. Angular unconformities separate the Proterozoic strata from both the underlying crystalline rocks and the overlying Cambrian strata. The Proterozoic strata are tilted about 10 degrees to the northeast below the pre-Cambrian unconformity and form a wedge which is thicker and includes younger rocks to the east and which has been completely eroded to the west where nearly horizontal Cambrian rocks overlie the Early Proterozoic crystalline basement. These unconformities, remarkably flat and mature surfaces of erosion, are described in detail by Sharp (1940).

The sedimentary wedge is broken into several blocks by high-angle, generally north-trending Precambrian faults which have down-to-the-west Precambrian displacements in central and eastern Grand Canyon. The thickest part of each block is commonly on the west sides of the faults which have rotated the Proterozoic rocks about 10 degrees to the northeast. The Precambrian sequence exposed in central Grand Canyon includes only Middle Proterozoic rocks whereas the sequence exposed in eastern Grand Canyon includes both Middle and Late Proterozoic rocks. Therefore, the structurally lowest areas of Precambrian deformation were to the northeast.

Middle Proterozoic sedimentary rocks have been downfaulted against Early Proterozoic crystalline rocks on some of the faults in central Grand Canyon. On the Butte fault in eastern Grand Canyon, Late Proterozoic sedimentary rocks are downfaulted against Middle Proterozoic sedimentary rocks, exhibiting as much as 10,500 feet of vertical offset.

## PROTEROZOIC UNITS

Based on his journey down the Colorado River in 1869, Powell (1876) gave a vivid description of the rocks exposed in the depths of the Grand Canyon. He described tilted sedimentary rocks between crystalline basement below and nearly horizontal rocks above and named the tilted sedimentary rocks the Grand Canyon group and the underlying metamorphic rocks the Grand Canyon schists. He was the first to describe the profound unconformities above and below the Grand Canyon group. Walcott (1883) later divided the Grand Canyon group into two groups separated by an unconformity and pointed out the notable change in character of the rocks across the unconformity within the Grand Canyon group. The upper group Walcott called the Chuar Terrane (1883), the lower group the Unkar Terrane (1894). The underlying crystalline basement rocks are about 1.7 billion years old (Pasteels and Silver, 1965) and have long been known as the Vishnu Schist (Walcott, 1890). The Vishnu includes a wide variety of granitic and metamorphic rock types (Noble and Hunter, 1916) which, for the purpose of the current study, are divided into two groups. One group consists predominantly of granite and the other predominantly of schist (Plate 1).

Elston and McKee (1982) assigned the Vishnu Schist to the Early Proterozoic and the Unkar and Chuar Groups to the Middle Proterozoic. More recently, based on radiometric dating and paleontologic and paleomagnetic correlations, Elston (1989) reassigned the Chuar Group to the Late Proterozoic.

## PROTEROZOIC SEDIMENTARY ROCKS

The Unkar Group consists of a basal carbonate and sandstone sequence, locally interbedded and underlain by lenses of conglomerate. The carbonate and sandstone grade upward into a red shale and pale purple sandstone, which in turn is disconformably overlain by a clean, purplish, fine- to medium-grained quartzitic sandstone. The quartzitic sandstone grades upward into a very thick sequence of reddish, silty, fine- to medium-grained sandstone, which is overlain by a thick sequence of basalt in eastern Grand Canyon (Figure 2).

Noble (1914) divided the incomplete Unkar Group in the Shinumo Quadrangle in central Grand Canyon into five formations, based on lithology, and reported a total thickness of 4,782 feet. His division includes the locally present Hotauta Conglomerate at the base overlain by the more extensive Bass Limestone. Overlying the Bass is the slope-forming Hakatai Shale, in turn unconformably overlain by the resistant Shinumo Quartzite. The Dox Sandstone overlies the Shinumo Quartzite and represents the uppermost unit of Noble's subdivision. Keyes (1938) referred to the basalt which overlies the Dox Sandstone in the eastern Grand Canyon as the Cardenas Lavas, now called the Cardenas Basalt. This basalt represents the uppermost unit of the Unkar Group and is 951 feet thick in the Basalt Canyon-Tanner Canyon area (Elston and Scott, 1976).

The Nankoweap Formation unconformably overlies the Unkar Group (Figure 2). Van Gundy (1934) first separated the Nankoweap from the Unkar Group and elevated the Nankoweap to group status. He based his group designation on the presence of unconformities which separated the Nankoweap from the Chuar Group above and the Unkar Group below, yet he did not delineate formations within the Nankoweap Group. Consequently, Maxson (1967) later reduced the Nankoweap to formational rank. The Nankoweap Formation consists of a ferruginous sandstone member at the base overlain by a predominantly red-bed sandstone unit (Elston and Scott, 1976). The Nankoweap Formation, only 330 feet thick at the type locality in Basalt Canyon, may represent a more considerable interval of geologic time than suggested by its thickness (Van Gundy, 1951). Elston and Scott (1976) estimated that the Nankoweap Formation could have been as much as 1,148 feet thick prior to pre-Chuar Group erosion. Elston (1989) places the boundary between the Middle and Late Proterozoic at the unconformity which separates the Nankoweap Formation from the overlying Chuar Group. The Nankoweap Formation is so thin that it is mapped with the Unkar Group on the subcrop map (Plate 1).

The Chuar Group unconformably overlies the Nankoweap Formation and it represents the notable change in lithology from the Unkar Group first noted by Walcott (1883). The Chuar Group is predominantly a gray to dark gray mudstone with several thin to medium beds of locally intercalated dolomite and sandstone. Ford and Breed (1972, 1973) subdivided the Chuar Group into the Galeros, Kwagunt, and Sixtymile Formations in ascending order (Figure 2). The Sixtymile Formation is predominantly a red-bed unit and was subsequently removed from the Chuar Group by Elston and McKee (1982). The Chuar Group, including the Sixtymile Formation, is 6,610 feet thick in eastern Grand Canyon (Ford and Breed, 1973).

Ford and Breed (1972, 1973) subdivided the Galeros Formation into the Tanner, Jupiter, Carbon Canyon, and Duppa Members, and the Kwagunt Formation into the Carbon Butte, Awatubi, and the Walcott Members (Figure 2). The Carbon Butte Member represents a basal sandstone shoreline deposit of the Kwagunt Formation (Reynolds and Elston, 1986). Horodyski (personal communication, 1989) noted that

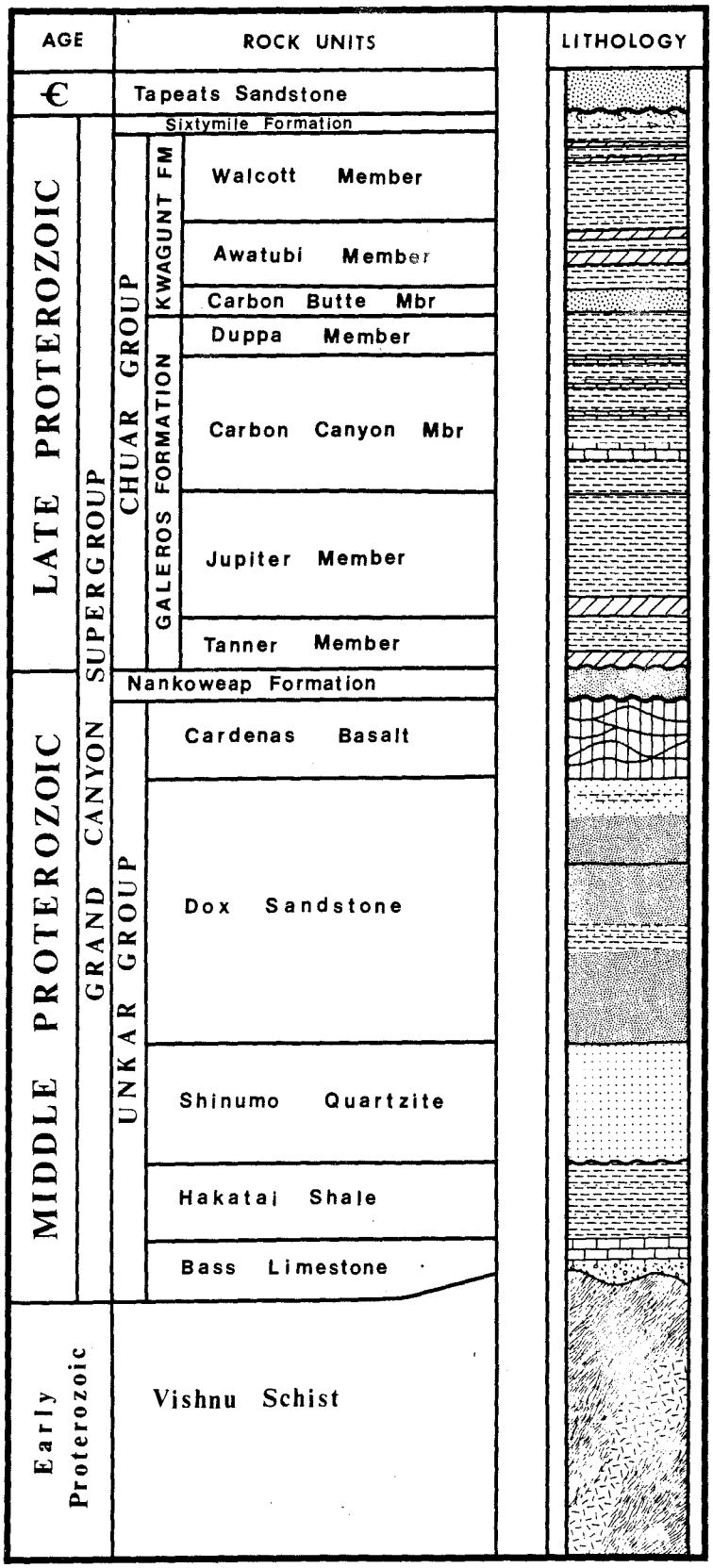


**Figure 2.** Proterozoic stratigraphy of the Grand Canyon, Arizona.

strong hydrocarbon odors were evident three to four feet away from carbonate outcrops in the Walcott member.

The Sixtymile Formation marks a distinct change in lithology from the underlying Chuar Group and it is the uppermost unit of the Late Proterozoic exposed in eastern Grand Canyon (Figure 2). Breed and Ford (1973) and Elston (1979) subdivided the Sixtymile Formation into three informal members of sandstone and breccia. The breccia includes distinctive carbonate clasts and blocks from the underlying Walcott member of the Kwagunt Formation and, possibly also derived from, the Nankoweap Formation (Figure 2).

## FAULTS

### Mesa Butte Fault

The Mesa Butte fault trend represents a fairly extensive Precambrian crustal break in northern Arizona and it tends to parallel the prevailing northeast trend of foliation (Damon and Giletti, 1961) in Early Proterozoic rocks. The generally north-trending Proterozoic Butte and Echo faults both terminate to the south against the ancient Mesa Butte fault trend (Plate 1). Shoemaker and others (1974) studied the Mesa Butte fault system from orbital images and from reconnaissance field studies. They pointed out the correspondence between a large northeast-trending magnetic anomaly and the Mesa Butte fault system which they described as a zone of major displacement in the Early Proterozoic crystalline basement. Gutman and Heckmann (1977) described geophysical and landsat evidence for the Mesa Butte fault system which they extended from Coconino Plateau on the southwest to Monument Valley on the northeast where they showed a north-trending fault branching from the northeast trend of Mesa Butte fault in the vicinity of Tyende Mesa (Plate 1). Both branches of Mesa Butte fault were extended by Gutman and Heckmann (1977) beneath the monoclines in northeast Arizona.

The monoclines in northeastern Arizona mostly trend northeast and include Cow Springs monocline in Arizona and Comb Ridge monocline in Arizona and Utah (Figure 3). However, just west of the town of Kayenta, Arizona, in the vicinity of Tyende Mesa, Cow Springs monocline bends north and becomes Organ Rock monocline. Comb Ridge monocline continues the northeasterly trend, east of Kayenta, before curving north into Utah. All of these monoclines are high on the north and west and dip steeply southeast and east (Figure 3).

The sense of Precambrian movement on the Mesa Butte fault system is critical to the distribution of Chuar Group strata north of the fault. Because Precambrian rocks are not exposed across Mesa Butte fault in the study area, assumptions must be made as to the sense of Precambrian displacement on the fault. One indication of the sense of Precambrian displacement on Mesa Butte fault is the widespread presence of Early Proterozoic granite beneath Paleozoic rocks in wells drilled south of the fault. The absence of Middle and Late Proterozoic strata indicates nondeposition or erosion, either of which implies structural uplift south of Mesa Butte fault. North of the fault, Middle and Late Proterozoic strata are present beneath Paleozoic rocks exposed in the Grand Canyon. This implies Precambrian structural depression north of Mesa Butte fault in the Grand Canyon area.

The monoclines in the study area provide another indication of the sense of Precambrian displacement on Mesa Butte fault. For example, Huntoon (1971) reviewed

the deep structure of West Kaibab, Phantom-Grandview, and East Kaibab monoclines exposed in Grand Canyon and showed that, in all cases, the monoclines exactly overlie pre-existing faults and exhibit displacement which is opposite to the Precambrian displacement on the faults. He noted that the monoclines in Grand Canyon are not unique features isolated in the middle of the Colorado Plateau and implied that the several generally east-dipping monoclines both east and west of Grand Canyon must have a similar structural relationship to Precambrian faults at depth. The down-to-the-southeast offset on Cow Springs monocline in Arizona thus suggests the opposite down-to-the-northwest Precambrian offset on the underlying Mesa Butte fault (Plate 1). Similarly, down-to-the-east offset on Organ Rock monocline (Figure 3) suggests down-to-the-west Precambrian offset on the north-trending branch fault beneath Tyende Mesa (Plate 1).

The Mesa Butte fault system extends beyond the southern edge of the mapped area in Township 24 North, Range 5 East (Plate 1). To the northeast, the Mesa Butte fault splits into two branches. One branch extends north beneath Tyende Mesa to Township 43 South, Range 14 East in Utah (Plate 1). However, the trend may extend farther north along the western flank of Monument uplift and may have influenced the eastern contact of the inferred Chuar Group in Utah. The southern branch continues northeastward at least as far as Monument Valley (Plate 1) but the trend may bend to the

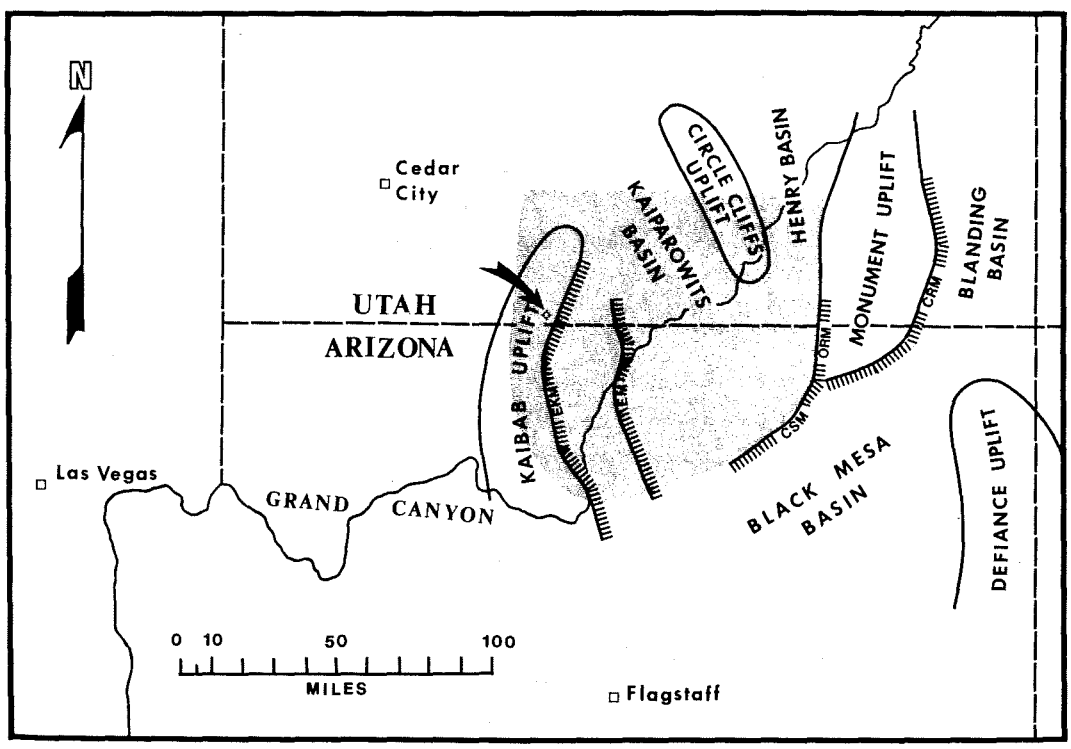


**Figure 3.** Map showing Chuar rocks, uplifts, basins, and monoclines of the study area. Stippled pattern represents possible distribution of the Chuar Group. The arrow points to the Tidewater Kaibab Gulch well. Hachured lines represent monoclines, with the hachures pointing in direction of dip. EKM - East Kaibab monocline; EM - Echo Cliffs monocline; CSM - Cow Springs monocline; ORM - Organ Rock monocline; CRM - Comb Ridge monocline.

north and extend northward beneath the closely spaced contour lines representing the Comb Ridge monocline in Utah.

## Butte Fault

Walcott (1890) described a down-on-the-west Precambrian fault which he named the Butte fault due to its influence on the origin and development of six great buttes in eastern Grand Canyon (Plate 1). He also described a post-Paleozoic reversal of displacement on Butte fault which was down on the east, as is the displacement now seen on East Kaibab monocline (Figure 3). East Kaibab monocline extends for several miles on the surface of the plateau from each end of Butte fault. Van Gundy (1946) indicated that the steeply east-dipping Kaibab monocline may represent the same line of displacement as Butte fault. Stratigraphic relationships across Butte fault record up to 10,500 feet of Proterozoic downthrow to the west which preserved the Chuar Group strata exposed in Grand Canyon. No Chuar Group outcrops are found east of Butte fault (Plate 1). This implies that all of the Chuar Group and most of the Unkar Group had been eroded from the upthrown eastern block before deposition of the overlying Cambrian rocks. However, the Proterozoic rocks exposed on the upthrown eastern block of Butte fault are tilted and include younger rocks to the east, implying the subsurface presence of Chuar Group rocks in that direction.

The Butte fault terminates to the south against the ancient Mesa Butte fault trend in the southwest quarter of Township 29 North, Range 8 East. It crops out in the eastern Grand Canyon, extending northward at least as far as the closely spaced contour lines that represent the East Kaibab monocline (Plate 1). Van Gundy (1946) suggested the extension of Butte fault northward beneath East Kaibab monocline. However, Elston and McKee (1982) pointed out that the Butte fault swings northeast to join the trend of the Bright Angel system rather than extend northward beneath the East Kaibab monocline. Thus the big depressed block between East Kaibab and Echo Cliffs monoclines (Figure 3) may be chopped up by a series of northeast-trending Proterozoic faults.

## Echo Fault

The north-northwest trending Echo fault is about 25 miles east of and approximately parallel to Butte fault (Plate 1). Unlike Butte fault, Echo fault is not exposed at the surface and thus its presence and sense of Precambrian displacement is based on indirect evidence, primary of which is the Echo Cliffs monocline (Figure 3). Gutman and Heckmann (1977) present geophysical and landsat evidence for the presence and Precambrian origin of Echo fault and extend the fault beneath the Echo Cliffs monocline which dips steeply east.

The Proterozoic strata exposed east of Butte fault may represent the western edge of a wedge of Proterozoic strata that extends eastward to Echo fault. If so, then the Proterozoic strata exposed east of Butte fault may be tilted to the northeast as a result of rotation due to downward displacement of the intervening block on the west side of Echo fault. The relationship thus suggests that Precambrian offset on Echo fault, like Butte fault, was down on the west (Plate 1).

Echo fault terminates to the south against the northeast-trending Mesa Butte fault in Township 31 North, Range 10 East. To the northwest, Echo fault can be traced with certainty at least to the northwest quarter of projected Township 38 North, Range 7 East

(Plate 1) where it probably bends to the north-northeast, as does the Echo Cliffs monocline, and extends beneath the closely spaced contours in the eastern half of Townships 39 and 40 North, Range 7 East. Conversely, the Echo fault trend may continue northwestward beneath Paria Plateau, from its northern extent on Plate 1, to intersect with East Kaibab monocline represented by the closely spaced contour lines north and west of Paria Plateau.

## Bright Angel Fault

Two northeast-trending Precambrian faults offset strata of the Unkar Group in central Grand Canyon between Point Sublime and Point Imperial (Plate 1). The following discussion centers on the eastern fault, which influences the trend of Bright Angel Creek and has long been known as the Bright Angel fault (Ransome, 1908). Van Gundy (1946) described a post-Paleozoic movement which was opposite to Precambrian movement on Bright Angel fault and noted that the fault passed upward into a monoclinal fold which had the same displacement as the post-Paleozoic movement on the fault. Sears (1973) pointed out that initial recorded movement on Bright Angel fault occurred at the end of deposition of the Hakatai Shale (Figure 2) and showed that subsequent Proterozoic offset on the fault was intermittent and down to the northwest.

Bright Angel fault extends northeastward to Butte fault (Plate 1). However, Shoemaker and others (1974) described the Bright Angel system as a continuous zone of normal faults which extend northeastward to the Echo fault, and perhaps as far northeast as Monument uplift in Utah. To the southwest, the Bright Angel fault is mapped as far as Township 30 North, Range 1 East (Plate 1) but it may extend slightly farther in that direction.

## Other Faults

The western part of the mapped area is characterized by nearly horizontal rocks typical of the Colorado Plateau structural province. There, the Early Proterozoic rocks have been successively downfaulted to the west by a series of prominent north-northeast-trending normal faults (Plate 1). All of the faults are a result of post-Laramide collapse (Elston, personal communication, 1990). That the faults are still active is indicated by recent seismic activity in the area. Stratigraphic displacement on the Hurricane fault reaches about 5,000 feet near the town of Hurricane, Utah. The Hurricane Cliffs and other north-northeast-trending cliffs in the area generally represent surface expressions of the faults.

Grand Wash is the westernmost fault and marks the western edge of the Colorado Plateau. Lucchitta (1987) estimated as much as 16,000 feet of Neogene (<25 Ma) western downthrow on the Grand Wash fault near the mouth of the Grand Canyon. West of the Grand Wash fault are isolated fault-block mountains, thrust faults, and steeply east-dipping strata of the Basin and Range Province. East of, and generally parallel to, the Grand Wash fault are numerous faults including Hurricane, Toroweap/Sevier, and Paunsagunt faults (Plate 1). Between the faults are a series of gently north- to northeast-dipping fault blocks that form the series of high plateaus north of the Grand Canyon.

The Chuar Group subcrop does not extend into the western half of the mapped area because of Late Proterozoic erosion or nondeposition. This implies that the western Grand Canyon was structurally elevated at the close of the Proterozoic Era. Thus, Pro-

terozoic movement on the western faults was possibly up on the west which would be consistent with structural elevation in that direction, i.e. to the west. It would also be consistent with the absence of both Middle and Late Proterozoic strata in that direction.

## LATE PROTEROZOIC STRUCTURAL SETTING

Sears (1973) described a series of Proterozoic faults trending north, northwest, and northeast in central Grand Canyon and showed that the initial decipherable movement on the faults took place at the end of deposition of the Hakatai Shale (Figure 2). The faults thus record Middle Proterozoic (about 1200 Ma) displacement in the central Grand Canyon area. By the Late Proterozoic (possibly < 800 Ma), uplift in the western Grand Canyon area restricted the ocean, located to the west and southwest, from the eastern part of Grand Canyon. Stratigraphic relationships show that displacement on Proterozoic faults in the central and eastern parts of Grand Canyon was generally down to the west and northwest. Displacement on Proterozoic faults in the western part of Grand Canyon was possibly up to the west as described above.

Elston (1979) unraveled the details of post-Chuar Group and pre-Cambrian uplift in the eastern part of Grand Canyon using the distinctive breccia clasts in the Sixtymile Formation. The distinctive clasts record intermittent yet prolonged displacement on the north-trending Butte fault. Stratigraphic relationships record a total displacement of 10,500 feet on Butte fault which removed all of the Chuar Group and most of the Unkar Group from outcrops on the upthrown eastern block (Elston and McKee, 1982). The entire stratigraphic section of the Chuar Group below the Sixtymile Formation was preserved in the downfaulted western block. The post-Chuar Group offset on Butte fault represents the final orogenic event of the Late Proterozoic in the Grand Canyon area. Elston (1979) referred to the post-Chuar and pre-Cambrian uplift as the Late Proterozoic Grand Canyon orogeny, and Elston and McKee (1982) refer to it as the Grand Canyon disturbance.

The absence of Middle and Late Proterozoic strata in western Grand Canyon implies significant Proterozoic structural elevation in that direction. That Middle and Late Proterozoic strata were preserved in eastern Grand Canyon indicates that the structurally lowest areas of Late Proterozoic deformation occurred in that direction, i.e. east and northeast of western Grand Canyon. Middle and Late Proterozoic strata are also absent in Black Mesa basin and on Defiance and Monument uplifts (Figure 3) where available well control indicates that Early Proterozoic rocks are widespread beneath Paleozoic strata. As in the western Grand Canyon, the absence of Middle and Late Proterozoic strata in those areas implies structural elevation at the close of the Proterozoic. These relationships suggest the existence of a yet unknown latest Proterozoic section buried under the Kaibab Plateau, between the Butte and Echo faults, or east of the Echo and north of the Mesa Butte faults (Plate 1).

## PRESENT-DAY STRUCTURAL SETTING

The broad uplifts and basins of the study area (Figure 3) were formed during the late Cretaceous to early Tertiary Laramide orogeny. These include the north-trending Kaibab uplift which extends from Arizona into Utah, the north-trending Defiance uplift in northeast Arizona, the north-trending Monument uplift mostly in southeast Utah, and the northwest-trending Circle Cliffs uplift in south-central Utah.

The broad basins include the Kaiparowits, Henry, and Blanding basins in Utah and the Black Mesa basin in Arizona (Figure 3). The Kaiparowits basin separates Kaibab and Circle Cliffs uplifts. The Henry basin is between Circle Cliffs and Monument uplifts. The Blanding basin lies between Monument uplift and, just beyond the mapped area, Uncompaghre uplift in Colorado. The Black Mesa basin in Arizona is separated from Kaiparowits basin in Utah by a northeast-trending broad ridge which forms a saddle between Kaibab and Monument uplifts. Defiance uplift bounds Black Mesa basin on the east.

Stratigraphic relationships indicate that some of these uplifts were structurally high in the Proterozoic whereas others were structurally low in the Proterozoic. For example, Early Proterozoic schist underlies Paleozoic strata on the crest of Monument uplift in southeastern Utah. The absence of Middle and Late Proterozoic strata beneath Paleozoic rocks on Monument uplift indicates that Monument uplift was structurally high at the close of the Proterozoic. Thus, in the case of Monument uplift, Laramide movement reactivated a Proterozoic high. On the other hand, nearly 14,000 feet of Middle Proterozoic Unkar and Late Proterozoic Chuar strata underlie Cambrian rocks on Kaibab uplift in Arizona and possibly Utah. The presence of 14,000 feet of Unkar and Chuar Group strata beneath Cambrian rocks on Kaibab uplift shows that Kaibab uplift was structurally low during the Middle and Late Proterozoic. In the case of Kaibab uplift, Laramide movement elevated a Proterozoic low.

Kaiparowits basin and Circle Cliffs uplift in Utah are considered to be a northward extension of the Proterozoic structural low represented by the stratigraphic relationships on Kaibab uplift. Chuar Group strata thus extend northward from Kaibab uplift beneath Kaiparowits basin and Circle Cliffs uplift in south-central Utah (Plate 1).

## PROTEROZOIC SUBCROP

### Distribution of Vishnu Group

Early Proterozoic granite crops out beneath Cambrian rocks along the Colorado River in western Grand Canyon. The granite subcrop extends from the exposures in western Grand Canyon northward to about the Utah state line. The eastern extent of the granite approximates the northerly trend of Toroweap fault (Plate 1). The granite subcrop extends from western Grand Canyon southward to the southern boundary of the mapped area and thence eastward to underlie Paleozoic rocks across the entire southeastern part of the map (Plate 1).

Early Proterozoic schist and gneiss crop out beneath Cambrian rocks in the Beaver Dam Mountains near the southwest corner of Utah (Hintze, 1986). The schist subcrop extends from the exposures in Beaver Dam Mountains eastward at least to the J. Ray McDermott well near the Sevier fault in Section 2-T43S-R8W, Kane County, Utah (Plate 1). Cambrian Tapeats Sandstone overlies dark gray to greenish mica schist in the McDermott well. The schist penetrated by the McDermott well extends southward to outcrops beneath Cambrian rocks in the central part of Grand Canyon. Schist forms another broad north-trending subcrop belt in southeast Utah and northeasternmost Arizona (Plate 1).

### Distribution of Unkar Group

The Middle Proterozoic Unkar Group crops out in several areas of central and eastern Grand Canyon. The most extensive exposures are in eastern Grand Canyon

below Cape Royal. The Unkar Group rocks in Grand Canyon generally strike northwest and dip about 10 degrees northeast. Due to the northeast tilt, the Unkar Group stratigraphic section forms a wedge that is thicker and includes younger rocks to the northeast. The Unkar Group subcrop probably extends from exposures in Grand Canyon northward into Utah.

Well control limits the westward extent of the Unkar subcrop in southern Utah. Unkar Group rocks are absent in the J. Ray McDermott well in Section 2-T43S-R8W in Kane County (Plate 1). There, Cambrian Tapeats Sandstone overlies dark gray to greenish mica schist.

Unkar Group rocks extend south of Grand Canyon along strike to a terminus against the southern extension of Butte fault (Plate 1). East of Butte fault the northward offset of the Unkar subcrop extends southeast along strike and terminates against the northeast-trending Mesa Butte fault. The Unkar Group subcrop is offset by Echo fault in Townships 31 & 32 North, Range 10 East where the south-southeast-trending Echo fault terminates against the northeast-trending Mesa Butte fault (Plate 1). The Unkar Group does not extend south of Mesa Butte fault because the area south of the fault was a Late Proterozoic structural high from which Unkar strata were removed or never deposited.

## Distribution of Chuar Group

The Late Proterozoic Chuar Group is exposed in eastern Grand Canyon below Point Imperial and Cape Royal (Plate 1). Like the underlying Unkar Group, the exposed Chuar strata strike northwest and dip about 10 degrees to the northeast. Chuar Group rocks extend from the outcrops in eastern Grand Canyon along strike northward into southern Utah. There, the Tidewater Kaibab Gulch Unit No. 1 well in Section 34-T42S-R2W in Kane County (Figure 3) penetrated Chuar Group strata below the Cambrian Tapeats Sandstone. The Chuar Group subcrop possibly continues into north-central Utah. Fossil and paleomagnetic evidence indicates that the Chuar Group of northern Arizona probably correlates with, and once may have been continuous with the Red Pine Shale, the uppermost unit of the Late Proterozoic Unita Mountain Group in north-central Utah (Elston, personal communication, 1989).

In the Tidewater well, AmStrat (log No. 869-R) logged 1,128 feet of predominantly gray to dark gray shale intercalated with numerous thin beds of siltstone and very fine- to fine-grained sandstone beneath porous Cambrian Tapeats Sandstone. Several thin beds of gray to brown dolomite with traces of anhydrite and pyrite are present in the shale 380 feet below the base of the Tapeats. AmStrat assigned the strata below the Tapeats Sandstone to the Precambrian Chuar Group.

Tidewater abandoned the Kaibab Gulch well after drilling 20 feet into a white, fine-grained, somewhat quartzitic sandstone below the shaly section. AmStrat tentatively assigned this white sandstone to the Shinumo Quartzite. The white sandstone is herein correlated with bleached sandstone at the top of the upper member of the Nankoweap Formation. Elston and Scott (1976) describe the upper member of the Nankoweap Formation as dominantly red, but having a capping unit of red and white quartzitic sandstone. Furthermore, stratigraphic relationships in the Proterozoic rocks exposed in Grand Canyon do not support the likelihood of Chuar Group strata resting directly on Shinumo Quartzite. Because Tidewater abandoned the well before penetrating crystalline basement, conclusive correlation of the white sandstone or the total thickness of the Proterozoic sedimentary section at this location cannot be determined from the well data.

Chuar Group rocks probably extend north and east of the Tidewater well into Kaiparowits basin and thence beneath Circle Cliffs uplift in south-central Utah where wells have not penetrated the pre-Cambrian unconformity.

The Dox Sandstone of the Unkar Group (Figure 2) is tilted to the northeast in the upthrown block east of Butte fault in eastern Grand Canyon (Plate 1). There, younger units of the Dox Sandstone are exposed to the east where the Dox is truncated by the overlying Cambrian strata. These stratigraphic relationships imply a Chuar Group subcrop northeastward of the truncated Dox Sandstone east of Butte fault. The Chuar Group subcrop, east of Butte fault, extends southward along strike to an inferred terminus against the ancient north-northwest-trending Echo fault in the northern half of Township 31 North, Range 10 East (Plate 1). The Chuar Group subcrop is offset to the north on the east side of Echo fault whence it extends southeastward along strike to a terminus against the northeast-trending Mesa Butte fault in the western half of Township 32 North, Range 12 East.

The strike of the uppermost units of the Chuar Group just north of Mesa Butte fault is assumed to parallel the northeast trend of the fault, as does the strike of the uppermost units of the Chuar Group exposed just west of Butte fault in eastern Grand Canyon. There, Elston (1979) showed that the sedimentary strike of the upper units of the Chuar Group were parallel to the strike of Butte fault. He attributed the preservation of the lower members of the Sixtymile Formation, exposed as isolated remnants just west of Butte fault, to deposition in an ancient sag pond associated with Butte fault, which thereby influenced the sedimentary strike of the upper units of the Chuar Group.

Chuar Group strata probably do not extend south of the Mesa Butte fault where well control indicates that Early Proterozoic granite is widespread beneath Cambrian rocks. Late Proterozoic elevation south of the Mesa Butte fault would have limited preservation of Chuar strata to as yet undetected Precambrian graben in that area, and may have influenced the southern margin of the ancient Chuar basin along the trend of the fault.

Chuar Group strata extend from outcrops in eastern Grand Canyon northeastward, forming a broad structural ridge beneath Kaibito and Shonto Plateaus, to the north-trending fault beneath Tyende Mesa west of Monument Valley (Plate 1). Chuar Group rocks are absent, northeast of the fault, in wells drilled on the crest of Monument uplift in Townships 40, 41, and 42 South, Ranges 18 and 19 East in Utah. There, Cambrian sandstone overlies Early Proterozoic mica schist and both Unkar and Chuar Group strata are absent because of nondeposition or erosion. If the Four Corners area, including Monument uplift, was structurally high during the deposition of Chuar Group strata then Chuar Group deposits would have been limited in that direction and areally restricted strandline and localized deltaic deposits would be present at some point down the western flank of Monument uplift. The north-trending fault beneath Tyende Mesa could have influenced the eastern margin of the Late Proterozoic Chuar structural and depositional basin in which case the fault could also mark the approximate location of the strandline and deltaic deposits.

## DEPOSITIONAL ENVIRONMENT OF CHUAR GROUP

Horodyski (1986) has noted that the preserved microbiotas in Chuar Group strata may not be representative of the Late Proterozoic oceans and pointed out that at least parts of the Chuar Group were deposited in a hypersaline setting. Reynolds and Elston

(1986) described a number of Chuar environments including a sediment-starved basin rich in organic material and noted the abundance of fossil microorganisms throughout the succession of dark mudstone and siltstone. This abundance was previously noted by Bloeser and others (1977), who calculated about 10,000 microfossils per cubic centimeter of rock in thin-sections of shale from the Kwagunt Formation (Figure 2).

The character and succession of Chuar Group strata led Reynolds and Elston (1986) to suggest accumulation of at least parts of the Chuar Group in a lacustrine setting in a subsiding region within the continent. The current report describes such a basin extending from north-central Arizona into south-central Utah, which formed as uplift to the west and south restricted the Proterozoic sea. Evidence for the extent of the basin includes the outcrops of Chuar Group rocks in central and eastern Grand Canyon and the presence of Chuar rocks in the Tidewater well in southern Utah. Stratigraphic relationships indicate that uplift which eventually separated the Late Proterozoic sea from the Chuar basin took place in western Grand Canyon where Middle and Late Proterozoic rocks are absent. The absence of Middle and Late Proterozoic rocks south of Mesa Butte fault and east of the north-trending fault beneath Tyende Mesa indicates that those faults may have influenced the southern and eastern margins, respectively, of the ancient Chuar basin.

Areally restricted near-shore environments in Chuar Group strata would be expected near the southern and eastern margins of the ancient Chuar basin. Sand bars and alluvial deposits may be localized along the trend of Mesa Butte fault and on the western flank of Monument uplift along the trend of the fault beneath Tyende Mesa (Plate 1). Turbidite flows could have been triggered by intermittent movement on Mesa Butte fault and on the fault beneath Tyende Mesa. Sand currents flowing basinward from the southern and eastern margins of the Chuar basin may have moved the near-shore deposits into the deeper parts of the ancient basin in which case turbidite deposits would be present along the northern flank of the broad ridge north of Mesa Butte fault and in Kaiparowits basin.

## OIL AND GAS POTENTIAL OF CHUAR GROUP

### Source Rock

Chuar Group strata in eastern Grand Canyon include at least 2,685 feet of organic-rich gray to black mudstone and siltstone intercalated with thin sequences of sandstone and stromatolitic and cryptalgal carbonate rocks (Reynolds and others, 1988). Summons and others (1988) pointed out that both the extractable and insoluble organic matter in the carbonate rocks are indigenous to the Chuar sediment and have not migrated from younger strata. Outcrop samples collected from the Walcott Member of the Kwagunt Formation (Figure 2) contain up to eight percent total organic carbon (TOC) (Palacas, personal communication, 1989) and average about three percent TOC (Palacas and Reynolds, 1989). They concluded that the Walcott Member has good to excellent petroleum source rock potential. Summons and others (1988) noted that samples of bituminous and argillaceous dolomite from the Walcott have not been affected significantly by biodegradation or weathering despite their age and collection from a surface outcrop. Their analyses indicate that the original organic matter comprised Type I-II kerogen and they place the source rocks in the mature region of the Van Krevelen diagram for kerogen types. Reynolds and others (1988) cite Rock-Eval $T_{max}$ values (430

to 440 °C) which indicate that Chuar Group source rocks are in the principal oil-generating window. They also point out that Hydrogen Index values (up to 190 mgHC/gC) and genetic potentials (up to 6 kg/ton) "demonstrate that the [Chuar Group] rocks still have potential for generating sufficient amounts of gaseous and liquid hydrocarbons for commercial accumulations."

## Oil and Gas Traps

Thin beds of siltstone and fine-grained sandstone are intercalated throughout Chuar Group mudstone penetrated by the Tidewater well in southern Utah. Some of the intercalated sandstone beds have up to 6 percent porosity and thus represent potential reservoir rock in the Chuar Group. The absence of the intercalated sandstone and siltstone beds in the Chuar outcrops in Grand Canyon implies sand pinchouts and the development of stratigraphic traps in northern Arizona between the Tidewater well and the Grand Canyon. These traps would be expected on the north plunge of Kaibab uplift and on the northern flank of the broad ridge north of Mesa Butte fault (Plate 1).

Oil migrating up the southern flank of Kaiparowits basin could have accumulated against the likely Proterozoic fault beneath East Kaibab monocline. Oil and gas may be trapped in Chuar strata which have rolled over into the fault in the vicinity of the closely spaced contours which represent the East Kaibab monocline west of Paria Plateau (Plate 1). There, northward extension of the Echo trend may intersect with the inferred Proterozoic fault beneath the East Kaibab monocline. Rollover anticlines are also possible where northward extension of the Bright Angel fault trend intersects with the Echo fault trend beneath Paria Plateau. These faults may have influenced the location of oil and gas accumulations in that area. Folding and faulting in Chuar Group strata at a scale too small to be identified on Plate 1 could have resulted in localized structural traps throughout the ancient Chuar basin and more particularly along the trends of Echo, Butte, and Bright Angel faults.

Oil and gas could have accumulated in distal and medial fan turbidite deposits on the northern flank of the broad ridge north of Mesa Butte fault and in Kaiparowits basin. Projection of the Bright Angel fault trend into Utah suggests possible locations for these traps. Oil and gas could have accumulated in proximal fan and channel fill turbidite deposits in northern Arizona westward of the north-trending fault beneath Tyende Mesa and on the broad ridge just north of Mesa Butte fault. Again, traps could form where Chuar strata have rolled over into the faults. Oil and gas could be trapped in the structural closure on the broad ridge beneath Kaibito Plateau. These accumulations would be expected in the coarser-grained deposits of the Chuar Group, at the pre-Cambrian unconformity, or in porous strata above the unconformity (Plate 1).

Areally restricted strandline and localized deltaic deposits including coarser-grained beach sands, longshore sand bars, delta front sands, and alluvial deposits may have formed traps around the margins of the ancient Chuar basin. Oil or gas from Chuar Group source rock in Kaiparowits basin could have accumulated in the beach and deltaic deposits. These deposits would be expected in northern Arizona near the trend of Mesa Butte fault, on the broad ridge north of Mesa Butte fault, and in proximity to the fault beneath Tyende Mesa west of Monument Valley (Plate 1).

Oil and gas from Chuar Group source rock could accumulate at the pre-Cambrian unconformity. Structural closure on the unconformity in northern Arizona is mapped east of Echo fault beneath Kaibito Plateau (Plate 1). Oil or gas trapped at the unconformity

could have migrated into overlying porous rocks. For example, oil shows from the Cambrian Tapeats Sandstone in the Collins Cobb Navajo #1-X well (Hager, 1948), just west of Echo fault in Section 35-T34N-R8E,* may be the result of migration from an oil and gas accumulation below the unconformity. The Tapeats Sandstone overlies the Chuar Group subcrop throughout the mapped area and it is in turn overlain by the impermeable Bright Angel Shale.

## Suggested Studies

In view of the source rock potential of the Chuar Group, an exploration strategy in north-central Arizona and south-central Utah should include efforts to locate and delineate Precambrian graben where Chuar Group source rocks have been preserved. A useful first step in a seismic investigation to locate these rocks in the study area would be to obtain accurate velocity data through the Paleozoic and Proterozoic units. This could be accomplished relatively inexpensively by re-entering the Tidewater well in Kane County, Utah, or by deepening one of the shut-in wells on the north plunge of Kaibab uplift in Arizona. If a sufficient velocity contrast exists across the pre-Cambrian unconformity in northern Arizona and southern Utah then the extent of Chuar Group rocks and the margins of the ancient Chuar basin could be mapped in considerable detail. Broadly spaced seismic lines located perpendicular and parallel to the possible margins of the ancient Chuar basin could identify anomalies for further investigation. Anomalies near the margins could represent areally restricted beach and deltaic sandstone deposits. The lines located perpendicular to the margins should be run far enough into the ancient Chuar basin to identify anomalies associated with possible turbidite deposits.

The margins postulated in the current report could be verified by running a minimum of three northwest-trending seismic lines in the study area. One northwest line should be run about midway between Butte and Echo faults, another northwest line across Kaibito Plateau, and another northwest line across Shonto Plateau (Plate 1). All three lines should begin south of Mesa Butte fault, where granite is known to underlie Cambrian rocks, and extend northwestward at least to the Utah state line in order to identify anomalies in the deeper parts of the Chuar basin as well as to provide control on the northeastward extension of Bright Angel fault. The northwest line between Butte and Echo faults should extend at least to the Tidewater well in Kane County, Utah, to incorporate important well control and to provide important data on the inferred Proterozoic fault beneath the East Kaibab monocline and to determine the presence of Echo or other Proterozoic faults beneath Paria Plateau. A northeast-trending seismic line shot along the trend of the broad ridge north of Mesa Butte fault would tie the three northwest-trending lines together and may indicate the need for another northeast tie-line farther to the north. The northeast-trending tie-line should cross East Kaibab monocline on the southwest and extend northeastward, through the Collins Cobb well just west of Echo fault, at least to the north-trending fault beneath Tyende Mesa west of Monument Valley. Anomalies identified on the seismic lines recommended above could be investigated by a more detailed seismic program. A detailed seismic investigation might also

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* The location of this well was listed as Section 2-T33N-R8E in previous printings of this report, but was field checked and corrected for this reprinting.

center around any of the numerous Phanerozoic structural features in the mapped area which may represent structural features, and thus oil and gas traps, in the underlying Proterozoic rocks. In this regard, the reader is referred to Davis (1975), who provides a discussion of the structural features in the Phanerozoic rocks of the Colorado Plateau based on landsat-1 imagery analysis, field reconnaissance structural mapping, and a compilation of published data. His work includes most of the known folds in the Colorado Plateau of Arizona.

Finally, no exploratory wells have penetrated the pre-Cambrian unconformity on the broad ridge north of Mesa Butte fault, in the Kaiparowits basin, or on the western flank of Monument uplift. Structural closure on the pre-Cambrian unconformity just east of Echo fault also remains untested even though oil shows have been reported in the overlying Tapeats Sandstone in the Collins Cobb Navajo #1-X well (Hager, 1948) just west of Echo fault in Section 35-T34N-R8E. The Collins Cobb well did not penetrate the pre-Cambrian unconformity.

## CONCLUSION

The Late Proterozoic Chuar Group accumulated in an ancient sediment-starved basin rich in organic material which extended from north-central Arizona into south-central Utah, and possibly into north-central Utah. These rocks have good to excellent petroleum generation potential. Chuar strata may serve as source rock for regional oil and gas accumulations. These accumulations are possible where Chuar strata roll over into a fault, in Chuar Group sand pinchouts, and at the pre-Cambrian surface. Oil and gas also may have migrated into Paleozoic strata above the pre-Cambrian surface and accumulated in a variety of structural and stratigraphic settings in this region.

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