

Grand Canyon National Park Research Project  
Principal Investigator: Noel Eberz, Begun June 1993, Final Report March 1999  
4433 Kathy Rd. Flagstaff Ariz. 86001, 520 774-3873

**Title: Redwall Limestone Karst and Colorado River Evolution in Grand Canyon:  
A case for stream capture!**

**Abstract:**

On the greater Colorado Plateau, the Colorado River has a long, complex and segmented history of evolution. Within the Grand Canyon region several models of this history have centered on the classic problem of how the river generally incised the Colorado Plateau and specifically the Kaibab upwarp of the Kaibab Limestone peneplain. Was the upwarp the topologic obstacle it appears to be today?

With many constraints on the river profile and radiometric age of basalts in the lower river basin, another look at the regional geomorphology and the erosional history of the Chuar Basin and Marble Canyon, transition areas to the upper river basin, is justified.

Numerous lines of evidence presented here suggest stream capture of an upper, mature river valley with a high water table by a youthful, high gradient stream through deep, high pressure karst conduits in the Redwall Limestone, 2000' below the peneplain in the vicinity of the Butte Fault and tunneling across a critical segment of the Kaibab upwarp. Many karst routes probably crossed into the youthful basin, with subsequent collapse and surface capture of the river at Cape Solitude, the lower and southernmost location. With isolation and reverse flow of other possible routes, a series of high buttes, Nankoweap Mesa to Chuar Butte remained as the new river course deepened.

**Introduction:**

A number of geophysical features stand out within and specifically related to the beauty of the Grand Canyon. Foremost is the peneplain of the Kaibab Limestone including the Kaibab Monocline (upwarp) as a topologic high across the incised Colorado River. Dutton(1882) remarked on the "Great Denudation" of this surface and Powell (1874) offered numerous ideas as to how rivers may cut through such barriers or that the Colorado River stands as a 'youthful' expression of river maturity in such a grand chasm. These and other ideas have inspired many workers since then to unravel the history of the river in the well exposed arid basin (Hunt, 1969). There is still a veil of uncertainty.

While there are many variations of the canyon evolution, the principal debate centers on the idea of a single drainage (Beus and Lucchitta, 1987) vs. a double (an upper and lower) drainage with subsequent stream capture (McKee, 1969). The latter model seems to satisfy the need for a longer, more complex erosional history in the lower reach compared to the more youthful appearance in the upper reach. However, as a contrary view, dating of

volcanics and peripheral deposits outline the present picture of a young lower canyon, particularly in the vicinity of the Grand Wash Cliffs.

While this earlier framework is extensive and well developed, it leaves unsettled the origin of many geomorphic appearances in the region. Most prominent is the Kaibab Limestone (Permian), an erosionally resistant formation about 400 ft. thick yet a continuous surface over 10,000 sq. miles even with elevations ranging from 5000 to 9000 ft. This surface known as the Kaibab peneplain and incised by the Colorado River in Grand Canyon inspired the Indigenous people to call the unique inversion 'mountain lying down'. Other features include the many deserted mature river valleys within the peneplain, the more open and extensive erosion of the lower canyon in comparison to the steeply incised upper canyon and numerous narrow erosion profiles of lateral canyons along the river corridor. However, recent work (Meek, 1989) suggests river incisement rates much more rapid than previously considered in the California Mojave Basin, part of the lower Colorado River system. This research could reopen the stream capture topic in a much shorter time-frame. Yet as a rule, stream capture by clastic transport in competing watersheds yields diminishing returns with headwall erosion, as knife-edge ridges often a thousand feet high in Hawaiian topography attest. However and most significantly here, abundant evidence of horizontal limestone karst cavities in the Redwall Limestone (Mississippian) in Marble Canyon and the Chuar Butte area may be the residual feature of another process for cutting across the Kaibab upwarp.

#### Discussion: Karst and stream capture

Karst as a stream capture mechanism was suggested by Hunt (1969) for the lower canyon from the Peach Springs area to the present Grand Wash. This idea was invoked to explain the river rerouting after the volcanics-blocked river valleys in Mid Miocene and a possible carbonate source for the younger Pliocene Hualapai Limestone member of the Muddy Creek Formation at Grand Wash, an area without appropriate clastic outwash deposits. The history of the river in this area is still problematic (Lovejoy, 1980).

In this case, the study area for stream capture is a smaller but distinctive region of the canyon between the east side of the Kaibab Monocline and the adjacent and parallel Colorado River corridor in Marble Canyon (see Fig. 1 Study Area Location ). To the west, but still on the east side of the Monocline, is the 'Chuar Basin' which is defined here as a series of upper basins (Lava-Chuar to Nankoweap) west of the Butte Fault eroded through the resistant Paleozoic formations and deep into the more friable Proterozoic Grand Canyon Series. Adjacent, but to the east of the Butte Fault, is the 'Nankoweap Corridor' of Marble Canyon defined here as a series of high buttes (Nankoweap Mesa, Kwagunt Butte, Chuar Butte) west of the river still capped with Kaibab Limestone, and with rich evidence of karst within the Redwall Limestone two thousand feet below the peneplain surface. A portion of the drainage out of the Chuar Basin area is west to east in multiple, steep, small streams. The rest is to the south of the area, including what might be considered the youngest and

narrowest profile of the present Colorado River, 3500 feet deep but only 6500 feet across from Cape Solitude to Chuar Butte, the proposed capture point (Photo 1).

#### Discussion: Redwall Limestone Appearances (Facies)

Another dramatic but also subtle feature of the Grand Canyon is the 'layer cake' geology of the Paleozoic strata, uniformly bedded sequential formations, superficially hiding the many complexities of discontinuities and erosional hiatus. Typically excluded from this profile is the Temple Butte and Surprise Canyon Formations, because they are not prominent everywhere or as easily differentiated, in part because they cut into earlier formations as modest stream channels. Equally dramatic and impressive in the canyon is the consistent and steep stair-step appearance of the formations, partially attributable to the very competent Coconino Sandstone and Redwall Limestone formations. The few trails into the canyon depend on exceptions to the rule of these impassable cliffs such as faults and debris slides or in the case of the Redwall, its local competency and accordingly it is these variations in place and time history of the Redwall Limestone that is most relevant to this topic.

The Redwall Limestone is very uniformly bedded but varies from 500 to 800 ft. thick in Grand Canyon, greater in the west and less to the east. It is subdivided into four members with different amounts of limestone, dolomite and chert bedding. The depositional environment was an extensive epeiric sea from shallow to deep marine. The initial Mississippian transgression is marked by a basal conglomerate and oolitic grainstone grading into finer sediments and fossil fragments higher in the section implying deeper water. While overall the unit is dense and competent, often highly polished in outcrop as found in Silver Grotto, Mile 30, in other areas of exposure it is quite broken-up, eroded or perforated with dissolution cavities. While not formally identified as 'facies' because many of these appearance modifications to the Redwall Limestone occurred well after deposition, they are relevant to further interpretation and can be recognized in the field as follows (See Fig. 2 Redwall Limestone Appearances):

**Surprise Canyon Formation** - Described as a separate and subsequent formation of Late Mississippian time, it was deposited locally in phreatic karst cavities or surface fluvial channels in a near-sea-level terrestrial environment within or upon the Redwall Limestone (Billingsley & Beus, 1985). It is recognized as a mixed reddish siltstone with light color chert fragments, conglomerate and limestone lenses. In the study area, in some cases the fluvial channels can be discerned but may also be seen as isolated cavity fill-in. Generally all the exposures are limited to the upper Mooney Falls member in eastern Grand Canyon.

**Breccia pipes** - Breccia pipes are circular collapse structures of various size and depth into the Redwall and into higher subsequent formations (Wenrich, 1988). The pipes are filled with mixed composition angular debris including some mineralization (e.g. uranium, barium etc.) These are interpreted to have been emplaced as early as Late Paleozoic to Mid Mesozoic possibly from an aquifer charged at the southern Mogollon highlands, with fluids

through the Redwall and surfacing in east-west trending lowlands between Mesozoic highlands further to the north (Billingsley, 1995). The related aquifer routes to these pipes (and facies changes) in the Redwall are not particularly identified in any study but read on.

Horizontal karst conduits - Horizontal karst conduits and caves are open or composed of Redwall breccia of high porosity or recrystallized with varying amounts of large crystal calcite spar. They appear as more recent erosional features usually in the upper Mooney Falls member but locally deeper. However, Huntoon (1983) discusses the present Redwall aquifer characteristics along the Fence and Eminence fault zones in Marble Canyon and assigning great antiquity to those caves perched thousands of feet above the present river. The lineaments and association of all the earlier karst features are most relevant and are interpreted further within this study. The caves, often poorly accessible are mostly terminated with rubble and animal middens. Some were lightly explored where possible but are generally not part of this study.

#### Discussion: Chuar Basin, the Butte Fault and Initial conditions

For this study the relevant geologic history of Grand Canyon and the Colorado River has both a local and regional aspect. The local character covers almost half the Earth's history in the area of the Chuar Basin near and with the Butte Fault and establishes the special conditions of the capture event. The regional character deals with many distant and tectonic changes during the Cenozoic development of southwest North America and establishes many of the initial conditions of the same event.

Chuar Basin is a deeply eroded, comparatively open basin within the park and here identified as the division of the upper and lower Colorado River. The geomorphic development of the Chuar Basin is poorly known. The area appears too large and complex for a passive or subordinate role in the incisement of the Colorado river, however as with any erosional development, evidence of its history is sparse and circumstantial, particularly with some 20 cubic miles of wasted stratigraphy.

The Butte Fault is a major feature within the basin and relevant to its geologic history. Sears (1990) identifies 5000 ft. offset of Proterozoic sediments prior to deposition of the Paleozoic section and reactivating with 2700 ft. of reverse movement during the Sevier orogeny creating the Kaibab Monocline (upwarp). The Chuar Basin and Butte Fault are depicted in Fig. 3 A Local Geologic History. However, over the length of the Monocline the effects are different. At the center there is 2700 ft. of thrust through the Grand Canyon Series rocks and shear or fold in the few remaining Paleozoic rocks along the fault, mostly visible now as residual uptilted Redwall Limestone. Toward the ends of the fault, north and south, there is only fold on the full and mostly present Paleozoic rock section. Together this is relevant in terms of the continuity and elevation of the Redwall Limestone throughout the area. In the Present Profile of Fig 3, two 'working hypotheses' are presented: Did the ancestral Colorado River cross the Kaibab upwarp by flowing upon Mesozoic rock layers,

probably in Early Tertiary time, cutting to its present course by a 'super-imposed stream' or was the river captured much later from a Paleozoic rock surface via karst conduits into a youthful rapidly cutting Chuar Basin? In the latter case, a mature river upon the Kaibab Limestone surface with a high water table would charge the Redwall aquifer creating as much as a 2000 ft. hydraulic head of pressure below, finding artesian outlets in the 'youthful' basin to the west. This supposition is shown in more detail in Fig. 4, Cross-over Phase and Present Profile.

The regional geologic history while a much shorter duration, possibly Mid Tertiary to the present is both complex and often subtle. For another diagrammatic summary of the river's history, see Chronic, 1983, (pg. 186). As a similar projection Fig. 5, A Regional Geologic History, is conceptual in space and time to broadly account for the segmented history of the total Colorado River. The history is a transition from a high elevation Intermontane basin between the western Sierra Nevada mountains and the eastern ancient Rocky Mountains. At an early stage it is characterized by many vast lake deposits with no discernible outlet to the sea and gradually changing to a new tectonic and erosional regime. This later phase opens the Gulf of California, introducing a sea level base and further dividing the region into a southwest dynamic pull-apart 'Basin and Range' province and a relatively stable higher 'Colorado Plateau' province. This complexity is depicted in Fig. 5, in quadrant form, incorporating many regional characteristics of formations and flow regimes over Cenozoic time, east and west of the Kaibab Upwarp. Lake formations such as the Claron, Bidahoche and Muddy Creek are representative of the earlier intermontane basin environment. The Bouse Formation is a great fluvial fan into the newly forming Gulf of California. The postulated capture is a late event connecting the two provinces: from a low area of youthful high-gradient streams to a high area of mature river valleys of low gradient and high water tables with a short circuit across the Kaibab upwarp.

#### Karst evidence: Marble Canyon

The dominant evidence for the karst capture process is along Marble Canyon and areas near and adjacent to the Butte Fault. While many areas were surveyed, Miles 30-37 along the river, Malgosa, Awatubi and 60 Mile Canyons and the confluence area of the Little Colorado River at Cape Solitude offered the most interesting detail. Most of the field work was done by traversing the bench on top of the Redwall and accompanying views from it, however in many significant areas of mass wasting, access into the lower levels of Redwall was also feasible (Photo 2).

In all these areas it was possible to differentiate between the recent and extensive horizontal karst routes, the older Paleozoic Surprise Canyon Formation and the Mesozoic aquifer/ breccia pipe dissolution structures. The horizontal karst has lineaments consistent with the present river direction but now dissected by it with deep river meanders. In numerous locations along the river the cave conduits are mirrored across the canyon walls or

frequently, one side has caves while the other side is extensively wasted away. The conduits not only contributed to the aquifer transport phase but produced many collapse structures possibly adequate to channel a surface flow 2000 ft. above at the Kaibab peneplain level. In addition to the limestone collapse breccias, the top of the Redwall is extensively eroded in hummocky terrain or in some cases still covered by slumping and highly fractured Supai formations. Mass wasting in the Redwall is most prominent in areas pertinent to the karst capture lineaments. Many mapped faults such as the Fence and Eminence Faults exhibit slumps and grabens that are similarly associated with the alignments.

Another distinguishing interpretation of the karst conduits is the 'phreatic' cavities, circular in profile which develop below the water table and the 'vadose' cavity incisement directly below them, indicating a subsequent falling water table or de-watering of the region. These structures are typically 50 to 80 ft. tall, presently visible from the river level (Photo 5).

Contributions to, or weakness from, the earlier karst features are minor or not clear. While there is some common lineament or location possibly related to the breccia pipes there seems to be little correlation with the Surprise Canyon Formation except being in the same Redwall horizon.

#### Karst evidence: Malgosa, Awatubi and 60 Mile Basins

Of the side canyons running east into the Colorado River along the north to south Nankoweap Corridor, only Nankoweap and Kwagunt Creek basins have significant watersheds off the North Rim area with continuous stream flows and have completely cut through the Redwall Limestone east of the fault. Malgosa, Awatubi and 60 Mile Creek basins have much smaller watersheds, mostly dry stream beds and cut only partially into the Redwall Limestone terminating in high falls-scarps near the main river. Each of the three basins, progressively to the south, displays more horizontal karst features (Photo 6).

In these side canyons many of the karst features are similar to those seen along Marble Canyon (Photo 2 & 3). However some massive collapse breccias are prominent in profile along the drainage (Photo 7). These breccias are in contact with competent Redwall and in major alignment with the side canyons. They do not appear as secondary slumps after the drainage channels formed. The clasts are very angular, totally Redwall in composition, often of similar fragment size and clast supported, suggesting a consistent crushing force and yielding an open structure with high porosity. Aureoles of 3 to 6 ft. in diameter with a leached altered color are rich in large crystal spar and appear as subsequent conduits through the collapse breccia. In some cases the fragmentation appears repetitive, re-fracturing subsequent spar growth suggesting an active flow and collapse regime.

#### Karst evidence: Along the Butte Fault

The Redwall limestone is the major folded formation visible along the fault. Many karst cavities occur here also but in vertical profile. They are not as clearly defined as other

locations as they are more exposed and the rock is considerably disrupted and eroded in the fault zone. While there are numerous possible examples, access is often difficult, however one significant vertical cave on the fault line was discovered. It was 4 to 8 ft. in diameter, with hydraulically smooth walls and was 'sounded' to 50 or more feet deep. While not initially explored more than a few feet down, the age of the cave appeared very recent thereby post-dating any fault movements, and an ideal conduit for an earlier artesian spring. Visitation was postponed to later and accomplished in Spring 1998.

The cave is located on Chuar Butte near the pass between 60 Mile and Carbon Creek drainages, at an elevation of 4990 ft. some 1200 ft. above the river and 2 to 4 miles away depending on approach direction (Photo 9). The cave depth from the entrance on the fault knife edge was only 100 to 120 ft. deep (Photo 10), with its base terminated by loose rubble obscuring any further course, although assumed to continue the Redwall vertical stratigraphy hundreds of feet further down. Any recent association with the North Rim Redwall Limestone is unlikely, being miles away and severed by the deep Chuar Basin. Cave ornamentation of minor travertine drapery and nodules suggest both a phreatic and vadose environment during development (Photo 11 & 12).

#### Karst evidence: At the Confluence

Along the Nankoweap Corridor and at the confluence of the Little Colorado River, lineaments, slumps and grabens can be observed across the river from the basins at the same stratigraphic level and consequently predating the incisement of the river. Such a major lineament inspected at Cape Bodaway includes massive breccias in the Redwall Limestone and slumps within the Supai formations, in addition to the mapped Breccia pipes directly across from the Chuar Butte - Cape Solitude precipitous profile. Many observations were made between these rather spectacular points at the Redwall level at points along the river corridor (Photo 8).

#### Synthesis and Possible sequence:

The initial conditions of a low gradient for the Colorado River and the Little Colorado River puts little restriction on where they exactly flowed. The main Colorado River may have been more north of the upwarp flowing east to west, possibly associated with the Kanab drainage. The Little Colorado River was flowing north along and channeled between the upwarp and Mesozoic rocks on the east side of House Rock Valley or Echo Cliffs further to the east. But both systems contribute to a high water table and charging the previous and ancient Redwall aquifer.

Equally important in the initial conditions is the youthful Hance drainage system, identified here as the pre-capture stream. Its characteristics would be similar and contemporary with the Kanab, Havasu and Bright Angel Creeks, each draining significant portions of rain-side flow off the Kaibab upwarp. In addition to the amount of runoff, the

progress in incising eastward would be controlled by the slope of the upwarp and would ultimately intercept the Butte Fault, a zone of structural weakness.

In addition to the extensive erosion of the Chuar Basin, it is postulated that the Butte Fault was instrumental in channeling the original karst flow at the Redwall Limestone level, through the developing Hance drainage to the south and west. At this location the Redwall would be at least 500 ft. below the surface of the high water-table of the mature Kaibab Plateau river valley to the east, because in spite of the reverse dip in this direction, the Redwall is stratigraphically 2000 ft. below the Kaibab Limestone. So indeed the flow would be up grade, maintained by the pressure head. Considerable amounts of erosional material may have been removed during this early artesian phase in both dissolved carbonates and collapse debris from the spring side. The additional clear spring flow would augment and further 'corrade' the young steep gradient stream, particularly when eroding the friable Proterozoic Grand Canyon Series formations now well exposed in the Chuar Basin.

The capture by karst wasting was inevitable under the conditions of the high water table but the detailed sequence was much more contingent and now speculative. Personally, while hoping to see some possible Chuar Basin history, the author did not anticipate the detail for a multi-step sequence as interpreted from many views around the basin. The residual broad valley profile across Awatubi Crest, across the fault and way south to the Hance area stands out. This erosional swath is at the Supai Formation level in the east and at the Tapeats Sandstone level to the west (Photo 4). The deeper erosional obstacles including the Cardenas basalt local to the Hance Rapid area, would have delayed the present extensive removal of the friable Grand Canyon Series rocks now observed. Some bizarre topography between Temple and Chuar Buttes suggest a complex and dynamic change in drainage conditions over time. A hypothetical phasing of the capture sequence integrating many aspects is presented in Fig. 6 An Intermediate Phase during the Capture Sequence

How much structural collapse might be required to facilitate the surface stream capture can be estimated. In the vicinity of the Butte Fault, the buttes are about 400 ft. higher than the Kaibab Plateau to the east, although considerably less near Cape Solitude. Present surface channels down the Monocline to the east (Photo 14), and like a remnant on Chuar Butte, may have reduced that figure further. So the actual surface capture channel may have been only a few hundred feet lower than the surrounding terrain. High spring floods could have defined the final course.

The erosional contrast between the vast open canyon to the west of Cape Solitude and Chuar Butte and the rugged steep Marble Canyon just prior to it, is significant. Even the knife-edge rim along Chuar Butte is amazingly fresh and erosionally precarious and as previously noted the narrowest river profile in the canyon, Kaibab to Kaibab Limestone (Photo 1).

### Principal determinants of the Capture sequence

- 1) The original karst routes were through Awatubi and 60 Mile canyons, with Redwall Limestone folded and exposed along the fault line, maybe to the 5500 ft. level. This artesian contribution would be effective in 'corrading' (a high sediment transport efficiency by clear spring water) the Chuar Basin drainage.
- 2) The present erosion profiles at Chuar/Lava Creek cutting through Cardenas basalt, Carbon Creek through Tapeats Sandstone and Crash Canyon through Redwall limestone suggest a later phase of artesian springs at these lower locations as the Hance drainage deepened and contributed to the final Colorado River capture at Cape Solitude. Note that along this southern area, the Redwall is continuous across the fault and considerably lower then it is at the middle of the upwarp.
- 3) Major controls of the karst process are the elevations of the charging surface to the Redwall aquifer on the Kaibab Plateau, and decent outcrops of the Redwall at appropriately lower elevations along the fault or farther to the southwest as the youthful stream cuts to that stratigraphic level in the Redwall Limestone.
- 4) To the north, the deeper cutting of the side canyons through the Redwall Limestone at Nankoweap and Kwagunt Creeks suggest these streams were not involved and maintained their original eastern flow as the main Colorado River corridor deepened after capture.

### Time of Capture and Other evidence:

The time of the capture event can be based on a few limiting approaches: The relative dating of the horizontal karst, some recent erosion rates and general topographic appearances. Foremost, the horizontal karst post-dates the destructive tectonics the Sevier orogeny along the Butte Fault eliminating all the other pre Tertiary karst and predates the incisement of Marble Canyon by simple crosscutting relationships at least down to the Redwall level. However while it establishes the method it still leaves a vary large time gap.

Based the nature of this event, other sources of information can be combined to develop an erosional profile with time as shown in Fig. 7, Incremental Elevations above the Present River. A structurally resistant nickpoint after joining the upper and lower river segments would be the Hance rapid area. The present canyon profile at Hance Rapid, Mile 75, is 3200' wide and 1400' deep through basement metamorphic and Grand Canyon Series intrusive rocks. Extrapolating an average erosion rate of 0.25 meters/1000 yrs of Machette and Rosholt (1989) in the Tanner Canyon area, Mi 68, would place a late capture event about 2 Ma with 1400 ft. of subsequent cut at this point. Proportionally there would be little or minimum additional cutting beyond Lava Falls, Mi 170 (Hamblin, 1989), while the Marble Canyon area would require 3000 ft. of cutting from the Kaibab peneplain surface. Erosion rates along the river corridor may substantiate such an erosional history including some relic gradient changes and as renewed base-levels in lower basin side-canyons such as Havasu (Photo 16), Matkatamiba and others near and above Kanab Creek, the effected reach.

In Fig. 8, Colorado River Profiles, the data are rearranged to show the subsequent river gradient profiles at capture, halfway in time and today. Other recent studies in the upper basin on sedimentary terraces in northeast Arizona with radiometric techniques suggest rejuvenated cutting compatible with this timing and nickpoint (Lucchitta, 1994). An earlier age for the capture event could be twice these estimates and still be after deposition of the Hualapai limestone of the Muddy Creek and Bidahochi lake deposit formations indicative of the low gradient intermontane initial conditions prior to opening of the Gulf of California.

So dating of the capture event is 'Relative' to the distant past and 'Radiometric' much closer to the present but still requiring considerable interpolation between. Other dating such as river gravels associated with the original mature river or travertines associated with the artesian phase would be helpful but not as likely to be observed in the highly eroded later phase of the capture. While numerous gravel deposits have been identified they have not been considered in this study or the question of large crystal spar, its density (remaining cavity porosity) at higher and lower breccia levels, their age or unusual development.

#### Summary: Denudation, super-imposed streams and rejuvenation

An important issue remains with the basic questions of Powell and Dutton, now more focused because of the tighter time constraints on the river's evolution. If indeed, the lower basin is very young as dated by various crosscutting peripheral deposits (~ 5 Ma for discussion purpose), we are then left with less time to have a 'denuded' Kaibab peneplain and the luxury of gradual super-imposition of the river through Mesozoic into Paleozoic strata across the Kaibab upwarp. In fact, residual cuesta-form structures such as the Vermilion and Echo Cliffs suggest other sluggish mature river courses possibly as old as 5 Ma and now left high and dry. What does become significant after 5 Ma on the Colorado Plateau is the full effect of the San Andreas transform fault creating the Sea of Cortes rift and Basin and Range tectonics inaugurating a new and steep gradient river channel, possibly augmented by more moist Late Tertiary weather patterns particularly on the higher Kaibab Monocline rain-side. Such a scenario could easily give the lower Grand Canyon basin an erosional history twice as long as that of the upper basin east of the upwarp as appearances suggest. In fact, in the conceptual diagram in Fig. 5 we can broadly interpret the long segmented history of the river in four parts. Starting with the Rockies in the upper right quadrant with river courses as 'very old', the upper left quadrant of mature streams on the Colorado Plateau as 'old', the renewed cutting to sea-level of the lower left quadrant toward the Gulf of California as 'young' and the captured Marble Plateau and its rapidly incised canyon as 'very young', hence an effective interpretation for putting the detailed pieces together.

So did this capture just short-circuit a mature surface river possibly flowing to the north and toward Kanab Creek? If so there was a corresponding utilization of a major subterranean drainage system over a large area and de-water it. Such a scenario might explain why Marble Canyon has but one significant side canyon, the Little Colorado,

compared to the many lengthy laterals of Glen Canyon farther upstream. Hydraulically, the Redwall Limestone is still a relevant factor today, a time of low water tables within the canyon. Grand Canyon Village on the South Rim of the canyon with south dipping strata actually obtains its water from North Rim springs high on the other side of the river.

In summary: Why did it happen? The topographic obstacle was there. The more recent the capture event, the more prominent it became. The karst evidence is abundant and a reverse direction of flow serves no other purpose. Erosion rates support a recent event about such a location and the consequences to it, giving the Colorado Plateau much of the fresh character we see today. Most of the evidence is circumstantial but still over all convincing.

Developing these ideas and where they fit in a regional geology will take additional study. Further work could look at regional characteristics, particularly a mature river course north of the Kaibab Monocline, grabens and collapse structures along Marble Canyon and possible access into additional cave conduits in the study area. But I leave this to younger and more energetic hearts.

#### Study Objectives and Methods:

Considerable time was originally spent on the river and various vista points within the Grand Canyon, reviewing the geomorphology as part and preliminary to formulation of the issues of this study. Much additional survey work was similarly done without special sanction, particularly in reviewing the mature and abandoned drainages but access to the basin from the river corridor was essential to review the proposed original karst routes. Within the specific request for field time in the study area, field work consisted of looking for, mapping and photographing residual erosional cuts, karsting features, any recently deposited remnant sediments or river gravels as access and time permitted. Sampling authorization was not requested. Misjudging the remoteness of the study area and the logistics for access precluded completing the original request for field time and the project extended over six years as described in the following brief log:

June 22-25 '93, Nankoweap backcountry hike-in. Camped near the Butte Fault on Nankoweap Creek with 2 days of excursions onto Nankoweap Mesa, along the Butte Fault viewing major drag folds within the Redwall Ls. and up to the Supai bench and viewing down on the Redwall along the deep narrow creek cut. There was no access above the sheer Coconino Ss. to view the obviously disrupted Toroweap and Kaibab formations at the north end of the butte and its nature, potentially a related question.

July 26-27 '93, Along the river corridor, Mi 38-52, Nautiloid to Nankoweap. Karsting in the Redwall Ls. is principally in the upper Mooney Falls member, with various stages of cavities to late stage residual pinnacles. Numerous conduit systems can be observed as continuous and cross-cut by the river and presently 70-100' above it. Further access above either from the river or the east rim would be beneficial along River corridor, Mi 52-76,

Nankoweap to Lava-Chuar. Characterization made of some detail features in the area for further study.

Sept. 4-6 '93, Jeep access to Navajo country along the rim of the Nankoweap corridor with overlooks at South Canyon, Malgosa Canyon, 60 Mi. Canyon and to 'Cape Bodaway' at the confluence of the Colorado & Little Colorado Rivers. with major views of the Buttes and Redwall karsting features along the canyon and side canyons. Closer views of the upper and lower levels of 60 Mile Canyon within the Redwall Ls. is a good objective on the next basin outing.

Sept. 15-19 '93, Tanner Trail to Lava-Chuar Basin. An attempt to access the upper basin of 60 Mi. Canyon over the adjoining pass to view Redwall karst features was unsuccessful for lack of adequate physical reserves from a hike-in river camp.

Feb. 26-28 '94, Access from Colorado River, up Kwagunt Creek, over to Malgosa Basin. Map karst features in Redwall at the Supai level out to the Colorado River with views of caves, breccia and collapse structures. Hike out and down Malgosa Canyon on the return. Scout for next trip to basins to the south.

April 17-22 '94, Access from Colorado River, map major karst features in the Redwall within Marble Canyon, Mi. 25-54. Starting at Kwagunt Creek, Mi. 54. Hike up to Kwagunt Basin, past Malgosa Basin into Awatubi and 60 Mile Canyon Basins. Field reconnaissance of karst and breccia structures above and within each canyon. Return via Lava/Chuar Basin, cross the river and out the Tanner Trail.

June 30-31 '94, Jeep and hiking access to Cape Solitude for views of Chuar Butte and 'Cape Bodaway' Redwall Ls. karst features from the Kaibab level.

Feb. 11-17 '95, Hike in Shinumo Creek trail and traverse the top of the Redwall Ls. from Silver Grotto, Mi. 30 to the Fence Fault, Mi. 36-37. With a river trip assist to Little Colorado confluence, Mi. 61. Egress from the canyon via the Walter Powell route through Redwall karsted features on the east wall in alignment and view of the Chuar Butte-Cape Solitude profile, to 'Cape Bodaway'. Accomplished many observations of karst conduits along the Marble Canyon corridor.

Apr. 11-20 '95 Helicopter access to 60 Mile Basin with adequate water and supplies for 9 days of field work. Detailed observation and mapping of 60 Mile and Awatubi Basins with traverse of the upper Redwall Ls. to and along the river corridor. General observation of the Chuar Basin, Awatubi, 60 Mile Basin for possible erosional history. Climb of Chuar Butte for 'closure' of the triple observation points of the proposed capture location.

Feb. 13-3 Mar. '96 NPS Spring Resources river trip as co-member and opportunity to study side canyons, including lower 60 Mile canyon.

Feb. 18-9 Mar. '97 Partially with the NPS Resources river trip but five days separate to study the upper Redwall levels at Harding and Eminence Fault area.

Apr. 29-16 May '98 Independent research river trip visiting Little Nankoweap canyon, the Chuar Butte cave entry on my 65th birthday and scouting lower basin stream profiles.

## Acknowledgments

While this project was supported by personal funding, I wish to thank Grand Canyon National Park for authorization, many access aids and particularly the encouragement and support of Kim Crumbo, Resources Officer, Robert Winfree, Senior Scientist and my field assistants Scott Wyeth, Steve South, Kent Wagner, Bob Dye, Michael Latendress, Steve Savage and BG Tackett who joined me at various stages, over the seasons and some six years extant in this rugged but spectacular canyon wilderness experience.

## References reviewed and cited

The history of the Colorado River is a classic problem. The following literature was reviewed for a general history of the work done and its relevance to this study. Many summarize with the enigma of the canyon and river's history. There is some literature on karsting in the Redwall Limestone but it is mostly related to breccia pipes and economic deposits therein. Features of karsting in stream capture are not specifically covered. As with this broad list of reference material, this report was written in a general style to address a broader audience that might be interested in the regional geology and a more narrative description associated with the project experiences.

Beus, Stanley & Lucchitta, Ivo, 1987, History of Colo Riv and its Grand Canyon: GSA field guide, Phoenix

Beus & Morales, Michael, 1990, Geology of the Grand Canyon: Oxford Univ Press

Billingsley, Geo. H & Beus, 1985, Surprise Canyon Fm.: USGS Bul 1605-A, pA27-A33

Billingsley, 1995, Per. comm, Breccia pipes and Surprise Cyn Fm.

Blackwelder, Eliot, 1934, Origin of the Colorado River: GSA Bull, V45, p551-566

Chronic, Halka, 1983, Roadside geology of Ariz: Mountain Press, Missoula, p320.

Dutton, Clarence, 1882, Tertiary history of Grand Canyon: USGS Monograph 2

Elston Donald & McKee EH, 1982, Age & correlation of Late Proterozoic GC disturbance: GSA Bul, V93, p681-699.

Elston D, & Young RA, 1989, Cenozoic landscape of Arizona, Cutting of Grand Canyon: in AGU field guide T115

Hamblin, WK, 1990, Late Cenozoic lava dams in W GC: in Grand Canyon Geology

Hunt, CB, 1969, Geologic history of Colo Riv, in Colo Riv and Powell: USGS Prof paper 669

Huntoon, Peter W, 1983, Karstification associated with the Redwall artesian aquifer: in Klimchouk A, ed., Speleogenesis, evolution of karst aquifers.

James, Noel & Choquette, Philip, 1990, Paleokarst: Wiley & Sons

Longwell, CR, 1946, How old is the Colo Riv: Am Jour of Sci, V244, p817-835

Lovejoy, EMP, 1980, Muddy Ck Fm at Grand Wash: Ariz Geol Soc Digest, Vol XII, p177-192

Lucchitta, Ivo, 1972, Early history of Colo Riv in Basin & Range: GSA Bull, V83, p1933-48

Lucchitta, 1979, Late Cenozoic uplift of SW Colo Plateau: Tectonophysics, V61, p63-95

- Lucchitta, 1984, Landscapes of NW Ariz; in Landscapes of Ariz: Univ Press of Am, p269-301
- Lucchitta, 1994, Per. comm, River erosion rates.
- Machette MN & Rosholt JN, 1989, Quaternary terraces in Marble Canyon and Eastern Grand Canyon: in AGU field guide T115.
- McKee, Edwin, & others, 1967, Evolution of Colo Riv in Ariz: Museum N Ariz, Bull 44, 67p
- McKee, & Gutschick, Ray. C, 1969, History of Redwall Ls.: GSA Mem 114, p726
- McKee ED & McKee EH, 1972, Pliocene uplift of Grand Canyon and drainage adjustment: GSA Bull, V83, p1923-32
- McKee ED, 1982, Supai Group at Grand Canyon: Geo Survey Prof Paper 1173, p504
- Meek, Norman, 1989, Rapid incision of Afton Cyn, Mojave Calif.: Geology, V17, p7-10.
- Palmer, Arthur, 1993, Per. comm, Large crystal calcite spar environments.
- Powell, John Wesley, 1874, Exploration of the Colorado River and its Canyons
- Sears, James W, 1990, Geologic structure of GC Supergroup: in Grand Canyon Geology
- Scarborough R, 1989, Cenozoic erosion: Geologic evolution of Arizona, Ariz Geol Soc, V17
- Wenrich, Karen & Sutphin, HB, 1988, Recognition of Breccia pipes in N Arizona: Az Bureau of Geology, V18, No. 1.
- Young RA & McKee EH, 1978, Early & Mid Cenozoic drainage and erosion in Ariz: GSA Bull, V89, p1745-50

## Glossary

Certain place names applicable to the area during the capture process or presently not established and some terms uncommon or deemed missing from a standard geologic dictionary are:

Cape Bodaway: The point opposite Cape Solitude and Chuar Butte on the Navajo Reservation and named after the local tribe chapter

Chuar Basin: A set of small basins from Lava/Chuar to Nankoweap

Corrade: A old geologic term used by C. Dutton to express the erosional striping during the Great denudation and the erosional potential of high-gradient clear-water streams

Hance Drainage: The youthful stream in Chuar Basin prior to Colorado River capture

Nankoweap Corridor: The north to south flowing portion of the river in Marble Canyon

Rain-side: A high precipitation area on the opposite side from the Rain-shadow or lee side. Cuesta-form or trough. Stream flow along strike upon a resistant layer (Kaibab Ls.) edging into a more friable one (Moenkopi Fm.).

Phreatic and vadose: Subaerial and and subaqueous ground waters above and below the water line.

# Redwall Limestone karst and Colorado River evolution; Diagrams and Figures

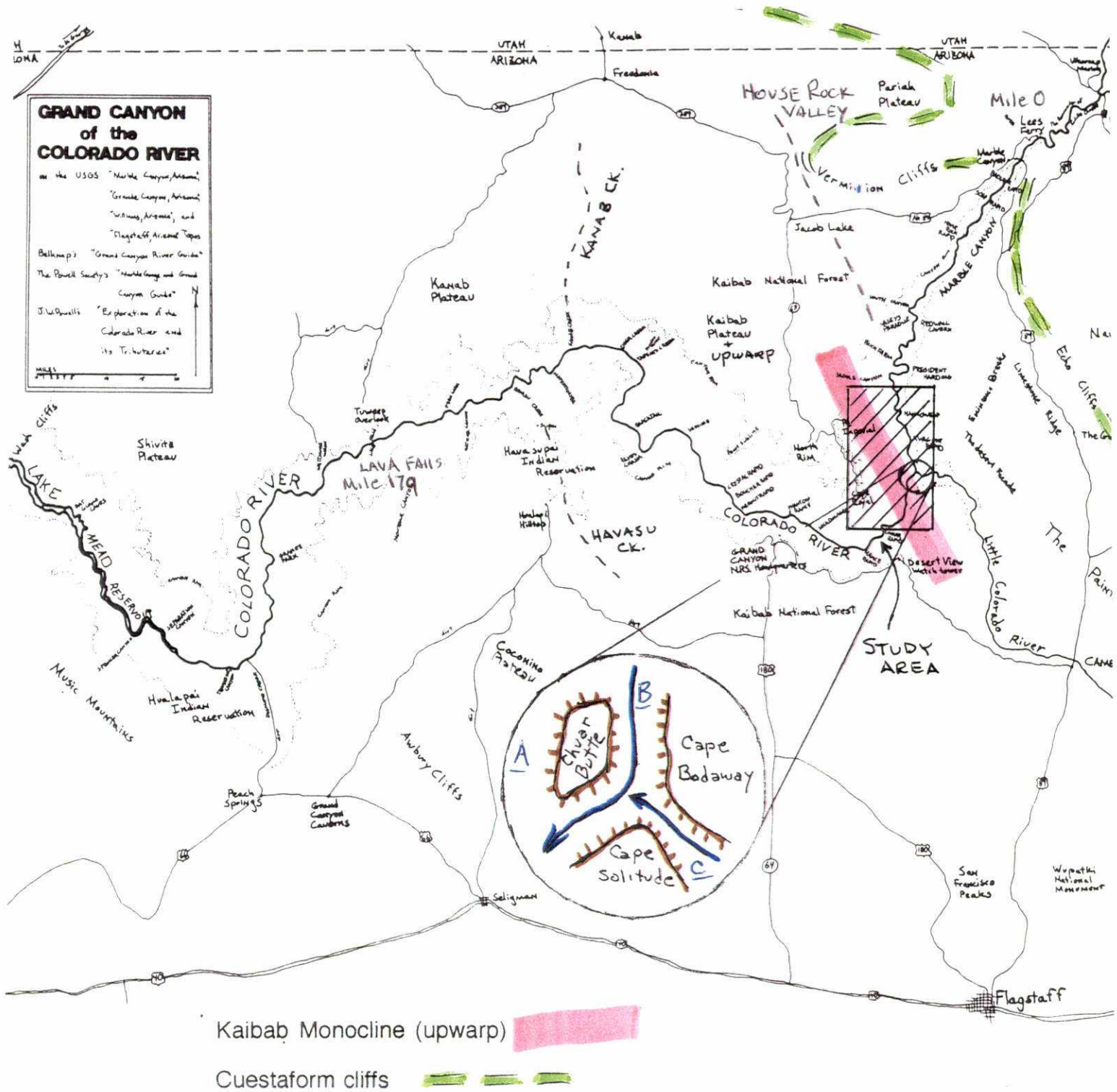
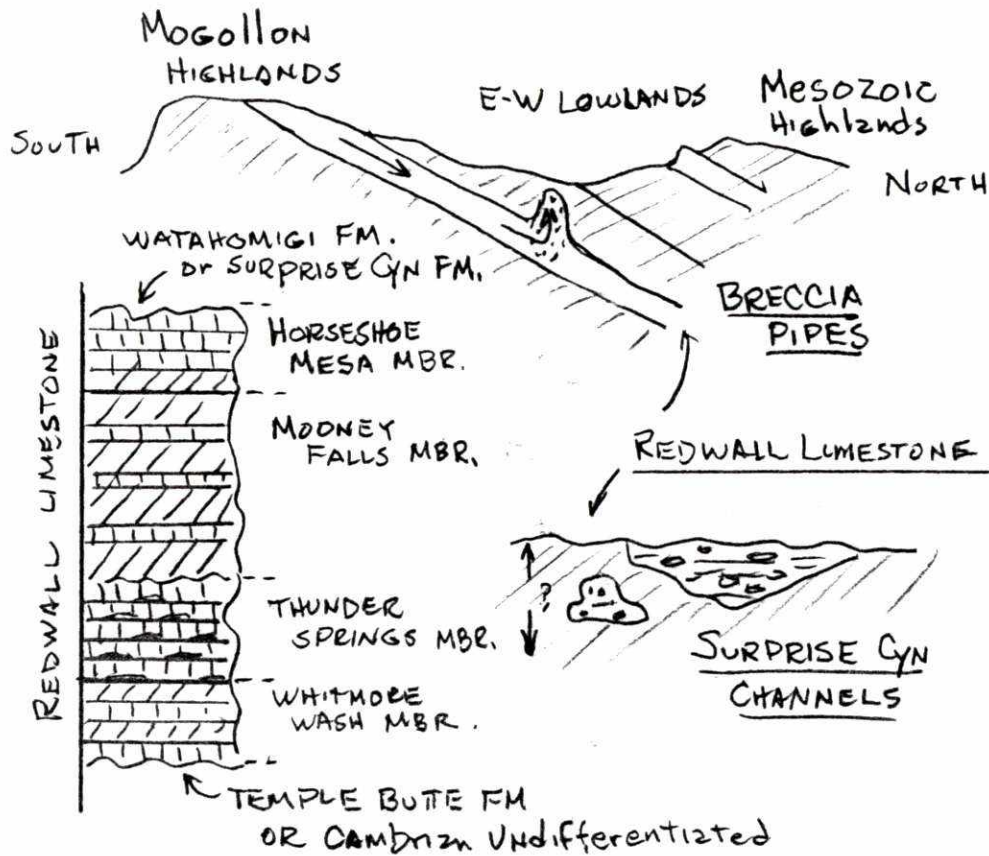


Fig. 1 Study Area location and some regional features described in the text. The circle detail is at the confluence of the Little Colorado River with the Colorado River and A - Chuar Basin area, B - Nankoweap Corridor, C - Little Colorado River



### Redwall Limestone Facies

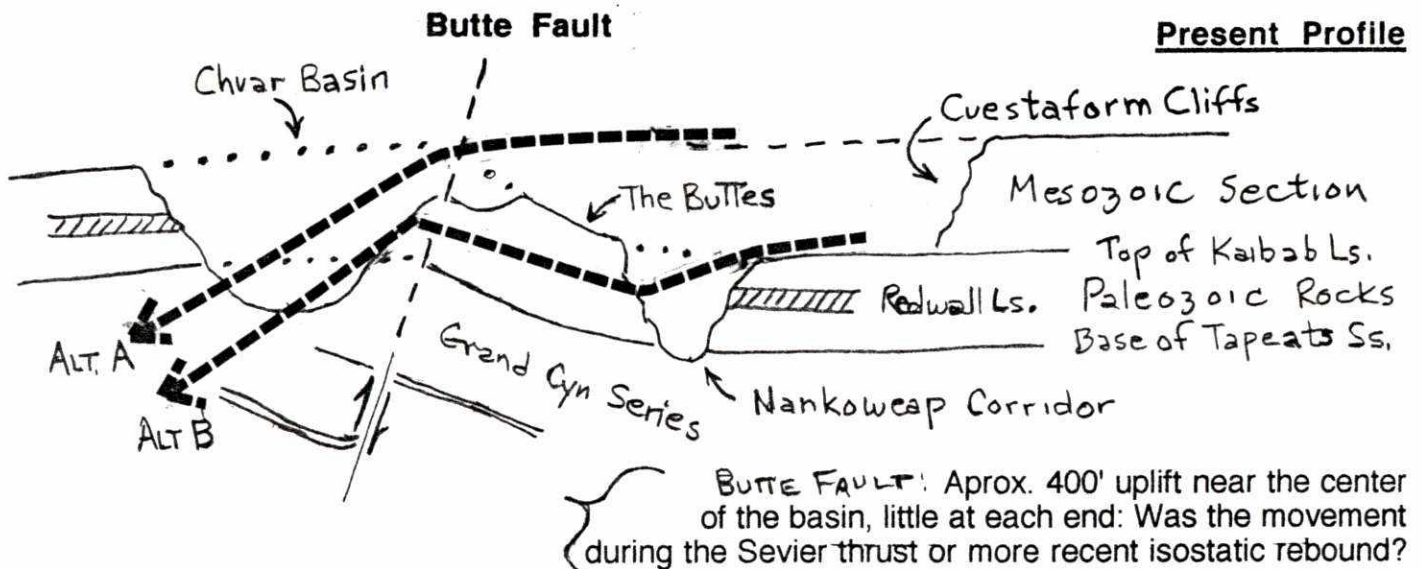
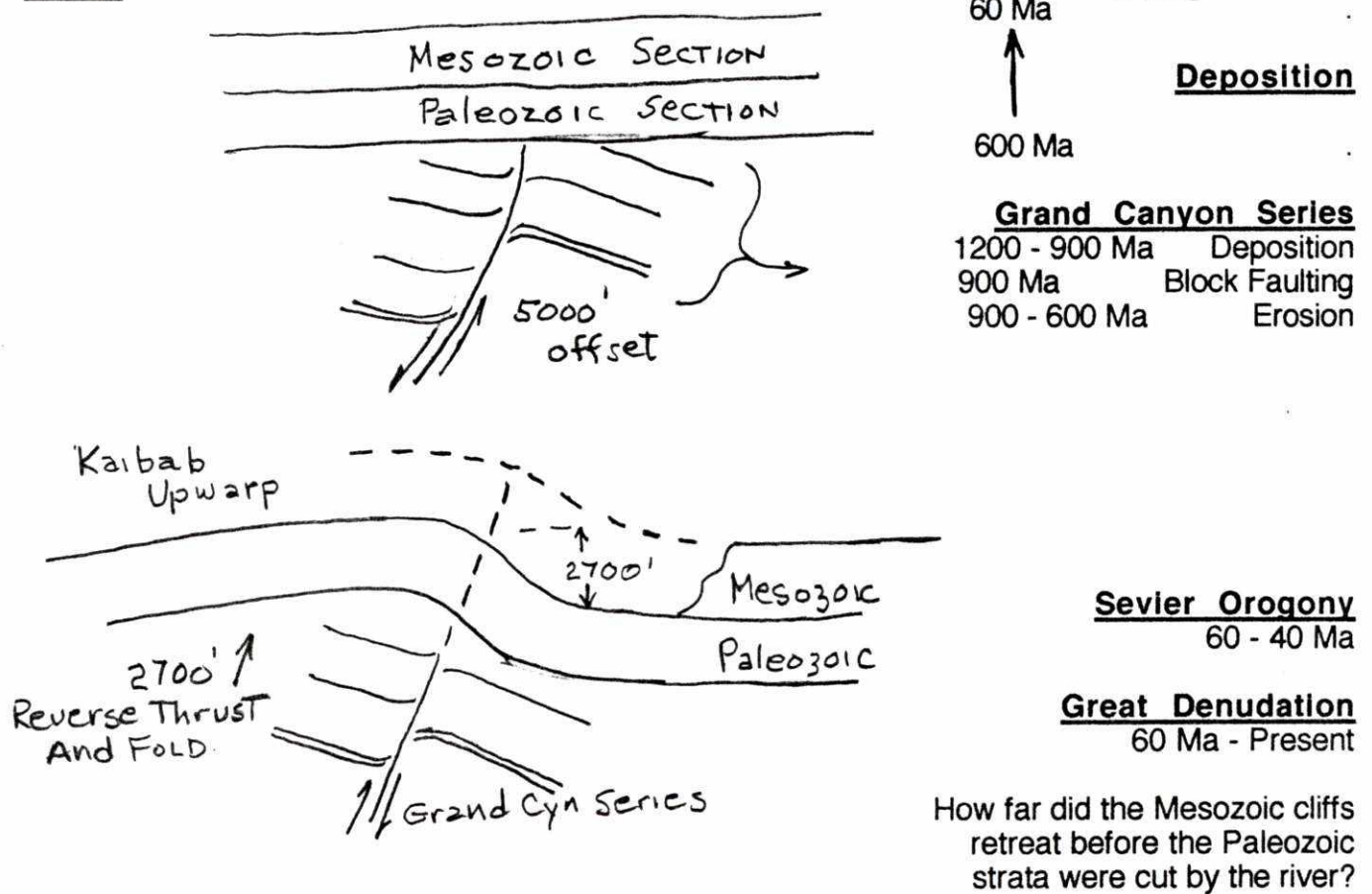
| <u>Redwall Features</u> | <u>Age</u>         | <u>Field Characteristics</u>                                                                        |
|-------------------------|--------------------|-----------------------------------------------------------------------------------------------------|
| Horizontal Karst        | Recent to Tertiary | Massive breccias, angular clasts<br>Only Redwall composition,<br>High porosity, caves and cavities. |
| Breccia Pipes           | To Mid Mesozoic    | Vertical stocks, mixed irregular composition, Multi formation, height, Variable porosity.           |
| Surprise Cyn Fm.        | Late Miss.         | Red siltstone, Conglomerate with chert pebbles, Competent Ss.                                       |
| Solid Redwall Ls.       | Mid Miss.          | Four members, Marine environments, Competent Ls.                                                    |

Fig. 2 Redwall Limestone Appearances (Facies), a variety of limestone textures within the Redwall Limestone and their relative ages. Diagrams identify the members within the Redwall and or their relationship with formations in contact with it.

# Redwall Limestone karst and Colorado River evolution

**West**

**East**



**Alt. A** Colo Riv development over Mesozoic rocks into Paleozoic rocks: Super-imposed stream.  
**Alt. B** Colo Riv development over and through Paleozoic rocks: Capture through karst conduits

Fig. 3 The Local Geologic History in three phases, deposition and erosion of the major sedimentary sections, movements on the Butte Fault and two major alternative hypotheses for river development

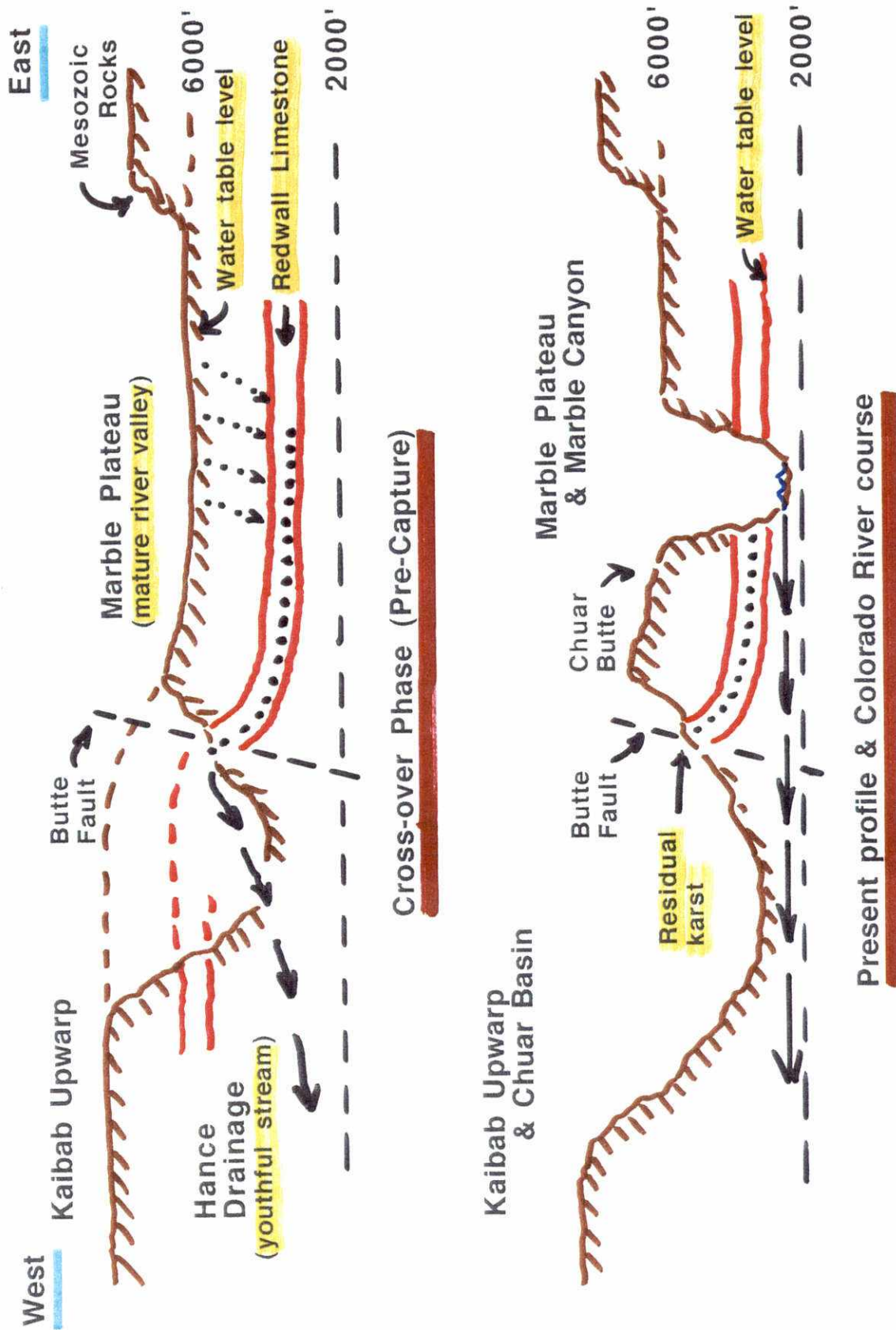


Fig 4 Cross-over Phase (Pre Capture) and Present Profile of the Colorado River course, looking North near Cape Solitude.

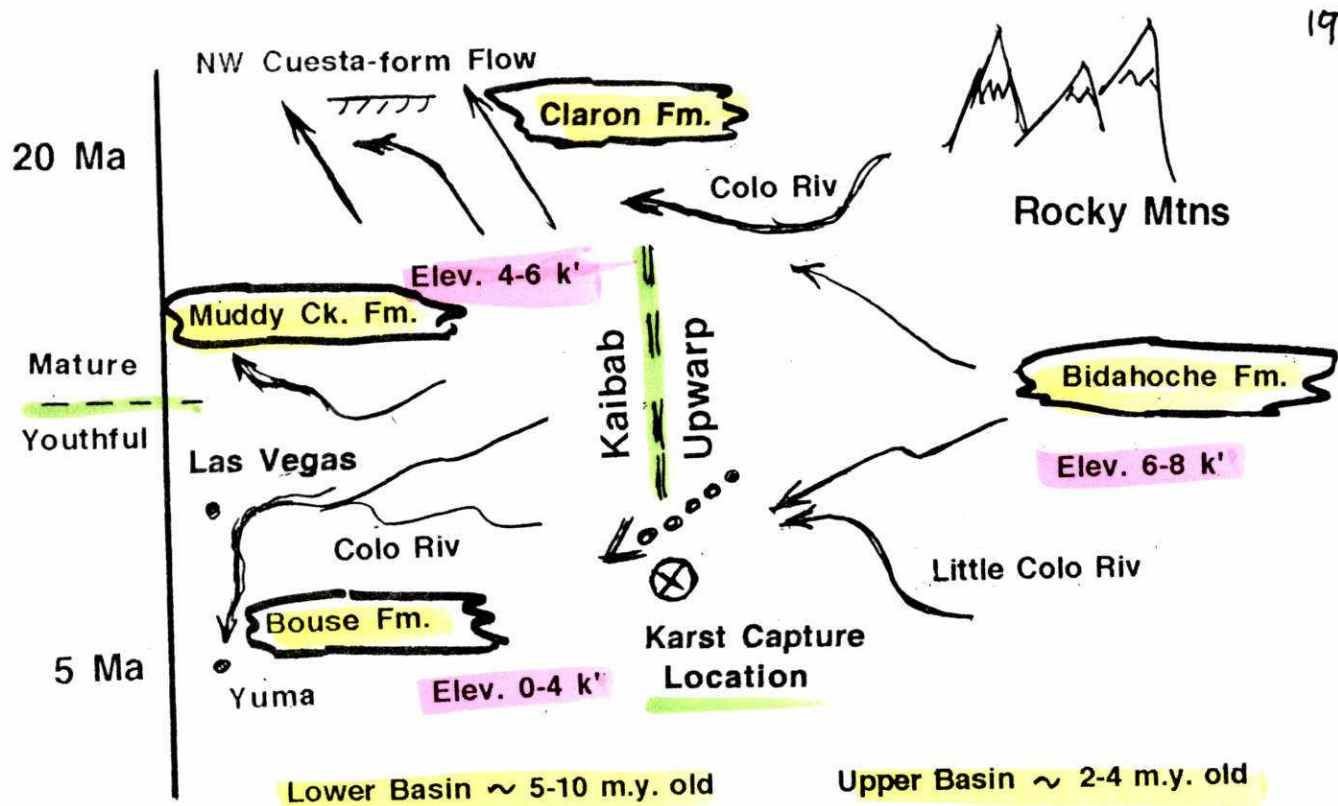


Fig. 5 A conceptual Regional Geologic History with four quadrants in space & time, correlating some Mid Tertiary Formations, flow regimes, possible elevations and the early conditions of the capture event.

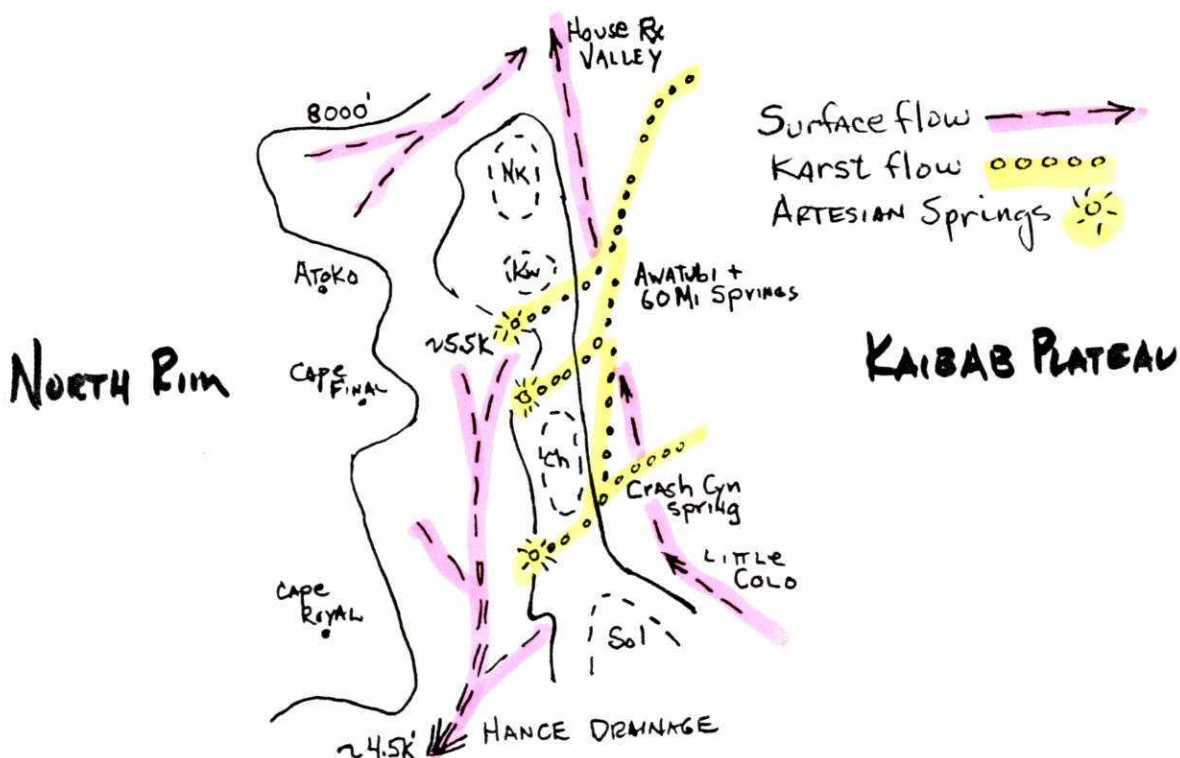


Fig. 6 A possible intermediate phase in the capture event showing surface stream flows and Redwall aquifer flow and artesian outlets.

| Today 0<br>(Meters) | Lava<br>Falls<br>Mi 200 | Havasu<br>Canyon<br>Mi 150 | Hance<br>Rapid<br>Mi 75 | Nanko.<br>Creek<br>Mi 50 | Stanton's<br>Cave<br>Mi 30 |
|---------------------|-------------------------|----------------------------|-------------------------|--------------------------|----------------------------|
| 40 Ka               |                         |                            | <u>25</u>               | 25                       | <u>30-40*</u>              |
| 150 Ka              |                         |                            | <u>50</u>               | <u>60</u>                | *hi level flood            |
| 500 Ka              |                         | "hanging<br>valleys"       | 125                     | 200                      |                            |
| 1000 Ka             | <u>&lt; 10</u>          | <u>50</u>                  | 250                     | 500                      |                            |
| 2000 Ka             | "no-change"             |                            | <u>500</u>              | <u>1000</u>              |                            |

Other sources —      My interpretation ~~~~~

Fig 7 Incremental elevations above present river levels extrapolated back to 2 Ma and some possibly related river corridor data. Little or 'No change' is established by volcanic ages below Lava Falls Rapid. 'Hanging valleys' are evidence of renewed cutting from an earlier base level in the lower river basin, in side canyons near or above Kanab Creek.

## River profiles with Hance as nickpoint

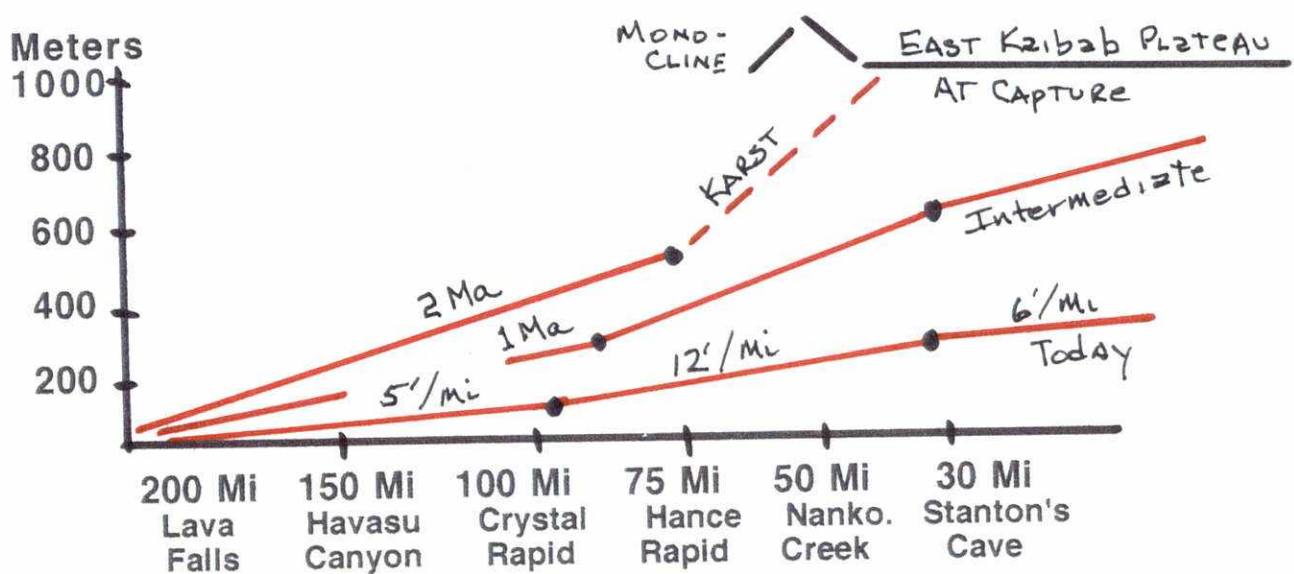


Fig. 8 Colorado River profiles with Hance Rapid (Pass) as the nickpoint with a postulated capture about 2 Ma and subsequent gradients at about 1 Ma and today.



**Photo 1** Looking west between Cape Solitude and Chuar Butte from Cape Bodaway, contrasting a rugged foreground with the distant open lower basin.



**Photo 2** Marble Canyon at River Mile 36 showing contrast between competent (river right) and mass wasted (river left) Redwall Limestone.



**Photo 3** 60 Mile Canyon showing multiple large dissolution cavities in the Redwall Limestone. Note person for scale to the right.



**Photo 4** View from Chuar Butte looking SW across the Butte Fault toward Hance Rapid at the Tapeats Sandstone Level. Desert Palisade in the distance.

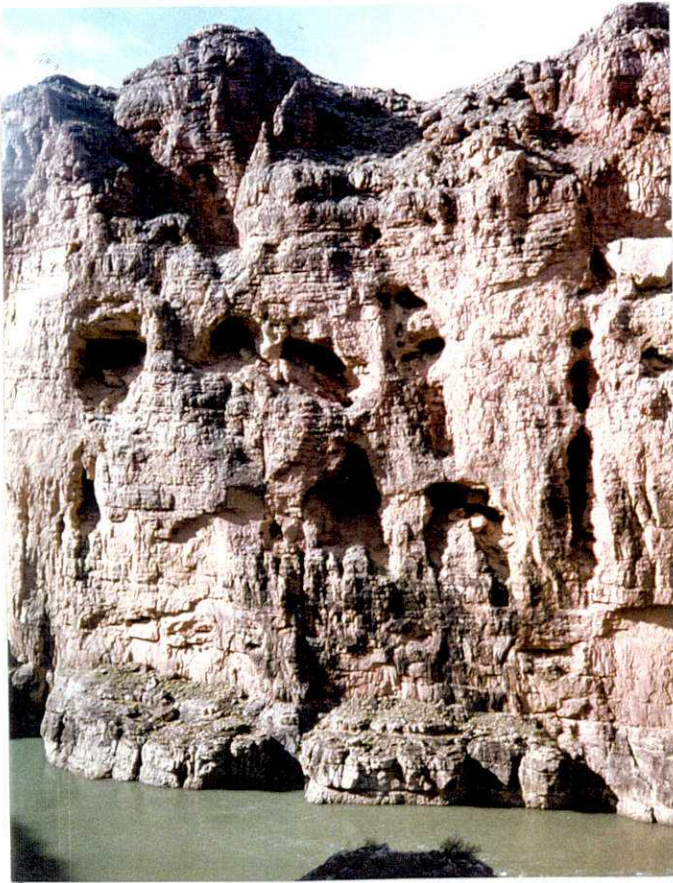


**Photo 5** River Mile 36, river right, showing multiple dissolution cavities in the Redwall limestone. The structures now dissected, are mirrored on river left.

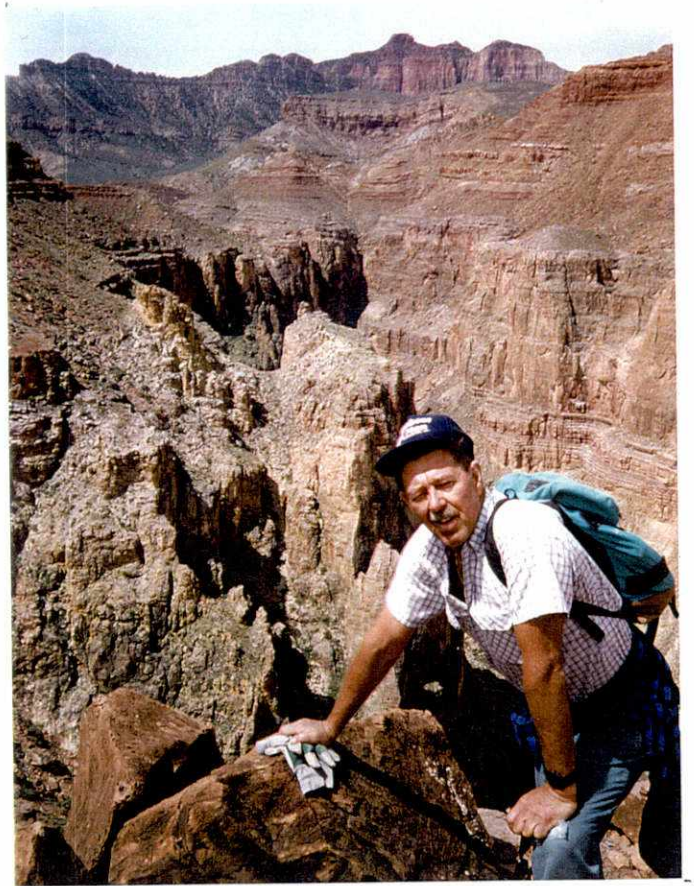


**Photo 6** 60 Mile Canyon looking to the west toward Butte Fault showing extensive mass wasting and lineaments of the karst features in the Redwall Ls.

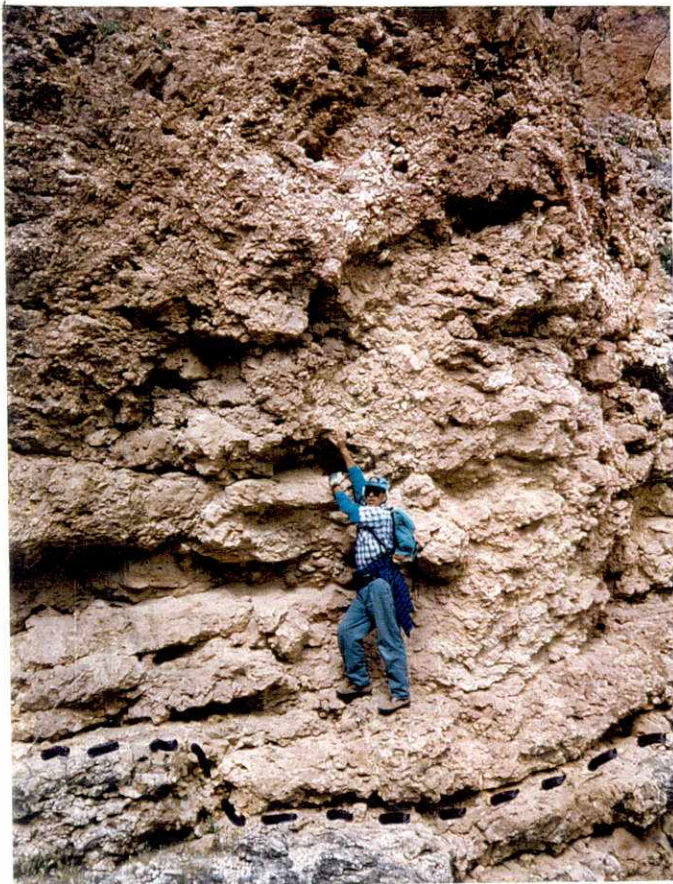


**Photo 7** 60 mile Canyon showing a massive collapse breccia in the Redwall limestone with lighter spar aureoles above and in contact with solid Redwall below.

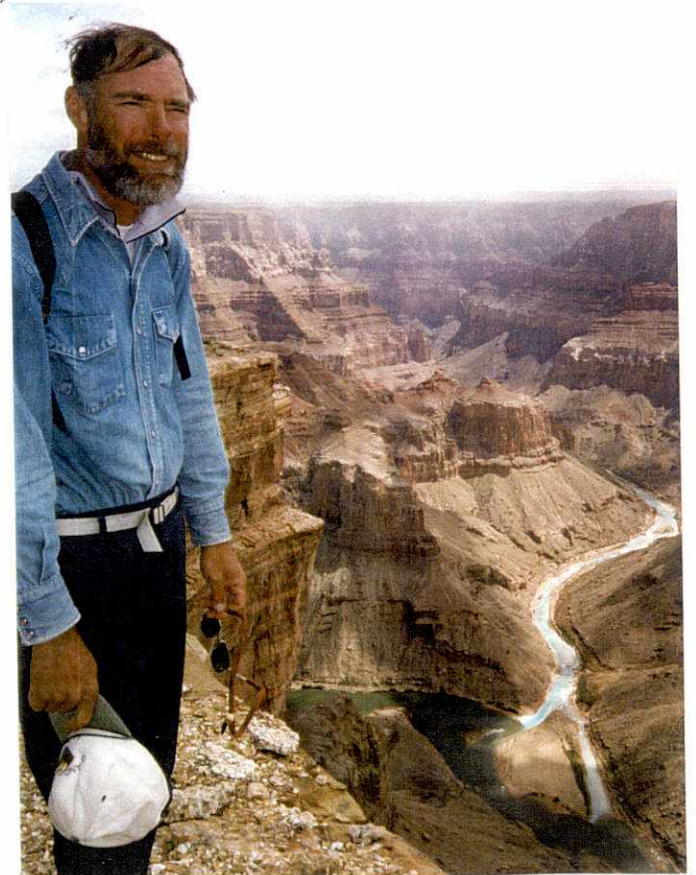


**Photo 8** On Chuar Butte looking south at Little Colorado River confluence showing mass wasting in the Redwall Limestone on the Cape Bodaway slope.



**Photo 9** Vertical cave entrance along the Butte Fault, elevation 4990 ft. Note Redwall Limestone ridge alignment to the south, the Desert Palisade and Comanche Point in far background.

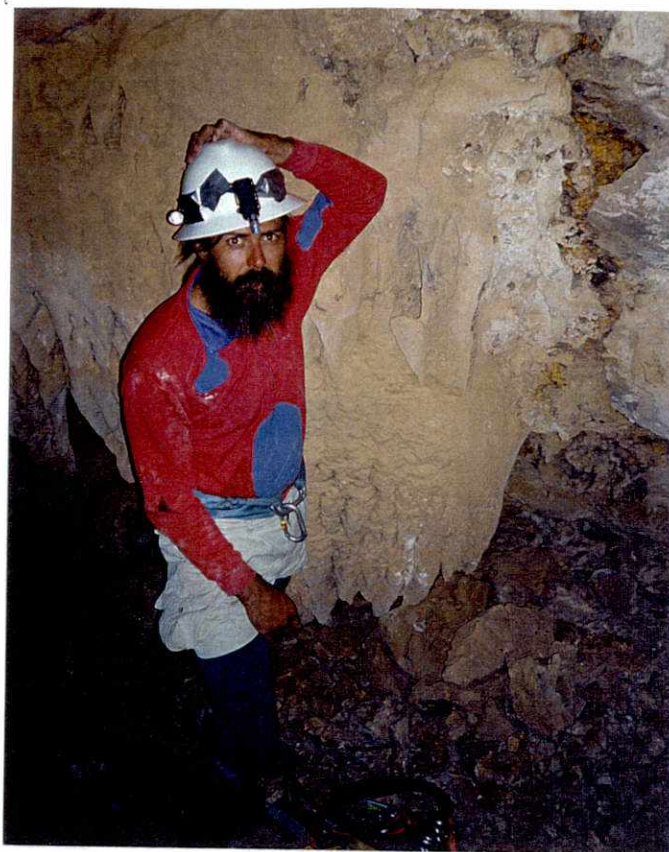


**Photo 11** Rubble filled bottom with subaerial travertine drapery. The cave could be 100's of feet deeper before trending horizontally with the Redwall stratigraphy.

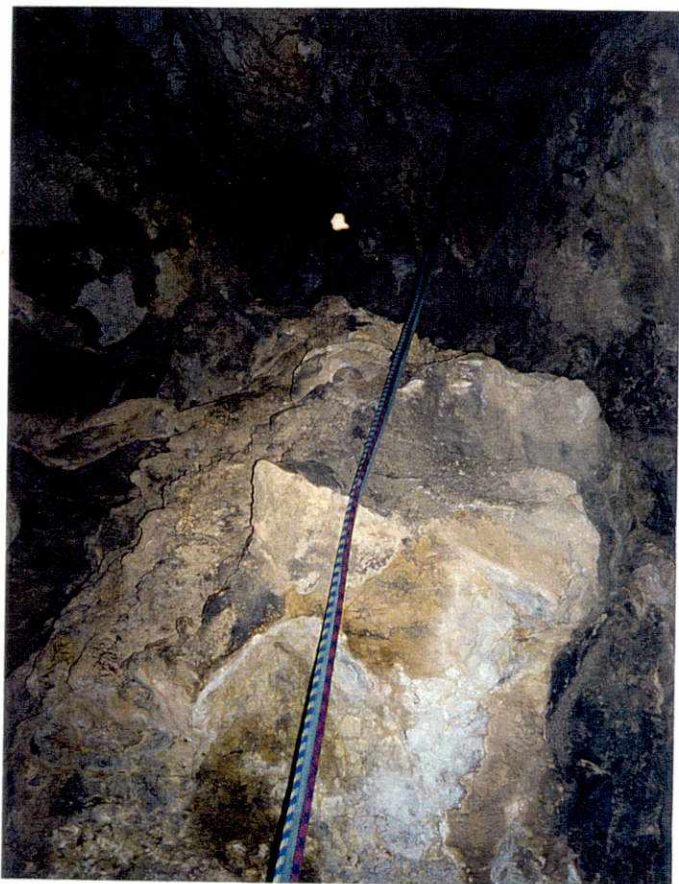


**Photo 10** Vertical cave descent about 120 ft., smooth but convoluted walls, 15 to 20 ft. diameter, interpreted as a former spring conduit to the surface.

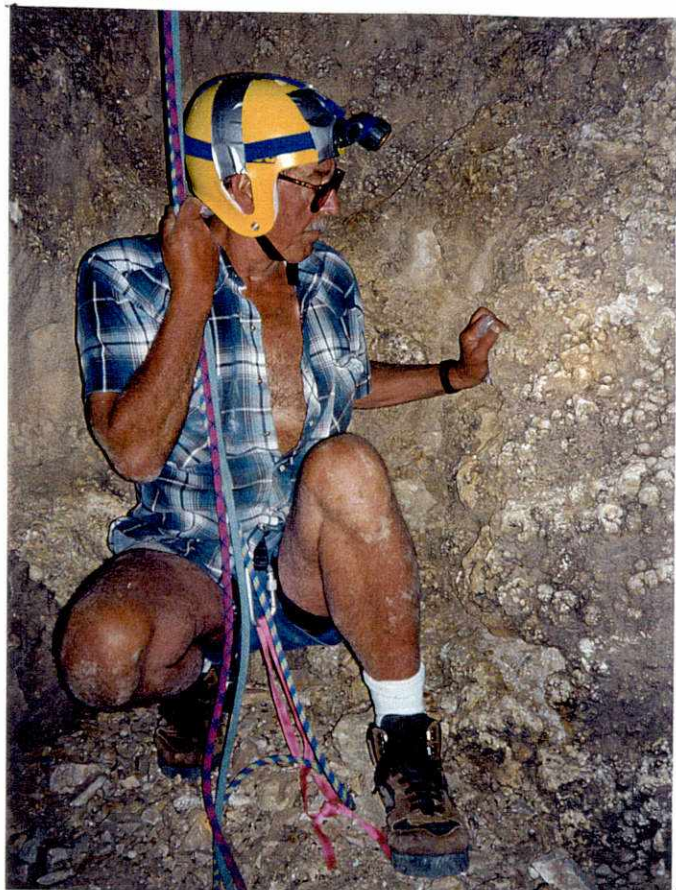


**Photo 12** Travertine nodules on cave wall, probably subaqueous, near-still water from a spring phase.



**Photo 13** House Rock Valley looking north, an abandoned low gradient course with the Kaibab upwarp to the left and the Mesozoic Vermillion Cliffs to the right.

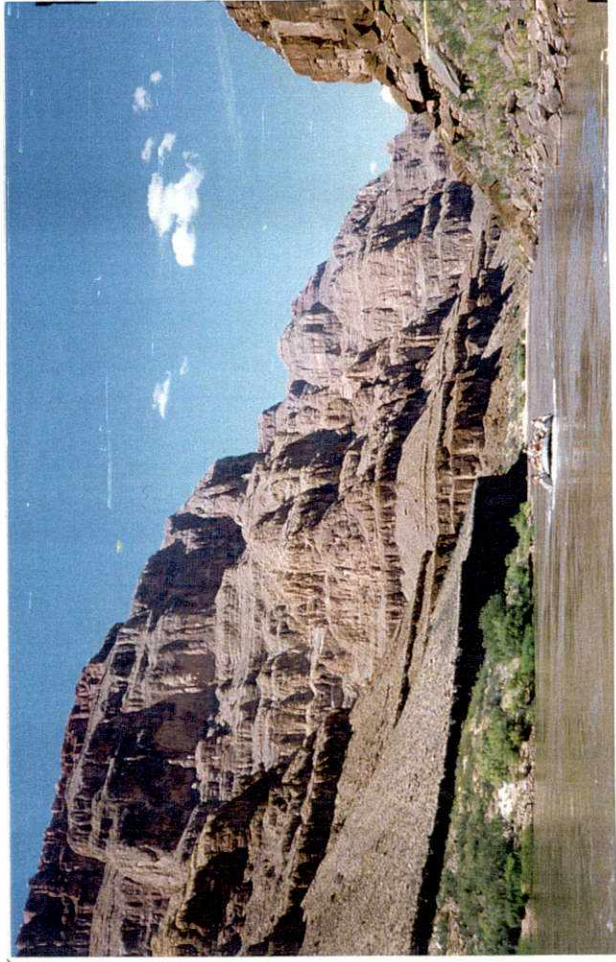


**Photo 15** The multi-stairstep aged erosional profile of the Redwall Limestone, common in the lower river basin below Lava Falls. Note basalt flow at river level.

**Photo 14**

The confluence of Havasu Creek, one of the larger side streams, with the Colorado River, showing a very narrow 'youthful' renewed cut of 30 - 40 ft.



**Photo 16** The Desert Palisade escarpment from Desert Tower to Comanche Point, looking west showing numerous truncated residual crenulated rivuletes from the missing Kaibab upwarp, now far to the background