HEAT AND DETACHMENT CONFERENCE

GRAND CANYON WALK

Grand Canyon Field Trip Guide

by

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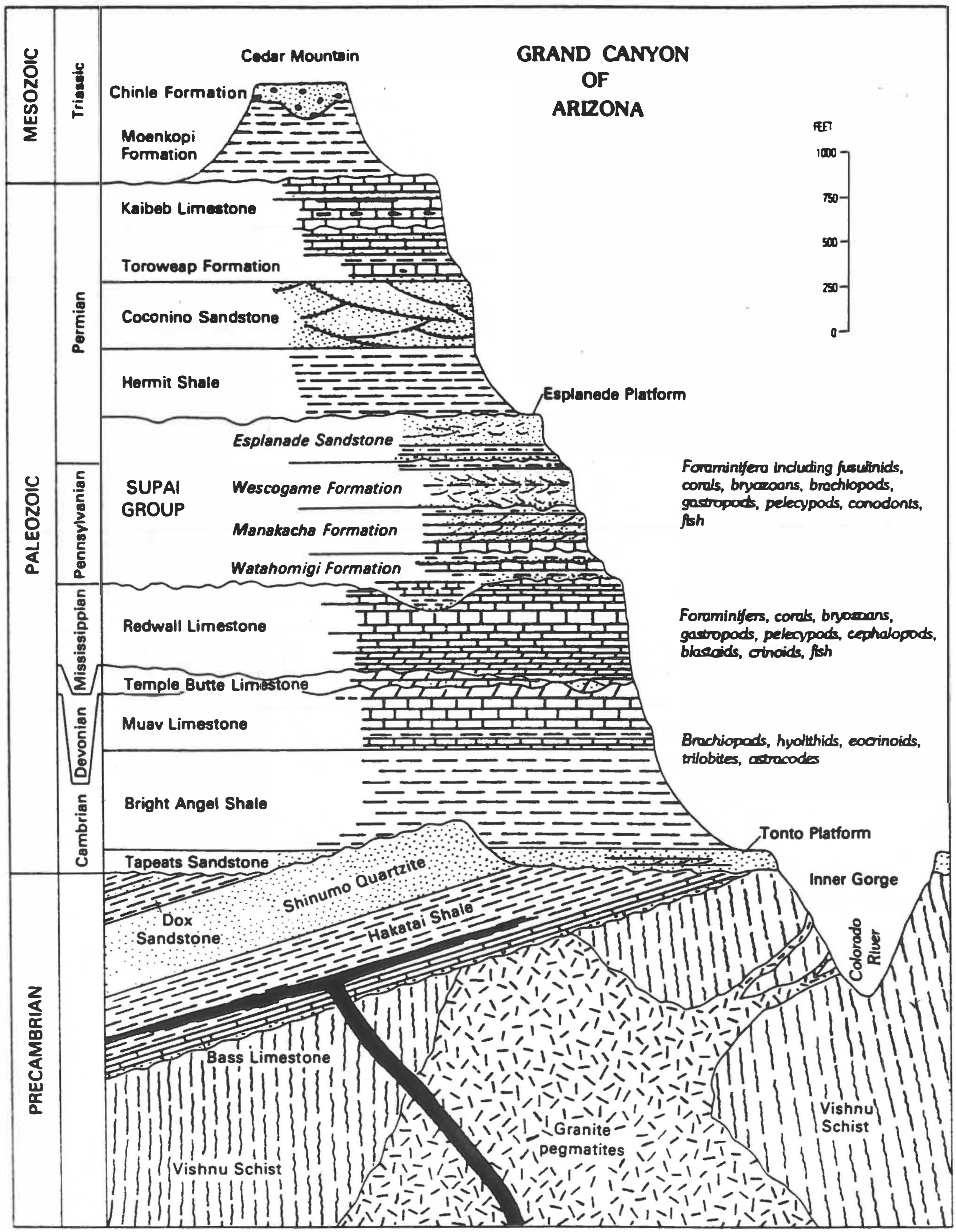
The field trip consists of a 2-mile (3.2 km) hike down the Kaibab trail with a descent of about 1600 feet (500 m). Trail gradient is moderately steep and uniform. Care should be exercised during the descent to walk softly and cushion knee joints, because the infamous and painful "canyon knee" is ever ready to pounce on hikers not accustomed to the long descents typical of canyon country. Light trail boots or sneakers are adequate for this walk. Water is essential and a hat advisable.

Whereas summer temperatures on the trail easily reach disagreeable or even downright dangerous values, mid-October should provide just about ideal conditions with pleasant temperatures and a relatively low sun angle that should emphasize both the geologic and the scenic aspects of the canyon.

The purpose of the trip is to view a continental area that has remained nearly undeformed for more than 1 b.y. This area is to be contrasted with the mobile terrane west of the Colorado Plateau that has been deformed extensively and repeatedly, notably by the extensional basin-range tectonism of mid- to late Tertiary time.

Stratigraphy (Fig. 1)

The section exposed in the general area of the field trip contains all the elements typical of the Grand Canyon: at the base, the Inner Gorge



From E.D. McKee, 1982

FIGURE 1

exposes lower Proterozoic metamorphic and plutonic rocks about 1.7 b.y. old with a steeply dipping fabric that trends about north-northeast, intruded by granite and pegmatite 1.7 to 1.35 b.y. old; next, upper Proterozoic sedimentary and igneous rocks of the Grand Canyon Supergroup, about 1.1 b.y. old and dipping gently northeast, are exposed near the top of the Inner Gorge; finally, horizontal Paleozoic sedimentary rocks form the cliff-and-slope topography so characteristic of the main part of the Grand Canyon. These rocks range in age from Cambrian to Permian. Triassic redbeds of the Moenkopi Formation -- the basal unit of the Mesozoic system -- crop out in scattered erosional remnants near the canyon. Two such exposures are Cedar Mountain, near Desert view at the southeastern edge of the Park; and Red Butte, south-east of Tusayan and a few km east of U.S. Highway 64, which is the main access route to the Park from the south. In spite of these Mesozoic exposures, most of the topographic surface near the canyon, and thus the canyon rim itself, is eroded to a stratigraphic level near the top of the Kaibab Limestone, the highest unit of the Paleozoic system. This situation, common in much of northern Arizona, occurs because the Kaibab is resistant to erosion under the semi-arid climate of the area, and is highly permeable, so that most precipitation sinks directly into the rock and thus is not available for runoff.

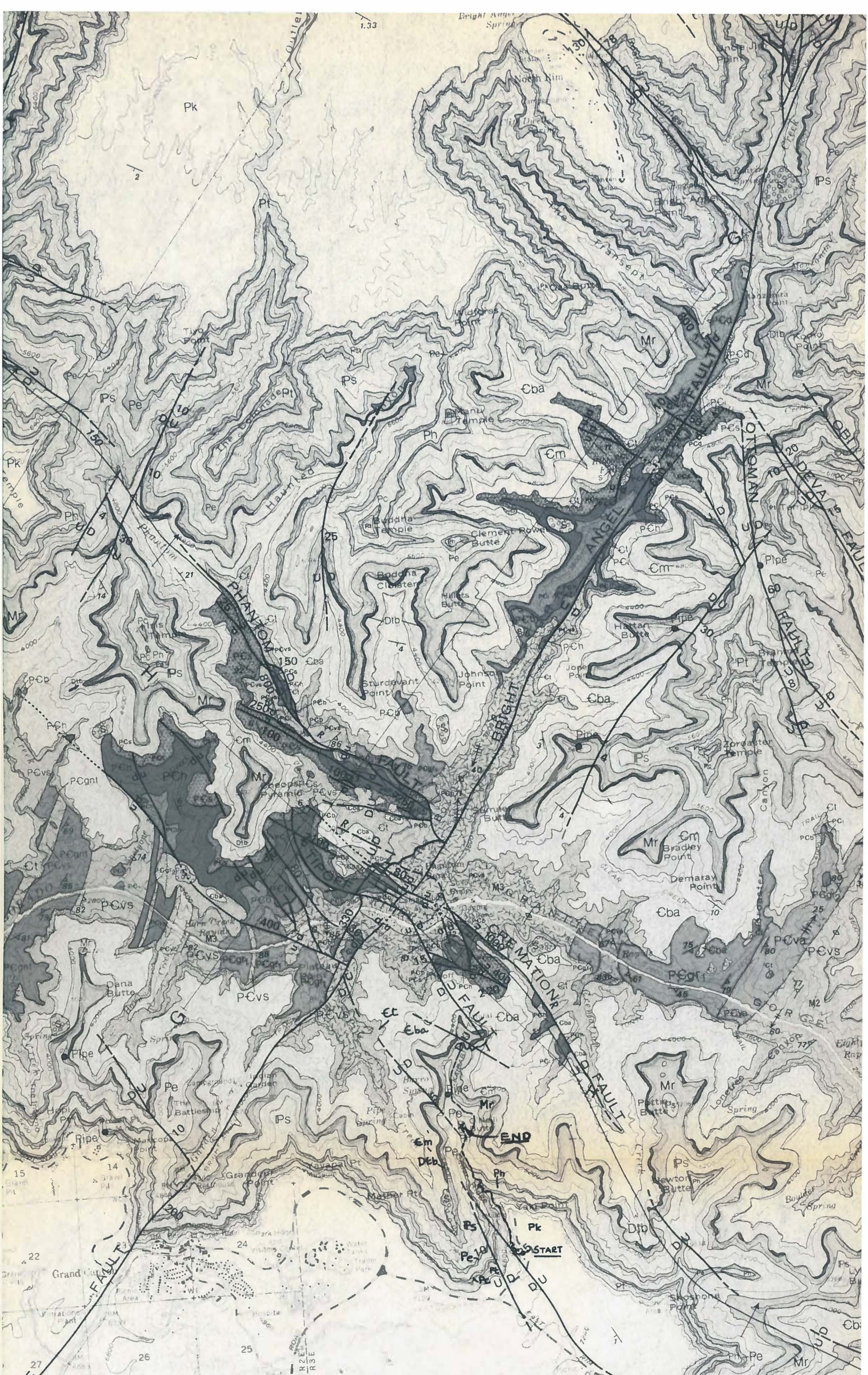
Several stratigraphic units lend the Canyon its distinctive appearance. The highest is the 500-foot cliff of the cross-bedded Coconino sandstone of aeolian origin, which forms a prominent whitish band near the top of the Canyon. The next lower distinctive unit is another 500-foot cliff, the fossiliferous Redwall Limestone, forming a reddish cliff about half-way down the Canyon wall. The Redwall is actually composed of white to light gray limestone and dolomite; the reddish color is the consequence of staining by redbeds above the Redwall. Finally, the prominent Tonto Platform directly above the cleft of the Inner Gorge is held up by the coarse conglomeratic cross-bedded Tapeats Sandstone of Cambrian age, the basal unit of the Paleozoic section. The prominent brick-red step-slope band between the Coconino and Redwall cliffs is composed of the sandstone and siltstone of the Hermit Shale and Supai Group, all of Permian and Pennsylvanian age.

The Paleozoic section spans the full spectrum of Paleozoic ages from Cambrian to Permian. Nevertheless, many age intervals (such as the Ordovician and Silurian) are not represented, so many contacts between units are disconformities or unconformities. As a result, in the Grand Canyon section more time is represented by erosion or non-deposition than by rocks that are preserved. This is even more true if the Proterozoic section is considered as well.

The Paleozoic rocks were deposited in shallow epicontinental seas that alternated with low-relief subaerial environments not far above sea level. The marine transgressions occurred in several cycles and typically from the west. The upper Proterozoic rocks were also deposited near sea level in basins that sank at a rate comparable to sediment accumulation. Basalts were emplaced as flows and sills as the Proterozoic sediments accumulated.

Rocks exposed along the trail (Figure 2)

The head of the trail and the switchbacks that occur in the first part of the trail are all in the marine fossiliferous Permian Kaibab Limestone. East and northeast of the Grand Canyon, the Kaibab becomes increasingly sandy and dolomitic, signalling the proximity of the ancient shoreline. In northernmost and northeastern Arizona, equivalent beds are continental in origin.



BRIGHT ANGEL FAULT
PHANTOM FAULT
TIPOFF FAULT
CREMATION FAULT
OTTOMAN FAULT
DEVA FAULT
GRANITE GORGE
North Rim
Transept
Tiyo Point
Haunted
Phantom
Buddha Temple
Clement Powell Butte
Buddha Cloister
Sturdevant Point
Johnson Point
Cheops Pyramid
Dana Butte
The Battleship
Indian Garden
Grandeur Point
Mather Pt
Yaki Point
Pattie Butte
Newton Butte
Shoshone Point
Hattan Butte
Zoroaster Temple
Bradley Point
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Below the switchbacks the trail straightens out and is cut into gypsiferous shale and sandstone, with local limestone beds, of the Permian Toroweap Formation. In the western Grand Canyon, the Toroweap includes massive sequences of limestone and documents transgression-regression cycles.

Another set of switchbacks heralds the descent through the Coconino Sandstone, an aeolian deposit of Permian age that is characterized by massive cross-bedding and tracks of land-dwelling animals.

Below the Coconino, the trail enters the distinctive red step-and-slope landscape formed by the continental Hermit Shale of Permian age and the Permian and Pennsylvanian Supai Group, which is dominantly continental and rich in plant fossils in the area of the Kaibab trail. Westward, the Supai becomes increasingly marine and calcareous. The Supai has been subdivided by E.D. McKee into formations whose Indian names are colorful but hard to remember or pronounce.

Structural features

One of the most striking features of the Paleozoic rocks visible from the Kaibab trail is their flatness and general lack of major deformation. This is remarkable not only because of the length of time in which there has been little deformation (about 600 m.y.), but also because areas beyond the western edge of the Colorado Plateau, as little as 160 km away, have been deformed deeply and repeatedly during the same time interval. The stratigraphy shows that the area oscillated above and below sea level repeatedly during Paleozoic time, but this resulted either from substantial changes of sea level or from epierogenic vertical movements not accompanied by significant tilting.

As a rule, Paleozoic and Mesozoic strata are flat and little disturbed throughout the Grand Canyon region and, indeed, the entire Colorado Plateau.

Locally, they are deformed by anticlinal and monoclinal flexures of late Cretaceous-early Tertiary ("Laramide") age, and by Tertiary high-angle faults, mostly of small displacement.

The main part of the Grand Canyon -- that accessible to most tourists -- is especially deep and impressive because it is cut across the Kaibab-Coconino plateaus, which are part of a Laramide upwarp trending about north and bounded east and west by monoclinal folds. The axis of the Kaibab-Coconino upwarp plunges gently southward, so that the south rim of the canyon is about 1000 feet lower than the north rim. The Kaibab upwarp is typical of many such upwarps on the Colorado Plateau, which are considered to represent draping of the sedimentary cover over basement structures. Monoclinal folds similar to those bounding the Kaibab are common in the Colorado Plateau region; some can be seen to pass downward into faults in the basement.

High-angle faults represent another class of structures typical of the Grand Canyon region. One such fault -- the Bright Angel -- controls the prominent linear canyon that is perpendicular to the Colorado River a few miles downstream from the trail. The fault trends northeast and is traceable for many miles south of the Grand Canyon, even though its post-Paleozoic displacement is minimal. At least six and possibly as many as nine episodes of movement can be documented for this fault since late Proterozoic time within the Grand Canyon. Slip directions have alternated with time; most displacements have been much greater than the post-Paleozoic one evident in the plateau country away from the canyon. Volcanic activity and recent earthquakes have occurred in the region along fault systems of the Bright Angel type. North- to northeast-trending high-angle normal faults farther west on the Colorado Plateau have down-to-the-west Tertiary displacements measured in thousands of feet.

A third class of structures is represented by north-northeast-trending features strikingly evident on the aeromagnetic map of Arizona. Some of these correspond to amphibolite belts in the Grand Canyon.

Proterozoic sedimentary rocks are exposed in fault-bounded blocks tilted gently northeast. The age of tilting is not known precisely. The Cardenas Lava, part of the Proterozoic section, have yielded a $^{Rb}/Sr$ age of about 1.1 b.y., and a $^{K}/Ar$ age of abut 800 m.y. The latter may be a reset age due to deepest burial under the Proterozoic sedimentary pile. If so, tilting would have occurred in the interval between 850 m.y. and about 550 m.y., the age of undeformed Cambrian strata overlying the tilted Proterozoic section.

In conclusion, there has been remarkably little deformation in the Grand Canyon area since about 1.1 b.y. ago. Deformation occurred chiefly at two times: late Proterozoic, and latest Mesozoic-early Tertiary ("Laramide"). The western Grand Canyon region has also experienced substantial extension in mid- to late Cenozoic time. Flaws in the Precambrian basement have influenced deformation, producing reverse faults under compression, and normal faults under extension.

History of the Grand Canyon and the Colorado River

The Grand Canyon has fascinated generations of geologists, partly because of its notoriety and scenic grandeur, partly because of the simplicity of the canyon's underpinnings -- flat-lying, little-deformed rocks -- which promise well for unravelling the canyon's history and applying this knowledge to the elucidation of general geomorphic principles. In spite of a century's efforts, however, the riddle of the Grand Canyon -- for a riddle it is -- has not yet elicited a solution that is acceptable to all.

Most of the earlier workers viewed the Colorado River as an integrated system from its beginning, and felt that the chief problem was to determine the age of the uplift that brought about canyon cutting. The uplift was generally thought to have occurred in early Tertiary time.

An alarm bell was rung in the 1930s by people working in the Basin and Range Province, downstream from the mouth of the Grand Canyon, where they found not only that Miocene deposits indicating interior drainage are universal, but also that little evidence for a pre-Miocene Colorado-like river system is present. By contrast, other workers have found much evidence for a Miocene or even pre-Miocene ancestral Colorado upstream from the Grand Canyon in northeast Arizona, Utah, and Colorado. In other words, the Colorado River seems to be old in its upper part, but young in its lower one. Thus, the riddle.

Several hypotheses have been advanced to resolve the dilemma, but most contradict facts now known. One hypothesis that, while not proven conclusively, is supported by circumstantial evidence and contradicts no known facts is this:

Until late Miocene time the ancestral Colorado River, then a mature stream flowing in a broad valley, reached the Kaibab Upwarp, which it crossed in an arcuate "racetrack" (such racetracks form where hard/soft couplets of strata cross a fold or domal uplift like the Kaibab). At that time, the river flowed on Mesozoic rocks, well above the stratigraphic level of the present topographic surface, but probably reached the level of the Permian Kaibab Limestone over the crest of the Kaibab uplift and was mildly entrenched in it. This uplift, while structurally high, probably was not then as topographically high as it is now. West of it, the river flowed northwestward along strike valleys. Its ultimate destination is a matter of conjecture, but in any case westward continuation along its present course in the western Grand Canyon is precluded by deposits as young as 6 m.y. that were laid down across this course.

About 5.5 m.y. ago the Gulf of California opened, and a river began to flow into its northernmost reach, as shown by the estuarine Bouse Formation, which crops out along the lower Colorado River. The new river eroded headward, gathering strength as it went. Its deposits consist of the Imperial Formation, a lateral equivalent of the Bouse that fills much of the Imperial Valley of California. Eventually the river worked its way headward to the Colorado Plateau, into whose edge it started cutting a canyon. This youthful river had a remarkable drop over its short distance, and therefore great erosive power -- much greater than that of the mature and sluggish ancestral Colorado. The upstart thus extended itself headward at the expense of pre-existing drainages, and eventually captured the older river. At this point the combined waters of the old and the new rivers flowed through the incipient western Grand Canyon, which was cut in record-breaking time: we know that about 6 m.y. ago the western Grand Canyon still did not exist; lavas a little over 3 m.y. old occur essentially at present river grade a few tens of kilometers downstream from the mouth of the Grand Canyon; and lavas about 1.5 m.y. old crop out widely at the bottom of the western Grand Canyon. Consequently, the Grand Canyon was cut to its present depth in at most 4.5 m.y. and possibly as little as about 3 m.y. The rate of downcutting was aided by about 880 m of uplift that have affected the western Grand Canyon region since about 5.5 m.y. b.p.

The moment of capture of the ancestral Colorado is recorded rather spectacularly by the sudden appearance in the Imperial Formation of Cretaceous coccolith fossils found only in the Mancos Formation of the Colorado

Plateau's interior. No such coccoliths are found beneath this stratigraphic level, but they are common above it.

Canyon cutting has not yet progressed far on the Colorado Plateau, most of which still retains its ancient aspect. Tributaries to the Canyon are short, steep, and immature. Those that are not -- the Little Colorado River, Cataract Creek, and Kanab Creek, probably are ancient tributaries to the pre-capture upper Colorado River.