Chapter 4 BUT WHERE IS THE RUBBLE?

The only place to cross the Grand Canyon by vehicle is a two-hour drive northeast from the Desert View vista point. The launch ramp for raft trips is there. To those who just want to get to Utah or the areas north of the canyon, this is a long, boring, dreaded drive on a two-lane highway through a sparsely vegetated landscape. Armed with a little geology, it is a remarkable traverse through some unique scenery and surprising natural history. I leave Desert View driving southeast and descend 1,700 feet over 14 miles. During the descent, the roadcuts reveal that the bedding layers of the Kaibab Limestone are lying parallel with the road surface even though I am now going downhill. They were nearly horizontal all along the South Rim but are now sloping downward! The road bends east, levels off, and I am travelling through a different world but still right on top of the Kaibab Limestone. Small cedars replace the junipers and pines, and a panorama slowly opens across an immense plain to the north. The gray ledges in the roadcuts are now horizontal again. The Kaibab Limestone has bent smoothly downward to the east from the heights at Desert View and has now levelled out again at a lower elevation! I have just driven down the southeast side of the Kaibab Uplift. Although not obvious to the casual traveler, the highway here was built on top of a gentle but dramatic warping of the Earth's crust. Something profound happened here. A sedimentary layer like the Kaibab Limestone that goes laterally from flat lying to sloping and then back to horizontal is a type of tectonic fold called a "monocline". The rest of the drive to Lees Ferry will be an adventure in visualizing an eroded land surface cut into this and yet another monocline to come. This segment going off the South Rim is the easiest part of the story.

Folds of this sort develop on the sides of a tectonic block analogous to a carpet on a brick patio wherein one of the bricks is pushed up from underneath. The upward bulge resembles the "half of a watermelon" shape of the Kaibab Uplift. An ant going down one side of the carpet bulge would be analogous to what I just did. It is a little different here, because there is another slope like the one now behind me but to my right and sloping toward me. The tectonic brick that pushed up must have an irregular protrusion here. To stay tuned to the geologic action here, it would be helpful to look from high above over the whole area and at the same time at a vertical cross section view of what lies underneath. Such a "block diagram" is standard practice in geology. Figure 4.1 illustrates the 3D situation here along the 27-mile drive from Desert View to the little town of Cameron (labelled "C" in the figure).

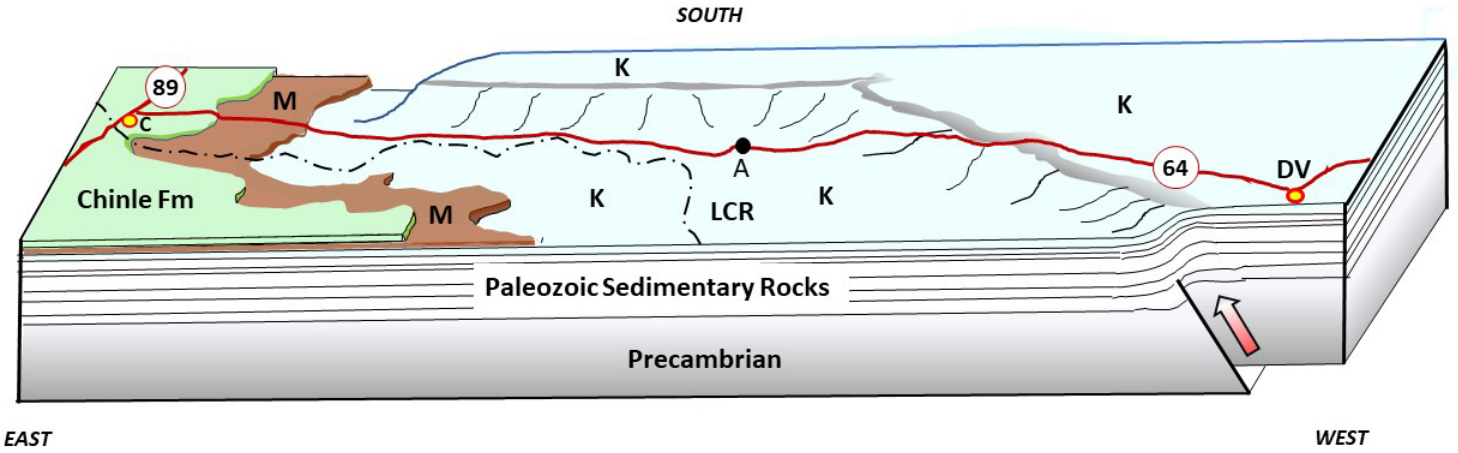

Fig 4.1. Block diagram giving perspective view looking southeast at cross-section and landscape around HW 64 as it descends from Desert View (DV) on the Kaibab Uplift to Cameron (C). The top of the block is 28 x 7 miles with vertical thickness of 2 miles exaggerated as shown. Driving from Desert View, the highway goes gently down the southeastern edge of the uplift, turns as it approaches an eastern extension of it, closes on the deep gorge of the Little Colorado River (LCR, dashed line), traverses up and over the layer of Moenkopi Formation (M) and meets Highway 89 atop the layer of Chinle Formation. The narrow canyon of the Little Colorado River passes immediately north of Cameron where the river cutting this deep gorge is flowing west. The cross section shows on the lower right how the Precambrian rocks are elevated west of a slanting, planar fault surface. The subsurface fault contact between the higher tectonic block to the right that pushed up over the lower block to the left is irregular with a huge bulge to the left across the top center of the diagram. The fault plane extends unseen in this diagram along the base of the Kaibab Uplift escarpment. It has bent east under point A and bends to the south again before the highway climbs over the Moenkopi. The Paleozoic strata are draped over the block boundaries to create two differently oriented monoclines. The Moenkopi and Chinle Formations once extended up and over the Kabab Uplift but have been stripped off by erosion back to their present positions. Thicknesses of the strata, locations, and subsurface representations have been arbitrarily altered somewhat for illustration purposes.

Monoclines are always draped over a fault zone deeper underneath. Here we could drill down to examine it-- or better to take a raft trip where all its fabulous details and complexities are plainly visible where it extends northward right across the Grand Canyon. Having done that many times before, I picture in my mind what I know lies 4,000 feet under the highway here.

I am at point “A” in the diagram over a spot where the underlying fault plane bends to the east. Highway 64 then runs along the base of the layers bent down over it. It is all still the top of the Kaibab Limestone. Off to the left a stunning gorge with columnar walls comes into view. No, it is not the Grand Canyon. It is the erosional chasm of the Little Colorado River cut down through the Kaibab Limestone as a major tributary of the Colorado River in the Grand Canyon. The “Little C” as it is called originates in high country along the eastern border of Arizona and runs to where it joins the Colorado River about 20 miles to the north here. It

seems as if the road will intersect it, but this scenic gorge instead bends sharply to run along the left side of the highway for six miles ("LCR"in Fig. 4.1). There are several places ahead where it is possible to look down into it (Fig. 4.2).

Fig 4.2. View north of the Little Colorado River canyon on lands of the Navajo Nation 0.4 miles north of HW 64 about 16 highway miles east from Desert View. The gorge is 1,300' deep here and elsewhere would probably be a National Park all by itself. This intermittently flowing river runs about 17 miles north and then bends west for 6 miles before joining the Colorado River in Grand Canyon. The small bumps on the extreme left horizon are the eroded, tilted edges of distant Kaibab strata plunging eastward down the Kaibab Uplift at the Grand Canyon. The eroded-back western edges of the dark Moenkopi and the overlying Chinle strata stand on the horizon at the extreme right.

The junipers and pine trees of the high country are now gone and here is a new world of scattered cedar trees. They quickly start to vanish about the same time as roadside markets with Native Americans selling jewelry and such indicate that I am now out of the National Park and on lands of the Naabeehó Diné Biyaad (Navajo Nation). A stunning view of the Little C canyon is sometimes easily accessible amid a large cluster of pavilions and tables with Diné people selling their homemade wares. That particular Native American bazaar is open some years and not others depending upon bizarre aspects of Diné politics. Preserved remnants of red mudstone, siltstone, and sandstone layers deposited over the Kaibab begin to appear, some as small buttes that gradually coalesce into a low cliff. What a change has transpired in the past 20 minutes! It is like being whisked through a tree-lined portal to the air of another planet. Remnants of the overlying red Moenkopi Formation are now all around the road and

straight ahead as a coherent unit. I drive up onto it and am surrounded by the cream-colored sands and maroon shales of the overlying Chinle Formation (left side of Fig. 4.1). The Moenkopi and Chinle once covered all the area behind me—even up the slope and over the Kaibab Uplift. Here they are preserved because they are lower down in elevation, but they are now being slowly washed into the Little C. Indeed, heavy rains create a striking sight when runoff filled with Moenkopi shale particles flows red over this highway. HW 64 ends, and it is time to turn northward on HW 89 to head back toward the Grand Canyon which had started trending northeast when I left it at Desert View. I turn left and arrive at the historic Cameron Trading Post.

Cameron is now a major tourist stop selling everything from authentic made-on-the-spot Navajo rugs to rubber tomahawks. The striking view out the big dining room window includes a geologic cross section of the sandstones and colorful shale at the base of the Chinle Formation. These were laid down here long after the great Permian extinction by a network of ancient streams and rivers, but I doubt many of those enjoying a famous Navajo Taco know or care. No time to stop for lunch, so I drive on and immediately cross the bridge over the Little C gorge. The river when it flows goes from right to left here, and a quick glance down into the chasm shows barely a trickle today. That is good news, because when the Little C flows red with mud from the Chinle and Moenkopi, it will really dirty up the Colorado River at the confluence, a place I will be at in three days on the raft trip. After crossing the bridge, the road gently climbs for 38 miles to get out of the huge, broad drainage basin of the Little C. The modern river channel is simply incised into this broad valley. A geologist looking at the Little C valley along HW 89 immediately notices how broad and worn down everything is and likely concludes that the Little C is a very old river, possibly one that together with its tributaries has been gnawing down the landscape for a very long time.

In contrast, a narrow gorge like the one I just drove over screams “young river” that has not had enough geologic time for its tributaries to smooth down the surrounding landscape. However, here the “young” narrow gorge lies along the center axis of the broader surrounding valley that screams “old, worn-down river.” Clearly, an older Little C was reactivated along a steeper path not long ago, but apparently after a much longer interval of erosion that produced such a broad, smooth valley. What is “recent” and what is “very long ago” in actual years? Ah, the age-old question everyone asks. It will keep coming back with increasing importance as I continue this pilgrimage. For now, I recall technical papers arguing that the new incision so pronounced under the bridge has happened in the last few million years with the broader valley representing erosion over a period of tens of millions of years--or possibly even much longer as some have suggested. How that happened is tied up in the controversy of how the Grand Canyon itself formed.

Now driving north, imposing cliffs of a sandstone called the “Echo Cliffs” have appeared to my right. They trend to the northwest and will intersect the highway within 20 miles. It is the Navajo Sandstone, a regional sheet about 200 feet thick. It undoubtedly covered this whole area once, including the Chinle, Moenkopi, and the whole Kaibab Uplift. Why hasn’t it

been stripped away over here to the east? The answer is that the highway is heading toward another monoclinal fold that dropped the area to the east. When it reaches the resistant cliffs near a town called “The Gap,” the road will bend more to the north and travel along the axis of the fold (Fig. 4.3).

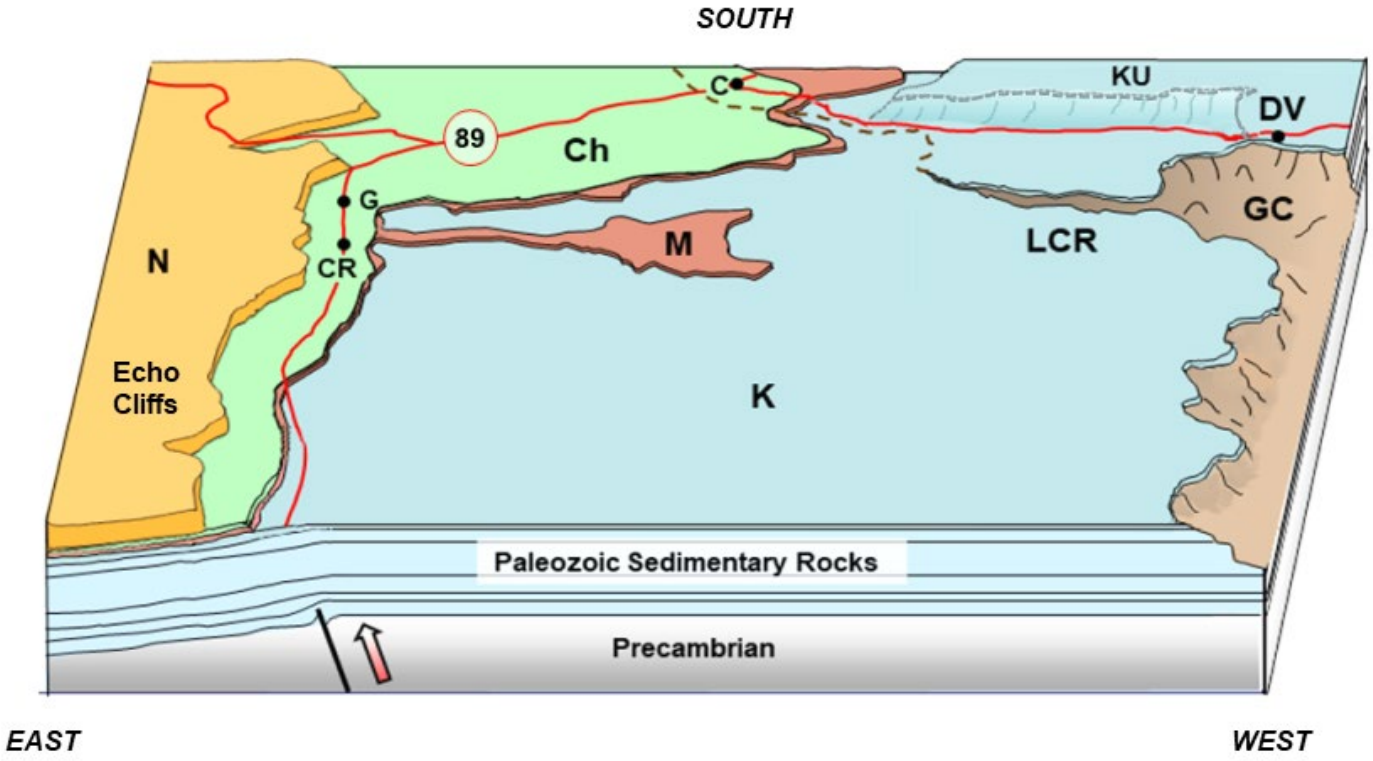

Fig 4.3. Block diagram giving perspective view looking slightly east of south at cross section and landscape around HW 89 as it extends from Cameron(C) through the Gap(G) and Cedar Ridge (CR) toward Lees Ferry. The smaller area of Fig. 4.1 lies across the upper right. The top of the block is approximately 45x45 miles with the two-mile vertical cross section exaggerated as shown. The highway climbs gently upward from Cameron to Cedar Ridge and then gently downward from its path on the Chinle Formation (Ch) through the Moenkopi Formation (M) then back onto the Kaibab Formation (K). The drive north on HW 89 approaches and then runs roughly parallel to the Echo Cliffs defined as the western edge of the Navajo Sandstone (N). A subsurface fault plane extends back from the cross section under Cedar Ridge and on to the southeast (upper left corner) under the edge of the Echo Cliffs. A Precambrian tectonic block pushed up along this fault and warped the overlying Paleozoic Sedimentary Rocks into a monocline as shown. The folded strata level off again starting at the left edge of the diagram.

The sloping surface of this monocline is very steep and has been vigorously attacked by past erosion. So, here we have 3 tectonic blocks that sit like steps on a staircase rising toward the west with the Kaibab Uplift being the highest. The road from Desert View descended first down the East Kaibab Monocline and has now encountered an almost parallel monocline less than 20 miles to the east. It will travel north along the western, top part of this second monocline for 45 miles.

The Little C behind me, new wonders appear as sagging Highway 89 just north of Cameron becomes a roller coaster ride called the "Chinle Rapids" by its frequent flyers. I am climbing slowly uphill out of the older, broad valley of the Little C and encountering some strange scenery indeed. All around are humps of gray, green, and maroon shale of the Chinle that clearly turn to gumbo when they get rained on. These "badlands" will soon wash back downhill toward the Little C. Here and there, harder layers of siltstone and sandstone cap and protect some of the humps of shale underneath or form irregular ridges that stick out the sides. Many of these are Triassic stream channel deposits. Afternoon has arrived, and the heretofore dull landscape colors start becoming more vivid. In a few hours they will blaze in the setting sun, a beautiful sight I have often viewed over white knuckles as the two-lane road rises, falls, and ripples amidst oncoming traffic racing way too fast for safety. The weak shales of the Chinle Formation simply sink and sag from the weight of the traffic. It is a killer highway that could only be made smooth by sinking pilings and basically making a highway bridge for many miles over the intermittently soupy mass below. Arizona taxpayers are not about to pay for it, so hang on. Some of the gray heaps out the window are ash from great volcanic explosions that blew up regularly about 200 million years ago somewhere in the area. The ash and dead trees washed into streams and rivers and accumulated in vast flood plains adjacent to the streams. Later ground waters during burial percolated through the riverbed sands and impregnated the rotting wood with opal and microcrystalline quartz to form petrified wood. This is the same layer which farther to the southeast hosts the Petrified Forest National Park. The petrified wood is also found here, but it is not as colorful as at the Petrified Forest.

In my mind's eye, I see the goings-on here back in those days of the Triassic (200-250 million years ago), but not for too long because this is quite a ride. Slow down and you get run over. Speed up and you are driving dangerously-- especially if you are having reveries about lush Triassic trees growing happily here until one day they get buried by ash or blasted down and turned into log jams in ancient rivers made muddy from all the ash washing in. Concentrating so much on highway safety, it is easy to miss seeing on the right that the massive almost white Echo Cliffs to the east are moving closer and closer to the road with every passing mile. Finally, I traverse the Chinle Rapids and reach another old trading post, "The Gap" (Fig 4.3).

*Fig 4.4 Broad drainage basin of the Little Colorado River. The land on both sides slopes gently down toward the river. A dramatic and deepening gorge is cut into the broad basin floor from around Cameron to the confluence with the Colorado River. The drive north from Cameron to the launch point of the raft trip is shown as a dashed line. It climbs uphill through "The Gap" (**G**) and reaches a drainage divide at Cedar Ridge (**CR**) after which it slopes down toward the Colorado River. (Diagram after Shannon 1, Wikipedia)*

Yikes… remorse. I should have bought one of those locally made $30 Navajo Rugs on the wall of the Navajo coffee shop here back in 1970 when I first came from the north along this once-lonely road. Now they probably aren't sold here because they can go for thousands of dollars at upscale galleries in Scottsdale. More to the task at hand, I look up to the east at the actual gap in the cliffs of the prominent thick layers of Navajo Sandstone. This physiographic gap in

the cliffs is the namesake for this little clump of old Navajo buildings. It is an overly broad U which looks for all the world like the cross section of a big river channel---a river went through here once? Having read all the theories for the origin of the Grand Canyon, I know that would not make sense in terms of the currently most popular one. However, geologists mapped out an extensive string of gravels on the far side and confirmed that there was indeed a river flowing through this gap in the cliffs. Ivo Lucchitta, a former United States Geological Survey (USGS) geologist who long championed a geologically young Colorado River system that formed within the last 3-5 million years led the mapping and called it the "elephant in the room" because it is clearly a very ancient riverbed not part of the Little C valley. When I heard him call it that at a conference, I smiled to myself and thought about my deceased friend Don Elston, one of Ivo's USGS colleagues who long ago argued that the Colorado River and its tributaries were already in place tens of millions of years ago. Don first pointed out this gap to me and argued that it is evidence for his theory that this landscape is much older than the popular theories nowadays. Young vs old is a battle still raging with new players who are somewhat less friendly to each other than Don and Ivo were.

Beyond The Gap, the highway still runs gently uphill on the north side of the vast Little C valley, but it now travels parallel to the steep escarpment to the right. For some time approaching the gap in these cliffs, the view out the passenger side window made it apparent that the underlying Chinle Formation layers are not horizontal like a stack of pancakes on a plate but rather are gently tilted downward toward the cliffs to the east like a plate of pancakes lifted slightly on one side. Indeed, I am now squat on the axis of a monocline, a much smaller scale version than the eastern margin of the great Kaibab Uplift. The tilted strata are part of the second monoclinal fold connecting this middle block I have been driving on with its neighboring block lower down to the east (Fig 4.3). The Chinle strata are diving down into the subsurface and under the Echo Cliffs to the right where they level off again out of sight. Those cliffs used to extend right above the highway I am on and onward to the west. They got stripped away by erosion gnawing at them going west to east. The tilted Chinle beds and the Echo Cliffs are the remnants yet standing. Out the driver's window to the left, the top of a gray ramp of Kaibab Limestone with its overlying Moenkopi strata all eroded off rises gently up into the sky. Ha! Here it is again. If I were to hike up that Kaibab ramp, it would flatten out and go 20 miles to the west where it would approach the northern part of the Kaibab Uplift that I just drove down the southeastern flank of from Desert View. The east side of that uplift defined by the monocline over there is gouged out by the Grand Canyon. Wow. If I could follow the ramp I am on downward to the east into the subsurface, I would see it sloping under the highway and then levelling off again under the Echo Cliffs, as monoclines do. Geology in action here. Using a bit of science to visualize in 3D here what the geology and my eyes are telling me turns this drive into a meaningful experience. How many eyes have seen this?

A few miles farther along, cedar trees appear again and the road levels off to end its long climb up from Cameron. Here is the sparse, scattered Navajo settlement at Cedar Ridge on the drainage divide between the Little C and the Colorado River ahead to the north. The

highway begins to descend through the stack of sedimentary layers again. The Echo Cliffs drift off to the right a bit, and the road is back again on the block I descended to from Desert View. Any remnants of the overlying Chinle and Moenkopi strata are being washed down into the Colorado River canyon to the northwest and then carried through the Grand Canyon to the Gulf of California. The road now travels along the top of the Kaibab Formation once again. Far to the north, the Vermillion Cliffs rise into view on the horizon. They are an even thicker stack of layers overlying the Kaibab and are well preserved to the north on into Utah. They are a coherent stack of the reddish-brown Moenkopi, Chinle, and almost white Navajo sandstone layers. The slightly slanting strata of the Echo Cliffs on the monocline to the right extend on ahead and join with the Vermillion Cliffs at the Colorado River at the very spot the boats will launch tomorrow.

This sometimes-harrowing drive that so many find tedious from Desert View to the Vermillion Cliffs is actually a colorful thing of wonder. What a story! It begins with the great extinction horizon that caps the Kaibab uplift. Then east down the monocline and into surviving remnants of the coastal muds and river deposits that were laid down subsequently. Then north into the younger, overlying Chinle with all its river deposits, volcanic ash and petrified wood that were subsequently covered by sand dunes possibly like those of the Sahara Desert--the Navajo Sandstone. What changes here! What is the complete story of how all this happened and why? It is something I would like to immerse myself in. But now the trouble starts.

The imposing cliff face of Navajo Sandstone to the right is there because blocks are falling off and causing it to retreat eastward. South of the crest at Cedar Ridge, the pieces of the cliff face that fell off were eroded downhill toward the south via a broad wash heading parallel to the highway back toward the Little C. North of the divide, the Echo Cliffs start trending northeast toward the Colorado River, and rubble that falls off is carried directly down to it via a tributary network of little streams. The standard explanation for the cliffs on the Colorado Plateau is that once tilted, erosion washes out the most erodible layers at the base of a cliff. An overlying resistant layer is left protruding until the overhang falls off (Fig 4.5).

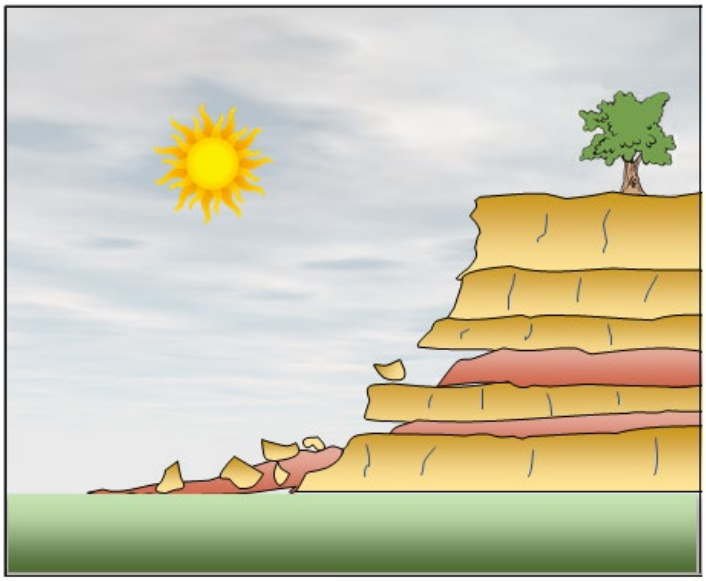

Fig. 4.5. Cliff retreat. Less resistant strata wash out from cliff faces leaving overhangs which break off and accumulate as rubble at the base of the cliff. That debris is eventually weathered, washed down to streams, and carried away.

The rubble is then washed away. In this way, the cliff slowly advances in the direction of the tilt. Indeed, the whole Colorado Plateau is not horizontal; it generally tilts on average about 11 degrees to the northeast. So, the process creates impressive cliffs like the Vermillion Cliffs ahead or smaller ones like the Echo Cliffs off to my right. This is in all the textbooks and sounds good.

However, I got a severe jolt once while driving the stretch from Cameron to Cedar Ridge with Howard Bond, an astronomer then with the Hubble Space Telescope. This curious observer was fixated on the majestic cliff faces to our right and asked a simple question "If erosion proceeds by blocks and pieces falling off this escarpment and getting eroded away, where is all the rubble at the base of the cliff waiting to be transported away"? There is a significant scattering of boulders there, but it is true there aren't nearly as many as one might expect from the high cliffs and the standard textbook explanation. "Well, I assume the dry wash here flows often enough to bang them to pieces and sweep the residue down to the Little C where they are carried to the Colorado River in Grand Canyon and then into the ocean" was my instant response. He did not seem convinced, and the more I looked at that gentle smooth wash and the relatively thin scattering of boulders along the base of the cliff, the more I realized that something is indeed wrong here. My thoughts nowadays tend to favor Don Elston's explanation that this is an older landscape eroding now at a much slower rate than it did in the past--a landscape mostly frozen in time. During this long standstill, the fallen cliff blocks have had ample time to disintegrate into sands that can be more easily carried downhill to the Little Colorado River. Elston argued that the regional climate was wetter in the more distant past and that erosion rates in the past 10-30 million years in this region have been drastically overestimated. How can the whole Grand Canyon system have formed in the past 5 million years in a landscape frozen in time? The "old vs recent" theories for the origin of Grand Canyon challenge me again.

Now a certain tribulation begins to menace my just-started pilgrimage—one that will grow and gnaw with every passing day. I am off to wallow in the results of science as applied to some of the most spectacular, majestic, and beautiful scenery on Earth. But which science will I use? Whose science? There are endless textbooks, guidebooks, and authoritative professional publications that I have absorbed. Yes, there are lots of disagreements, but are these only about details? No, they deal with the major features associated with Grand Canyon geology. Science is an ongoing effort, but it tempts us to accept the current conventional wisdom that has been promulgated in the most effective fashion. I always practiced critical inquiry before I started, but here my whole plan is suddenly threatened as the veil of uncertainty begins to drop over me.

The Grand Canyon is one of geology's premier features, so it is embarrassing that its erosional history is so little understood and so controversial. John Wesley Powell was both the first white explorer and the first geologist to traverse the thing. He reasoned in 1869 that the river course was ancient and that the land surface rose under it at tectonic speeds (very slowly). The river then simply cut persistently downward analogous to raising a thick book up under a spinning saw blade. About 60 years later, a great geologist named Eliot Blackwelder noted that there were dried-up lake beds lying athwart the Colorado River channel at the mouth of the Grand Canyon at the Grand Wash Cliffs way to the west of here. These sediments which I will pass through at the end of the raft trip were clearly younger than all the uplift and tectonic disturbances in the area--but the river has cut only a small incision in them. In other words, the river could not have been flowing when these lake beds formed and dried up; it had to have entered the area more recently. In the 1960's, a volcanic ash bed in those playa lake sediments was age-dated as approximately 8 million years. So, the Colorado River mouth at the end of the Grand Canyon had to have formed within the last 8 million years. Subsequent age dates of lavas and other arguments based on geologic deposits along the lower river course convinced Edwin McKee, Ivo Lucchitta, and others that the gorge had to have developed between 4 and 6 million years ago. Lucchitta has even argued that the down cutting to present depth at the west end may have occurred rapidly just prior to 5 million years ago. This phenomenally rapid erosion would have astonished all who had worked on the problem previously. Meanwhile, a dissenting voice remained amidst the charismatic advocacy of McKee and Lucchitta. After 25 raft trips along its length, USGS geologist Don Elson argued that the river had been there long before the problematical lake beds but had been flowing northward toward Utah--not southwest to the Pacific Ocean. The Rocky Mountains had not yet risen, so there was no melted snow to supply the river. A great interval of aridity occurred in the southwest, and the river basically dried up. For an interval, local rains and floods simply dumped debris into the river where it piled up for several million years, possibly even to the top in some areas. Playa lake deposits of this age are all over Arizona, so such a long period of aridity is not out of the question. One of these in Elston's view is the one lying on the river course at the Grand Wash. Then the Uinta Mountains lifted in Utah across the almost dried up flow path. Then the Rocky Mountains heaved up and began supplying voluminous snow melt

to the ancient river gorge--only now the flow went southwest toward the Gulf of California which was forming at this time. The reverse, renewed flow cleaned out the canyon rubble, cut through the blocking playa deposits, and erosion of the Grand Canyon started anew with all now heading toward Gulf of California. This ends the problem at the west end according to Elston. In this solution, all the sediment of the great denudation which has never been convincingly found downstream of the modern Grand Canyon went north to lakes in Utah where there are indeed large lake deposits of the right age. Several of these lake deposits have puzzled geologists because they have no obvious source areas for the sediment. Like his colleagues, Don was a great observer and deep thinker, but he was not a prolific writer or articulate speaker. His ideas never gained traction. Indeed, at a geology conference on the origin of the Grand Canyon in 2010, a young investigator told me his "new" idea that maybe the river was flowing north and reversed course after the Gulf of California opened. He had never heard of Don Elston or his work. In fact, Don's ideas were never mentioned at the conference. There was, however, a major controversy after some Caltech investigators offered data from a new geochemical technique that the deep gorge was already there 60 million years ago! Subsequent published exchanges regarding this in Science Magazine revealed people deeply entrenched on both sides of the question. I hope my deceased friend Don Elston has one ear attuned while he rafts the rivers of the hereafter.

Not having a dog in the fight, I simply remain open-minded and perplexed. After running a graduate seminar on the origin of the Grand Canyon in the late 1990's where we read all the literature up to the current date, I was struck at the sometimes-careless scholarship, twisting, stretching, cherry-picking of data, and personality-driven advocacy science that I prefer now to be comfortable just not knowing. Things may be getting better now, but I keep feeling there is much more to the story than is being discussed. I did come to recognize how unacceptable this position of not taking sides is to the public as well as to most of my scientific colleagues when in response to a short talk on a public field trip where I explained that the origin of a specific feature we were looking at could have formed this way…or that way…or…."Stop" a woman slammed her right fist into her left palm and said, "Dammit, this isn't satisfactory; I need answers!" Not knowing is apparently an uncomfortable place for many people; they must believe something conclusive about everything. I am happy to carry multiple hypotheses that can explain things in different ways until the evidence for one explanation becomes overwhelming.

The road finally reaches the two side-by-side bridges that span the uppermost gorge of the Grand Canyon about five miles downstream from where the Echo Cliffs merge with the Vermillion Cliffs. I park at a Visitor Center and walk out onto the old bridge now abandoned to vehicular traffic but open to gawking. The river is 460 feet below and is flowing a beautiful translucent green color. The huge Glen Canyon dam 20 miles upstream has tamed this great river and is now gently discharging cold bottom water from Lake Powell behind it. Any mud transported to the lake has long since settled out in quiet waters far upstream of the dam. Algae love the clear water and give it a greenish color. Trout love the cold water and the algae

and the micro-critters that feed on it, so trout bred elsewhere are dumped in here to flourish for the sport fishermen who congregate at Lees ferry. The only significant source of mud, silt, and sand these days is the normally ankle-deep Pariah River which enters from the north just one mile downstream from where the rafts launch. From the bridge view, brown water would mean the Pariah has been flooding into the river. This can be good or bad depending upon whether you are about to launch on a raft trip. Good if you are not because this is a major source of sand to support the ecology and replenish the vanishing, eroding beaches downstream that make the best campsites. Bad if you are, because everything on the boat is going to get very dirty, including you. I thus love that green color today.

The rock excavations made for the parking lot present a cross section through the gnarly, jumbled, uppermost surface of the Kaibab Limestone I seem to have driven on for much of the day. It is the same paleokarst I had just wandered over at Desert View, but here the colorful cherts are not as abundant. It is kind of an ugly-looking rock. So, I drive east down the spur road toward where our raft trip will launch tomorrow. All along the south side of this road, the contact between the gray Kaibab Limestone and the overlying Moenkopi Formation snakes around on the nearly flat surface sloping gently toward the river. The veneer of basal Moenkopi is in the process of being washed off. Most of it is gone, but I can't resist stopping where the road crosses the uppermost reach of what is known as Cathedral Wash. A short crunchy walk across dried-out red shales brings me to where the "wash" turns into a deep slot canyon heading down toward the river (Fig. 4.6).

Fig. 4.6. Upper reach of Cathedral Wash near where the road to Lees Ferry crosses it. It joins the Colorado River 3 miles downriver from Lees Ferry (where some call it "Three Mile Wash"). The contact of the red Moenkopi Shale with the underlying gray Kaibab Limestone is exposed here with flagrant clarity. The gnarly top of the Kaibab is a paleokarst residuum. It is possible to walk down to the river from here, but it is a "non-trivial" hike.

Instead of climbing down into the wash, I walk along to a place where the Moenkopi has been eroded back allowing me to sit on a long natural bench of soft red Moenkopi shale with feet on an underlying ledge of the Kaibab. Body above, and legs below, I am sitting in the late afternoon sun directly athwart one of the most significant stratigraphic horizons in Earth history. It is the same one at Desert View only there the Moenkopi was entirely eroded away. The time interval of the great Permian extinction is what I am straddling. Here it is not only easily accessible, but the red shale makes a soft warm seat if you squirm around a bit. As at Desert View, the extinction reveries set in again, especially because the top of the Kaibab here is up close, gnarly, and chewed up with slumps, swirls, and filled dissolution cavities (Fig. 4.7).

Fig. 4.7. Closeup of topmost part of the Kaibab Limestone in Cathedral Wash (Fig. 4.6). Wholesale dissolution and slumping occurred prior to deposition of the Moenkopi Formation. The jumble includes abundant red clay—an insoluble residue in this paleokarst. Paleokarst on top of the Kaibab is as variable as the composition of the parent dolostone over the huge part of northern Arizona where it occurs.

The tremendous end-Permian weathering episode is so clearly recorded here I puzzle why no one has ever written about it. A small remnant of an incredibly old land surface is reappearing as the Moenkopi covering washes off. The sun is shining again on a land surface that was buried for 250 million years. Simply amazing and worth meditating on. However, there is no time to dally now, so I drive on down toward the river.

Oh…wonderful…. a glorious view of the far-side wall of the Colorado River appears and shows the razor-sharp contact I was just sitting on, but now in full cross section and still covered with a thick section of Moenkopi. From the little picnic area at river level, you will never find a more scenically spectacular view of the contact between the Paleozoic and Mesozoic strata (Fig. 4.8).

Fig. 4.8. A stunning exposure of the contact between the light-colored Kaibab Limestone and the red shale layers of the basal Moenkopi Formation where the Colorado River has cut rapidly down through the strata. The topmost layers of the Kaibab are paleokarst rubble. The picnic area consists of sand, mud, and rock debris that was dumped here by the tributary Pariah River which enters the river just to the left of this image. Debris brought in by the Pariah extends all the way to the far wall but is now being washed away by the small rapid. Large flows of the Colorado River before the Glen Canyon Dam was built upstream would have covered this area with a large rapid and carried all the foreground material downstream. Controlled releases of the dam are now often conducted when the Pariah is in flood stage to hopefully push more of its debris downstream to replenish river beaches eroding away at an alarming rate.

The river bottom is here obviously entrenched into the top of the Kaibab, and it is apparent that a raft trip will descend through the Kaibab and into the layers below. I have been driving through later geologic times, but once on the river I will not see these young rock layers again. It will be a different, older series of worlds within and below the Kaibab for the rest of the raft trip.

The picnic area sits beside the small rapid created where the Pariah River enters immediately upstream of the place. It has dumped piles of sediment trying to naturally dam the Colorado river. This large river flows so fast that it pushes all downstream, but it gets rippled into little whitecaps trying to do so. Many have noted that the air takes on a certain exhilarating quality over a rapid. Maybe it is the invisible mist of aerosols created by the whitecaps in this otherwise dry climate. Whatever, it is sheer magic standing here looking at the geologic exposure on that rock wall and hearing the splashy sound of this tiny rapid.

I will see the boat launch area tomorrow morning, so I turn off the route to it and take instead a short road to the north just this side of the Pariah River to a place called "Lonely Dell." This is the homestead of Mormon pioneer John D Lee who settled here with two of his wives to hide out after a massacre of a wagon train he apparently initiated back in 1867. He was caught and executed by the US Government, but the ferry operation that subsequent Mormon brethren established here carried his name, and the overall locale still does. I walk up to the little family cemetery there and am heartbroken contemplating the graves of three children with tombstone dates indicating that each died one after the other over three consecutive days. The background story is that a diphtheria-bearing blanket was probably given to the family by a ferry passenger. A well-intentioned deed apparently led to a gut-wrenching tragedy. The loss of a child is all of us parents' worst nightmare. I viscerally sense the anguish of those that stood here the days these graves were filled in. Horrible.

Walking back to the homestead and sitting on one of the park tables in the cool quiet shade of one of the giant cottonwoods adjacent to a big fruit tree orchard, the sound of the wind rustling the green leaves is balm for psychic distress. I rejoice that I have not had catastrophic things happen to me or my family and that I am able to emotionally immerse so easily in the splendors of nature. I think about how so much human history has funneled through this spot created by that second monoclinal fold that brought the Kaibab Limestone down to river level here. Geology with its oil, minerals, building stones, tectonic events, and resources shapes human history. The Earth's topography typically mixes people with all their foibles, tragedies, joys, and imagined histories together with geology and its actual history. National parks are typically celebrations of scenic geologic features that need to be protected and preserved. My pilgrimage will traverse through four of them. I joyously await this journey where I get to literally float down through the insides of the Kaibab Uplift into an exposure of natural history that is beyond belief. All troubles that set in on the drive and at the cemetery begin to fade as I daydream here in this silvan refuge. But…but…where is the rubble?