Ch 13 **THROUGH THE PORTAL** Mile 65-65.3

From most campsites on the river, the sunset spectacle plays out mostly on the west-facing walls that erupt in splendor from the low angle lighting. Pinnacles and columns that might be overlooked during a daytime pass get bounded by shadows and stand in relief (Fig. 13.1).

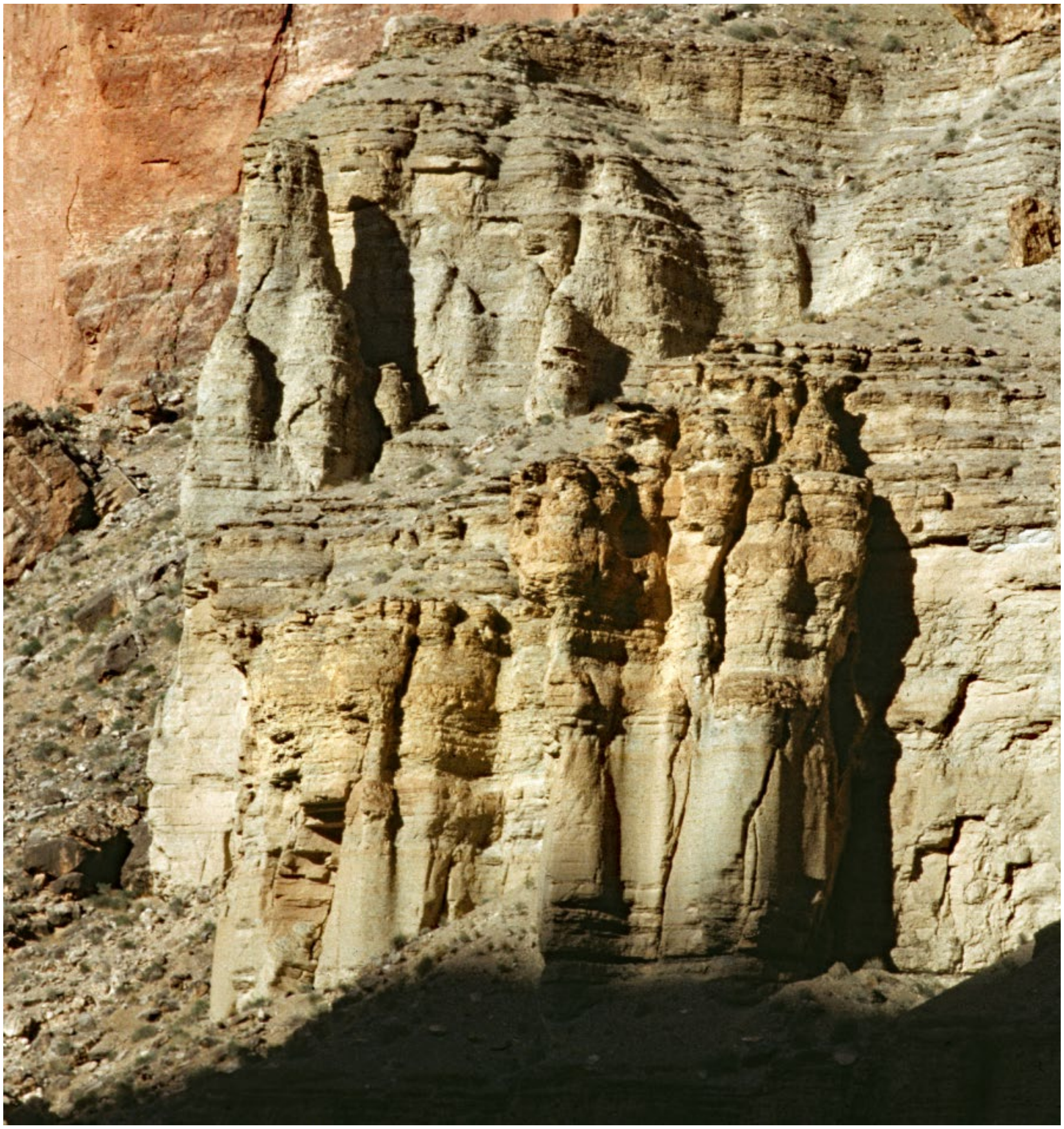

Fig. 13.1. Erosional pillars of the Muav Formation dolostones are typically not the rectilinear four-sided blocks observed for formations higher up in the stratigraphy. The expansion fractures that bound those blocks formed during the latest uplift of the region. They penetrated down through the Muav which had been uplifted once before prior to deposition of the overlying strata and thus carried its own incipient block-producing fractures that were in a different orientation. Modern erosion of the Muav dolostone can thus produce more faceted columns with their edges rounded by dissolution. The result is pinnacles weathering out from the wall rather than the more angular blocks typical of the higher strata. The lighting of these during sunset can be very dramatic.

Patchy cloud shadows are slowly wafting across the layered, multicolored sunset spectacle on the wall across from our campsite at the mouth of Carbon Canyon. Here a glowing highlight intensifies, while there another fades. By itself spellbinding, this colorful light-show of browns, reds, tans, and whites extending up from the dark green vegetation along the banks of the river streaming past is truly mind-boggling when integrated with the geologic story. There, above where the river enters the view is the complete stack of Paleozoic strata from the white salt-encrusted base of the Cambrian Tapeats Sandstone to the ragged summit of the Permian Kaibab Formation (Figure 13.2).

Fig 13.2. Sunset camp at mouth of Carbon Canyon in Grand Canyon looking northeast. Far center left half shows the complete Paleozoic section from Cambrian Tapeats Sandstone to the top of the Kaibab Limestone. All these layers are slightly tilted away from us. The underlying brown/red Precambrian Dox Sandstone slopes up from the river going from lower center left to the lower half of the right edge. The lower cliff face of the Tapeats is caked with white salt from brine weeping out.

All 3,400 ft are seen in one gulp. It is the story of the Cambrian Fauna giving way to the much longer story of the Paleozoic Fauna, the great inland Redwall sea when this area was like the Bahamas, the glacial symphony singing in the red Supai, and the hot equatorial Persian Gulf world with the seas retreating and life on Earth approaching possible extinction. The serrated top of the Kaibab stretching across the scene makes palpable this last skirt with apocalyptic death. The white, salt caked Tapeats cliff slopes up to the right to fully expose itself across the river from us. Knowing that the white was once salt in the sea and is now being fed into the seaward-headed river showcases the cyclical nature of many natural processes. The brown, coarsely layered cliff slanting up underneath the Tapeats dominates the near-river view to announce itself as a new enigma. Geologists interpret this to be part of the Dox Formation dating back about a billion years. What is it and what does it represent? There is a beautiful cliff exposure of it in the shadows behind me where I sit, but I do not feel motivated to take on yet another geologic mystery today.

All day since leaving the Nankoweap delta we have been travelling southward roughly parallel to the east front of the great Kaibab Uplift, the north rim of the Grand Canyon. The river had previously been approaching it from the northeast and dutifully bent southward when it encountered the uplift in its way. Looking at a physiographic map, this would suggest that the uplift was already present when erosion of the river valley began. But wait! Our float down through the rock layers themselves displayed no evidence that they are along the eastern edge of an uplift. Both sides of the river have had the same nearly flat-lying stratigraphy; the westside strata do not start sloping up to the North Rim. The river is still just cutting down through the layers and is clearly not being diverted by the modern topography. However, something subtle has been happening to the strata higher up on the west side to our right. One by one the uppermost strata have been disappearing. We were not looking at this on our hike over the Nankoweap delta, but the Kaibab is pretty much completely eroded away there. Withing three river miles, the Toroweap is almost gone. A mile more downriver, and the Coconino is reduced to knobs atop a narrow east-west ridge with its eastern end a striking sight from the river (Fig 13.3).

Fig 13.3. Last erosional remnants of Coconino Sandstone at the east end of Malgosa Crest on the west side of the river at mile 57.2. Telephoto view looking north from on the river at about mile 58.2.

A binocular or telephoto lens view of this erosional remnant stirs feelings of the relentless, destructive power of erosion. A yet surviving little knob is mantled with hard slabs as if Thor swung his giant hammer and shattered pieces down the slope (Fig. 13.4).

Fig. 13.4. Close-up of where erosion looks like Thor's hammer descended from above. The entire overlying Toroweap and Kaibab Formations had been removed before the hammer struck. Heretofore on the raft trip, the Toroweap and Kaibab layers were always present above exposures of the Coconino. This exposed and shattered knob signals unusual goings-on along this stretch of the river.

A mile to the south, and this hard Coconino Sandstone is gone altogether. It makes a brief appearance opposite the Little C, but by the time we get to Carbon Canyon only the last of the Supai, Redwall, Muav, and Bright Angel sequence is seen on the west side as an imposing edifice still resisting whatever was removing the upper strata. Thor's erosional hammer has been pounding the west wall to pieces, but not the eastern wall! We have not seen this before in the 55 miles of our river journey.

The west wall of the Dox overlooks our camp here capped only with a remnant layer of Tapeats. Surprisingly, the Tapeats here is completely free of the white salt that dominates its wall surfaces on the east side. Why no brine here? What could be happening on this west side that we can't see from here that is between the river and the forested Kaibab uplift now less than five miles to the west? There is still no sign of an upward ramp toward the Kaibab Uplift. Tomorrow morning, we will seek such a thing by hiking straight west up Carbon Canyon. I will tell the hikers that if there is any justice, we should see the strata start rising upward somewhere over there like they do over on the South Rim as you approach Desert View from Navajo lands to the east. If I did not already know, I would lay on my cot tonight completely perplexed with that issue piled on top of all else we witnessed today.

As I walk in the last glimmer of twilight from the kitchen area up to where I think my cot is set up, the dark form of a large snake slivers at lightning speed straight across my path. It startles me and I go from a committed step forward to a midair jerk backward. The snake is trying to get away faster than I am, so I tell myself not to worry. Sure, but this place is full of rattlesnakes that like to come out hunting at night. I look up and see someone perched on a high ledge reading a book under a bright white light. The next day I find out that it was the young nurse from San Francisco. She set up her cot high above to watch the sunset spectacle alone and read poetry on into the darkness. And I had sized her up as a party girl! What I have learned about the depths of souls in people of all walks after three decades of raft trips through the Grand Canyon could fill a book. We may be the most ferocious predators to evolve in Earth History, but something else has evolved that is not even hinted at in the rock record. The Cambrian explosion of pain-filled animal life and consciousness has produced something extraordinary indeed. Thoughts of these things growl in my brain as I fall asleep next to, of all things, a brain-rock boulder.

We load our gear onto the boats early the next morning as sunlight fires up the very top of the Tapeats cliff to our west and starts slowly descending layer by gritty layer down across the new Dox Formation to soon impinge on our shadowy gathering spot. I am standing on one of the larger brain rocks fully aware of its significance and anxious to lead a hike west up Carbon Canyon to one of the most unique areas accessible (by mortals) from the river. Our other boatman and the swamper are going to leave us here and take the two boats about a mile down the river to the mouth of Lava Canyon that trends almost parallel to the canyon we will hike up. We are going to sightsee Carbon Canyon, turn south where it ends, intercept east-trending Lava Canyon, and return to the boats where lunch will be waiting. A few non-hikers will go with the boats and lounge around the babbling brook in "Lava", but most are ready to go exploring up Carbon Canyon with JP following along for safety.

All is ready and the hikers gather before me to hear that the brain rocks are boulders from several Precambrian layers that outcrop way up in the watershed region of Carbon Canyon. The brain pattern is a cross section through a well understood sedimentary structure known as a "stromatolite." It is common throughout Precambrian sedimentary rocks and is normally interpreted as bacterial slime that secreted and/or trapped tiny particles of calcite. There is strong evidence that the microbes were "cyanobacteria," the same green slime that grows in your dog dish. "Cyanos" get their energy by photosynthesis and thus must live in water shallow enough to be thoroughly penetrated by sunlight. The slime is exceedingly nutritious, so we rarely find thick accumulations today because they get eaten by animals. Prior to the Cambrian, there is no evidence of widespread animal life, so the cyanos could thrive in the shallow waters of the Precambrian world. Waves, currents, and rapid growth shaped them into these mounds. The tiny carbonate particles got transformed into limestone and dolostone during early burial. Some must have been silica secreters like silica sponges because “stroms” are often full of chert. Silicification preserves the morphology of some of the bacterial filaments and often the very organic matter itself. Until the arrival of animals, stromatolites and microfossils in cherts are nearly all the evidence we have of life in the Precambrian. Here we are standing near boulders of them conveyed here by many past debris flows. The large number suggests that those pouring out this slot in the west wall must have been derived from fallen cliff faces somewhere up this drainage. Indeed, they are common there. I once came across an astounding boulder that had toppled down seven miles northwest of here (Fig. 13.5).

Fig 13.5. Cliff-fall boulder of late Precambrian stromatolites in the Chuar strata. It lies in the bed of a creek about seven miles away. Mudstone above the mounds has been washed away leaving visible the external form of the stromatolites. The bush in the lower right corner is about three feet high.

There are many examples in that area. Smaller, columnar stroms are more common (Fig. 13.6).

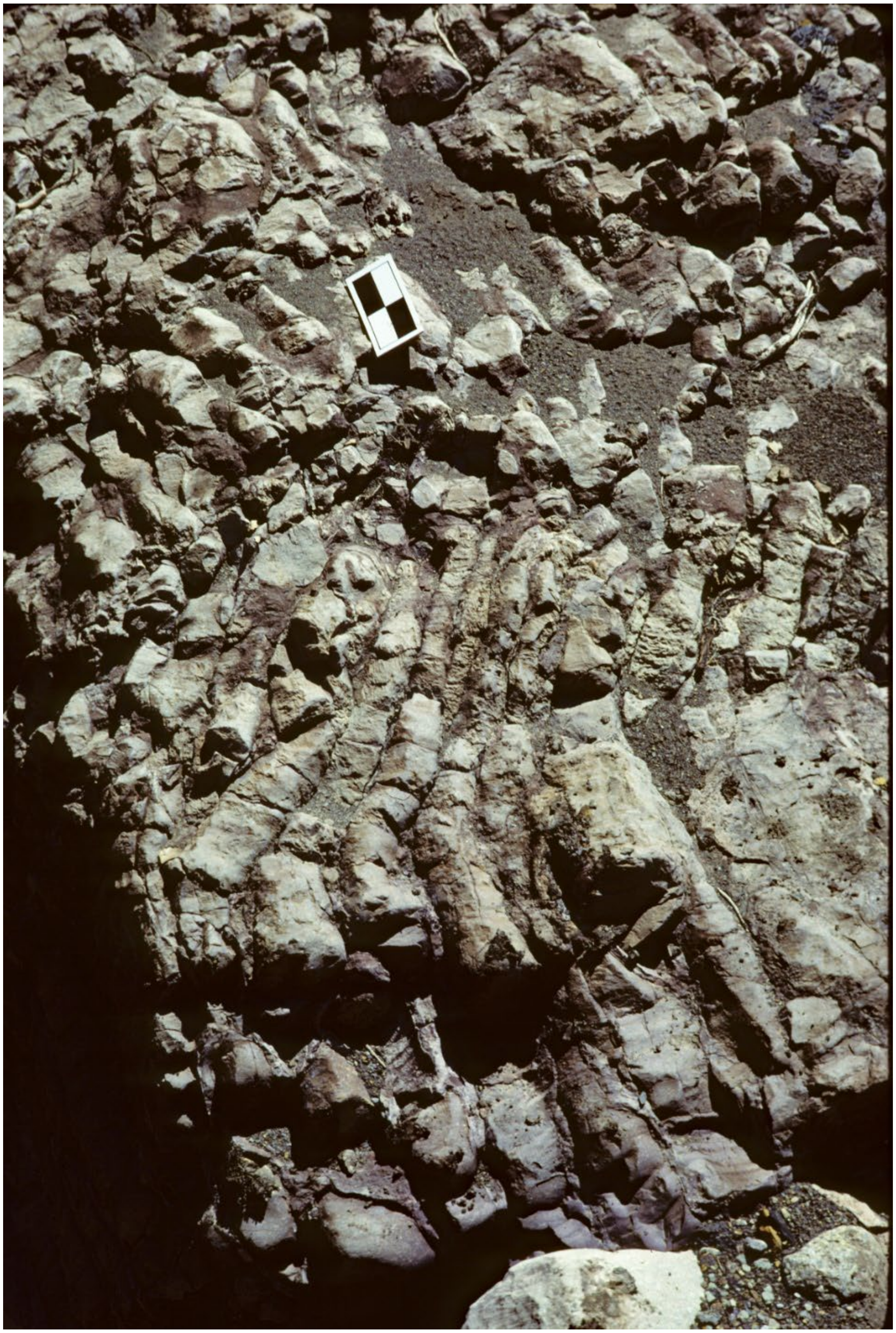

Fig. 13.6. Columnar stromatolites in place on an erosional bench near the giant mounds shown in Fig. 13.5. The cyanobacteria like to grow upward to stay in the sunlit water and above the mucilage they secrete. Waves sloshing through the columns bring nutrients and remove the photosynthetic oxygen produced as waste.

Once emerging from the slot in the wall that is Carbon Canyon, each debris flow would take a new direction across this little fan-shaped deposit. One would go right, the next divert to the left, and the next surge between the previous piles. More commonly, heavy rains sent torrents that cleaned out the slot and dug channels which then filled with gravel, sand, and mud as the flow waned. For us, it is a unique chance to do a long loop hike that will surely traverse wonders and possibly see where the brain rocks come from. What the group does not know is that this will be our first confrontation with a level of complexity we have not seen before and introduce us to one of the grandest of all the grand themes of geology.

The world shrinks as we enter the sunlit mouth of this narrow gorge to focus us on a reality all Grand Canyon hikers experience. Hike up any side canyon of the Colorado River and you will soon get blocked by a rock wall that you must climb over or climb around. Heavy rains create waterfalls at such spots and often polish the floor into an incredibly smooth surface. A debris flow creates a different scene. It must shoot over the lip of a dry waterfall the way kids do when they shoot off the end of a slide in the park. No one has ever witnessed or filmed a debris flow doing this so far as I know. Anyone who tried would probably be killed. These dry waterfalls need be only six feet high to end a side canyon hike. Today, we encounter a 15-footer right after we start up the floor of Carbon Canyon. Fortunately, it has some roughhewn ledges sticking out that can be used as handholds to climb up and over. Everyone makes it, including those who have never done anything like this in their lives. I see the boats depart shortly after that and realize the drivers had been waiting in case someone changed their mind about doing the loop hike. We hikers are now beyond the point of no return.

After walking and climbing steadily upward over cobbles, boulders, and small ledges, we see a blocking wall ahead that looks like a trip ender. However, a trail of sorts begins at the base of a huge talus pile to our left and after much huffing allows us to climb high above the dry waterfall. We find ourselves on a bench looking down at erosional fissures through joints in the Tapeats that can take us down to the floor of this narrow canyon. We descend into one of the biggest openings and find ourselves walking along ledges that marshal us the way to go (Fig 13.7).

Fig 13.7. Carbon Canyon. Here is a good definition of a slot canyon. Fortunately, there are gritty sandstone benches above the narrowest part of the slot that allow hikers to continue. It also helps that the hikers can step down to the benches from the high climb up a talus pile they took to avoid the slot and the dry waterfall it turns into.

As we walk carefully along, benches on both sides of the slot soon merge and widen into the floor of the upper canyon. There we gather up in a more open space to reassemble the scattered train of hikers. Water trickles along weaving through small sand patches and then sinks into crevices as it approaches the deep slot leading to that dry waterfall we just climbed around. We are in a shady place with walls rising over 50 ft to catch the morning sun. The lighting here is magical. People are speaking softly in this silent place--almost reverentially. JP is sweeping along behind us and suddenly appears with his ever-present backpack filled with emergency supplies. Most do not notice his arrival because they are perplexed by red-colored bands that swirl around in the smooth sandstone underfoot. Many form concentric arrays apparently in response to pore waters that migrated through the sand while spaces between the sand grains were filling up with the microscopic cementing minerals that make sandstone out of sand (Fig 13.8).

Fig 13.8 Liesegang bands in Tapeats Sandstone, Carbon Canyon. Pocket knife is 3 inches long.

These are known as "Liesegang bands" after a German chemist who studied diffusion of ions in gels, a process used nowadays to determine gene sequences in DNA. These bands are telling us something very important about the geochemical and cementation history that made sandstone out of loose sand. The problem is, we do not yet know what it is! It must have something to do with the movement of dissolved iron as the fluids moved through the yet uncompacted sand. Maybe the rings record pulses of fluid with different dissolved oxygen content because iron solubility depends on that. But why the concentric bands and rings? Everyone looks to me to explain and then seems relieved when I tell them that it is all a mystery. They are fine with that because they are anxious to move along and explore this enchanted realm. I hang back to reflect on such colorful rock hieroglyphics. Liesegang bands are not uncommon, but the best examples I have seen are here and near the base of the stratigraphically similar Cambrian sandstone in the Marble Mountains of California. (Fig. 13.9)

Fig. 13.9. Liesegang bands in Lower Cambrian sandstone in the Marble Mountains, California. There is a famous trilobite collecting locality there just off of old Route 66 in the Mojave Trails National Monument. It is legal to collect fossils there from the Latham Shale. I collected this from stratigraphically underlying basal Cambrian sandstone exposed immediately adjacent to the west. It was a Liesegang Band wonderland. My idea was to figure out what caused these. I never did.

Over there, the unit is Lower Cambrian and possibly some 10 million years older than the mid Cambrian here. But both are found in likely beach sands or coastal flood plains formed when the sea migrated inland so long ago. Could it instead be something about the Cambrian environment that produced them shortly after burial? Could it be brines at the base of the pile that pooled here when the whole Paleozoic stack of strata lay above? I shall never know.

So, I go forward and catch up with a few hikers waiting for me to explain new features under their feet. They are large, disk-shaped objects in the sandstone--some with bulbous tops (Fig 13.10).

Fig 13.10. Large concretions on the floor of Carbon Canyon. There is never time to study what the cementing agents are and how and when they formed during the burial history of this unit. It is not even clear if these are in the Tapeats Sandstone or whether the floor of the side canyon here is tapping downward into an erosional remnant of the Dox Formation that was a small island in the Cambrian Sea. Big concretions like these were found in the Dox by one of my grad students, Bryce Winter, in the hills immediately northwest of the Lava Creek campsite just over 1 mile southeast of here. He was distressed we had to leave the area so fast. He had done fabulous work on large concretions like this in the Precambrian of Canada and their implications for early bacterial life. Geologists sometimes get frustrated on a raft trip where they can't linger.

These huge concretions are somewhat like the Moki Marbles in that they are cementation zones in the host rock arrayed in semi-spheroidal shapes here seen in horizontal cross section. Big concretions like this are found in sandstones and shales in rocks of many ages and settings. They can form in different ways. I stand looking at these while memories of other giant concretions I have seen and studied flash through my brain. Alas, the stories that account for them are all different and complicated. What to say here? There is no “25 words or less” explanation for how concretions form in any of the known situations. As I hear people making noise farther ahead, I start to wonder if these are not in the Tapeats, but instead in the Dox Formation underneath. Maybe they are in a hump that was standing higher when the Tapeats sands were deposited here. This would be a minor detail, and then I realize that both the Liesegang bands and the concretions are but minor details on this hike. I know that the faster hikers have just encountered a major wonder of this hike. So, I say, “It’s a long story; let’s go on ahead and we’ll talk about it later.”

Several hikers are climbing around just this side of where our narrow slot suddenly opens into a vast area. Normally, this would cause a hiker to accelerate to see what lies beyond. Not here. Our soldiers of science have discovered layers of the Tapeats Sandstone suddenly standing vertically like two enormous pillars astride an open gate. It is a shocking sight utterly unlike anything we have seen before. The layers extend continuously from the nearly horizontal ledges we have been walking along to ledges bent upward at an almost right angle (Fig13.11).

Fig 13.11. The great upward fold in the Tapeats Sandstone in Carbon Canyon.

They go straight up into the morning blue sky. It is possible to trace the bend from horizontal to vertical without seeing a significant crack. It is a perfect cross section through a tight fold as good or better than any likely to be encountered anywhere in the world. This enormous fold is on both sides of Carbon Canyon and surely extends for some distance to the north and south. The best place to view the extent of this astonishing upward bend in the Earth's crust is from high above. I hate the tourist helicopters and airplane noise above parts of the Grand Canyon. However, "if you can't lick 'em, join 'em." So, my youngest daughter and I once took one of the commercial helicopter rides. I must admit it was spectacular. I was agog and photographed like crazy when it flew just to the north of this spot. The view showed upturned beds of the Redwall and younger strata (Fig 13.12).

Fig. 13.12. Helicopter view toward the north about 4 miles north of the Carbon Canyon fold.

Look above the center of the right boundary of the image and note the deep, shadowed gorge of the Grand Canyon. It is cut down through the flat-lying Paleozoic strata that the raft trip has traversed. The same flat-lying strata lie along the left edge of the image but are about 1000 feet higher in elevation. Going left to right, note how the top of this stack defining the skyline arcs down to the right (the thin white band is the Coconino Sandstone). The arc flattens out immediately to the right of the image (not visible here). That arc is a side view of the East Kaibab Monocline. It is the eastern side of the half watermelon Kaibab Uplift—here all carved out by erosion to expose its innards.

The striking, thin ribs running straight up to the center are layers of the Redwall Limestone (gray) and the Supai Formation (red) that have been bent straight up so that we are looking at their sides. The Butte Fault plane which divides the high western strata from those lower to the east (right side) lies immediately to the left of the gray Redwall ribs. The fault plane bends east after passing through the center and heads straight under the left center of the monocline arc (Fig. 13.13). There, the Redwall is a giant rubble pile separating the faulted strata below from the folded layers above.

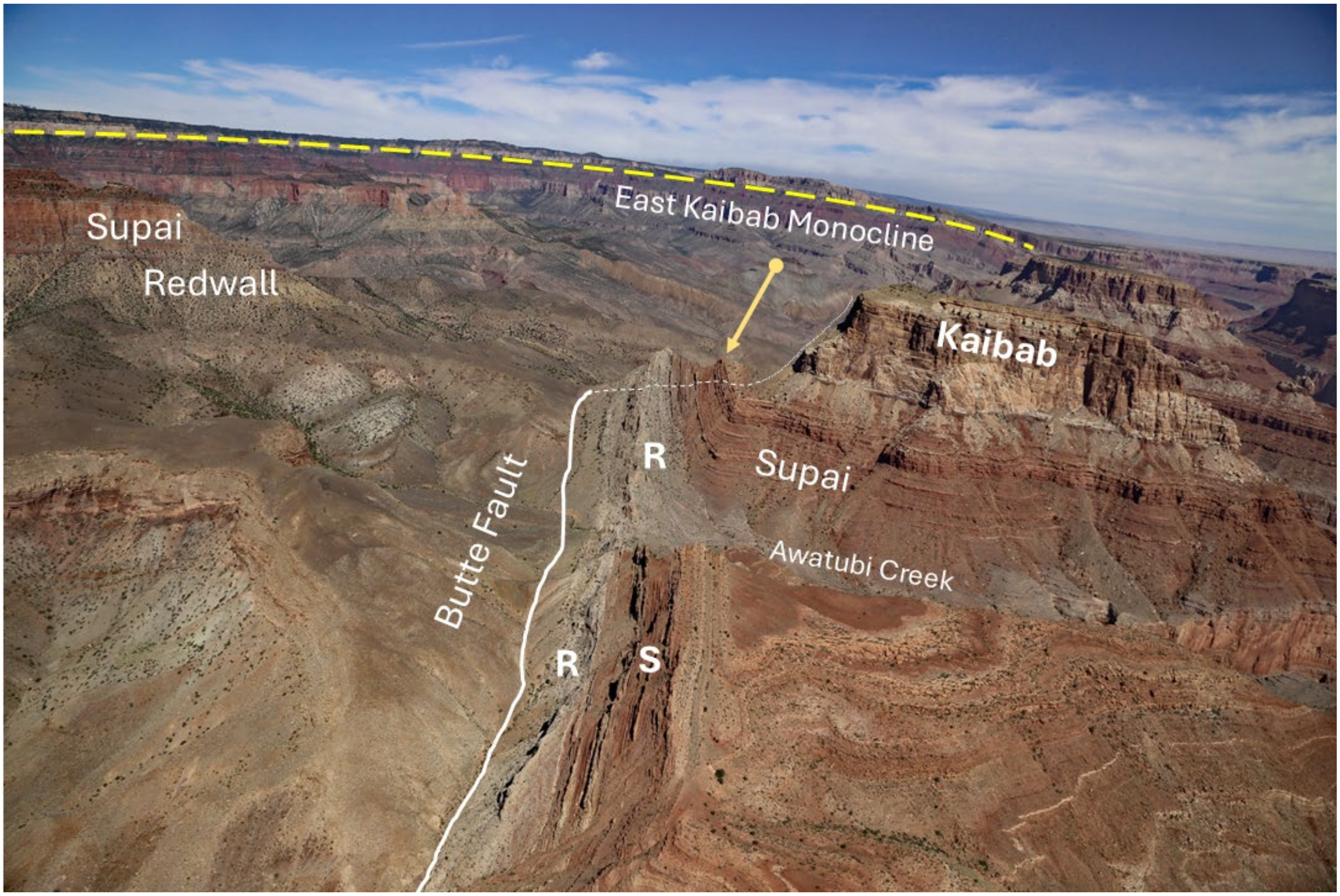

Fig. 13.13. Key to photo in Fig. 13.12. The Redwall Limestone (R) and overlying Supai strata (S) are bent straight upward in the center of the image at an almost 90-degree angle. See text for explanation.

The white line is where the nearly planar fault contact emerges on the modern surface. Note how it bends around the upturned ridge north of where Awatubi Creek originates. It then continues northward and is buried under the monocline. It is the Kaibab uplift that pushed up the left side. The beds immediately to the right of the fault plane were dragged and warped upward into a nearly vertical position. The fault plane itself is not vertical, but slices into the ground at an angle similar to the sloping land surface under the “S” label in the figure. Displacement along it rapidly diminishes upward and is basically gone at the level of the capping Kaibab Limesone (yellow dashed line in the figure). It extends south to well past Carbon Canyon where the upturned Tapeats strata are encountered on our hike. The upper strata on the skyline folding down to the right used to extend over the whole area of the photo but have been removed by modern erosion. The excavated area is called “Chuar Valley” which extends and widens for 10 miles south of the monocline.

The yellow arrow is a view line from the ground toward the backside of the Vertical Supai/Redwall hump at the tip of the arrow. The round tail marker of the arrow is on top of

Nankoweap Butte (not to the confused with Nankoweap Mesa). Figure 13.14 is a photo from near the top of Nankoweap Butte looking back at the drag fold on the east side of the Butte Fault.

Fig. 13.14. View southeast from atop Nankoweap Butte at deformation along the Butte Fault. The foreground shows the area immediately around the butte. The Awatubi Creek valley crosses left to right behind the closer left to right ridgeline holding the fold. The huge mass capped with Kaibab Limestone on the other side of Awatubi Creek is called "Kwagunt Butte." The skyline to the upper left is in the distance is the eastern wall of the Grand Canyon. Nankoweap Butte is made of Precambrian strata much older than the Redwall but stands higher here because they were elevated over 1000 ft by the Kaibab Uplift. All the strata below the Redwall were sharply bent upward as well. The upper Supai and the strata above it did not rupture but instead bent over the fault to form the monocline (all removed here by modern erosion).

From the air, I better understood why the west side of the river gorge has endured so much erosion relative to the east once a raft trip heads south from the Nankoweap delta. As erosion created the broad valley along the Butte Fault, the wall to our right on the river once we departed the Nankoweap delta was attacked by erosion from two directions. Material is being shed off the walls east directly into the river and to the west into Chuar Valley. Chuar Valley is then being cleaned out by shedding its material into the river via side canyons that cut back east into the river for the next 20 miles. This starts with Nankoweap Creek and continues with Kwagunt, Malgosa, Awatubi, 60-Mile, Crash, Carbon, Lava, Basalt, and Unkar side canyons. So, we have just hiked up one of these, Carbon Canyon, and are about to cross the Butte Fault into Chuar Valley. No wonder we were watching the higher layers vanish as we moved south from Nankoweap. No wonder there were no brines leaking out on the west side when we first encountered them; they leaked out long ago going east and west along the shrinking ridge dividing Chuar Valley from the river. Also, no wonder that the Little C has such a small amount of debris at its mouth. High walls that could crash down to form debris are gone from the west side. The river isn't so choked with wall debris as it nears the Little C. Debris shed from the Kaibab uplift that fed so much into Nankoweap Creek feeds instead into Chuar valley where it gets perched before bleeding off into at least 7 outlets. The little C mainly transports red muds of the Moenkopi that blanket its watershed region. Starting around Cameron, it does pick up some Limestone and Dolostone rock falls and lots of more red mud from the Supai, but there just isn't much in the way of bouldery debris to surge down it after major storms. What debris that does make it is rapidly pushed down stream to form small humps, beaches, and bars that are largely destroyed or moved out within a mile or two downstream. Chuar valley explains a lot of minor mysteries. Unfortunately for those trying to keep track of what science tells us what we are seeing, Chuar Valley suddenly presents us with profound new mysteries and issues not so easy to resolve.

For days we have been floating downward through layer after layer, all nearly horizontal. It has become a reference frame for us in our thinking about what sedimentary rock layers look like in the subsurface. We have been able to reasonably imagine what the scene was at the time each layer and sublayer was deposited over 250 million years ago. All were simply buried and left undisturbed once the sediment compacted and sealed itself off from percolating groundwater. Following deep burial, the entire pile was uplifted to its present altitude. Here all at once, the very basal layer of this thick Paleozoic stack is before us in Carbon Canyon going straight up as if our layered world has been rotated sideways. It is here being eroded downward leaving some of the more resistant sandstone layers as rock fingers pointing into the sky.

I have been here many times, but on this journey, I am in a different emotional state; it is dizzying to witness this dramatic change from all we just descended through. Thin erosional remnants of the stratigraphically overlying Bright Angel shale also stand bent upward this side of the risen wall of Tapeats at the top of Carbon Canyon. I once approached this place by walking along the top of the Tapeats on the south side and could see this Bright Angel tightly folded upward in its entirety (Fig. 13.15).

Fig. 13. 15. Looking north over Carbon Canyon where the Tapeats gets wrenched upward in a great fold. Erosional remnants of the Bright Angel Shale show how it was also bent upward.

All the strata we floated down through once covered this place. The folding occurred deep down in the earth and came up during the Kaibab Uplift. It is now eroded away and has been replaced by air.

Looking at this fold from down in the slot canyon is jolting more than usual for me this morning. My soul, which has been in a universe of order, awe, and wonder these past several days is now smashed by some tectonic force of inconceivable power and violence. An instantaneous fantasy erupts. I feel a rumbling coming up through my feet and legs which shake uncontrollably. Now my body trembles making the walls seem to swing from side to side. Rock slabs quiver and crash as dust billows. A monstrous mass bulldozes upward out of the ground shrieking and shedding rock rubble that tumbles down. I lurch back and turn to the right to see the strata before me bending and getting dragged upward against this vibrating mass. The deafening, rumbling sound of thousands of rocks cracking, banging, and grinding together echoes up and down the slot canyon as I duck and dodge until it suddenly stops while residual slabs of sandstone splinter off and fall into billowing clouds of choking dust. But…blink … no! Not true.

The sun is shining, the air is clear, and all is quiet save some human chatter from upstream. This is a silly reverie—"a false creation proceeding from the heat oppressed brain" --not one based on science. A heat oppressed brain that apparently once saw a Godzilla movie! There was never a catastrophic uplift shedding rubble piles to do this. Here instead is a vivid example of the kind of tectonic uplift that has shaped the real world. Here we see before us something that happened slowly during the regional uplift of the Colorado Plateau starting about 60 million years ago. But putting that off for a minute, how can a rigid rock layer get bent like this? Why isn't it cracked to pieces? That smooth bend with only a few cracks hints that this folding may have happened deep down in the metamorphic zone where pressures and temperatures deform rocks in a ductile rather than brittle fashion. But how hot and how deep? From this fold alone, it is not clear. Metamorphic minerals that form at extreme burial pressures and temperatures are not present here, so the Tapeats was not glowing cherry red during deformation. It was probably never buried deep enough to be in what geologists call the "Ductile Zone" where the solid rocks become kind of rubbery. A better explanation is based on an analogy with marble slab benches in parks dating back to colonial times in New England. Many have sagged downward from the weight of the heavy slabs and the generations of people who sat on them. Somewhat like wood boards, solid rocks can deform if you bend them slowly--even while they are brittle enough to shatter under a hammer blow. Yes, this deformation was probably aided by the increased pressure and temperature of significant burial, but stress applied over long time intervals was clearly the major factor. No Godzilla fantasy is necessary here. Rather this is another stunning display of how slow processes operating over great lengths of geologic time can produce extraordinary results. But why is this unusual example of deep time here? And what is through that notch ahead?

Here is a good place to return to the analogy of a stack of thin carpets placed on a brick patio. We are the size of mites approaching from the east toward a north-south oriented patio brick that for some reason rose to create a huge bulge under the carpets. Erosional scuffing has worn away the eastern edge of the uplifted brick and whatever overlying carpets draped down over it. Only a small remnant of upward folded carpet on one side remains—this upward projecting layer of Tapeats Sandstone. All is blue sky above us and in the direction we are heading. Looking through the notch in this vertical wall of Tapeats, we should see remnants of the side of the brick that was pushed upwards. Indeed, there is something there, but the worn-down brick stripped of its overlying carpet seems itself to be made of thin rock layers unlike any we have seen before with much of it removed by erosion (Fig. 13.16).

Fig. 13.16. The portal at the top of Carbon Canyon. This erosional notch is cut into a wall of Tapeats Sandstone which has here been folded from nearly horizontal into a vertical position such that we are walking top-down through the Tapeats while going forward on a nearly level hike. Once through this notch, the hiker can stand right on the Butte Fault that bounds the eastern side of the Kaibab Uplift.

The thin rock layers seen in the distance through the portal appear to be slanting somewhat northward and to the west away from us by an amount greater than that of the nearly horizontal strata we have been heretofore floating downward through! The notch invites us to pass through this portal to remnants of an older world. We advance, but little do we know that we will now encounter some of the most complicated geology in the Grand Canyon.

JP leads us west through the portal and then to the left up a trail to the top of a small hill where we can see the route to the south that we will take (Figs 13.17 and 13.18).

Fig. 13.17. Looking south from hilltop adjacent to the portal of Carbon Canyon down a dry creek bed that drains into Lava Canyon.

Fig. 13.18. Hike route looking south from portal at top of Carbon Canyon to Lava Creek.

Our plan is to hike down into the dry stream bed winding tightly almost due south until it joins Lava Creek. We will then follow Lava Creek as it flows back down to the east (left) where our boats await us. We will be walking along the Butte Fault zone, the contact between the uplifted brick to our west and the nearly horizontal strata we have been travelling down through. Looking south over the route ahead, it is important to visualize where the Butte Fault is and its approximate three-dimensional orientation (Fig. 13.19).

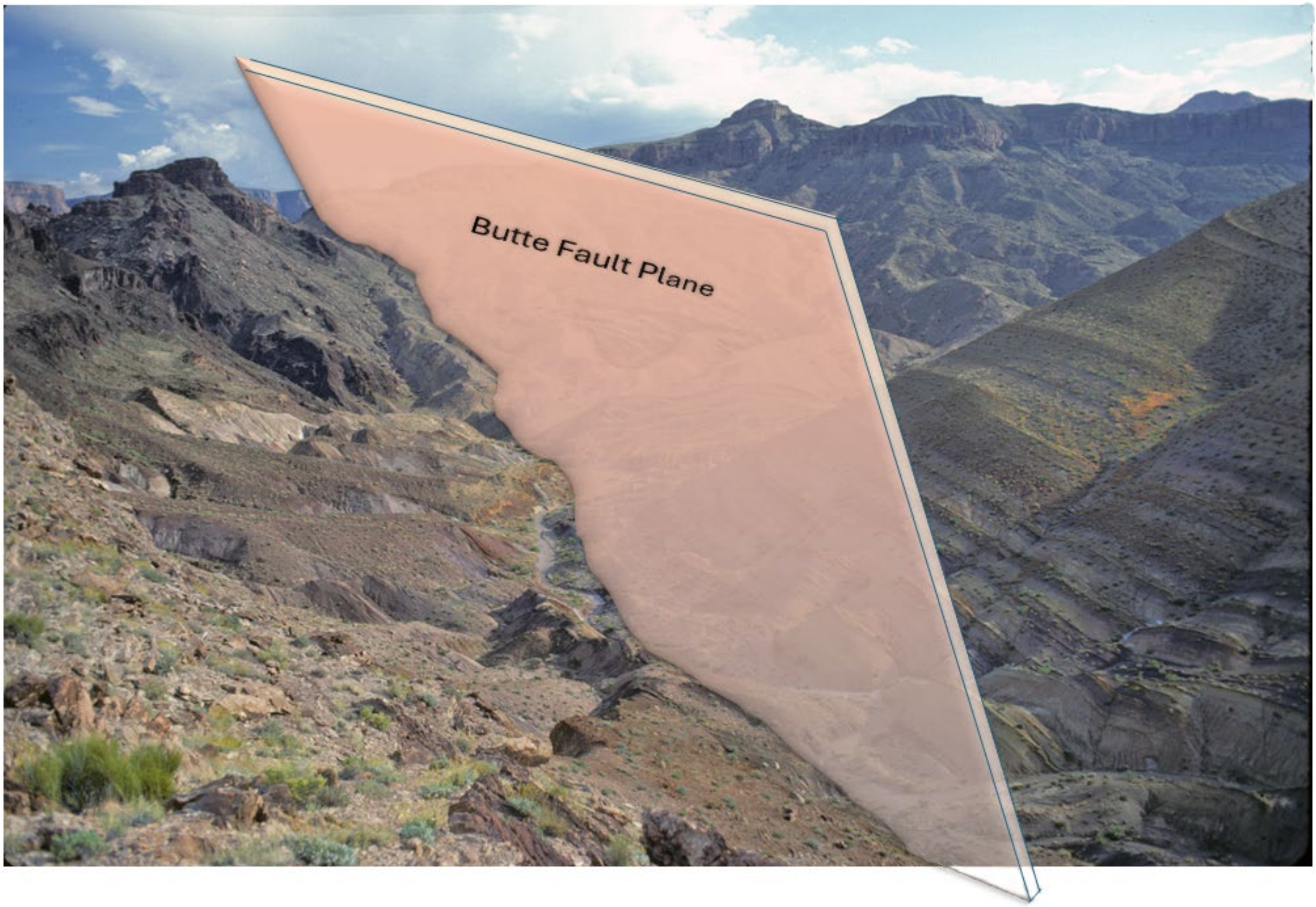

Fig. 13.19. Visualization of the Butte Fault Plane and its intersection with the surface. Note that it is not vertical but tilts down toward the west. The Chuar Strata have pushed up on top of it—which is what dragged the Tapeats beds on this side up into a tight fold. The fault is not a thin plane or even as straight as shown here. It is a zone with many blocks and much rubble caught up in it. There are "splays" that split off and join back around the tortured rocks in the fault zone itself. The width of the zone varies from a few yards wide to football fields wide—all internally disrupted.

We start down into the gulley eroding out the fault plane. The beautiful stack of layers called the "Chuar Group" are now in full view to our right as we walk past an enormous hill of them (Fig.13.20).

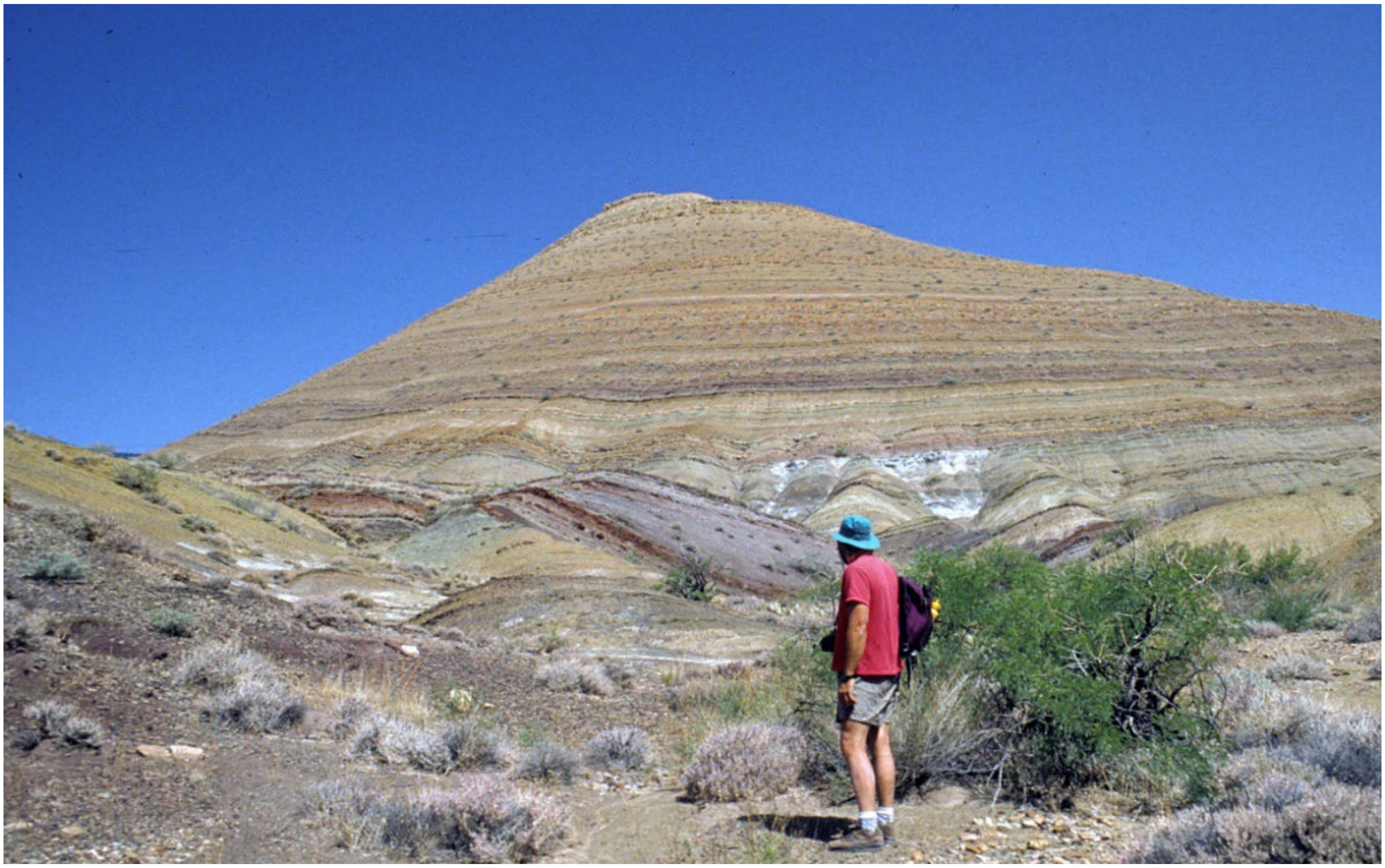

Fig 13.20. Layers of the Precambrian Chuar Group one hiking mile inland from the river and between Carbon Canyon and Lava Canyon. The Chuar strata are some of the youngest of the Precambrian rocks in the Grand Canyon. The white patches are gypsum formed by weathering of pyrite in certain layers.

The red, green, yellow, and brown colors of the Chuar strata are striking and beautiful in the morning sunshine. White zones and patches occur here and there and appear to streak downward in places. Salt? No need to climb up to see because there are some in view ahead. This is such a wondrous place that someone calls it "Disneyland."

As we walk downhill to the south, we see ahead a dark brown horizontal layer capping the skyline (Fig. 13.21).

Fig 13.21. View southwest walking down toward Lava Canyon in an erosion channel developed in the Butte Fault zone. The dark skyline layer is the Tapeats sandstone lying horizontally here 1,200 ft higher than where we last stood at the Carbon Canyon portal. The colorful slanting beds ahead are blocks of Chuar that rotated in the fault zone which trends here north-south to intercept the skyline Tapeats just to the left of the image.

The Tapeats Sandstone on the skyline ahead is 1,200 ft higher than where we last left it before it got bent upward at the portal. The Tapeats and all the layers above it have been lifted this amount west of the Butte Fault we are walking along. It is part of the great Kaibab Uplift. If we could look west over this huge hill of finely layered green Chuar, we would see the tree-covered North Rim, the top of the Kaibab Uplift. We could trace the Tapeats in front of us all the way to the west where it takes its place at the bottom of the Paleozoic section. Directly above us here, this great stack of Paleozoic strata has been entirely washed off into the Colorado River and carried away. The east side of the uplift has been gouged out. Falling rains are now eating downward through the Chuar which underlies the Tapeats and carrying its mud and sands down this very channel we are walking in. The channel is reaming out the fault zone. The fault heads to the south straight toward the Desert View vista point 7.7 miles to the south but bends to the east just before and runs under the monoclinal ramp that HW 64 slopes down. That is the one I drove several days ago and illustrated in Fig 4.1. Here I am at that monocline again but seeing the raw action that was deeply buried under that drive.

As shown in Fig. 4.1, the deepest of the draping strata get severely deformed next to the underlying fault in the Precambrian parts of the uplifted block. That is what we just saw as we walked through the portal where the Tapeats was bent almost straight up adjacent to the fault. Presumably, the horizontal bed of Tapeats we see this side of the fault once extended over us and somehow connected downward to that folded-upward wall at the portal behind us. Did it bend sharply down and join with the rising section we saw, or was it broken along the fault plane? Being now eroded away, we can never know. However, on the larger scale it must have been something like the sketch in Fig 13.22 which requires a bit of reorientation to understand.

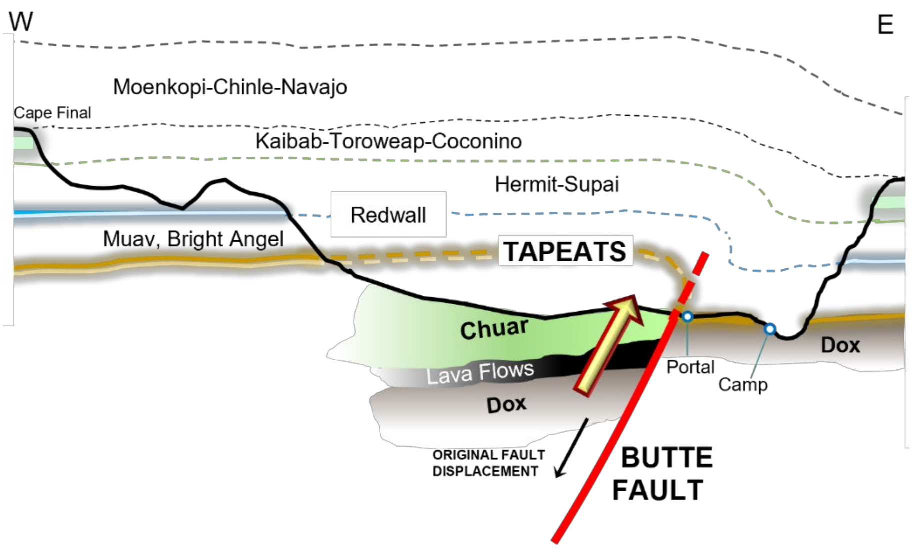

Fig. 13.22 West to east cross section going 6 miles from Cape Final on the North Rim directly over the intersection of Carbon Canyon with the Butte Fault, the portal where the Tapeats is folded straight up. The west side of the fault went down thousands of feet before deposition of the Tapeats. It came back up about 1,200 ft (yellow arrow) after deposition of all the strata including the Tapeats and younger layers now eroded away. Reactivations and reversals of much more ancient fault displacements are not uncommon in geology. The Dox at river level east of the fault is probably one of the lowest parts of the Dox, while that to the west is one of the uppermost parts. A hike from Carbon Canyon camp traverses up from the Dox, into the Tapeats, through the upturned Tapeats portal, and then into the Chuar Group.

The diagram is a view from the south toward a cross-section diagram that extends west to east from high on the North Rim at Cape Final to the portal and then along the path we initially hiked coming up Carbon Canyon from the river and a bit beyond to the east. It is a subsurface interpretation based on geologic maps and published studies of this specific area. The Butte Fault extends as a plane coming out of the page with all to the left lifted about 1,200 ft. We are standing now where the Fault plane exits the ground (immediately to the left of the "Portal" mark and looking out toward the reader). Follow the Tapeats Layer along our hike from right to left starting at "Camp," and you see it suddenly bend tightly upward against the fault (Fig. 13.22). The Tapeats must have extended upward and then bent back into a horizontal position going west. This upward displacement of the west side of the fault took place about 50-70 million years ago while the whole area was buried with younger sediment including the Moenkopi, Chinle, Navajo Sandstone, and even younger strata. Note that the entire region was uplifted at this time; the whole Colorado Plateau was uplifted. It is as if the whole patio rose upward with one of the bricks, the Kaibab Uplift, getting pushed up a bit more than the others. After this regional uplift, erosion has scraped away all those younger, overlying strata down to the present topography as shown in the figure.

Imagine our imaginary patio bricks under the Paleozoic carpets not laid out neatly but rather as a pile of dominos that got pushed over. Then, the jagged top surface of the pile smoothed down to a horizontal plane before the first carpet, the Tapeats Sandstone was laid down. We crossed over from one to another of the tilted dominos as we crossed the Butte Fault. The tilting happened long before deposition of the Tapeats. During that tilting event, the block we are now on slid down and set the Chuar against the Dox in the block to the east (Fig. 13.22). Actually, our block initially slid down even deeper than this where it sat until the more "recent" regional uplift of everything about 50-70 million years ago pushed it back up to its present position.

Here is a splendid example of an ancient fault getting reactivated almost a billion years later. Geologists have long recognized that once the crust gets broken by a fault, that fault is subject to future slippage again. The Butte Fault was recognized as a fault where a tectonic block once went down a fault plane and then came back up by paleontologist C.D. Walcott when he searched this area for Precambrian fossils at the end of the 19th century. It is now estimated that the block west of the Butte Fault went down possibly 10,000 ft in the Precambrian and then came back up about 1,200 ft in this last tectonic event. Could it crack again? Maybe even while we are walking along it? Yes, and yes. Faults are cracks that never heal.

Trying to explain all this to hikers without Fig. 13.22 produces a lot of blank looks and then frets over how rapidly this day is warming up. However, the teacher in me slams home this major point about the susceptibility of faults to reactivate, no matter when they originally formed. I describe how my first great geology teacher, Wilfred Elders at the University of Chicago, stressed this point on the first field trip I ever took as a student. We stopped near Fredericktown Missouri to view an abandoned railroad trestle built right over an ancient fault (Fig. 13.23).

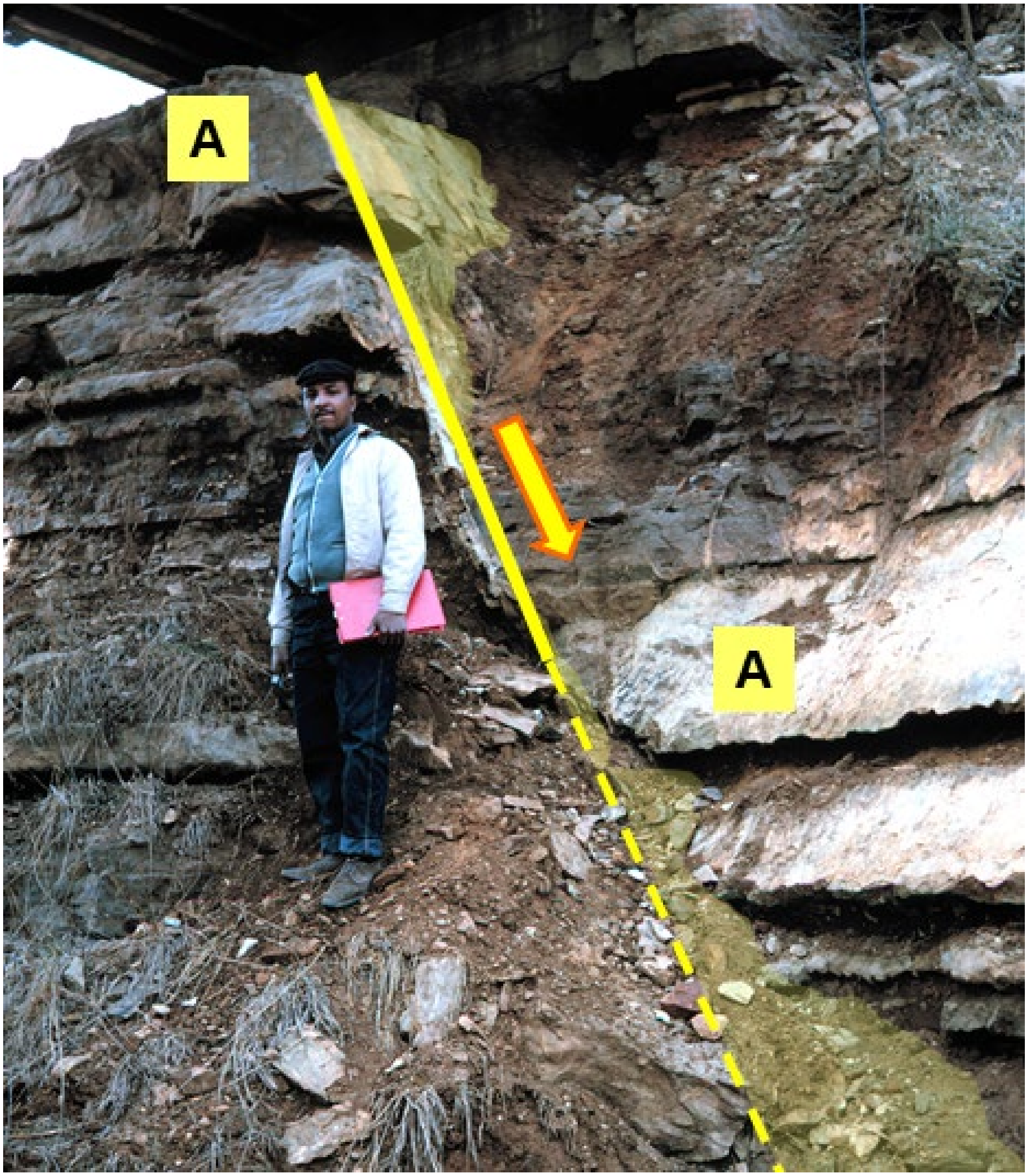

Fig 13.23. Geology student in 1965 under a train trestle built over a fault in Missouri. The fault plane (shaded yellow) emerges along the line. Sedimentary layer A has been displaced downward on the right side of the fault. Faults, even if inactive, are cracks that remain permanent zones of weakness susceptible to renewed activity. Building anything directly over one of them is a bad idea.

Imagine if the layers on the right side of this image moved back up later and you have an illustration of what happened with the Butte Fault. I have shown this first geology photo I ever took to countless classes to illustrate a fault and why it is not wise to build over any known fault even if the area is not known for seismic activity.

What does it look like if you could walk along one of the great fault planes that underlies a Colorado Plateau monocline? It looks like what we are seeing before our eyes. It is not a sharp contact, but rather a narrow zone with blocks that got broken off the adjacent layers and disoriented during the displacement. We pause to look at the top surface of a big block in the fault zone that rotated up into a steep angle. I yell out because here is the kind of exposure that tells a story. All stop! It is a resistant block tilted upward to show eye-catching geometric patterns on a bedding plane surface (Fig 13.24).

Fig. 13.24. Interference wave ripples on block in the Butte Fault Zone.

This pattern can be generated on the bed of a shallow sea or lake by waves that came in from one direction and then were overprinted by another current that came in at almost right angles to the first. The waves from the first sloshed the sand back and forth to make ripple marks on the sandy bottom that look like a washboard. The second sloshed those sand ripples at right angles and tried to rearrange them at right angles. Before that could happen, the currents stopped altogether, and the suspended load of mud settled over the surface. During burial, all hardened into rocks. During modern weathering, the overlying mudstone got washed off—and bingo! Geologists love it when they get information like this as they try to figure out depositional environments.

Then we come across another that tells a different story (Fig. 13.25).

Fig. 13.25. Likely shrinkage crack patterns on surface of rotated fault block in the Butte Fault zone. Geometric cracks developed when wet mud dried following deposition. A renewed influx of water washed in fine sand which filled the open cracks of this hard, dried out surface. Deposition of other sands and muds then continued. All was compressed and turned to rock during deep burial. Modern weathering removed those later deposits after this block in the fault zone was rotated up to its present position. This appears to be a block of the Dox Formation deposited about a billion years ago. Outcrops like this indicate very shallow water deposition alternating with periods of desiccation.

Which sedimentary layer shed these blocks into the fault zone rubble? It does not look like the Chuar which has distinctive strata like those in Fig 13.20. Neither does the rubble all around it which has the same color of those Dox strata we started out in. This appears to be a rotated block of Dox from the east side that got dragged up during the uplift. It is not clear exactly which part of the thick Dox Formation this comes from. In fact, how can we tell just from the exposures we see on this hike which is older, the Dox or the Chuar? All we know is that both are older than the Tapeats and thus are Precambrian strata older than at least 500 million years.

We first try to age-date sedimentary rocks using fossils. Unrelenting searches have been made in the Chuar Group to no avail for the kind of animal fossils so common in Cambrian and younger rocks. Numerous stromatolites occur in certain layers of the Chuar indicating a time when there was plenty of bacterial slime growing in the shallow waters, but no evidence of animal life. Starting with Walcott's work, it has become increasingly apparent that these rocks are in the latest Precambrian, but how late is difficult to determine. From microfossils of silicified cyst-like bag-shaped clumps of organic matter and from the morphology of the stromatolites that outcrop in the Chuar to the north (Figs 13.5, 13.6), a case can be made that these fall in the "Neoproterozoic" interval extending from about 750 million years ago to the time of the Cambrian explosion of animal life 540 million years ago. Some geochemists have tried to correlate layers in the Chuar with other Neoproterozoic strata globally based on the isotopic composition of carbon atoms in the stromatolitic dolostone, but the methodology used to do this has been subsequently shown to be erroneous. Age matters here because certain geologists adamantly claim that the surface waters of the Earth—including the oceans--froze completely during the Neoproterozoic. Others are skeptical and interpret the geologic evidence differently. No evidence of global freezing has been found in the Chuar. Those who make the extraordinary claims of this "Snowball Earth" that has so resonated with science journalists and the public are thus a bit perplexed by the Chuar. Not to let go of their paradigm, advocates of the Snowball Earth simply conclude that the Chuar must be older or younger than their global catastrophe. Nearly all have assumed that it is a marine deposit, but the character of the sediments suggests to a growing number of us that much of the Chuar was deposited in a lake. University of Oregon's Greg Retallack even presented evidence for numerous soil horizons that developed atop many of the upper layers of the Chuar. Such ancient horizons are called "paleosols," and represent intervals where an ancient aqueous deposit became land long enough for soil to develop. Retallack even argues that certain famous vase-shaped microfossils in the Chuar are not marine but were living in soil and not the ocean as generally assumed. The Chuar is emerging as quite a controversial sedimentary unit that has not yet been convincingly age-dated. What about stromatolites in the Dox? None have been found, although some spectacular concretions are often mistaken for "algal mounds." Fossils are not going to help much here.

We encounter some of the bright, white patches of the Chuar that at first appear to be salt but are tasteless. This is likely all gypsum ($CaSO_4$) derived from modern weathering of fine-grained pyrite (FeS_2, iron sulfide) apparently present in the shaly layers. Drill cores to the north have encountered this unit where it is unweathered and dark gray. It has oil in it that appears to have been derived from organic matter in the Chuar shales—probably the cyanobacteria that made the stromatolites. For organic matter to be buried in significant amounts the initial pore fluid environment must have been depleted in dissolved oxygen or else the organic matter would decay away. Pyrite forms in such environments, so it is likely that these shales before us had pyrite and that the gypsum patches are derived from modern weathering of it. The free oil in the Chuar encountered was not enough to provoke further drilling, but someone asks if there is a danger that fracking will begin soon in the shale. Yikes! It could in the areas to the north of the National Park boundary. But why is pyrite in organic-rich sediments like this?

Bacteria feeding on organic matter goodies during early burial strip oxygen from the pore fluids and from the dissolved sulfate (sulfur bonded to 4 oxygen atoms) so common in the oceans and in lakes. Any iron in the shale goes into solution in the oxygen-free water common in deep lake waters or restricted marine basins like the Black Sea where it reacts with the sulfur stripped off its oxygen atoms. Little crystals of pyrite are thus common in shales but cannot survive exposure to oxygen upon uplift and weathering. The iron rusts and the sulfur combines with oxygen again to form sulfate and then gypsum again. The cycle goes on and on as sulfur cycles from pyrite to sulfate, and back again to pyrite as sediments cycle endlessly through weathering, renewed accumulation, burial, uplift, and weathering again. Those white patches are a snapshot of the sulfur cycle as is the red coloration from iron turned to rust. Hold some flakes of rusty red Chuar shale and imagine that it may eventually wash back into the sea, get stripped of its oxygen by bacteria, react with sulfur also stripped of its oxygen to form pyrite, get uplifted, weathered and then the cycle starts again. All this white is part of an endless geochemical cycle. Geologists have their endless cycles of erosion, burial, uplift, and erosion. Geochemists have their own cycles. To be aware of both intersecting here can leave you flummoxed in the morning sunshine with your friends calling for you to get moving or we will be here all day. Yes, we may, because there is so much more to the Chuar, and we are now in a vortex of complexity as we note thick black layers to the east on the other side of the fault where the Dox and Tapeats should be. It is a whole giant hill of black layered rock. And there are the same jet-black layers ahead as we descend into Lava Canyon. What are these black rocks? They look like lava flows stacked one on the other! But how old are they and how did they get here where we expect to see something else?

While previously we were descending downward through a stack of sediments going into progressively older times in Earth history, we have just descended into even deeper time by walking sideways instead of going downward. A layer-cake stack of sedimentary rocks is one of the easiest to understand, but such stacks can get folded, sliced, shoved up, shoved down, and mangled in unexpected ways. The scale of this chaos can be large—much larger than we tiny humans can easily fathom. When we passed through the portal, we passed across a fault plane into part of our stack that had dropped down deeply and then been pushed back up part of the way. We are going to find similarly juxtaposed blocks as we travel through a Precambrian wonderland for the next several days. We will look up at those simple Paleozoic layers high on the walls with envy. How easy those are! Fortunately, we should be able to quickly understand the basic goings-on thanks to heroic research by several generations of geologists. Three successive geological maps of the eastern Grand Canyon have been made, each building on the previous. A particularly ambitious assault by University of New Mexico's Karl Karlstrom and his students, colleagues, and associates has added important details to the geologic maps, clarified many of the puzzles, and provided better age estimates of what happened in this cosmic jumble. But what ultimately caused all this tectonic chaos both here and elsewhere in the world will be the question that torments. Pondering Precambrian rocks in the Grand Canyon is like looking at veins in the wrist and wondering why they are the way they are. Veins cannot be understood without understanding the heart and the vascular system altogether. Geologists today think they have gotten to the heart of their field with the theory of Plate Tectonics. Indeed, nearly all textbooks start with that theory and explain the rest of geology with it. It has been remarkably successful at understanding long-standing mysteries. But the plate tectonic theory as espoused has a dark side, and we are about to hike right into it as we descend Lava Canyon toward our waiting boats.