Chapter 9 **REDWALL RISING** Mile 21-33

Downriver from us, the top of a distinctive gray ledge extends into the near distance slightly above river level. A small rapid is splashing downstream. It is the beginning of one after another from mile 21-30 called the “roaring twenties.” None are big, but there are real thumpers and a lot of fun ahead. But here we sit on small rock ledges of a hard, lumpy, jumble of limestone embedded with disoriented chert nodules and dark maroon clay. It is a sight new to the group. It was also new to John Wesley Powell on the first-ever raft trip through the Grand Canyon. He wrote with exaggeration that he walked here along a mile-long ledge of river- smoothed marble. It does look like marble, and a quarter mile walk along this shoreline interrupted everywhere by large and small talus piles might seem like a mile. Little did he know that he was at the top of the Redwall Limestone that would rise over the next 16 miles to form smooth vertical walls 600 feet straight up from the riverbank. For the rest of the trip, whenever we can look upward along the walls, we will see this as a gray wall coated with reddish muds from the overlying Supai and Hermit formations that wash down the cliff faces during rains. As the muddy water dries, it clings to the wall and becomes a thin adobe coating. Where pieces of the wall have broken off recently, the Redwall Limestone is almost white. Seen from the rim above, this cliff-forming layer extends from horizon to horizon. It is the easiest of the units to spot and identify. So thoroughly do protrusions from the walls fall off that there are probably only a dozen or so places where a hiker can go up or come down through the Redwall without ropes. It is the only noteworthy limestone of all the carbonate layers in the Grand Canyon; the others are nearly all dolostones which seem to weather into stacks of ledges. Redwall cliff faces seem to collapse in huge spalls that leave behind those tall, unclimbable walls.

The unit is full of chert nodules. Colorful ones that have weathered out dominate the gravels from here on down the river. Shales disaggregate immediately and wash down the river as mud. Sandstone blocks fall apart a bit slower and turn into sands washed along the river bottom. The cracked limestone and dolostone blocks abrade easily and tend to dissolve to make the river water “harder” as it flows along (Fig. 9.1).

Fig. 9.1. Large block of Redwall Limestone that dropped off the steep walls into the river. The scallops are largely unique to limestone boulders because they are softer and more soluble in fresh water. Chert nodules weather out as polished cobbles that tumble along the river bottom.

Personal duffel bags that we load and unload daily at the campsites will gradually become heavier with hidden, colorful chert cobbles collected surreptitiously. This is prohibited by the National Park. However, on the river--the eye winks at the hand.

The full Supai/Hermit/Coconino/Kaibab story is displayed with exceptional clarity on the opposite wall gleaming gloriously in the morning sunlight. That wall of layers we have now descended through records a rich history of Earth's crust that sagged here continuously for about 80 million years. While that growing stack of sediment subsided, the sea repeatedly came in and retreated. Sediment was deposited layer over layer to keep the region near sea level. Then came that final, huge lowering of sea level at the time of the end-Paleozoic mass extinction 250 million years ago. There it is forming the skyline visible from our ringside seats. What a classroom! We have already immersed enough in the story of those layers, so I draw attention to the peculiar layer at the top of the Redwall Limestone that we have just encountered. To me, it is a familiar story--a better than textbook paleokarst of the kind I was standing on two days earlier at the South Rim of the Grand Canyon. Yes, following deposition of layer upon thick layer of limestone that makes up the Redwall, global sea level dropped enormously. The region then became land repeatedly drenched in rainfall that severely affected the topmost limestone layer. Dissolution during weathering was extensive enough in some areas to leave insoluble residues of chert, red clay, and remnant limestone chunks before sea level rose again to initiate deposition of the overlying Supai Formation. Right in front of everybody, I scratch red clay out of this coalesced rubble that was once soil on the Redwall and let it fall between my fingers. It is once again loose soil in the morning sunlight after 330 million years of burial. It will soon wash away, get transported down to the sea, and possibly wind up someday again as a minor constituent in limestone forming elsewhere in the world. That new limestone could become exposed again and the red clay wind up again as insoluble soil residue--and then get washed away to start the cycle again. I tell the story of paleokarst and hope that this significant rubble fascinates others as it does me. This is not just a rock ledge here that John Wesley Powell walked on 140 years ago and that we are sitting on today. This is a time and place to release inner thoughts of wonder regarding deep time and endless cycles. Without knowing what science tells us, it is just red dirt.

And then, there is that famous phallic pinnacle of the Supai sandstone across the river immediately downstream at mile 23½ (Fig 9.2).

Fig 9.2 Famous erosional pinnacle at 23 Mile Rapid, the start of the "Roaring Twenties." Gray ledge just above river level at the rapid is the top of the Redwall Limestone.

This feature that once carried a culturally insensitive name is an erosional remnant bounded by fracture surfaces. It stands on the hardened, red paleokarst soil atop the Redwall that is shot through with stringy white fossil root traces (Fig 9.3).

Fig 9.3 Paleokarst rubble on top of the Redwall Limestone at 23 Mile Rapid. The famous pinnacle of the Supai Formation looms directly overhead here. The white vertical streaks are calcite encrustations that developed around roots of plants growing in the insoluble residue of red clay and fragments of limestone and chert during the great sea level drop at the end of the Mississippian. Some call this paleokarst rubble here part of the "Surprise Canyon" Formation.

Some geologists not so interested in this as a paleokarst (or not recognizing it as such) consider it to consist of valley-fill deposits that become thicker and better defined as such farther to the west. They call it the "Surprise Canyon Formation." In central Arizona along the Mogollon Rim near the hamlet of Christopher Creek, this same Redwall limestone was initially much thinner and in places completely dissolved away to leave discontinuous layers of chert fragments embedded in maroon-colored claystone. At the ASU summer field school that I taught there for 15 years, we mapped this remnant of the Redwall as it came and went through all the phases shown in Fig. 3.5. Here at mile 23½, it is in an early stage of development going left to right in that figure. Having studied paleokarst so much of my life, I am able throughout this trip to look high up the walls and spot various phases of it at the very top of the Redwall. It did not develop deeply in northern Arizona like it did farther south. Hereafter, it is so high, far away, subtle, and restricted to the topmost layer of Redwall that it will be my secret.

To stress the significance of stopping here, I relate a closing story of how graduate student Mark Beeunas and I used the recognition of paleokarst to explore when in Earth history life first occupied the land. I had always been skeptical that there was no life on the land for the first 3.5 billion years of Earth history as textbooks used to imply. The problem is that land surfaces in ancient strata are difficult to recognize if there are no root or animal fossils. Rooted land plants leave plenty of evidence as we have seen, but the oldest root traces are preserved in strata about 450-500 million years old. So, it was always assumed that the land surfaces were barren of life before that. But what about fungi, mosses, lichens, and other ground-hugging organisms that do not leave obvious calling cards in the fossil record? Land surfaces tend to get eroded and are therefore not readily preserved amidst layers of marine sediment.

Fortunately, plants that grow on land surfaces do respire and convert some of their hydrocarbon molecules into CO_2 and H_20. This is the opposite of their day job of making hydrocarbon molecules and releasing oxygen to the air via the miracle of photosynthesis. Respired CO_2 dissolves into the soil waters which wash down through the soil and into cracks in the rocks. Because of certain chemical reactions during photosynthesis, this respired CO_2 is greatly depleted in the heavy variety of carbon atom known as ^{13}C. When calcite crusts and cements form in or below soils, they incorporate this ^{13}C-depleted fingerprint of land life which is very different from the carbon atoms in limestone ($CaCO_3$). So, it occurred to me that a great project would be to sample such calcite in successively older paleokarsts back to the time we no longer find this isotopic fingerprint. From this, we could infer when photosynthetic organisms first appeared on land even though we do not have fossils of it.

A paleokarst just like the one here had been described atop the 1.2 billion-year-old Mescal limestone in Arizona's rugged Sierra Ancha mountains to the south (Fig. 9.4).

Fig. 9.4. Chert rubble in the 1.2-billion-year-old Mescal Limestone in central Arizona that is similar to the rubble observed at Desert View for the Kaibab, and at Mile 21 on the very top of the Redwall Limestone.

Surely, the Mescal Paleokarst that developed about 700 million years before the first then-known land plant fossils should have been barren of life according to the then existing paradigm. The secondary calcite in the cemented karst rubble would therefore just show the same isotopic signature as the parent limestone because it only involved solution and reprecipitation of the carbonate without getting "contaminated" with the low ^{13}C isotopes from photosynthesizers. What a great master's thesis. Beeunas would learn how to do all this and establish the base line from which we could work forward in time. So, we backpacked into the Sierra Ancha, camped overnight and collected samples. Beeunas learned all the analytical techniques and came to my office one day saying that the emerging data indicated that the Mescal paleokarst actually carries the telltale isotopic signature of land life. Something was already growing there. Astounding! Sure enough, he went back and got enough samples and data to make a compelling case. Mark presented this at a national professional meeting in 1985, and we published a paper arguing that the isotopes indicated land life 1.2 billion years ago. Reaction from the scientific community was nonexistent. Isotope studies back then attracted little attention. Beeunas went on to be a successful oil company geochemist, then formed his own business, and then retired early to have fun. Part of that fun was going on several of my raft trips and sitting on this outcrop while I told the story. After Beeunas, Ray Kenny, a subsequent PhD student of mine, explored the Mescal paleokarst more extensively as well as a younger one in and near Death Valley to bolster and expand the case. He did just that and something else more remarkable. While examining his samples under a microscope before analyzing for isotopes, he found the first evidence of possible microfossils of the organisms themselves. He presented his isotopic results at a national professional meeting and showed the microfossil evidence as well. Claims of microfossils in the Precambrian in those days received a great deal of critical scrutiny from experts in the profession. I did not think a strong enough case could be made for biogenicity to assuage this tough community of skeptics; more and better examples were needed. Ray did find a bona fide microfossil in one of his samples, but he had gotten too far ahead of everyone else. He went on to a successful career as a professor and published results of several other creative studies still ahead of their time.

The evidence that scraps of land life might get entombed in the quartz crystals that grow in the spaces of the chert rubble brought the great Precambrian paleontologist Bob Horodyski into the picture. Horodyski and I launched a multi-year, multi-paleokarst project to explore for microfossils everyone might believe. He and I became great friends--even scientific soul mates. Horodyski was relentless as a field geologist and patiently spent hours and hours examining rocks under the microscope looking for microfossils. His highly credible work in the field of Precambrian marine microfossils had been very successful. Fortunately, we struck paydirt, and our long paper “Life on Land in the Precambrian” was published in 1994 in the journal Science, at that time one of the most prestigious professional journals. So, paleokarst like the one we are sitting on here may have great significance--and my trip participants get a dose of it this morning. The sun rises over the high eastern wall and blasts us in blinding light. It is time to re-board and go rafting. As people start departing, I am happy that I had a chance to relate all this to them, even if much of it was rather narcissistic. A h … w e l l … lecturing as I have experienced and practiced it in my career seems to involve a lot of acting and narcissism. I am not confident this one was so successful, but the example here is so spectacular that it had to erupt out of me.

Everyone signed on for a geology trip, but geology does not always conform to a human schedule. So, after splashing and slamming through a series of the roaring 20’s rapids, we pull over to some rocks now well down in the Redwall and just upriver of a protruding ledge on the right. Our boat ties up next to this unusual ledge sticking out into the river. The second boat ties up to us because there is only space for one boat to nudge in here. This is a common way for everyone to exit over one of the bows when there is not much space to pull in. We pull ourselves up through a thicket of thorny bushes and over a pile of rocks to get to the ledge.

The flat space is flooded in sunshine and projects out into the path of the blue/green river sparkling from all the turbulence, bubbles, and wavelets typical of this river stretch. During higher flows of the past, even the near past, this high protruding ledge got regularly flooded.

The limestone surface is exquisitely polished and covered with numerous little scour marks (Fig 9.5).

Fig 9.5. River polished Redwall Limestone with scour marks on ledge about 15' above river level (U.S. quarter for scale center left). The flow moved in the direction of the long axis of the scallops. If asymmetric, the wider end is the downstream direction. Geologic detective work. Powell walked along surfaces like this near here and called it "marble." Geologists nowadays reserve that term for pressure-cooked limestone. This stretch of the river was thus called "Marble Canyon" until it was incorporated into Grand Canyon National Park.

Scours on flat surfaces can result from tiny current vortices that develop in depressions and abrade and/or dissolve hard substrates with enhanced vigor. These are modern features formed when the river flowed over this ledge during floods or possibly prior to downcutting when the channel floor was at an older, higher level. Slabs often protrude from cliffs to reveal ancient bedding plane surfaces that hold indicators of past current directions, water depth, climate, and other aspects of the depositional environment. This is a good example of how ambiguous such indicators can be. Surely these scallops should point in the downstream direction if they were caused by the river flowing over this ledge. Some of the troops looking closely comment that the scallops appear to widen in the upstream direction! This gives me a chance to explain something they may notice after running a big rapid. River flow shooting out of a channel constriction into a wider space pulls water in from the sides once through the constriction. This produces a current near the banks that moves upstream that fills in the spaces where the water pulled away. A horizontal swirl or vortex known as a “back eddy” thus forms immediately downstream of a big rapid. A common problem encountered by rafters is that they veer out of the main current and start circling in the back eddy. The stories of people getting sucked down in the center until they drown are exaggerations--I think. It is not something I wish to personally test. It does require some energy to get out of a vigorous back eddy, but it is a problem mainly for those rowing. So, these scours could indicate that this rock surface was once downstream of a large rapid no longer here. The issue is not one of science’s greatest problems, so we quickly move to the more significant features beautifully exposed here.

The ledge is covered with obvious fossils— fragments of crinoids, bryozoans, and others a paleontologist would hold us here exploring for hours (Fig 9.6).

Fig 9.6 Fossil fragments ripped off reefs or mounds by storms, waves, or strong currents. Once aggregates of disordered microcrystals of calcite, the fragments dissolve and reprecipitate in place into larger discrete microcrystals of calcite. The red areas are where microcrystals of quartz replaced shell fragments.

And here are splendid examples of chert nodules with evidence of how small ones can grow and coalesce into large ones (Fig. 9.7).

Fig 9.7. Bedding plane view of chert nodules. Large irregular masses develop as nodules grow outward and coalesce. Cherts form when calcite shell fragments reconstitute themselves into interlocking crystals of calcite. Microcrystals of quartz precipitate incrementally in spaces created as the calcite shell fragments dissolve to reform as larger crystals of calcite. The nodules cease growing when the permeability with respect to pore water flow decreases due to compaction and complete transformation of shell calcite into limestone.

The fossils are not directly at the spot where they were living on the sea floor; they were tossed around and broken up by strong currents or waves that crashed against reef structures. This is the typical case for most fossils found in limestones. These were partially silicified during early burial, so the limestone around them erodes more rapidly as water washes over the slab today. Together with spectacular bedding plane views of chert nodules, this ledge is a great place to convey important geological messages.

Preservation of intact fossils is rare. Soft parts of organisms are quickly eaten by scavengers or decompose during shallow burial. Hard parts get disaggregated and disarrayed by scavengers and currents that push and bang them around. The best usually found is a shell fragment, bone chip, or tooth if such existed at the time. The shell fragments people collect from rocks this old are not pieces of the original shells. You cannot pick up a fossil in rocks of this age and get a misty feeling that you are holding the original shell exactly as it formed so long ago. It typically had beautiful colors and was not as heavy as what you hold. The original shell was made of millions of microscopic-sized crystals of calcite or aragonite (same chemistry but different crystal structure) and pervaded with a micro-labyrinth of tubes, openings, and cavities where living tissue resided. The original mineral constituents dissolved rather rapidly during early burial and reprecipitated to form larger interlocking crystals of calcite, dolomite, or quartz—often in the exact same spot. Yes, some of our best fossils are made of quartz—like in petrified wood. The three-dimensional form of a shell can be beautifully preserved during the transformation depending upon many factors. Even if an original, highly intricate shell were buried free of degradation by physical or predatory processes, the form usually gets altered or even obliterated as all turns into rock. Rejoicing is in order when you find a fossil beautifully preserving its shape from a previous life.

The implications of everything exposed on this grand ledge are profound and worthy of deep contemplation. However, profound experiences are difficult to have in blazing morning sunshine. Everyone at least has a chance here of experiencing what a good fossil exposure can do for the human spirit. My astronomer friend Howard Bond told me his lifelong memory of how he remained alone once late in the day in Nautiloid Canyon farther downstream riveted by nautiloid fossils on a polished Redwall surface. Erosion had cut one in half such that you could see the coiled nature of these conical creatures that were once jetting around in the sea. He was stunned thinking about all the things that had to have happened to bring him face to face with this evidence of ancient life. Fossils carry many messages.

This ledge is not very large, and I have spent too much time talking about ancient life and how the cherts formed here. It is getting hot, and we are now WAY behind schedule for our desired campsite tonight. Schedule is defined this morning by a plan to eat lunch in a giant shady overhang still an hour downstream. So, we scramble back down over loose rocks with people slipping, sliding, and getting entangled in thorny bushes. I remain behind for a few moments of solitude to reflect here in the dazzling sunshine. This is just one thin stratigraphic horizon in what is going to be a 600-foot wall that will rise as we float downstream today. We will descend through to the bottom by late afternoon. Every little horizon that we float past I know is loaded with fossils, amazing cherts, burrow traces, and features that a person could spend a lifetime interpreting. Here I get lost in a reverie about the clear, shallow, sea that spread over northern Arizona about 325 million years ago when past continental drift brought it near the equator. Like the Bahamas today, it contained innumerable reef tracts shedding white sands that got spread laterally and piled up during storms and high tides to form shoals and countless islands both large and small. Swimming and crawling predators feasted on the rich array of marine life and crunched shells into pieces that got pounded into white sand by currents, storms, and waves. As the crustal platform underneath slowly subsided, the sands accumulated in layers piled on layers. Larger fragments of shells occasionally got buried as we can see here. Rainwater sank into the islands and flowed slowly offshore as ground water. It dissolved the opaline sponge spicules that washed in with the shell fragments and white sands. This ground water became increasingly rich in dissolved silica as it flowed through the subsurface dissolving more and spicules on its way toward the sea. All that silica in the coastal pore fluids caused microcrystalline quartz to form in tiny openings left when the mineralogically unstable calcite and aragonite fragments reconstituted themselves into a stable mass of interlocking calcite crystals known as limestone. Here I stare and can imagine the history of this and other cherty limestones formed in such tropical glory. I am spellbound.

Someone is yelling. I am holding up the show, so I crash down to the bow of the boat and call for a count-off to make sure we have not left some dreamer on shore. Everyone was assigned a number the first night and the drill is to sound out in numerical order as fast, as loud, and as clearly as possible. I razz the crowd a bit about the lousy quality of their sequential count-off. We cannot go back upstream, so it is an important drill that relieves the boatmen a bit from counting bodies. Although I never tell anyone, the boatmen count anyway and know if someone is missing. My mandatory count off is as much about bonding people into a group as it is about safety.

Smooth gray and red stained walls rise straight up from each riverbank as we float along deeper into the stratigraphy of the Redwall Limestone that is tilted slightly toward us. The canyon here is narrow and takes on a commanding aspect. There is no way to climb out, so we are now truly in the grip of the Grand Canyon. Numerous caves and solution-enlarged joints emerge to provoke the feeling that we are descending through a cave network down into the Earth like the explorers in Jules Verne's Journey to the Center of the Earth—or more like Wotan and Loge descending into Niebelheim in Wagner's great opera Das Rheingold. The caves range from small openings barely large enough for a mouse to big ones a person can walk in. We stop to explore the musty innards of a large cave that has a sandy beach spread out like a welcome mat (Fig 9.8).

Fig 9.8. Dissolution cavern in Redwall Limestone at Mile 25.

While passing around apples and oranges on our cave break, I explain that we are now passing through an exhumed groundwater aquifer zone. Everyone knows there is something called "ground water." I suppose some think it is an underground reservoir you can swim around in. Most hydrologists envision aquifers as subsurface sands in which water occupies and moves slowly through pore spaces between grains. Volumes of technical literature deal with the physics of flow in porous media--usually quartz sands. Limestone is not porous. Water flows through it along fractures that become enlarged by dissolution until it holds all the dissolved carbonate it can. The enlargement allows more water to travel farther which allows more dissolution which allows more water which allows…well. As the water flux increases, caves can widen along the fractures. Indeed, casual examination across from our big cave shows the vertical cracks that were enlarged by solution of the limestone. Where a big vertical crack (joint) intersects a bedding plane in the limestone, an almost cylindrical tube seems to develop. There is no water flowing out of these now because all of them above river level have drained into the big stream. This is what a limestone aquifer looks like. There were indeed small subsurface reservoirs here that you could flipper around in before the river cut down into them and drained the water out. Cave networks are present in the Redwall Limestone across all of northern Arizona. Spelunkers have squiggled into the openings and gone exploring. They keep the entrances secret and dream of crawling and then walking into a kingdom of stalactites, stalagmites, and all the amazing cave-filling features that form in limestone caverns. Sometimes they succeed beyond expectations-- like in the spectacular Kartchner Caverns in southeastern Arizona. These occur in an extension of the Redwall Limestone called there the Escabrosa Limestone. Where not drained by uplift above the groundwater table, cavern networks can transmit enormous amounts of groundwater. Explorers for water wells in any kind of bedrock know to study aerial photographs and topographic maps for places where big fractures intersect. Literally, a right angle "X" of little drainages or streaks of vegetation marks the spot to drill. There, a well can extract water from two joint directions to the maximum extent. Con artists can study the maps and walk around with forked branches that magically dive down near the joint intersections to wow their clients. Fractures in limestone are of special importance because they can widen by dissolution. Nowhere is this more visible than along this stretch of the river cut into the upper parts of the Redwall.

There has been some discussion about whether the caves along this stretch of the river have been dissolved out by the river itself as it cut down through the unit. The idea is that river water seeps in along the tiny, vertical uplift cracks or joints and enlarges them by dissolution. An altogether different interpretation stems from the paleokarst at the top of the unit. Caves develop under karst land surfaces, so maybe these relate to the time the Mississippian sea pulled away and left the recently deposited limestone high and wet in late Paleozoic rains. Then they were buried by the overlying strata, possibly after getting filled with red soil from the karst surface above. Explore modern caverns in limestone of the same age in Missouri and you will see red clay plastered everywhere and filling side passages completely. It has been and is being washed out by rainwater trickling down during the modern uplift. So maybe here we are just looking at cleaned out, mostly exhumed caves that formed initially 330 million years ago. The idea that the cave network was formed or enlarged mainly by the river itself has led to a recent theory that from this general area westward, the river once travelled underground all the way to the Grand Wash cliffs and discharged into a lake to produce what is called the Hualapai Limestone. When published in 2008, it attracted attention because it could reconcile some of the geologic contradictions encountered at the very west end of the Canyon when trying to explain its origin. A similar story for the last 52 miles before the river exits at the Grand Wash Cliffs was proposed decades ago by Charles Hunt, one of the first to struggle with how the Grand Canyon formed. This more recent theory involving subsurface flow in a cavernous limestone for 150 miles is possible because flow of groundwater for hundreds of miles has been documented for limestone aquifers elsewhere.

I choose not to air this theory at our cave stop because we are getting hungry for lunch at a spot that is still far downstream. I also am personally skeptical because large caves and collapsed caves are common in the Redwall throughout its subsurface extent in Arizona. There are hundreds of mapped “breccia pipes” in this area. These are small areas of rubble many yards wide that extend right down from the top of the skyline Kaibab Formation to collapsed caves in the Redwall. One of these vertical “pipes” of rubble is bisected by the canyon wall just to the south of our first stop today when we first encountered the Redwall. Looking back into the sun, I could not point it out and did not try. All these caves throughout the Redwall were not enlarged or formed by the Colorado River. The alternative idea thus seems more likely that these are ancient caves being exhumed and rinsed out during uplift. I am also skeptical regarding the Colorado River as an aggressive limestone dissolving agent. Except when swollen by local rains, it is already “hard water” approaching saturation with respect to dissolved carbonate. And then, there is all that cave-riddled limestone and paleokarst of the same age in Missouri and Kentucky where no river dissolution scenario is likely.

We reboard and pass a big cavern on the right called “Stanton’s Cave” where equipment of a failed early expedition was stashed while the explorers skedaddled up a side canyon to get out (Fig 9.9).

Fig 9.9. Approaching Stanton's Cave above the right bank in the Redwall Limestone.

Ancient people had long before used the adjacent side canyon known as South Canyon. There are degraded ruins to see here if you want to scamper a short distance up some of the cliffs. In fact, Stanton's Cave itself is where pioneer river runner Buzz Hatch found some little four-legged animal figurines made of cactus fibers. Buzz's son, Ted Hatch, subsequently took over his dad's company and ran it until his own death in 2010. Ted and his wife Jan would bring the duffel from our trip back to my house in the Phoenix area so that participants could bring whatever they wanted and did not have to carry it out in the helicopter at the end. We would have lunch where my wife and I would enjoy some of the greatest river stories imaginable. One was how as a kid, he used to play with the "split twig" figurines until a visiting archeologist recognized the significance of them and had them radiocarbon dated at over 4,000 years old. These date back to the oldest known occupation of the Canyon by Native Americans and were quickly relocated from Ted's toy collection to a museum.

Stanton's cave and the ruins are powerful because they alert us to the incredible story of the Native Americans who occupied extensive areas of the southwest wherever there was available water and built still extant structures starting about 600 AD. By 1150 AD, most of these structures were apparently abandoned rather quickly for unknown reasons. While the boatmen tell the crowd about the history, I waft off into thoughts about how these ancient people built truly inspiring structures amidst the cliffs and crannies everywhere around here. There is even a controversial theory invoking an immense population of Native Americans all over the continent that was rapidly and catastrophically reduced almost to extinction by diseases introduced after the first contact with Europeans. The subsequent white invaders then encountered shell-shocked remnants of a once vastly larger number of civilized tribes and tribal alliances. Were Native Americans really the savages described by the invaders or was it a Mad Max situation resulting from the apocalypse? While out geologizing in Arizona, I have often come across low walls, ruins, and black middens where long-lived campfires once blazed. Questions about these obviously once populous people always torment me. I once found a small beauty of a ruin with 2 circular walls tangent to a central room secluded in the forest on the South Rim. It sits only a cross-country mile from a road in the National Park travelled by thousands every day. There were potsherds and no trails or evidence of recent visitors. Just a lonely little ruin all to myself. The archeology bug can bite hard and fast in this part of the world because there is so much to discover off the beaten path. I sat in the now roofless, rock-cleared area of my little ruin and tried to connect with the people who built it. What did they look like? How were they able to live in such dry country away from the river? Were they indeed Rosseau's "noble savages?" There is compelling evidence they had a rich spiritual life. It is illegal to backpack in the National Park without a permit. Getting one to visit an Indian ruin seems unlikely. Someday, I am going to visit my little ruin at the end of the day, decree myself too exhausted to continue, throw down a pad, and sleep in the middle of the biggest room until dawn. What else can an exhausted day hiker running out of daylight do? I want to commune with the spirits still inhabiting this space, even if they do not exist. I must know. What dreams might come?

Thinking on all this, I notice something peculiar about Stanton's Cave. The top has slanted surfaces and the floor is covered with angular slabs and fragments that clearly fell off the ceiling (Fig 9.10).

Fig 9.10. Stanton's cave with its odd-shaped roof and large pile of fallen roof slabs. A steel gate with openings for bats has been erected by the Park Service at the back of the shadow. It is not clear how far back the cave goes as something a person could crawl through. Excavations uncovered over 100 split twig figurines age dated at 4,000 years and animal bones extending back to 20,000 years.

It just does not look like any solution cavern I have ever seen. Were those piles of fragments on the floor split off the top by the ancients who used to frequent this place? Were they starting to reshape it to be a special religious place? Was it…OK…stop…the imagination can go wild in a place like this. There is no way to know. There will always be unanswered questions about those who were here before recorded history.

My daydreams are interrupted when the motor speeds up and we drive over to the front of a little cave high up issuing water that cascades down stepped layers of the Red Wall and disappears in a plunge pool hidden behind rich greenery (Fig 9.11).

Fig 9.11. Vasey's Paradise. Snow melt from the North Rim supplies an aquifer that has been breached here by downward erosion of the river. Flow varies from year to year depending on the amount of winter snow. The flow shown here is about the maximum normally seen. Paradise indeed.

This is Vasey's Paradise named by J.W. Powell in his recorded history of the first expedition. He named it in honor of a botanist colleague at Illinois Normal University (now Illinois State University). Flowing water sings and splashes as it emerges from the lush thicket of soft, big green leaves and then slivers down into the river. Here is a modern aquifer in action! Melting snow high on the north Rim sinks somewhere and intersects the cavern network that the river is now breaching. It really gushes out in late spring after high snow years. Not flowing so much this day, it is nevertheless exhilarating to see it below a beautiful blue sky. My friend Bill Lieske and I once camped at a point jutting out from the North Rim that allowed us to see across the top of this vast area a thousand feet below. The gorge of south Canyon was easily visible, so we studied where the entry point of the snow-melt draining from our high level might funnel together and enter subsurface joint networks that could debouch at Vasey's Paradise. It was easy. We know exactly where it is, and I long to visit the spot and dump fluorescent dye into the spring-fed stream where it sinks out of sight there to find out how long it takes to emerge at Vasey's. JP tells me people have already done something similar.

After a long morning, I start nodding off into sleep as the river turns straight south and heads toward a wall that seemingly blocks the river with no obvious bend to the right or left (Fig 9.12).

Fig 9.12. Approaching a wall of Redwall Limestone.

An elongated, enormous black hole slowly appears at the base of the cliff and the river pours into it with a great sucking sound. We all scream in terror as the boat descends toward oblivion into a black, whirling vortex. I suddenly awake and am relieved that the river indeed bends to the right. No vortex--just a giant undercut at the base of the wall which the river centrifugally dug out while making its sharp turn. The huge overhang is known as “Redwall Cavern.” Powell wrote exuberantly that it could seat 50,000 people. It is merciful shade on a day shaping up to be rather hot. We glide in and the crew sets up lunch. It is not nearly as big as Powell said, but I bet you could cram in one of Caesar’s legions. Not today, people run around on the sand piled in by past high flows of the river, throw frisbees, and take the iconic photo looking out that you see in every guidebook (Fig 9.13).

Fig 9.13. In Redwall Cavern which is not really a solution cavern but rather an undercutting into the wall as the river makes a sharp turn to the west.

Meanwhile, I am disbelieving that anything natural or manmade is strong enough to support the wide column of rock above this gouged-out part of the wall. Indeed, there is a huge slab spalled off the roof on the upstream side, and people are drying out life preservers on some other fallen blocks. All those thousands of breccia pipes in collapsed caves in the Redwall are not much wider than this. Better to not think about it and instead confront a real geologic problem exposed running horizontally on the wall across the river here. Several broad, smooth, hump-shaped layers are seen instead of the nearly horizontal layers we have been travelling through (Fig 9.14).

Fig 9.14. Looking north at one of several rare mounds in the Redwall Limestone opposite Redwall Cavern. They are likely not depositional mounds but rather remnant highs from an episode of dissolution slumping when this thickness of Redwall was laterally flushed with fresh ground waters early in its burial history.

Someone wrote that these were likely broad algal mounds on the seafloor in Redwall time. Such things do exist, but they are finely laminated, smaller, and not shaped at all like this. Walking over to a wall of the cavern, I see again that there are numerous thin beds of jumbled chert fragments defining certain layers here and on the far side (Fig. 9.14).

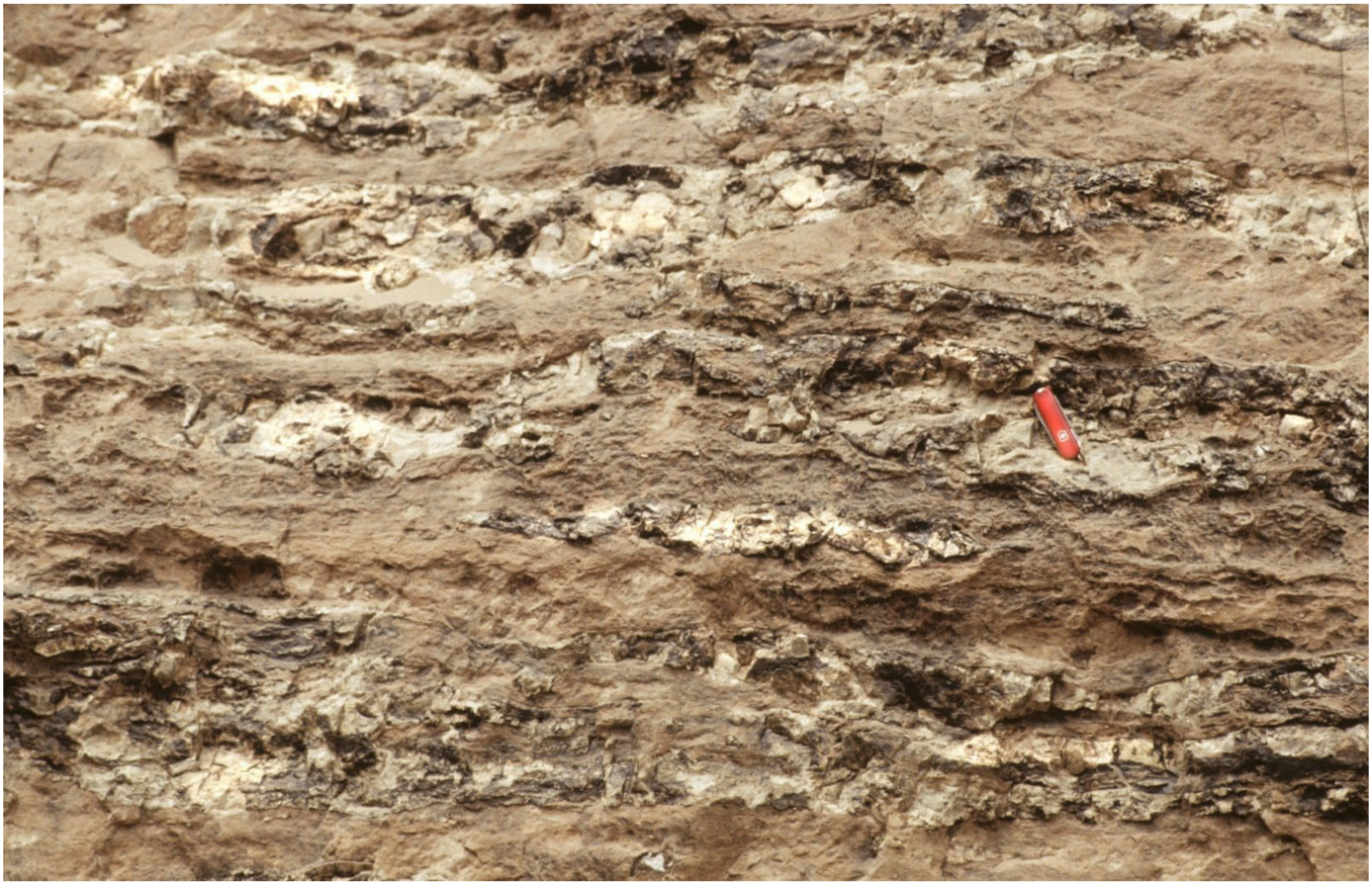

Fig. 9.14. Rows of fractured, jumbled cherts on the wall at the west end of Redwall Cavern.

Having studied other examples, I long ago concluded this was a likely but unusual example of paleokarst, like what we saw this morning at the top of the Redwall. Here, however, dissolution from huge fluxes of groundwater were moving laterally during early burial. It happened before cherts had grown too big and before the unit had turned to hard limestone. Everything just slowly compacted as the limestone particles dissolved and moved in solution laterally in the subsurface flow direction toward an ancient beach zone. One of my PhD students, the indefatigable mapper Steve Skotnicki, wrote a dissertation involving just this kind of paleokarst in the 1.2 billion-year-old Mescal Limestone in central Arizona that also displays rubble at its very top. My master's degree grad student Merry Wilson made extensive oxygen and carbon isotope measurements on the Redwall exposed farther to the south near Prescott and documented in her thesis how extensive and pervasive groundwaters were intermittently flushing through the Redwall during the millions of years it was accumulating. Here we can see an extensive cross section showing how some areas gently compacted more than others to produce the broad billowing pattern we see on the walls across the river here. The walls on this side show up-close how thin layers of fragmented cherts remain after the carbonate matrix was extensively dissolved and transported away laterally during early burial. No karst pits here, it is those thin layers of chert fragments that reveal the likely story.

Looking at a great thickness of limestone like this, with its evidence of having been intermittently exposed to rain waters during its overall deposition in a shallow tropical sea. We typically fail to appreciate how discontinuous the deposition really was. It is a profound geologic lesson that few appreciate while staring at apparently smooth walls. Individual sedimentary formations can and typically do contain many hiatuses where deposition stopped and started again--often with considerable erosion of the earlier, underlying deposit. There were many local retreats of the sea during Redwall deposition that left the shell debris exposed to rainwaters for a time before the ocean came in once again. Sea level is always slowly rising or falling, both locally and globally. Always. The reasons here may be different from the glaciations, tectonic bobbing up and down like a cork, or rise and fall of sea floor mountain ranges. Clyde Moore, an expert on carbonates and a colleague of mine in my first faculty job at Louisiana State University once told me his idea that I am not sure he or anyone else ever published. But looking at the Redwall all these years, it continues to resonate. He suggested that because in clear, shallow, warm waters, production of carbonate shell debris can be enormous and rapid (in geologic terms) so that filter feeder animals can grow right up to the water surface so extensively that the shallow water ecosystem shuts down. Rainwater locally sinks in intermittently across broad areas. This is, effectively, a relative sea level fall caused by overpopulation at that spot. Eventually it gets submerged again from slow subsidence or after dissolution and physical erosion from rains, currents, and high tides. Then, new organisms flourish and start the cycle over again once the water gets deeper and widespread over the rubble pile. There are no modern examples of extensively flooded continents to study where this is happening today. The Redwall certainly has numerous layers that may have formed in this way even though burial conversion to limestone and, in places, dolomite, obliterated many original textural differences. In any case, there is abundant evidence that it emerged from, and then sank beneath the sea repeatedly during the 25 million years it accumulated. It is odd that so few geologists or graduate students have studied this famous layer. Arizona universities have never had many faculty who study carbonates--for reasons I never understood. If the Redwall were near Texas, Oklahoma, or Louisiana where there are major universities training graduate students with skills useful for employment in the oil industry, there would have been numerous theses, dissertations, papers, and books written about the fascinating stories the Redwall holds. The sea comes in and the sea goes out, and we learn about it amidst the vagaries of puzzling academic priorities.

But enough musings in the shade here. Lunch is over. Time to launch out into the hot sun. Not many splashy rapids ahead, so the search for a shady spot to do geology begins. We will encounter more variety this afternoon, including aspects that are scenic, sobering, enigmatic, alarming, and wonderful. Our group remains excited about the wonders unfolding and wonders to come. I am even more excited because all this is framed in the context of my journey onward to the shining summits of the distant Sierra Nevada mountains.