Chapter 17 **Against Better Instincts** Mile 108-117.5

The smell of breakfast cooking summons everyone to the kitchen area after being chased into tents last night by the rain that started right after dinner. High thin clouds dull the sunrise but fail to diminish the grand spectacle looming over us to the west (Fig. 17.1).

Fig. 17.1 Morning view to the west at the "Grassy Knoll" campsite, mile 108. Tilted strata in the nearer distance are capped by the slanting Shinumo Quartzite, the top of an ancient island in the Cambrian Sea. The Redwall Limestone is the prominent red layer in the skyline stack of strata. Those strata have eroded back to uncover this ancient island.

Although everything is remarkably dry, raingear and clothes are still spread over rocks and bushes. Following the epic run through the rapids of the inner gorge yesterday, river life today will be more leisurely. People were clearly thrilled by the rapids and deservedly feel more at home on the river. I am energized to visit, expound, and reflect on what I know is coming. Before noon, we will arrive at the gravity center of Grand Canyon geology. But first, we will stop at a little-visited side canyon to start tuning into the meaning of deep time.

Several people waiting for breakfast look at the red bandanna diagram I have put on a big rock (Fig. 3.9) and struggle to match it with the view to the west. Distinguishing the actual layout of sedimentary strata from how it appears in an erosional landscape is easy for me because I have done it for many decades. For others without this experience, I must briefly go over the whole story again several times while different people show up lugging their bags to a growing duffle pile near the boats. Several who are really interested in geology pull out a guidebook that has a series of cartoons showing how the Shinumo and those layers under it accumulated on the schist and granite after it had been uplifted and eroded down to sea level. Following renewed uplift, tilting, and further erosion, the encroaching Cambrian Sea came in leaving the hard, tilted upward Shinumo Quartzite as an island. We can't see the contact from this vantage point between the Tapeats island and the ancient island, but it is shown on geologic maps. It appears the island was not submerged until the middle Cambrian Sea came in over this area and deposited the Bright Angel Shale (Fig. 17.2).

Fig. 17.2. Tilted tectonic block capped by the resistant Shinumo Quartzite remains while all around it is being eroded away. This knob was an island in the Cambrian Sea that initiated deposition of the horizontal stack of layers seen behind it. It is now shining again in the morning sunshine as it once did over 500 million years ago.

This old island now being weathered again is less than 30 miles from where the distressed pilgrim visualized life battles in the middle Cambrian Sea at the Bright Angel Shale cliff face in

Nankoweap Creek. It might have been visible if any eyes had peered above sea level on a clear day. As subsidence and deposition continued, both the ancient mountain and the entire stack of overlying Paleozoic strata were deeply buried. Then, starting about 50 million years ago, the crust in this area rose yet again during the Laramide Orogeny. Following renewed erosion, this ancient island of Shinumo Quartzite is now exhumed and shining again in morning sunlight as parts of it did over 500 million years ago. It appears to us now as a small mountain peak standing in front of the Paleozoic strata around and behind it. Judging from facial expressions, the recognition of this as an ancient mountain in the Cambrian Sea is as thrilling to my little audience as it is to me. I love it when I see the wonder in faces suddenly realizing that the pretty scenery before them is a profound expression of Earth history. An island in the sea that was flooding North America during expansion of earliest animal life is looking down on life again but is now looking at it after 500 million years of subsequent evolution. If mountains could think, I bet this one would be as amazed at the sight of us as we are of it. I briefly think on what this place and its life will look like 500 million years from now because all will be inconceivably different for sure.

The rapids we contested and shot through yesterday no longer displace appreciation of the beauty, variety, and mystery of these oldest rocks in the Grand Canyon. The schist here seems totally different from what we saw initially. Why do we see so many splotches and masses of brown and pink granite all interspersed in this black rock that can weather out into splintery jagged ridges where the river hasn't polished it smooth (Fig. 17.3)?

Fig 17.3. Stringers of coarsely crystalline granite in the schist of the inner Gorge. A zone of particularly large crystals of feldspar and quartz in the granite is visible in the center of the image. Note hammer for scale. Such zones of large crystals are referred to as "pegmatites." Many granite stringers in the schist are pegmatitic like this.

How do the white veins shooting through the schist that we passed yesterday fit into the story? The guidebook declares all this is about 1.7 billion years old. How is that known with such assurance? What does it even mean for rocks like these? I do some intellectual bobbing and weaving to defer answering questions from a curious few because breakfast is being served and because we are positioned to visit Garnet Canyon ahead. It is probably the most geologically spectacular of the least visited side canyons and a great place to ponder deep questions. In two geology stops today, I can indulge and vent my prejudices regarding the most important impact geology has had on the human psyche. A palpable euphoria appears to be setting in on the group as it does on all river runners after traversing the fury of the inner gorge. It is the perfect time to restart this as a geology trip.

We embark and almost immediately pass Bass Camp. It is empty, and JP says he can tell someone was there the night before by all the tracks in the sand. I decide not to rub it in that there are always lots of tracks there and that we likely gave it up yesterday. However, exploring the Native American ruins there and the wonderful waterfall and splash pool in adjacent Shinumo Creek was not on my preferred agenda, so no matter (Fig. 17.4).

Fig. 17.4. Bass Camp at mile 109. One of the most popular and difficult to snag campsites amidst walls of schist.

We run a few rapids, Waltenberg being the most difficult, and then notice that the cliff faces on the south side below the Muav limestone are covered with what looks like gray rubble and occasionally what look like draperies of stone. It is travertine again—a gnarly, complex jumble of large and small blocks of calcium carbonate. Big chunks of the drapes have broken off and fallen away (Fig. 17.5).

Fig. 17.5. Cross section of thick travertine deposits mantling the steep south wall of the river near Elves Chasm. A huge mass of it fell off the wall to allow examination of the innards of this material. The wall section of Paleozoic layers originally covered by the travertine that fell off are to the lower right of center. The travertine is a mass of talus here up to 20' thick and strongly cemented with calcite.

The travertine extends up to the Muav Formation and was once almost a wall upon the wall. The simplest explanation is that ground water in the Muav here debouched in numerous springs that wept down the walls. As it did, it degassed carbon dioxide and warmed thereby causing the chemical precipitation of millions of submicroscopic crystals that stuck together as slime on the wall. It is the same kind of sludge we observed and frolicked in at the confluence with the Little Colorado, only here were numerous springs weeping out of the Muav Formation. In short order, the sludge hardened into coatings and vertical layers that broke, slid, and tumbled into cemented talus that covers the walls. There have been local accumulations of travertine-cemented talus all along our voyage but nothing like this. Why so abundant here and not more widespread remains a question that has not been fully answered.

Big travertine deposits are also often present in the Mogollon Rim area of central Arizona where the Paleozoic strata lie over big faults in the underlying Precambrian rocks, so some have proposed a similar cause for the travertine in the Grand Canyon. However, there are big faults everywhere in Arizona's Precambrian crystalline rocks unassociated with any travertine. The draining of an aquifer in the Muav is surprising. Was there a large cavern network once in the Muav? Big caverns in dolostone are not common, so maybe the Muav is a limestone along this stretch? Somebody needs to climb up and explore the source of the immense travertine wall coating here. Maybe it was the usual caverns in the Redwall that drained into fissures in the Muav? So many questions. Whatever the significance of its origin, big blocks of this travertine coating fall off readily and pile up on the slopes and in the small side canyons.

One of the most iconic places to visit on a raft trip through the Grand Canyon is "Elves Chasm." It is a big pile of these fallen blocks choked together in one of the side canyons. A little stream of water spills over to make a 15-foot waterfall typically bordered with attractive green plants and slime. The travertine blocks have lots of nooks and crannies behind the plunging strands of water as they fall into a shallow plunge pool. People like to wade in, climb up behind and through the cascading water, and jump in while friends take their picture. It is a lot of fun. If you are first to arrive in the morning, the scene is reflected off the crystal clear water. See that and you will want to adopt this magical place (Fig. 17.6).

Fig 17.6. Elves Chasm before the translucent pool gets stirred up by frolickers. Anyone who can resist walking under that little waterfall, climbing up behind the lower part, and jumping into the plunge pool has no soul.

Photographs of it in morning light are publicized everywhere, and thus it is rare to pass the place and not see a gaggle of boats tied up--often one to another on out into the river. This photogenic feature is actually a very small alcove. A boatload of river runners must crowd together to fit in. I have seen it in its magical form and also seen it so desecrated--even participated riotously in such desecration. People whoop and holler as splash after photographed splash transpire to turn the place into a mud bog. I stopped going with the groups years ago and instead would sneak over to a secret plunge pool lower down for a brief swim before the water turned too muddy coming down from above (Fig 17.7).

Fig 17.7. Secret plunge pool lower down the wall from Elves Chasm.

JP has consented against his better instincts to indulge me today with Garnet Canyon instead of joining the other groups that will likely be there. This was, after all, advertised as a geology trip.

We pass a private trip of about 5 rowboats and pull up against the small rock pile at the mouth of “Garnet.” It doesn’t look like much, and few people stop here because famous Elves

Chasm is just ahead. The lead boat from the private group of rowers we just passed comes close and asks if this is Elves Chasm. They aren't sure exactly where they are. Private groups seem to have a lot of memorable adventures on raft trips resulting from inexperienced leaders. The only National Park Service requirement besides equipment inspections is that at least one in the group has been down the river before in any capacity. A whole mystique has developed about rafting the Grand Canyon as a confrontation with danger because of the justified challenges of the white water. I am always grateful to be with a commercial operation where I don't have to fear for my life every day or test my ability to overcome dangerous obstacles. However, the adrenaline rushes, thrill of discovery, and adventure are part of the mystique for these rowers--so God bless them. JP explains that "Elves" is still about two more miles ahead. We disembark and immediately face a steep, 15-foot wall of granite with water trickling down in thin cascades over narrow stair steps caused by the jointed surface. The wet granite is made of large, beautiful crystals with stringers of schist embedded here and there. Frosty white patches and streaks of salt coat many surfaces of wet gravel. People gather at the base of the wall around a little plunge pool to see tiny rafts of salt floating around. The water trickling down the granite surface is so loaded with dissolved salt that the slightest evaporation causes crystals of sodium chloride to precipitate. Everyone seems more confident now about going up slanting cliffs and scampers up without delay.

The going gets easier as we transition to broad, easy steps. The stream-polished granite with its stringers of schist is gorgeous, one of the prettiest climbs in the Grand Canyon. In a hundred feet or so the canyon broadens and terminates against a giant wall of the Tapeats sandstone sitting directly on the granite. The shady big bench we stop on has pools of salt water ponded on a surface of granite with several bench-like steps going up one side of the alcove. Waiting for everyone to arrive, several of us go behind the bottom corner of a big, tilted slab that fell off the wall and see a paradise of salt stalactites, crusts, nodules, pillars, and delicate salt flowers--many newly formed in water dripping and sliding down the wall of Tapeats (Figs. 17.8 and 17.9).

Fig. 17.8. Small amphitheater at top of Garnet Canyon Climb. Here is the Great Unconformity between the Tapeats and the Precambrian granite/schist basement rock. The fallen brown slab just to the left of center leans against the wall with an opening behind it at the bottom. Brine is leaking down the backside to make cave "formations" of salt like carbonate versions found in limestone caverns. It forms a small pool before sinking into the gravel and reemerging down the slope. (Photo by JP Running).

Fig. 17.9. Salt stalactites, nodules, crusts, and flower like aggregates forming in dripping brine behind the brown slab shown in the previous figure. Red pocketknife is about 3 inches long.

We see a few salt-coated stalks of vegetation that probably grew after rains swamped the saltwater springs coming out of the Tapeats. And there is a daddy long-legs spider that got caked and petrified in the salt water. How did that happen? This salt is exactly what we saw earlier on the trip when we encountered the Hopi Salt mines. Apparently, brine is lodged here as ground water at the base of the thick stack of Paleozoic strata above the almost impermeable granite and schist. It is weeping out as erosion carves into the wall.

This isn't a Native American sacred site, but it seems like a sacred classroom to me. What a perfect place to gather and talk geology (Fig. 17.10).

Fig 17.10. Class time in Garnet Canyon. People are sitting on the granite and schist here overlain by the Tapeats Sandstone. The contact is the Great Unconformity again, representing over 1.2 billion years of missing rock record. Brine is leaking out along the unconformity, forming a small pool, and then sinking into the gravel where it flows in the shallow subsurface down toward the river. The groundwater brine is perched along the top of the granite/schist where it severely rots the lowermost sandstone beds before leaking out. The combination of schist and granite observed here is more properly referred to as "gneiss." (Photo by JP Running)

We see here the Great Unconformity in a place where the upper Precambrian strata are entirely absent. The Tapeats Sandstone is lying directly on the basement "crystalline rocks" as illustrated along the right margin of the bandanna diagram (Fig. 3.3). Regardless of what term to use to describe the basement rocks here, they constitute a most wonderful exposure of what geologists considering the globe as a whole call "granitic" rocks that make up mid-level continental crust. It looks remarkably like what is observed under sedimentary rocks that cover, or once covered, all North America and probably every other continent as well (Fig. 17.11).

Fig. 17.11. Granite extensively invading schist. Floor of Garnet Canyon. The floor is constantly bathed in clear, gently moving brine that leaks out from the Great Unconformity. This apparently keeps the granite and schist shiny and beautiful—possibly by quickly removing surficial coatings of clay minerals and microbial films.

I am always delighted walking into the alcove---providing it is in this magical morning shade. It would be an insufferable hellhole with no magic if it were afternoon in the summer sun here. This beautiful morning is perfect. I am on a high with so much to talk and think about amidst this splendor. What rages in my mind now is how and when such continental crust forms, the triumph of radiometric age dating of rocks, the profundity of deep time, and the relevance of this place for the creationist attacks on science. But it must be short.

Geologists probe the inner Earth by studying the speed at which vibrations from earthquakes or explosions travel through rocks. An early discovery was that the speeds suddenly and dramatically increase at depths of about 30-50 km under continents, a transition called the "Morohovicic Discontinuity," or "Moho" for short to keep tongues from tying in knots (Fig. 17.12).

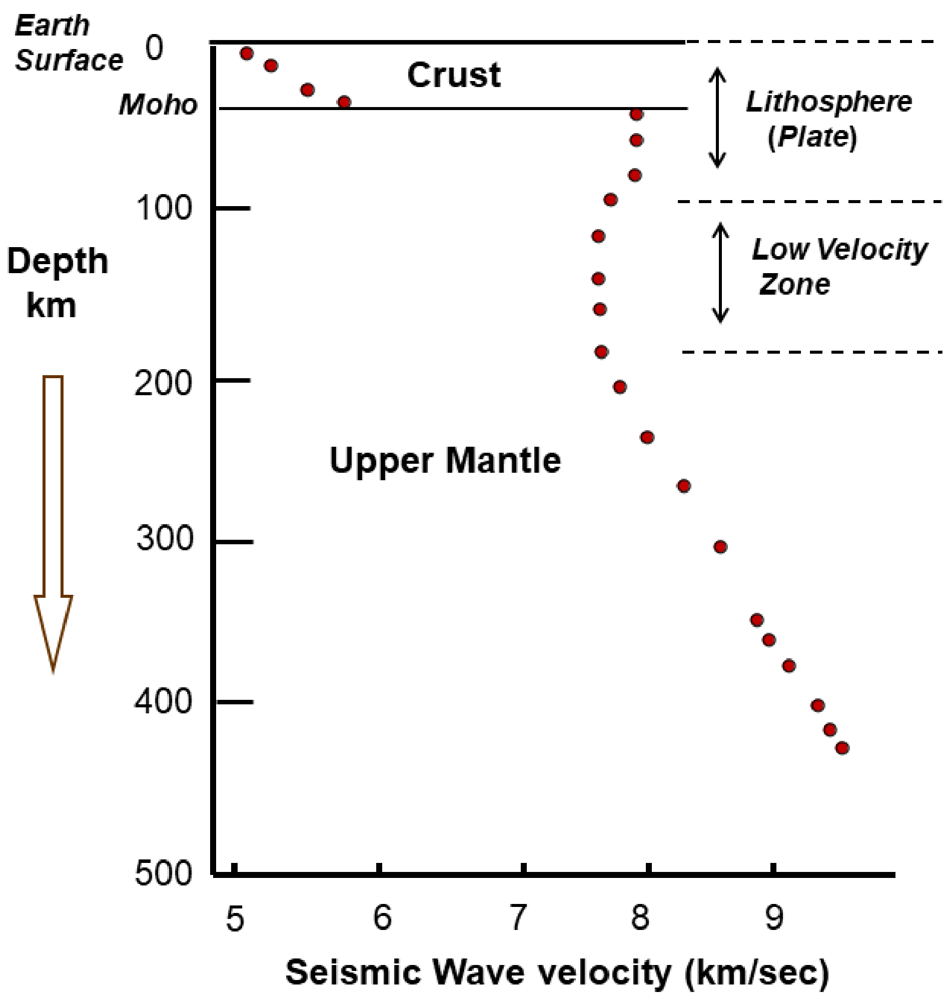

Fig 17.12. Velocity of sound in rocks going down 500 km into the Earth. It rises steadily as pressure makes the rocks denser and suddenly jumps to 8 km/sec at some depth less than about 50 km. This defines the base of the "Crust." All below it is called the "Mantle" down to the boundary of the core at 2,900 km (1,800 miles). The velocity decreases starting at about 100 km depth and does not start increasing again until depths greater than about 200 km. Where the velocity begins to increase again is defined as the base of the "Lithosphere." The lithosphere is broken into plates that can move around on the "Low Velocity Zone," which is interpreted to be partially molten.

Everything above the Moho is called "The Crust." Everything below down to halfway to the center of the Earth is called the "Mantle." Below that, rocks are so hot they melt despite the great pressure. The velocities and studies of wall-rock fragments brought up from depth in volcanoes suggest that the average composition of the continental crust is what we are sitting on here in Garnet Canyon. Compositionally, this is almost certainly the proverbial "granitic" crust. Remarkably, the Moho is encountered only a few kilometers when going down under the ocean basins. The crust there under ocean sediments is not granite but has a composition almost the same as common lavas called basalts. These are the black lava rocks that make up the Hawaiian Islands, Iceland, and numerous other places. Smaller amounts even occur here in the Grand Canyon. We encountered some that erupted here hundreds of millions of years ago on our hike into Chuar Valley and wondrous examples are ahead. Where basalts erupt on continents, they originate in the mantle and rise through tens of kilometers of granitic crust. Basalts erupt on the ocean floor and oceanic islands, but they come up only through thin basaltic crust. There are thus two kinds of crust with thicknesses ranging from about 1-50 km. Note in Fig. 17.12 that the crust/mantle boundary is strictly defined by the Moho which lies entirely within the great tectonic plates that are about 100 km thick (100 km). The great tectonic plates apparently slide on the "Low Velocity Zone" where seismic velocities do not increase as they do above and below it. This is interpreted as a partially molten zone where the increase of temperature with depth is almost enough to overcome the effects of pressure trying to keep the rocks solid. Below it, pressure wins totally until the edge of the core region is reached about 2,900 km down. This can get confusing; just remember that continents are not plates. They are embedded in the tops of plates and stay there as the plates move, divide, rub against each other, or slam together. The denser oceanic crust is likewise embedded in the tops of the plates, but it can sink down more readily into the squishy plate materials underneath made of almost the same thing.

So why is there this incredible dichotomy of composition between the more buoyant, thick continental crust standing high and the denser oceanic crust at lower elevations? The question remains unanswered despite over a hundred years of intense investigation. There are now some reasonable hypotheses backed by lots of evidence, but the time and way continental crust first developed on Earth remains contentious. Tectonic plates that include both crust and upper Mantle constitute the "Lithosphere" and develop from the top down as internal heat is lost to space. Their bottoms represent the transition to hotter, more deformable material. The continents embedded in the tops of these tectonic plates are a special problem. Granitic rocks like the floor of Garnet Canyon have never been seen on the moon, Mars, or any other planetary object. No meteorite like it has fallen from the sky. Granitic crust appears to be unique to the Earth. We are not just standing and sitting in an alcove of pretty rock; we are starting our day amidst a wondrous puzzle. We even slept on it last night.

Granite can be radiometrically age-dated with considerable precision--the age meaning when it solidified from a molten mass. The granites in the Grand Canyon vary in age somewhat, but all seem to have formed about 1.7 billion years ago. The oldest granites across the southwest date back to this age, but no older. Many are about 1.5 billion years old, and many are even younger. The granites of the Sierra Nevada Mountains in California, the targeted end of my pilgrimage are “only” about 60 million years old. In Wyoming, some are found that date back to about 3.4 billion years. We find similar variations in the ages of granites on all continents. Granite older than 3.5 billion years is rare. Exhaustive searches in the cobbles found in very ancient river gravel deposits in Australia and in enclaves of metamorphic rocks in the oldest parts of Canada have yielded samples with ages older than 4 billion years. Evidence is compelling that the Earth itself formed about 4.6 billion years ago, so the absence of abundant granite older than 3.5 billion years is perplexing. Some argue that tectonic upheavals and metamorphic alteration likely wiped out the earliest rock record on Earth. Others suspect that the formation of long-lived “granitic” continental land masses didn’t begin to form until about 3.6 billion years and remained rare until about 2.5 billion years ago. The actual geologic record of the earliest crustal rocks is so fragmentary that many interpretations are possible.

Of interest to us in Garnet Canyon is the global problem of whether new continental crust appears episodically-- or did a granitic cooling scum form after the Earth accreted from solar system debris that got entirely melted from the violence of the accretion events. Did continental crust form early and then get episodically remelted by tectonic events. Is this granite we are standing on original new crust, or did it rise from deeper granite remelted by the tectonic events that mangled the buried sea floor muds to form the schist? New crust or recycled crust, that is the question. In lab experiments, rocks like the schist can be heated beyond the point of melting. However, they don’t melt all at once. Instead, little droplets rich in potassium, aluminum, sodium, and silica are sweated out first and form little blebs and pods of granitic composition. So, maybe here we are seeing those blebs and pods that froze by rising and coalescing during this deep burial metamorphic event. In that case, this is new granite being added to a growing continent about 1700 million years ago. Following these melting experiments in labs, geologists once got excited that maybe all granite forms in this manner and slowly adds together to form the granitic crust. But there is a problem.

In the lab experiments with rocks like schist, the whole mass melts shortly after just a few, tiny melt drops of granitic composition appear. When all is done, the rock is closer in bulk composition to a basalt with only negligible amounts of granite embedded on the surface. Here in Garnet Canyon and throughout the schist, there are huge amounts of granite in relation to the amount of schist. There appears to be too much granite to have formed as material sweated out from the schist. It seems more likely that there is continental crust deeper down that got remelted and rose to intrude the shist. If so, this is part of an older continent platform that got recycled analogous to hacking a wedge out of a tree trunk and then packing the fragments back into the wound. It would be fun to hear some geologists who study this issue stand in Garnet Canyon and argue. Or not; the amount of granite in the schist really screams that there is granitic continental crust deeper down that was being melted and rising upward. But let multiple hypotheses thrive!

The expression on faces suggests that this is more than most who demand definitive answers want to gulp. I therefore do not mention that some geologists have also suggested that the jumble of schist and granite accumulated as fragments of a continent somewhere else, and that it all rafted in here and docked on the west side of North America as part of Precambrian continental drift. All the explanations require us to be sitting in an area that underwent some kind of major tectonic upheaval or collision. Whatever their origin and significance, these are certainly beautiful pods and stringers of coarsely crystalline granite of the floor of this grand classroom.

But class is not over. All of this involves age-dating of the granite intrusives here. Just how is “radiometric age dating” done? Although fundamental to the modern science of geology, this highly developed and repeatedly tested methodology is considered invalid by those insisting on a literal interpretation of the Bible. Indeed, polls often reveal that more than a third of American adults believe the Earth to be no more than 6,000 years old because this age can be supposedly deduced from scripture. Faith-based political operatives have so influenced local public school boards that textbooks and teachers are often required to present the radiometric age of the Earth as just one of several alternative possibilities. To be sure, the method and the appropriate way to sample in the field can seem complicated. I doubt that there are many (if any) critics of scientific age-dating who understand the method sufficiently to credibly challenge its logic. However, the basic idea is simple and is ultimately based on the assumption that we can deduce the decay rate of radioactive elements. That we understand radioactive atoms well enough to explode nuclear bombs, successfully generate nuclear energy, and make incredibly useful medical and technological gadgets utilizing radioactive atoms gives confidence that our basic assumptions and methods are remarkably accurate. In the case of the granite in Garnet Canyon and elsewhere in the Grand Canyon, it is the tiny zircon crystals that offer us a reliable way to date the crystallization age of these formally molten rocks.

As discussed in Chapter 2, the tremendous heat in the Earth that ultimately provides the energy to lift mountains probably arises mostly from the radioactive decay of uranium atoms that became trapped within the zircon crystal structure when it formed. As the uranium decays into lead, the amount of lead trapped in the crystal increases. So, if we knew the amount of uranium originally present, the amount of lead vs amount of uranium in a zircon crystal could tell us its age providing we knew how fast the uranium atoms decay. The decay rate is confidently known, but there is no way to tell how much uranium was originally present because uranium atoms are not a regular part of the $ZrSiO_4$ crystal lattice. They were engulfed by the growing crystals in amounts that vary from crystal to crystal. Fortunately, there are two different kinds of uranium atoms, one having 235 protons and neutrons in its nucleus and one having 238. The one having 235 decays at a faster rate than the one with 238. The latter decays into lead atoms having 207 protons and neutrons, while the other decays into lead having 206 nuclear particles. There are thus two different nuclear “clocks” ticking at different known rates in the zircon crystals. We thus need only to measure the amounts of these four atoms to obtain an age. From the ratio of lead 206 to uranium 238 to and lead 207 to uranium 235, we can calculate the age (Fig. 17.13).

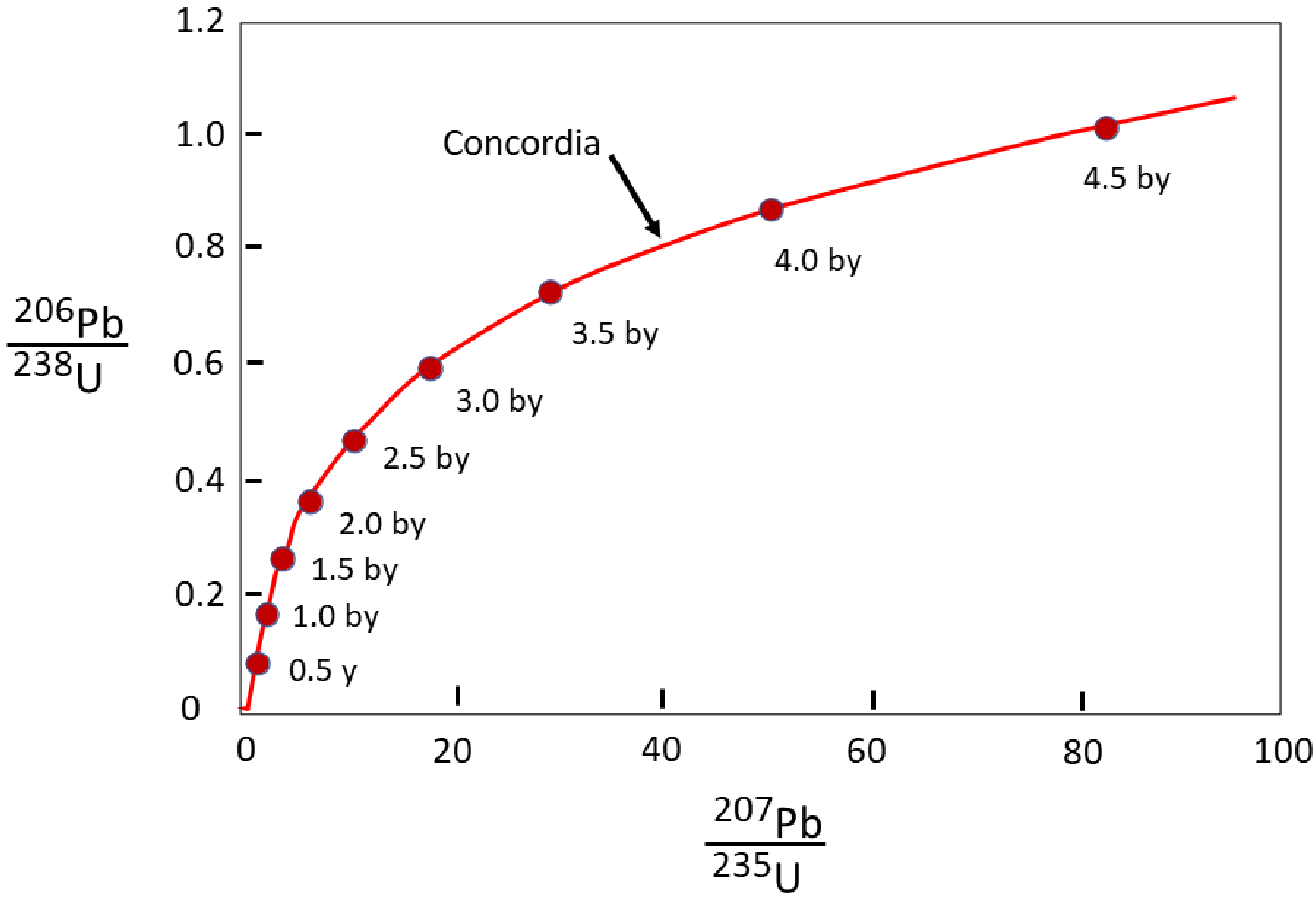

Fig 17.13. ^{238}U is a variety of uranium atoms that decays with time into ^{206} Pb, a variety of lead atoms. ^{235}U decays at a faster rate into ^{207}Pb. The "Concordia" curve shows how the ratios of these 4 kinds of atoms change with time. Upon initial crystallization, there would be no lead; the measurement would plot at (0,0). As time progresses, ^{207}Pb increases faster than ^{206}Pb by amounts shown on the theoretical curve. By measuring the amounts of these 4 atoms in a zircon crystal, the age at which the crystal formed may be calculated from the curve. If a later metamorphic event heats the zircon crystals enough to cause lead loss, the data depart from the Concordia curve in a systematic way that allows both the initial age and the age of the metamorphic event to be calculated (methodology not shown here). In many cases, data hopelessly scattered below the Concordia curve indicate multiple metamorphic events, hydrothermal alteration, or intense weathering. Microscopic examination of the zircons with a polarizing microscope and their host rocks can reveal that such alteration has occurred. Samples obviously disturbed by such events are not suitable for age determinations.

Make the measurements, do the math, and there is an age. The technology of making the measurement is now such that the ratios can be quickly measured from crystal to crystal and even different parts of the same microscopic zircon crystal! All the granites in Grand Canyon yield radiometric age dates of about 1.7 billion years--as do many elsewhere in Arizona.

All along the walls of the inner gorge, we have seen evidence of granite moving upward. Vertical veins cross the apparent bedding and fracture orientations to indicate that the buoyant molten material was freezing in place as it worked its way toward the surface (Fig 17.14).

Fig 17.14. Zircon crystals in light-colored granite fingers like this in the Schist have been age dated at about 1.7 billion years. At that time molten granite was rising vertically through deeply buried ocean mud that was being deformed and converted into schist by the great pressure and temperature. It is likely that some of the rising granite magma reached the surface to form explosive volcanoes. Much later tectonic uplift tilted this mass up to the right long after solidification.

Did any of these viscous intrusives make it all the way to the surface to erupt as volcanoes? Artistic drawings of the schist with the overlying sedimentary rocks replaced with tall volcanoes erupting great clouds of ash, steam, and smoke are not uncommon. Granitic magma is barely molten and highly viscous. Gas pressure builds up behind plugged vents and finally blows everything out in a violent eruption. Looking up into the blue morning sky, it is not unrealistic to envision towering volcanic constructs with blast clouds rising into the stratosphere. The whole edge of the North American Continent was undergoing massive remelting in response to basalts rising from the mantle, pooling under and within the lower crust, and causing catastrophic disruptions to the landscapes above. Granite and volcanic rocks of granitic composition occur in Missouri and elsewhere, so the tectonic upheaval recorded here in Garnet Canyon was widespread and part of goings-on so far back in time that it is difficult to piece everything together.

No one seems to blink when they hear that we have a reliable method that indicates we are sitting on granite that formed 1,700 million years ago. The words are short and easy to apprehend, but how to comprehend such an interval of time? How to feel it? Silence helps. The drip, drip, drip sound coming off the wall gives some sense of time moving on. A fingernail grows about 1.4" per year. At that rate, it would take 1.1 billion years for a fingernail to grow all the way around the world. The granite here is yet another half billion years older still. Staring at your thumb with this in mind and hearing the rhythmic drips, the immensity of geologic time begins to set in. It cannot be truly conceived, but we can at least have a moment of silence to reflect on it. The growth and recycling of continents, the crystalline beauty of smooth, water wetted granite, the nature of time---this is the magical alcove in Garnet Canyon.

People start drifting off for the descent across broadly stepped granite ledges. Many study the beautiful green and dark red minerals in the schist, the brilliant white quartz veins and pods, clusters of large crystals, and enchanting little salt rafts floating around in bowls of polished granite. Where the pools are undisturbed, the salt rafts grow wider as water evaporates. The center sinks down as ledges grow upward around the periphery. They look like miniature, upside-down stepped pyramids pointing straight down. When they get heavy enough, they sink. Such "hopper" shapes are sometimes found in ancient deposits. We saw some impressions in the mudstones of the Dox Formation earlier in the trip (Fig. 14.19).

The steep wall next to the river is more difficult to descend than to go up. People stand below and guide feet down for others. I go awkwardly down part way on my backside. JP follows us and scampers down like this is nothing. We pull out and cruise along walls of the schist and the overlying Tapeats lying like a blanket on it. Withing two miles there is suddenly an astonishing sight on our right. The granite/schist ends abruptly against a curled-up wall of Tapeats folded upward as strongly as we saw in Carbon Canyon. However, here it is not Tapeats layers over Precambrian sedimentary layers; it is the great unconformity with the Tapeats directly on top of the crystalline basement that has been wrenched up into a tight fold (Figs 17.15 and 17.16).

Fig 17.15. Monument Fault at mile 116.4

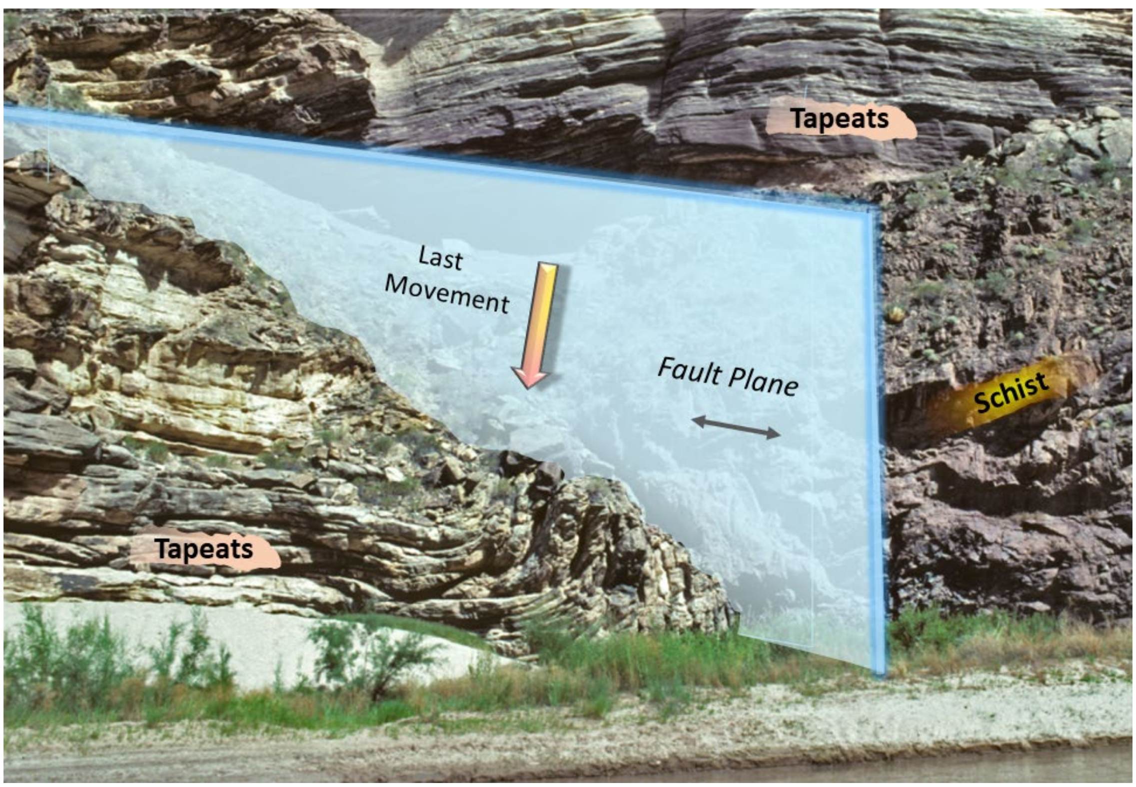

Fig 17.16. Interpretation of the fault plane direction and relative tectonic movements on the Monument Fault. The Tapeats Sandstone overlies the schist and was dropped downward as shown in its last movement that created the notable drag folds at river level.

The fault runs almost parallel to the river, and where it emerges here, only the lower part of the cliff sticks out as a rumpled drag fold (Fig 17.16). Within another half mile, we pass 3 groups of private boats clustered at the pull-in for Elves Chasm. People are going in bright sunshine up and down the route to the little grotto. There may or may not be magic there today, but the magic of deep time, the morning beauty, and past tectonic upheavals revealed in Garnet Canyon resonate with the sight of the canyon walls floating slowly past the boats.

The rims of the canyon step far back from the river here, and we see only a steep cliff on the left extending up to the Redwall Limestone. Gray, gnarly travertine masses drape down over it to conceal the stratigraphic horizontality that has been with us from the outset. Large blocks and boulders of it have sluffed off and we can note even from a distance that these travertine curtains are sometimes almost vertical layers parallel to the wall faces. Springs indeed once streamed down the cliff face. Just like the localized springs that create the base flow of the Little Colorado River, the water warmed and released dissolved carbon dioxide to induce precipitation of billions of microscopic crystals of calcium carbonate. In the Little Colorado River, the floors and banks got lined with this particulate sludge which quickly hardened into the variety of surficial limestone we call travertine. Here, the sludge adhered to the walls and thickened outward. The large masses of travertine are thus localized where springs were larger or more numerous. The age of the steep canyon wall here is obviously older than the travertine that covers it. If we could radiometrically age-date the travertine, we could get a minimum age of the canyon wall.

Despite the technological difficulties, age-dating travertine is possible in principle using a method involving the incredibly small amounts of uranium present in the carbonate. The problem is that it is still forming and recycling today from rainwater flowing over surfaces and penetrating cracks and micro-paths all through the older, quite permeable deposits. Here, it would be the travertine adhering closest to the wall that would yield the age most useful to those exploring the controversial age of the gorge. But how to find the oldest travertine without doing hundreds of analyses on samples that had been carefully screened under the microscope to be sure recent vein deposits that plugged millions of hairline cracks were not present? Some analyses have been made and publicized, but some who have studied thin sections of travertine under the microscope are not convinced. There is even the issue of how the microscopic calcite crystals reform themselves after deposition—like those loose ice cubes in a bag of ice transform themselves into big solid masses in a freezer in just a matter of hours. The calcite you find today may not be the calcite that originally precipitated as a metastable phase.

However, a great place to get further insight into erosion rates could be within a quarter mile downstream of Elves Chasm where the westward flowing river makes a sharp turn to the north. Floating sleepily by this one day years ago I suddenly bolted up and yelled “Eureka.” A tall, pointed pillar of travertine stands completely isolated there far in front of a large alcove called Buckhorn Canyon (Fig. 17.17).

Fig 17.17. Remarkable pillar of travertine in center above boat standing like a monument in the mouth of Buckhorn Canyon. It once coated the wall of the Grand Canyon here and was left standing after erosion excavated around and behind it to make this side canyon. Remnants still coat the hill to the right of center and the cliff to the upper left. All three remnants were once connected along the wall that was scooped out.

Embedded on the back side of the pillar are obvious pieces of Bright Angel Shale still in their horizontal position. The travertine coated the wall when it sloped here straight up from the riverbank. It was part of a three-mile long coating on the wall before it stopped forming. Two small side canyons, one upriver from the pillar and one downriver, eroded back and joined together to carve out the big alcove around the pillar and the slot canyon behind it. It now stands there isolated as a travertine monument. By age-dating travertine samples taken from the contact of the travertine and the remnants of the wall stuck on the back side of this pillar, the oldest travertine at this spot might be determined. This would give the age of when the wall was there against the river and how long it has taken to erode out the big alcove behind this pillar. If nothing else, this would help answer how long it took to form these erosional alcoves and embayments we have passed cut into the walls all along the river. Of course, this would still require lots of sampling and extensive microscope work before doing the actual age analysis. Proposals for the age of the Grand Canyon range from "very young," about 6-10 million years, to "very old," about 60 million years or even older. Although this is just a short stretch of river, getting the erosion rate of a wall at one spot might be useful.

While passing this spot on trips since I spotted this thing, I always bemoaned the fact that we never have time to climb up the back side of this pillar to get a sample. A crew member on one trip, the indefatigable Spencer Mann, said to me, "Pull over and I bet I can go up, look if it's feasible to sample, and get back in 20 minutes." Screech…we nose in, and Spencer hops out. Of course, a permit is required to take even a small rock sample from a National Park. The permit procedure is long and involved, so Spencer could only look at feasibility that might warrant a permit application. It took him about 26 minutes to do it, something that still amazes me--especially considering that he was wearing only flip flops on his feet! He reported that getting a piece of travertine cemented on remnant Bright Angel wall material would be easy. In fact, a piece broke off in his hand when he pulled up to take a close look. Holding it, he reckoned he could just let it fall or bring it back for me to see. So, here he stood with a sample collected inadvertently. So, either I could throw it overboard because we did not have a permit--or take it to someone who can do the Uranium Disequilibrium age dating analysis to get at least a preliminary idea. It is usually best to do that which is reasonable.

About 6 months later I handed this accidental sample to Professor Kate Maher at Stanford University while I was giving a couple of seminars there. She had just set up a lab that could age-date carbonates. Basically, uranium atoms dissolved in water are trapped in the calcite crystal structure resembling what happens when zircon crystallizes in a molten mass of magma. Uranium eventually decays into lead, but it starts by decaying into thorium atoms on time scales of hundreds of thousands of years which themselves decay into other atoms along the way to lead. Understanding the decay rates of the various radioactive atoms allows ages in carbonates to be determined. The method only works for carbonates precipitated less than 500 thousand years ago. While many previously analyzed Grand Canyon travertines from various places yielded ages much younger than this, the sample Spencer inadvertently sampled was older than the 500-thousand-year cutoff date. The canyon wall was here at least 500 thousand years ago rising straight up from the river. How much older than that we can't say. Had it been younger, those who want a really young age for Grand Canyon would have here a supporting argument. My own take-away from the result is that surprisingly little downcutting has occurred here in the past half million years and that alcoves such as this take a very long time to develop. This certainly does not rule out the popular idea that the entire Grand Canyon was carved in the last 3-8 million years. It does suggest (to me) that the canyon is now expanding laterally faster than it is downcutting. There are only a few places where the channel floor is sawing downward into bedrock rather than flowing over boulders, gravel, and sands—so this is not surprising. I never sought publication of this result because a single measurement on a grab sample is not the best way to do science and because it only bears peripherally on the overall age of the Grand Canyon. It nevertheless appears that some of the travertine is a lot older than what investigators have publicized.

Young…old…which is what in terms of geologic time? Two miles up the river, the morning started immersed in deep time addressed in billions of years. Now it is travertine addressed in hundreds of thousands of years. That is "young." But I am an old man and that is addressed in terms of less than 100 years. I once talked with a chap who had been deeply moved by an exhibit of treasures from King Tut's tomb. He held his hand near his face and exclaimed, "I was this far from objects that were 8,000 years old! Can you imagine!" I had just returned from doing field work and collecting 3.5-billion-year-old sedimentary rocks in South Africa, so what could I say? While there, a local geologist kept referring to a broad plateau in the distance holding 2.5-billion-year-old sedimentary rocks that once covered the entire area as "the overburden." That is a geologic term normally used for the more recent erosional debris covering bedrock. In Louisiana where I lived at the time, the "overburden" was atop "bedrock" less than a million years old. And at this spot there is a debate about whether the Grand Canyon is "old" as in tens of millions of years or "young" as in less than 11 million years. Time telescopes and compresses when you look back into it. There is no way to viscerally feel a difference between a million-year-old rock and a 3.5-billion-year-old one. Geologic time is so vast that even cool reason can't force the appropriate feeling. But at our next stop, it can and does.