CHAPTER 2 ON THE RIGHT PATH

It does not take long to figure out the exact path for my scientific pilgrimage. I launch from home in the Phoenix area and head north toward the South Rim of the Grand Canyon. After taking in views from some of the vista points, the route will take me around the east end of that deep canyon to Lees Ferry. This is the only place for hundreds of miles where a paved road goes down to the Colorado River. From there, I will join my annual charter raft trip to float through the whole 280-mile length of Grand Canyon to the shores of Lake Meade. Following a ragged path of roads and back roads from there, I'll cross southern Nevada into the Mojave Desert of California, enter Death Valley, explore right up its 150-mile length, go out the northwest end, and ascend to the crest of the Sierra Nevada Mountains in Yosemite National Park. It will be at least 1000 miles altogether with elevation changes of over 12,000 feet. This route will be many weeks of total immersion free of city distractions that can only impede this pilgrim's progress. More importantly, from having already explored most of the route, I know that this will be a way to experience unsurpassed manifestations of the grand themes of geology and much of the science that affects our modern outlook and psyche.

The final 25 miles of the drive north from Phoenix to the south rim of the Grand Canyon goes from the little tourist stop of Valle through an open plain with scattered cedars to an increasingly thick juniper forest and then into tall pines at the gates of the park. After passing through Valle, I spot an antelope bounding along on the plains not far from the road and watch for an iconic leap as it approaches a wire fence. Instead, this palomino sprinter slows abruptly, flattens, squiggles under the fence on its belly, jumps up, and bounds on. What? Well, maybe the fence jump is harder than it looks because the antelope is bounding decidedly uphill. Yes, approach the Grand Canyon from the south and you go uphill. The slope is gentle enough to usually evade notice but rise it does. This is why the plain becomes a juniper forest and then pines. From Navajo lands to the east, highway travelers also approach uphill from the already high desert to a pine forest and then a startling view of the gorge, all within about 8 miles. From the north, a similar ascent occurs over a short six-mile rise and is followed by a 60-mile level drive through a paradise of pines, aspens, and firs before encountering the gorge. Surprising as these uphill approaches may seem, a topographic map leaves no doubt that the Grand Canyon is not just a ditch in the ground but is a gash through a mountain range (Fig 2.1).

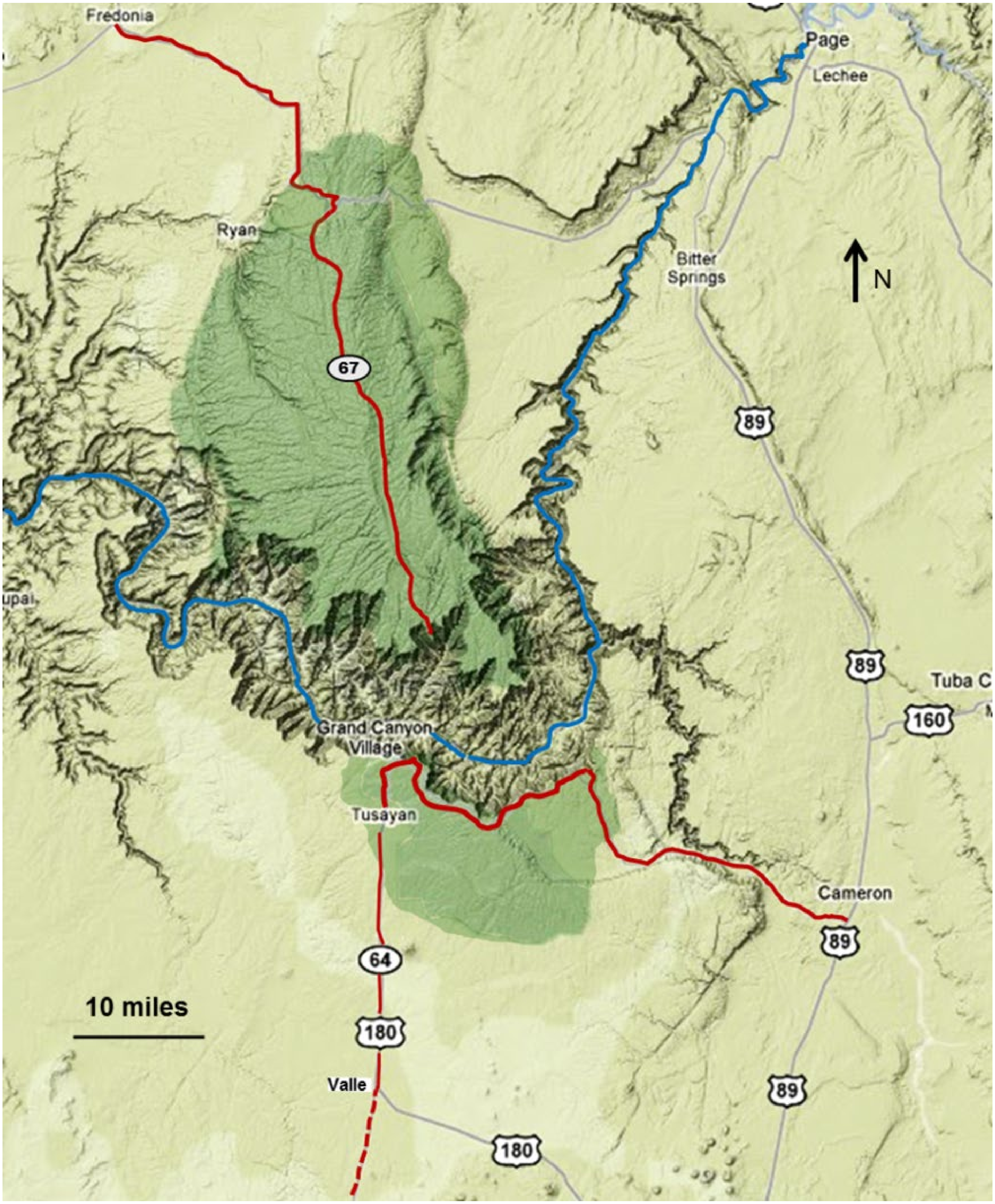

Fig 2.1 Kaibab Plateau, Northern Arizona. The Colorado River approaches from the northeast and appears to get diverted to the south as it approaches the uplift. As it approaches the south end, it makes a remarkable turn to the west and cuts through the highest part of the uplift to form the deepest part of the Grand Canyon.

This mountain range is not the usual string of serrated peaks separated by great divides and ravines but is rather a gently rounded plateau with smooth sides rising all around. Imagine half a watermelon lying on its lengthwise cut surface and you have it. The long axis of this half-melon, the "Kaibab Plateau," runs almost north south and protrudes between the southern and eastern highway approaches up its sides. The Colorado River approaches the half melon from the northeast and then runs south down its side as if it encountered a topographic barrier and got diverted. This seems like a reasonable thing for a river running downhill to do. But then, against all common sense, it makes a right-angle bend to the west and carves straight into the southern end of the half melon. The grandest, deepest, and most visited part of the spectacle is where it cuts through this strange mountain lump. Why would a river do this? It astonished John Wesley Powell, the first geologist to explore it, and I'm sorry to admit that geologists are still struggling to explain this. Maybe it will make more sense as the journey progresses. The afternoon is wearing on, so I am anxious to get to a vista point before sundown. One of the first geology reports of this area by Clarence Dutton in 1881 noted that at the Grand Canyon, "…the sun sets amid splendors that seem more than earthly." I am all for that, so I head straight to the parking area for Shoshone Point. The gate across the mile-long road out to the point means you walk. And that means you will pretty much have the place to yourself for sunsets, even at the height of tourist season.

Forget the road-hike out to the point. It is a greater experience to walk gently uphill cross-country from the parking area directly north through the beautiful forest of tall pines until you get startled when half the world suddenly falls away before you. As you approach, there is hardly any suggestion of what is about to occur. An approach through the woods is a unique experience and certainly the most spectacular way to encounter the Canyon. I still have not figured it out, but on my hike today in the long shadows of late afternoon, there seems a premonition while still immersed in the forest that something different lies ahead. While high-stepping over fallen tree limbs and rocky ledges, I note the glorious sound of a high wind in the treetops quickly fading into a hush just as blue sky and distant cliff faces begin to part the trees. Maybe this wind just laid itself down for the approaching evening, or maybe there is some kind of wind shadow created as air lifts over the rim? It is something to investigate another day, because now I am standing on the edge with the awesome view before me (Fig.2.2).

Fig 2.2. Canyon vista looking northwest from Shoshone Point. The skyline is the top of the great Kaibab Uplift. The Colorado River is here cutting directly across the core of the uplift. Erosion has clawed the landscape down toward the river where it is carried away to the west as if on a giant conveyer belt. Cliffs collapse and retreat to open the gorge. Between such catastrophic events, softer rock layers wash out in rainstorms and move downward. Note material currently perched during its intermittent descent in the inexorable pull of gravity from upper right to lower left across the lower center of this image.

The expanse is so vast that no matter how many times you encounter it you must blink and pinch yourself to accept that it is real. The impact is so great that it takes a few moments to engage the senses. Colorful layers seen in cross-section on the far side of this enormous chasm are glowing brightly through a diaphanous blue haze. Views of limitless cliff faces abound, but so do numerous ridges jutting outward. Isolated pyramids, columns, and layered outliers stand within enormous embayments on both sides of the abyss. The vertical sequence of horizontal layers in all this complexity is exactly matched between adjacent cliffs and pinnacles, and all can be carefully traced from left to right as far as the eye can see. The cliff edge I am standing on drops down a thousand feet to distinctly red ledges that step steeply down and down until out of sight. It is a majestic staircase no one can physically traverse. The shadow-filled indents and side canyons look like giant claw marks. Are these really dug-out scars, or did the land pull apart to open this chasm? It is a reasonable question a first-time visitor might ask. The question is quickly answered by recognizing that the openings clearly would not close neatly if pushed back together--especially the main canyon itself. A careful comparison yields a match between the layered sequence on the nearside with that on the far side and across every gap. It is clear from this that layers once bridged the spaces between walls and were subsequently scooped away by erosion. For a geologist, this view is a snapshot of a vast battle between a land mass that rose and erosion that is now tearing it down. The Grand Canyon is an immense gorge left after removal of an unimaginable amount of material. Where did it all go?

While this apparently chaotic landscape has a layered order to it, there is a visceral feel that any such order is being chaotically scraped away. And yet, there are elements of order in all this disfigurement as manifested by the very geometric, block-like remnants of pinnacles and cliffs (Fig 2.3).

Fig 2.3 Blocks produced by erosion along geometric fracture patterns are abundant at Shoshone Point and are seen from all other vista points. This spectacular example dusted with winter snow is at Desert View.

Blocks that fall off the walls into the side canyons even shatter into smaller geometric blocks (Fig 2.4).

Fig 2.4 Geometric blocks litter and fill side canyons everywhere in the Grand Canyon. Here in Tuckup Canyon an entire wall face collapsed and shattered along fracture planes. Future debris flows following exceptionally heavy rains will further shatter and push this material down to the river. Side canyons everywhere are currently being widened by these processes.

Ridges that have so far survived the erosive forces jut outward and extend down toward the central axis of the gorge. And there, in the deepest views, short segments of the Colorado River peep through the fantastical landscape to provide a kind of bottom to the scene. The river course generally parallels the irregular rims and causes the analytical side of human nature to ascribe great significance to it even though it is one of the smallest features visible.

After the initial trance looking at such a scene, I walk along a faint footpath to the east toward Shoshone Viewpoint that the blocked-off road leads to. As I arrive, I interrupt the trance of a solitary figure sitting on a block-like outcrop of rock who is staring into the almost unreal expanse. He is friendly, so I sit down for a canyon chat. I quickly discover that he is a creationist who believes with certainty that the Grand Canyon was formed as Noah's flood drained away. I have interrupted him here actually worshipping as he stares at what he considers evidence of the flood and reflecting on God's biblical promise to humanity after it. Here we sit, two people bound together in separate spiritual ecstasies-- both of us transfixed by the beauty and significance of the Grand Canyon. But our emotions and interpretation of how it formed and what it signifies are utterly irreconcilable. They are as different as night and day in every aspect. I reflect to myself on how remarkable this is, what it says about our humanity, and what it means for my planned scientific pilgrimage.

My new friend doesn't know my prejudice for science, so he cautiously but emphatically volunteers his consternation over how anyone could think that tiny river we see way down at the bottom of our view could possibly have carved this enormous expanse. In his view the layers themselves were deposited during Noah's great flood and then got dug out when the global flood waters receded. He subtly flinches as I tell him in a friendly tone that I am a geologist. I can never resist telling people about geology, so I volunteer that in a scientific view the river is not so much a clawing agent now as it is a conveyer belt. Rocks crack internally when they are uplifted by mountain building processes and form fracture-bounded blocks at all scales. I point out the vertical fractures that make the Canyon look in detail like a giant stack of rectilinear blocks everywhere you look, including the one we are sitting on. This very block will soon crash down into the side canyon adjacent to us, probably after an extended heavy rain washes out the last muddy layer beneath it. The mass of broken rock and water will surge down the side canyon as an awesome debris flow and hurtle into the river. Until the broken-up rock thus dumped into the river is washed away, a white-water rapid will exist at that spot shooting water through ever widening gaps. So, the river really isn't sculpting the Canyon walls in this day and age; it is just carrying all that obstructing debris downstream to the ocean where it accumulates offshore in new sedimentary layers that may someday rise up and get eroded into a future Grand Canyon.

I point to a barely visible, tiny white-water rapid way down below and want to explain how yes, the river is the great facilitator in the erosional goings-on here however small it may look to us so far away. But I see my friend's chin tilt up and eyes glaze. It is that politely indignant look of someone you are not likely to connect with further. He does not respond to my science spiel, but we do exchange exclamations of how transcendently beautiful the view is in the afternoon shadows. We sit silently to enjoy the sun setting amidst splendors that indeed seem more than Earthly. Without further proselytizing my scientific prejudices, I try as part of my pilgrimage to reflect internally on something new while looking at this great panorama. What is it trying to tell me?

We are sitting on a great hump of the continent, the Kaibab Uplift, which here goes horizon to horizon in all directions. The North Rim at over 8,000' elevation has fossils of organisms that lived in the ocean, so this enormous weight of the hump has been tectonically uplifted at least 1.5 miles above sea level. The Kaibab Uplift is a weight of rock at least 60 miles long, 20 miles wide, and 1.5 miles thick. It thus weighs over 26 trillion pounds. I think how much effort and energy it takes to personally lift a small block of rock. How much energy did it take to lift the Kaibab Plateau as now seen--and not even including the thousands of feet of strata above it that must have been stripped off by erosion? I am suddenly struck dumb. Use diesel, coal, electricity-- it does not matter. Lifting all this rock 1.5 miles as well as lifting any mountain anywhere would probably require more energy than humans could unleash or conceive. Where did such energy come from?

Based on our current knowledge of science, it occurs to me that the energy derived from within to accomplish all this is inherited from events that transpired in the nearby Cosmos before the Earth even existed. Miners have known for generations that it gets hotter and hotter as you descend deep into the Earth. Extrapolate the rise of measured temperatures in mines and boreholes to depths of 20 miles and the rocks are glowing cherry red and ready to melt were it not for the great pressure caused by the overlying weight. Based on studies of how seismic vibrations from earthquakes ricochet around at depth, the temperatures apparently increase all the way down until molten conditions are finally reached at depths of 1800 miles despite the overwhelming pressure. The regions above this molten core are solid but so white hot they have the consistency of toothpaste and actually churn around in slow motion turmoil. Geologists and seismologists argue over the nature of plumes, convection currents, and sinking masses that very slowly move around in these white-hot depths. No matter the exact nature of these unseen goings-on, all agree that internal heat is relentlessly trying to escape the Earth and thereby causes this churning. How this causes mountains to rise depends on the particular area. In some subsurface realms, plumes of slowly rising hot material may push the overlying crust upward. In other places, a more rigid crust may thicken as it cools simply in response to heat loss to space. The bottom parts of those crustal regions carry the overlying weight and can get pressed into denser rocks that simply peel off and fall downward through the putty-like hot material allowing the delaminated crust above to rise, somewhat like a cork pulled down into water until the bottom falls off. In other areas, enormous plates of the cooler, more rigid outermost part of the spherical Earth are held up like an arched bridge. If the bridge cracks, one side can slide under the other causing the overlying segment to rise. What is going on beneath the Kaibab Uplift is still much debated, but all explanations ultimately involve relentless, heat-driven churning of the deep Earth. But where does this heat within the Earth come from? What is the ultimate source of this unimaginable amount of heat energy that fueled the uplift and all other mountains on Earth?

Some once thought that it is mostly heat left over from a time when the Earth was entirely molten after it accreted violently from rock debris left over from the origin of the Solar System. That cannot be the answer because the current age estimate of the Earth greatly exceeds the time it would take for a completely molten Earth to leak away that initial heat. Surprisingly, a simple and likely explanation for most of the heat within the Earth appears to be uranium atoms--the largest, heaviest, naturally occurring atoms.

Although sometimes concentrated in highly localized ore deposits, most uranium atoms on Earth are present as tiny impurities in relatively common minerals. For example, a common variety of granite countertop has a few microscopic crystals of the uranium-bearing mineral zircon. Zircon crystals form when huge volumes of continental crust melt, move upward, cool, and the atoms moving willy-nilly around in the liquid slow down and sort themselves into the various crystals that make up granite. During crystallization, the tiny, growing zircon crystals unlike the others entrap rare uranium atoms into their atomic structures because there is a space just the right size and electric charge to accept them. It is like the cowbird that lays an egg amidst the legitimate eggs in another bird’s nest. Like the cowbird analogy, the resultant chick begins to be something quite different from its siblings. Tucked in its interloper position in the Zircon crystal structure, the unstable, “radioactive” uranium atom begins to decompose slowly but relentlessly (Fig. 2.5).

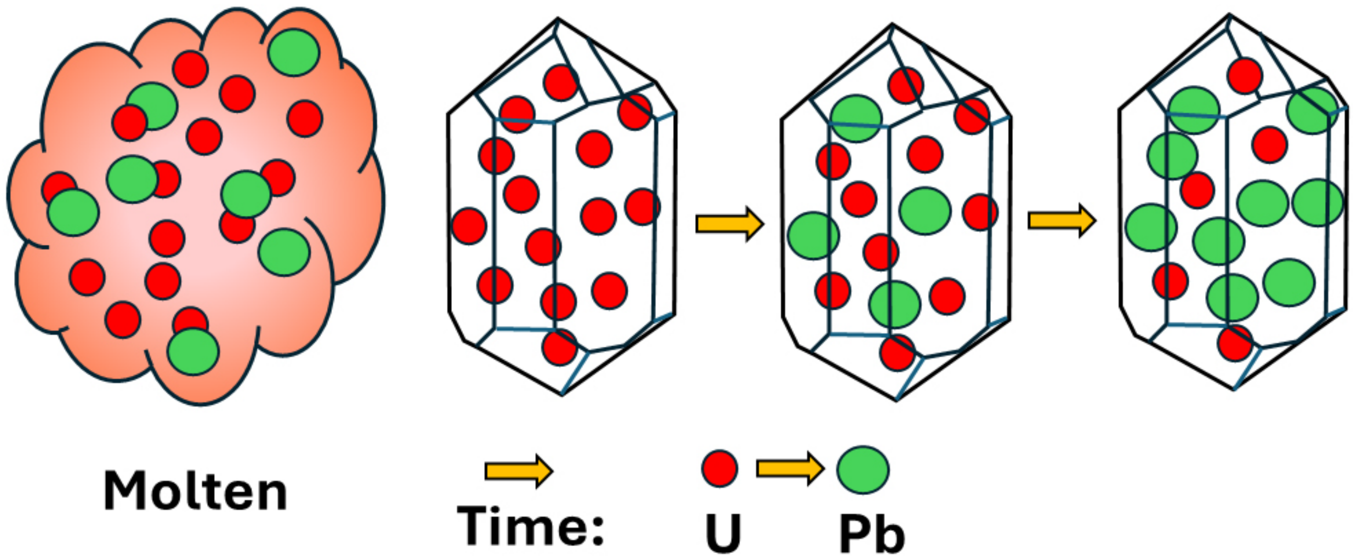

Fig. 2.5. Uranium atoms (U) are trapped inside of growing crystal of zircon but lead atoms (Pb) will not fit into the structure and are excluded. With time, the U atoms decay into Pb atoms which are trapped within the crystal. Each decay gives off heat.

It does so by spitting off pieces of its nucleus as helium atoms until it becomes a smaller, lighter atom of lead after billions of years. Lead is an atom that would not fit into the zircon structure, but here it sits trapped after transforming from the original uranium atom that did fit. The vastly smaller helium atoms slowly migrate out of the damaged crystal structure, move upward through the Earth, and collect in the same kinds of reservoirs oil gets trapped in. If our scientific story is correct, that helium in floating balloons you are familiar with was once part of individual uranium atoms down in the Earth! All of them. This is something to ponder at your next birthday party.

But here is the point. Every time a radioactive atom decays, heat is emitted. In a nuclear power plant, uranium is induced to decay in a much faster, controlled way to release heat that drives electricity generators. The amount of heat produced from the natural radioactive decay of individual uranium atoms is small, but rocks conduct heat very inefficiently--so it builds up within them. A perfectly insulating blanket put around a common granite countertop would trap the heat being generated and eventually melt it. Rock itself is an extremely efficient thermal insulator, so the heat down deep builds up over time--something we have a lot of in geology. Most of the heat making the inner Earth white hot thus probably comes from this relentless emission of accumulating heat from radioactive decay of dispersed uranium and other, less abundant radioactive elements over vast intervals of time. Like the churning in a pot of hot water, it causes the slow turbulence that lifts land masses that could never be raised by human means. While we certainly don't know the answer for sure, the heat from radioactive decay of uranium and other radioactive elements is a likely explanation for the hot churning that ultimately lifted the Kaibab Plateau and all other mountains on Earth. The amount of heat energy necessary to do all this is enormous, but the calculations work so this is at least a reasonable scientific explanation

But wait. Where does the energy contained in the uranium atoms that does all this heating come from? Our initial question has not been answered yet. Why really is the deep Earth ultimately such a storehouse of immense energy found in the uranium atoms? Geologists do not know. They must take what the Earth has and go from there. Astrophysicists, however, think they have it figured out. It is ultimately from ancient stars.

A star is basically a continuous hydrogen bomb contained and held together by gravity. The hydrogen atoms that make up the bulk of stars are fused and converted in this continuous hydrogen bomb into the kinds of common atoms we know and love from our chemistry labs--and make up everything around us--including us. Uncommonly heavy atoms such as uranium are created when an exceptionally large star depletes its hydrogen fuel so fast that gravity overpowers the explosive pressure keeping it from collapsing. The star then implodes rather quickly causing pressures and temperatures to rise to the point that helium and other atoms fuse together violently. The star blows itself apart from the energy produced by this fusion, and all the atoms created inside are strewn into space (Fig. 2.6).

Fig. 2.6. Remnants of supernova explosion spreading outward. Heavy atoms are formed during the event and seed the interstellar medium with Uranium and other radioactive elements. (NASA/JPL-Caltech)

Uranium atoms are formed in the extreme conditions of this “supernova” explosion when smaller atoms slam together at velocities sufficient to overcome a nuclear force that causes the nuclei of atoms to repel each other. When slammed together at such velocities, it is if little hooks on the nuclei grab each other and prevent the nuclei of the atoms from repelling each other as they do at lower energies. The uranium atom then contains a tremendous amount of energy somewhat analogous to a mass of compressed springs.

The enormous uranium atoms born in such a violent fashion are composed of atomic nuclei held together tenuously. Such a big, energetic atom wants to eventually break apart, and it does this mainly by spitting off helium atoms and heat energy. As it does so, it transforms itself into a less complicated atom. It is a slow process, but a collection of uranium atoms would be half converted into stable atoms of lead after 4.5 billion years. In the meantime, all the atoms spewed out in the supernova explosion including the newly created uranium and other radioactive atoms fan out in the arms of our galaxy and mix with the hydrogen gas and solid dust particles of the interstellar medium. New stars and solar systems are born when clouds of this material collapse gravitationally. According to the strongest current theory, the Earth formed in such a manner 4.5 billion years ago and trapped the tiny amounts of uranium created by these catastrophic stellar detonations. Here it sits slowly spewing off helium atoms to this day. And every time a uranium atom flies apart, heat is given off. The heat builds up and keeps the hot interior churning around and lifting mountains here and there.

So, the Kaibab Plateau is rising because of energy released from old supernova explosions! Imagine an action-adventure movie you have seen where explosions hurl off incandescent pieces like roman candles that then fall and lie around sputtering and flaming until the scene shifts. The uranium atoms are analogous to the bits on the ground, still sputtering and flashing billions of years after being trapped in the interstellar mix of atoms that aggregated to form Earth.

As the plateau rises driven by this ancient supernova energy, rain falls to form running surface water that continuously wears away that which is being uplifted. We see this vividly in action today at the Grand Canyon, especially in the erosional debris being pushed and carried down the Colorado River toward the sea. The rain itself is derived from water vapor lifted off the oceans by the heat of the sun and moved inland with shifting air masses also driven by the energy of the Sun. It is this solar energy that is powering the erosion of the Grand Canyon. The Sun is our local star more stable than those that become supernova and shines its heat smoothly, steadily, and benevolently. As we look at the immensity of the Grand Canyon with all its deeply etched side canyons, we are indeed witness to the classic “battle” geologists talk about between tectonic uplift and erosion, but we can recognize it now as a battle between energy released by the Sun and that released from supernovae long before the Earth was born. It is a battle raging between our local star and ancient stars that packed energy into the uranium atoms. This is the real “Star Wars.“

None of this is known to that bounding antelope laboring uphill toward the Canyon, but it may be the ultimate reason the antelope dropped to its belly and scurried under the fence instead of making a more energetic and graceful leap. Or maybe antelopes always crawl under fences. We probably can't understand antelope behavior, but we may at least understand why that uphill slope is there and what its fate will be as the Sun tears it down via erosion and washes it into the Grand Canyon.

Once the blazing sunset colors begin to fade, I bid my creationist friend Adieu to go find some place to camp in the National Forest to the south. He remains sitting there with visions of Noah's flood, and I depart with a profound cosmic battle raging in my brain. I take a final look back at him sitting there in the twilight and wonder which vision is on the right track. He is filled with a kind of ecstasy pondering it all and so am I. Both visions cannot be right. Is my pilgrimage a fool's errand because it is based on our current understanding of science, a body of knowledge and concepts that evolve constantly as we make more discoveries? Could the faith-based revelation my friend believes be right and our science progressing down erroneous tracks? I think of all the old science textbooks that are now almost laughable because we have made so many subsequent discoveries. Then I further worry about several current and very popular scientific paradigms that I feel after decades of my own research and critical examination are almost certainly wrong. And then there is the steady conversion of the modern scientific endeavor at universities, research institutions, government agencies, and corporations into money generating enterprises prone to hype, exaggeration, and even willful misrepresentation. A scientific journey along my envisioned route is not going to be a straightforward intellectual or spiritual adventure. It is going to be wrought with critical thinking, an awareness of possible erroneous take home messages, and a constant attempt to calibrate on what we have overwhelming evidence for versus what just sounds good as "believed" by the broader scientific community in all its manifestations. We are always driven by primitive instincts. In this case, it is a choice between revealed knowledge vs that derived from observation, reasoning, and sincere scientific evaluation of alternative explanations. Our scientific understanding has been used to create technology, medical treatments, weather predictions, and so much else that revelation is incapable of; why reject it when trying to deduce and appreciate natural history? So no, I go forth feeling more than ever that I am on the more likely path to the truth than this enchanted chap. He could just as well have been one of a million other people who visit here with their own religious considerations, oral traditions, or on-the-spot revelations. I choose the scientific approach, however flawed and uncertain. I know from experience that looking at a landscape with geological eyes can yield inspirations, reveries, and meaning at all levels that touch the soul as profoundly as any imaginable. Eager to get on with it, I walk in the last light back to my 4X4 Toyota FJ Cruiser, eat a sandwich, drive a few miles east, and take the road south from near Grand View Vista Point until it quickly exits the National Park into the National Forest. There, I can park in an isolated spot, legally pull out a cot, and get some sleep. Not exactly elegant camping, but it is wonderful to fall asleep looking up at the stars through the tall pines of this silent forest. The reality of tomorrow can come tomorrow. I am on the right path.