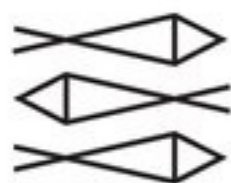


ANNALS OF
THE FORMER WORLD

JOHN MCPHEE



ANNALS

OF THE

FORMER

WORLD

Yolanda Whitman

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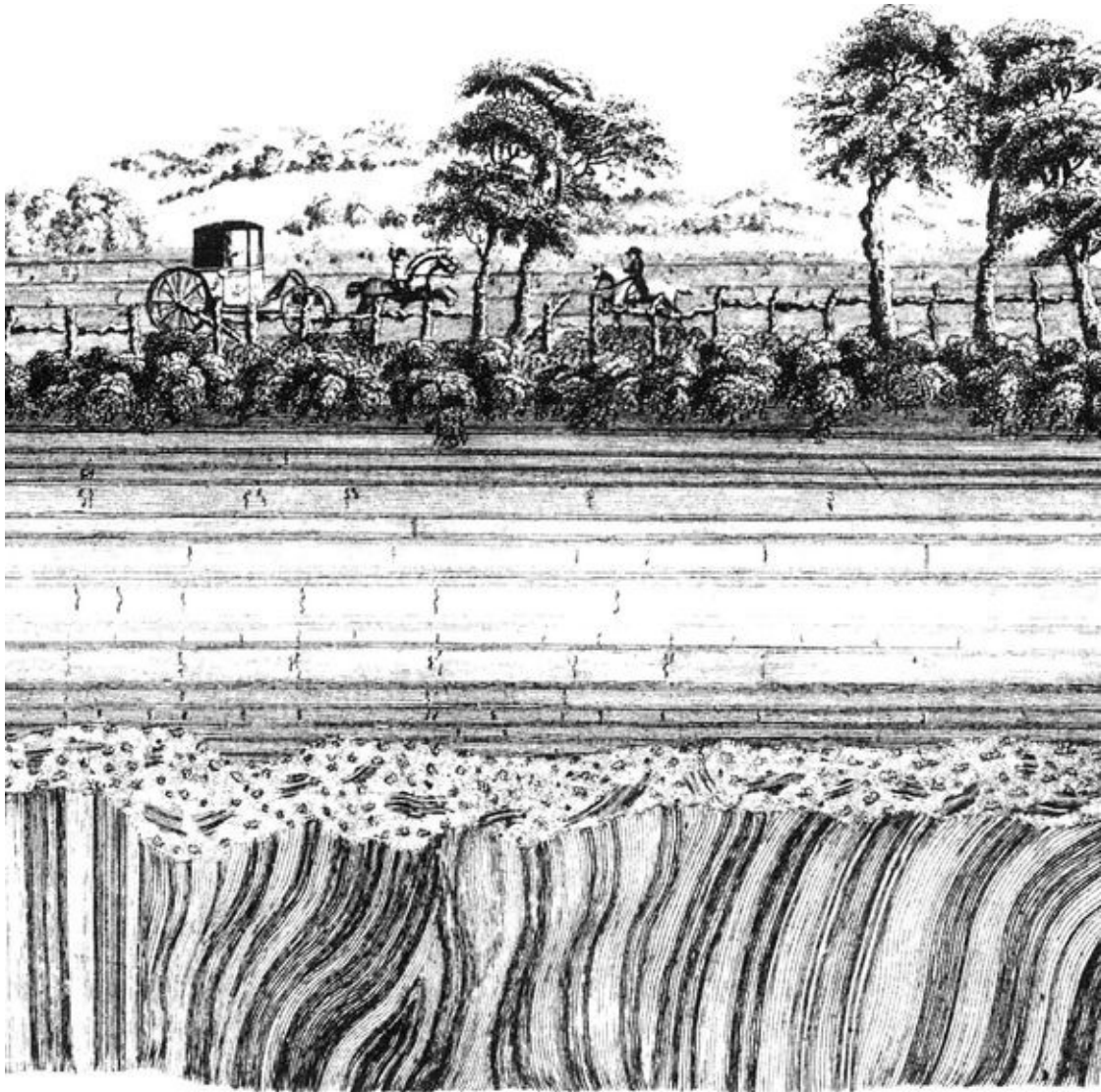
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Book 1

Basin and Range



The poles of the earth have wandered. The equator has apparently moved. The continents, perched on their plates, are thought to have been carried so very far and to be going in so many directions that it seems an act of almost pure hubris to assert that some landmark of our world is fixed at 73 degrees 51 minutes and 53 seconds west longitude and 40 degrees 51 minutes and 14 seconds north latitude—temporary description, at any rate, as if for a boat on the sea. Nevertheless, these coordinates will, for what is generally described as the foreseeable future, bring you with absolute precision to the west apron of the George Washington Bridge. Nine A.M. A weekday morning. The traffic is some gross demonstration in particle physics. It bursts from its confining source, aimed at Chicago, Cheyenne, Sacramento, through the high dark roadcuts of the Palisades Sill. A young woman, on foot, is being pressed up against the rockwall by the wind booms of the big semis—Con Weimar Buick Transportation, Fruehauf Long Ranger. Her face is Nordic, her eyes dark brown and Latin—the bequests of grandparents from the extremes of Europe. She wears mountain boots, blue jeans. She carries a single-jack sledgehammer. What the truckers seem to notice, though, is her youth, her long bright Norwegian hair; and they flirt by air horn, driving needles into her ears. Her name is Karen Kleinspehn. She is a geologist, a graduate student nearing her Ph.D., and there is little doubt in her mind that she and the road and the rock before her, and the big bridge and its awesome city—in fact, nearly the whole of the continental United States and Canada and Mexico to boot—are in state of motion, in a manner moving in the direction of the trucks. She has not come here, however, to ponder global tectonics, although goodness knows she could, the sill being, in theory, a signature of the events that created the Atlantic. In the Triassic, when New Jersey and Mauretania were of a piece, the region is said to have begun literally to pull itself apart, straining to spread out, to break into great crustal blocks. Valleys in effect competed. One of them would open deep enough to admit ocean water, and for some years would resemble the present Red Sea. The mantle below the crust—exciting and excited by these events—would send up fillings of fluid rock, and with such pressure behind them that they could intrude between horizontal layers of, say, shale and sandstone and lift the country a thousand feet. The intrusion could spread laterally through hundreds of square miles, becoming a broad new layer—a sill—within the country rock.

Unconformity at Jedburgh, borders, by John Clerk, 1787, courtesy Scottish Academic Press, Ltd., Edinburgh

This particular sill came into the earth about two miles below the surface, Kleinspehn remarks, and she smacks it with the sledge. An air horn blasts. The passing tires, in their numbers, sound like heavy surf. She has to shout to be heard. She pounds again. The rock is competent. The wall of the cut is sheer. She hits it again and again—until a chunk of some poundage falls free. Its fresh surface sparkles with crystals—free-form, asymmetrical, improvisational plagioclase crystals, bestrewn against a field of dark pyroxene. The rock as a whole is called diabase. It is salt-and-peppery charcoal-tweed savings-bank rock. It came to be that way by cooling slowly, at depth, and forming these beautiful crystals.

“It pays to put your nose on the outcrop,” she says, turning the sample in her hand. With a small hammer, she tidies it up, like a butcher trimming a roast. With a felt-tip pen, she marks it “1.” Moving along the cut, she points out xenoliths—blobs of the country rock that fell into the magma and became encased there like raisins in bread. She points to flow patterns, to swirls in the diabase where

solidifying segments were rolled over, to layers of coarse-grained crystals that settled, like sediment in beds. The Palisades Sill—in its chemistry and its texture—is a standard example of homogeneous magma resulting in multiple expressions of rock. It tilts westward. The sill came into a crustal block whose western extremity—known in New Jersey as the Border Fault—is thirty miles away. As the block's western end went down, it formed the Newark Basin. The high eastern end gradually eroded, shedding sediments into the basin, and the sill was ultimately revealed—a process assisted by the creation and development of the Hudson, which eventually cut out the cliffside panorama of New Jersey as seen across the river from Manhattan: the broad sill, which had cracked, while cooling, into slender columns so upright and uniform that inevitably they would be likened to palisades.

In the many fractures of these big roadcuts, there is some suggestion of columns, but actually the cracks running through the cuts are too various to be explained by columnar jointing, let alone by the impudence of dynamite. The sill may have been stressed pretty severely by the tilting of the fault block, Kleinspehn says, or it may have cracked in response to the release of weight as the load above was eroded away. Solid-earth tides could break it up, too. The sea is not all that responds to the moon. Twice a day the solid earth bobs up and down, as much as a foot. That kind of force and that kind of distance are more than enough to break hard rock. Wells will flow faster during lunar high tides.

For that matter, geologists have done their share to bust up these roadcuts. “They’ve really been *through* here!” They have fungoed so much rock off the walls they may have set them back a foot. And everywhere, in profusion along this half mile of diabase, there are small, neatly cored holes, in many ways resembling the shot holes and guide holes of the roadblasters, which are larger and vertical, but also small horizontal borings that would be snug to a roll of coins. They were made by geologists taking paleomagnetic samples. As the magma crystallized and turned solid, certain iron minerals within lined themselves up like compasses, pointing toward the magnetic pole. As it happened, the direction in those years was northerly. The earth’s magnetic field has reversed itself a number of hundreds of times, switching from north to south, south to north, at intervals that have varied in length. Geologists have figured out just when the reversals occurred, and have thus developed a distinct arrhythmic yardstick through time. There are many other chronological frames, of course, and if from other indicators, such as fossils, one knows the age of a rock unit within several million years, a look at the mineral compasses inside it can narrow the age toward precision. Paleomagnetic insights have contributed greatly to the study of the travels of the continents, helping to show where they may have been with respect to one another. In the argot of geology, paleomagnetic specialists are sometimes called paleomagicians. Enough paleomagicians have been up and down the big roadcuts of the Palisades Sill to prepare what appears to be a Hilton for wrens and purple martins. Birds have shown no interest.

Near the end of the highway’s groove in the sill, there opens a broad, forgettable view of the valley of the Hackensack. The road is descending toward the river. At an even greater angle, the sill—tilting westward—dives into the earth. Accordingly, as Karen Kleinspehn continues to move downhill she is going “upsection” through the diabase toward the top of the tilting sill. The texture of the rock becomes smoother, the crystals smaller, and soon she finds the contact where the magma—at 2000 degrees Fahrenheit—touched the country rock. The country rock was a shale, which had earlier been the deep muck of some Triassic lake, where the labyrinthodont amphibians lived, and paleoniscid fish. The diabase below the contact now is a smooth and uniform hard dark rock, no tweed—its crystals too small to be discernible, having had so little time to grow in the chill zone. The contact is a straight clear line. She rests her hand across it. The heat of the magma penetrated about a hundred feet into the shale, enough to cook it, to metamorphose it, to turn it into spotted slate. Sampling the slate with her sledgehammer, she has to pound with even more persistence than before. “Some weird, wild minerals turn up in this stuff,” she comments between swings. “The metamorphic aureole of this formation

about the hardest rock in New Jersey.”

She moves a few hundred feet farther on, near the end of the series of cuts. Pin oaks, sycamore aspens, cottonwoods have come in on the wind with milkweed and wisteria to seize living space between the rock and the road, although the environment appears to be less welcoming than the center of Carson Sink. There are fossil burrows in the slate—long stringers where Triassic animals travelled through the quiet mud, not far below the surface of the shallow lake. There is a huge rubber sandal by the road, a crate of broken eggs, three golf balls. Two are very cheap but one is an Acushnet Titleist. A soda can comes clinking down the interstate, moving ten miles an hour before the easterly winds catch the traffic. The screen of trees damps the truck noise. Karen sits down to rest, to talk, with her back against a cottonwood. “Roadcuts can be a godsend. There’s a series of roadcuts near Pikeville, Kentucky—very big ones—where you can see distributary channels in a river-delta system, with natural levees, and with splay deposits going out from the levees into overbank deposits of shales and coal. It’s a face-on view of the fingers of a delta, coming at you—the Pocahontas delta system, sheared off the Appalachians in Mississippian-Pennsylvanian time. You see river channels that migrated back and forth across a valley and were superposed vertically on one another through time. You see it all there in one series of exposures, instead of having to fit together many smaller pieces of the puzzle.”

Geologists on the whole are inconsistent drivers. When a roadcut presents itself, they tend to lurk and weave. To them, the roadcut is a portal, a fragment of a regional story, a proscenium arch that leads their imaginations into the earth and through the surrounding terrane. In the rock itself are the essential clues to the scenes in which the rock began to form—a lake in Wyoming, about as large as Lake Huron; a shallow ocean reaching westward from Washington Crossing; big rivers that rose in Nevada and fell through California to the sea. Unfortunately, highway departments tend to obscure such scenes. They scatter seed wherever they think it will grow. They “hair everything over”—as geologists around the country will typically complain.

“We think rocks are beautiful. Highway departments think rocks are obscene.”

“In the North it’s vetch.”

“In the South it’s the god-damned kudzu. You need a howitzer to blast through it. It covers the mountainsides, too.”

“Almost all our stops on field trips are at roadcuts. In areas where structure is not well exposed, roadcuts are essential to do geology.”

“Without some roadcuts, all you could do is drill a hole, or find natural streamcuts, which are few and far between.”

“We as geologists are fortunate to live in a period of great road building.”

“It’s a way of sampling fresh rock. The road builders slice through indiscriminately, and no little rocks, no softer units are allowed to hide.”

“A roadcut is to a geologist as a stethoscope is to a doctor.”

“An X-ray to a dentist.”

“The Rosetta Stone to an Egyptologist.”

“A twenty-dollar bill to a hungry man.”

“If I’m going to drive safely, I can’t do geology.”

In moist climates, where vegetation veils the earth, streamcuts are about the only natural places where geologists can see exposures of rock, and geologists have walked hundreds of thousands of miles in and beside streams. If roadcuts in the moist world are a kind of gift, they are equally so in other places. Rocks are not easy to read where natural outcrops are so deeply weathered that a hammer will virtually sink out of sight—for example, in piedmont Georgia. Make a fresh roadcut almost anywhere at all and geologists will close in swiftly, like missionaries racing anthropologists to a tribe just discovered up the Xingu.

“I studied roadcuts and outcrops as a kid, on long trips with my family,” Karen says. “I was probably doomed to be a geologist from the beginning.” She grew up in the Genesee Valley, and most of the long trips were down through Pennsylvania and the Virginias to see her father’s parents, North Carolina. On such a journey, it would have been difficult not to notice all the sheets of rock that had been bent, tortured, folded, faulted, crumpled—and to wonder how that happened, since the sheets of rock would have started out as flat as a pad of paper. “I am mainly interested in sedimentology, and sedimentary structures. It allows me to do a lot of field work. I’m not too interested in theories of what happens x kilometres down in the earth at certain temperatures and pressures. You seldom do field work if you’re interested in the mantle. There’s a little bit of the humanities that creeps in into geology, and that’s why I am in it. You can’t prove things as rigorously as physicists or chemists do. There are no white coats in a geology lab, although geology is going that way. Under the Newark Basin are worn-down remains of the Appalachians—below us here, and under that valley, and so on over to the Border Fault. In the West, for my thesis, I am working on a basin that also formed on top of a preexisting deformed belt. I can’t say that the basin formed just like this one, but what absorbs me are the mechanics of these successor basins, superposed on mountain belts. The Great Valley in California is probably an example of a late-stage compressional basin—formed as plates came together. We think the Newark Basin is an extensional basin—formed as plates moved apart. In the geologic record, how do we recognize the differences between the two? I am trying to get the picture of the basin as a whole, and what is the history that you can read in these cuts. I can’t synthesize all this in one morning on a field trip, but I can look at the rock here and then evaluate someone else’s interpretation.” She pauses. She looks back along the rockwall. “This interstate is like a knife wound all across the country,” she remarks. “Sure—you could do this sort of thing from here to California. Anyone who wants to, though, had better hurry. Before long, to go all the way across by yourself will be a fossil experience. A person or two. One car. Coast to coast. People do it now without thinking much about it. Yet it’s a most unusual kind of personal freedom—particular to this time span, the one we happen to be in. It’s an amazing, temporary phenomenon that will end. We have the best highway system in the world. It lets us do what people in no other country can do. And it is also an ecological disaster.”

In June, every year, students and professors from eastern colleges—with their hydrochloric-acid pickaxe and their hammers and their Brunton compasses—head west. To be sure, there is plenty of absorbing geology under the shag of eastern America, galvanic conundrums in Appalachian structures and intricate puzzles in history and stratigraphy. In no manner would one wish to mitigate the importance of the eastern scene. Undeniably, though, the West is where the rocks are—the vastness of exposed rock—and of eastern geologists who do any kind of summer field work about seventy-five per cent go west. They carry state geological maps and the regional geological highway maps that are published by the American Association of Petroleum Geologists—maps as prodigally colored as dramatic paintings and equally formless in their worm-trail-and-paramecium depictions of the country’s uppermost rock. The maps give two dimensions but more than suggest the third. They tell the general age and story of the banks of the asphalt stream. Kleinspehn has been doing this for some years, getting into her Minibago, old and overloaded, a two-door Ford, heavy-duty springs, with odd pieces of the Rockies under the front seat and a mountain tent in the gear behind, to cross the Triassic lowlands and the Border Fault and to rise into the Ridge and Valley Province, the folded-and-faulted deformed Appalachians—the beginnings of a journey that above all else is physiographic, a journey that tends to mock the idea of a nation, of a political state, as an unnatural subdivision of the globe, a metaphor of the human ego sketched on paper and framed in straight lines and in riparian boundaries between unalterable coasts. The United States: really a quartering of a continent, a drawer in North America. Pull it out and prairie dogs would spill off one side, alligators off the other—a terra

crisscrossed with geological boundaries, mammalian boundaries, amphibian boundaries: the limits of the world of the river frog, the extent of the Nugget formation, the range of the mountain cougar. The range of the cougar is the cougar's natural state, overlying segments of tens of thousands of other states, a few of them proclaimed a nation. The United States of America, with its capital city on the Atlantic Coastal Plain. The change is generally dramatic as one province gives way to another; and halfway across Pennsylvania, as you leave the quartzite ridges and carbonate valleys of the folded and-faulted mountains, you drop for a moment into Cambrian rock near the base of a long climb, a ten-mile gradient upsection in time from the Cambrian into the Ordovician into the Silurian into the Devonian into the Mississippian (generally through the same chapters of the earth represented in the walls of the Grand Canyon) and finally out onto the Pennsylvanian itself, the upper deck, the capstone rock, of the Allegheny Plateau. Now even the Exxon map shows a new geology, roads running everywhere which way like shatter lines in glass, following the crazed geometries of this deeply dissected country whereas, before, the roads had no choice but to run northeast-southwest among the long roopy trends of the deformed mountains, following the endless ridges. On these transcontinental trips, Karen has been driven as much as a thousand miles in a day at speeds that she has come to regard as dangerous and no less emphatically immoral. She has almost never slept under a roof, nor can she imagine why anyone on such a journey would want or need to; she "scopes out" her campsites in the late-failing light with a strong affection for national forests and less for the three-dollar campgrounds where you roll out your Ensolite between two trailers, where gregarious trains honk like Buicks, and Harleys on instrumented climbs climb escarpments in the night. The physiographic boundary is indistinct where you shade off the Allegheny Plateau and onto the stable craton, the continent's enduring core, its heartland, immemorably unstrained, the steady, predictable hedreocraton—the Stable Interior Craton. There are old mountains to the east, maturing mountains to the west, adolescent mountains beyond. The craton has participated on its edges in the violent creation of the mountains. But it remains intact within, and half a nation wide—the lasting, stolid craton, slowly, slowly downwasting. It has lost five centimeters since the birth of Christ. In much of Canada and parts of Minnesota and Wisconsin, the surface of the craton is Precambrian—earth-basement rock, the continental shield. Ohio, Indiana, Illinois, and Missouri—forth—the greater part of the Midwest—is shield rock covered with a sedimentary veneer that has never been metamorphosed, never been ground into tectonic hash—sandstones, siltstones, limestone dolomites, flatter than the ground above them, the silent floors of departed oceans, of epicratonic seas in Iowa. Nebraska. Now with each westward township the country thickens, rises—a thousand, two thousand, five thousand feet—on crumbs shed off the Rockies and generously served to the craton. At last the Front Range comes to view—the chevroned mural of the mountains, sparkling white on granite and on its outfanning sediments you are lifted into the Rockies and you plunge through a canyon to the Laramie Plains. "You go from one major geologic province to another and—whoa!—you really know you're doing it." There are mountains now behind you, mountains before you, mountains that are seen on top of mountains, a complex score of underthrust, upthrust, overthrust mountains, at the conclusion of which, through another canyon, you come into the Basin and Range. Brigham Young, when he came through a neighboring canyon and saw rivers flowing out on alluvial fans from the wall of the Wasatch to the flats beyond, made a quick decision and said, "This is the place." The scene suggested settling for it. The alternative was to press on beside a saline sea and then across salt barrens so vast and flat that when microwave relays would be set there they would not require towers. There are mountains, to be sure—off to one side and the other: the Oquirrh, the Stansburys, the Promontories, the Silver Island Mountains. And with Nevada these high, discrete, austere new ranges begin to come in waves, range after range after north-south range, consistently in rhythm with wide flat valley basin, range; basin, range; a mile of height between basin and range. Beside the Humboldt you wind around the noses of the mountains, the Humboldt, framed in cottonwood—a sound, substantial, yearning

round-flowing river, among the largest in the world that fail to reach the sea. It sinks, it disappears, an evaporite plain, near the bottom of a series of fault blocks that have broken out to form a kind of stairway that you climb to go out of the Basin and Range. On one step is Reno, and at the top is the Donner Summit of the uplifting Sierra Nevada, which has gone above fourteen thousand feet but seems by no means to have finished its invasion of the sky. The Sierra is rising on its east side and is hinged on the west, so the slope is long to the Sacramento Valley—the physiographic province of the Great Valley—flat and sea-level and utterly incongruous within its flanking mountains. It was not eroded out in the normal way of valleys. Mountains came up around it. Across the fertile flatlands beyond the avocados, stand the Coast Ranges, the ultimate province of the present, the berm of the Pacific ocean—the Coast Ranges, with their dry and straw-brown Spanish demeanor, their shadows of the live oaks on the ground.

If you were to make that trip in the Triassic—New York to San Francisco, Interstate 80, say roughly at the end of Triassic time—you would move west from the nonexistent Hudson River with the Palisades Sill ten thousand feet down. The motions that will open the Atlantic are well under way (the things appear in present theory), but the brine has not yet come in. Behind you, in fact, where the ocean will be, are several thousand miles of land—a contiguous landmass, fragments of which will be Africa, Antarctica, India, Australia. You cross the Newark Basin. It is for the most part filled with red mud. In the mud are tracks that seem to have been made by a twoton newt. You come to a long, low north-south-trending, black, steaming hill. It is a flow of lava that has come out over the mud and has cooled quickly in the air to form the dense smooth textures of basalt. Someday, towns and landmarks of this extruded hill will in one way or another take from it their names: Montclair, Mountainside, Great Notch, Glen Ridge. You top the rise, and now you can see across the rest of the basin to the Border Fault, and—where Whippany and Parsippany will be, some thirty miles west of New York—there is a mountain front perhaps seven thousand feet high. You climb this range and see more and more mountains beyond, and they are the folded-and-faulted Appalachians, but middle-aged and a little rough still at the edges, not caterpillar furry and worn-down smooth. Numbers do not seem to work well with regard to deep time. Any number above a couple of thousand years—fifty thousand, fifty million—will with nearly equal effect awe the imagination to the point of paralysis. This Triassic journey, anyway, is happening two hundred and ten million years ago, or five per cent back into the existence of the earth. From the subalpine peaks of New Jersey, the descent is long and gradual to the lowlands of western Pennsylvania, where flat-lying sedimentary rocks begin to reach out across the craton—coals and sandstones, shales and limestones, slowly downwasting, Ohio, Indiana, Illinois, Iowa, erosionally losing an inch every thousand years. Where the Missouri will flow, past Council Bluffs, you come into a world of ruddy hills, Permian red, that continue to the far end of Nebraska where you descend to the Wyoming flats. Sandy in places, silty, muddy, they run on and on, near sea level, all the way across Wyoming and into Utah. They are as red as brick. They will become the red cliffs and red canyons of Wyoming, the walls of Flaming Gorge. Triassic rock is not exclusively red, but much of it is red all over the world—red in the shales of New Jersey, red in the sandstones of Yunan, red in the banks of the Volga, red by the Solway Firth. Triassic red beds, as they are called, are in the dry valleys of Antarctica, the red marls of Worcestershire, the hills of Alsace-Lorraine. The Petrified Forest. The Painted Desert. The South African red beds of the Great Karroo. Triassic red rock is red through and through, and not merely weathered red on the surface, like the great Redwall limestone of the Grand Canyon, which is actually gray. There may have been a superabundance of oxygen in the atmosphere from late Pennsylvanian through Permian and Triassic time. As sea level changed and changed again all through the Pennsylvanian, tremendous quantities of vegetation grew and then were drowned and buried, grew and then were drowned and buried—to become, eventually, seam upon seam of coal, interlayered with sandstones and shales. Living plants take in carbon dioxide

keep the carbon in their carbohydrates, and give up the oxygen to the atmosphere. Animals, from bacteria upward, then eat the plants and reoxidize the carbon. This cycle would go awry if a great many plants were buried. Their carbon would be buried with them—isolated in rock—and so the amount of oxygen in the atmosphere would build up. All over the world, so much carbon was buried in Pennsylvanian time that the oxygen pressure in the atmosphere quite possibly doubled. There is more speculation than hypothesis in this, but what could the oxygen do? Where could it go? After carbon the one other thing it could oxidize in great quantity was iron—abundant, pale-green ferrous iron which exists everywhere, in fully five per cent of crustal rock; and when ferrous iron takes on oxygen it turns a ferric red. That may have been what happened—in time that followed the Pennsylvania Permian rock is generally red. Red beds on an epic scale are the signs of the Triassic, when the earth in its rutilance may have outdone Mars.

As you come off the red flats to cross western Utah, two hundred and ten million years before the present, you travel in the dark, there being not one grain of evidence to suggest its Triassic appearance, no paleoenvironmental clue. Ahead, though, in eastern Nevada, is a line of mountains that are much of an age with the peaks of New Jersey—a little rounded, beginning to show age—and after you climb them and go down off their western slopes you discern before you the white summits of alpine fresh terrain, of new rough mountains rammed into thin air, with snow banners flying off the matterhorns, ridges, crests, and spurs. You are in central Nevada, about four hundred miles east of San Francisco, and after you have climbed these mountains you look out upon (as it appears in present theory) open sea. You drop swiftly to the coast, and then move on across moderately profound water full of pelagic squid, water that is quietly accumulating the sediments which—ages in the future—will become the roof rock of the rising Sierra. Tall volcanoes are standing in the sea. Then, at roughly the point where the Sierran foothills will end and the Great Valley will begin—at Auburn, California—you move beyond the shelf and over deep ocean. There are probably some islands out there somewhere, but fundamentally you are crossing above ocean crustal floor that reaches to the Chukchi Sea. Below you there is no hint of North America, no hint of the valley or the hills where Sacramento and San Francisco will be.

I used to sit in class and listen to the terms come floating down the room like paper airplanes. Geology was called a descriptive science, and with its pitted outwash plains and drowned rivers, its hanging tributaries and starved coastlines, it was nothing if not descriptive. It was a fountain metaphor—of isostatic adjustments and degraded channels, of angular unconformities and shifting divides, of rootless mountains and bitter lakes. Streams eroded headward, digging from two sides in a mountain or hill, avidly struggling toward each other until the divide between them broke down, and the two rivers that did the breaking now became confluent (one yielding to the other, giving up its direction of flow and going the opposite way) to become a single stream. Stream capture. In the Sierra Nevada, the Yuba had captured the Bear. The Macho member of a formation in New Mexico was derived in large part from the solution and collapse of another formation. There was fatigued rock and incompetent rock and inequigranular fabric in rock. If you bent or folded rock, the inside of the curve was in a state of compression, the outside of the curve was under great tension, and somewhere in the middle was the surface of no strain. Thrust fault, reverse fault, normal fault—the two sides were active in every fault. The inclination of a slope on which boulders would stay put was the angle of repose. There seemed, indeed, to be more than a little of the humanities in this subject. Geologists communicated in English; and they could name things in a manner that sent shivers through the bones. They had roof pendants in their discordant batholiths, mosaic conglomerates in desert pavements. There was ultrabasic, deep-ocean, mottled green-and-black rock—or serpentine. There was the slope of the barchan dune. In 1841, a paleontologist had decided that the big creatures of the Mesozoic were “fearfully great lizards,” and had therefore named them dinosaurs. There were festooned crossbeds and limestone sinks, pillow lavas and petrified trees, incised meanders and defeated streams. There were dike swarms and slickensides, explosion pits, volcanic bombs. Pulsating glaciers. Hogbacks. Radiolarian ooze. There was almost enough resonance in some terms to stir the adolescent groin. The swelling up of mountains was described as an orogeny. Ontogeny, phylogeny, orogeny—accent syllable two. The Antler Orogeny, the Avalonian Orogeny, the Taconic, Acadian, Alleghenian orogenies. The Laramide Orogeny. The center of the United States had had a dull geologic history—nothing much being accumulated, nothing much being eroded away. It was just sitting there conservatively. The East had once been radical—had been unstable, reformist, revolutionary, in the Paleozoic pulses of three or four orogenies. Now, for the last hundred and fifty million years, the East had been stable and conservative. The far-out stuff was in the Far West of the country—wild weirs, a leather-jacket geology in mirrored shades, with its welded tuffs and Franciscan mélanges (internally deformed, complex beyond analysis), its strikeslip faults and falling buildings, its boiling springs and fresh volcanics, its extensional disassembling of the earth.

There was, to be sure, another side of the page—full of geological language of the sort that would have attracted Gilbert and Sullivan. Rock that stayed put was called autochthonous, and if it had moved it was allochthonous. “Normal” meant “at right angles.” “Normal” also meant a fault with a depressed hanging wall. There was a Green River Basin in Wyoming that was not to be confused with the Green River Basin in Wyoming. One was topographical and was on Wyoming. The other was structural and was under Wyoming. The Great Basin, which is centered in Utah and Nevada, was not to be confused with the Basin and Range, which is centered in Utah and Nevada. The Great Basin was topographical, and extraordinary in the world as a vastness of land that had no drainage to the sea. The Basin and Range was a realm of related mountains that coincided with the Great Basin, spilling over slightly to the north and considerably to the south. To anyone with a smoothly functioning bifocal mind, there was no lack of clarity about Iowa in the Pennsylvanian, Missouri in the Mississippian, Nevada in the Nebraskan, Indiana in the Illinoian, Vermont in the Kansan, Texas in the Wisconsinan time. Meteoric water, with study, turned out to be rain. It ran downhill in consequent, subsequent, obsequent, resequent, and not a few insequent streams.

As years went by, such verbal deposits would thicken. Someone developed enough effrontery to call a piece of our earth an epieugeosyncline. There were those who said interfluve when they meant confluence, and a perfectly good word like mesopotamian would do. A cactolith, according to the American Geological Institute's *Glossary of Geology and Related Sciences*, was "a quasi-horizontal chonolith composed of anastomosing ductoliths, whose distal ends curl like a harpolith, thin like a sphenolith, or bulge discordantly like an akmolith or ethmolith." The same class of people who called one rock serpentine called another jacupirangite. Clinoptilolite, eclogite, migmatite, tinalconite, szaibelyite, pumpellyite, Meyerhofferite. The same class of people who called one rock paracelsian called another despujolsite. Metakirchheimerite, phlogopite, katzenbuckelite, mboziite, noselite, neighborite, samsonite, pigeonite, muskoxite, pabstite, aenigmatite. Joessmithite. With the X-ray diffractometer and the X-ray fluorescence spectrometer, which came into general use in geological laboratories in the late nineteen-fifties, and then with the electron probe (around 1970), geologists obtained ever closer examinations of the components of rock. What they had long seen through magnifying lenses as specimens held in the hand—or in thin slices under microscopes—did not always register identically in the eyes of these machines. Andesite, for example, had been given its name for being the predominant rock of the high mountains of South America. According to the machines, there is surprisingly little andesite in the Andes. The Sierra Nevada is renowned throughout the world for its relatively young and absolutely beautiful granite. There is precious little granite in the Sierra. Yosemite Falls, Half Dome, El Capitan—for the most part the "granite" of the Sierra is granodiorite. It has always been difficult enough to hold in the mind that a magma which hardens within the earth as granite will—if it should flow out upon the earth—harden as rhyolite, that what hardens within the earth as diorite will harden upon the earth as andesite, that what hardens within the earth as gabbro will harden upon the earth as basalt, the difference from pair to pair being a matter of chemical composition and the differences within each pair being a matter of texture and of crystalline form. With the darker rock at the gabbro end and the lighter rock the granite. All of that—not to mention such wee appendixes as the fact that diabase is a special texture of gabbro—was difficult enough for the layman to remember before the diffractometers and the spectrometers and the electron probe came along to present their multiplex cavils. What had previously been described as the granite of the world turned out to be a large family of rock that included granodiorite, monzonite, syenite, adamellite, trondhjemite, alaskite, and a modest amount of true granite. A great deal of rhyolite, under scrutiny, became dacite, rhyodacite, quartz latite. Andesite was found to contain enough silicon, potassium, sodium, and aluminum to be the fraternal twin of granodiorite. These points are pretty fine. The home terms still apply. The enthusiasm geologists show for adding new words to the conversation is, if anything, exceeded by their affection for the old. They are not about to drop granite. They say granodiorite when they are in church and granite the rest of the week.

When I was seventeen and staring up the skirts of eastern valleys, I was taught the rudiments of what is now referred to as the Old Geology. The New Geology is the package phrase for the effects of the revolution that occurred in earth science in the nineteen-sixties, when geologists clambered on to seafloor spreading, when people began to discuss continents in terms of their velocities, and when the interactions of some twenty parts of the globe became known as plate tectonics. There were few hints of all that when I was seventeen, and now, a shake later, middle-aged and fading, I wanted to learn some geology again, to feel the difference between the Old and the New, to sense if possible how the science had settled down a decade after its great upheaval, but less in megapictures than in day-to-day contact with country rock, seeing what had not changed as well as what had changed. The thought occurred to me that if you were to walk a series of roadcuts with a geologist something illuminating would in all likelihood occur. This was long before I met Karen Kleinspehn, or, for that matter, David Love, of the United States Geological Survey, or Anita Harris, also of the Survey, or Eldridge Moore

of the University of California at Davis, all of whom would eventually take me with them through various stretches of the continent. What I did first off was what anyone would do. I called my local geologist. I live in Princeton, New Jersey, and the man I got in touch with was Kenneth Deffeyes, senior professor who teaches introductory geology at Princeton University. It is an assignment that angled wide. Students who have little aptitude for the sciences are required to take a course or two in the sciences en route to some cerebral Valhalla dangled high by the designers of curriculum. Deffeyes' course is one that such students are drawn to select. He calls it Earth and Its Resources. They call it Rocks for Jocks.

Deffeyes is a big man with a tenured waistline. His hair flies behind him like Ludwig van Beethoven's. He lectures in sneakers. His voice is syllabic, elocutionary, operatic. He has been described by a colleague as "an intellectual roving shortstop, with more ideas per square metre than anyone else in the department—they just tumble out." His surname rhymes with "the maze." He has been a geological engineer, a chemical oceanographer, a sedimentary petrologist. As he lectures, his eyes search the hall. He is careful to be clear but also to bring forth the full promise of his topic, for he knows that while the odd jock and the pale poet are the white of his target the bull's-eye is the future geologist. Undergraduates do not come to Princeton intending to study geology. When freshmen fill out cards stating their three principal interests, no one includes rocks. Those who will make the subject their field of major study become interested after they arrive. It is up to Deffeyes to interest them—and not a few of them—or his department goes into a subduction zone. So his eyes search the hall. People out of his course have been drafted by the Sacramento Kings and have set records in distance running. They have also become professors of geological geophysics at Caltech and petrology at Harvard.

Deffeyes' own research has gone from Basin and Range sediments to the floor of the deep sea to unimaginable events in the mantle, but his enthusiasms are catholic and he appears to be less attached to any one part of the story than to the entire narrative of geology in its four-dimensional recapitulations of space and time. His goals as a teacher are ambitious to the point of irrationality: At the very least, he seems to expect a hundred mint geologists to emerge from his course—expect perhaps to turn on his television and see a certified igneous petrographer up front with the starting line of the Sacramento Kings. I came to know Deffeyes when I wondered how gold gets into mountains. I knew that most old-time hard-rock prospectors had little to go on but an association of gold with quartz. And I knew the erosional details of how gold comes out of mountains and into the rubble of streams. What I wanted to learn was what put the gold in the mountains in the first place. I asked a historical geologist and a geomorphologist. They both recommended Deffeyes. He explained that gold is not merely rare. It can be said to love itself. It is, with platinum, the noblest of the noble metals—those which resist combination with other elements. Gold wants to be free. In cool crust rock, it generally is free. At very high temperatures, however, it will go into compounds; and the gold that is among the magmatic fluids in certain pockets of interior earth may be combined, for example, with chlorine. Gold chloride is "modestly" soluble, and will dissolve in water that comes down and circulates in the magma. The water picks up many other elements, too: potassium, sodium, silicon. Heated, the solution rises in fissures in hard crust rock, where the cooling gold breaks away from the chlorine and—in specks, flakes, in nuggets even larger than the eggs of geese—falls out of the water as metal. Silicon precipitates, too, filling up the fissures and enveloping the gold with veins of silicon dioxide, which is quartz.

When I asked Deffeyes what one might expect from a close inspection of roadcuts, he said they were windows into the world as it was in other times. We made plans to take samples of highway rock. I suggested going north up some new interstate to see what the blasting had disclosed. He said if you go north, in most places on this continent, the geology does not greatly vary. You should proceed in

the direction of the continent itself. Go west. I had been thinking of a weekend trip to Whiteface Mountain, or something like it, but now, suddenly, a vaulting alternative came to mind. What about Interstate 80, I asked him. It goes the distance. How would it be? "Absorbing," he said. And he mused aloud: After 80 crosses the Border Fault, it pussyfoots along on morainal till that levelled up the fingers of the foldbelt hills. It does a similar dance with glacial debris in parts of Pennsylvania. It needs no assistance on the craton. It climbs a ramp to the Rockies and a fault-block staircase up the front of the Sierra. It is geologically shrewd. It was the route of animal migrations, and of human history that followed. It avoids melodrama, avoids the Grand Canyons, the Jackson Holes, the geologic operas of the country, but it would surely be a sound experience of the big picture, of the history, the construction, the components of the continent. And in all likelihood it would display in its roadcuts rock from every epoch and era.

In seasons that followed, I would go back and forth across the interstate like some sort of shuttle working out on a loom, accompanying geologists on purposes of their own or being accompanied by them from cut to cut and coast to coast. At any location on earth, as the rock record goes down in time and out into earlier geographies it touches upon tens of hundreds of stories, wherein the face of the earth often changed, changed utterly, and changed again, like the face of a crackling fire. The road beside the road exposes one or two levels of the column of time and generally implies what went on immediately below and what occurred (or never occurred) above. To tell all the stories would be to tell pretty much the whole of geology in many volumes across a fifty-foot shelf, a task for which I am in every conceivable way unqualified. I am a layman who has travelled with a small core sampling of academic and government geologists ranging in experience from a student to an *eminence grise*. I wish to make no attempt to speak for all geology or to sweep in every fact that came along. I want to choose some things that interested me and through them to suggest the general history of the continent by describing events and landscapes that geologists see written in rocks.

To poke around in a preliminary way, Deffeyes and I went up to the Palisades Sill, where I was to return with Karen Kleinspehn, borrowed some diabase with a ten-pound sledge, and then began to travel westward, traversing the Hackensack Valley. It was morning. Small airplanes engorged with businessmen were settling into Teterboro. Deffeyes pointed out that if this were near the end of the Wisconsinan time, when the ice was in retreat, those airplanes would have been settling down through several hundred feet of water, with the runway at the bottom of a lake. Glacial Lake Hackensack was the size of Lake Geneva and was host to many islands. It had the Palisades Sill for an eastern shoreline, and on the west the lava hill that is now known as the First Watchung Mountain. The glacier had stopped at Perth Amboy, leaving its moraine there to block the foot of the lake, which the glacier fed with meltwater as it retreated to the north. Some two hundred million years earlier, the runway would have been laid out on a baking red flat beside the first, cooling Watchung—glowing from cracks, from lava fountains, but generally black as carbon. Basalt flows don't light up the sky. Three hundred million years before that, the airplanes would have been settling down toward the same site through water—in this instance, salt water—on the eastern shelf of a broad low continent, where almost pure limestone was forming, because virtually nothing from the worn-away continent was eroding into the shallow sea. Three random moments from the upper ninth of time.

In Paterson, I-80 chops the Watchung lava. Walking the cut from end to end, Deffeyes picked up some peripheral shale—Triassic red shale. He put it in his mouth and chewed it. "If it's gritty it's a silt bed, and if it's creamy it's a shale," he said. "This is creamy. Try it." I would not have thought to put it in coffee. In the blocky basaltic wall of the road, there were many small pockets, caves the size of peas, caves the size of lemons. As magma approaches the surface of the earth, it is so perfused with gases that it fizzes like ginger ale. In cooling basalt, gas bubbles remain, and form these minicaves. For a century and more, nothing much fills them. Slowly, though, over a minimum of about a millio

years, they can fill with zeolite crystals. Until well after the Second World War, not a whole lot was known about the potential uses of zeolite crystals. Nor was it known where they could be found in abundance. Deffeyes did important early work in the field. His doctoral dissertation, which dealt with two basins and two ranges in Nevada, included an appendix that started the zeolite industry. Certain zeolites (there are about thirty kinds) have become the predominant catalysts in use in oil refineries, doing a job that is otherwise assigned to platinum. Now, in Paterson, Deffeyes searched the roadcut vugs (as the minute caves are actually called) looking for zeolites. Some vugs were large enough to suggest the holes that lobsters hide in. They did indeed contain a number of white fibrous zeolite crystals—smooth and soapy, of a type that resembled talc or asbestos—but the cut had been almost entirely cleaned out by professional and amateur collectors, undeterred by the lethal traffic not more than a few inches away. Nearly all the vugs were now as empty as they had been in their first hundred years. In the shale beyond the lava we saw the burrows of Triassic creatures. An ambulance from Totowa flew by with its siren wailing.

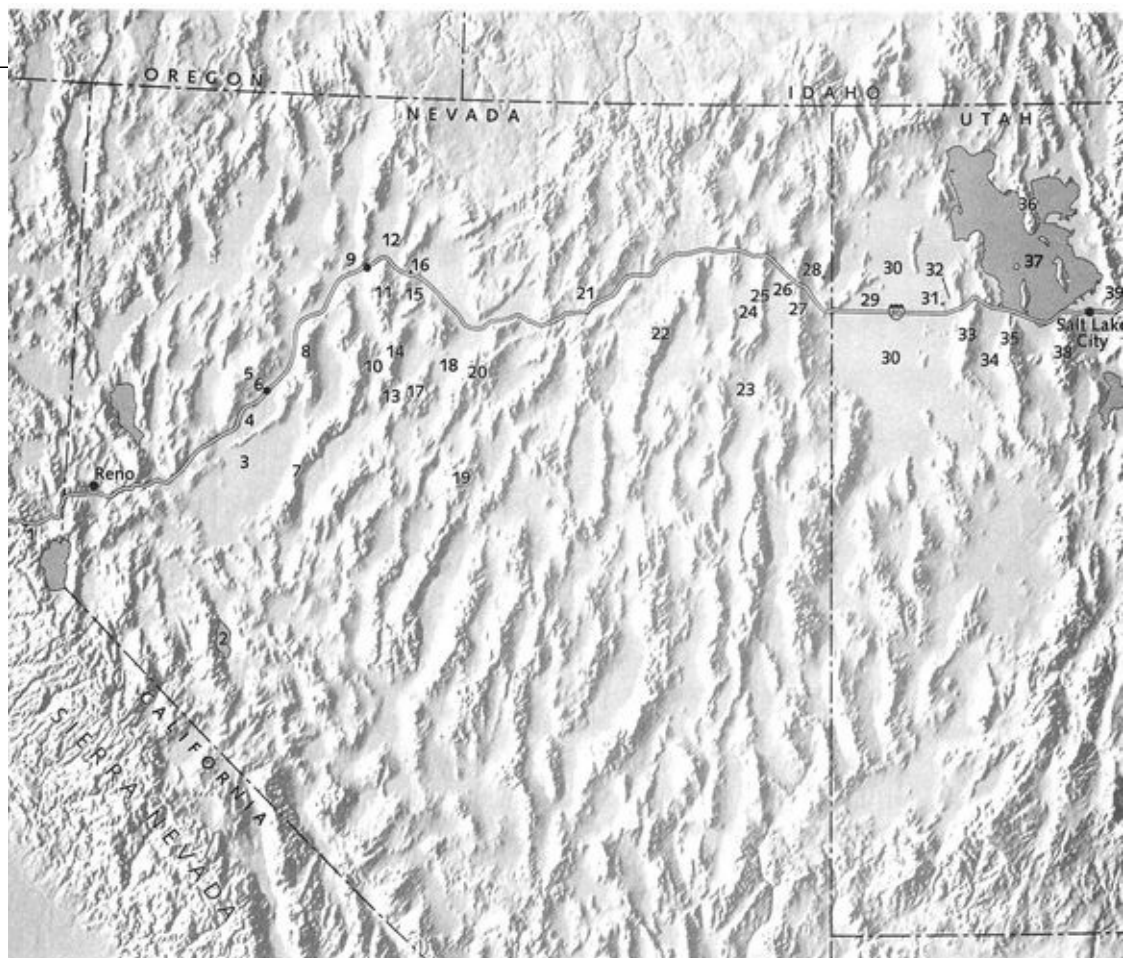
We moved on a few miles into the Great Piece Meadows of the Passaic River Valley, flat as a lake floor, poorly drained land. A meadow in New Jersey is any wet spongy acreage where you don't sink in above your chin. Great Piece Meadows, Troy Meadows, Black Meadows, the Great Swamp—Whippany, Parsippany, Madison, and Morristown are strewn among the reeds. The whole region, very evidently, was the bottom of a lake, for a lake itself is by definition a sign of poor drainage, a varicose aneurysm in a river, a highly temporary feature on the land. Some lakes dry up. Others disappear after the outlet stream, deepening its valley and eroding headward into the outlet, empties the water. The one—Glacial Lake Passaic—vanished about ten thousand years ago, after the retreating glacier exposed what is now the Passaic Valley. The lake drained gradually into the new Passaic River, which fell a hundred feet into Glacial Lake Hackensack, and, en route, went over a waterfall that would one day in effect found the city of Paterson by turning its first mill wheel. At the time of its greatest extent, Lake Passaic was two hundred feet deep, thirty miles long, and ten miles wide, and seems to have been a scene of great beauty. Its margins are still decorated with sand spits and offshore bars, wave-cut cliffs and stream deltas, set in suburban towns. The lake's west shore was the worn-looking escarpment of the Border Fault, and its most arresting feature was a hook-shaped basaltic peninsula that is now known to geologists as a part of the Third Watchung Lava Flow and to the people of New Jersey as Hook Mountain.

Deffeyes became excited as we approached Hook Mountain. The interstate had blasted into one end of the former peninsula, exposing its interior to view. Deffeyes said, "Maybe someone will have left some zeolites here. I want them so bad I can taste them." He jumped the curb with his high-slung Geology Department vehicle, got out his hammers, and walked the cut. It was steep and competent, with brown oxides of iron over the felt-textured black basalt, and in it were tens of thousands of tiny vugs, a high percentage of them filled with pearl-lustred crystals of zeolite. To take a close look, he opened his hand lens—a small-diameter, ten-power Hastings Triplet. "You can do a nice act in a jewelry store," he suggested. "You whip this thing out and you say the price is too high. These are beautiful crystals. Beautiful crystals imply slow growth. You don't get in a hurry and make something that nice." He picked up the sledge and pounded the cut, necessarily smashing many crystals as he broke their matrix free. "These crystals are like Vietnamese villages," he went on. "You have to destroy them in order to preserve them. They contain aluminum, silicon, calcium, sodium, and an incredible amount of imprisoned water. 'Zeolite' means 'the stone that boils.' If you take one small zeolite crystal, of scarcely more than a pinhead's diameter, and heat it until the water has come out, the crystal will have an internal surface area equivalent to a bedspread. Zeolites are often used to separate one kind of molecule from another. They can, for example, sort out molecules for detergent, choosing the ones that are biodegradable. They love water. In refrigerators, they are used to adsorb

water that accidentally gets into the Freon. They could be used in automobile gas tanks to adsorb water. A zeolite called clinoptilolite is the strongest adsorber of strontium and cesium from radioactive wastes. The clinoptilolite will adsorb a great deal of lethal material, which you can then store in a small space. When William Wyler made *The Big Country*, there was a climactic chase scene in which the bad guy was shot and came clattering down a canyon wall in what appeared to be a shower of clinoptilolite. Geologists were on the phone to Wyler at once. ‘Loved your movie. Where was that canyon?’ There are a lot of zeolites in the Alps, in Nova Scotia, and in North Table Mountain in Colorado. When I was at the School of Mines, I used to go up to North Table Mountain just to wham around. Some of the best zeolites in the world are in this part of New Jersey.”

There were oaks and maples on top of Hook Mountain, and, in the wall of the roadcut, basal rosettes of woolly mullein, growing in the rock. The Romans drenched stalks of mullein with suet and used them for funeral torches. American Indians taught the early pioneers to use the long flannel leaves of this plant as innersoles. Only three miles west of us was the Border Fault, where the basin had touched the range, where the stubby remnants of the fault scarp are now under glacial debris. Deffeyes said that the displacement along the fault—the eventual difference between two points that had been adjacent when the faulting began—exceeded fifteen thousand feet. Of course, this happened over several millions of years, and the mountains fronting the basin were all the while eroding, so they were never anything like fifteen thousand feet high. Generally, though, in the late Triassic, there would have been about a mile of difference, a mile of relief, between basin and range. In flash floods, boulders came raining off the mountains and piled in fans at the edge of the basin, ultimately to be filled in with sands and muds and to form conglomerate, New Jersey’s so-called Hammer Creek Conglomerate—multicircled, polka-dotted headcheese rock, sometimes known as puddingstone. Here, where the basin met the range, the sediments piled up so much that after all of the erosion of two hundred million years what remains is three miles thick. “I was in a bar once in Austin, Nevada,” Deffeyes said, “and there was a sudden torrential downpour. The bartender began nailing plywood over the door. I wondered why he was doing that, until boulders came tumbling down the main street of the town. When you start pulling a continent apart, you have a lot of consequences of the same event. Faulting produced this basin. Sediments filled it in. Pull things apart and you produce a surface vacancy, which is faulting, and a subsurface vacancy, which causes upwelling of hot mantle that intrudes as sills or comes out as lava flows. In the Old Geology, you might have seen a sill within the country rock and said, ‘Ah, the sill came much later.’ With the New Geology, you see that all this was happening more or less at one time. The continent was splitting apart and the ultimate event was the opening of the Atlantic. If you look at the foldbelt in northwest Africa, you see the other side of the New Jersey story. The folding there is of the same age as the Appalachians, and the subsequent faulting is Triassic. Put the two continents together on a map and you will see what I mean. Fault blocks like this one are still in evidence, but discontinuously, from the Connecticut Valley to South Carolina. They are all parts of the suite that opened the Atlantic seaway. The story is very similar to the Great Basin—in the West, in the Basin and Range. The earth is splitting apart there, quite possibly opening a seaway. It is not something that happened a couple of hundred million years ago. It only began in the Miocene, and it is going on today. What we are looking at here in New Jersey is not just some little geologic feature, like a zeolite crystal. This is the opening of the Atlantic. If you want to see happening right now what happened here two hundred million years ago, you can see it all in Nevada.”

Basin. Fault. Range. Basin. Fault. Range. A mile of relief between basin and range. Stillwater Range. Pleasant Valley. Tobin Range. Jersey Valley. Sonoma Range. Pumpnickel Valley. Shoshone Range. Reese River Valley. Pequop Mountains. Steptoe Valley. Ondographic rhythms of the Basin and Range. We are maybe forty miles off the interstate, in the Pleasant Valley basin, looking up at the Tobin Range. At the nine-thousand-foot level, there is a stratum of cloud against the shoulders of the mountains, hanging like a ring of Saturn. The summit of Mt. Tobin stands clear, above the clouds. When we crossed the range, we came through a ranch on the ridgeline where sheep were fenced around a running brook and bales of hay were bright green. Junipers in the mountains were thick and hung with berries, and the air was unadulterated gin. This country from afar is synopsisized and dismissed as “desert”—the home of the coyote and the pocket mouse, the side-blotched lizard and the vagrant shrew, the MX rocket and the pallid bat. There are minks and river otters in the Basin and Range. There are deer and antelope, porcupines and cougars, pelicans, cormorants, and common loons. There are Bonaparte’s gulls and marbled godwits, American coots and Virginia rails. Pheasant. Grouse. Sandhill cranes. Ferruginous hawks and flammulated owls. Snow geese. This Nevada terrain is not corrugated, like the folded Appalachians, like a tubal air mattress, like a rippled potato chip. This is not—in that compressive manner—a ridge-and-valley situation. Each range here is like a warship standing on its own, and the Great Basin is an ocean of loose sediment with these mountain ranges standing in it as if they were members of a fleet without precedent, assembled at Guam to assault Japan. Some of the ranges are forty miles long, others a hundred, a hundred and fifty. They point generally north. The basins that separate them—ten and fifteen miles wide—will run on for fifty, a hundred, two hundred and fifty miles with lone, daisy-petalled windmills standing over sage and wild rye. Animals tend to be content with their home ranges and not to venture out across the broad dry valleys. “Imagine a chipmunk hiking across one of these basins,” Deffeyes remarks. “The fauna in the high ranges here are quite distinct from one to another. Animals are isolated like Darwin finches in the Galapagos. These ranges are truly islands.”



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|---------------------|--------------------------|----------------------------|--------------------------|
| 1. Donner Pass | 11. Sonoma Range | 21. Carlin Canyon | 31. Grayback Mountain |
| 2. Walker Lake | 12. Paradise Valley | 22. Ruby Mountains | 32. Ripple Valley |
| 3. Carson Sink | 13. Jersey Valley | 23. Steptoe Valley | 33. Cedar Mountains |
| 4. Humboldt Sink | 14. Tobin Range | 24. Independence Valley | 34. Skull Valley |
| 5. Trinity Range | 15. Pumpernickel Valley | 25. Pequop Mountains | 35. Stansbury Mountains |
| 6. Lovelock | 16. Golconda Summit | 26. Goshute Valley | 36. Promontory Mountains |
| 7. Stillwater Range | 17. Fish Creek Mountains | 27. Toano Range | 37. Great Salt Lake |
| 8. Humboldt Range | 18. Reese River Valley | 28. Pilot Peak | 38. Oquirrh Mountains |
| 9. Winnemucca | 19. Toiyabe Range | 29. Bonneville Salt Flats | 39. Wasatch Range |
| 10. Pleasant Valley | 20. Shoshone Range | 30. Great Salt Lake Desert | |

Supreme over all is silence. Discounting the cry of the occasional bird, the wailing of a pack of coyotes, silence—a great spatial silence—is pure in the Basin and Range. It is a soundless immensity with mountains in it. You stand, as we do now, and look up at a high mountain front, and turn your head and look fifty miles down the valley, and there is utter silence. It is the silence of the winter forests of the Yukon, here carried high to the ridgelines of the ranges. “It is a soul-shattering silence,” the physicist Freeman Dyson wrote of southern Nevada in *Disturbing the Universe*. “You hold your breath and hear absolutely nothing. No rustling of leaves in the wind, no rumbling of distant traffic, no chatter of birds or insects or children. You are alone with God in that silence. There in the white flat silence I began for the first time to feel a slight sense of shame for what we were proposing to do. Do we really intend to invade this silence with our trucks and bulldozers and after a few years leave it a radioactive junkyard?”

What Deffeyes finds pleasant here in Pleasant Valley is the aromatic sage. Deffeyes grew up all over the West, his father a petroleum engineer, and he says without apparent irony that the smell of sagebrush is one of two odors that will unfailingly bring upon him an attack of nostalgia, the other

being the scent of an oil refinery. Flash floods have caused boulders the size of human heads to come tumbling off the range. With alluvial materials of finer size, they have piled up in fans at the edge of the basin. ("The cloudburst is the dominant sculptor here.") The fans are unconsolidated. In time come, they will pile up to such enormous thicknesses that they will sink deep and be heated and compressed to form conglomerate. Erosion, which provides the material to build the fans, is tearing down the mountains even as they rise. Mountains are not somehow created whole and subsequently worn away. They wear down as they come up, and these mountains have been rising and eroding in a fairly even ratio for millions of years—rising and shedding sediment steadily through time, always the same, never the same, like row upon row of fountains. In the southern part of the province, in the Mojave, the ranges have stopped rising and are gradually wearing away. The Shadow Mountains, The Dead Mountains, Old Dad Mountains, Cowhole Mountains, Bullion, Mule, and Chocolate mountains. They are inselberge now, buried ever deeper in their own waste. For the most part, though, the ranges are rising, and there can be no doubt of it here, hundreds of miles north of the Mojave, for we are looking at a new seismic scar that runs as far as we can see. It runs along the foot of the mountains along the fault where the basin meets the range. From out in the valley, it looks like a long, buff-colored, painted, essentially horizontal stripe. Up close, it is a gap in the vegetation, where plants growing side by side were suddenly separated by several metres, where, one October evening, the basin and the range—Pleasant Valley, Tobin Range—moved, all in an instant, apart. They jumped sixteen feet. The erosion rate at which the mountains were coming down was an inch a century. So in the mountainous contest with erosion they gained in one moment about twenty thousand years. These mountains do not rise like bread. They sit still for a long time and build up tension, and then suddenly jump. Passively they are eroded for millennia, and then they jump again. They have been doing this for about eight million years. This fault, which jumped in 1915, opened like a zipper far up the valley, and, exploding into the silence, tore along the mountain base for upward of twenty miles with a sound that suggested a runaway locomotive.

"This is the sort of place where you really do not put a nuclear plant," says Deffeyes. "There was no other action in the neighborhood at the same time—in the Stillwater Range, the Sonoma Range, the Pumpernickel Valley. Actually, this is not a particularly spectacular scarp. The lesson is that the whole thing—the whole Basin and Range, or most of it—is alive. The earth is moving. The faults are moving. There are hot springs all over the province. There are young volcanic rocks. Fault scarps are everywhere. The world is splitting open and coming apart. You see a sudden break in the sage like this, and it says to you that a fault is there and a fault block is coming up. This is a gorgeous, fresh, young active fault scarp. It's growing. The range is lifting up. This Nevada topography is what you see *during* mountain building. There are no foothills. It is all too young. It is live country. This is the tectonic, active, spreading, mountain-building world. To a nongeologist, it's just ranges, range after ranges."

Most mountain ranges around the world are the result of compression, of segments of the earth's crust being brought together, bent, mashed, thrust and folded, squeezed up into the sky—the Himalaya, the Appalachians, the Alps, the Urals, the Andes. The ranges of the Basin and Range came up another way. The crust—in this region between the Rockies and the Sierra—is spreading out, being stretched, being thinned, being literally pulled to pieces. The sites of Reno and Salt Lake City, on opposite sides of the province, have moved apart sixty miles. The crust of the Great Basin has broken into blocks. The blocks are not, except for simplicity's sake, analogous to dominoes. They are irregular in shape. They more truly suggest stretch marks. Which they are. They trend nearly north-south because the direction of the stretching is roughly east-west. The breaks, or faults, between the blocks are not vertical but dive into the earth at angles that average sixty degrees, and this, from the outside, affected the centers of gravity of the great blocks in a way that caused them to tilt. Classically, the

high edge of one touched the low edge of another and formed a kind of trough, or basin. The high edge—sculpted, eroded, serrated by weather—turned into mountains. The detritus of the mountains rolled into the basin. The basin filled with water—at first, it was fresh blue water—and accepted layer upon layer of sediment from the mountains, accumulating weight, and thus unbalancing the block even further. Its tilt became more pronounced. In the manner of a seesaw, the high, mountain side of the block went higher and the low, basin side went lower until the block as a whole reached a state of precarious and temporary truce with God, physics, and mechanical and chemical erosion, notwithstanding, far below, the agitated mantle, which was running a temperature hotter than normal, and was almost surely, controlling the action. Basin and range. Integral fault blocks: low side the basin, high side the range. For five hundred miles they nudged one another across the province of the Basin and Range. With extra faulting, and whatnot, they took care of their own irregularities. Some had the high sides on the west, some on the east. The escarpment of the Wasatch Mountains—easternmost expression of this immense suite of mountains—faced west. The Sierra—the westernmost, the highest, the predominant range, with Donner Pass only halfway up it—presented its escarpment to the east. As the developing Sierra made its skyward climb—as it went on up past ten and twelve and fourteen thousand feet—it became so predominant that it cut off the incoming Pacific rain, cast a rain shadow (as the phenomenon is called) over lush, warm, Floridian and verdant Nevada. Cut it off and kept it dry.

We move on (we're in a pickup) into dusk—north up Pleasant Valley, with its single telephone line on sticks too skinny to qualify as poles. The big flanking ranges are in alpenglow. Into the cold clear sky come the ranking stars. Jackrabbits appear, and crisscross the road. We pass the darkening shape of cattle. An eerie trail of vapor traverses the basin, sent up by a clear, hot stream. It is only a couple of feet wide, but it is running swiftly and has multiple sets of hot white rapids. In the source spring there is a thumping sound of boiling and rage. Beside the springs are lucid green pools, rimmed with accumulated travertine, like the travertine walls of Lincoln Center, the travertine pools of Havaas Canyon, but these pools are too hot to touch. Fall in there and you are Brunswick stew. "This is a direct result of the crustal spreading," Deffeyes says. "It brings hot mantle up near the surface. There is probably a fracture here, through which the water is coming up to this row of springs. The water is rich in dissolved minerals. Hot springs like these are the source of vein-type ore deposits. It's the same story that I told you about the hydrothermal transport of gold. When rainwater gets down into hot rock, it brings up what it happens to find there—silver, tungsten, copper, gold. An ore-deposit map and a hot-springs map will look much the same. Seismic waves move slowly through hot rock. The hotter the rock, the slower the waves. Nowhere in the continental United States do seismic waves move more slowly than they do beneath the Basin and Range. So we're not woofing when we say there's hot mantle down there. We've measured the heat."

The basin-range fault blocks in a sense are floating on the mantle. In fact, the earth's crust is everywhere in a sense is floating on the mantle. Add weight to the crust and it rides deeper, removing cargo and it rides higher, exactly like a vessel at a pier. Slowly disassemble the Rocky Mountains and carry the material in small fragments to the Mississippi Delta. The delta builds down. It presses even deeper on the mantle. Its depth at the moment exceeds twenty-five thousand feet. The heat and the pressure are so great down there that the silt is turning into siltstone, the sand into sandstone, the mud into shale. For another example, the last Pleistocene ice sheet loaded two miles of ice onto Scotland and that dunked Scotland in the mantle. After the ice melted, Scotland came up again, lifting its beaches high into the air. Isostatic adjustment. Let go a block of wood that you hold underwater and it adjusts itself to the surface isostatically. A frog sits on the wood. It goes down. He vomits. It goes up a little. He jumps. It adjusts. Wherever landscape is eroded away, what remains will rise in adjustment. Older rock is lifted to view. When, for whatever reason, crust becomes thicker, it adjusts downward.

All of this—with the central image of the basin-range fault blocks floating in the mantle—may suggest that the mantle is molten, which it is not. The mantle is solid. Only in certain pockets near the surface does it turn into magma and squirt upward. The temperature of the mantle varies widely, and would the temperature of anything that is two thousand miles thick. Under the craton, it is described as chilled. By surface standards, though, it is generally white hot, everywhere around the world—white hot and solid but magisterially viscous, permitting the crust above it to “float.” Deffeyes was in his bathtub one Saturday afternoon thinking about the viscosity of the mantle. Suddenly he stood up and reached for a towel. “Piano wire!” he said to himself, and he dressed quickly and went to the library to look up a book on piano tuning and to calculate the viscosity of the wire. Just what he guessed— 10^{22} poises. Piano wire. Look under the hood of a well-tuned Steinway and you are looking at strings that could float a small continent. They are rigid, but ever so slowly they will sag, will slacken, will deform and give way, with the exact viscosity of the earth’s mantle. “And that,” says Deffeyes, “is what keeps the piano tuner in business.” More miles, and there appears ahead of us something like a Christmas tree alone in the night. It is Winnemucca, there being no other possibility. Neon looks good in Nevada. The tawdriness is refined out of it in so much wide black space. We drive on and on toward the glow of colors. It is still far away and it has not increased in size. We pass nothing. Deffeyes says, “On these roads, it’s ten to the minus five that anyone will come along.” The better part of an hour later, we come to the beginnings of the casino-flashing town. The news this year is that dollar slot machines are outdrawing nickel slot machines for the first time, ever.

Deffeyes' purposes in coming to Nevada are pure and noble. His considerable energies appear to be about equally divided between the pursuit of pure science and the pursuit of noble metal. In order to enliven humanity's understanding of the basins, he has been taking paleomagnetic samples of basin sediments. He seeks insight into the way in which the rifting earth comes apart. He wants to perceive the subtle differences in the histories of one fault block and another. His ideas about silver, on the other hand, may send his children to college. This is, after all, Nevada, whose geology bought the tickets for the Spanish-American War. George Hearst found his fortune in the ground here. There were silver ores of such concentration that certain miners did nothing more to the heavy gray rocks than pack them up and ship them to Europe. To be sure, those days and those rocks—those supergenetic enrichments—are gone, but it has crossed the mind of Deffeyes that there may be something left for Deffeyes. Banqueting Sybarites surely did not lick their plates.

We rented the pickup in Salt Lake City—a white Ford. “If we had a bale of hay in here, we’d be Nevada authentic,” Deffeyes remarked, and he swept snow off the truck with a broom. November. Three inches on the ground and more falling, slanting in to us from the west. We squinted, and rubbed the insides of the windows, and passed low commercial buildings that drifted in and out of sight. WILD DUCKS & PHEASANTS PROCESSED. DEER CUT & WRAPPED. DRIVE-IN WINDOW 7:00 TILL MIDNIGHT. Behind us we could not see, of course, the wall of the Wasatch, its triangles and pinnacles white, but westward of the city visibility improved, and soon other mountains—the Oquirrh Mountains—came looming out of the blankness, their strata steeply dipping and as distinct as the stripes of an awning. “Those are Pennsylvanian and Permian sandstones and limestones,” Deffeyes said. “There was glaciation in the Southern Hemisphere at the time. The ice came and went. Sea level kept flapping up and down. So the deposition has a striped look.”

When a mountain range comes up into the air, a whole lot comes up with it. The event that has lifted the Oquirrhes—the stretching of the crust until it broke into blocks—was only among the latest of many episodes that have adjusted dramatically the appearance of central Utah. As we could plainly see from the interstate, the rock now residing in that striped mountainside had once been brutally shoved around—shoved, not pulled, and with such force that a large part of it had been tipped up more than ninety degrees, to and well beyond the vertical. Overturned. Such violence can happen on an epic scale. There is an entire nation in Europe that is upside down. It is not a superpower, but it is a whole country nonetheless—San Marino, overturned. Basin and Range faulting, on its own, has never overturned anything. The great fault blocks have a maximum tilt of thirty degrees. The event that deformed the rock in the Oquirrhes took place roughly sixty million years ago—fifty-two million years before the Oquirrhes came into existence—and it was an event that made alpine fresh compression mountains, which had their time here under the sun and were disassembled by erosion, taken down and washed away; and now those crazily upended stripes within the Oquirrhes are the evidence and fragmental remains of those ancestral mountains, brought up out of the earth and put on view as a component of new mountains. The new mountains—the mountains of the Basin and Range—are packages variously containing rock that formed at one time or another during some five hundred and fifty million years, or an eighth of the earth's total time. It was thought until recently that older rock was in certain of the ranges, but improved techniques of dating have shown that not to be true. Seven-eighths of the earth's time is lost here, gone without evidence—rock that disintegrated and went off to be recycled. One-eighth, for all that, is no small amount of earth history, and as the great crustal blocks of the Basin and Range have tipped their mountains into the air, with individual faults offset as much as twenty thousand feet, they have brought to the surface and have randomly exposed former seafloors and basaltic dikes, entombed rivers and veins of gold, volcanic spewings and dunal sands—chaotic, concatenated shards of time. In the Basin and Range are the well-washed limestones of clear and sparkling shallow Devonian seas. There are dark, hard, cherty siltstones from some deep ocean

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